SYMPOSIUM ON

CROPPING SYSTEMS RESEARCH AND DEVELOPMENT FOR THE ASIAN RICE FARMER

THE INTERNATIONAL RICE RESEARCH INSTITUTE

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FOREWORD

FARMERS in Asia generally have two alternatives for increasing food production. They can either increase crop yields or increase the number of crops grown each year. Cropping systems research is concerned with each of these alternatives, but places special emphasis on efforts to increase cropping intensities.

The development of high yielding, pest-resistant rice varieties with a short growth duration and the improvement of direct seeding techniques for rice have created a marked potential for increasing cropping intensities in rainfed areas. Both advances make possible the growing of two crops in some rainfed areas where only one crop used to be grown. In some areas with supplemental irrigation, a third crop may be feasible.

About half the world's rice is grown in areas of unirrigated rainfed conditions. The potential for increased food production through increased cropping intensity in such areas is large.

A network of scientists from cooperating countries have developed an international approach to cropping systems research. This research is designed to help farmers more effectively utilize their biophysical and socioeconomic resources to intensify cropping and to produce more food.

IRRI organized the symposium on cropping systems research and development for the Asian rice farmer to provide key scientists and specialists an opportunity to exchange ideas, research results, and concepts on rice-based cropping systems. The scientists met to review, discuss, and develop strategies for planning and implementing cropping systems research programs to help the small rice farmers of Asia increase their farm income and to improve the quality of farm life.

Twenty-five technical papers were presented during the five sessions of the symposium held at IRRI headquarters in the Philippines. The papers covered the general subjects of environmental description and design of cropping patterns, testing of cropping patterns, component technology (weed and insect pest management and varietal requirements), and cropping systems approach to food production.

These published proceedings include the papers presented and the discussions at the symposium. They document the concern for and attention to orienting rice-based cropping systems toward the rice farmer in Asia.

NYLE C. BRADY
Director General, IRRI, Philippines

WELCOME ADDRESS

N.C. Brady

Distinguished guests, symposium participants and observers, and ladies and gentlemen :

It is my pleasure to welcome you to the International Rice Research Institute (IRRI) and to officially open this symposium on *Cropping Systems Research and Development for the Asian Rice Farmer.* On behalf of my colleagues on the IRRI staff I extend to you an official welcome and a word of sincere appreciation for your joining us today. We appreciate your time and efforts to prepare and present papers and to participate in discussions during this conference.

This is a significant occasion for IRRI. It is the first major symposium on rice-based cropping systems to be sponsored by the Institute. Also, it is the first function to be held in this auditorium of the Institute's new Laboratory and Training-Conference Center. This building is the first major addition to IRRI's facilities since the original buildings were dedicated in 1962.

It is appropriate that these two events be associated, since the decision in 1973 for IRRI to expand its activities to include a significant program on rice-based cropping systems coincided with a decision to seek funds for additional research and training facilities. This symposium today, along with the facility in which it is being held, is indeed a dream come true.

The International Rice Research Institute from its beginning has concentrated its research efforts on the development of improved rice varieties and associated technologies. Along with cooperators in national research programs, IRRI scientists have helped to develop the rice varieties and associated technologies which would yield at least twofold more than the traditional varieties and practices. The term "green revolution" was coined to describe the high yielding potential of the new rices, which many thought could solve the major food production problems in rice-eating countries.

History has shown that it was too much to ask of these new varieties. In spite of their yield potential as demonstrated in the experimenters' plots, and in spite of associated improved technologies, they have had only modest effects on national rice-production levels. Worldwide rice production has barely been able to match population increases. Adverse weather has caused severe rice shortages, increased rice prices, and, in some countries, starvation, especially among the poor.

That discrepancy between assumed crop potential and actual plant performance appears to be due to a complex of factors. In some situations, the social and economic policies have not encouraged the use of the new rices and associated technology which could make them profitable. Lack of credit, fertilizers, pesticides, and dependable water supplies, or the high cost of inputs relative to the price of rice, have discouraged the adoption of the new rices.

In other situations, the environment does not foster maximum performance of the new rices. For millions of hectares, floodwaters annually reach levels which are too deep for short-statured rice of the IR8 type. Few of the new varieties are adapted to upland conditions where about 10% of the world's rice is grown. Most of the high yielding rices are not suited to conditions of low temperatures common in areas of high elevation, or to saline conditions which characterize coastal saltwater areas and inland regions of saline and alkali soils.

A third factor which may limit food production levels in rice-growing countries is the cropping systems in which the rice is grown. In the later 1960's, Dr. Richard Bradfield and scientists in national food production programs called attention to the potential for total food production in the tropics. Their work suggested that rice farmers in the tropics were not utilizing to capacity their available soil, water, and climatic resources. The total production of rice and other crops on Dr. Bradfield's plots was four to ten times greater than that produced by farmers in the vicinity.

IRRI's research and training programs have been modified during the past few years to place additional emphasis on each of those three major factors. In cooperation with scientists from other countries, IRRI is endeavoring to identify the constraints on the yields and production of rice—whether the constraints be biological, physical, economic, or social—and to seek ways to overcome them. A network of cooperating scientists are addressing those problems.

IRRI's Genetic Evaluation and Utilization (GEU) program is being expanded to place in the hands of cooperators in national research organizations rice genetic resources with resistance or tolerance to the major factors constraining yields. A greatly expanded rice germ plasm bank, an enlarged crossing program, and the International Rice Testing Program are working to develop rices that will yield well under the numerous adverse conditions under which rice is grown.

You are here this week for discussions of a third area of expansion in IRRI's programs. In cooperation with scientists from national programs, IRRI has also expanded its research and training concerned with rice-based cropping systems. Those efforts are designed to help the world's rice farmers make more effective use of their available human and natural resources.

In 1972, the Institute decided to expand its efforts on cropping systems, and financial support was obtained in 1973. Seven senior scientists joined the staff to assist in the effort. Also, the research objectives of departments concerned only with rice were modified to take into consideration the objectives of the rice-based cropping systems program.

Because cropping systems are dictated largely by local environments, IRRI's expanded research and training efforts have been strongly oriented toward field applications. The traditional procedure of doing preliminary research work in the laboratory, greenhouse, and experimental fields prior to taking results to the farmers has been changed. Although some work is done at the IRRI experiment station and in the Institute's greenhouses and laboratories, most of IRRI's rice-based cropping systems research is conducted on farmers' fields. The farmer, his family, and his labor supply become components of the research process. Furthermore, the new knowledge is expected to be applicable to farm conditions.

Cropping systems research requires an interdisciplinary effort seldom achieved by scientists working on only one crop. It also requires the careful selection of field research sites that must be representative of sizable, important, agroclimatic zones, so that the results can be applied over reasonably wide geographical areas.

Many scientists participating in this symposium today helped to develop the basic strategy for an international, rice-based, cropping systems program with which IRRI is associated. They are currently planning and implementing innovative rice-based cropping systems. They are involved in research to characterize the soil and climatic environments where rice-based cropping systems are located, as well as in efforts to educate and train others in improved cropping systems.

The cropping systems concepts and techniques which this group of cooperating scientists has developed are innovative and unique. This symposium will provide an opportunity to further develop those concepts to refine the techniques. Also, through the published proceedings of this symposium, the participating scientists will share their knowledge and discussions with thousands of scientists throughout the world who are interested in cropping systems generally and in rice-based systems in particular.

We at IRRI are grateful to you for your attendance and participation. We appreciate the efforts of the organizing committee headed by Drs. Zandstra, Carañgal and Vega, who arranged the four-day program. We are especially indebted to the Ministry of Economic Development of the German Federal Republic for generous financial support of this symposium, and to the International Development Research Centre (IDRC) of Canada and to the Government of Japan for their support of the Institute's overall cropping systems research and training program.

Lastly, we wish you success in making your presentations and in the productive discussions that they will stimulate.

WELCOME ADDRESS

W. Treitz

Dr. Brady,
Ladies and gentlemen:

I consider it a great honor and privilege to address the participants and organizers of this symposium on behalf of the Government of the Federal Republic of Germany and especially of the Federal Ministry of Economic Cooperation.

Furthermore, I have been asked by the Ambassador of the Federal Republic of Germany, Mr. Wolfgang Eger, to say that to his regret he is not able to attend this symposium. He conveys his best wishes for a successful execution of it.

Ladies and gentlemen, it is not by chance that the German Government is sponsoring this symposium. In a world where more than 400 million people are suffering from malnutrition and undernourishment and where population is growing at a very fast rate, the rapid increase of agricultural production is one of the main problems humanity is facing today. It is for this reason that my government is giving the agricultural sector highest priority in its assistance program. This includes a great number of bilateral technical assistance projects, and financial aid for agricultural investments and for the supply of production means such as fertilizers, seed and plant protection material. This assistance program is supplemented by substantial contributions to a large number of international organizations such as the European Community, UNDP, World Bank, FAO. The German Government pays special attention that an appropriate share of the development program of these institutions will be conveyed to the agricultural sector.

We all do know that the basis for agricultural development is research. Contrary to that in industrialized countries, agricultural research for the tropical, subtropical and semiarid areas is still at a beginning, especially if the focus is on food crops. Only during the last years through the Consultative Group on International Agricultural Research (CGIAR) has a systematic approach to that problem been found. This group, consisting of a number of donor countries, development agencies and private foundations, finances a number of international research centers, of which IRRI is one. Through these international research centers, the most important food crops are studied and developed. The results of this work, especially from the so-called older centers like IRRI and CIMMYT, are well known to us.

My government, being a member of the CGIAR from its very beginning, has increased its financial contributions during the last years at a very fast rate, namely, from 2.8 million US$ in 1974 to 4.0 million US$ in 1975 and 4.8 million US$ in 1976. For 1977, an amount of 5.6 million US$ will be available. Most of these funds are direct budget contributions to research centers maintained by the CGIAR, including CIMMYT, CIAT, CIP, ICRISAT, IITA, ILCA, ILRAD, IRRI, and ICARDA.

However, it is the intention of the German Government to assist CGIAR not only by financial means but also through scientific cooperation. I do hope that through this symposium, research links can be established between German research institutes on one hand and IRRI as well as other research centers in tropical countries on the other hand.

I wish that the organizers of and all participants in this symposium may establish fruitful scientific links, and that the results of this symposium will lead directly or indirectly to an improvement of the living conditions of a great number of underprivileged people in this world.

Thank you.

Framework for cropping systems research and development for the Asian-rice farmer

CROPPING SYSTEMS RESEARCH FOR THE ASIAN RICE FARMER

H.G. Zandstra

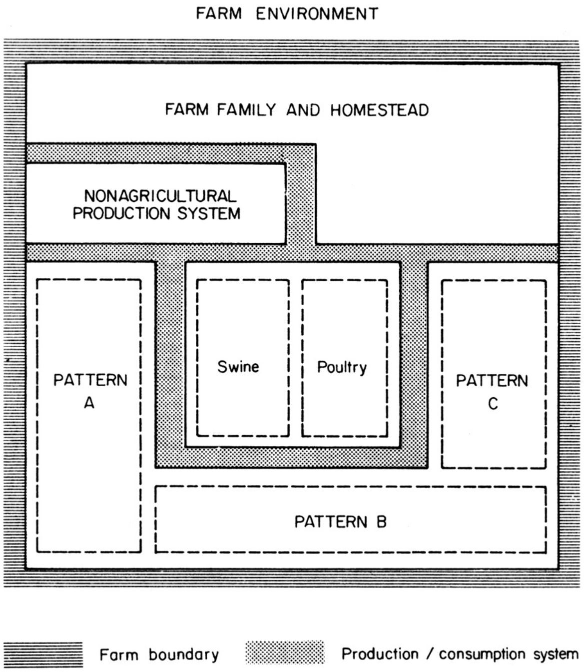
Cropping systems research is not a widely understood concept. It is generally recognized to cover a broad subject matter area, making an interdisciplinary approach necessary. But there is less agreement about the characteristics that set it apart from agronomic research and from resource management. The difference between cropping systems research and farming systems research also merits clarification. Before we consider the research process involved, further definition of the cropping systems research concept appears in order.

In general, cropping systems research seeks to increase the benefits derived by crop production from available physical resources (such as rainfall, solar radiation, available irrigation, or certain soil types) that are not readily changed. It differs from resource management, which concerns itself with the increase in quantity and quality of resources available for production or other processes. It also differs from agronomic research which seeks to optimize input levels of such variable crop production factors as fertilizers and insecticides. Whereas agronomic research increases the resource-use efficiency of a given crop, cropping systems research in its quest for more efficient utilization of physical resources, considers the cropping pattern[1] as a variable.

Strictly speaking, therefore, the objective of cropping systems research is to increase the efficiency of use of a given quality and quantity of physical resources in crop production. The physical resources considered important to crop production are land, water, and solar radiation. The

[1]The spatial and temporal combination of cultivars in any one plot. Generally time is limited to one year, and a plot is defined as a contiguous area of plant planted in a homogeneous manner during the defined period.

H.G. Zandstra. Head, Cropping Systems Program, Department of Multiple Cropping, The International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines,



1. Schematic presentation of small family farm.

efficiency of their use is generally measured by the quantity of crop produced per unit of resource in a unit of time. Crop production may be expressed in produce weight, protein weight, calories, or monetary units.

Most farms, particularly small ones in developing countries, combine several production activities. In fact, the farm can best be considered a combination of production and consumption activities (Fig. 1). Farming systems research addresses itself to each of the farm's enterprises, and to the interrelationships among these enterprises and between the farm and its environment. It employs information about the farm's various production and consumption systems and about the farm environment (physical-institutional, social, and economic) to increase the efficiency with which the farm utilizes its resources. Cropping systems research, on the other hand, is confined to the farm's crop-production enterprises. It takes into account relationships among the various crop-production activities, between the crop-production enterprise and other production or consumption activities on the farm, or both, and between other environmental factors (physical, institutional, social, and economic) and the farm's crop-production enterprise. Strictly speaking, cropping systems research isolates the crop-production enterprise. It does not address itself to changes in resource allocations between the farm's production and consumption activities and, therefore, considers existing resource interrelationships between these activities and the crop-production enterprise as given.

The differences among the roles of cropping systems research, agronomy, farming systems research, and resource management are, undoubtedly and fortunately, not strictly observed by scientists. An agronomist may pursue his research to the point of suggesting changes in seeding dates or planting arrangements that change a cropping pattern. The cropping systems researcher will often strive for redistribution of resources within the farm or, having identified production potentials, may actively pursue improvements in the physical resource base of the farm through irrigation; by so doing, he moves into farming systems or resource management. More frequently, cropping systems research suggests crop varieties and specific management practices, in order to evaluate their relative performance in different environments. At that point, advantageous modifications in the component technology (Harwood, 1975) may turn the process into an agronomic-research activity.

CROPPING SYSTEMS

The productive base of a cropping system is plant growth, which is influenced by environment and management. Environmental conditions are factors that influence plant growth but are not subject to modification by management.[2] Plant growth and crop yield ($\bar{Y}$) can then be considered to be the result of two multidimensional vectors, the environment ($\bar{E}$) and management ($\bar{M}$), so that

$$\bar{Y} = f(\bar{M}, \bar{E}) \qquad (1)^3$$

For the cropping systems researcher, management includes the type and arrangement of crops in time and space (the cropping pattern) and their management. It covers the choice of variety, and the methods of crop establishment, fertilization, pest management (weeds, insects, diseases), and harvest (component technology) for all crops in the pattern. The environment is composed of such land- and climate-related variables as available rainfall and irrigation, textural profile of the soil, phreatic level, soil toxicities, the topographic position of the field, use or nonuse of bunding, day length, solar radiation, and temperature, and of the availability of such resources as power, labor, and cash (Beek and Bennema,

[2] Note that this is a default relation: The set of environmental variables considered is a result of the researchers' decision about the extent to which he controls environment by management.

[3] This treatment was inspired by the treatment of soybean development (Y) used by Keller et al. (1973).

1972; Harwood, 1974). The distribution of many farm resources, such as land qualities, water, and access to information, credit, and markets, is not homogeneous among farms within a region, and generally reflects transactional relations existing in the region.

The economic performance of the cropping systems depends, of course, on additional factors such as the cost of capital and material inputs, and product prices. In the economic evaluation of cropping systems, those factors should be incorporated into the vector for the environment—if the researcher does not plan to change them—or they can be incorporated into the management vector if the researcher does plan to change them. The latter case applies, for example, to studies of institutional constraints on increased crop production, which consider the desirability of changes in input costs, product prices, or credit availability. Those variables are, in effect, moved into the realm of crop production management. Cropping systems researchers more often than not predict the values of those factors, and incorporate the values into the environment vector, treating them as invariants. Resource management, farming systems, cropping systems, and agronomy also tend to treat factors influencing crop production differently (Table 1). That leads to a different specification of the environment vector $\bar{E}$ and the management vector $\bar{M}$ in each type of research.

To evaluate the relation $\bar{Y} = f(\bar{M}, \bar{E})$, the cropping systems researcher focuses on the interaction between $\bar{E}$ and $\bar{M}$, and seeks to determine how he should vary his cropping patterns $\bar{M}$ to optimize returns for different production environments. From his understanding of the relation $\bar{Y} = f(\bar{M}, \bar{E})$, he seeks to predict the best management vector $\bar{M}$ from information about the environment factor $\bar{E}$. The estimation of $\bar{Y} = f(\bar{M}, \bar{E})$ is the primary activity of cropping systems research and will be discussed in an

Table 1. Differences in the way various research activities treat factors influencing crop production.[a]

Research activity	Physical resources			Economic resources (power, cash, labor)				
	To farm	Within farm	Within crop production	To farm	Within farm	Within crop production	Crop	Management
Resource management	△	△	△=	=	=	=	=	=
Farming systems	=	△	△	=	△	△	△	= △
Cropping systems	=	=	△	=	=	△	△	△
Institutional constraints	=	=	=	△	△	△	=	=
Agronomy	=	=	=	=	=	=	=	△

[a] △ : treated as variable; =: treated as invariant.

introductory fashion in this paper, and in detail in the papers presented in following sessions of this symposium.

Because $\overline{Y} = f(\overline{M}, \overline{E})$ refers to a wide variety of crop production environments, the cropping systems researcher must eventually come up with a statement about the effect of different management practices on cropping systems performance for a given environment. His recommendation must specify the management vector and the environment for which he recommends it. To do so he evaluates:

$$\overline{Y} = f_i\ (\overline{M} | \overline{E}_i) \tag{2}$$

That function describes the relation of the management vector $\overline{M}$ to the crop production vector $\overline{Y}$ for a specific environment $\overline{E}_i$. Operationally, the transfer from equation 1 to equation 2 changes the environmental vector from a vector of variables to one of fixed constraints. Interaction terms in $\overline{E}$ and $\overline{M}$ of equation 1 become, therefore, terms in $\overline{M}$ only, for equation 2.

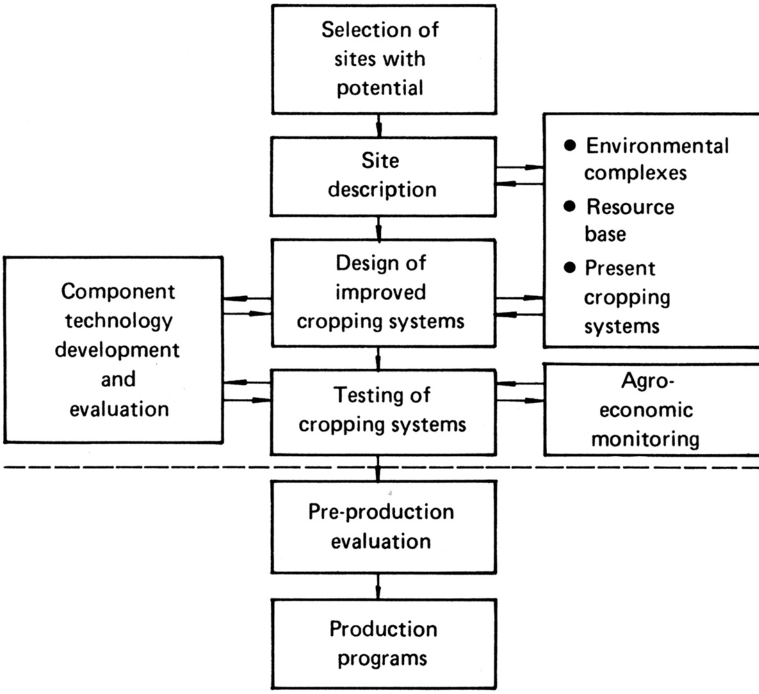
By evaluating equation 2 for selected performance criteria ($\overline{Y}$ may represent yearly returns per hectare to land and family labor, or yearly protein yield per millimeter of rain), the researcher can identify management vectors that result in high performance and recommend them for the cropping systems. Similarly, by measuring the farmers' $\overline{M}$ and $\overline{E}$, the researcher can specify the existing cropping systems as a crop production process that is used to derive benefits in a given environment. The production process is described in terms of cropping patterns and their management $\overline{M}$, and the environment is described in terms of physical and economic resources and conditions. On these bases, a cropping system can be defined as the cropping patterns and their management used to derive benefits from a given resource base under specific environmental conditions.[4] The term cropping system can be applied to the farm (Fig. 1) or to a region.

THE CROPPING SYSTEMS RESEARCH PROCESS

Site selection. To increase benefits derived from the physical resources available to the cropping system, the researcher identifies and tests alternative cropping patterns and management practices. Considerable emphasis is given to crop intensification as a means of utilizing slack resources encountered in existing cropping systems.

In his choice of the management vector (cropping system), the researcher must address himself to a specific environment, because cropping systems

[4]A single cropping pattern and its management can be looked upon as a subsystem, but the interrelations with other subsystems within the cropping system must also be taken into account



2. Components of IRRI's Cropping Systems Program.

are site specific. In terms of equation 1, the vector $\bar{M}$ which results in an optimal $\bar{Y}$ depends on the value of $\bar{E}$. The first step in the general cropping systems research process (Fig. 2) as specified by the Cropping Systems Working Group (1975) is, therefore, the selection of sites that have potential for increased cropping intensity. Dr. V.R. Carangal, the next speaker in this symposium, will describe in detail the criteria used for site selection.

One of these criteria is the estimated potential for crop intensification. The estimate is based on knowledge about the relation between the environment and the crop intensification potential of several agroclimatic regions. Undoubtedly, the extent to which the potential for crop intensification can be estimated depends on how well the relation $\bar{Y} = f(\bar{M}, \bar{E})$ is understood and how well the environment has been defined. In effect, the estimate involves the same process as that described for cropping systems design, but it uses limited information about the environment.

For a reliable estimate of the crop intensification potential of different agroclimatic regions, results of cropping systems research at IRRI and elsewhere are applied to environmental classifications (climate and land). Examples are the recently published agroclimatic maps of Java (Oldeman, 1975), Bangladesh (Manalo, 1976), and the Philippines. Continuous interpretation of cropping systems research results obtained from different, well-described (see next section of this paper) environments will provide the source material for a more precise classification of cropping systems potentials.

Site description. The first activity of the cropping systems researcher is to describe the existing cropping systems in a selected area. The researcher needs to identify the different production complexes of the region and to relate them to physical and economic differences in the enviroment. An example of environment classification based on production complexes is that used in Lampung, Indonesia, where irrigation regimes and settlement periods were used to stratify the environment. Another example based on environmental complexes (the production complex was dominantly rice-fallow) is that used in the IRRI-BPI (Bureau of Plant Industry, Philippines) site at Iloilo. There, soil texture and topographic position were used to classify the environment. The use of environmental stratification in the testing of cropping patterns will be discussed by Dr. K.A. Gomez during this symposium.

The cropping systems in the different production complexes represent the vectors $\overline{M}$ selected by farmers to fit the different environments $\overline{E}_i$. Unless the relationships between the actual cropping systems and the environment are thoroughly understood, it will be difficult to judge the impact of alternative cropping patterns. There has been considerable debate about how accurate a farmer is in trying to choose the optimum $\overline{M}$ for his environment $\overline{E}_i$. Assuming optimum $\overline{M}$, researchers have no alternative but to change $\overline{E}_i$ (structural intervention) or to resort to management techniques (additional components of $\overline{M}$) that have not been evaluated by farmers, thus removing the information-processing constraint. Identification of the structural and informational (component technology) constraints can be of great help in the design of improved cropping systems.

The estimate of the crop-intensification potential of a region also depends on the extent to which the environment vector $\overline{E}_i$ can be specified. Once $\overline{E}_i$ is specified, the most appropriate cropping systems can be identified using the relation $\overline{Y} = f(\overline{M}, \overline{E})$. If an adequate description of the environment and the current cropping systems of a region is available, cropping systems researchers can limit to a consirable degree the number of cropping patterns to be field tested.

To improve on this design capability so that more confident predictions can be made, not only of the cropping patterns best suited to a specific environmental complex, but also of the performance of those and other patterns in that complex, cropping systems researchers must become more adept at measuring the environmental vectors. A recent workshop on Environmental Factors in Cropping Systems has provided a framework within which to relate these factors to cropping systems potential (Zandstra, 1976b):

1. Environmental factors include physical resources (climate- and land-related), economic resources (availability of land, labor, cash, power, equipment, and materials) and socioeconomic conditions, product prices, input costs, marketing costs, and customs reflecting preference for certain foods or management practices.

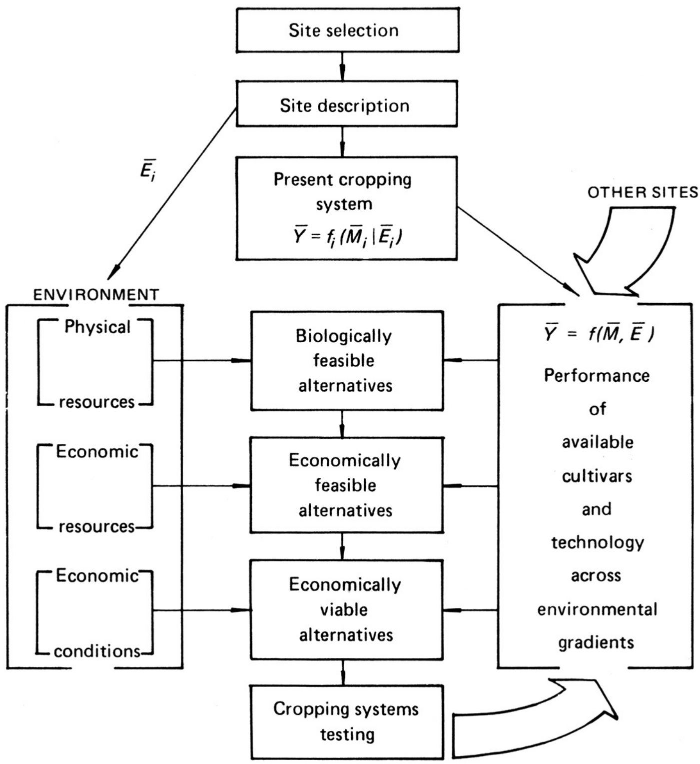
2. The cropping systems researcher specifies the factors he wants to operate on, and those he wants to consider invariant. The first set will be included in the management vector (subject to optimization), and the second set will be part of the environment vector of equation 1.

3. In environmental classification, readily modifiable physical factors should be excluded: nitrogen and phosphorus fertility; easily corrected, microelement deficiencies; and the normal incidence of pests. The relation $\overline{Y} = (\overline{M}, \overline{E})$ is thus reduced to one in which standard crop-management practices in $\overline{M}$ are assumed to correct for variations in the readily modifiable factors in $\overline{E}$. Those factors remaining in $\overline{E}$ are cropping-pattern determinants and should be used for environmental classification.

4. A union of sites that have similar cropping pattern determinants is defined as an environmental complex; a union of sites in which the relative performance of cropping patterns is substantially the same is defined as a production complex (Zandstra, 1976a). A production complex is measured by cropping pattern performance and is, as such, an ecological unit. It may contain more than one environmental complex because there are various ways in which cropping pattern determinants can interact to produce a particular cropping pattern performance. Rubel (1935) referred to this as the replaceability of factors. If the performance of cropping patterns is substantially different for any subset of sites within an environmental complex, one or more important determinants must have been overlooked in the description and specification of that complex.

Substantial progress has been made in the identification of physical cropping pattern determinants (FAO, 1971 ; IRRI, 1974), but their measurement and the measurement of associated pattern performance have been sadly lacking.[5] In addition, the analysis and interpretation of research results has more often than not been related to the site and not to the environmental characteristics of the site.

[5] During the Fourth Cropping Systems Working Group Meeting (IRRI, 20 and 27 Sept. 1976) more concrete methods for site description, covering physical-biological as well as socioeconomic aspects, were discussed.



3. Schematic presentation of the design of alternative cropping systems for a selected environment.

Cropping systems design. In terms of equation 1, cropping systems design is the specification of the management vector $\bar{M}$. The Asian Cropping Systems Working Group (1976) defined it as a synthetic activity which employs the physical and socioeconomic site characteristics obtained at the descriptive stage, together with knowledge of the effect of those characteristics on the performance of cropping patterns, to identify intensified patterns that are well adapted to the site.

The design activity (Fig. 3) is focused on a certain environmental complex. A limited assembly of practices from the available component technology can be employed in design. The technology includes cultivars; tillage practices; planting methods; plant population considerations; knowledge of optimal spatial relations between intercrops; crop interactions; effects of crop combinations and cropping sequences on weeds, insects, and diseases; water management methods; and pest control methods (by hand, pesticides, crop resistance, or escape). The technology also includes accumulated knowledge about the performance of cultivars and about the management practices listed above, under the conditions specified in the environmental vector. Among those conditions are drought, saturated soil, high precipitation and humidity during the crop-establishment and harvest periods, temperature and day-length variations, extreme soil conditions, and predictable flooding.

Cropping systems program specialists have gained considerable experience in the management of various crop intensification techniques such as intercropping, relay cropping, sequential cropping and ratoon cropping (Herrera and Harwood, 1973; Baker and Norman, 1975). Intercrops and relay crops have been found to use available light more efficiently. By choosing cultivars, planting times, and spatial arrangements, crops can be ordered with heights and densities that extend the time of full leaf spread, with maximum leaf area occurring for each component crop while high solar energy is available to its canopy (Herrera and Harwood, 1973; Sooksathan and Harwood, 1976). Nutrient uptake and utilization have proved more efficient in corn-rice and corn-soybean intercrops than in those crops as monocultures (Suryatna and Harwood, 1976). In addition, intercropping provides a mechanism to reduce the effects of insects and diseases (such as corn borer and downy mildew) on production (Suryatna and Harwood, 1976). Canopy manipulation can also be used to reduce weed populations (Litsinger and Moody, 1976). Intercropping can mitigate losses from damage to one crop through compensatory yield of other crops in the canopy. (For simulated canopy loss, see Liboon and Harwood, 1976; for reduction of drought risks see description of the corn/sorghum intercrop used in El Salvador by Cutie, 1975.) The effects combine so that most well-designed intercrops have overall production that is 30 to 60% higher than that of sole crops (Herrera and Harwood, 1973; Syarifuddin et al., 1974). Yearly labor requirements of intercropped patterns are higher than those of monoculture, but the labor demand is better distributed throughout the year (Norman, 1970).

Intensification of cropping systems for rainfed or irrigated paddy rice primarily involves the addition of crops to the sequence. Where monthly rainfall is high (> 200 mm) for 4 to 5 months, the rice crop can generally be followed by an upland crop or intercrop. When 6 to 8 months of high rainfall are expected, a double-cropping pattern with paddy rice can be established. That pattern often requires the use of early maturing varieties and dry seeding of the first crop. In addition to a double rice crop, drought-tolerant upland crops can follow rice to utilize available soil moisture and low rainfall during the tail end of the rainy season (Harwood and Price, 1976; Herrera et al., 1976). The discussion above does not take into account important effects of soil texture and topographic position, which substantially modify the cropping pattern potential in paddy rice systems. The topographic position of a paddy determines whether farmers can accumulate water from other paddies for a rice crop; whether they can drain the paddy when needed, for good establishment of a direct-seeded crop (wet or dry); or whether they can shift to upland crops while rainfall has not completely subsided. Light-textured soils have shown much less potential for double-rice cropping patterns, but they allow great flexibility for the establishment of upland crops after rice (Palada, et al., 1976; IRRI, 1976). The quality of cropping systems design will improve as more information becomes available on the performance of crops and management techniques in different environments.

The process of cropping systems design (Fig. 3) by necessity employs certain criteria. Those criteria have been poorly defined, and the question of whether or not the design phase should include estimates of cropping-pattern performance has arisen (Asian Cropping Systems Working Group, 1976). It is at times felt that the available resources and a pattern's resource requirements should provide adequate design criteria. Simply stated, the resources required by the pattern should be available. Such treatment ignores the fact that cropping pattern performance is a continuous function of available resources, and that an all-or-nothing argument rarely applies when fitting a pattern to a specific environment. Another difficulty arises in determining the resources available to the cropping pattern. The resources are most easily determined by substitution; slack resources of the farming system are added to the resources used by the cropping pattern that is to be changed. A more rigorous treatment (as a resource allocation problem) requires linear programming or similar routines for optimizing the total cropping system[6] or farming system. That demands knowledge of the performance of all the component activities of the system as a function of resource allocation, which goes far beyond an approximate estimate of cropping pattern performance.

The usefulness of expected pattern-performance as a design criterion depends, of course, on the accuracy with which performance can be estimated prior to testing in farmers' fields. The estimate is generally obtained by extrapolating the measured performance of patterns or component crops from similar environments. The expected performance can then be compared with that of the cropping pattern it is intended to replace, or with more general performance criteria based on studies of farmers' decision-making (Zandstra et al., 1975).

[6]In which case the substitution principle is applied to the cropping system, considering resource allocation to other production or consumption activities on the farm, or both, as fixed.

Table 2. Grain yields per millimeter of rain at Batangas and Los Baños for six upland rice-based cropping patterns. Rainfall varied from 1826 to 2262 mm/crop year.

Cropping pattern	Batangas 1974[a]	Batangas 1975[b]	Los Baños 1975[b]
Rice–corn	1.3 (17)[c]	3.3 (3)	2.8 (1)
Rice–sorghum–sorghum (ratoon)	2.1 (11)	3.4 (3)	3.0 (1)
Rice–mung beans	0.8 (15)	1.7 (3)	1.6 (1)
Rice–soybean	1.0 (3)	1.8 (3)	1.8 (1)
Rice–peanut	1.0 (3)	2.1 (3)	2.2 (1)
Rice	0.6 (10)	1.4 (18)	1.5 (1)

[a] Low management and critical drought during rice crop. [b] High management. [c] Numbers in parentheses represent number of patterns tested.

There is a great need to incorporate present knowledge of farmers' decision-making into manageable design criteria. These criteria should probably include returns to cash, labor, and land compared to their cost in the region; cash requirement compared to its availability; the required level of indebtedness compared to actual cash income of the farm; and risk as a function of yield variations (preferably the subjective estimates of farmers) and levels of cash input. Another criterion to consider is the return to the factor most critically limiting to crop intensification: available water. The efficiency of the use of rainfall by cropping patterns, tested in farmers' fields under upland and rainfed bunded situations, varied widely; but that of the most efficient patterns reached 3 or 4 kg/mm rain (Tables 2, 3). They are similar to those obtained by Rastogi (1974) and by Krantz and Kampen (1974); the indexes may provide a point of comparison

Table 3. Grain yields and net returns per millimetear of rain of 11 cropping patterns in a rainfed, bunded rice-growing area, Iloilo 1975.[a]

Cropping pattern	Tested	Total yield (kg grain/mm)	Returns[b] (USS/mm)
Rice	10	1.7	0.12
Rice–corn	8	3.3	0.15
Rice–sorghum	3	3.2	0.16
Rice–corn/peanuts	2	2.7	0.50
Rice–corn/mungbeans	2	2.1	0.09
Rice–mungbeans	9	2.2	0.12
Rice–cowpeas	10	2.2	0.10
Rice–soybeans	6	2.0	0.07
Rice–soybeans	6	2.1	0.34
Rice–rice	31	4.5	0.32
Rice–rice–pulses	13	4.7	0.29

[a] Rainfall during crop season ranged from 1,882 to 2,114 mm among locations. [b] Returns over variable costs, including family and exchange labor, but excluding cost of land.

for the efficiency of cropping systems with different rainfall regimes. Equally important design criteria relate to biological stability. They include maintenance of soil fertility and the prevention of erosion, of buildup of pests, and of reduction in subsoil water availability.

A final question is raised about the relation between design criteria and criteria used to evaluate the performance of cropping patterns in field tests. If ex-ante performance estimates are to be used for cropping pattern design, should design criteria be different from the criteria applied to the ex-post analyses of cropping patterns tested in the field? The issues raised require further definition to arrive at a clearer framework for the cropping systems research process discussed in this paper.

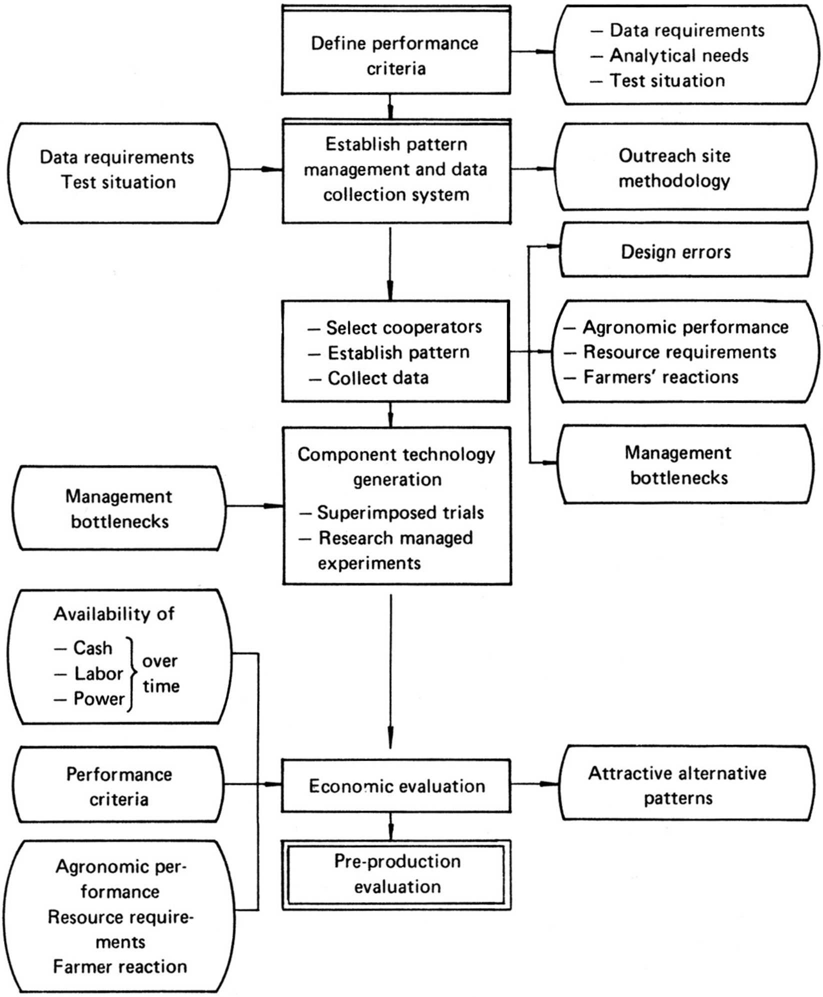
Cropping systems testing. While cropping patterns and their management are being tested in farmers' fields, the assumptions made in the cropping systems research process, particularly those at the design stage, are to be verified. The assumptions are:

1. The proposed system is biologically suited to an important physical environmental complex of the site. Yields of crops in the pattern should therefore be adequate, and biological instability should not occur.
2. The system's requirement for economic resources, such as cash, labor, and power can be met.
3. The management of the specified pattern is optimal.
4. The system satisfies economic performance criteria such as net returns to farm resources[7] and returns to cash inputs.

The testing process (Fig. 4) requires more time and research personnel than the other activities described in the cropping systems research process (Fig. 2). The monitoring of patterns and the data collection system must be both manageable and sufficiently rigorous to allow reliable estimates of the cropping pattern's performance, its resource requirements, and the farmers' reactions to it. Identified management bottlenecks should be attacked preferably at the research station, but may at times require on-site studies.

A major activity of cropping pattern testing is the fine tuning of the component technology. It is rare that the management identified at the design stage is adequate. For this reason, on-site research compares different varieties, planting methods, fertilizer regimes, and insect- and weed-management methods. A pattern's agronomic performance, its input requirements and its optimal component technology allow an economic evaluation of its suitability according to the performance criteria established for that purpose.

[7] I feel that, because of farmers' control over on-farm resources (land, farmer's time, family labor including exchange labor, water, light, and farm implements), the net returns to these resources provide a useful estimate of the overall benefit derived from a cropping system by the farm enterprise.



4. Testing of cropping patterns.

The specific details of cropping systems testing are treated in the third session of this symposium, and I will confine myself to a short discussion of one aspect of the testing methodology: the nature of on-farm cropping pattern testing. By on-farm testing I mean testing on farmers' fields of patterns that are managed by farmers (Harwood, 1975).

It can be argued that there are efficient research methods for testing the first and third assumptions listed above, at research stations or under research management in farmers' fields. After an initial investment in measurement and surveys, the time and labor requirements of most operations can be estimated with sufficient accuracy to allow testing of the second and fourth assumptions. Why, then, insist on farmers' management and large plots (700–1000 sq m) for cropping pattern testing? The reasons, gathered from IRRI's cropping systems program, are the following:

1. Many management problems do not manifest themselves in small plots, because the researcher who has complete control over timing of operations often makes subtle modifications in pattern management to avoid problems. The site of research-managed trials is rarely selected at random within a defined environmental complex, and is often determined with the experiment in mind.
2. Resource conflicts between the proposed cropping system and existing systems are difficult to measure in research-managed trials, because labor and power inputs are supplied by the researcher.
3. Farmers' modifications of cropping patterns and their management, particularly the timing of operations, are telltale indications of resource conflicts. Farmers' observations, although not easily interpreted, provide variable insights into the potential and the limitations of cropping systems tested under their management.
4. By using superimposed treatments that do not interfere with the farmers‘ operations, the component technology specified for a pattern can be more realistically evaluated under farmers' management in research-managed trials.

Those reasons all point to a need to expose the researcher to the farmers' reality and to arrive at an interactive method for identifying new cropping systems. Undoubtedly that requires a careful structuring of the test situation to which the farmer is exposed. Farmers' observations must be interpreted with caution, and the interpretations must be fed back to the farmers for verification.

I consider that the structuring of the relationship between cropping systems researchers and the farmer merits study by the Cropping Systems Working Group. An additional subject for further discussion and research is the performance criteria for cropping patterns. As stated before, this issue affects both the design and testing of cropping patterns.

Applied research and preproduction testing. Applied research evaluates alternative cropping patterns at many sites that are representative of the environmental complexes for which the patterns were designed. The specification of the environmental complex is important. Applied-research testing not only must provide extension or production agencies with alternative cropping systems with clearly specified management; it must also clearly delineate the situations to which those cropping systems are adapted. The domains of adaptation of recommended cropping systems must therefore be specified in terms that can be used to differentiate the action of production programs for different environments. That requires that the domain be mapped or associated with existing geographical boundaries, or be described in site-differentiating terms, such as soil texture or drainage characteristics, that can be handled by extension agents on the basis of simple observation.

A combination of methods for stratifying recommendations for alternative cropping systems is usually required in order to fit the recommendation to the varying environments encountered. The fine adjustment of a recommendation to the environment is directly reflected in the increased benefits derived from the recommendation and the reduced risks associated with its adoption (Table 4). In cropping systems research, the recommendations are prone to vary even more widely than those for P-fertilization illustrated in Table 4, and the increased benefits and reduced risks obtained from an appropriate stratification of cropping systems recommendations will undoubtedly be more substantial.

It is not easy to achieve location specificity for recommended cropping systems, because applied research is situated at a crossroads of institutional activity. Applied research draws on research institutions as the source (or sanction) of new technology; it transmits its own results to organizations responsible for the formulation of production programs. Because of this institutional complexity, I contend, a thorough regionalization of research and extension is the most efficient way to achieve location specificity for cropping systems recommendations. Development research, applied research, and extension activities should be formulated area by area. Each area must be described in terms of environment, resources, socioeconomic

Table 4. Estimated phosphorus requirements and net gains and risks associated with four P-recommendation strategies based on geographical divisions of Eastern Cundinamarca (Colombia). [a]

Strategy	P_2O_5 (kg/ha)		Expected	Risk [c]
	Recommended	Required [b]	gain (US$/ha)	(US$/ha)
Five townships combined	20	20	8.30	7.90
Two groups of townships	0,41	15	12.60	6.20
Three groups of townships	0,19,41	18	15.30	7.20
Separate townships	0,14,18, 20,41	20	15.70	5.90

[a] From Zandstra, 1974. [b] Assuming all corn farmers applied recommended rate. [c] Expected loss of those who applied the recommended rate.

condition, and existing cropping patterns. Research and extension can then be addressed to a specific region along the lines very much like those described for the cropping systems research process (Fig. 2). Once classified as to environment, a site can utilize results from studies of similar environments. It can also be useful to biological researchers developing new component technology, and to researchers working with such agricultural development processes as the adoption of new technology, constraints to increased production, and institutional analysis.

Preproduction testing follows applied research. It focuses on training of extension personnel and on discovering the availability of credit, seed, and agricultural chemicals. In general, it identifies and prepares the institutions and personnel required for implementation of recommended practices on a wide scale. Preproduction testing also evaluates the performance of a recommended practice on a large scale.

One difficulty with production programs that seek to change farmers' cropping systems lies in the great variety of crops involved. Each crop has its own specific management package, its own credit and input requirements, and its own critical location in a cropping sequence and in a specific environment. That is a lot of information to carry through a delivery system, and the production program methods to be used will undoubtedly require critical assessment. The final session of this symposium treats the organizational and institutional aspects of that important methodology of agricultural development.

CONCLUSION

Cropping systems research can substantially increase food production and income for Asian rice farmers. The cropping systems research process developed by the Asian Cropping Systems Working Group provides a useful framework for an attack on the complex interactions between cropping systems performance and environment. In that framework, research deals progressively (or at times simultaneously) with site selection, site description, cropping systems design, component technology generation, cropping systems testing, and preproduction testing, leading finally to the formulation of production programs.

A number of major research areas, however, continue to call for strengthening. Today we need:

1. An adequate description of the environment in terms of the determinants of cropping system performance.
2. A methodology to analyze and interpret the biological performance of cropping patterns as a function of the physical environment.

3. The development of cropping systems performance criteria.

4. Continuing evaluation of component technology under different environmental conditions, with particular emphasis on creating a wide array of varietal alternatives, crop establishment methods, and insect- and weed-management techniques.

5. A clear understanding of each test situation by both researchers and farmers, to allow an efficient combination of the farmers' experiences and the researchers' expertise.

6. A critical evaluation of the institutions that are needed to assure the success of production programs based on cropping systems research.

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DISCUSSION

HOQUE: Because of the site dependency of cropping pattern adaptation, IRRI's cropping systems program has been very active in the development of cropping systems research sites in the Philippines and throughout the network. Do you think that IRRI still needs to continue to refine basic concepts, principles, and methodologies for the advancement of the science of cropping systems, and that it needs to place its emphasis on the development of component technology? This appears to be an important and suitable role for IRRI's program because of its high capability, resources, and excellent facilities.

Zandstra: Your question addresses itself to many important aspects of IRRI's cropping systems program and its present focus. The major information requirements for a further increase in the capacity of cropping systems researchers to contribute to increased food production lie probably in a better understanding of the relation between environmental factors and the performance of cropping patterns. This has led to the present emphasis of IRRI's program on the establishment of cooperative research sites under different environmental conditions. The time has now come to specify measurement and testing methodologies that will allow the organizations cooperating in the Asian Cropping Systems Network to pool their observations. In this way, crop intensification potential can become understood as a function of the environment, and results obtained can be extrapolated to sites with similar conditions. In this effort we are indeed continuing to invest a lot of our time and personnel in the area of component technology research (the identification of management techniques and their performance in different environments). The reason for this is that the array of component technology available to a cropping systems researcher very much determines how well he will be able to utilize the environmental resources available to him. Crop intensification successes invariably can be traced back to the recent advent of component technology that has enabled this intensification. Important examples of such components are short-duration varieties, crop-establishment techniques, relay and intercropping techniques, disease-resistant varieties, and crop species previously not common to a region.

SOMNUK: In your presentation you emphasize the importance of determining physical or biological feasibility in cropping systems design. Do you not consider that economic conditions such as demand and market relations eventually determine the suitability of intensified cropping systems for a region? If so, why do you consider biological suitability of such importance?

In addition, the biological performance of a cropping system does not take into account the economic and political objectives of a country which may address themselves to regional disparities in income and land and labor utilization or to income distribution within a region. Don't you think that cropping systems researchers of different countries should formulate their work according to the situation that prevails in their country with respect to these factors?

Zandstra: I am certainly concerned with you that cropping systems researchers should consider the resource base and politico-economic objectives and conditions of their country in the design of cropping patterns. In my schematic presentation of cropping systems design (Fig. 3), these aspects of the site environment are considered to arrive at the economic feasibility and the economic viability of alternative cropping systems for a region.

In effect, site description in socioeconomic as well as biological sense, and the subsequent formulation of cropping systems design and testing in terms of the conditions encountered give local relevance to cropping systems research.

Understanding biological feasibility (as a function of the physical environment) independent of socioeconomic considerations offers the potential for extrapolation of this knowledge to sites with similar physical environmental conditions. These sites may have vastly different resource bases or economic environments but can still refer to a set of biologically adapted cropping systems to select those that suit their socioeconomic conditions. In effect, the accumulated knowledge about the agronomic performance of cropping systems, as influenced by the environment, can serve as a resource for cropping systems research in any country in which these physical environments occur.

THE ASIAN CROPPING SYSTEMS NETWORK

V.R. Carañgal

Rice is the most important staple crop in Asia. About 90% of the world's rice is produced in Asia where ½ of all farms are less than 1 ha and ¾ are less than 2 ha. The crop is produced mostly on small farms. A very small percentage of the rice land is irrigated. Of the irrigated areas, a still smaller portion receives year-round water. That portion grows three rice crops a year or five rice crops in two years. In some areas, vegetable and upland crops are planted after one or two crops of rice, but such areas constitute a very small fraction of the irrigated rice land. The rainfed rice areas constitute 70% of Asia's total. They grow only one rice crop. Some areas are planted to another crop of rice or upland crops, but those are only a small fraction of the total.

The main goal of the Asian Cropping Systems Network is to develop cropping systems technology that will increase cropping intensity in Asian rice farms and make more efficient use of resources that are available or can be made available to the farmer. Priority is given to areas with potential for increased production during a crop season and for two crops or two to three crops a year. Those areas are the rainfed lowland rice and partially irrigated rice areas (irrigated only during the rainy season). There the potential is tremendous, as shown in programs of the International Rice Research Institute (IRRI) and of various countries. Although major efforts are concentrated in those areas, irrigated and rainfed upland rice areas are also given attention, particularly in countries where priorities are given for development of the rice lands.

Cropping systems are dependent on their physical and socioeconomic environments. They are highly environment specific. To develop the technology for Asia, research has to be done in different environments in the region. In collaboration with national programs, a network of

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experimental sites is being established in major rice-growing areas that represent major agroclimatic zones. Technology developed in each site will be extrapolated to other areas with similar ecological conditions.

The objectives of the network are:

1. to provide a mechanism for joint program planning and review by the national programs of the region and IRRI;
2. to provide a series of data points on the Asian agroclimatic grid for determining the cropping systems potential in major zones of the region;
3. to develop cropping systems technology for the major rice-growing regions of Asia;
4. to enable IRRI to extend relevant methodology and technology to national programs; and
5. to provide a mechanism for long-term upgrading of national efforts.

SELECTION OF SITES

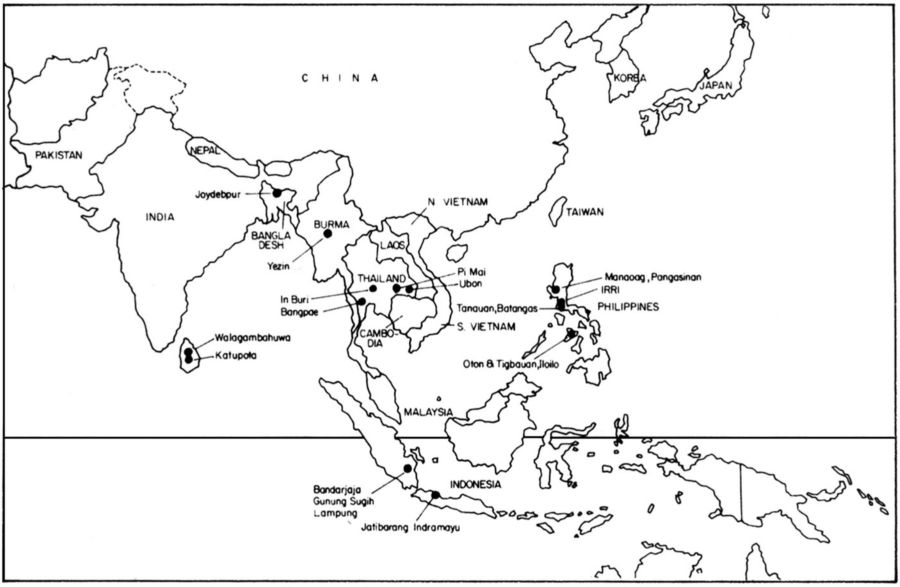
Test sites should be carefully selected, with at least one in each major rice-growing country. When viewed together, the selected sites should present the spectrum of physical and social environments of rice-growing areas in Asia. A test site should (1) represent a major agroclimatic zone; (2) be rainfed or partially irrigated with low cropping intensity but with potential for increasing intensity; (3) represent priority development areas of the host country; (4) have competent scientific leadership, not only to implement the cooperative research but also to plan with research leaders from other cooperating countries the overall research strategy of the entire program; (5) have scientists who can carry out cropping systems research; and (6) have national institutional support.

In addition, the site should have convenient physical infrastructure, communications facilities, utilities research provisions, markets, and transportation network.

Thirteen sites have already been selected. Six became operational in 1975 (Fig. 1); the rest will begin functioning in 1976. More sites will be identified in 1976 and 1977.

Operational sites. *Indonesia.* IRRI operates two outreach sites in Indonesia in collaboration with the Central Research Institute for Agriculture (CRIA). The base-line survey started in August 1975 and field experiments in October 1975. The two sites are described below.

1. Central Lampung in Bandarjaya and in Gunung Sugih has four wet months (consecutive months with 200 mm or more rainfall/month) and two dry months (consecutive months with less than 100 mm rainfall/month). There is gradual transition from dry to wet and from wet to dry. Soil is



1. Cropping systems network of experimental sites (operational and proposed).

red-yellow podzolic, which is relatively low in pH, poor in NPK, and rather light-textured. Research concentrates in (a) partially irrigated rice with 5 to 6 months of irrigation, (b) old-settlement upland rice areas, and (c) newly settled upland rice areas.

2. Indramayu, West Java, has four wet months and five dry months with gradual transition from dry to wet and from wet to dry. Soils are alluvial. The terrain is level, with an elevation of from 20 m above sea level to 20 m below sea level. Most rice areas are irrigated. However, water during the dry season is not enough to irrigate rice in many areas. We are studying cropping systems in three irrigated rice areas: (a) those with 10 months of irrigation, (b) those with 7 months of irrigation, and (c) those with 5 months of irrigation.

Philippines. Three sites in the Philippines are run in collaboration with the Bureau of Plant Industry (BPI). IRRI directly manages the three sites with personnel contributed by the BPI. Experiments at the Batangas site started in 1973. IRRI's farmer-participation research approach was developed in the site. The two other sites became operational in March 1975. The three sites are:

1. Cale, Tanauan, Batangas. The site grows upland rice. It has five wet months and five dry months. The rainfall pattern has rapid transition from dry to wet and gradual transition from wet to dry. Cropping intensity

is high. Soil is well-drained clay loam. The research in this site is expected to be terminated early next year.

2. Oton and Tigbauan, Iloilo. The test areas are located in seven villages. The rainfall pattern has five wet months and five dry months, with rapid transition from dry to wet and gradual transition from wet to dry. Soil ranges from light, silty loam to heavy clay, with intermediate types. The areas represent rainfed and partially irrigated rice areas with potential for double rice-cropping, or for a single crop of rice followed by an upland crop.

3. Manaoag, Pangasinan. Test areas are in two barrios. The rainfall pattern has four wet months and six dry months, with one month of greater than 500 mm rainfall. There is gradual transition from dry to wet and rapid transition from wet to dry. One test barrio has a nearly level plateau with a high water table; another has a nearly level plain with a low water table. Soil varies from loamy sand to sandy loam. The areas represent rainfed lowland and partially irrigated rice areas with potential for double and triple cropping.

Bangladesh. In Bangladesh the program is run in collaboration with the Bangladesh Rice Research Institute (BRRI). The research program has two phases: the application phase and the developmental phase. In the first, available technologies are tested in farmers' fields in the BRRI pilot area (13,986 ha). The developmental phase involves systematic research at BRRI research stations on varietal selection, component technologies, and development of potential cropping patterns for both rainfed and irrigated rice areas. Although most research projects are done in the BRRI station, some were recently carried on in farmers' fields to study the present cropping systems in rainfed rice areas preparatory to the introduction of new patterns. Sites are to be operational in 1976–77.

Thailand. Work at four sites in Thailand will be in collaboration with the Department of Agriculture, Kasetsart University, and the Division of Agricultural Economics. The base-line survey in two sites was recently completed. Field experiments began in January 1976 at In Buri, and in May 1976 at the two other sites. The four sites are described below.

1. In Buri, Singhburi, in the Central Plain, where rice is a major crop, has only two wet months and six dry months, with a total annual rainfall of about 1,200 mm. Supplementary water can be supplied to secondary crops because the area has access to an irrigation system. Soils are medium to heavy clay. The site represents a lowland rice area with partial irrigation.

2. Bangpae, Rajburi, represents the Greater Mae Khong development project area which covers six provinces. The annual rainfall is about 1,400 mm. There are about three wet and four dry months. The area re-

presents rainfed and partially irrigated rice areas.

3. Pi Mai, Nakhon Ratchasima, in the northeast region of Thailand, has bimodal rainfall with two wet and six dry months. There is gradual transition from dry to wet and rapid transition from wet to dry. The total annual rainfall is about 1,200 mm. The soil ranges from light to heavy clay. Low humic grey soils, gray podzolic, and alluvial soils predominate. Soil fertility is low in most cases. Studies will concentrate on rainfed rice areas, and will focus on increasing the efficiency of water use through the more frequent inclusion of upland crops in the cropping pattern, and through the concentration of water in those parts of the landscape most suitable for rice cultivation.

4. Ubon Ratchathani is also in the northeast region of Thailand where rice productivity is low. It is a rainfed lowland rice area with a bimodal rainfall like Pi Mai's. It has three consecutive wet and six dry months, with rapid transition from dry to wet and gradual transition from wet to dry. The soils are similar to those in Pi Mai but differ in proportion and fertility.

Sri Lanka. Three sites proposed in Sri Lanka are to be operated in collaboration with the Department of Agriculture. Two sites have been selected and the base-line survey is already complete. Field experiments will start in September 1976. The third site in Anaradhapura district has not yet been identified. The two identified sites are described below.

1. Alanbara, Katupota, has a bimodal rainfall distribution, with two wet months in April and May and another two wet months in October and November. There is gradual transition from dry to wet and from wet to dry. Total annual rainfall (1931–1961) has been 2,100 mm. The soils are imperfectly drained to moderately well drained, with moderately deep profiles. Surface horizons range from dark-brown or brown sands to sandy loam. The pH is 6 to 6.5. Elevation is about 100 m. Studies will focus on rainfed lowland rice areas.

2. Walagambahuwa, Thirappana, Anuradhapura, has a bimodal rainfall distribution, with three wet months in October, November, and December and four dry months. There is rapid transition from dry to wet and from wet to dry. The soils are low humic grey, hard when dry and sticky when wet. The site is partially irrigated, with a small tank used to irrigate rice during the wet season. Rice farmers practice shifting cultivation in addition to rice cultivation.

Other sites under consideration. There are other countries that would like to join the cropping systems network. The Malaysian Agricultural Research and Development Institute is interested in establishing six sites in several irrigation schemes and rainfed rice areas. That institute sent seven researchers to IRRI for IRRI's one-month training of site coordinators and supervisors. Three researchers are now at IRRI undergoing training in economic analysis. The sites may be operational in 1977.

The Office of Rural Development in South Korea has indicated interest in collaborating with the network. The office is thinking of cropping systems research in the north, southwest, and southern parts of South Korea. The network will thus have sites in temperate rice-growing regions.

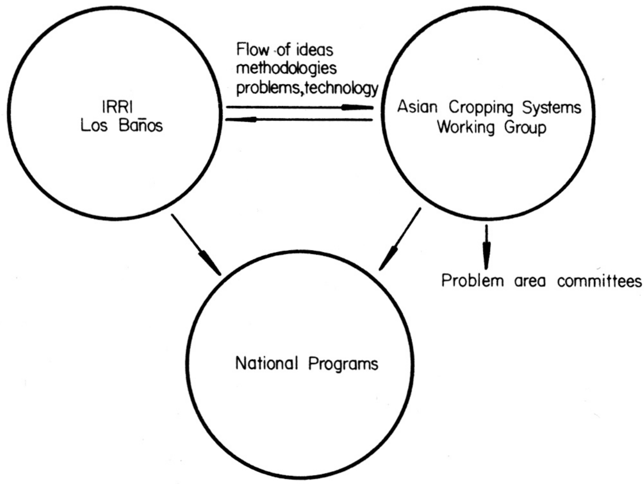
Burma is interested in establishing cropping systems research in irrigated, partially irrigated, and rainfed rice areas, particularly in major irrigation schemes. Three scientists are being sent for six months' training at IRRI in September, 1976. They will start cropping systems research after completion of their training.

IRRI is also interested in collaborating with India, Nepal and Vietnam. It is hoped that arrangements can be made in the near future.

CROPPING SYSTEMS WORKING GROUP

Several countries are involved in the Asian Cropping Systems Network. For a more effective implementation of collaborative research in the network, a working group has been created to (a) develop general research plans, (b) review and evaluate research data from the test sites, (c) discuss research approaches and methodologies, and (d) help IRRI in developing its research program. The relationship between IRRI and the working group is indicated in Figure 2.

The members of the working group are the program leaders from collaborating countries and IRRI, the network coordinator, and selected scientists from outside the region. Each of the following countries has one representative in the working group: Bangladesh, Burma, India, Indonesia, Malaysia, Nepal, the Philippines, South Korea, Sri Lanka, and Thailand. The group meets twice a year. The meeting place rotates among the collaborating countries to give the members an opportunity to observe and learn from each other's work not only in collaborative research but also in the national cropping systems research program. Meetings have already been held at IRRI and in Indonesia and Thailand. The fourth meeting is scheduled at IRRI before and after this symposium. Discussion in previous meetings concentrated on research methodologies, varietal testing, efficient collaboration in the network, and review of the general research program in each participating country. A conceptual framework for cropping systems research and development, evolved by the working group, is being adopted by most national programs (Fig. 3). Future emphasis will be placed on the discussion of research results, the incorporation of

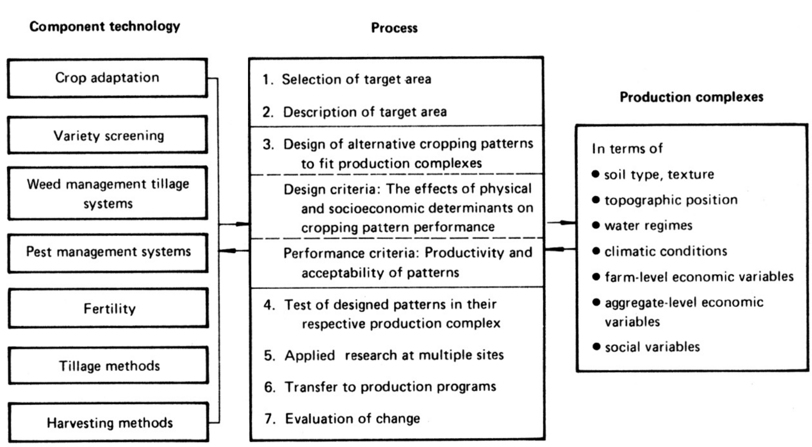


2. Relationship of IRRI with the Asian Cropping Systems Working Group.

these results into a general framework, the standardization of methods and measurements, and the extrapolation of results to other sites in the network.

COMPOSITION OF THE RESEARCH TEAM

Each site's team should have a professional staff of at least five: a co-ordinator (preferably an agronomist), two agronomists, an economist, and



3. The conceptual framework of the cropping systems research programs.

a crop-protection specialist. It also must have field assistants. The number of research staff members will vary from site to site, depending on the volume of work. The Philippine test sites have three to four agronomists, one of whom is the coordinator; one crop protection specialist; and one economist. The Indonesian site has two or three agronomists and one economist. The number of field assistants varies from 5 to 11. Team members should live in their project area to ensure the efficient implementation of the research projects. It may be that the extension worker covering the selected village is not a regular member of the team; however, he should be involved in the base-line survey and selection of farmer-cooperators, and he should be informed of research developments in the project. Likewise, extension chiefs up to the provincial level should be involved in selecting the experimental site and should be informed of the progress of research. Research findings can thus be easily fed into the ongoing production programs.

RECOMMENDED RESEARCH SCHEME AT EACH SITE

Base-line survey. To obtain a complete description of a site, a base-line survey is usually conducted. All available data on weather, topography, irrigation, soil type, and relevant infrastructure should be obtained. The existing patterns, cultural practices, constraints on production, use of agricultural inputs, available farm resources, farm types, farmer characteristics, credit facilities, off-farm income, livestock, markets, and related characteristics should be surveyed. All such information is necessary for planning research priorities and for selecting farmer-cooperators.

Design and testing. The design of an improved cropping pattern considers the physical and socioeconomic description of the target site and the component technology for the crops available in the country research program and other programs. The improved cropping patterns are then tested in farmer's fields, under farmer management, in selected villages within the target site. The selected farmer-cooperators should have different management skills. They become members of the research team. They are made to understand that the trials are for research, not for demonstration.

The research team discusses in detail with all farmer-cooperators the cropping patterns and other experiments that will be superimposed on each pattern. Each farmer will provide one replication of a system and an area of about 800 to 1,000 sq m for each pattern. He may grow two patterns.

In most cases, the project provides seeds, fertilizer, and pesticides as incentives for planting the pattern specified for the initial trials. The

Table 1. Cropping patterns tested in Iloilo rainfed lowland outreach site, 1976.

corn–rice–cowpea	rice–mung beans
rice–rice–rice	rice–cowpea
corn–rice–sorghum	rice–peanut
rice–rice–mung beans	rice–sweet potato
rice–rice–cowpea	rice–sorghum
rice–soybeans	rice–muskmelon
rice–corn	

farmers provide the land, labor, and needed data. In some experiments, the project will guarantee the price of the produce if markets are not immediately available for a crop that has production potential and a ready export market, but the farmers should provide the labor and all other inputs.

The cropping patterns being tested in the Philippines and in Indonesia (Table 1, 2; Fig. 4, 5, 6) include upland crops of corn, sorghum, soybeans, peanuts, rice beans, mung beans, muskmelons, and cassava. The network is concentrating on those food crops, but other countries may work on others which fit their systems.

The network is studying the following cropping patterns:

Lowland rice area: rice-rice-rice, rice-rice-upland crop, upland crop-rice-upland crop, rice-rice, rice-upland crop, upland crop-rice

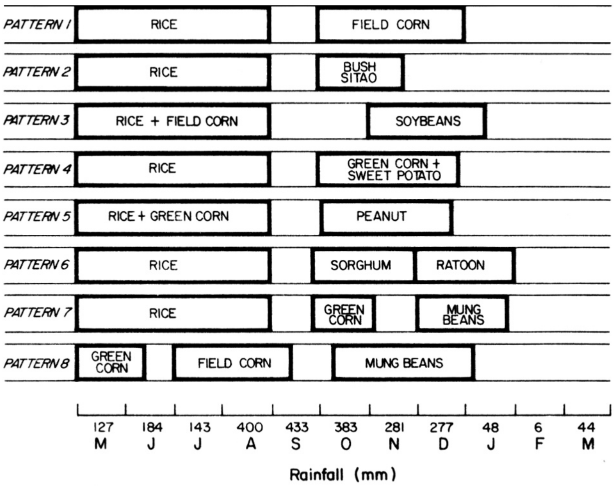
Upland rice area: rice-upland crop, rice-upland crop-upland crop, rice-upland crop (intercrop), rice-upland crop intercrop-upland crops (intercrop or monocrop)

Costs and returns of improved cropping patterns should be analyzed to determine the profitability of the patterns. The farmer-cooperator keeps a record of all operations in the experimental area with the help of the field assistant (village assistant).

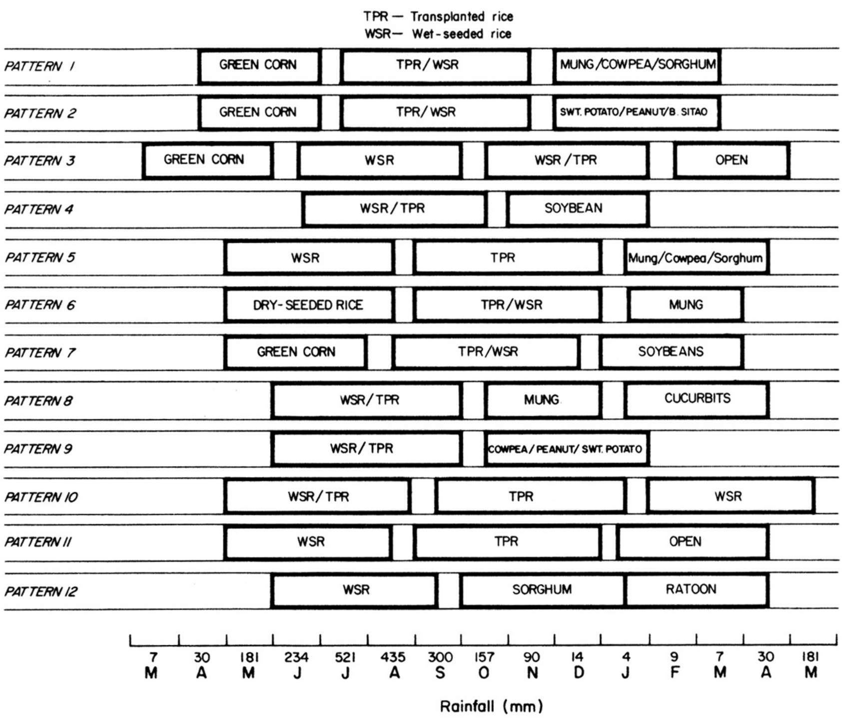
Farm records should be kept at the outreach sites to monitor all farm operations, land utilization, income and expenses, crop inputs, and labor

Table 2. Cropping patterns tested in Indramayu, Indonesia, 1975–76.

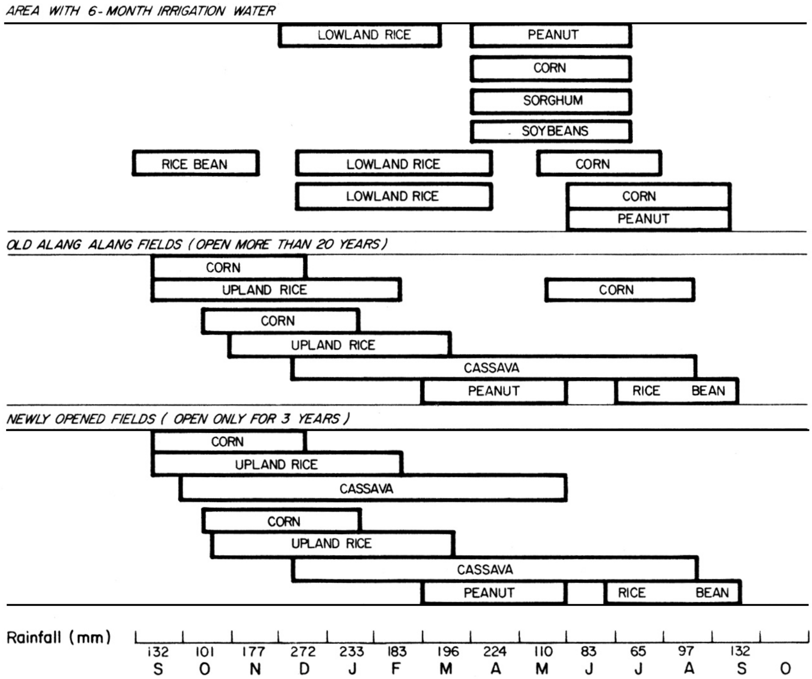
Cropping patterns where irrigation water is available		
10 mo	7 mo	5 mo or less
rice–rice	rice–rice–cowpeas	rice–cowpeas
rice–rice–soybeans	rice–rice–mung beans	rice–rice–cowpeas
rice–rice–rice	rice–rice–soybeans	rice–rice–soybeans
rice–rice–mung beans		rice–rice–mung beans
rice–rice–cowpeas		
rice–rice–cucumber		
rice–rice–corn		
rice–rice–tomatoes		



4. Alternative cropping patterns being tested graphed against the average monthly rainfall distribution. Cale, Batangas, 1976.



5. Alternative cropping patterns being tested graphed against the average monthly rainfall distribution. Manaoag, Pangasinan, 1976.



6. Cropping patterns being tested showing monthly rainfall distribution. Lampung area, October 1975–76.

utilization. Usually about 10 to 20% of the economic cooperators involved in recordkeeping are also agronomic cooperators involved in cropping pattern testing.

Component technology. Research on component technology is an integral part of a cropping systems research program. Studies of tillage practices, fertility, crop establishment, weed management, disease and insect control, adapted varieties, and water management are important. They are usually conducted in experiment stations under carefully controlled conditions. However, they may also be conducted at the test sites, managed by either the farmer or the research workers.

Under farmer management, experiments are superimposed on the cropping pattern trials or conducted in separate fields. In such a scheme, the farmer conducts the total farm operation except the application of the treatment being studied. When the experiment is superimposed on the pattern, care is taken that it does not interfere too much with farmer management. An experiment usually occupies 1/3 to 1/2 of the cropping pattern trial's area. It may be replicated in each farmer's field or across farms. A more complicated experiment with several treatments is usually placed under the management of the research worker. He can rent the land, or he can use it and turn over all the produce to the farmer after getting the data he needs.

For varietal evaluation, the network provides a mechanism with which to introduce promising varieties developed by national breeding programs and the University of the Philippines at Los Baños (UPLB). The International Development and Research Centre is funding UPLB screening of varieties and lines of food crops (corn, sorghum, soybeans, mung beans, cowpeas, eggplant, tomatoes, and sweet potatoes). IRRI is screening for intensive cropping such other crops as rice, peanuts, and cowpeas. The outstanding entries are tested at the various network sites. In some countries, evaluation is also done at the experiment station nearest the site. The testing program is not a uniform trial. Other elite entries from the national breeding programs are included in the trial. Evaluation is carried out whenever the crops fit the patterns.

TRAINING

One major activity of the IRRI cropping systems program is training of research and extension workers involved in cropping systems who are directly involved in collaborative projects in the network and national research programs. Since trained technical manpower in the network is limited, we are working with the national program leaders in carefully selecting the trainees in order to rapidly upgrade scientists in the collaborating countries.

IRRI offers several types of training. One provides research experience to young scientists through degree or nondegree programs. Under arrangements with the UPLB College of Agriculture, degree candidates complete their course work at the College and conduct their thesis research at IRRI. Twenty scholars are pursuing graduate studies leading to the MS or the PhD degree this year (Table 3). Two have already finished their PhD work and are back in their own countries.

A special nondegree training program for site coordinators and supervisors is conducted to acquaint them with research methodologies used at the outreach sites, and the operation and organization of the sites. Another special training program is conducted to upgrade the economic research staffs of collaborating countries. A one-month training in economic analysis of cropping systems has just ended. Twenty-four persons participated in the site coordinator and supervisor training (Table 4) and eight in training in economic analysis (Table 5). To support the network, we plan to continue special training as the need arises.

Another type of training is designed to improve the competence of

Table 3. Students (no.) pursuing advanced degree training in 1976 at IRRI under the direction of cropping systems senior staff members.

Country	MS[a]	PhD[b]
Bangladesh	2	–
Burma	1	–
Indonesia	3	3
Thailand	4	1
Philippines	4	1
United States	1	–
Total	15	5

[a] Four are coming in October, one each from Bangladesh, Burma, Thailand, and Indonesia. [b] Two (one from Thailand and one from Indonesia) have finished the PhD. Mr. Tirso Paris from the Philippines prepared his PhD dissertation at IRRI but will get his degree from Michigan State University.

extension and research workers. It allows the participants to learn the principles of cropping systems, and to acquire skills and practical experience in production technology and applied research. This type of training, scheduled once a year, lasts about six months. Since 1974, we have trained 40 extension and research workers; 34 more started training on 20 September 1976 (Table 6).

SHARING OF RESEARCH INFORMATION

The network provides a forum for exchange of ideas and research information among scientists working on cropping systems in the region and in other parts of the world. It sponsored a workshop in March 1975, a seminar for research administrators in 1976, and three meetings of the Asian Cropping Systems working group. Our present symposium on *Cropping Systems Research and Development for the Asian Rice Farmer* is running from 21 to 24 September 1976, and the fourth meeting of the cropping

Table 4. Site coordinators and supervisors (no.) trained for one month at IRRI, 1976.

Country	Jan.–Feb.	July–Aug.
Malaysia	–	7
Indonesia	2	–
Thailand	3	1
Sri Lanka	3	3
Philippines	5	–
Total	13	11

Table 5. Trainees (no.) in one-month training program in economic analysis of cropping systems at IRRI, 16 Aug.–17 Sept., 1976.

Country	Number
Thailand	3
Malaysia	3
Indonesia	2
Total	8

Table 6. Trainees (no.) in the six-month course on cropping system at IRRI.

Country	1974	1975	1976 [a]	Total
Bangladesh	–	2	2	4
Burma	–	–	3	3
India	–	–	3	3
Indonesia	6	11	10	27
Japan	–	–	1	1
Malaysia	–	1	4	5
Israel	1	–	–	1
Philippines	4	5	3	12
South Korea	1	–	1	2
Sri Lanka	1	–	2	3
Thailand	2	6	5	13
Total	15	25	34	74

[a] To be trained 20 September, 1976–11 March, 1977.

systems working group on 20, 24, and 25 September 1976. We plan to have more meetings in the future to efficiently pool information from the different sites and from national research programs.

IRRI is also coordinating the distribution of the cropping systems research papers to scientists in the region and in other parts of the world. The program encourages scientists in the network to write up their data. The papers are submitted to IRRI for reproduction and distribution in the network.

TIE-UP WITH NATIONAL RESEARCH PROGRAMS

The collaborative project is part of the national research program. In some countries, it may be the beginning of a cropping systems research program, while in others it strengthens and intensifies the national research programs. Its role will therefore vary from one country to another. To establish direct linkage between collaborative research and national programs, the program leaders are in most cases selected to be members of the Asian Cropping Systems working group.

The three outreach sites in the Philippines are considered regional research stations for rice-based cropping systems research. The work at the sites is done in collaboration with the Bureau of Plant Industry (BPI], the research agency of the Department of Agriculture of the Philippines. To link this with the national system, the IRRI program leader and a representative from the BPI are included as members of the Multiple Cropping National Management Committee, a coordinating committee composed of representatives of different government agencies involved in multiple cropping work, not only with rice but also with corn and coconuts. IRRI staff are involved in the design of cropping patterns for the national pilot production program which is being implemented in one province and 18 municipalities. That program is being described in this symposium by Dr. Arturo Gomez. IRRI is also involved in an applied research component of the national program that is implemented in cooperation with the Philippine Council for Agriculture and Resources Research, the Bureau of Agricultural Extension, and agricultural schools.

The two outreach sites in Indonesia are operated in collaboration with the Central Research Institute for Agriculture (CRIA), the research agency for food crops of the Ministry of Agriculture. The coordinator of the multiple cropping program of CRIA is also the project leader of the collaborative work. The project emphasizes the rice-based cropping systems research program. Through the collaborative project, research in cropping systems is intensified, with emphasis on rainfed and partially irrigated rice areas. The project includes (a) training of extension workers, not only at the two research sites but also at the IRRI station, and (b) a mechanism for establishing applied research in key locations like the two testing sites.

In Bangladesh, IRRI is cooperating with the Bangladesh Rice Research Institute (BRRI). The Division of Rice Cropping Systems was created by BRRI in November 1974 to carry out research on rice-based cropping systems. Collaboration in Thailand is with the Department of Agriculture, the Division of Agricultural Economics, and Kasetsart University, all main research agencies of the government. The project is jointly undertaken by many divisions in the Department of Agriculture and other agencies, with a coordinator from the Rice Division. In Sri Lanka, cooperation is with the Department of Agriculture; it marks the beginning of cropping systems research in that country. The national coordinator is the head of the Maha Illuppallama Experiment Station, the national center for cropping systems research. In Malaysia, Burma, and South Korea, arrangements are being made with the major research organization of each country.

Obviously, the tie-up with national programs will vary from country to country. It will depend on the existing research programs, the organizational setup of each cooperating agency, and the national production programs. The Asian Cropping Systems Network will not set up independent programs; it works with existing organizations.

DISCUSSION

VILLAREAL : In Fig. 3, the arrows seem to show that the national programs do not contribute any ideas, methodologies, problems, or technologies to the cropping systems program. Please comment.

Carañgal: National programs have contributed through the working group members. The members are, in most cases, the program leaders for cropping systems in their respective countries.

Physical aspects of cropping pattern design

INTRODUCTION

R.R. Harwood

The general methodologies for cropping systems research, as currently carried out in several Asian countries, were clearly outlined in an earlier paper by Dr. H.G. Zandstra. The approach is centered upon the concept of cropping systems design. The design capability entails the assembling of component technologies within an environmental matrix of physical, socioeconomic, and biological determinants, to produce a cropping system that gives the farmer optimum productivity. It extends the methods used by Dr. R. Bradfield in the late 1960's as he designed systems to maximize productivity of land and water resources.

Cropping systems potential depends on site environment. The potential changes with changes in location, and with changes called gradients in the determinant variables. Many variables, such as rainfall, temperature and soil type, have been defined in various systems of classification. Those classifications, for the most part, define ecological zones. An ecological zone is one across which a relatively uniform potential for vegetative growth is found. Cropping systems, however, include the capability of man to manage crops within his socioeconomic environment. We need, then, descriptions of "production complexes" or agroclimatic zones across which cropping potential remains uniform.

It is appropriate that this session on description of environmental variables receive major attention in the first cropping systems symposium. During the next few years considerable attention must be given to this aspect of systems design. It is essential that broad descriptions be made as soon as possible, with future cropping systems research then being related to those environmental gradients.

DESCRIPTIVE CRITERIA

Systems design ultimately involves the matching of existing conditions for crop growth and management with requirements of potential crop

R.R. Harwood. Rodale Press, Inc., 33 East Minor St. Emmaus, Pa. 18049, USA.

combinations. It is important, when considering the many environmental variables, to identify and describe only those which affect crop growth and management. Also, the descriptive categories must correspond to those used to describe crop growth and management requirements.

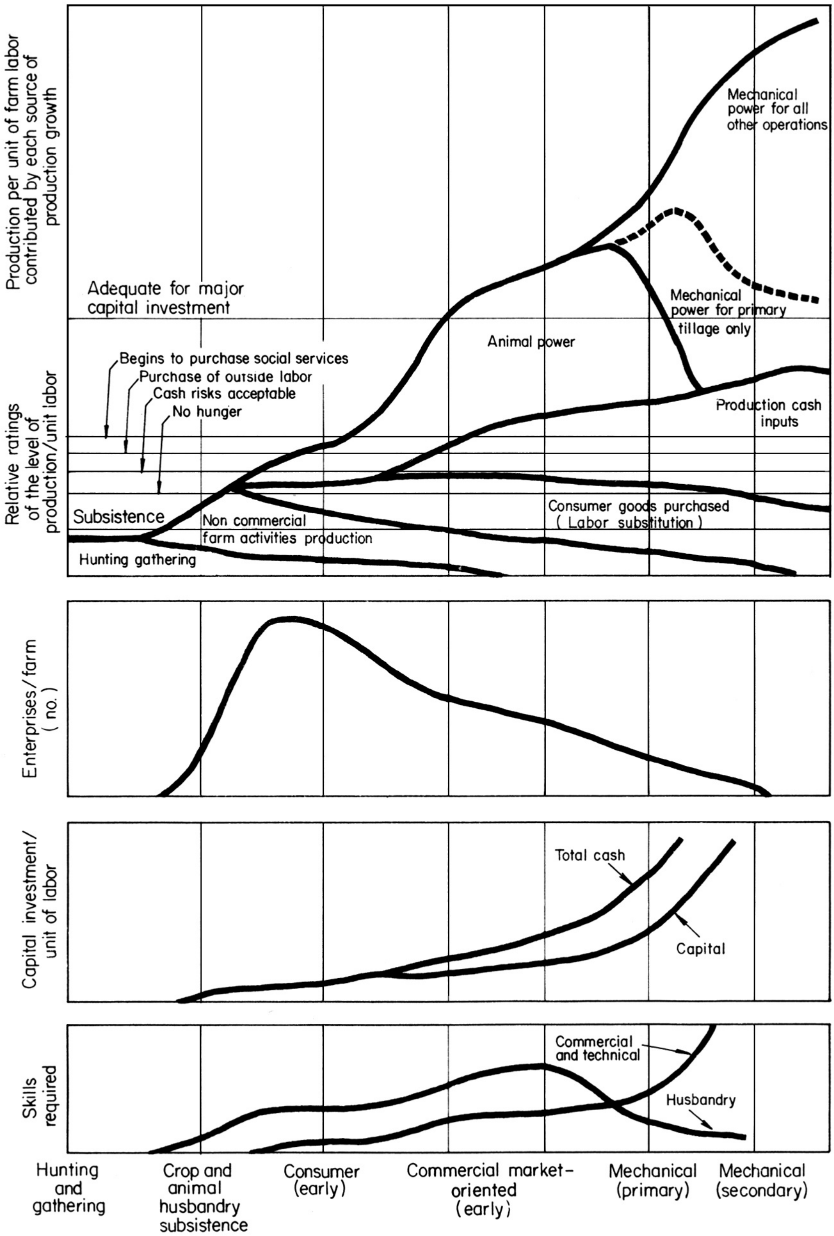
The three categories of determinant variables are the physical, the socioeconomic and the biological. Variables within each category may, in turn, be of three types. There are, first of all, variables having very gradual gradients; they may be mapped over large areas. Cropping systems potential, as limited by those determinants, can then be determined for the areas having uniform classification. Rainfall exhibits such a gradient. Second, the determinants with sharp gradients which are difficult to map, such as field drainage or paddy bund position, must be classified.

The second classification is associated with the cropping systems alternatives at the research level rather than related to the geographical area. Technology is thus designed to apply to a given segment of the determinant's gradient. The technology fits wherever that segment of the gradient is present. The description of such variables must be in terms and units that a farmer or extension worker can relate to and identify in the field. The rice-bund-type class is an example.

Still a third classification may be used to indicate socioeconomic environment. It may classify the economic status of the farmer or his production resource levels. The parameters described may not be "determinants" in the sense that they limit crop potential as does rainfall, but they indicate farmer economic status and economic capabilities. Farm growth stage (Fig. 1) is such a class. The categories may be directly related in this case to farm economic potential. Such descriptive classifications will become extremely useful as the range of farm economic levels is broadened with the expansion of site locations in the region.

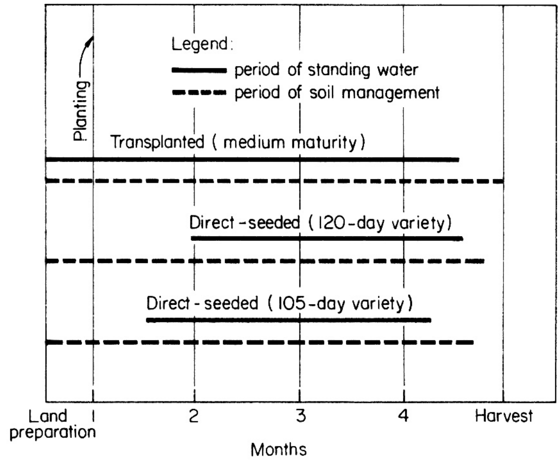
CROP GROWTH AND MANAGEMENT REQUIREMENTS

A final aspect of systems design involves the identification of crop growth and management requirements. General guidelines are available for crop requirements for water, temperature, and drainage. While this symposium does not deal specifically with the topic, those requirements must be identified in terms that correspond to the environmental classification. Crop-management requirements must likewise be defined. Maximum and minimum rainfall levels for various crop-management operations, such as seedbed preparation, planting, cultivating, and harvesting, must be determined. At present little thought is given to such requirements. Sorghum production schemes throughout Southeast Asia have failed



1. Production per unit labor, number of farm enterprises, each investment and skills associated with different agricultural growth stages when markets are limited for high-value crops.

because harvest operations have been planned during periods with expected rainfall above 25 mm per week. The requirement for dry weather



2. Optional time periods for standing water in lowland rice culture.

at harvest is as critical a determinant for sorghum production in Asia as is the lack of field flooding. Another example, of flooding requirements for rice, is shown in Figure 2. The planting of direct-seeded rice only in paddies that have a high probability of flooding soon after planting would greatly increase the likelihood for success! Such guidelines seem elementary, but how often do we overlook them.

Those parameters which vary over time, such as rainfall and flooding, can be broadly defined on a monthly basis to give very general crop requirements. Specific needs must be determined on a 5 or 7 day basis. Crop requirements and environmental descriptions should coincide in type and level of classification.

Finally, a word should be said about precision of classification. The determination of crop requirements and the classification of environmental parameters will always be imprecise. Design will be on the basis of probabilities. Considerable latitude must be allowed as a margin for safety where critical determinants are involved.

I must conclude that systems design will never be a completely mechanical or automatic process. Our hope is to refine the process to the point that experienced agricultural development workers can expect to estimate cropping systems potential with an accuracy that calls for only minor adjustment of the systems during adaptive testing. We have come a long way in our understanding of the design process, but considerable further effort is needed during the next few years of research involvement.

SOIL-RELATED DETERMINANTS OF CROPPING PATTERNS

H.W. Scharpenseel

Charles E. Kellog, the internationally known US soil scientist, produced the aphorism, "The most important thing is not the soil itself, but the people living on it" (Manshard, 1968). His statement is subject to two interpretations: (1) Considering basic values, mankind is more valuable than mere capital goods like "soil." Nobody will argue that claim. (2) To achieve the transformation potential of an agrobiotop, the professional caliber of the farmer matters even more than the value and natural fertility of the soil. The latter proposition was probably what Kellog had in mind. It is a bold statement, conceived from a long life's experience. It emphasizes the inherent interdependence between soil-related determinants and training. This Institute has recognized that interdependence, and has made it part of her vocation.

The basic facts of agricultural structure and cropping patterns mirror this relation between soil and management potential. In most countries of the world, two basic models exist : modern agriculture (culture moderne) and traditional agriculture (culture ancienne). Modern agriculture, with or without irrigation, is mostly an exporting ecosystem, with replenishment of the nutrients and humic substances that have been lost from their respective pools. Traditional agriculture usually presents itself as a self-consumptive, self-sustaining, recycling ecosystem, a closed reservoir with a temporary man-made leak. It has numerous features, but only three principal mechanisms: (a) shifting cultivation with movement of fields and villages; (b) land rotation: seminomadic structures are abandoned, fields are rotated and there is bush burning, but the villages are sedentary; and (c) crop rotation with frequent fallow years. Transitional is amended traditional agriculture, based on land rotation with a combination of field

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cropping and reforestation, sometimes even with a mixed cropping system; it represents an agrotechnological level comparable, perhaps, with that of rice farming. Systems of amended traditional agriculture are more or less exportative, with the nutrients withdrawn being partially replaced by fertilizers or by Rhizobium-N derived from legume intercropping.

All three systems can induce loss of soil fertility by using too narrow a ratio of field to fallow years (especially in the humid tropics), by overgrazing (mostly in semiarid and subhumid areas), or by prolonged periods of bare soil exposure and neglect of sheet or gully erosion. Dreaded consequences of such management failures are sinking of the ground water level, induration of near-surface soft plinthite, induced or derived savannah, and desertification.

That is how the basic agricultural systems and cropping patterns influence soil formation and degradation. The topic of my paper, however, touches primarily on the reverse: the effect of soil-related determinants on cropping patterns. The origin of life itself might be related to weathered rock material of clay particle size, precursor of soil. Degens et al. (1970) drew attention to the possible racemic structure of kaolinite, stating that the left-turning racemic forms we find in physiological materials might reflect the origin of primordial organic molecules in catalytic contact with templates of the left-turning type of clay.

Further, clay and clay stone are absolutely the decisive matrix for protection of organic matter against the biotic and photochemical forces of mineralization. Hunt (1968) estimates that about 95% of the 4×10^{15} *t* of organic substance that exist in worldwide sediments is attached to clay or clay stone.

Knowing the importance of soil classifications (Soil Survey Staff, US Department of Agriculture, 1975; US National Academy of Sciences, 1972), we have to admit that a soil's systematic position in order, suborder, great soil group, and subgroup has less influence on its transformation potential in supporting cropping patterns than the factors sorption capacity, nutrient reserve, matrix potential characteristic of soil moisture, soil structure (tilth), or soil reaction. Generally, any soil whose texture and chemistry are not too extreme is suited for crop production unless it is too shallow to allow appropriate rooting, too dry to adequately support plant growth and eventually has salt or alkaline problems, or too wet for upland field crops because of high ground or perched water tables (leaving an alternative usefulness for paddy or pasture culture).

Soil factors that especially impede rice culture, as discussed by Ponnamperuma and Castro (1972), are iron deficiency in neutral and alkaline soils, manganese and aluminum toxicity in acid soils of aerobic character, contrary iron toxicity in acid sulfate soils, phosphorus fixation and deficiency of latosols and acid sulfate soils, zinc deficiency, and toxic reduction products.

Hope exists that dry soils can become highly productive with the use of flooding-ditch-, sprinkler-, center-pivot-, or dripping-irrigation, provided that they are rather sandy or loessic, or that their geomorphological position allows good drainage, or that their winter rainfall will leach out salt accumulated during the summer irrigation period (Ollat et al., 1969a,b; Splinter, 1976). Irrigation on demand, for instance, by sprinkler, and maintenance of a soil moisture level close to 80% of field capacity promise about 1 t of dry matter in return for each 100 mm of irrigation water (Kopp, 1975).

In discussing the influence of soil moisture, interference between soil- and climate-related determinants of cropping is inevitable. Even at the very basic level there exist soil- and climate-related differences in the photosynthetic mechanism. In temperate environments we find mainly the "normal" Calvin type C-3 mechanism (Craig, 1953). Under the hot-climate conditions especially associated with corn, sorghum, sugarcane, and grasses (Lerman, 1972; Vogel, 1976), the Hatch and Slack C-4 type mechanism prevails. Under semiarid to arid conditions, particularly with opuntia, cactus and other succulents, the mixed CAM-mechanism occurs. We know little up to now about how an unadapted environment, climatic and edaphic, might affect the photosynthetic mechanism of plant species, or how far growth failures might sometimes even be associated with soil- and climate-related influences on the photosynthetic pathway. With rice, we tried growing varieties from the Philippines (Kn-lh-361-1-18-6, HB 359) and Hungary (Zavaosanszkij 238) under Hambourg conditions with long-day and artificial short-daylight climate. Analyses of the photosynthetic mechanism of seeds, leaves, and roots indicated no dramatic deviation from the Calvin type mechanism for the Hungarian as well as the Philippine rice varieties.[1]

It seems unnecessary to enumerate to this audience the well-known nutritional and climatic growth-factors related to soil. For rice culture, the influence of soil nutrients on yields has been described by many authors. The efficiency of N fertilizer, including rhizospheric N-fixation, received special attention, for example, in the works of Yoshida and Ancajas, 1970, 1971; Sanchez, 1972; De Datta et al., 1974; Khind and Datta, 1975. Ponnamperuma and Castro (1972) elaborated the varietal resistance to adverse soil conditions. The Atomic Energy Agency of the

[1] Dr. Willkomm of the Institute of Nuclear Physics, Kiel University, carried out the mass spectrometric measurements.

UN carried out joint studies in several East Asian countries on nitrogen and phosphorous nutrition of rice, applying isotopic tracers such as ^{32}P, ^{33}P and ^{15}N (IAEA, 1970).

It would be more reasonable to project the soil-related determinants of cropping patterns in the light of *horizontal, vertical, and meridional* zonality of soil distribution. The zonality related to climate and that related to vegetation in conjunction with bedrock facies and relief, exert a dominant influence on locally possible cropping patterns.

Meridional zonality means particularly more oceanic or continental climate influencing the soil site. Oceanic climate favors processes like carbonate leaching and clay infiltration, but it allows all cropping patterns, including cover crops and mixed cultures. It also favors rice production. Continental climate sites with cold winter and hot summer have more pedogenetic stability due to short, ice-free leaching periods, but also have a limited growth season, with cereals dominating the cropping patterns.

Vertical zones including catenae are subject to erosion and colluvial and alluvial redeposition (processes that are accelerated by man's wood-clearing activities). They favor forest and fruit tree cultures in the shallow soils of higher elevations; pasture in cleared maquis and bushy, hilly lands; rice on terraces; and field crops, especially when irrigated, including rice, in the plains and piedmont areas.

Horizontal soil zones begin with the *tundra soils.* Those are characterized by frost marks, solifluction, and cryoturbation. They are shallow soils that allow cropping, at best, for a short summer cereal culture. Rice culture is unthinkable.

The following zones may also have been exposed temporarily to periglacial conditions and are not free from traces like those of ice wedges, especially from the influence of solifluction, soliplanation, and cryoclastics.

The podzols (Spodosols) are the final morphogenetic product of intense leaching and chelate transport under cool and moist conditions. To a minor scale, they also exist in tropical highlands; accompanied by pine, fir, birch, and heath vegetation (taiga), they develop mostly on glacial and other sands. Cropping patterns are needle-forest or acid-soil crop rotations, such as rye, potatoes, oats, and lupinus. Rice is found only on some of the 6 or 7 million ha of tropical lowland podzols.

Near the 50th parallel, we find *brown earth* (Inceptisols) under deciduous forest. While the base-rich brown earth derived from calcareous parent material begins the lessive process of clay infiltration directly after the loss of free carbonates, thereby turning into Alfisols, the more acidic rocks like those of the varistic greywacke, sandstone, and shale facies directly form acidic brown earth (Ochrept) with Al-fixed clay. Both are typical soils for most field crops because of good water permeation and pore space. With the temperate Inceptisols begin the sparse fringes of marginal rice growth.

Directly after loss of the free carbonates, clay migration and infiltration proceed between pH 6.5 and 4.5. Soils with horizons of clay accumulation, often with perched water tables upon this zone of clay enrichment, are formed (Alfisols, Ultisols). Often they are relicts, such as in Argids, witness to an earlier moist climate. Clay accumulation horizons of Alfisols and Ultisols in the tropics can favor rice paddy construction due to the impervious argillic horizon. Besides, they impede root growth, limit the space for rooting, make soils very moist during the wet season, and make it dry and compact during drought. Most of the Mediterranean soils and the Cinnamon soils of the Balkans are also under this regime. However, soils of only slight acidity and clay disproportionation, many of them on loess or in older alluvial deposits, can be among the highly productive soils. Those with perched water tables are often difficult to drain. Pipes in the clay horizon are ineffective. Subsoiling becomes the method of choice. Although high nutrient reserves and favorable soil structure conditions benefit paddy rice culture as well as terrestrial cropping systems, subsoil compaction, for instance, by an argillic horizon of Alfisols or Ultisols, can turn out to promote paddy stabilization.

Adjacent to the Alfisol belt we find the mostly loessic steppe soils (*grey, wooded soils; prairie soils; brunizems; chernozems; Chestnut soils; and Mollisols*), which are superior sites for field crops and are stable as long as evapotranspiration and precipitation are in balance, and as long as free carbonates stay in place. Many of them, however, are already afflicted with lessivage. Top yields are impeded by lack of moisture; irrigation often causes ascent of salts and alkali, as was the case in the Russian southern steppe because of eustatic changes in the Caspian Sea level. Alkali soil problems are often associated with steppe environment. Rice culture is possible but rare.

Serozems and burozems (*Psamments, Ustolls*), transitional to desert soils, require supplemental irrigation. If salt and alkali problems can be controlled, fruit orchards, berries, sugarbeets, vegetables, and other crops whose value exceeds the cost of irrigation can be grown with excellent returns. Rice irrigation is possible but uncommon. Without irrigation, scanty pasture plants and nomadism prevail as the management pattern.

Beyond the desert belt, a continuity from thorn shrub savanna via grass savanna, bush savanna and park landscape towards monsoon and rain forest is paralleled by decreasing areas of nomadism and pasture;

acreage of field crops, mostly following a land rotation pattern, increases. Modern mechanized and fertilized plantations, mostly in selected sites, reflect the true yield potential. Nye and Greenland (1960) have assessed the plant production potential in natural habitat. Increasing occurrence of *Latosols* and *ironpans* in the subsoil of Alfisols, Ultisols, and Oxisols indicates impoverishment of the soils by long-time leaching, kaolinization, and gibbsite formation. In the inner tropics, the most appropriate and stabilizing land use pattern is based on shrubs and trees of economic value. Field crops like rice, sugarcane, sorghum, grain legumes, and pineapples need skilled management.

Not mentioned so far are intrazonal and azonal soils, such as the dark clay soils, the *Vertisols,* mostly of the savanna belt, that give special promise as plantation soils for cotton, sugarcane, sorghum, rice, etc., because of their high montmorillonite concentration and nutrient reserve; and the *alluvial soils* which, despite their limited area, support crops that meet the nutritional needs of most people, especially in the arid and humid tropics. Because of their plains topography, they are ideal for irrigation if the problem of soil salinity can be controlled. Large alluvial plains are dominantly under rice paddy culture, mostly by monsoon flooding, less frequently by true irrigation. Clay content and management impediments often increase with distance from the river beds, and are more frequent in estuaries and deltas than on the flood plains. *Volcanic ash soils* (Andepts) are mostly slightly acidic, but usually are excellent for field crops because of their constant nutrient supply and favorable physical makeup. Like the Latosols (Oxisols and Ultisols), Vertisols, and alluvial soils, the soils with volcanic ash are heavily used for upland as well as for lowland rice culture.

Acid sulfate soils with yellow jarosite develop mainly under litoral mangrove areas; rice is among the few crops that can tolerate their extreme acidity. Soil-related determinants that often exert a negative influence on cropping patterns are most of the pedolites, fossil remnants of chemical or diagenetic soil induration processes. Classic representatives are fragipan, bog iron and meadow marl, expecially in temperate climates; caliche, calcic, and gypsic (petrocalcic and petrogypsic) horizons in the semiarid lands; and plinthite and laterite in the humid tropics.

In rice culture, the dependence on moisture or even water in the profile (azonal man-made gleys) makes the physical aspects of soil, soil hydrostatic and hydrodynamic principles and, in consequence, oxygen availability predominant among the soil-related determinants of cropping patterns. In a workshop on environmental factors in cropping systems held in April 1976, at IRRI (Moormann et al., 1976), differentiations were made between pluvial, phreatic and aquatic rice land, and also between natural aquic and man-made anthraquic flooding conditions. Because puddling eliminates soil structure and pore distribution, and creates a traffic pan, the desired enrichment of rice crop rotation by upland cultures has to be thoroughly evaluated in the light of opposing principles that favor paddy over upland crops, or vice versa.

SUMMARY

The effect of ecological and land-use systems on soil conservation and degradation is briefly surveyed. The effects of soil-related determinants, partly interwoven with climate-related factors, on cropping patterns, especially rice culture, are interpreted. An evaluation of determinants in the light of meridional, vertical, and horizontal soil zonality concludes the *tour d'horizon,* as it best can be called considering the broad scope of the topic and the limited time for discussion.

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CLIMATIC DETERMINANTS IN RELATION TO CROPPING PATTERNS

L.R. Oldeman and D. Suardi

"Man has been able to develop skills to deal with his environment, but he has not been able to master climate and has remained under the threat of drought. With limited water and with the increase in population and the need for more and better food production, water has become the most precious natural resource in most regions of the world" (Saouma, 1975). Throughout history, agricultural communities have selected environments that are associated with specific crop requirements. Vink (1963) points out that the oldest agricultural communities in Europe are in areas with less deposits that have high natural fertility.

Because of its unique ability to grow under submerged conditions, rice has been cultivated for thousands of years on frequently flooded river deltas with young and often rich alluvial soils. Core areas of certain crops give information on specific environmental factors. The core area of rice is characterized by a long rainy season and monthly mean temperatures above 25°C. Although yields in such areas are moderate, there is little risk of failure, since the environment meets the specific growth requirements of the crop.

However, increasing demands for food create demands for increased yields per unit area. Research programs seek to optimize the combination of production factors for maximum yields. The combination of high light intensity, ample water supply, and highly fertile soils, for example, results in high production. However, that combination is seldom met in nature. Irrigation systems were developed to meet the water requirements. In irrigated areas, production has increased significantly; but areas with controlled irrigation are limited.

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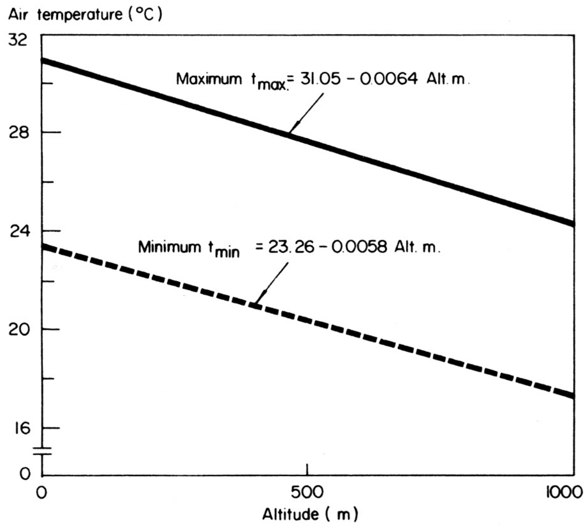
Instead of adjusting the environment to the needs of the crop, it is also possible to adjust the crop to the environment. Cropping systems research in rainfed agriculture aims to indicate the best possible year-round cropping pattern in a specific, existing environment. It is the task of agroclimatological research to describe the existing environment so that its relation to crop requirements can be seen. Since plant growth is a function not only of available water, available nutrients, atmospheric gases, temperature, and light, but of a mechanical support (Northcote, 1964), any environmental study should include a description of soil as well as of climate. Without information on the terrain, soil profile characteristics, and so on, an agroclimatic classification is incomplete. However, some conditions justify a separate discussion of the climatic system : (1) the soil system varies only in place, while climate varies not only in place but also in time, and (2) cropping pattern research implies a combination of agricultural practices throughout the year or major portions of the year.

During an International Rice Research Institute (IRRI) workshop in November 1973, the first step to characterize agroclimatic zones was taken. The main objective was to identify macro soil/climate zones that together present a first approximation of a representative spectrum of the rice-growing physical environment of Southeast Asia (IRRI, 1974). Because of the limited availability of climatic information other than rainfall data (the great local and seasonal variability of rainfall compared to other climatic factors, and the major importance of available water for crop production), a classification was set up. At its highest level, its classes are determined by quantity and duration of monthly precipitation. That approximation was presented during a FAO/UNDP consultation on the use of improved technology for food production in rainfed areas of tropical Asia (Oldeman, 1975a). As a follow-up to the workshop, an agroclimatic map of Java (Indonesia) was prepared (Oldeman, 1975b) and similar work was attempted for the Philippines. This paper will review the principles of the classification, critically discuss the criteria, and correlate the established zones with existing production patterns.

CLIMATIC ENVIRONMENT OF SOUTHEAST ASIA IN RELATION TO PLANT GROWTH

In the isothermal climates that prevail over most of Southeast Asia, air temperature, on the average, decreases 4 to 5°C/1,000 m (Fig. 1). Therefore, temperature variation can be inferred if the 500-m and 1,000-m contour lines are included on agroclimatic maps. However, in areas with a non-isothermal climate (generally at latitudes north of 17°), temperature may



1. Relation between elevation above sea level and air temperature (calculated with data from Boerema, 1946).

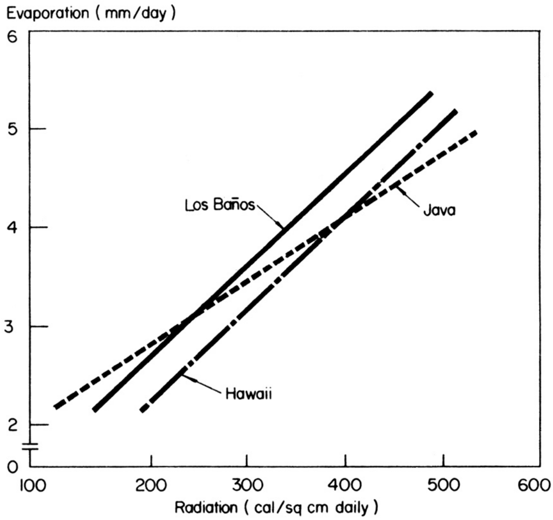
become a limiting crop production factor and will require mapping. In these regions rainfall and temperature, are clearly correlated, as will be seen later.

Solar radiation is a very important climatic determinant in crop production. Numerous studies have established its positive correlation with crop yields. Solar radiation is determined mainly by the type and duration of cloud cover and is indirectly related to rainfall.

Relative humidity and wind speed in Southeast Asia generally do not inhibit crop production, except when devastating cyclones occur. Cyclones occur only outside a 7-degree belt north and south of the equator, mostly during late summer and over tropical oceans. They commonly affect the northern part of the Philippines, the southeastern part of Vietnam, and the west coast of Burma. The probability of their occurrence should be indicated on maps.

Evaporation is an important climatic determinant, particularly with reference to the water requirements of the crop canopy. It is closely related to solar radiation, particularly in the humid tropics where relative humidities are high and wind speed is low (Fig. 2). The seasonal variation is closely related to that of solar radiation.

The importance of the aforementioned climatic determinants, in particular temperature and solar radiation, should not be underestimated ; observations of these parameters are essential in any cropping pattern research performed at benchmark stations. However, these parameters do

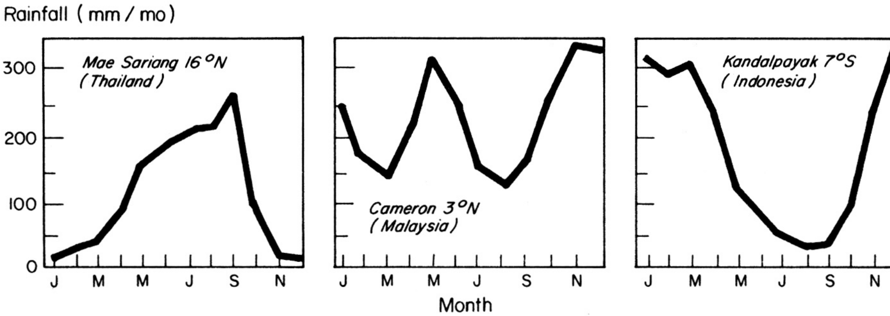


2. Relation between solar radiation and open-pan evaporation.

not readily lend themselves to mapping because of paucity of observations, brevity of records, and their relatively small seasonal variation. Nevertheless, they can be estimated within reasonable confidence limits.

The climatic determinant that shows the greatest variability with place and time is rainfall. Rainfall may vary from zero to more than 1,000 mm/month and may prohibit crop production during certain parts of the year unless irrigation or drainage facilities, or both, are available. In spite of its variability throughout the year and its irregularity from year to year, its seasonal distribution follows a well-understood pattern, which can be summarized as follows :

The equatorial low-pressure belt causes trade winds, directed towards the equator and deviating westerly because of the earth's rotation. The solar declination causes heating of the Eurasian continent during the northern summer, resulting in a broad southwesterly stream of humid air across the equatorial low-pressure belt over Southeast Asia. The arrival of the southwest monsoon north of the equator marks the onset of the rainy season. Cooling of the Eurasian continent during the northern winter and simultaneous heating of the Australian landmass cause a northwesterly stream of humid air over Eastern Asia, including Indonesia. The arrival of the northwest monsoon marks the beginning of the rainy season in regions south of the equator. The movement of the equatorial low pressure belt, following the solar path but lagging in time, causes rainfall peaks during August



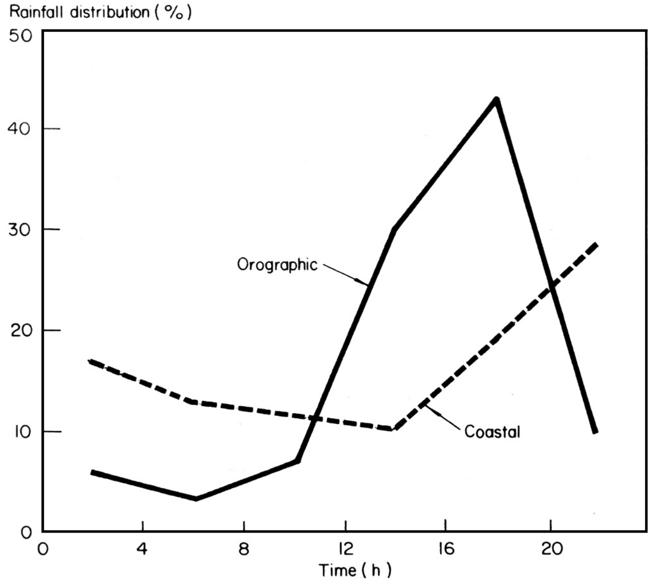
3. Monthly rainfall patterns at three locations in Southeast Asia.

and September at its northern limit and during January and February at its southern limit. The simultaneous retreat of the equatorial low-pressure belt and the rapid cooling of the Eurasian continent result in an abrupt end of the rainy season north of the equator and a rather sharp onset of the rainy season south of the equator. Near the equator two rainfall peaks, around November and again around April, can be observed. Figure 3 illustrates these three typical rainfall profiles.

The monsoon rainfall can be disturbed by local phenomena. Orographic lifting has the most pronounced effect on the rainfall distribution. Humid air, blown inland, is cooled as it is pushed against mountains, causing afternoon rains. Coastal areas are influenced by daily temperature gradients between the landmass and the sea, resulting in afternoon sea breezes and evening rain showers. The condition reverses at night, resulting in clear, sunny morning skies. These daily rainfall patterns are illustrated in Figure 4.

Although the seasonal rainfall patterns are understood, there are great variations from year to year. One of the major weaknesses of climatic classifications is that they are based on statistical averages that may never occur. Therefore, rainfall probability curves should be calculated. A frequently used, practical, and realistic value for rainfall is the monthly precipitation that is likely to occur 3 years out of 4. The value has been calculated for 10 locations in Java, ranging from very wet to very dry (Fig. 5).

If the mean monthly rainfall is plotted against the 75% probability of rainfall, a significant correlation can be observed: $Y = 0.82 \times - 29$ ($r^2 > 0.9$). This implies that we can calculate the rainfall that may be expected at least 3 years out of 4 if we know the mean monthly rainfall (X). Another factor to consider is effective precipitation. The effectiveness of rainfall depends not only on rainfall intensity but also on cultivation

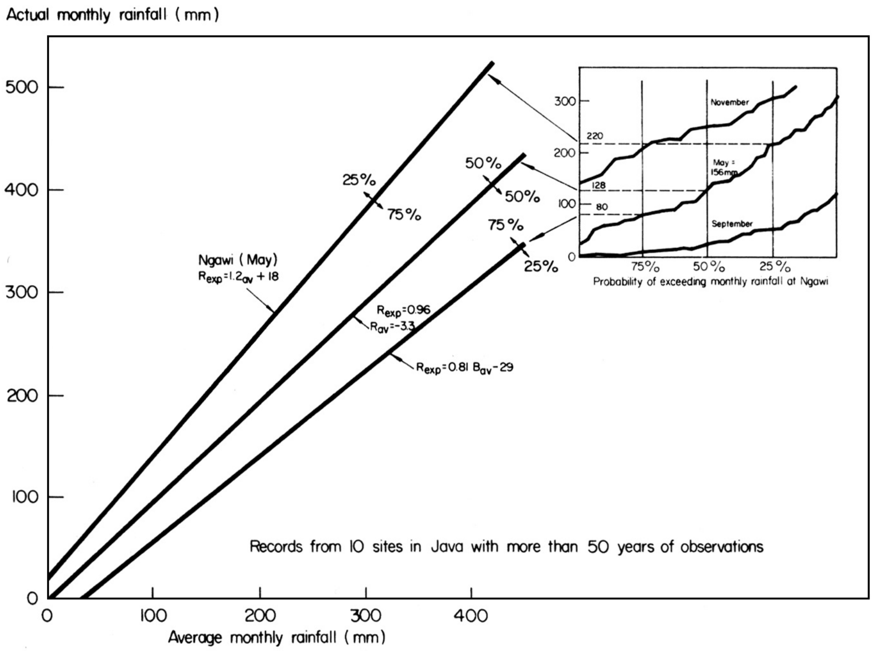


4. Effect of topographic location on the daily rainfall distribution (4-h amounts expressed as a percentage of 24-h total rainfall in 1974).

practices, topography, and soil and crop characteristics. Rainfall intensity varies with location and with season.

As discussed earlier, orographic lifting may result in heavy afternoon precipitation. In Bogor (Indonesia), a city near Mount Salak, about 75% of the total annual rainfall is recorded between 1200 and 2000 hours, and less than 10% between 0400 and 1200 hours.

There is no unanimously accepted method of describing effective rainfall in relation to daily intensity. According to Kung (1971) effective rainfall in India is taken as the mean rainfall, excluding daily rainfall of less than 12 mm/day or in excess of 75 mm/day. In Burma, less than 12 mm/day is considered ineffective, and only 80% of the daily rainfall in excess of 12 mm/day is termed effective. In Thailand, 80% of November and 90% of December-to-March rainfall are considered effective. In Japan, rainfall is considered 80% effective, but daily rainfall below 1.85 mm or above 30 mm is disregarded. In Vietnam, daily rainfall below 5 mm or above 50 mm is disregarded. Using these last criteria for two extreme locations in Indonesia gives an effective rainfall that varies between 75 % and 96%, with most months having more than 85%. Only during the wet season may heavy downpour occur.



5. Relationship between the average rainfall at a site and the 75, 50, and 25%, probabilities of exceeding that average in any particular month.

Effectiveness should also be considered in relation to the crop grown. For bunded rice, rainfall will be almost 100% effective because runoff is restricted. For an upland crop in its early stages, effective rainfall will be much less because of runoff as well as low consumptive use. The Soil Conservation Service of the USDA relates the average monthly effective rainfall to the average monthly crop evapotranspiration (USDA, 1967). If, for example, the mean monthly rainfall equals 100 mm, then 65% is effective when the consumptive use is estimated at 100 mm/month; 82% is effective when the consumptive use is 200 mm/month. The effectiveness generally decreases as rainfall increases.

In summary, if the probability of monthly rainfall is set at 75% and the effectiveness of rainfall per month is assumed to be 65 to 85% for upland crops and 100% for bunded rice, we can calculate the water from rainfall that will be available to the plant in 3 years out of 4.

Bunded rice: $Y = 0.82 \times - 29$ (Eq. 1)
Upland crop (early stage): $Y = 0.54 \times - 29$ (Eq. 2)
Upland crop (full ground cover): $Y = 0.71 \times - 29$ (Eq. 3)

(Y represents the effective monthly rainfall that may be expected in 3 years out of 4, and X is the mean monthly rainfall, calculated for a period of at least 25 years).

CROP WATER REQUIREMENTS

Although it is generally recognized that climate is one of the most important factors that determine the consumptive use of water by the crop, it should be realized that such use of water is also affected by crop characteristics (leaf area, roughness of the leaf surface, location and abundance of stomata), crop development stages, the rooting systems of the plants, and soil characteristics. In addition, management practices affect consumptive use. To relate the water requirement to climatic conditions, one writer has defined the reference crop evapotranspirations as "the rate of evapotranspiration from an extended surface of 8- to 15-cm-tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water" (Doorenbos and Pruitt, 1975). Several methods have been developed to calculate that reference crop evapotranspiration (ET_o).

The Blaney-Criddle approach, which is most widely used, is based on measured observations of the mean temperature t and percentage of daytime hours p. The empirically established formula is $ET_o - p(0.46t + 8.13)$, where t is expressed in degrees centigrade. In the humid tropics, where the seasonal temperature variations are small, the approach is not recommended.

The radiation method, based on measured air-temperature and measured hours of sunshine or radiation, is recommended particularly for equatorial zones, small islands, or high elevations. The method requires only general levels of humidity and wind. In areas with a mean relative humidity of 70% or more and a moderate wind speed (2–5 m/sec), the empirically established formula is $ET_o = -0.3 + 0.81\ W \times R_s$, in which W is a weighting factor for the effect of radiation on ET, at different temperatures and altitudes, and R_s the measured solar radiation in millimeters per day (1 mm/day is equivalent to 59 cal/sq cm per day).

The modified Penman approach takes into account energy as well as aerodynamics. It requires measurements of temperature, humidity, wind speed, and solar radiation. It is particularly recommended for regions with high wind speed and for more arid regions.

The open-pan evaporation method has the advantage of simple calculations. Its accuracy depends on the location of the open pan and the precision of the measurements. The pan coefficient K_p for the class-A pan surrounded by a green crop equals 0.8 in areas with high mean relative

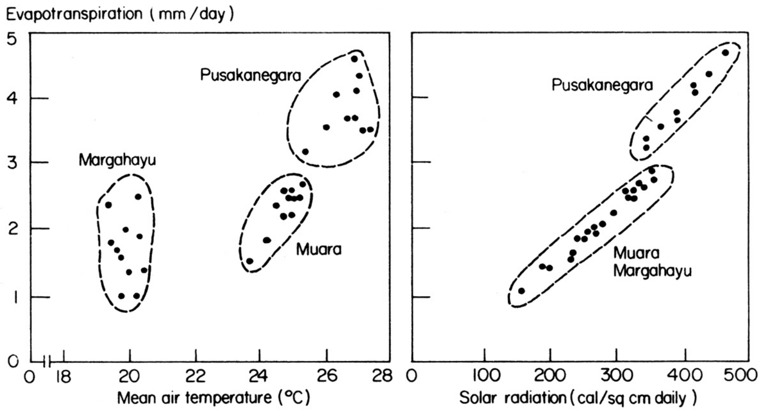
Table 1. Mean air temperature *t*, solar radiation R_s and crop reference evapotranspiration for three locations in Java in 1974. (Source: CRIA, 1976)

	Pusakanegara			Muara			Margahayu		
Month	*t* (°C)	R_s (cal/ sq m per day)	ET_o (mm/ day)	*t* (°C)	R_s (cal/ sq m per day)	ET_o (mm/ day)	*t* (°C)	R_s (cal/ sq m per day)	ET_o (mm/ day)
January	25.3	350	3.2	23.6	240	1.5	19.9	190	1.4
February	26.0	400	3.6	24.2	250	1.8	19.7	235	1.6
March	26.3	425	4.0	24.5	325	2.4	20.2	345	2.5
April	27.0	450	4.3	25.3	360	2.7	19.9	285	2.0
May	27.0	350	3.3	25.0	325	2.5	19.6	255	1.7
June	26.9	400	3.7	24.9	340	2.6	19.3	330	2.4
July	26.7	400	3.7	24.9	335	2.5	19.4	265	1.8
August	26.8	475	4.6	25.1	325	2.5	19.4	270	1.8
September	26.8	450	4.3	24.7	340	2.6	20.2	275	1.9
October	27.2	375	3.5	24.9	325	2.5	20.2	160	1.0
November	27.3	375	3.5	24.9	300	2.2	19.7	160	1.0
December	26.9	425	4.1	24.7	300	2.2	20.4	205	1.4

humidity and low-to-moderate wind speed. The formula reads $ET_o = K_p \times E_{open\ pan}$. It is often stated that no protective screen should be mounted over the pan. However, Campbell and Phene (1976) strongly support mounting of a screen over the open pan. They found a near 1 : 1 relationship between screened-pan evaporation and potential evapotranspiration computed from established equations.

The aforementioned methods, described in detail by Doorenbos and Pruitt (1975), were used to calculate the ET_o for benchmark stations in Java. Table 1 shows ET_o for three locations: Pusakanegara, in the coastal plain, with a pronounced dry season; inland Muara, at 250 m above sea level, with no pronounced dry season; Margahayu at 1,200 m above sea level on the southern slope of a mountain, with heavy cloud cover. In graph form (Fig. 6), the data show that evapotranspiration is closely correlated with solar radiation, but that the relationship between temperature and ET_o is confusing.

The reference crop evapotranspiration should be related to the actual evapotranspiration of the desired crop. To bring that about, coefficients have to be selected. They depend on crop characteristics and development stages. The wide variations among crop coefficients are due to differences among plant species in resistance to transpiration (location of stomata, waxy leaves, and so on), crop height, crop roughness, and so on. The percentage of ground cover and the leaf area also influence crop coefficients. Finally, the soil surface itself and the moisture at the soil surface that can evaporate will affect the crop coefficients to be used.



6. Relation between evapotranspiration and mean air temperature, and between evapotranspiration and solar radiation.

At the initial stage, when the soil surface is not covered or is sparsely covered by the crop, actual evapotranspiration depends mainly on the moisture characteristics of the soil surface. Under dry conditions, crop evapotranspiration (ET_{crop}) is around 0.3 times ET_o; under submerged conditions (bunded rice) ET_{crop} is around 1 to 1.15 times ET_o. With increasing ground cover, the crop coefficient increases to values of 0.95 (for peanuts) or 1.05 (for corn). At the late-season stage, indicated by discoloration or dropping of the leaves, the evaporative demand of the crop is reduced. The crop coefficient drops to 0.45 (for soybeans), or 0.55 (for peanuts), but will stay around 0.9 for sweet corn. The crop coefficient drops only slightly for bunded rice. By multiplying the calculated value for ET_o and the crop coefficient for a specific crop, one can roughly estimate the crop's water requirement. For bunded rice, the water requirement is between 2 and 5 mm/day, depending on the ET_o. For upland crops, water requirements are low in the early stages in both dry and wet seasons, and are between 2 and 4 mm/day during mid-season. At the end of the growing season, they may drop again to about 1 mm/day.

The total water requirement in the humid tropics for bunded rice varies from 75 to 150 mm/month; for most upland crops, 50 to 100 mm/month. Kung (1971) reports total water consumption for a number of crops:

Rice . . . . 380–880mm, or 2.9–6.3mm/day, or 85–185mm/month.
Soybeans . . . 300–350 mm, or 2.5–3.5mm/day, or 75–100mm/month.
Corn . . . . . . 350–400mm, or 2.9–3.5mm/day, or 85–100mm/month.
Peanuts . . . . 400–500 mm, or 2.7–3.5mm/day, or 80–100mm/month.

So far, only climatic and crop variables have been accounted for. It should now be stated that almost all of the water consumed by a crop canopy is taken up by plant roots. The soil moisture regime throughout the soil profile is therefore of utmost importance. While bunded rice thrives best in water-saturated soil, most upland crops require a well-aerated soil.

In bunded rice, the percolation rate should be included as part of the total amount of water required. Percolation rates vary considerably (from less than 1 mm/day up to more than 10 mm/day). However, most rice soils have a very low rate of percolation, either naturally (heavy clays) or artificially induced (plowpan). NEDECO (1973) recommends the use of a value of 1 mm/day for the alluvial soils in Java.

In upland crops, the water-holding capacity of the soil should be considered. That capacity depends, among other things, on the texture of the soil profile, on the rooting depth of the crop, and on the soil-water depletion levels tolerated by the crop. That last factor, in turn, depends on the crop-development stage. For most upland food crops in medium-textured soils, a value of 50 mm of available water may be assumed for an average rooting depth of 75 cm.

CLASSIFICATION OF CLIMATIC DETERMINANTS

Climatic classifications should never be based on arbitrarily fixed thresholds; they should be natural and should describe units recognized by other sciences (Papadakis, 1970). The major constraint to traditional agriculture in the humid tropics is the amount of available water for evapotranspiration by the crop canopy. In the absence of irrigation systems, the climatic determinant that has the highest priority in a classification system is precipitation. The main objective of cropping-pattern research is to indicate year-round alternative cropping systems. Therefore, precipitation classes should be based on year-round rainfall profiles. Rainfall profiles in Southeast Asia are governed by the occurrence of the monsoons with alternating dry and wet seasons. Rainfall classes should describe the length of those seasons and the intensity of precipitation during the seasons. The intensity should in turn be related to the crop water requirements.

Cropping systems in Asia generally include bunded rice. As discussed before, water requirements for bunded rice are different from those for upland crops. Thus, two rainfall quantities should be selected.

Selection of monthly rainfall intensities. In detailed water-management studies, mean monthly rainfall may not give necessary information because it does not describe the rainfall distribution in a given month. In general, the lower the monthly rainfall, the longer is the period of

Table 2. Frequency of occurrence of dry periods of less than 5 consecutive days, 5–10 days, 11–15 days, 16–20 days. and more than 20 days in relation to monthly rainfall at 10 locations in Indonesia, 1974 and 1975. (Source: CRIA, 1974, 1976)

Rainfall (mm/mo)	Occurrence in 10 locations (no.)	Frequency (%) of total consecutlve dry periods[a]				
		Less than 5 days	5–10 days	11–15 days	16–20 days	More than 20 days
More than 200	114	62	31	6	1	0
100–200 mm	64	8	58	26	8	0
50–100 mm	32	3	6	59	22	9
Less than 50 mm	22	0	0	4	23	73

[a]A dry day receives less than 5 mm rainfall.

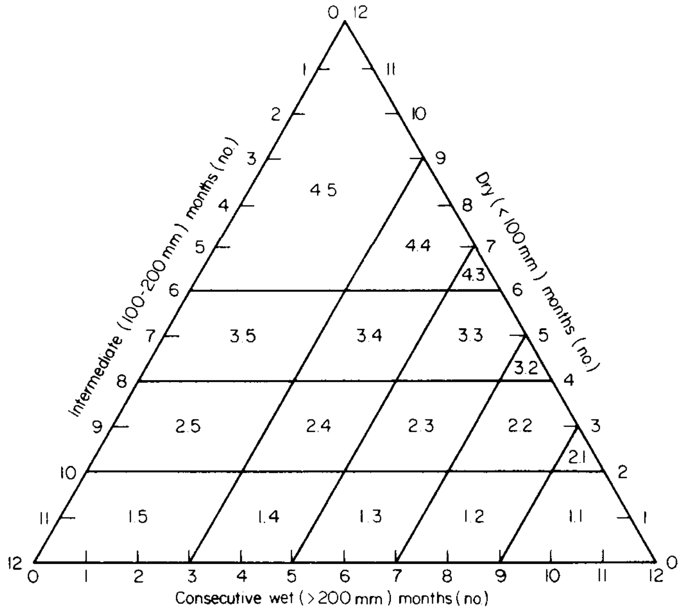
consecutive dry days. In Table 2, the frequency of occurrence of a dry period is related to the monthly rainfall. Data are for the years 1974 and 1975, at 10 locations in Indonesia representing various rainfall profiles. In an earlier section, the probability of a certain monthly effective rainfall was expressed in relation to the mean monthly rainfall as observed for a period of at least 25 years.

The crop water requirements for upland crops vary from 30 mm/month in the initial stage to 120 mm/month when the crop is fully developed. Assuming a water-holding capacity of 50 mm/75 cm rooting depth, the average monthly rainfall should be 100 to 140 mm/month (derived from equations 2 and 3).

For bunded rice the consumptive use is around 125 mm/month throughout its growing season. Assuming a percolation loss of 30 mm/month, the average monthly rainfall should be at least 200 mm (derived from equation). If mean precipitation is lower than that required by upland crops, the month is considered dry. The lower boundary is set at 100 mm mean monthly precipitation. If the monthly rainfall is above the amount required for bunded rice, the month is considered wet. The upper boundary is set at 200 mm mean monthly precipitation.

Selection of consecutive dry and wet periods. The first-level classification of rainfall profiles is determined by the number of "consecutive" dry months. If there are fewer than 2 dry months, there will be no restraint upon continuous cropping. If there are 2 to 4 dry months, careful planning of upland crops during the dry spell is required. With 5 to 6 consecutive dry months, continuous cropping under rainfed conditions during the period is hazardous. Only deep-rooting crops on soils with high water-holding capacity may be possible.

The second level of classification, based on the number of "consecutive" wet months, gives an indication of suitability for growing bunded rice.



7. Classification of agroclimatic zones.

If there are more than 9 "consecutive" wet months, bunded rice cultivation is possible throughout the year. If there are 7 to 9 wet months, two crops of rice can be cultivated. With 5 to 6 wet months, at least one crop of rice is possible, and with careful planning two crops of rice can be grown. A period of 3 or 4 wet months allows one crop of bunded rice at the most. A rainfall profile with less than 3 "consecutive" wet months is unsuitable for rice growing under rainfed conditions.

Agroclimatic zones. The combination of four dry-period classes and five wet-period classes is illustrated in Figure 7. It makes only 17 climatic zones, because some combinations are impossible within a 12-month period. Other zones call for only one possible combination (the dry period is immediately followed by the wet period). The complete classification follows.

1.1. less than 2 dry months and more than 9 wet months (Al)[1]
1.2. less than 2 dry months and 7–9 wet months (Bl)
1.3. less than 2 dry months and 5–6 wet months (Cl)
1.4. less than 2 dry months and 3–4 wet months (Dl)
1.5. less than 2 dry months and less than 3 wet months (El)

[1]Symbols in parentheses are those used in the agroclimatic map of Java (Oldeman, 1975b).

2.1. 2–4 dry months and more than 9 wet months (A2) (Only one combination is possible: 2 dry and 10 wet.)
2.2. 2–4 dry months and 7–9 wet months (B2)
2.3. 2–4 dry months and 5–6 wet months (C2)
2.4. 2–4 dry months and 3–4 wet months (D2)
2.5. 2–4 dry months and less than 3 wet months (E2)
3.1. not possible
3.2. 5-–6 dry months and 7–9 wet months (B3) (Only one combination is possible: 5 dry and 7 wet.)
3.3. 5–6 dry months and 5–6 wet months (C3)
3.4. 5–6 dry months and 3–4 wet months (D3)
3.5. 5–6 dry months and less than 3 wet months (E3)
4.1. not possible
4.2. not possible
4.3. more than 6 dry months and 5–6 wet months (C4) (Only one combination is possible: 7 dry and 5 wet)
4.4. more than 6 dry months and 3–4 wet months (D4)
4.5. more than 6 dry months and less than 3 wet months (E4)

The definition of a wet period calls for a consecutive number of wet months. Within such a period, 1 month may have only 100 to 200 mm of rain. If there is an interval in the wet season that includes more than 1 month with rainfall between 100 and 200 mm, or any month with rainfall less than 100 mm, or both, the longest wet period is considered primary and is the only one counted. If there are two or more periods of equal length, the one with the greatest total rainfall is counted.

In addition to this scheme, a zero (0) before the second digit denotes rapid transition from wet to dry; a zero (0) after the second digit indicates rapid transition from dry to wet. The criterion "rapid" means the occurrence of 1 month or less that separates monthly rainfall equal to or less than 50 mm from monthly rainfall equal to or greater than 200 mm.

The number 6 at the end of a classification indicates that at least 1 month experienced a mean rainfall greater than 500 mm.

SIGNIFICANCE OF THE CLASSIFICATION SYSTEM

A classification implies the grouping of items in a logical and usable framework. Grouping means that certain boundaries separating the items have to be defined. The number of boundaries is an indication of the complexity of the classification. With the classification presented, we have attempted to keep the number of classes to a minimum because the principal objective is a classification system that can be used by many persons and that at the same time can identify broad homogeneous climatic zones.

Significance in relation to actual rainfall observations. As rainfall varies from year to year, the classified rainfall profile will not always occur. In Table 3 the climatic class according to the mean rainfall profile is compared with the actual rainfall profile for six locations in Java. The data show that the occurrence of the classified rainfall profile varies from 24 to 84%. However, the actual rainfall class is seldom more than one class away from the classified profile. In Indramayu, a low 24% of the years of observation is in class 3.4. However, only 4% of the years had fewer than 2 dry months, and only 10% recorded more than 4 wet months. This means that 86% recorded 3 or more dry months and fewer than 5 wet months, while the mean profile suggests 5 or 6 dry months and 3 or 4 wet months.

Significance in relation to cropping patterns. To relate the climatic zones to existing cropping patterns, four regions in Java were analyzed in detail. Agricultural information was collected from the extension service. Table 4 indicates the percentage of area harvested monthly for bunded rice, corn, cassava, soybeans, and peanuts, as well as the total yearly harvested area for these crops. The results are summarized as follows:

The Bogor district has an almost continuous wet season, with a short break, usually between June and August. A rice-harvest peak occurs in May and June, but rice is harvested throughout the year. The upland crops in the district are less important and occupy a relatively small area except for cassava, which is grown on sloping, nonterraced land. Cassava shows no harvest peaks. Corn is harvested in the wet season, while peanuts are harvested throughout the year with a minor peak in October.

The Banyumas region is characterized by a short dry season and a long wet season (class 2.2). Two harvest peaks (around September and again around April) indicate that most rice farmers get two harvests from the same area. While the total rice area in the region is around 39,000 ha, farmers harvest around 58,000 ha annually. The other upland crops (except cassava) are less important. Corn is harvested at the peak of the rainy season, while soybeans are harvested either at the end of the dry season (October) or at the end of the rainy season (May). Peanuts are harvested at any time of the year from fewer than 2,000 ha.

The Sragen district is characterized by a 4-month dry season and a 5- or 6-month wet season. The harvest peaks for rice are less pronounced. Farmers generally grow two rice crops. The first crop uses the so-called gogo-ranca system. Rice is sown at the end of the dry season as an upland crop to take advantage of the November-December rains. That crop,

Table 3. Relationship between the rainfall profile class and the actual rainfall profiles for 6 sites in Java.

Site	Years of observation (no.)	Rainfall profile class[a] (mean)	Rainfall profile classification (observed)[b] 1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.2	3.3	3.4	3.5	4.3	4.4	4.5
Bogor	62	1.1 (A)	84	6	0	0	0	6	4	0	0	0	0	0	0	0	0	0	0
Banyumas	53	2.2 (82)	4	17	4	0	0	2	38	11	4	0	9	11	0	0	0	0	0
Ngawi	61	2.3 (C2)	0	3	3	3	0	0	21	38	10	3	3	10	5	0	3	3	0
Sidoarjo	61	3.3 (C3)	0	0	0	0	0	0	0	26	5	3	0	28	26	0	3	7	2
Indramayu	54	3.4 (D3)	0	0	0	1	3	0	0	6	17	24	0	4	24	15	2	2	2
Rembang	54	3.5 (E3)	0	0	0	0	0	0	0	2	15	26	0	2	13	32	2	4	4

[a]Symbols used in the Agroclimatic classification of Java (Oldeman, 1975). [b]% of all profiles for a site.

Table 4. The area harvested yearly and area harvested monthly for bunded rice, corn, cassava, soybeans, and peanuts in four districts in Java. (Data compiled from records of the extension service.)

Month	Harvested area (% of annual harvest)					Mean Rainfall (mm)
	Rice	Cassava	Corn	Soybeans	Peanuts	
			Bogor (1.1)			
January	5	10	23	8	9	411
February	7	9	22	8	9	388
March	4	9	16	8	10	378
April	9	10	5	6	8	422
May	13	8	3	2	4	393
June	22	9	4	4	9	265
July	9	7	4	8	7	205
August	5	7	4	8	7	216
September	6	10	5	23	7	290
October	6	9	4	6	13	437
November	6	8	4	8	9	386
December	6	7	6	8	7	363
			Annual harvest (ha)			
	85,900	12,115	1,650	50	2,670	
			Banyumas (2.2)			
January	0	6	30	2	9	350
February	3	5	17	2	11	294
March	11	4	3	1	7	346
April	27	4	5	9	8	261
May	13	7	3	21	10	190
June	2	9	1	5	8	149
July	2	14	2	10	3	79
August	12	18	5	11	12	64
September	16	15	4	3	10	89
October	9	8	4	22	7	312
November	3	5	11	14	7	416
December	1	4	15	0	4	433
			Annual harvest (ha)			
	57,850	10.815	4,260	3,460	1,780	

continued next page

table 4 continued

Month	Harvested area (% of annual harvest)					Mean Rainfall (mm)
	Rice	Cassava	Corn	Soybeans	Peanuts	
			Sragen (2.3)			
January	4	2	46	0	10	334
February	20	3	10	0	11	283
March	10	3	0	0	1	322
April	13	3	0	0	2	246
May	17	4	0	3	30	144
June	15	10	1	9	30	82
July	7	41	1	6	3	42
August	5	27	2	3	1	24
September	1	4	4	12	2	46
October	1	2	3	56	1	135
November	1	1	2	1	0	211
December	0	1	30	3	3	232
			Annual harvest (ha)			
	66,680	19,770	23,950	160	5,400	
			Tuban (3.4)			
January	1	2	15	1	2	256
February	0	2	27	3	11	216
March	1	1	13	5	19	199
April	15	3	2	6	3	119
May	43	7	3	2	10	90
June	31	5	6	4	25	64
July	5	10	5	26	23	30
August	0	26	5	30	2	19
September	0	24	7	9	1	19
October	2	14	7	6	2	52
November	2	4	6	5	1	105
December	1	3	6	5	0	204
			Annual harvest (ha)			
	45,405	14,960	60,990	7,060	15,675	

which is harvested in February, is immediately followed by a second rice crop that will be harvested in May or June. The second crop may fail to produce high yields because rainfall during the growth months may be very low. Therefore, the farmer who does not want to take a risk grows only one rice crop (November-March). The upland crops show definite peaks. Corn is sown at the end of the dry season and harvested in December and January, while peanuts are generally harvested in May or June. One typical cropping pattern found in the region is as follows: At the end of September, upland rice, corn, and cassava are planted together. The upland rice is harvested around January or February, and the corn a little earlier. Then farmers plant peanuts, to be harvested in June. Finally, cassava is harvested in July.

The Tuban district is characterized by a long dry season (6 months) followed by a short wet season varying from 3 to 4 months. A very pronounced rice-harvest peak is observed between April and June; there is little to no rice harvest during the rest of the year. The soybean and peanut harvests are from June till August. Only corn is cultivated during the end of the dry season; it is harvested about February.

In general, crop patterns are closely related to climatic patterns, especially to rainfall profiles. Cropping patterns are more complicated in areas with 5 or 6 wet months and 3 or 4 dry months than in areas with continuous wet climates and in those with very short rainy seasons. In Java, areas of the first group are located alongside mountain slopes (wet climate); those of the second are along the coast (dry climate). If those coastal areas are located in river deltas like those on West Java, they will have enough irrigation water for year-round rice cultivation and may, in fact, belong to the most productive zones because of high light-intensity accompanied by heavy and fertile soils. Without any catchment area, however, production is low.

Indeed, climatic zones are useful tools for understanding and planning cropping patterns if climatic maps include topographic features and if soil information is available.

SUMMARY

Crop growth and production are governed by climatic and soil-related determinants. Cropping patterns are primarily determined by the seasonal variability of climatic determinants. In the humid tropics, the seasonal variability of temperature, solar radiation, evaporation, relative humidity, and wind speed is relatively small compared with that of rainfall. The major constraint in cropping patterns is the availability of water to the plant. The reference crop evapotranspiration (ET_o), strongly related to climate, is determined. Crop coefficients to relate ET_o to crop evapotranspiration are estimated, and the consumptive use of water for a bunded rice canopy as well as for several upland crops is established. Using a 75% probability of receiving effective monthly rainfall, we define a wet month as one with at least 200 mm of rainfall, sufficient for cultivation of bunded rice; a dry month has a precipitation of less than 100 mm, generally not sufficient for growing upland crops. Rainfall classes are defined first according to dry-period length and the classes are subdivided according

to wet-period length. The climatic zones, mapped for Java according to rainfall class, are then correlated with existing agricultural production patterns. Although the method indicates broad agroclimatic zones only, cropping patterns show a clear relation to these zones.

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DISCUSSION

PRICE: Do you have evidence that variability of rainfall, in addition to average rainfall, affects the fit of cropping patterns to an environment? A hypothesis is that two locales with identical average rainfall patterns may, because of different variability in those averages, have quite different optimum cropping systems. My evidence is that average rainfall would be far more favorable to production than any actual years of rainfall. In an analysis of this we quantified a relationship between moisture and crop response. Based on average annual rainfall in Cale, Batangas, the relationship predicted a far higher crop yield than the average of crop yields predicted over many actual years of rainfall.

Oldeman: We have related the variability of rainfall to the average rainfall. For 10 locations in Java during 50–60 years we found a good correlation between the average rainfall and the level of rainfall that is likely to be exceeded 75% of the time (see Fig. 5). We have no answer yet to completely account for the variability of rainfall, but I agree that it affects your cropping pattern.

BANTA: To cover both variability of rain and soil characteristics would it he possible to use a basic minimum rainfall level and then take the length of time to planting for a group of farmers? If the farmers expect a steady rain and the soil has good water-holding capacity, they should start planting right away. If there is an unreliable rainfall pattern, or if the soil does not retain water, I would expect a slower planting response.

Oldeman: Yes, that is correct. We have calculated that the basic minimum rainfall of 100 mm/month (on the average) is needed. By calculating crop water-requirements we know that for the first period (sowing to established crop) water needs are increasing from 1 mm/day to 5 mm/day. If the soil is at field capacity and assuming a 50 mm water-holding capacity, a farmer can go ahead with planting.

NURJADI: The map you showed is the map of the climatic zones of Java; I think it is not a map of agroclimatic zones, because types of soil are not considered. So, to have a map of the agroclimatic zones of Java, we need another map of soil types to be combined with climatic zones. Please give me more detailed information for making a map of agro-climatic zones. Thank you.

Oldeman: I agree that the terminology is not completely accurate. Moreover, the specified zones are based on crop requirements and not on arbitrarily fixed boundaries. It is the task of the working group to combine the most relevant soil characteristics with the most relevant climatic determinants.

MORRIS: Is it possible to use a moisture-budgeting model, using typical values for water-holding capacity and percolation rates for major soil groups in the climatic zones, crop-determined rates of extraction and evapotranspiration (weekly), to develop subclassifications based mainly on soil groups that are better suited and more quantified for cropping systems research purposes? Can irrigation water be introduced? Can a prediction of the percentages for bumper crops, average crops, short crops, and crop failures be estimated if weather data for a number of years are used? Can the results be verified from past yields?

Oldeman: Climatic determinants and soil determinants should be selected in such a way that a water-balance model can be set up. By monitoring the systems on a daily basis for climatic soil, and agronomic determinants, answers can be given to your questions.

INCORPORATION OF PHYSICAL DETERMINANTS IN CROPPING PATTERN DESIGN

H. Brammer

The two preceding papers have described climatic and soil factors as independent determinants in the design of rice-based cropping patterns. The purpose of this paper is to describe how these physical factors interact to provide the complex agroecological determinants which must be considered in designing cropping patterns. For in practice we are usually considering not simply a rainfall zone or a soil zone, but the whole complex of agroecological factors which determine the length of the growing season or seasons, the crops or crop combinations that are practical in a particular area, and the extent to which management practices can modify natural constraints.

This paper draws heavily on experience in Bangladesh. That country provides a useful source of illustrations. Not only is there a wide range of environmental conditions, but also the high population density (averaging more than 600 persons/sq km) ensures that crops and cropping patterns are finely adjusted to the different environmental conditions.

Mean annual rainfall in Bangladesh ranges from about 1,250 mm to more than 6,000 mm. It falls in a single monsoon season of 4 to 7 wet months, overlapping three agroclimatic zones (IRRI, 1974). Bangladesh extends beyond the tropics into a zone where winters are cool enough to interrupt rice flowering and growth for some weeks, but not cold enough to prevent the cultivation of many tropical and temperate crops during that season. Day length varies between about 10.5 hours in December and 13.5 hours in June.

Bangladesh also includes a wide range of soil and flooding conditions. Moreover, the soils of the whole country have been mapped on a detailed reconnaissance scale and classified in terms of land capability and crop suitability. An agroecological map has been drawn and gross acreages

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suitable for a range of important crops, including high-yielding rites (HYV), have been calculated, both regionally and nationally. This has provided a basis for identifying agroecological subregions with high potential for increased crop production under both rainfed and irrigated conditions (FAO, 1971). Thus, a great deal of agroecological information exists in Bangladesh which can be used both for designing new cropping patterns (or improvements to traditional patterns) and for studying correlations between physical determinants and crop or cropping pattern adaptability.

MAJOR AGROECOLOGICAL CONSIDERATIONS

Whether rice, as well as associated crops, can be successfully grown is not directly determined by rainfall zones or soil zones (or hydrological zones or altitude zones). Their cultivation is determined by the combination of physical factors which determine the length of the growing season, or seasons, and whether the crop or crops can obtain adequate physical and nutritive support during this period without undue risk of destruction by meteorological, hydrological, or other, nonphysical, elements. Agroecological maps are drawn to show areas with significantly different combinations or degrees of expression of the physical factors which determine crop growth and performance, sometimes under specified management conditions.

Length of the rice-growing season. The length of the rice-growing season is determined by a number of factors: day length, temperature regime, rainfall regime, soil moisture-holding capacity, hydrological regime and, sometimes, soil chemical conditions.

In Bangladesh, rainfall regime, temperature regime and day length can be regarded as primary determinants of rice sowing and harvesting dates. However, the influence of the rainfall regime is widely modified by soil and hydrological factors. In fact, boundaries on the agroecological map of Bangladesh (Brammer, *in draft*) reflect soil and hydrological determinants much more strongly than they do climatic determinants. The three rainfall-regime zones described by the International Rice Research Institute are not ignored, but where the boundaries of the latter lie close to important physiographic boundaries, preference is given to the firm boundary provided by physiographic features rather than to the transitional boundary between rainfall zones. Only one major physiographic unit (the Barind tract) is subdivided solely on climatic grounds.

Climatic determinants. In irrigated areas (and in some perennially wet sites), the effective beginning of the rice-growing season is determined by winter temperatures. Night temperatures in December, January, and part of February fall below 13°C, which severely retards the growth of rice. Although many farmers, in fact, sow boro[1] seedbeds in November or December and transplant in December or January, there seems to be little advantage in doing so. In fact, such early sowing may expose the crop unnecessarily to pest and disease attack, and may waste irrigation water and labor. Probably, the optimum date of sowing is one which will allow boro seedlings to be transplanted in time to become established just as night temperatures begin to stay above 13°: in early February near the coast; from mid-February to late February inland.

In rainfed areas, the beginning of the rice-growing season is normally determined by the onset of the premonsoon rains. That ranges from early April in the northeast and near part of the coast, to late May in the extreme west. It should be noted that the optimum sowing date of aus and deep-water aman[2], which are normally sown as upland (that is, they are not transplanted) rices, is not necessarily determined by the date on which rainfall normally begins to exceed evaporation. Sowing normally takes place several weeks earlier. That is possible because the farmer prepares and sows his land after the first heavy premonsoon rainfall which saturates the topsoil. Thereafter, he harrows the topsoil and weeds the crop to conserve moisture. Also, the evapotranspiration loss by the young rice plants is much less than the evaporation loss recorded by meteorological instruments. For rainfed upland rice, therefore, the beginning of the growing season may be several weeks earlier than might be suggested by simple water-balance analysis.

The end of the rice-growing season in both rainfed and irrigated areas is determined partly by day length and partly by the date on which night temperatures begin to fall below 20°C. Both traditional aman varieties, which are photoperiod sensitive, and other varieties (including HYV) which are not, must be sown and transplanted by a date which will ensure that the plants will have grown beyond the flowering stage before night temperatures fall below the critical level which interferes with pollination. The critical date is reached sometime in November: early in the north, late near the coast. Detailed analyses of daily temperatures need to be carried out to determine the probable dates of occurrence of the two critical temperatures (13° and 20°C) in different parts of the country,

[1] There are three main seasonal rice crops in Bangladesh. Boro (1.2 M ha) is sown and transplanted in winter for harvesting before the monsoon season. Aus (3.2 M ha). mainly grown as an "upland" crop but transplanted locally, is sown in the premonsoon season and harvested in the monsoon season. Aman is of two kinds: deep-water (or broadcast) aman (1.8 M ha), sown as an "upland" rice in the premonsoon season and growing through the monsoon season, usually under flooded conditions; and transplanted aman (3.8 M ha), sown and transplanted in the monsoon season. Since traditional aman varieties are photoperiod sensitive, both deepwater and transplanted crops mature with shortening day length after the monsoon season.

[2] See footnote 1.

which determine the optimum dates of planting specific rice varieties in the aman and boro seasons.

Soil and hydrological determinants. Soil and hydrological conditions modify the "normal," climatically-determined length of the rice-growing season in certain areas. For example:

- Some silty Tista flood plain soils retain moisture throughout the dry season. That is due partly to a high water table, partly to the soils' unusually high moisture-holding capacity. Sowing of the upland rice crop, aus, commences in February or March on these soils, before the pre-monsoon rains begin.
- Sowing is delayed on soils of low moisture-holding capacity. Those include pervious, light-textured, flood-plain-ridge soils and permeable, red-brown terrace soils on the Madhupur and Barind tracts. Sowing of aus may not be safe until the end of May on those soils, because they do not have enough moisture-storage capacity to carry rice seedlings through dry spells between premonsoon showers.
- The puddled silty or clay topsoils of grey terrace soils on the Barind tract in the west of the country also lack the moisture-storage capacity for aus to be safely sown on the basis of the moisture provided by premonsoon showers. On these soils, aus is normally omitted and a single crop of transplanted aman is planted in June and July after there has been enough monsoon rainfall to flood the puddled fields. Where aus is late-sown, it unduly delays transplanting of the main aman crop, with consequent reduction in yields.

Within the same rainfall zone, therefore, soil and hydrological conditions may vary the sowing date of rainfed aus between late February and late May, or prevent it from being grown at all.

Elsewhere, the effective length of the rice-growing season is determined by other soil and hydrological factors. For example:

- by the probable date of onset of flash floods in foothill areas or of deep flooding in depression sites, which may set a limit to the safe harvesting period of boro or aus ;
- by the dates between which topsoil salinity is reduced to tolerable levels by monsoon rainfall; and
- by poor soil moisture-holding capacity or rapid drainage properties (or both) which cause some soils to become too dry for transplanted aman in September or October, before the normal maturity period for traditional photoperiod-sensitive varieties and before night temperatures fall to the critical level that normally ends the growing season.

Number of rice crops. The length of the rice-growing season partly determines whether one or two rainfed rice crops can be grown. For example:

- Traditionally, quick-maturing "upland" aus is followed by photo-period-sensitive transplanted aman on soils which hold moisture satisfactorily during both cropping seasons and where deep flooding or salinity is not limiting. Such soils occur most extensively in the east and north.
- A single crop of upland aus is typically grown on permeable flood-plain-ridge soils which cannot be puddled for transplanted rice, or in areas where the growing season is too short for aman. Such soils and conditions occur most extensively in the west. An early aus crop is also grown on some low-lying soils where rapid rise of floodwater later prevents deep-water aman from being grown.
- A single crop of transplanted aman is grown on soils that can be puddled or are shallowly flooded at the end of the monsoon season, but where the growing season is restricted by dry-season salinity or by the short duration of the rainy season. Extensive areas of such land occur in the west and south.
- A single deep-water aman crop is transplanted in some northwestern areas. Such a practice is followed on basin clays which stay too dry and hard for the land to be prepared before the pre-monsoon rains but which are liable to early and rapid flooding after heavy premonsoon showers, thus preventing normal broadcast sowing. Seedlings up to 60 or 80 cm long are often used for transplanting in such sites, where flooding depth may eventually reach 100 to 150 cm.

In addition to the above patterns, determined mainly by climate and soil conditions, there are patterns determined mainly by hydrological conditions. Restrictions imposed by early flash floods and deep flooding have been referred to above, in relation to aus and boro. Deep flooding prevents aman from being transplanted over wide areas of the country. In deeply flooded areas, there are three main rice cropping patterns :

1. mixed aus and deep-water aman, grown mainly on relatively permeable flood-plain-ridge soils which are not flooded deeper than 60 to 90 cm by July (when the aus is harvested, leaving the aman to continue growing with the rising floodwater until it is harvested, on recession of the floodwater, from October to December);
2. deep-water aman alone, grown mainly on deeply flooded basin and valley sites in areas where the risk of loss by rapidly rising floodwater is not too great;
3. boro, on basin and valley sites which remain wet through the dry season (or where irrigation can be provided) and where the risk of early flooding (in March or April) is not too severe.

Some deeply flooded land is not used for rice at all. This may be due to lack of irrigation water for boro, water too deep in the dry season for transplanting boro, risk of early floods, mucky soils with low bearing-capacity, salinity, or acid sulfate conditions.

NON-RICE ASSOCIATE CROPS

Dry-land crops. Non-rice, associate crops are widely grown in Bangladesh, both sequentially and as intercrops with rice. Their cultivation depends more on hydrological conditions and soil-moisture properties than on other soil factors or on climate. Almost all associate crops are dry-land crops, but arum is sometimes grown under wetland conditions, and some other crops (such as jute, sesame, millets, sorghum, chilies) apparently tolerate flooding when near maturity. Dry-season crops depend on residual soil moisture (where not irrigated), although they benefit in some years from chance winter rainfall.

Dry-season (rabi) crops include both tropical and temperate species. They can be divided into three broad groups—early, middle and late—according to sowing time (Table 1). The grouping is determined mainly by time of recession of floodwater.

Early rabi crops are sown in September and October. They generally follow aus, either on land above the normal flood level or on land from which floodwater recedes early. Since heavy monsoon rainfall often continues into the period, only permeable soils are suitable for those crops.

Table 1. Time of sowing of dry-season (rabi) crops.

Crop type	Time of sowing		
	Early	Middle	Late
Cereals	–	Wheat, barley	Millet[a], sorghum
Pulses	Black gram *(Phaseolus)*	Black gram, lentils, grass peas *(Lathyrus),* green gram *(Cicer),* field peas	Cowpea *(Vigna* spp)
Oilseeds	Mustard, rape-seed	Linseed, groundnuts, safflower *(Carthamus),* nigerseed *(Guizotia)*	Sunflower, sesame
Vegetables	Cabbage, cauli-flower, radishes	Late cabbage, tomatoes, potatoes, sweet potatoes	Eggplant, okra, melons, other cucurbits
Spices	–	Onions, garlic, several *umbelliferae*	Chilies
Narcotics	Virginia tobacco	Hookah/snuff tobacco	–
Fibers	Cotton	Sunnhemp	–

[a] Includes *Setaria, Panicum,* and *Pennisetum* spp.

Middle rabi crops constitute the major group. They are sown mainly in November and December, although yields of some crops, especially wheat, decline markedly if they are sown after early December. Middle rabi crops mainly follow aus or deep-water aman. Sometimes they also follow transplanted aman, but yields are generally poor because this aman crop is harvested mainly in December, after the cold weather has started ; also, the puddled topsoil, which either stays saturated for some weeks or quickly becomes dry and hard, provides an inhospitable seedbed for dryland crops.

Late rabi crops are sown mainly in January or February (even March) on land which stays too wet for earlier sowing and which retains moisture satisfactorily during the remainder of the dry season. Deep-water aman is the usual preceding crop. There are extensive areas of low-lying, deep, silty soils under this cropping pattern in the east of the country.

Intercropping. Some of the rabi crops are normally intersown with rice. The most common combinations and practices are:

- Khesari (grass peas), rapeseed, or black gram broadcast on the wet soil through standing deep-water aman (sometimes transplanted aman also) 2 to 4 weeks before the rice crop is harvested.
- Aus and deep-water aman, both separately and intermixed, sown broadcast through standing late rabi crops, especially sesame and chilies.
- Aus and deep-water aman, both separately and intermixed, intersown with millet (mainly *Setaria* sp) or sorghum. In this practice, the late rabi crops are harvested in June or July, as floodwater rises.
- Aus intersown with sesame, beans, hill cotton, and other crops in eastern hill areas where shifting cultivation is practised.
- Deep-water aman intersown with jute in some areas, mainly near major river channels where there is a risk that rapid, deep flooding might drown a rice crop that jute could survive. (Jute is also intersown with sesame and chilies in those areas where the latter crops are also grown intermixed with aman.)

Jute is a normal rotation crop with aus and aman in many parts of Bangladesh. It is substituted for aus or deep-water aman every 3 or 4 years, usually on loamy soils where the fine seedbed required by jute can be provided. Jute is followed by transplanted aman on relatively higher land in areas where early rains or moisture-retentive soils allow jute (like aus) to be sown early enough for harvesting in July or August, and where the soils can later be puddled for transplanted rice. Elsewhere, jute is usually followed by rabi crops. Jute makes a useful rotation crop with rice, since it allows weed rices to be cleaned out. It is grown most extensively near main river channels because of its resistance to sudden or deep floods.

Dry-land fallow. Much rice land remains fallow in the dry season because of adverse physical or chemical conditions. Most is transplanted aman land. Puddled silty or clay topsoils, often with a strong plowpan, commonly stay wet early in the dry season, then quickly become dry and hard, providing both a poor seedbed and little available moisture. Extensive areas of transplanted aman land in tidal coastal areas also become saline in the dry season. Much broadcast aman land, too, remains fallow in the dry season, mainly where basin soils stay wet late into the dry season, or have a clay topsoil which becomes very hard when dry, or both. Most hill soils and some sandy, flood-plain-ridge soils used for aus remain fallow in the dry season because of low moisture-holding capacity.

AGROECOLOGICAL CONSIDERATIONS IN CROPPING PATTERN DESIGN

The extensive description of agroecological determinants in Bangladesh given above illustrates how climatic, soil, and hydrological factors interact to determine:

- the length of the rice-growing season;
- the rice cultivation practices (broadcast, transplanted, deep-water, intermixed; also irrigated); and
- the kind of associate crop, if any, which is grown either intermixed with, sequential to or as an alternate to rice.

This environmental information combined with information on traditional cropping patterns and with knowledge of the characteristics of traditional, improved, and new crops and management practices, provides the basis for designing new or improved cropping patterns. Some important considerations to be kept in view in introducing new crops[3] and practices are outlined below.

"Fit". Crops and practices must fit within the limits prescribed by physical determinants, unless management practices (such as irrigation, improved cultivation techniques, use of plastic cloches over nursery beds, and so on) modify the natural limits. This may seem obvious, but the principle often seems to be ignored, presumably mainly through ignorance (excusable or otherwise) of the limitations set by one or more of the physical determinants or of the growth characteristics or requirements of a new crop or cultivar. Apart from adequate sunlight and temperature, a site must have soils providing physical support, tillage properties, moisture supply, root aeration, hydrological conditions (including time and depth of flooding or risk of flood damage), and chemical conditions appropriate

[3] Including cultivars.

for the crop or crops to be grown during their season of growth. It would be useful to develop a checklist of physical determinants to be considered before testing or introducing a new crop, cropping pattern, or management practice.

Specialization. Where a dominant limitation is imposed by one physical factor (such as soil salinity, deep flooding, extreme climatic conditions, and so on) specialized cultivars, cropping patterns, or management practices (alone or in combination) will usually be needed. Those cultivars, patterns, and practices may also be appropriate for maximizing yields in areas with reliable climatic and hydrological regimes and where soil conditions are not extreme, so that production can be maximized.

Flexibility. In areas of variable or unreliable climatic or hydrological conditions (such as variable rainfall, flooding depth, or date of onset of rains or flooding), cultivars and patterns should be flexible rather than specialized. Many farmers have to contend with such conditions, and traditional cropping patterns and practices are often well adjusted to them. Under such conditions, the cropping program objective should be to optimize production by providing security against natural adversities. For example, rice cultivars with one or more of the following properties may be needed to provide security against uncertain environmental conditions:

- seedlings which can stay in the seedbed 2 to 3 weeks longer than normal, as a precaution against drought or floods that might prevent transplanting on time;
- long seedlings, with capacity to elongate rapidly or to tolerate submergence, or both, as safeguards against variable and uncontrollable flooding depth at time of transplanting or immediately afterward;
- capacity to tiller over a relatively long period, as a means of recovery from early drought or other damage;
- capacity to tiller rapidly for a crop that must fit a growing season that is short, either naturally or because of delayed planting;
- tolerance of drought, salinity, acidity, cold, or combinations of such constraints (both at early and late growth stages);
- quick maturation and lack of photoperiod sensitivity when a crop has to fit a short or abbreviated growing season;
- photoperiod sensitivity when a crop has to fit a short growing period at the end of the growing season (in latitudes where day length varies significantly).

Cropping patterns, too, may have to be flexible enough to accommodate annual differences in dates of onset of rains, end of rains, onset and recession of floodwater, and so on. Those variations may determine, in different years, whether rice is dry-sown, broadcast wet or pregerminated, or transplanted; whether it is followed by a second rice crop or not and whether that is period-fixed or photoperiod sensitive; and whether an early, middle, or late dryland crop or fallow follows the main rice harvest. Many Bangladesh farmers keep seed of several rice and non-rice varieties to provide security against such uncertain conditions.

Such flexibility, both in choice of cultivars and in cropping sequences, deserves to be studied in areas where environmental conditions are variable. Variability may have to be simulated under controlled research station conditions to find optimizing patterns and practices.

The same principle of flexibility must be kept in view in areas subject to such disasters as cyclones (typhoons or hurricanes), saline incursions, or damaging floods, which periodically disrupt normal cropping patterns. Wherever possible, cropping patterns in such areas should be designed either to maximize production outside the disaster season or, alternatively, to provide crops or techniques which can be substituted for the lost crop (or the crop which would normally follow in the sequence) so as to speed recovery from the disaster. Disaster-recovery crops or patterns may not be used every year, but they need to be studied, elaborated, and demonstrated so that they are ready for use when needed.

Farmers' conditions. Cultivars, cropping patterns, and management practices must be appropriate for farmers' conditions. Cultivars, patterns, and practices developed on research stations—where the soils have usually been deeply plowed, heavily fertilized, and regularly irrigated—may be unsuitable or impractical on farmers' land where the growing environment is different.

Soil physical properties. Soil properties need to be taken more fully into account, particularly those which determine moisture storage, drainage, tillage conditions, bearing capacity, depth of rooting, and erodibility. Those properties can be influenced, to varying degrees, by bad or good management.

In particular, studies are needed on plowpan formation. Strong plowpans develop under fields where there is long-continued cultivation of transplanted rice, especially in silty and kaolinitic soils. Under traditional farming conditions, the pan may lie only 5 to 8 cm below the surface, restricting the volume of water that can be stored in the puddled topsoil for transplanted rice. It may also prevent dry-land crops from being grown after the rice, because of impedance to root development. Destruction of this plowpan by deep plowing can be disastrous in certain kinds of soil, especially if the soils are also kept continuously wet by irrigation : the soils lose their capacity to bear either animals or tractors. Studies are needed to find means of reestablishing bearing capacity in such soils by reforming a plowpan at greater depth. In practice, the plowpan should be broken up and reestablished within one season. Farmers cannot afford to suffer decreased yields or to lose several crops while bearing capacity is being reestablished.

Diversity and complexity. The diversity and complexity of environmental conditions need to be taken more fully into account. This particularly applies to soil and hydrological conditions in alluvial areas. Because of the way in which rivers deposit their sediments, soil texture and elevation often change within short distances. Different rivers may also bring down different kinds of sediment, and length of time since deposition influences the degree to which physical and chemical changes have taken place in these sediments under different climatic and hydrological conditions. The result, in a country such as Bangladesh, is both diversity and complexity of soils. Often, there are many different soils, varying particularly in their moisture regimes, so that changes in permeability, moisture-holding capacity, and flooding characteristics occur within short distances. Similar differences in soil and hydrological properties can occur in undulating uplands.

In areas of such diversity and complexity, it is probably unhelpful to think in terms of agroecological zones. No single cultivar, cropping pattern, or management practice is likely to suit all the environmental conditions within such complex areas. Because of differences in soil-moisture properties, hydrological conditions and, sometimes, soil-chemical conditions, there may be significant differences in the length of the rice-growing season, flood depth and duration, and suitability for associate crops in areas only a few hundred meters apart.

Fortunately, such diversity and complexity are usually not random. The physical components of the complex usually form a repetitive pattern, associated with differences in relief (which may be slight in flood-plain areas). Many—probably most—units shown on agroecological maps are, in fact, agroecological complexes. Typically, maps differentiate, not between single physical factors, but between complexes of determinant factors varying with topographical site within the mapped boundaries. The specific combinations of physical determinants may not be confined to a single mapping unit. They may occur, to a greater or lesser extent, as components of several other mapping units. Transfer of specific cropping patterns must therefore be made between defined agroecological components of mapping units, not between mapping units regarded as entities.

Contribution of individual determinants. In view of the diversity and complexity of environmental conditions referred to above, studies are needed to isolate the contribution of individual physical determinants so that predictions can be made regarding the geographical area over which particular cultivars or cropping patterns can be extended, both nationally and internationally, without the need to test crops, patterns, and practices on a multitude of sites. This will involve evaluations of:

- the length of the rice-growing season;
- soil-moisture storage capacity in relation to rainfall probability (as modified perhaps, by flooding and water table position) and seasonal demand by adapted crops ;
- soil tillage properties and bearing capacity;
- frequency of damaging floods, cyclones, and so on, and their probable times of occurrence ;
- harmful soil chemical properties.

At the same time, the feasibility of modifying environmental conditions by appropriate management techniques needs to be evaluated : for example, modifying soil moisture regime (by irrigation, mulching, or improved tillage), soil chemical regime (by irrigation or chemical amendments), temperature regime (by use of plastic cloches, and so on), and disaster risk (by early sowing, flood protection, cultivation on raised beds, and so on).

Additional research considerations. Finally, two recommendations are made for improvement of cropping pattern design, testing and extension.

1. Soil scientists should be more fully associated with design and testing of cropping patterns, both for identifying and evaluating soil determinants or hydrological determinants, or both, and for studying the feasibility of modifying them (where that might be desirable).
2. As recommended by Moormann et al. (1975), trials should be conducted across toposequences,[4] where relevant, as a means of identifying and isolating the influence of individual soil physical, chemical, and hydrological determinants on particular crops, cropping patterns, and management practices.

SUMMARY

Examples from Bangladesh illustrate how climatic, soil, and hydrological factors interact to determine the length of the rice-growing season, rice cultivation practices, and the kinds of associate dry-land crops (if any) grown sequentially, intermixed, or as alternates with rice. Important considerations in designing new cropping patterns are that crops (including cultivars), cropping patterns, and management practices should be suitable

[4]The sequence of topographical sites which occur between the highest and lowest parts of an individual landscape.

for the site; suitable for farmers' conditions; specialized where one or more physical conditions are extreme or, alternatively, where environmental conditions are reliable; and flexible where climatic or hydrological conditions are variable or occasionally disastrous. Studies are needed to relate rainfall probability with soil moisture-holding capacity in order to determine the suitability of soils for particular crops and cropping patterns; to isolate the contribution of major physical determinants in order to improve predictions regarding the geographical extensibility of crops or cropping patterns, or both; and to investigate the problems caused by plowpans. Soil scientists need to be more closely associated with the design of cropping patterns.

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Economics of cropping systems: description and pattern design

INTRODUCTION

H. Nataatmadja

I feel honored to chair this economic session, which is probably the most difficult part of our comprehensive research activity, not because economists are less endowed with economic skill than agronomists are endowed with agronomic skill, but because economists are to deal with the most complex creature that ever lived on this globe.

For noneconomists, probably I should say beforehand that economics is whatever economists talk about. We deal with everything that interests us. So Prof. W.H. Vincent will discuss the science of decision-making. Mr. Manu Seetisarn will talk about descriptive strategy related to the whole set of base-line farm data that are presumed to be meaningful. Mr. Gordon Banta will make another addition to the huge collection of information needed to barely understand what cropping systems are all about. Finally, Dr. Edwin C. Price will try to select criteria, major issues, and procedures to enable us to develop proper designs for cropping patterns suitable to local environments, both physical and social.

As physical and biological scientists, you are fortunate in many respects. When you talk, fundamental terms like “atom” have the same operational meaning to all of you. But the term “man” used by an economist does not necessarily convey his meaning to another social scientist, or even to another economist. That is the real source of misunderstanding in the social sciences.

Given that limitation (I hide others for the sake of my profession), I might be able to induce proper expectations of what a group of economists can do. But as an economist I would like to stress that there is no getting away from them if you are to understand human behavior; you have to cooperate with economists and other social scientists. Economics is not a monopoly, but a simple tradition of specialization. Economists are dependable partners.

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To offer you some guideline to the subjects dealt with in this session, I would like to remind you of the already-agreed-upon phases of research activity, namely:

- identification
- design
- testing, and
- extension

Not specifically in that order, considering the overlapping nature of the phases, the first two papers will present basic ideas about the scope, objectives, coverage, and methodological approaches of the economic aspect of cropping systems study.

The next three papers provide perspective, with more details, utilizing data already collected, analyzed, and interpreted in the development of the study.

With this preliminary guideline, Professor Vincent, I offer you the floor.

RESOURCE BASE AS A DETERMINANT OF CROPPING PATTERNS

N.S. Jodha

A region's natural factor endowment, in association with its level and type of trade and technology, sets the broad limits within which the cropping pattern potential of an area is determined. However, the extent to which that potential is realized depends upon farmers' capacity to harness it. That in turn depends upon farmers' resource position. In such a sense alone, resource position may be considered a major determinant of cropping patterns. The impact of resource base on cropping patterns may be demonstrated by (1) changes in cropping patterns over time following changes in resource base, or (2) differences in cropping patterns of farmers with varying farm-level resource endowments.

A few points that are central to any discussion of the impact of resource base on cropping patterns need to be stressed at the outset.

1. Viewed retrospectively, the quantitative and qualitative makeup of the farm-level resource base is generally an accumulated outcome of the cropping pattern itself. The agronomic and related requirements of crops determine (from the demand side) the type and quantity of man-made and other resources, and the returns from the crops determine (from the supply side) the ability of a farmer to acquire and sustain a certain type and quantity of resources. However, because it could lead to a prolonged hen-versus-egg type of argument, I do not intend to discuss this point further.

2. The direct impact of resource base on cropping patterns is mainly as an input in the production process. Since the utilization of a resource in crop production is not always rigidly tied with its ownership, the association between resource position of individual farms and their cropping patterns is not straightforward. Moreover, the apparent association between the two may give a misleading picture.

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Consider family labor. The availability of a household's own resource definitely influences the deployment of that resource on the farm. However, the actual decision about the use of resource is significantly dictated by the availability of alternatives within and outside the farm that offer different levels of return. The crops possible on one's own farm offer only some of the possibilities for use of family labor. Other possibilities of employment on one's own or on other farms, or engagement in off-farm activities are alternatives which must be taken into account. If a resource is deployed off one's own farm, the impact of total resource availability will not be reflected in one's cropping pattern.[1]

One way to account for the resource problem is to separate farm-level resources or production factors into two categories: (a) resources for which utilization is more or less rigidly determined by ownership, and (b) resources for which that is not true. The first category comprises resources like land, the availability of which, for a given household, is fixed at least for a crop season. There is little possibility of intraseason lease/sale transactions, hence cropping decisions may be influenced by what land is available. The second category comprises resources like labor, bullocks, farm equipment, and so on, whose utilization need not be tied to their ownership. The hire or purchase market for such resources is never dormant (as is that for land after the crop season begins), and the possibility of acquiring them or supplying them to others is always open.

In such cases, the pattern of household utilization of resources may differ greatly from the pattern of possession. Furthermore, their utilization or demand by individual farmers may be determined by cropping pattern rather than vice versa. Thus it is accessibility to the resources through factor markets rather than possession of them (as a part of households' fixed resource base) that is of relevance in studying their impact on cropping patterns. However, the difference between the two resource categories based on difference between ownership and utilization may tend to disappear when one moves from the microlevel to the macrolevel of observation. The utilization of a resource will be more rigidly determined by ownership as one moves from household to village, from village to village cluster, and from village cluster to a bigger geographical unit like a district or a region.[2] That is so because mobility of most of the physical resources becomes more difficult as one moves from smaller to bigger spatial units.[3]

[1] For instance a household with a large number of family workers should go in for labor-intensive crops. But they are likely to go in for crops that are not labor intensive and which spare labor for exploiting better earning opportunities offered by other farms during the crop season.

[2] The term "more rigidly determined" broadly implies that ownership in a household or local availability in a village or a region operates as a major constraint on the utilization of a resource.

The above arguments have the following implications for the subsequent discussion.

a. Impact of the household resource base on cropping patterns can be meaningfully analyzed largely in terms of the relationship between operational landholding and cropping pattern. Such analysis is justified not only by the relatively rigid relationship between effective possession and the utilization of resources but also by the fact that in traditional agriculture, landholding primarily determines one's capacity to hire in or hire out other factors like labor or bullocks. Impact of resources other than land are more appropriately analyzed at the village or regional level than at the household level.

b. A related point is that if some massive transformation of the resource base (through an irrigation project, for instance) takes place at the regional level, its impact, which overshadows the impact of other resource differences, could be reflected in changed cropping patterns at both the household level and the more aggregative level. That has been demonstrated by the impact of canal irrigation and the introduction of tractors on cropping patterns, as discussed in the following section.

IMPACT OF MAJOR RESOURCE INVESTMENTS

As mentioned earlier, a convenient way of observing the role of resource base in determining the cropping pattern is to examine the changes in the resource base and consequent changes in the cropping pattern. The changes may take place for a variety of reasons, such as increased input absorption capacity of the land, changes in agrobiological and physical constraints on land use, changes in the cost-to-benefit ratios of different crops, and so on. The substantial changes in cropping patterns which can occur due to a large-scale increase in the resource base are clearly illustrated in Tables 1 and 2. The resource changes and consequent crop shifts are qualitatively very different in the two cases, but the point under consideration—that resource improvement leads to rapid changes in cropping patterns—is testified to by both.

Impact of canal irrigation. Table 1 contains data for 1966–67 and 1971–72 from four villages in the semiarid tropical district of Kota in Rajasthan State of India. That largely rainfed area received irrigation for the first time in the early 1960's from the Chambal Irrigation Project, which initiated the transformation of the whole area (AERC, 1970; Bapna,

[3]Difference between resource possession and its extent and pattern of utilization—for a whole region, for example—may persist because of weather variability. For example, in rainfed areas. how intensively a resource can be used and what crops can be planted during a year will be determined by timing and amount of rain, notwithstanding the availability of complementary resources.

Table 1. Cropping pattern changes after increases in irrigation in the semiarid villages of Kota, Rajasthan. India.[a]

Village	Irrigated area[b] (%)	Share of crops (%) in total cropped area						
		Paddy	Sorghum and mixed crops[c]	Other kharif crops[d]	Irrigated wheat	Dry wheat and mixed crops[e]	Chick-peas	Other rabi crops[f]
				1966–67				
Dhakarkheri	76	8	4	10	48	11	9	10
Kishanpur	36	2	37	8	–	27	16	10
Kishorepura	21	–	21	5	14	20	25	15
Digod	34	1	31	5	18	23	9	13
				1977–72				
Dhakarkheri	92	27	1	7	56	1	6	2
Kishanpur	72	7	10	4	49	–	9	21
Kishorepura	50	2	3	2	41	11	30	11
Digod	60	15	16	2	39	14	5	9

[a] Data extracted from Bapna (1973). [b] Irrigated area as % of net sown area. [c] Crop mixtures mainly include pulse crops and sorghum; latter is grown as a main crop in mixed crops. [d] other kharif (monsoon) crops include maize, pulses, sesame, groundnut, and fodder crops mainly. [e] Includes local (non-HYV) wheat raised generally as a mixed crop with barley and gram (chick-peas) and also raised as a sole crop. [f] Includes linseed, coriander, vegetable crops, etc.

Table 2. Cropping pattern changes following tractor introduction in an arid area of Rajasthan, India.[a]

Farm size (ha)	Year	Tractor culti-vation[b] (%)	Land use inten-sity[c] (%)	Share of crops (%) in total cropped area						
				Pearl millet	Sorghum	Sesame	Green gram	Moth beans[d]	Clus-ter bean	Fodder sorghum
1.0–6.1	1964–65	1	89	30	25	2	1	20	16	6
	1973–74	64	95	37	31	12		78	4	1
6.2–12.1	1964–65	7	73	28	24	5	4	14	14	11
	1973–74	58	88	31	28	16	13	4	7	1
12.1 and above	1964–65	5	68	22	24	9	5	17	13	10
	1973–74	88	93	29	28	12	13	6	10	2
					For tractor users					
	1964–65	4	86	25	24	7	3	16	15	10
	1973–74	74	94	30	29	14	12	5	9	1
					For nonusers of tractors[e]					
	1964–65	–	84	26	20	7	6	13	15	13
	1973–74	–	87	24	21	5	5	15	17	13

[a] The data relate to a sample of 112 farms from a cluster of three villages from Nagaur, an arid district of Rajasthan. For details see Jodha (1974). [b] Tractor cultivated area as a percentage of total cropped area. [c] Cropped area as a percentage of total cultivable area including current fallow, old fallow, permanent fallow, and cropped area. [d] *Phaseolus aconitifolius.* [e] Nontractor users (23) are those who did not use a tractor at all in either year.

1973). The proportion of irrigated area to total cropped area in different villages increased from a range of 21 to 76% in the base year, to between 50 and 92% respectively, in the later year. The increase in turn initiated a new cropping pattern. An important feature of the patterns is that high-value crops like paddy, irrigated wheat, and vegetables in some cases have substantially replaced low-value crops like sorghum, maize, pulses, chick-peas, and barley. Furthermore, the mixed crops (dominated by sorghum in kharif, and by non-high yielding wheat, chick-peas, or barley during rabi), which are important features of the cropping patterns in rainfed, semiarid, tropical India, have lost ground to high-value crops that are mostly sown as sole crops. The gradual disappearance of low-value crops, particularly coarse cereals, following the upgrading of the resource base through irrigation is a common feature observed in different areas of India (Jodha, 1973). In the Kota villages, the pace of disappearance of low-value crops and mixed cropping seems to have been accentuated by almost simultaneous availability of high yielding varieties (HYV) of paddy and wheat.[4] The reasons for the changes range from poor competitiveness of the low-value crops in the changed context, redundance of mixed cropping as a strategy against risk once irrigation has lessened the risk, and the advent of HYV technology which has an apparent bias for sole cropping.

Impact of tractor introduction. A qualitatively different but equally strong tendency of crop succession in yet another situation is illustrated in Table 2. In a certain cluster of villages in India, the annual average rainfall is 31.9 cm, and not even 1% of the cropped area has irrigation facilities. The only change in the factor endowment of the area during the last 15 years has been the replacement of bullocks by tractors for cultivation on a substantia1 scale. The extent of tractor cultivation, embracing all sizes of farms, increased from 4% of the cropped area in 1965–66 to 74% in 1971–72.[5] On the face of it, the agroclimatic conditions of the area—low and unstable rainfall and sandy loam soils—would seem to make the tractor a risky, most uneconomic, and wasteful innovation. In reality those very conditions have enhanced the spread of tractor cultivation.

Not only does the area have low rainfall, but the rain occurs mainly in two to four showers during July and August. That limits the wet periods (or sowing period) to 2 to 4 weeks for the whole season. The wet period is further shortened by strong winds in the area. The success of the crop is determined by the farmer's capacity to exploit the short wet periods. The consequences of delayed sowing (for want of sufficient draft power during

[4] For details of spread and impact of HYV in Kota District, see AERC (1970) and Bapna (1973).

[5] Average size of farms ranged from 8 to 12 ha. For details, see Jodha (1974).

peak periods) are a need for resowing, or lower crop yields, due to poor germination; and poor crop stand of a late-sown crop because of desiccating winds (described as *Jhola*) during mid-September to October which damage the late-sown crops during seed formation. [6] Any facility which helped the farmers overcome the problem created by a short wet period vis-a-vis their limited draft power was readily acceptable. Further, the tractor user did not need to own the tractor. Informal custom-hire services offered by larger tractor-owning farmers (or groups of medium farmers) became popular. One reason was their flexibility in terms of time and the form of payment of the charges. Payment was called for only when the customer was in a position to pay, during the harvest period, for example. Payment was welcomed in any form, including cash, grain, fodder, fuel, labor, or leased-out land. For their owners, the tractors became important sources of income as well as instruments of influence in the village-level product markets, in the factor markets, and in the noneconomic sphere of community life. The process, supported both by demand and supply forces, including Land Development Bank loan facilities to buy tractors, has brought about a significant qualitative change in the resource base of the community. [7] Mechanization's first impact was to increase the intensity of land use by reducing the extent of fallowing, which had been due partly to the inability to plant large areas within the very short wet periods. The increased use of tractors increased the net cropped area on selected farms—from 86% of the total operational area in 1964–65 to 94% in 1973–74.

Before tractors, the cropping pattern used crops like pearl millet and sorghum which were planted during the early wet periods. Toward the end of the wet periods, crops like moth beans, cluster beans (*guar*), and fodder sorghum were raised. Since maturation of late-sown crops was uncertain, farmers preferred the above crops because even when not fully ripe, they ensured at least fodder if not grain. Moreover, they require relatively little moisture. Other crops like sesame and green gram, although higher priced, neither met subsistence needs of the farmer nor ensured partial returns through fodder. Hence they received lowest priority in acreage allocation.

Table 2 shows the changes induced by tractors. For all tractor-using farms (that is, those that used tractors for crop planting, at least), the share

[6] More than 50% of the plots of the area sown after 7 to 15 days of soaking showers required resowing. Pearl millet yields with those delays were 31 to 79% less than the yields of pearl millet sown within 7 days of soaking rains. For details see Jodha (1974).

[7] The process worked so effectively that in an area of just 6 villages, the number of tractors (mostly 35 HP Massey-Ferguson) increased from 10 in 1964–65 to 35 in 1968–69 and 59 in 1973–74 (Jodha. 1974).

of pearl millet increased from 25% of the total crop in 1964–65 to 30% in 1973–74. Sorghum increased its share from 24 to 29%, sesame from 7 to 14%, and green gram from 3 to 12%. Moth beans, cluster beans, and fodder sorghum had their shares reduced from 16 to 5%, from 15 to 9%. and from 10 to 1%, respectively. The changing pattern is also visible across different farm-size groups. That the new crop ratios are for a much larger total area than was cropped before adds to the significance of the changes.

Attributing the changes in cropping pattern to introduction of tractors—a major qualitative and quantitative change in the resource base of the community—is further supported by the lack of similar changes in the cropping pattern of the non-tractor-using farms during the same period.[8] The latter continued to allocate substantial area to the more drought-resistant crops, as they could not plant all of their land during the brief moisture period.

CROSS-SECTION ANALYSIS OF IMPACT OF RESOURCE DIFFERENCES

In what follows, I shall use data from six villages in the semiarid tropical areas of India where the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is conducting studies.[9] The results are preliminary; final processing of the data is in progress.

Farm-level resource base. The resource positions of farms in different landholding groups at the beginning of the 1975–76 agricultural year are summarized in Table 3. The average size of operational holdings broadly follows a pattern dictated by rainfall and irrigation. The Sholapur villages, with the lowest rainfall, have operational landholdings averaging 4.5 and 5.8 ha. Corresponding figures for the Mahbubnagar villages, which have slightly better rainfall and substantially higher irrigation, are 1.6 and 2.6 ha. The average size of landholdings in the Akola villages, which have higher and stable rainfall, are 3.7 and 4.3 ha.

Furthermore, owing to the low intensity of land use in low-rainfall areas and the limited capacity of the farmers to maintain bullocks through frequent droughts, the number of bullocks per 10 ha of operational area in the Sholapur villages was almost half that in most of the other villages. Possession of farm machinery and equipment, as indicated by their value per hectare of operational area, was largely dictated by the availability of

[8] Incidentally, 1964–65 and 1973–74 were two of the best rainfall and crop years in the area. Mild droughts occurred in the years immediately preceding them. Hence, the differences in cropping pattern at two times cannot be attributed to impact of weather conditions in the current year or in the preceding year.

[9] For details, see Jodha and Ryan (1975), Jodha (1976b). and Binswanger and Jodha (1976).

Table 3. Some details of the resource base of farms by size of operational landholdings in six villages of semiarid tropical India, 1975–76.[a]

Village landholding size	Range of operational area (ha)	Av. size of holding (ha)	Irrigable area (%)	Bullocks (no./10 ha)	Land area (ha/bullock)	Family workers (no./10 ha)	Land area (ha/worker)	Value (Rs) of farm equipment[b]	
								/farm	/ha
Aurupalle (M)									
Small	0.2–1.2	0.8	4.8	5	2.1	47	0.2	186	226
Medium	1.3–3.2	2.3	10.8	3	2.8	18	0.5	902	401
Large	> 3.2	4.9	13.9	4	2.8	4	2.8	3657	317
Total	–	2.6	13.0	4	2.7	8	1.3	1582	325
Dokur (M)									
Small	0.2–0.8	0.6	75.3	3	3.0	31	0.3	493	813
Medium	0.9–2.1	1.7	53.3	4	2.9	19	0.5	872	507
Large	>2.1	2.4	39.3	6	1.6	8	1.3	2845	601
Total	–	1.6	38.3	5	1.9	12	0.8	1403	596
Shirapur (S)									
Small	0.2–2.0	1.4	10.3	4	2.8	20	0.5	321	231
Medium	2.1–5.3	4.5	5.4	2	6.0	10	1.0	785	163
Large	> 5.3	7.3	10.2	2	2.7	5	2.1	1656	227
Total	–	4.5	10.1	2	4.5	8	1.2	787	175
Kalman (S)									
Small	0.2–3.6	2.9	11.4	4	2.9	12	0.9	256	90
Medium	3.7–8.5	6.5	7.8	1	8.1	4	1.6	947	146
Large	> 8.5	8.0	11.1	2	6.2	5	3.0	1692	129
Total	–	5.8	11.0	2	5.8	4	2.3	985	129

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table 3 continued

Village landholding size	Range of operational area (ha)	Av. size of holding (ha)	Irrigable area (%)	Bullocks (no./ 10 ha)	Land area (ha/ bullock)	Family workers (no./ 10 ha)	Land area (ha/ worker)	Value (Rs) of farm equipment[b] /farm	/ha
Kinkheda (A)									
Small	0.2–2.0	2.4	1.7	4	26	11	0.9	198	85
Medium	2.1 –4.5	4.3	3.8	2	4.1	7	1.4	395	93
Large	>4.5	6.4	1.3	3	4.1	3	3.4	767	61
Total	–	4.3	2.1	4	3.9	5	2.1	454	71
Kanzara (A)									
Small	0.2–1.8	1.4	17.0	1	14.2	33	0.3	282	199
Medium	1.2–5.3	3.9	2.0	2	4.4	15	0.7	316	80
Large	> 5.3	5.8	4.5	2	3.5	5	2.3	120	132
Total	–	3.7	4.5	3	3.9	9	1.1	724	125

[a] Data in this table and in subsequent ones relate to six villages two each in three regions of semiarid tropical India where the International Crops Research Institute for the Semi-Arid Tropics has been conducting studies since May 1975. Villages 1 and 2 belong to the red soil area with annual average rainfall of 71 cm in Mahbubnagar district, indicated by (M) with village names, in Andhra Pradesh state. ,Villages 3 and 4 with medium and deep black soils, 69 cm of annual rainfall, belong to Sholapur district (S) in Maharashtra. Villages 5 and 6 belong to Akola district (A) in Maharashtra and have medium black soils and 82 cm of annual average rainfall. The table shows the resource position as of 1 July 1975. Number of sample farms in each group of every village is 10. [b] Includes farm implements, irrigation equipment, hand tools, and other farm machinery.

irrigation. Dokur and Aurupalle villages have more extensive irrigation and more equipment than the other villages. The intervillage, or rather interregional differences in the broad resource positions illustrated by Table 3, may help explain the differences between cropping patterns if they are not explained by the resource position differences among farms of different sizes. The reasons were discussed earlier.

Cropping patterns. An important feature of cropping patterns in the semiarid tropical areas in India and elsewhere (Aiyer, 1949; Norman, 1974) is the predominance of mixed cropping. Depending upon the crops and a number of agronomic factors and economic considerations, the crops are

Table 4. Extent of sole and mixed cropping by size of operational landholdings in six villages of semiarid tropical India, 1375–76.[a]

Village land-holding size	Share of crops in total cropped area (%)[b]				
	Sole crop	2-crop mix	3-crop mix	4- to 5-crop mix[c]	Total
Aurupalle (M)					
Small	30 –	– –	– –	70 –	100 –
Medium	52 (28)	1 –	– –	47 (5)	100 (14)
Large	57 (26)	9 (2)	– –	34 (1)	100 (15)
Total	53 (25)	6 (2)	– –	41 (2)	100 (13)
Dokur (M)					
Small	88 (59)	12 –	– –	– –	100 (52)
Medium	92 (73)	8 –	– –	– –	100 (67)
Large	a2 (57)	15 –	3 –	– –	100 (47)
Total	85 (62)	13 –	2 –	– –	100 (53)
Shirapur (S)					
Small	97 (17)	3 –	– –	– –	100 (17)
Medium	93 (12)	7 (9)	– –	– –	100 (11)
Large	82 (74)	14 (6)	4 –	– –	100 (11)
Total	86 (14)	11 (6)	3 –	– –	100 (13)
Kalman (S)					
Small	44 (22)	40 –	16 (63)	– –	100 (10)
Medium	47 (14)	27 (1)	20 (1)	6 –	100 (6)
Large	66 (23)	21 (4)	10 (22)	3 –	100 (15)
Total	57 (21)	27 (2)	14 (11)	2 –	100 (14)
Kinkheda (A)					
Small	6 (40)	31 –	53 –	10 –	100 (2)
Medium	12 (19)	27 –	57 –	4 –	100 (2)
Large	19 –	28 –	46 –	7 –	100 –
Total	16 (5)	27 –	50 –	7 –	100 (1)
Kanzara (A)					
Small	12 (44)	27 –	39 –	22 –	100 (5)
Medium	26 (11)	30 –	39 –	5 –	100 (3)
Large	32 (8)	49 –	17 –	4 –	100 (3)
Total	30 (10)	40 –	24 –	6 –	100 (3)

[a] See note [a], Table 3. [b] Figures in parentheses indicate the extent (%) of irrigated crops in the respective categories. [c] 5-crop mixes occur only in Aurupalle village.

mixed in rows or the seeds are mixed in sowing. Patch-cultivation is also practiced; within one plot, small patches are put under different crops because of such special problems as shading, salinity, severe erosion, water stagnation in depressions, and so on.

Mixed cropping. Some details of mixed cropping in the six villages are in table. Table 4 indicates that, in all the villages except Dokur and Shirapur, sole cropping tends to increase with size of operational landholdings, which implies that smaller farms have a stronger preference for mixed cropping. Mixed cropping on the same plots fits well into small farmers' crop diversification strategy against uncertainty and risk. Also,

Table 5. Important crop mixtures and number of crop combinations characterizing mixed cropping in six villages of semiarid tropical India 1975–76[a].

Crop mixture codes[b]	Share of crop mixtures (%) in villages					
	Aurupalle (M)	Dokur (M)	Shirapur (S)	Kalman (S)	Kinkheda (A)	Kanzara (A)
S + P	–	57	–	–	–	–
S + B	–	–	–	–	4	7
S + Sf	–	–	–	23	–	–
S + Gg	–	–	–	–	9	–
S + B + Gg	–	–	–	–	17	–
S + Gg + P + Pm	–	–	–	–	6	–
S + Pm + Op + V + Ov	75	–	–	–	–	–
P + Ov	–	–	22	–	–	–
P + Mm	–	–	–	7	–	–
P + Op	–	–	–	7	–	–
P + Sf	–	–	–	8	–	–
P + Oc + Pm	–	–	22	–	–	–
P + Pm + Ov	–	–	–	5	–	–
Op + Ov	–	–	16	–	–	–
C + P	–	–	–	–	9	38
C + P + S	–	–	–	–	39	16
C + P + Gg + S	–	–	–	–	7	–
C + B + P + S	–	–	–	–	–	16
W + Ch	–	–	7	–	–	–
Cr + V	12	–	–	–	–	–
G + P	–	40	–	–	–	7
Sc + v	–	–	18	–	–	–
Others	13	3	15	50	9	16
	Crop combinations in villages (no.)					
Crop mix (Types)						
2-crop mix	6	2	10	26	6	9
3-crop mix	–	1	2	22	6	7
4 + 5–crop mix	2	–	2	12	9	9

[a] See note [a] under Table 3. [b] B = Black gram; C = Cotton; Cp = Chick-peas; Cr = Castor; G = Groundnut; Gg = Green gram; Mm = Minor millets; Oc = Other cereals; Op = Other pulses; OV = Other fiber-cum-vegetable crops; P = Pigeonpeas; Pm = Pearl millet; S = Sorghum; Sc = Sugarcane; Sf = Safflower; Sn = Sunflower; V = Vegetables; W = Wheat.

Table 6. Cropping pattern by size of operational landholdings in six villages of semiarid tropical India, 1975–76.[a]

Village, landholding size	Share of major crops (%) in total cropped area[b]										
	Sorghum	Paddy	Wheat	Other cereals[c]	Pigeon-peas	Chick-peas	Other pulses[d]	Ground-nuts	Other oil-seeds[e]	Vege-tables	Cotton and other crops[f]
Aurupalle (M)											
Small	– (100)	– –	– –	– –	– –	– –	8 –	– –	92 –	– –	– –
Medium	1 (98)	25 –	– –	– –	– –	– –	1 –	– –	53 –	20 (2)	– –
Large	4 (80)	35 –	– –	2 –	– –	– –	5 (15)	– (1)	50 –	4 (4)	– –
Dokur (M)											
Small	3 (47)	97 –	– –	– –	– –	– –	– –	– (53)	– –	– –	– –
Medium	16 (27)	56 –	– –	3 –	– –	– –	– –	25 (73)	– –	– –	– –
Large	19 (42)	53	– –	12 –	– –	– –	– –	15 (58)	– –	1 –	– –
Shirapur (S)											
Small	42 –	– –	12 –	4 (14)	7 (32)	15 –	– (19)	4 –	9(22)	3 (13)	4 –
Medium	26 (18)	4 –	4 (27)	1 (8)	21 (31)	12 –	14 (6)	4 (5)	7 –	1 (5)	6 –
Large	36 (35)	1 –	6 –	3 (12)	15 (36)	14 –	8 (11)	1 (1)	2 (5)	4 –	10 –
Kalman (S)											
Small	61 (30)	8 (2)	3 –	3 (2)	3 (45)	4 (9)	– (9)	1 –	15 (3)	1 –	1 –
Medium	64 (43)	6 (2)	5 (3)	5 (2)	5 (39)	3 (3)	4 (7)	3 –	1 –	3 (1)	1 –
Large	65 (32)	6 (2)	7 (2)	4 (1)	1 (50)	7 (4)	4 (6)	3 –	1 (2)	1 (1)	1 –
Kinkheda (A)											
Small	– (53)	9 –	36 –	– –	– –	13 –	26 –	– –	– –	16 –	– (47)
Medium	– (50)	2 –	8 –	– –	– –	21 –	7 –	25 –	6 –	10 –	21 (50)
Large	18 (46)	4 –	5 –	– –	– –	33 –	23 –	3 (5)	– –	– –	14 (49)
Kanzara (A)											
Small	46 (22)	– –	43 –	– –	– –	– –	– –	11 (19)	– –	– –	– (59)
Medium	45 (13)	4 –	18 –	– –	– –	12 –	14 –	4 (17)	– –	3 –	– (70)
Large	23 (20)	5 –	17 –	1 –	– –	3 (4)	– –	18 (5)	1 –	1 –	31 (71)

[a]See [a] under Table 3. [b]Figures outside the parentheses indicate the share (%) of each crop in total area under sole crops. Figures in parentheses indicate the share of crop mixtures dominated by the same crops in the total area under mixed crops. [c]Includes maize, finger millet, and pearl millet. [d]Includes green gram, black gram and moth beans. [e]Indicates castor in Aurupalle and safflower, sunflower, and sesamum in other villages. [f]Indicates cotton in Kinkheda and Kanzara villages and mainly sugarcane in other villages

small farmers resort to mixed cropping to achieve diversification because they do not have many plots on which to plant different sole crops. Large farmers, on the other hand, are able to diversify by using their more numerous plots.

The possibility that the risk factor[10] influences the extent of mixed cropping in different landholding-size groups is supported by other details in Tables 4 and 6. For instance, the greater the certainty of the crop (through germination, early growth, and so on), the less should be the need for crop diversification through mixed cropping. The bulk of the irrigated (and therefore less risky) crops were raised as sole crops on farms of most sizes.

Extent of irrigation ranges from 1% (Kinkheda) to 53% (Dokur) of the total area cropped in different villages (Table 4). Further, barring the small-farm group in Kalman, the proportion of irrigated crops is higher in the case of sole crops. If irrigated crops alone are considered, 83 to 100% of the irrigated acreage is occupied by sole crops in different villages (Table 7). The greater extent of sole cropping in Dokur village in general and on small farms in particular may be explained in terms of greater availability of irrigation. The hypothesis about .disappearance of mixed cropping following the availability of canal irrigation in Kota villages (Table 1) is thus supported by the Dokur situation.

The decline in the extent of mixed cropping with the decline in farm size in Shirapur village, though representing a situation contrary to the trend in most of the other villages, indirectly supports the risk-based argument about mixed cropping. Shirapur and Kalman villages are characterized by deep, black soils and a bimodal rainfall pattern. Two rainfall peaks occur in June and September, separated by a phase of low and variable rainfall. Not only are deep, black soils difficult to work after the onset of the monsoon, but the soil profile is not fully recharged by the first rains. Consequently, most farmers with deep, black soils keep the land fallow during monsoon and plant rabi (winter season) crops, such as sorghum and safflower, after the monsoon recedes. Since the moisture-retention capacity of deep, black soils is high, crops planted after the monsoon can mature. The soil profile is full of moisture in a broad qualitative sense; it offers usually lower but assured crop prospects similar to those of irrigated farms. The need for guarding against risk through mixed cropping is reduced. Moreover, the large farmers have more land—some

[10] Other factors may influence the extent of mixed cropping. They include the self-provisioning character of subsistence farming which induces the farmer to add a few rows of crops like chillies, coriander, oilseeds, or tobacco to the main crop; possibility of increased and more evenly distributed utilization of family labor through mixed cropping, relative economics of specialized versus diversified cropping in different categories of farms, and so on. However, in the absence of usable data at this stage, it is difficult to discuss those factors meaningfully.

Table 7. Crop distribution in irrigated area by size of operational landholdings in six villages of semiarid tropical India, 1975–76.[a]

Village, landholding size	Share of crops (%) in total irrigated crops									Total area irrigated (ha)
	Paddy/ Wheat[b]		Sugar cane	Vege- tables	Ground- nuts	Maize	Sor- ghum	Other sole crops[c]	All mixed crops[d]	
Aurupalle (M)										
Small	–	–	–	–	–	–	–	–	–	–
Medium	72	(29)	–	–	–	–	2	11	15	4.8
Large	88	(62)	–	2	–	–	4	3	3	13.2
Total	85	(53)	–	2	–	–	2	5	6	18.0
Dokur (M)										
Small	100	(90)	–	–	–	–	–	–	–	3.4
Medium	68	(63)	–	–	32	–	–	–	–	16.3
Large	90	(85)	–	1	8	–	–	1	–	26.9
Total	83	(78)	–	–	17	–	–	–	–	46.6
Shirapur (S)										
Small	33		–	16	24	20	–	7	–	3.1
Medium	5		38	10	–	8	31	3	5	3.6
Large	9		25	22	7	5	9	16	7	10.4
Total	12		23	19	9	8	12	11	5	17.1
Kalman (S)										
Small	11		–	5	–	–	57	13	15	4.4
Medium	25	(4)	–	18	3	26	17	7	4	4.7
Large	20		4	4	5	3	34	13	17	18.7
Total	19	(1)	3	5	4	6	35	12	15	27.8
Kinkheda (A)										
Small	92	(92)	–	8	–	–	–	–	–	0.5
Medium	44	(44)	–	56	–	–	–	–	–	0.9
Large	–	–	–	–	–	–	–	–	–	–
Total	62	(62)	–	48	–	–	–	–	–	1.4
Kanzara (A)										
Small	100	(100)	–	–	–	–	–	–	–	0.8
Medium	100	(100)	–	–	–	–	–	–	–	1.2
Large	87	(43)	4	9	–	–	–	–	–	3.3
Total	92	(65)	3	5	–	–	–	–	–	5.3

[a] See note [a] under Table 3. [b] Indicates paddy in Aurupalle and Dokur villages and wheat in the remaining villages. Figures in parentheses indicate the shares of high yielding varieties of the respective crops in total irrigated area. [c] Other sole crops include cotton, fodder crops, garden crops in total irrigated area. Other sole crops include cotton, fodder crops, garden crops and in some cases chick-peas, sunflower, and castor. [d] Mixed crops mainly include vegetables, wheat, chick-peas and oil seeds.

of it relatively shallow-on which they plant during the monsoon. They use mixed cropping to alleviate risk.[11] Kalman village, in the same region, does not compare with Shirapur village largely because it has much greater proportion of medium, black, shallow soils which are usually cropped

[11] Yet another set of data not presented in the tables showed that the area kept fallow during kharif (monsoon season) and put under rabi (winter season) crops constituted 78, 50, and 55% of the total cropped area on small, medium, and large farms respectively in Shirapur. The corresponding extent of rabi cropping in Kalman village was 50, 60, and 64%.

only in the monsoon season. Moreover, Kalman has more bunded plots, [12] which allow more opportunities for small-patch cropping involving coriander, linseed, vegetables, and paddy near the bunds where water stagnates. These small-patch crops also add to the extent of mixed cropping.

In view of the extent of mixed cropping, and lacking information about the proportions of individual crops in the crop mixtures, it is difficult to discuss areas of individual crops in the cropping patterns. [13] In most of the subsequent tables, data about a particular crop raised as a sole crop and as a main crop of the mixture (without specification of its actual share in the mixture) have been presented side by side. Table 6 presents the details of individual crops in the manner indicated above.

Mixed cropping characterizes all the villages, but there is considerable difference in the number as well as in the types of crop combinations (Table 5). For instance, Kalman village has 26 and 22 different crop mixtures in two-crop and three-crop patterns, respectively. Dokur, on the other hand, has only one or two crop combinations. Other villages fall between those extremes. In Kalman, the heterogeneity of circumstances, such as availability of deep black, medium black, and shallow soil permitting raising of both rabi and kharif crops in different areas, small-patch cultivation due to bunding, and so on, seems to be responsible for the large number of crop combinations.

Regardless of the number of crop combinations, the inclusion of relatively drought-resistant and relatively drought-sensitive crops such as sorghum, cotton, and pigeon peas is significant in all villages except those in Sholapur. In the Sholapur villages, the reduced number of drought-sensitive crops, combined with drought-resistant crops, is partly due to the delayed 1975 monsoon. When the rains are late and inadequate to start with, drought-sensitive crops like sesame and groundnuts are seldom planted even as mixed crops.

Regardless of the total availability of irrigation in different villages, more than 50 to 100% of the irrigated area is devoted to high-value sole crops like paddy, wheat, sugarcane, groundnuts, vegetables, and others (Table 7). That pattern persists when different landholding-size groups are considered. The Sholapur villages (particularly Kalman) are the exception, where low-value crops like sorghum, maize, and chick-peas also

[12] Kalman village as a whole, nearly 84% of the farm households have 90 to 100% of their land area bunded In Shirapur, with extensive areas of deep black soils, only 25% of the farm households have bunded land. Deep black soils make it difficult to maintain bunding. Bunds can cause damage to crops (Jodha, 1976b)

[13] Data collection involved recording the main crop in crop mixtures as first crop. Other components depending upon their declining share in the mixture, were recorded as second, third, fourth crop, and so on, for the same plot (Binswanger and Jodha, 1976). The share of the main crop (or first crop) in the crop mixture could range from 50 to 90%, of the total acreage under that mixture.

account for a substantial proportion of irrigated area. The difference is due to the low and undependable extent of recharge in most of the wells, which could not facilitate raising of high water-consuming (high-value) crops in those villages, compared with, say, tanks and wells in Mahbubnagar villages, which ensure intensive irrigation during different seasons. In view of the differing quality of irrigation systems, high-value crops probably utilize a much higher proportion of the available irrigation facility than what is suggested by the irrigated area under them.

Table 7 indicates that paddy occupies most of the irrigated land in the Mahbubnagar villages, unlike the other villages. The situation is largely due to differences in the irrigation systems. In Mahbubnagar, community tanks that collect the runoff water during the monsoon are the major source of irrigation. Historically, tank irrigation is used for paddy cultivation only. In Sholapur and Akola, wells with varying depths and stability of recharge are the only sources of irrigation. Crops are chosen according to water availability. Vegetables are preferred in small or bigger measure everywhere because they (1) are more labor absorbing, early maturing, and an almost perennial source of cash income during the season, and (2) can be marketed with no institutional restriction.

Further examination of Table 6 reveals that a clear-cut relationship between farm size and extent of individual crops obtains mainly in the cases of sorghum, paddy, wheat, other cereals, groundnuts, and cotton in some of the villages. More importantly, the relationship in most cases is not uniform. For example, the acreage of sorghum (sole crop) increases with size of farm in Dokur and Kalman, but the opposite is true in Kanzara.

This is maybe partly due to the fact that farmers' cropping preferences (for instance, large farmers going in for drought-sensitive risk crops and small farmers allocating more area to food grain crops) are based on groups of crops with common attributes (drought-resistance and others) rather than on individual crops. The relationship between farm size and cropping patterns can be seen better if crop groups are considered. Table 8 presents the relevant data. In keeping with the complex of goals that govern farmers' decisions about allocation of area to different crops, the crops have been put into two categories: food-grain crops and cash crops. They have further been broadly subclassified into drought-resistant crops and drought-sensitive crops.[14]

The conventional presumption is that the small farmer devotes a greater proportion of his land to food-grain crops and to drought-resistant crops because of his subsistence requirements, inability to take risks, and so on. Preferences of the larger farmer should be the opposite, as the maximization of profits is presumably his main goal, and he is presumed to be able to take the greater risk involved in drought-sensitive crops.[15] These hypotheses will now be further examined.

In Aurupalle village (Table 8), if mixed crops alone are considered, the hypothesis of small farmers' concern for subsistence and risk is supported by the increase in area under both food-grain-crop-dominated and drought-resistant-crop-dominated mixtures with the decline in size of operational holding. The support for the hypothesis is strengthened by Table 5 which indicates that most mixtures in Aurupalle consist of food-grains, and almost all the mixtures consist of drought-resistant crops.

When sole crops are considered, paddy and castor distort the trend. The area under food-grains increases with the size of holding. In fact, paddy is more a cash crop than a subsistence crop and implies no violation of the food-grain-based hypothesis. Similarly, the increase in proportion of cash crop mainly due to castor with decline in size of holding does not go very much against the expected behavior of small farms, as castor has numerous virtues like low input cost, drought resistance, long duration of crop conducive to a dispersed pattern of labor use, and supply of fuel materials as a byproduct. The greater extent of drought-resistant crops in large farms than in medium farms is largely due to castor and to kharif pulses, which could be described as large farmers' "subsidiary crops."

In Dokur village, lying in the same tract as Aurupalle but having significantly better irrigation, the situation is quite different. The proportion of drought-sensitive crops declines with the size of landholding. In other respects, such as the area of food-grain crops (raised either as sole crop or the main crop of a crop mixture), the area of cash crops, and the area of drought-sensitive crops, the table does not suggest any clear trend. The principal reason for the above situation is the greater extent of irrigation (Table 3, 4, and 7) on small farms and consequent higher area allocation to paddy and groundnuts as the main crops of mixtures (Table 6). The higher proportion of food-grains and drought-resistant crops on large farms than on medium farms may be attributed to the "subsidiary crops",[16] as Dokur is one village where land concentration is high (Jodha, 1976b).

[14] Categorization of crops as food-grain and cash crops has lost much of its sharpness with the increased commercialization of agriculture, as food-grains in many cases are raised not only for subsistence but also for cash marketing. However, in the absence of a more convenient alternative. this classification has been used. Accordingly, the crops falling in each subcategory are as follows:

a) Drought-resistant food-grain crops: pearl millet, sorghum, finger millet, other minor millets, pigeonpeas, chick-peas, black gram, and other pulses except green gram.
b) Drought-sensitive food-gram crops: paddy, wheat, maize, green gram.
c) Drought-resistant cash crops: castor, sunflower, safflower.
d) Drought-sensitive cash crops: groundnuts, sesame, mustard, linseed, cotton, sugarcane, vegetable crops (except rainfed).

[15] For a discussion of the conventional presumptions and empirical work supporting or contradicting them, see Krishna (1963). Also see Bharadwaj (1974).

Table 8. Relative share of drought-resistant and drought-sensitive crops in total crop acreage by size of operational landholding groups in six villages of semiarid tropical India, 1975-76.a

Village, landholding size	Relative share (%)							
	Food-grain crops			Cash crops			All crops	
	Drought; resistant	Drought-sensitive	Total	Drought-resistant	Drought-sensitive	Total	Drought-resistant	Drought-sensitive
Aurupalle (M)								
Small	8 (100)	– –	8 (100)	92 –	– –	92 –	100 (100)	– –
Medium	2 (99)	25 –	27 (99)	53 –	20 (1)	73 (1)	55 (99)	45 (1)
Large	11 (80)	35 –	46 (80)	50 (15)	4 (5)	54 (20)	61 (95)	39 (5)
Total	9 (88)	30 –	39 (88)	53 (9)	8 (3)	61 (12)	62 (97)	38 (3)
Dokur (M)								
Small	3 (47)	97 –	100 (47)	– –	– (53)	– (53)	3 (47)	97 (53)
Medium	19 (27)	56 –	75 (27)	– –	25 (73)	25 (73)	19 (27)	81 (73)
Large	34 (42)	53 –	87 (42)	– –	13 (58)	13 (58)	34 (42)	66 (58)
Total	27 (40)	58 –	85 (40)	– –	15 (60)	15 (60)	27 (40)	73 (60)
Shirapur (S)								
Small	65 –	16 –	81 –	5 –	14 (100)	19 (100)	70 –	30 (100)
Medium	72 (55)	10 (27)	82 (82)	4 –	14 (18)	18 (18)	76 (55)	24 (45)
Large	76 (89)	8	84 (89)	1 (5)	15 (6)	16 (11)	77 (94)	23 (6)
Total	73 (83)	10 (3)	83 (86)	3 (4)	14 (10)	17 (14)	76 (87)	24 (13)
Kalman (S)								
Small	69 (96)	14 (4)	83 (100)	15 –	2 –	17 –	84 (96)	16 (4)
Medium	77 (93)	16 (6)	93 (99)	1 –	7 (1)	8 (1)	78 (93)	22 (7)
Large	77 (92)	18 (4)	95 (96)	– (3)	5 (1)	5 (4)	77 (95)	23 (5)
Total	76 (93)	17 (6)	93 (99)	3 (1)	3 –	6 (1)	79 (93)	21 (7)

continued on opposite page

Table 8 continued

Village, landholding size	Relative share (%)							
	Food-grain crops			Cash crops			All crops	
	Drought-resistant	Drought-sensitive	Total	Drought-resistant	Drought-sensitive	Total	Drought-resistant	Drought-sensitive
Kinkheda (A)								
Small	3 (53)	82 –	85 (53)	– –	15 (47)	15 (47)	3 (53)	97 (47)
Medium	21 (50)	17 –	38 (50)	– –	62 (50)	62 (50)	21 (50)	79 (50)
Large	51 (45)	32 –	82 (45)	– –	16 (55)	16 (55)	51 (45)	49 (55)
Total	44 (47)	32 –	76 (47)	– –	24 (53)	24 (53)	44 (47)	56 (53)
Kanzara (A)								
Small	45 (21)	44 –	89 (21)	– –	11 (79)	11 (79)	45 (21)	55 (79)
Medium	56 (13)	37 –	93 (13)	– –	7 (87)	7 (87)	56 (13)	44 (87)
Large	36 (24)	13 –	49 (24)	1 –	50 (76)	51 (76)	37 (24)	63 (76)
Total	40 (21)	19 –	59 (21)	1 –	40 (79)	41 (79)	41 (21)	59 (79)

[a]See note [a]under Table 3. [b]For details of drought-resistant and drought-sensitive crops, see the text. [c]The two sets of figures under each column give details of sole crops and mixed crops at one place. The figures outside the parentheses indicate the percentage share of different crop groups (sown as sole crops) in the total area under sole crops The figures within the parentheses indicate the share of crop mixture dominated by the corresponding crops in the total area under mixed cropping. Thus the figures in parentheses do not indicate the extent of area under particular crop groups but under the crop mixes dominated by the said crops.

The cropping pattern in Shirapur reveals trends that are completely contrary to the ones hypothesized. Accordingly, the extent of both drought-resistant crops and food-grain crops increases with farm size. That applies to both sole crops and mixed crops.

The trends can be explained in terms of the extent of rabi cropping in the deep, black soils which varies considerably among different farm-size groups in the village. As mentioned earlier, the extent of rabi cropping declined with size of holding in Shirapur. That implies that the larger the farm, the greater is the extent of kharif cropping. This is due partly to the fact that larger farms have some lands that can be planted to drought-resistant crops in the kharif season, and partly to their ability to take added risk. Hence, in terms of risk behavior, growing kharif crops (regardless of type) is comparable to using drought-sensitive crops and is thus in keeping with the risk-related hypothesis about crop preferences of large and small farms.[17]

Rabi cropping, on the other hand, usually provides more assured moisture prospects. The actual choice of rabi sorghum versus wheat, safflower, chick-peas, and so on, during 1975 was influenced by the continuation of monsoon till early November. Most small farmers could not plant sorghum during the short period available, hence, the greater use of crops like wheat (which fall into the drought-sensitive category) and safflower (Table 6).

The situation in Kalman village is fairly different from that in Shirapur. In the case of mixed crops, which have more use in Kalman and the use of which increases as the size of farm declines (Table 4), the cultivation of food-grain crops is inversely related to farm size. There are also more drought-resistant mixed crops on small farms than on farms in other size groups, though there is no clear trend. But there is a clear inverse relationship between farm size and drought-resistant crops when sole crops are considered. The positive relationship between farm size and the extent of cultivation of food grain (sole crops), which contradicts the subsistence-related hypothesis, is largely due to the greater use of drought-resistant (sole) crops like safflower and sunflower on small farms.

In Kinkheda village, if mixed crops are considered, the proportion of

[16] When resources of large farms are not suited to uniformly intensive use, farmers may concentrate their efforts on their better lands (in terms of fertility, irrigation facility, and so on). The remaining lands are used for "subsidiary crop enterprises." If the proportion of inferior lands in total operated area is large, the "subsidiary crops" may dominate the cropping patterns of large farms. Moreover, the large farmers' preferences for particular cash crops may be neutralized by the unavailability of timely and adequate rains. For instance, in Sholapur villages, in medium black soils groundnuts and sesamum crops are replaced mainly by pulse crops in such a situation.

[17] Moreover, delayed and inadequate rains in the early part of monsoon season (1975-76) favored more drought-resistant food-grain crops rather than cash crops like sesame and groundnuts, which further led to more use of food-grain crops on large farms.

food-grain crops declines with the size of holding. In constrast, the share of drought-sensitive cash crops increases with size of holding. Those trends support the subsistence and risk-related hypotheses.

In the case of sole crops, the extent of food-grain crops on small farms is greater than that of other groups, but there is no clear trend. The extent of drought-sensitive crops declines with the size of farm. This is mainly due to higher extent of wheat crop on small farms.

In Kanzara, another village from the cotton tract, however, the cropping pattern does not show clear trends in any of the crop categories under discussion. Of course, compared to large farms, the small farms have larger proportions of food-grain crops and smaller proportions of drought-sensitive crops.

Besides subsistence and risk considerations that have been examined in these six villages, a few more variables have an important influence on the land allocation to food-grain crops and drought-resistant crops. Large farms depend on hired labor to a great extent. They frequently make wage payments in kind and consider drought-resistant, low-value crops like sorghum, pearl millet, and minor millets as wage-goods. They devote considerable area to such crops, not only for their own subsistence purposes but also for the production needs of the farm enterprise.

At times institutional factors, like the custom of releasing water from irrigation tanks during specific times to irrigate paddy crops, may make cropping decisions or cropping patterns different from those that the households' own resources would suggest.[18] Also, to avoid problems with land reform laws, a large farmer may plant low-cost, drought-resistant crops rather than let land go unused.

The fact that cropping patterns vis-a-vis size of farm do not reveal uniform trends in different villages suggests that, influenced by numerous complex factors, the cropping pattern cannot be fully explained by using landholding size. Furthermore, the factors which convincingly explain the cropping pattern in one situation prove utterly ineffective in another. The diversity of both the cropping patterns and the factors underlying them magnifies one dimension of the problem of cropping systems research for rainfed areas.

CONCLUSIONS

My discussion, based on microlevel details from different locations in arid and semi-arid areas of India, may lead to the following inferences.

[18] For instance, farmers with sufficient irrigation from tanks in Dokur village cultivate paddy. In Sholapur, farmers with dependable irrigation from wells plant sugarcane.

Cropping patterns are affected by a multiplicity of factors of which resource position is one. Within the resource base, the land type, irrigation, and rainfall play the most important roles. Those basic resources, together with the availability of plant varieties, determine the comparative advantages of different crops and crop mixes on the various soils. They also determine the rate of return to investment for other components of the resource base. In the long run, the availability of resources of capital (and of labor) are also determined by the land and water resources and the state of technology.

Massive resource transformation that relaxes major constraints (as indicated by canal irrigation and tractorization) and overshadows the impact of other resource differences can lead to shifts of cropping patterns on farms of all categories. Such resource improvements orient the cropping patterns towards high-value crops and reduce the importance of mixed crops.

Major resource shifts may have a stronger and quicker impact on cropping patterns than marginal improvements of various cultural practices or even of crop mixes.

Similarly, introduction of new varieties tends to change the comparative advantages of different crops and may lead to massive shifts in cropping patterns as well as in incentives for investment in other capital items.

The more heterogeneous the resource base, mainly in terms of soil types, the more complex and heterogeneous will be the cropping pattern and the more numerous the crop mixtures observed. That tendency is reinforced by quantum, temporal, and spatial variability of rainfall. The feasible choices in such cases are limited, yet to adjust for uncertainty and risk caused by variability, the farmer tries to multiply his alternatives (through crop combinations) within the limited possibilities. Kalman village illustrates the situation.

On the other hand, greater uniformity of the resource base leads to simple, one- or two-crop-based cropping patterns, even under rainfed conditions. The castor crop in the Mahbubnagar area or sole crops of sorghum and wheat in rabi (winter) cropping in deep-black soil areas of Sholapur are illustrations.

Irrigation imparts uniformity and stability to the resource base and opens a wide range of cropping options. Nevertheless, the cropping pattern tends to become less and less heterogeneous, partly because the uncertainty-induced need for diversification has disappeared. More importantly, the stable cropping environment generated by irrigation permits clearer perception of the comparative advantages of different crops; crop preferences are more easily narrowed down to the few that are clearly most profitable.

Where overall cropping options are limited, the cropping patterns are varied and complex. Where cropping options are numerous, the tendency is toward simple and one- or two-crop-based patterns. In the former, the farmer is forced to multiply cropping options within narrow limits; in the latter it becomes easy for him to select a few from the large number of options. The size of landholding seems to matter little.

The situation has a number of implications for agricultural research.

First, in view of the association between mixed cropping and poverty of resource base, e.g., smallness of farm, any breakthrough in intercropping research is likely to help the poor more than the rich. This is a unique instance where research can be deliberately biased in favor of the poor.

Second, where cropping options are numerous, as in better watered areas, the crop breeders have greater flexibility and opportunity for crop or variety selection. Even where the environment is not so favorable as in the irrigated areas, but where the resource base is more homogeneous, their task may be less difficult, as the evolved crops do not have to be tested under many different microlevel situations within the same region. Serious problems arise once crops or cropping systems are to be generated for a very heterogeneous resource base. The thought of generating a cropping system to incorporate as many as 26 crop combinations for the micro-units of a heterogeneous tract (as illustrated by mixed cropping in Kalman village) is quite demoralizing. It may create numerous problems even in simple designing of experiments and their replication.

The problems faced in any effort to generate cropping systems for rainfed areas where, in the absence of irrigation, the inherent micro-level heterogeneity of the resource base persists, are the following.

First, the logistics of multilocation and multicrop combination experimentation, to capture the total cropping possibilities to satisfy the varied timing and site requirements of the rainfed areas, is tremendous and costly. Further, it is difficult to avoid the location specificity of experimental results.

Second, the realism and relevance of a new cropping system depends largely upon the extent to which it has been rigorously compared with farmers' prevailing systems. But that poses more serious problems than do multilocation trials. The complexity of the farmer's system stems from his adjustments to diminish the instability and uncertainty of rainfed agriculture. Unless the adjustment mechanism is fully understood and replicated in some form by researchers, injecting the desired degree of diversity and complexity in the prospective cropping system may prove impossible. Understanding and replicating farmers' adjustments are difficult; the systems are sensitive to small changes which are difficult even to perceive at the research farm.

Moreover, the farmers' own cropping systems are a result of informal experimentation over a long period.[19] Given the resource base and varieties, how far formal experimentation can improve upon the cropping system evolved by the farmer is an open question.

The formal research to evolve new cropping systems may have very limited payoff unless what goes into the prospective cropping systems is radically new. The new elements can be new crop varieties, or improvements (including better management) in the land and water resources.[20] The research directed toward generating these new elements obviously should get high priority. As and when the new elements become available, it will be the principal function of cropping systems research to indicate broadly the alternative ways in which farmers' crops can be tied to them. The detailed evolution of cropping systems to suit microlevel heterogeneity may be conveniently left to the informal experimentation of the farmers.

Finally, in the whole process, it is critically important to coordinate the cropping systems research with prior research in adapting varieties to local conditions, and with the research aimed at finding efficient ways to conserve and improve the land and water resource base.

ACKNOWLEDGEMENT

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[19] The choice of 26 crop combinations in mixed cropping planted in a single village like Kahnan is a result of such informal experimentation.

[20] For a detailed discussion of such issues, see Binswanger et al. (1976).

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DISCUSSION

ZANDSTRA: Cropping systems research needs to go beyond the description of different cropping systems encountered in farms with given resource bases. Given an alternative (new) system, how would you evaluate its fit or lack of fit to a given resource base? What criteria would you use in this evaluation?

Jodha: To my mind, description of the existing cropping pattern and its rationale is essential as an input for evolving new cropping patterns. Further, unless there is something new in a new cropping system, the farmer may not accept it. For more about this, see the last two pages of my paper.

HOQUE: How do you account for a definite trend for the percentage of mixed cropping to be determined by the number of plots?

Jodha: Large farms have more land and more plots. By putting in crops as sole crops in more plots, they are able to achieve a degree of crop diversification which small farms with small land cannot. Hence, small farms achieve a degree of crop diversification through mixed cropping on the same plots.

BOWRING: Is there any evidence of cropping systems being adopted on tenant farms that are different from those on owned farms—given of course, that other factors such as farm size are equal?

Jodha: From ICRISAT studies we do have data about each plot—owned or leased. Details are available not only for crops, but for inputs and outputs. As the processing of the data is still in progress, no answer is possible at this stage. However, we will look into it.

FARMER'S DECISION-MAKING BEHAVIOR WITH REGARD TO CROPPING SYSTEMS RESEARCH

W.H. Vincent

This paper introduces a farmer-behavior dimension into the discussion of cropping systems research. An appreciation of the process of decision-making and its role in the total farm-management task is presumed to contribute to an understanding of whether or not farmers will adopt partially or totally, quickly or slowly, the results of research on improved cropping systems.

The paper will first present a conceptualization of the decision-making aspect of management from a systems point of view; second, it will review briefly a few research efforts which suggest alternative approaches to the problem; and finally, it will draw implications from the preceding sections for analyzing the management-behavior aspects of a cropping systems research program.

CONCEPTUALIZATION OF DECISION-MAKING IN MANAGEMENT

I was instructed to identify in my contribution to this part of the program the determinants of farmers' choices among alternative cropping systems. Previous papers have stressed the importance of natural resources and their use for predicting cropping systems' performance. Introducing the human being into the system now makes it more difficult to keep our attention solely on cropping systems.

Household decisions to use resources in crop production are conditioned upon decisions to use resources in other activities. Hence, it seems appropriate to look at general decision-making activity by managers before setting up decision criteria for cropping systems in particular. I will use Figure 1 as a guide.

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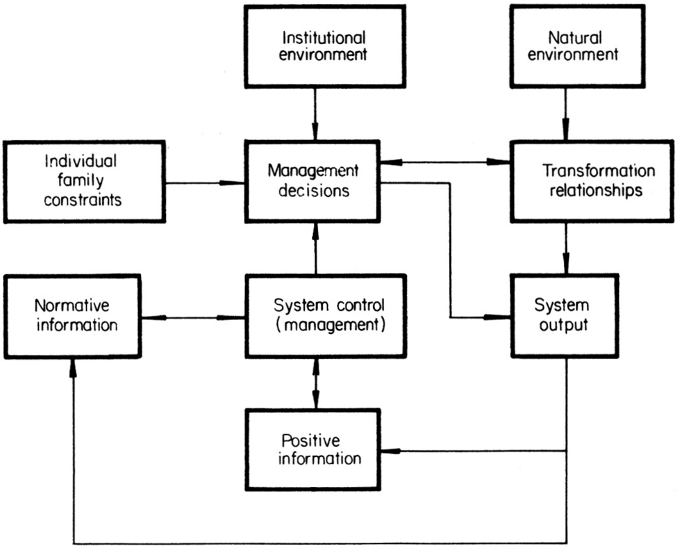

1. The information processing aspects of management.

Attention is drawn first to the system-control unit in the diagram. In it is found the full range of functions which yield management decisions. Those functions have been identified and taught in farm-management classes around the world. They include *problem identification, observation* (representing the information-search behavior of managers), and the *analysis* of alternatives, which lead to decisions (including the decision to do nothing).

The management-control unit is perceived as a processor and evaluator of information. Here diagnosis takes place, and the managers' assessment of the system's performance is weighed against the managers' own standards of performance. What is acceptable performance is an individual matter. It is subjective and it is normative. Even though research may indicate that a particular cropping system is "good" for a particular farmer, the system may not be "right" for him. Pinstrup-Anderson and Diaz (1975) conclude that one of the main reasons for low adoption rates of new technology in peasant agriculture is failure of technology to meet most on-farm needs and personal preferences of farmers. A manager will not deviate from what he is doing if, in the process of evaluating "what is" in relation to "what ought to be," he finds nothing wrong with what he is doing, or he finds something substandard in what he would like. His understanding of the alternatives convinces him to remain in his present position.

In any case, the management functions of problem definition, observation, and analysis entail a complex utilization of both normative and positive information. Since the decisions that interest us come out of this process, it is relevant to ask what we wish to do about the values held in the farm household. The answer is to be found in the researcher's philosophical posture toward the problem at hand. I am reminded of a conversation with a highly competent biological scientist regarding the potential for social science research in a multiple cropping project in Thailand. His position was that decision-making involves the use of concepts such as "right," "wrong," "good," "bad," "better than," "worse than," and so on, which are unmeasurable. He would not deny that both normative and positive information is used by Thai farmers; he simply stressed that since, in his view, normative information is not descriptively empirical, it must be ignored in the cropping systems research agenda. This philosophical position of the positivist would lead the researcher to concentrate on that part of Figure 1 which deals with physical production relationships as they take place in their natural environment. Although positivism has been called *the* philosophy of science, we may be forced to consider other philosophic positions if we are to take seriously research into managerial activities which are so laden with value issues. Johnson (1976) has repeatedly called attention to the matter and has outlined some alternatives which bear on how research will be conducted.

One alternative to the positivist position is to evaluate peasant decision-making behavior assuming that the peasant's goals are known or given. It thus becomes possible to prescribe desirable action for the farmer without subjecting his values to empirical investigation. That approach is frequently used by economists and farm management advisors when they, in effect, say, "Tell me what you want to maximize or minimize and I can provide you with the analysis of alternatives which will allow a right "decision." That conditional normative position has intuitive appeal because the researcher is satisfied that prescriptive information can be supplied in the context of the decision maker's presumed dominant goal. In the context of cropping systems research, that philosophical position suggests a rather straightforward methodological approach. By assuming, for example, that the Asian farmer is a profit maximizer, and by using linear-programming procedures, we can specify an optimum combination of cropping activities if we know the unit costs and returns for the alternatives and the level of the resources which are thought to most significantly constrain the system outcome. Some thought-provoking conclusions about peasant household behavior have been generated using such an approach, as will be seen later. However, before choosing that approach to the exclusion of others, we should be aware of two difficulties. First, there is room for error in the specification of the objective function to be maximized or minimized. We may be insufficiently informed on the preeminence of the goal in the decision maker's total goal set, or on the full range of contingencies that would permit that objective function to serve as an instrumental goal or as a proxy for all other possible goals.

Second, the approach is static and deterministic. Even though time-dependent and stochastic elements can be considered, it can prescribe only for the specific set of conditions built into the model. The results may be of interest to a decision maker as guides to what is possible, or they may serve as a possible representation of how rational man would be expected to behave under the conditions specified. However, they do not speak to the learning processes by which decisions are actually made, nor to the feedback mechanism in management which allows for a reformulation of goals on the basis of experience and new information.

That leads to another possible philosophic position regarding management research. It is pragmatism, which holds that positive and normative information are mutually dependent. If Figure 1 were drawn to represent the pragmatic view, the normative information and the positive information blocks would be connected and interacting.

To summarize to this point, the determinants of cropping systems choice or of any other problem-area choice will be closely tied to the manner in which the decision maker uses normative and positive information in problem definition, observation, and analysis. Models designed to study that behavior will depend on whether or not the researcher feels that normative information can be handled empirically.

In addition to calling attention to the problem of what to do with normative information, Figure 1 illustrates that decisions are the output of management and that these decisions conform to the limits imposed by individual family resources, and by features of the institutional environment. I use the term "institutional environment" to refer to institutional conditions which influence choice but are largely out of the individual manager's jurisdiction. Those conditions include such things as price relationships among products and between inputs and products (to the extent that inputs and products flow in commercial market), land-tenure rules, taxation policies, credit availability and its terms of use, accessibility to markets, and community mores which affect individual choice and action. In an article on concepts in systems engineering, Hall (1973) points out that living systems not only exist in an environment; they exist by means of their environment. The research implication is that it is necessary to understand the way in which and the extent to which institutions constrain decisions, and to understand their supportive roles as well. The various policies of government are in that module of the system. Those policies clearly affect what actually happens on farms, and also affect expectations of what, will happen. They can either increase or decrease risk in decision making, depending on whether they impede or contribute to the formulation of improved expectations. Hence, the research apparatus for studying farmers' criteria for choice in cropping systems must take into account at least the more important features of the institutional environment which affect decisions, actions, and outcomes. In addition, it should measure the anticipated changes in system performance that could result from changes in the institutional environment. One aspect of that area of concern will be treated later in the symposium when the capacity of national institutions to introduce and service new technology is assessed.

The relation between farm-household decisions and the level and nature of resource endowments was recognized in the previous paper. Little will be added here. But in that module of the system many hypotheses about farm-household behavior are offered. One variable in the subsystem is amount and composition of family labor. If the resource situation is one of capital shortage with an excess of family labor, the cropping systems design should seek ways to market the "excess" labor profitably. But the problem is too complex to be solved merely by examining the peaks and troughs of the seasonal farm labor profits. As will be discussed later, the total available farm labor supply is allocated to nonagricultural working activities and to household production and consumption activities as well as to agricultural activities. Cognizance of the full range of "legitimate" family labor activities and an understanding of the decision rules by which family labor is allocated could easily lead to the conclusion that under-employment in peasant agriculture has been overstated. If that is true, the expectation that small farmers eagerly await more-labor-intensive patterns of crop production may need to be discounted. The literature on the formation of human capital, the use of time, the components of utility and the demand for quasi-public goods is treated in Ferber's survey (1973) of work in consumer economics.

To complete the representation of the decision-production process in Figure 1, the relationship between the natural environment and the physical production transformation functions has been included. That relationship is much more the concern of other speakers. The manager decides what crops to produce, what technology to employ, and how to commit resources for crop production. How he views the vagaries of the natural environment and how he translates the results of research conducted in a natural environment unlike his own are relevant considerations in evaluating the prospects for adoption of a revised cropping system.

I will make a final comment on that conceptualization before turning to the next section. Figure 1 shows information flow rather than physical flow. The system output is datum. Output measurements are fed to the positive data bank of the manager, but they may also affect the value system of the management system. The output of management is decisions. The input to management is normative and positive information. The knowledge used in decision making, however, is imperfect. Costs are associated with any value that can be assigned to improve the information base (Perrin, 1976) as well as with making a "wrong" decision (Havlicek and Seagraves, 1962). I conclude that research to isolate the determinants in a farmer's choice of cropping system may appropriately include the following : farmer's search behavior, application of information theory to farmer's decision processes, and the economics of information.

SOME EXAMPLES OF HOUSEHOLD-DECISION RESEARCH

This section aims to indicate how the conceptualization of the problem dictates the methodology of research on household-decision behavior. It is neither exhaustive in its identification of relevant research, nor does it claim to make adequate review of the individual selections. It intends to show that significant strides have been taken in identifying the most significant variables in farmer decision behavior. Research which seemed of interest to the overall research program at IRRI and for the purposes of this conference was deliberately sought.

Peasants' response to modernization project in Minifundia economies. Using a stochastic linear-programming model, Benito (1976) incorporated many factors believed to explain differential adoption rates for recommended technical practices, and evaluated the model, using experience and data obtained at the Pueblo Project in Mexico. His model of the peasant economy shows total time available in the peasant household as being allocated among agricultural activities, nonagricultural activities, and other household activities. Agricultural time is allocated to farming, learning and information-gathering, and organization activities. Nonagricultural includes self-employment and activities in the labor market. The stochastic production function includes as independent variables labor time, agro-inputs, services from physical capital, services from human capital, and a stochastic factor (such as weather). Low levels of human capital indicate knowledge of "traditional" practices, while high levels indicate knowledge of "modern" practices.

Total labor time is constrained by the availability of other resources.

Off-farm occupational opportunities are limited in the short run but are enhanced through investment in on-the-job experience. Accessibility to modern input markets and to credit markets is included in the model. Peasant household motivations are expressed by a discounted utility function which is maximized, subject to a survival constraint. The peasant's household-decision behavior under uncertainty and under different degrees of information is represented in the model by a safety-first rule.

The linear-programming model is solved for two situations. Once an optimal solution is obtained for the average peasant family, the quantitative changes in adoption data are investigated for (1) the case when physical and capital endowments of the family differ from the average, and (2) the case when the equilibrium is disturbed in a family with permanent job opportunities when the wage rate changes.

Benito's conclusions (1976) indicate that the distribution of adoption rates among peasant households is determined by differences in the combinations of human-capital endowments, physical-capital endowments, and organizational power. The combinations, in turn, determine the differences in opportunity-cost of human time, transaction costs, and behavior in the face of risky events. A further conclusion challenges the view that labor-intensive technologies per se will rapidly increase agricultural production and improve peasants' welfare. Benito stresses the need for generation of less risky technologies, such as research for new, high yielding crop varieties adapted to differences in environmental conditions, and continued development of improved varieties and practices for cropping systems. For further research, he proposes that the model include the complexities in crop combinations and the seasonal and intrafamilial allocation of human time. Those suggestions may serve as signals for this conference.

Locus-gain research. Probably the most common explanation for peasant farmers' reluctance to adopt new technologies is their aversion to risk. The literature on research methodologies for measuring the effects of risk on farmer decision making is very extensive. Without doubt, the entire proceedings of the Agricultural Development Council-sponsored Conference on Risk and Uncertainty in Agricultural Development, held at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in March 1976, are relevant to our discussions on determinants of farmers' cropping system decisions.

Risk problems may be formulated in many ways. Webster and Kennedy (1975) view farmers' attitudes toward risk within a focus-loss framework and compare the results with those obtained from deriving quadratic utility functions in terms of income. Focus-loss analysis is based on Shackle's

(1961) argument that decision makers consider, not an entire set of rival and mutually contradictory "possible-seeming" outcomes but rather the outcomes resulting from particular actions. The extreme outcomes, favorable and unfavorable, which are thought possible and which are of great interest to the decision maker, are termed the focus-gain and focus-loss of the decision, respectively. The formulation by Webster and Kennedy (1975) assumes that the decision maker will maximize expected income E subject to some specified probability a of obtaining a given minimum level of income F. The analysis uses interview procedures that allow the drawing of indifference lines which show the willingness of farmers to trade E for F while maintaining a given level of utility. Our interest is in the marginal rate of substitution (C) of E for F, which can be obtained from the indifference lines. That is an extension of previous work, and so the minimum income F need not be set at some arbitrary level. The conclusions deal with methodological issues surrounding this and alternative methods. Perhaps of greater interest for our immediate purposes is calling attention to the fact that focus-loss concepts may be useful in evaluating optimality in cropping systems research. The hypothesis that peasant farmers seek strategies which insure system performance at some minimum level, or at some level to avoid disaster may be reasonable as one contemplates the prospects of adoption of new cropping systems.

Optimizing crop production on small farms. Gomez (1975) developed a farm-level computer-simulation model to evaluate alternative cropping patterns. Since he appears on this program, no attempt will be made to explain details of the work. However, the three objective functions of his model have relevance to the immediate topic. They are (1) profit, measured as the difference between value of yield and cost of production, (2) net return, defined as the difference between value of yield and cash input cost, including hired labor, and (3) minimum profit, defined as the difference between profit and one standard deviation less than profit. The variance for computing standard deviation is obtained from the Monte Carlo analysis of the stochastic components of the simulation model. The optimization procedure includes judging the acceptability of a management package on the basis of profit and risk; the ideal package has high profit and low risk.

Another farm-level computer-simulation model for evaluation of rice-based cropping systems has been developed by Paris and Price (1976). The structure of their model conforms closely to the diagram for management processes (Fig. 1). The components are crop environment, land allocation, labor utilization, product and input markets, production components, and an income component. Correspondence to Figure 1 is found by comparing crop environment with natural environment, product and input markets with institutional environment, production component with transformation relations, and income component with system output. The land allocation and labor utilization components handle the decision rules found in the management-control unit of Figure 1. The work is still in a preliminary state and the model is admittedly primitive in some respects. Nevertheless, its power to evaluate a wide range of management and policy alternatives makes it promising for cropping systems research. Some alternatives that can currently be evaluated in the model include comparison of (1) the effect of different planting dates on profit for given input levels, (2) the effect of cropping intensity on other variables in the system, and (3) the effects of favorable and unfavorable weather conditions on crop yields under different management practices. As is typical of simulators, the model's computer program is unique. Its limited use of standardized auxiliary routines and program algorithms is both a weakness and a strength: a weakness because of difficulties in using the program outside its place of origin, and a strength because of the opportunity to add to its power and potential. It can be viewed as a laboratory under construction. As the needed experiments grow in complexity, so grows the experimental apparatus. This brings us to an earlier point, namely, that the value of the model as well as the value of the information it generates needs to be evaluated in terms of worth to the decision maker who will use the results.

Regardless of the model used to study the farmer's decision behavior, I share the conviction of Hatch (1976) that research designed to deal with farmers' problems at the household level should benefit from the farmers' expertise. The farmer knows more about why he does what he does than researchers do. We must integrate what he knows with what we know. It may not be enough to test cropping systems research "under farm conditions". If we recognize that farmers are knowledgeable in ways that we are not, and that they are the policymakers to use microlevel research, it seems most reasonable that their ideas of what is good or bad or possible should be incorporated into the research design.

SUMMARY

A conceptualization of the management function has been offered. It considers the manager as a processor of imperfectly held normative and positive information which leads to the decisions that are his management output. The execution of these decisions is conditioned by the resource endowment of the individual farm family; it is further constrained or advantaged by the institutional and natural environment.

The research approach used for modeling this process depends upon the philosophical position of the researcher, because the question of how to deal with normative information must be answered either implicitly or explicitly.

A review of available research suggests a wide range of variables which define the criteria for cropping systems decisions. The institutional environment includes accessibility to and general performance of the market; the relationship between prices paid and prices received, which helps determine the relative profitability of alternative enterprises; government policies with regard to price and production incentives; taxation and land tenure rules; and the commodity mores which define what is possible and acceptable. The amount and quality of such resources as land, family labor, and capital under the manager's control are of paramount importance.

How farmers recognize and handle risky events is suggested as a dominant phenomenon in decision behavior. Methodologies for analyzing risk behavior are diverse.

A multitude of factors affecting choice highlight the multidisciplinary nature of problem-solving research. The establishment of research priorities and the choice of research methodologies may call for contributions from and interactions with a broad disciplinary base. Nor should substantial learning from and interacting with the farm decision maker be neglected.

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DISCUSSION

SMITH: You characterize linear programming (conditionally normative) methods as static. Doesn't this assume that the analysis is not to be repeated as new management skills develop, new technologies remove old constraints, and so on?

It seems to me that both farmers and researchers can incorporate new knowledge into their analytic systems. As an example, wouldn't it be possible to use linear programming both to screen cropping patterns using best-guess information on prices, resource coefficients, resource supplies, and so on, and to retest as new evidence becomes available.

Vincent: Static was a poor word choice. LP models may be made "dynamic." I was not criticizing LP as an analytical tool. Rather, I was concerned that it may not offer much in studying decision processes. The farmer is a learner, and his data for decision-making change with new knowledge. The LP can analyze the effects of new knowledge, but it does not trace the learning process.

FARM AND AGGREGATE-LEVEL DESCRIPTION OF MULTIPLECROPPING

M. Seetisarn

The March 1975 workshop on cropping systems suggested a conceptual framework for cropping systems research that contained four phases: (1) observation and description, (2) design of new multiple cropping technology, (3) testing, and (4) extension. Those phases or steps are not completely separable but are in fact intimately connected and interdependent. They are never finally completed but are iterative. The title of the first phase also seems to be misleading. It gives the impression that no research effort is involved, when as a matter of fact the phase involves research as much as the others. More appropriately, the first phase should be called analysis and evaluation of traditional systems.

This paper deals primarily with that first phase. However, one hardly knows where to begin with such a broad topic. At best, it is possible to sketch out the particular aspects of cropping systems that need to be observed and described both at the farm and aggregate levels, and to show how the description is related to other phases, especially to actual design and testing. An attempt will be made to draw some lessons from our research at the Multiple Cropping Project (MCP), Faculty of Agriculture, Chiang Mai University.

WHAT TO DESCRIBE

Multiple cropping is regarded as a key strategy for increasing food production, rural employment, and income in a country facing land shortage and labor surplus—characteristics of many countries of Asia. Interest in cropping systems research is growing in many countries in South and Southeast Asia. As used here, cropping system means growing crops in

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sequence on the same piece of land in one year; intercropping and relay planting are included in the definition.

Cropping systems have many dimensions and are products of many factors in combination. They have four broad groups of variables: physical environment, production technology, resource constraints, and socio-politico-economic conditions. The classification of some variables may not be clearcut. The groups given here only serve the purpose of exposition. Cropping systems and the variables interact. For successful cropping systems research and development, information on existing or traditional cropping systems, natural factor endowments, production technology, resource availability, and socioeconomic environment will be most useful.[1]

Production technology and physical environments. Production technology is conceived as a package of practices essential for growing crops. As agricultural production is location-specific, so is production technology. That is not to imply that transfer of technology is impossible. Under certain conditions, technology may be successfully transferred from one agricultural environment to another. But unless a new technology is created for a particular area, the objective of increasing food production may not be realized. As economists, we are interested not in technology per se but in the relationships between output and input, among inputs, and among outputs.

Given the natural physical endowments and the resources at his disposal, and his socioeconomic environment, the farmer will always choose the production technology which best serves his own interest; where opportunity and demand exist, multiple cropping systems will be practiced. In the long run, those systems must be stable and efficient or they will break down and eventually disappear.

Before attempting to offer an alternative system, one must study the factors that contribute to stability and efficiency. There are two reasons why the physical environment must be studied, First, its influence on existing cropping systems should be known. Second, we should know whether the environment can be improved for the new cropping systems. Since other papers already deal with the second aspect, it will not be discussed here in detail. There is a need to study not only the present cropping systems or patterns but also soil, climate, rainfall and water, topography, and input-output relationships of crops, as well as the interaction among crops in the system.

Resource constraints. To study resource availability, it is not enough to group resources under the labels land, labor, and capital. Their quantity,

[1]What Dr. A.T. Mosher listed in his book *Getting agriculture moving: Essentials for development and modernization* (Agricultural Development Council, 1966) as five essentials and five accelerators for agricultural development are also applicable to successful multiple cropping development. Attention to these elements helps later research and design.

quality, status, and time of availability must be studied in detail. For instance, the farmer may feel insecure if he rents land. Thus tenure status is important. As for labor, one needs to know not only the quantity and quality (sex, age, and education of laborers) but also the time it is most demanded. Labor may become critical if a new cropping system requires the shortening and combination of certain operations.

Capital items and input supplies should be divided into those owned and those purchased. Capital limitation is perhaps the most serious problem for farmers who face new cropping alternatives. They may not accept the new technology if, for example, it requires a substantial increase in cash expenditures.

Multiple cropping is usually measured in the same way as is the level of land utilization (using the so-called cropping-intensity index). That is understandable, since the idea that land is a limiting factor is taken for granted. However, if new cropping systems are introduced, the situation may change. Resources other than land may become constraints upon the adoption of new technology. Such a situation can be anticipated if the relationship among factors and their availability can be established. The new technology that can be fitted into the farmer's present and expected resource constraints is more likely than others to be accepted and adopted on a broad scale.

Socio-politico-economic environments. Cropping systems are also influenced by socio-politico-economic factors. Although many of those factors are beyond the control of researchers or farmers, their impact on farmers' behavior should be studied. Beliefs, values, and goals are social factors that are often cited as important. Sometimes they are considered obstacles to change.

Several economic variables also have bearing on the decisions of farmers about utilizing resources and adopting technology. The obvious variables are prices of inputs and products. Often overlooked but also important are markets for inputs and for products. Crops without ready markets will not be adopted even though their impact on production might be high.

Other institutional and macroeconomic factors need to be investigated. If not adjusted, those factors may impede the adoption and spread of multiple cropping. If land reform, credit institutions, farmer organizations, or irrigation-management problems exist, they must be taken into account. Other government policies and political actions are also important, for they may have adverse effects and thus cancel the benefits of new technology. If such problems exist, the effect of new technology may be negligible.

The above discussion deals mainly with the farm level. At the aggregate level, the picture should be turned around; that is, interest should be focused on the impact of multiple cropping on a given area. Specifically, impact on production, income, consumption, market, and price movements, and resource utilization (employment), both before and after the new technology, should be evaluated. Information on consumption habits, kinds of food crops consumed, and nutritional values will also be useful for directing research efforts. New technology has often been criticized as more suitable for the larger and better farmer than for the smaller farmer with fewer resources. A given area, although rather homogeneous, may have several cropping patterns. The impact of new technology on different groups of farmers will therefore vary. New cropping systems technology should be developed for the benefit of the majority of the farmers of the area.

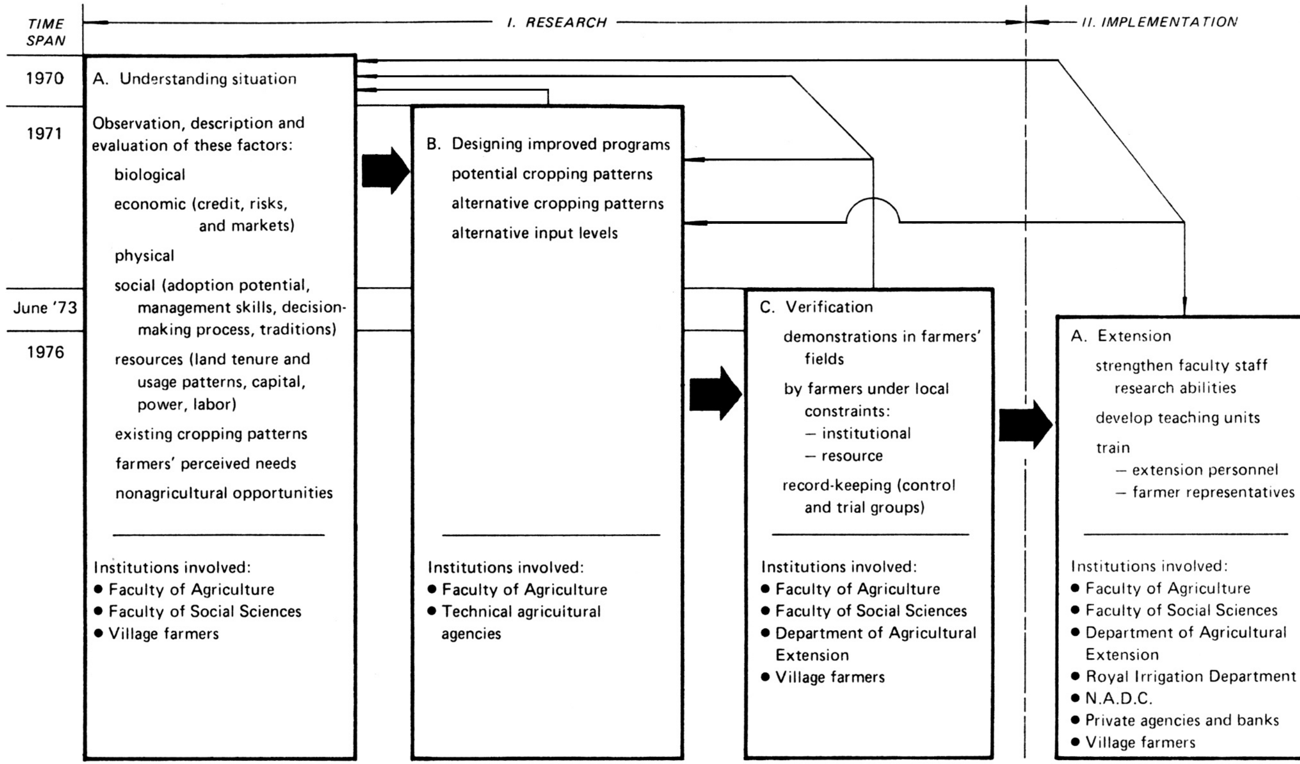
EXPERIENCE OF THE MULTIPLE CROPPING PROJECT

I have so far suggested only what needs to be done in multiple cropping research and development. I shall now describe how Chiang Mai University carries out studies to bring to light some of the variables mentioned above. Then I shall relate those studies to actual design, testing, and extension of new multiple cropping technology.

Although multiple cropping has been well established in the valleys of Northern Thailand, especially in the Chiang Mai Valley, for many decades[2] it was given very little systematic study until the Faculty of Agriculture, Chiang Mai University, with the assistance of the Ford Foundation, embarked on multiple cropping systems research in 1969. The Multiple Cropping Project (MCP) aims to develop multiple cropping systems adapted to irrigated areas of Northern Thailand, particularly of the Chiang Mai Valley. During the project's first two and one-half years, much effort was directed towards developing an experimental site and structures, and in outlining the research components of the MCP. Although those research components are divided into agronomy and social science programs, what has been done and what is intended fall within the suggested framework. Figure 1 shows the components of the multiple cropping program and its iterative nature.

Using the 1963 census of agriculture for Chiang Mai Province as best available data, it was determined that the average farm size was 7.5 rai (1 rai = 0.16 ha). For practical purposes, a production area of 8 rai was laid out at the experimental site. After measurement of a considerable number of farmers' fields, it was decided to use one-half rai plots as fairly

[2] For detailed description of the Chiang Mai Valley, see Seetisarn (1975).



1. Chiang Mai University's multiple cropping program. Heavy arrows = information flow; light arrows = feedback on problems requiring further analysis.

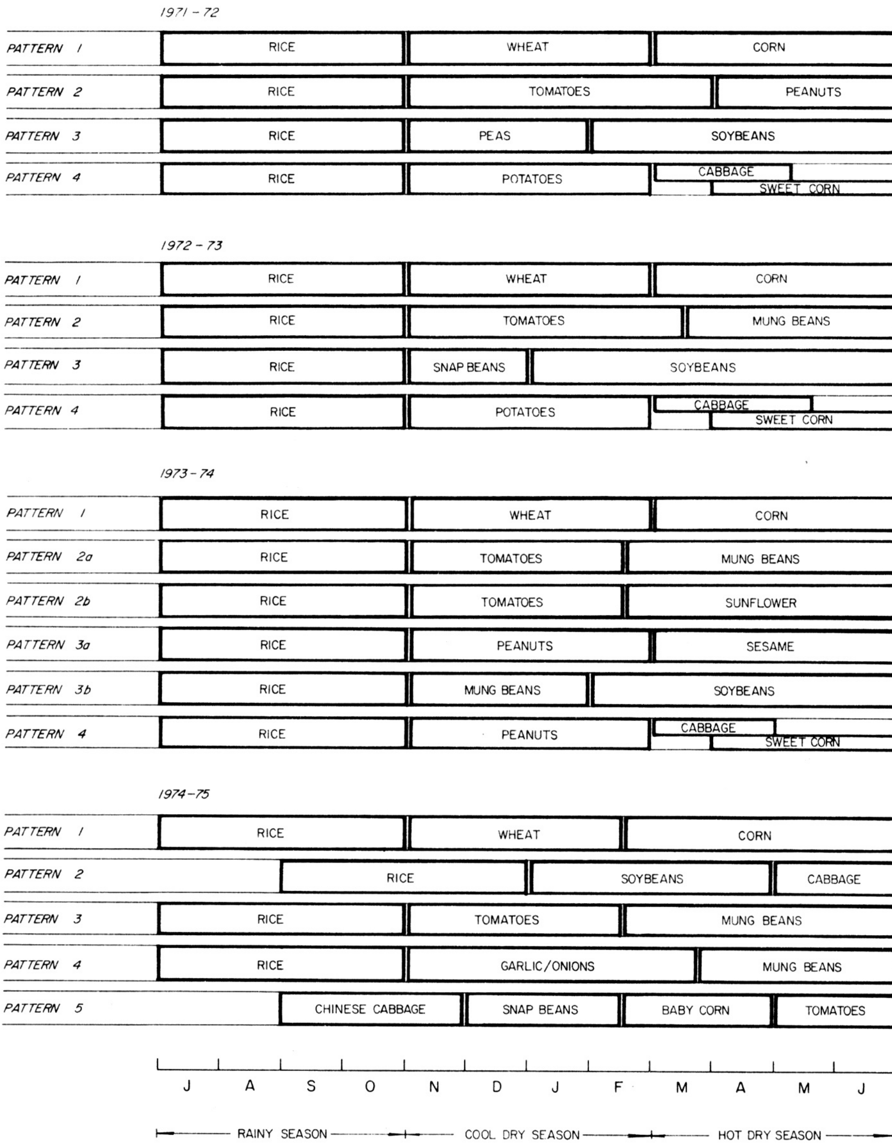
representative for experimental purposes. Our agroeconomic survey of the Chiang Mai Valley in 1972–73 gave the average farm size as about 8.8 rai (1.4 ha). Thus, the production plot was slightly smaller than the average farm.

Prior to the 1974-75 cropping calendar, four cropping systems were designed and tested. All systems were built around rice as a main crop for the rainy season. Each system was tested on a one-half rai plot with replications. Since the crop year 1974–75, an all-vegetable system has been included, and each system has been replicated three times on one-half rai plots (Fig. 2).

To obtain information describing existing multiple cropping systems, crop production technology, resource use and limitations, and other economic situations, farm economic surveys and market and marketing studies were developed. They serve four objectives. First, the present agro-socioeconomic conditions under which existing cropping systems exist can be studied both extensively and intensively. Second, resource availability, utilization, and other socioeconomic constraints can be established, and new cropping systems and technology can be designed to fit the existing and expected situations. Third, there will be a base against which the new system can be evaluated. And finally, the survey data can be used to evaluate the impact of multiple cropping.

Two agroeconomic surveys have been conducted in the Chiang Mai Valley since July 1971. One survey covering two villages, Ban Pa Mark and Ban Dong, near Chiang Mai, was repeated every 6 months. Ban Pa Mark was selected because, prior to the completion of the Mae Tang Irrigation Project in mid-1971, it traditionally had produced only one crop—rice-in the rainy season. When the irrigation project was completed, the situation changed. More land is now used for dry-season cropping (Table 1). Ban Dong has some second-cropping of tobacco, peanuts, and soybeans, and uses supplemental water from a traditional irrigation system. That village will also benefit from the new irrigation project. The adoption and changing patterns of multiple cropping in those villages can easily be monitored. Ban Pa Mark has also been used since 1973 as a test site for the multiple cropping systems developed by the Project. In addition, 30 farmers there were selected for an intensive daily record-keeping study of their economic and other activities for one year from 1 July 1973 to 30 June 1974.

Another survey was conducted that included farmers from all parts of the valley. It was felt that looking at sample farmers in one or two villages would not give an accurate account of the agro-socioeconomic condition of farmers throughout the large valley. A multistage sample was used. The



2. Multiple cropping systems tested by Multiple Cropping Project (MCP) 1971–76. Chiang Mai Valley, Thailand.

Table 1. Area in crops, Ban Pa Mark 1970–72, Chiang Mai Valley, Thailand.

Crop/Year	Area	
	Rai (1 rai = 0.16 ha)	% of total farm area
Rainy season 1970		
Rice	529.6	96.5
Dry season 1970–71		
Soybeans, peanuts, others	Negligible	
Rainy season 1971		
Rice	548.8	100
Dry season 1971–72		
Soybeans	273.1	49.8
Peanuts	31.6	5.8
Garlic	2.7	.5
Rice	17.7	3.2

Source: Ban Pa Mark farm survey, 1972.

villages were selected first, then the farmers.[3] The sample had 22 villages and 20 farmers from each village (a total of 440 farmers). Since no direct effort was made to influence the cropping systems and technology of the selected farmers, the sample was a fair representative of the entire valley.

The surveys collected data on (1) cropping systems, (2) availability and use of resources, (3) farm outputs and sales, (4) production methods, inputs and costs, (5) use of labor, (6) costs and returns of non-farm activities, (7) household income and expenditures, and (8) other household information. Using such data, the characteristics of the households as well as farming activities were described (Tables 2 to 4).

In addition, market and marketing studies of several crops were conducted to assess the effectiveness and efficiency of the existing marketing system and the expected market situation. It appears that the existing marketing system is working relatively efficiently. It has considerable capacity to expand and is not likely be a major obstacle to the increased production of storable commodities and vegetables for processing (Wibo-onpongse and Thodey, 1974).

Data from the studies have been used in the design and testing of the MCP cropping systems (Fig. 2). The tested cropping systems have changed through time. In the beginning, only cereal crops and high-protein food crops were included. There were two reasons for that decision. First, Chiang Mai Valley is a rice-deficit area, with a population growth of

[3] For more details on the selection of villages and farmers see Tongsiri et al. (1975).

Table 2. Area planted to selected crops, 1970–73, Chiang Mai Valley, Thailand.

Crop	Area planted (%)				
	Dry season 1970–71	Rainy season 1971	Dry season 1971–72	Rainy season 1972	Dry season 1972–73
		(% of area planted in rainy season 1971)		*(% of area planted in rainy season 1972)*	
Glutinous rice	1.3	91.4	1.6	91.5	7
Nonglutinous rice	6.4	84	7.1	8.4	11.2
Soybeans	14.3	.1	15.1	–	16 9
Peanuts	4.6	–	5.1	–	62
Mung beans	4.6	–	5.0	–	50
Garlicionions	6.5	.1	71	.1	6.7
Tobacco	2.4	–	2.6	–	1.9
Peppers	.3	–	.3	–	.6
Vegetables/other	3	–	.5	–	.7
Balance (not planted)	59.3	–	55.6	–	50.1
Total	100.0	100.0	100.0	100.0	100.0
Area planted (rai) by sample farmers	1,499.38	3,687.88	1,637.79	3,795.73	1,897.81

Source. Chiang Mai Valley Agro-economic survey. 1972–73.

2.8% per year. The situation could become worse in the future. Thus, a new cropping systems technology designed to meet the need of the future received high priority. Second, the systems were oriented toward the

Table 3. Farmers growing selected crops, 1970–73, Chiang Mai Valley, Thailand.

Crop	Farmers (% of sample)				
	Dry season 1970–71	Rainy season 1971	Dry season 1971–72	Rainy season 1972	Dry season 1972–73
Glutinous rice	2.7	95.0	3.7	97.9	1.8
Nonglutinous rice	10.7	11.6	11.8	12.9	21.6
Soybeans	23.2	.2	27.0	–	35.7
Peanuts	14.8	–	18.2	–	27.3
Mung beans	8.2	–	9.5	–	10.2
Garlicionions	25.5	.2	28.2	.2	33.4
Tobacco	11.4	–	12.0	–	10.7
Corn	.5	–	.5	–	.5
Peppers	1.8	–	2.2	–	4.5
Vegetables	3.0	.2	4.3	–	7.5
Nothing grown	32.0	2.7	23.0	–	15.0
Crops grown per growing farmer	1.4	1.13	1.58	1.11	184
Farmers growing crops (no.)	299	440	339	440	374

Source: Chiang Mai Valley Agro-economic survey. 1972–73.

Table 4. Land area by land use. Chiang Mai Valley, Thailand.

Area (rai)	Paddy land	Upland	Orchard	Undeveloped
		% of total area		
None	–	80.2	86.3	99.3
0.1-0.99	0.5	6.1	4.5	–
1.00-2.49	5.8	7.9	4.8	–
2.50-4.99	20.5	4.1	3.2	.2
5.00-7.49	27.2	.9	1.2	–
7.50-9.99	13.9	.5	–	.2
10.00-14.99	19.14	.2	–	
15.00-19.99	7.1	–	–	–
20.00-29.99	4.8	–	–	–
30.00 and over	.8	–	–	–
Total	100.0	100.0	100.0	100.0
Area for household with land (av.)	8.80	2.07	1.85	10.26
Area for all households (av.)	8.80	41	.25	.07
Households with land (no.)	440	87	60	3

Source: Chiang Mai Valley Agro-economic survey, 1972–73

problem of malnutrition. Although the problem is not widespread, its existence in a food-surplus country is of great concern to policymakers and research institutions.

Some systems did not go well with the prevailing situation and systems used by the farmers. As a consequence, some have been redesigned and changed. It is hoped that the systems developed and currently tested by the project will better serve needs in the valley in the years to come.

The surveys show that the two-crop system-rice followed by an upland crop or rice—is the most common in the valley. The second crops are tobacco, soybeans, peanuts, garlic, onions, mung beans and vegetables (Table 2). Some farmers grow three crops per year—rice followed by two upland crops or by one upland crop and rice. The percentage of farmers growing a second crop is increasing. It rose from 68% in the 1970–71 crop year to 85% in the 1972–73 crop year (Table 3). The farms are small, ranging from 0.9 to 48.5 rai with an average of 9.3 rai—8.8 rai of paddy land, 0.4 rai of upland, and 0.2 rai of orchard (Table 4). Most farmers owned their land; 70% owned all or part of the land they farmed, the remainder were full tenants. Almost all paddy land is irrigated, but only 69% of the area farmed has reliable water, to varying degrees, in the dry season. The farm households varied in size from 2 to 12 members, with an average of 5.7. The number of persons able to work full-time in farming averaged 3.2. Hired labor is more important in the dry season than in the rainy season because most farmers usually exchange labor in the rainy season.

From those findings, the factors which influence the existing cropping patterns in the Chiang Mai Valley can be summarized. First, the physical environments are favorable; water availability in the dry season is the most important reason. Second, most farms are small, compelling the farmers to use their land intensively. Third, a well-developed market exists for a wide range of crops. And fourth, farmers desire higher income and are willing to work hard for it.

The project is now involved in a village program to do on-farm testing and evaluation of the systems developed and tested at the experimental site. Although the farm testing program started in the 1973–74 crop year, only in the 1975–76 crop year has it been conducted systematically. In addition to Ban Pa Mark, three more villages (Ban Han Keo, Ban Mae Kung, and Ban Klang Nua) were selected as testing sites. It is anticipated that the testing will influence the adoption and extension of new technology; thus the village program is also concerned with communication between the Project's staff, extension workers, and farmers.

The primary objective of the village program, however, is to test and evaluate new cropping systems under actual farm conditions. As such, it is not basically an extension program. The purpose of testing is to compare the traditional farmers' system with the new systems developed by the project in terms of resource use and profitability. The traditional systems will be carried on by the farmers in their usual way. Operations of the new systems will be supervised by the Project's staff. The results of the testing are still incomplete and cannot be given here.

I would mention, in passing, that in anticipation of the role that the project will play in the extension phase, the planners are interested in the farmers' decisions on resource utilization, in their choices of crops and cropping characteristics, and in the factors that will facilitate as well as hinder the adoption of a multiple cropping system. Such knowledge will help the project to select new technology that meets farmers' needs and to suggest the most effective extension method for getting it used. To this end, two studies related to the village program were conducted. The results of those studies will not be discussed as they are beyond the scope of this paper.

CONCLUSION

Multiple cropping is affected by physical, social, political, and economic factors. Those factors are in turn affected by multiple cropping. A knowledge of the factors and their interaction with the traditional cropping systems can help research institutions select new cropping technology which will be useful to farmers. To identify and describe the factors, agroeconomic surveys, market and marketing studies, and a daily record-keeping study of economic activities of the selected farmers were employed.

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INFORMATION REQUIRED FOR DESCRIPTION OF CROPPING SYSTEMS

G.R. Banta

Before discussing the information required to describe a cropping system, it is important to know why the description is necessary. Who need the description? What are they going to do with it? How will it fit into a total program? What is the objective of the program? In most cropping systems work, the people requiring the information are involved in a research group in a university or an experiment station, a national program, or an international program.

The first question examines the need for the description. Is the description meant to further understanding and knowledge of what farmers are currently doing? Is it meant to enable someone to understand and predict the system's future evolution, assuming that certain factors may undergo change that is either planned or natural? Is it meant to interpret resource utilization and then use the information to allocate resources within the cropping system more efficiently? Is it meant to help find ways to include new technology and to increase either production or stability, or both? Depending on what is to be done with the information, the required data will vary considerably.

The next question relates to how the required data fit into the program of the organization carrying out the study. If it is a single study with no direct connection with other plans, it will be self-contained and less concerned about relating the units for measurement to those in other studies. If it is part of a total program, particularly a base-line study, considerable thought has to be given to the points which follow and the units which will be used, with the study being made as generally applicable as possible. It is particularly important that sufficient data be gathered in a major base-line study so that comparisons which may be required later

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will be possible. If the study is a continuation of previous studies, that is, a follow-up of a base line, it should be based on the earlier studies for continuity. A general framework is mandatory before starting a study.

A final concern is with the objective of the program. The goals of cropping systems programs usually fall into one of three categories: to understand what is happening, to fit into existing technology, or to use collected data as a base for developing new technology. A program is likely to involve all three goals, but the emphasis changes as the program develops.

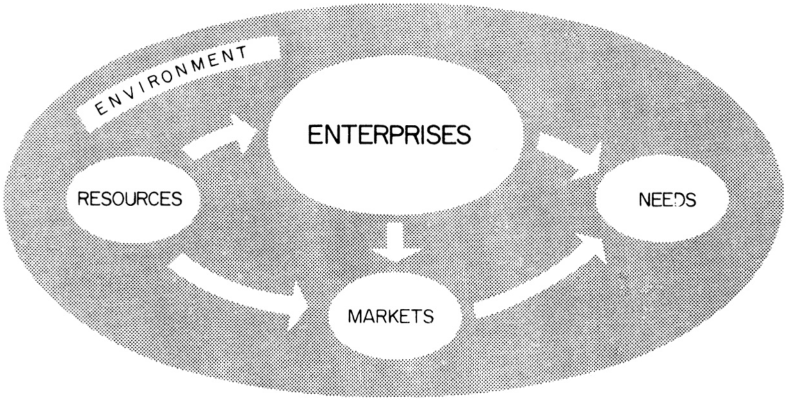
ASSUMPTIONS

Any collection of data is underlain by a set of assumptions, both explicit and implicit. Implicit assumptions should be transformed into explicit statements. Some examples of assumptions which have been implicit in previous cropping systems studies and yet had a major bearing on the studies and the information gathered are presented below.

That a farmer is efficient in certain situations is an implicit assumption in some cropping systems studies. Use of the assumption suggests that a description of the cropping system is needed only as a base for further research in developing new technology or for transferring it to another location. A second assumption inherent in most studies touches on the goals or objectives of the farmer. Most economic studies assume that the farmer is concerned with maximizing profit; in many biological studies, concern is with maximizing yield or some other physiological measure. The assumption often is implicit. In reality, the farmer has a set of goals, some of which may conflict. A third assumption implicit in many studies is the homogeneity of factors. That creates many problems for people utilizing the work or conducting follow-up studies. It is important that those factors be explicitly defined because in many cases they are not homogenous. A fourth assumption in many studies is that the farmer has a wide decision-making power. In many instances, particularly in small rural Asian villages, the decisions the farmer can make are relatively limited due to social, economic, biological, physical, and political factors in his environment.

FRAMEWORK

After the reasons for and the assumptions inherent in a study have been defined clearly, the next step is to define the problem. The definition should include a statement of the factors thought to be causing the situation of concern, followed by a concise statement of the goals or purpose of the study.



1. Components of cropping systems research.

To help define purpose, a theoretical framework is needed to guide the detailed design of the study. That framework can be considered a skeleton of general knowledge on which more information will be built, developing certain knowledge of cropping systems. The framework comes from one or more of the many disciplines involved in cropping systems research. It assures researchers that the data they are collecting will fit into a testable program and will be related to past studies and, it is hoped, future studies.

An initially simple framework with only five components is suggested for cropping systems research (Fig. 1). Those components are environment, resources, enterprises, markets, and needs. The framework assumes that a farm operation is a process by which the farmer transforms resources into products that can be used to meet his needs. Within that framework, cropping systems are one component of a total farming system; although it may be the most important component for most farmers, it is neither a beginning nor an end, but rather a means to the end of meeting the farmers' needs.

Environment. The environment, the first part of the framework, is divided into five major factors: physical, economic, social, biological, and political. Each factor can have a direct effect on the cropping system or an indirect effect on the other enterprises or on the resources available to the farmer. It is not always possible to quantify or even define all variables in a Southeast Asian environment, but it is important to define those which have a major effect on a particular cropping system (Table 1).

Resources. Resources are the things which are currently used by the farmer which interact in the processes associated with his cropping system.

Table 1. Rank[a] of environmental factors for cropping systems.

Environmental factor	Base line	General	Specific
Political			
Agricultural objectives	5	5	6
Agricultural assistance	5	5	5
Agricultural advice	5	5	5
Agricultural credit	3	5	5
Agricultural marketing assistance	3	5	5
Stable price policy	4	5	6
Cheap food policy	4	5	6
Physical			
Topography	2	3	2
Altitude	3	3	3
Mountains	3	3	3
Rainfall			
Pattern	2	3	2
Probability	3	3	2
Amount	2	2	2
Winds	3	3	2
Temperature	3	3	2
Soil classification	1	1	1
Biological			
Weeds	2	3	2
Pests	3	5	2
Insects	2	5	2
Diseases	3	5	2
Plantation crops	2	5	2
Tree crops	2	5	3
Social			
Traditions	2	2	4
Community size	1	1	2
Community organization	2	2	2
Schools	1	3	2
Schooling	1	3	1
Migration	3	5	5
Age of community	6	6	2
Facilities	1	1	1
Crime	5	5	5
Migration pattern	3	5	5
Family structure	2	3	2
Debt attitudes	1	4	1
Traditional vs. modern	1	4	1
Economic			
Roads	2	3	2
Transportation	2	3	2
Tenure	2	3	2
Markets	2	5	2
Standard of living	2	5	2
Credit	1	2	2
Stability	2	3	3

[a] Ranks are described in Table 5.

Table 2. Rank[a] of resource factors for cropping systems.

Resource factor	Base line	General	Specific
Land			
Area	1	1	1
pH	1	3	1
Cation exchange capacity	3	3	1
N	1	2	1
P	1	2	1
K	1	2	1
Texture	2	3	1
Surface soil depth	1	3	1
Irrigation			
Amount	2	2	1
Availability	2	2	1
Solar radiation			
Distribution	2	3	2
Probability	2	3	2
Day length	2	3	2
Labor			
Family	1	2	1
Hired	1	2	1
Hired cost	1	2	1
Power			
Animal number	1	1	1
Value	1	2	1
Mechanical	1	1	1
Cost	1	2	1
Operating capital			
Cash	1	2	1
Credit amount	1	2	1
Credit cost	1	2	1
Market inputs			
Cost	1	1	1
Availability	2	2	1
Reliability	2	2	1
Markets			
Minimum quantity taken	2	2	1
Cost	1	2	1
Information supplied	4	5	4
Reliability	4	5	4
Management			
Biological	4	6	4
Economic	4	6	4
Social	4	6	4
Physical	4	6	4

[a]Ranks are described in Table 5.

They are land, water, solar energy, labor, management ability, technical knowledge, available power, cash, available nonfarm inputs, credit, and markets (Table 2). They are studied in detail and considerable energy is spent in defining and, wherever possible, quantifying them. Except management ability and technical knowledge, all can be quantified, and existing procedures give them fairly precise quantitative values. Markets are not usually considered resources, but a farmer considering potential crops can take a good market as a resource. By market I mean not only the transferring of physical products, but also the feedback on potential prices, and desired quantities and qualities. Other papers will discuss in detail each of these resources, some problems in quantifying them and solutions in cropping systems work, and other component analyses related to cropping systems.

Enterprises. Even though one may be concerned primarily with cropping systems, he must be aware of the farmer's allocation of resources and the interaction between enterprises, particularly as those enterprises interact with cropping systems. An analysis which ignores those other enterprises often concludes that the farmer is allocating his resources efficiently; yet when the total system is considered, the farmer is seen doing an efficient job under the circumstances he faces and considering his total needs.

The framework outlined here requires the farmer to allocate all resources to one or a combination of five possible enterprises: resource marketing, community stability, livestock production, cropping systems, and fixed family factors (Table 3).

Resource marketing refers to the farmer‘s selling of his resources or utilizing them on the farm to meet his needs directly. Quantification of this enterprise is easy, for money is usually received for resources. Consider, for example, the farmer who spends part of his labor in off-farm employment.

Community stability is another enterprise to which a farmer can allocate certain of his resources. Considering community stability as an enterprise using resources helps us understand the farmer's way of allocating resources, and to understand the potential for technology which may be introduced. Examples of resources used for community stability are cash paid as taxes, and labor put into community projects.

Livestock production is an important enterprise on many Asian farms. First, and of prime importance, livestock is a power source. Many farmers in Asia use water buffaloes or cows for land preparation and other heavy cultivation. Livestock are easy to quantify in number and value. Many farmers have other livestock for sale or for home consumption. A cropping system may be designed with products fed directly into the livestock system, without entering the marketplace. An analysis of the cropping system alone may suggest that the crops grown are far from reaching an

Table 3. Rank[a] of enterprise factors for cropping systems.

Enterprise factor	Base line	General	Specific
Family resource requirement			
Land, house and yard	1	2	1
Trees	2	3	1
Water	2	3	1
Labor time	1	3	1
Community stability			
Tax	1	3	1
Labor	3	3	3
Cash	3	3	2
Resource marketing			
Labor	1	3	1
Power	2	3	1
Land	1	3	1
Livestock			
For each type			
Cash requirement	2	3	2
Land requirement	2	2	2
Crop requirement	2	2	2
By-product requirement	2	3	2
Labor requirement	2	3	2
Production	2	2	2
Production values	2	2	2
Value	2	3	2
Cropping system			
Cropping pattern			
Area	1	1	1
Crops	1	1	1
Sequence	1	1	1
Crop			
Cultivar	1	1	1
Weed management	1	2	1
Insect management	1	2	1
Disease management	1	2	1
Soil physical management	1	2	1
Soil chemical management	1	2	1
Water management	3	2	1
For each above			
Costs	1	1	1
and practices	1	1	1

[a]Ranks are described in Table 5.

economic optimum, but specific data on the return from crops used by the livestock enterprise may prove the total system efficient. The by-products of the livestock enterprise go back to the fields to increase fertility. The livestock enterprise also acts as a reserve. If crops fail or if the farmer needs a large amount of money to meet a family crisis, livestock gives him a degree of economic stability.

A cropping system is the main method that small farmers throughout Southeast Asia use to transform their resources into products to meet their needs. Cropping systems can be broken down into cropping patterns (that is, crops grown on each piece of land over one period, usually a year). A cropping pattern, in turn, may consist of crop sequences, intercropping, interplanting, relay interplanting, or mixed crops. Study of cropping patterns requires knowledge not only of the sequence but also of the duration of each crop and of special management characteristics which may be required. Knowledge of cultivars can also be important: knowledge of their resistance to disease and insects, ability to stand adverse water conditions, ability to withstand typhoons, early seedling vigor, high population densities, height, shade characteristics, and harvesting characteristics. The cultivar also influences the quality of the finished product. Does it have a high market value and does the consumer or farmer like to eat it? A knowledge of cultivars used is essential.

Weeds are a continual problem and often cause loss of income through either the cost of the weeding to keep yields up or the decrease in yield when weeding is not done. Understanding the farmer's weed management practice is important. It means knowing not only what the farmer is doing currently, but what his previous crops and his previous weed management have been. The interaction among crops, weeds, cultivation, and herbicides can thus be understood. Looking at a single crop and the weed management practices used with it, however, does not give an understanding of weed management for different crops grown in sequence.

Insect management is another important part of the total management system. Cultivar resistance, cultural practices, time of planting, off-season insect-control practices, and controls used for insects on the growing crops are all factors to consider when deciding on the data to collect for insect management.

Soil management can be divided into two main areas: physical management and chemical management. To study physical management of the soil, one first defines the soil by employing the usual classification techniques. One also gets some measure of the soil's wet plowing characteristics, or the speed with which the farmer can continue cultivating or plowing after a heavy rain. Determination is made of the amount of work required to change soil from the puddled to the friable upland condition in any cropping pattern combining puddled rice and upland crops. Chemical management of the soil is usually the farmer's attempt to increase fertility with nitrogen, phosphorus or potash. In a few areas, liming or the use of micronutrients may be included, but the practices are rare on small Southeast Asian farms. The data required for chemical management are amount, timing, and cost of fertilizer. In addition, data will be required on crop residues incorporated into the soil, either from the crop grown on it or from others.

Data on water management provide crucial information but are difficult to get. Some understanding of a field's rainfall-holding characteristics and the movement of water from one paddy to the next, particularly in puddled rice, is needed. Topography affects the rainfall-holding capacity of the field. Physical soil management is closely tied to topography. Up to the present, little work has been done on the actual use of rainfall other than simply relating inches of rainfall and yields.

Fixed family requirements are the final enterprise. It is useful to look at the family as an enterprise with certain resource requirements. Those resources are not available to other enterprises. The two resources most often used by the family are cash and labor, which can be measured quantitatively in amount and in distribution over time. A simple example of the effect of fixed-resource requirements is seen on very small farms where the house and the yard have a measurable impact on the amount of land available for agriculture. In certain areas of West Bengal, Bangladesh, and Java, the land requirement for the family is becoming significant.

Markets. The usual way to study markets is to learn the cost of transporting a product from the farm gate to the market and to subtract that cost from market price. However, an understanding of the importance of marketing in cropping systems requires considerably more detailed information. The first and, perhaps most important question is: What markets are available for the crops that can be grown? Markets can be divided into two major categories: the home market and the commercial market. The home market is that for all products used by the family, while the commercial market is the usual market where buyers and sellers exchange products for money, as well as the barter market which may be found in some villages or small communities. There is no easy way to get information on markets. Average national prices are relatively useless in determining how the market affects local production of crops or interactions within the cropping system. Detailed day-to-day information is needed, not only on the actual price received but, perhaps more important, on the farmer's anticipated price and the variance he expects around that price. One of the basic goals of more intensive crop production is to have the farmer market more of his crops; therefore, the farmer must understand how the market operates. The farmer's faith in the market, that it will purchase his products at an acceptable price and that it will feed back probable prices for future sales, needs attention. Attitudes and beliefs may be of critical importance in marketing. If a farmer feels that the people of the market are cheating him and that he has difficulty in learning the true worth of his products, he may not want to market them; if he does go to market, he will accept the fact that he has no say in pricing, will take whatever is given, and may avoid expanding production of his products.

Needs. For the purposes of data collection, a farmer's needs can be divided into five major categories: food, consumer items, social acceptance, stability, and improvement (Table 4). Food needs are basically carbohydrates and proteins; the farmer is also concerned with taste, variety, and social acceptance of what he is eating. Carbohydrates and proteins, because they are essential, must be provided either by crops grown or by the marketplace. Any change in a cropping system which brings about a major change in the amount of protein or carbohydrate produced must consider the source of replacements.

Table 4. Rank[a] of farmer needs.

Farmers' needs	Base line	General	Specific
Food			
Staple amount	2	3	2
Staple source	2	3	2
Protein amount	2	3	2
Protein source	2	3	2
Taste preference	4	5	4
Extra source			
Extra cost	2	3	2
Consumer items			
Housing	3	3	3
Clothing	3	3	3
Transportation	2	3	3
Education	3	3	3
Health care	3	3	3
Extras	2	3	3
Social acceptance			
Norms of nation	6	6	6
Norms of community	5	5	6
Norms of family	4	5	5
Stability			
Food	2	3	2
Consumer items	2	3	2
Social acceptance	2	3	2
Economic	2	3	2
Peace and order	6	5	5
Improvement			
Food	4	4	2
Consumer items	4	4	2
Social roles	5	5	3
Stability	5	5	3

[a] Ranks are described in Table 5.

Taste must be accepted as it exists; the farmer simply likes or does not like a certain crop or a certain variety. The taste for rice is one good example. Although their carbohydrate and protein contents may be exactly the same, different varieties of rice meet with varying degrees of acceptance in different areas of Asia. Finally, some crops have social acceptability; some don‘t. In certain areas, sweet potatoes are considered a poor man’s food and anyone who can avoid them does so. In other areas, other crops are considered socially inferior, or not good for certain people at certain times of life.

Consumer items form the next large group of farmers’ needs. They have one characteristic in common—cash is required to obtain them. They include housing, clothing, entertainment, transportation, health care, and things to make life generally more enjoyable for the family. In quantifying consumer items, two factors are to be considered: one is the total cash required; the other is the distribution of the cash requirement over time. A farmer’s need for cash does not usually coincide with the cash available from his cropping system or total farming system. The farther apart the two figures are, the more difficulties the farmer is likely to experience. Credit becomes important.

Another farmer need is social acceptance. He must do what is acceptable to his family, his friends, his community, and his nation. The nation has very little concern with the farmer’s cropping system, except to say that crops considered illegal must not be grown. It does, however, want the farmer to grow those crops which are needed most to meet the country’s existing food and export requirements. The community is a little more critical in its acceptance of the farmer’s cropping system. If the farmer is totally out of sequence with the rest of the community or has a system with a lot of weeds, he may not be in harmony with the community and with his immediate neighbors. If there is any interaction with neighbors, it then becomes even more critical that his cropping system coincide with theirs. Finally, the family must approve of the crops, the sequence, and the way the farmer produces them. The amount of labor they are required to put into the system is important to them. That need for social acceptance, although real, is difficult to measure and can be defined, when some change is made or anticipated only by checking with the people of the community or the family about acceptability of the new idea.

The next need is stability of all the above factors. The farmer requires that each need be met this year and in the future. He is not interested in carrying out an activity which meets his needs in the present but has a high possiblity of ruining his chance to meet future needs. The most obvious example is that of a farmer who sells his land. Although the sale meets all his present needs, the probability of its meeting his future needs is very slim. The farmer, facing a variety of risks and uncertainty due to nature and the market, wants a system with stability built in. The factor of stability is critical. To accomplish it, the farmer pays his taxes, acts as a conscientious member of his community, and plans a cropping system which is both biologically and economically stable.

The final need—the need to increase the level of well-being—is behind most farmers' attempt to improve their systems, their willingness to test new enterprises, and their interest in new technology. The farmer is interested in more and better food, better education, more consumer items for his family, and greater stability. Although the need for well-being is almost impossible to define quantitatively, certain patterns emerge. The farmer wants a better social infrastructure, a better general market infrastructure, and more stable personal income.

AGRONOMIC EXPERIMENTS

A survey of social, biological, economic, and physical factors is not sufficient to provide an understanding of cropping systems. In addition, on-site agronomic experiments are required. A range of simple single-factor treatments added to a farmer's field is sufficient to give a clear indication of which factors are constraints. One can add 100 kg/ha of phosphorus or potassium to part of a farmer's field, measure the result, and learn whether either is really a limiting factor. One can keep several small plots weed-free in farmers' fields to find the potential for increased weed-management practices. The same method, although not as accurate, works with insect management. A combination of systemic insecticide and quick-kill chemicals can keep plots relatively insect-free and give some idea of the potential for insect management. Such a method of control is probably sufficient because anything above this level of control requires such tremendous cost that it is really of no interest to the farmer and has no economic possibilities. Farmers in almost any area of the world are willing to try new varieties in small test plots at their own management levels. An easy method of cultivar evaluation in an existing cropping system is to have the farmer grow a new variety. Disease management is more difficult to measure, as a disease under study does not always occur.

Farmers are usually willing to give small plots for trial of different cultural practices, if they understand what is being done and if researchers do not ask for too much land. All farmers are willing to test new fertilizers in existing cropping patterns. Water management and an understanding of it will initially take much effort; studies at The International Rice Research

Institute seem to indicate that the work can be done. The results from such single-factor experiments can be compared with farmers' statements about the response of each factor. Those statements provide a good check for many factors. For example, some inputs might not have been properly used in the past because the extension work which went with them was not efficient. The factor under consideration may have potential in the existing cropping systems.

Another observation is that single-factor experiments elicit a great deal more information from farmers than simple responses regarding the experiments. The farmers comment on things that they have previously tried; such information would not normally be obtained from surveys. They also discuss their needs in detail and compare the new factors' effect with what they feel their needs are and will be. Thus, single-factor experiments have proved useful not only in producing quantitative data but also as effective survey tools to learn the farmers' current cropping systems and what farmers feel to be the constraints. It is also possible to learn changes the farmer would like to have in his cropping systems in the type of crops to be grown, the characteristics needed in those crops, and the management techniques required for development.

Single-factor experiments have been found very effective in testing how well the researchers understand a particular cropping system. They are also used as checks on the reliability of the data obtained from farmers. Some farmers tend to give erroneous data. Checks from the field make it easy to spot such farmers, who can then be removed from the studies. It is important that single-factor experiments be well conducted. If farmers discover that researchers cannot grow a crop of corn or a crop of rice, or cannot function in a village setting, the future of a program and a whole experimental plan is in jeopardy. The researchers who go to the barrio must know what they are doing and be able to get along with people.

DATA REQUIREMENTS

It is apparent that the amount of data discussed in the previous sections would be impossible to obtain. Therefore, goals and purposes must be so specified that only relevant data will be collected. When too much data are gathered, results become unmanageable, impossible to describe or analyze. On the other hand a research project can be defined too tightly, with important factors not considered or undescribed. The contribution of undescribed factors to the understanding of total cropping system will be extremely limited. A major current problem is how to relate to a total cropping system much of the research being conducted in other disciplines.

Table 5. Relative importance of data for cropping systems research.

Rank	Criterion
1	Must be as accurate as possible
2	Must have a quantitative estimate
3	Should have a quantitative estimate
4	Must have a qualitative estimate
5	Should have a qualitative estimate
6	Helpful to have some estimate

A second major problem is data reliability. We are all familiar with the joke about the man who collects data to the nearest kilogram and expresses the mean to the nearest gram. In cropping systems, certain data can be obtained with great accuracy, while others may be only qualitative. The precision demanded for data will depend on the objective of the study, the relevance of particular data to the objective and, of course, the available resources. There are no set rules on the resources to spend to obtain a particular level of precision. Only experience and the hard knocks of field research can offer insights. For those reasons, most cropping systems studies should begin on a relatively small scale with tightly defined objectives.

Another critical factor to consider is resources that can be allocated to describe a cropping system before other work is started or while it is going on. We must face the fact that adequate resources for a complete job will not be available; therefore, we must set some priorities on the data to be collected for different levels of knowledge required. There are three major levels; the one to be used depends on the study being undertaken. First is the base-line study to obtain understanding of a current system; it will be. used as a reference point for further work. Second is the general survey of an area, to educate the people concerned with current systems, so that further work can be planned. Third is the specific study of a few farmers to gain as complete an understanding as possible of a specific system or pattern. The third level is usually needed when a highly productive system is found and its concepts are to be transferred to other areas. For each level of study, each piece of data assumes a different importance (Table 5). Priorities can be established for each study and each type of data.

Tables 1 to 4 clarify the conceptual framework outlined in Figure 1. The estimates of importance of particular data are first approximations and should be modified according to country and specific objective. The tables are given as a guide for thinking about and planning a cropping system study.

SUMMARY

Before deciding what data are needed to describe a cropping system, the purpose of the description must be clearly defined. The assumptions which will be used in a study should be clearly stated, as they have a major impact on the results that are obtained. To help keep the gathering of data within reasonable limits and on track, a conceptual framework of the farm as a process is presented. The framework has five components : environment, resources, enterprises, markets, and needs. Each is sub-divided and described. Methods of gathering data and some of the problems involved are discussed briefly. Due to the great amount of data that are relevant to cropping systems, study priorities must be established. Three types of study are suggested as representative of the first stage of most cropping systems research. Considering those three types of study, tables provide first approximations of the relative importance of the required data.

ECONOMIC CRITERIA FOR CROPPING PATTERN DESIGN

E.C. Price

Design aims to combine crops into patterns and specify the techniques required to execute the patterns. I am defining a crop as a cultivar at a uniform stage of growth, and a technique as a farmer-controlled event which affects crop growth and uses farm resources. A cropping pattern is a spatial and temporal arrangement of crops on a plot in such a way that, at all times during a year, plants of each cultivar at the same stage of growth are uniformly spaced throughout the plot.

A small number of crops can be combined to form many alternate patterns. Furthermore, a given cropping pattern can be executed using various techniques (each set of techniques implies different rates of resource use). Therefore, even a small number of alternate crops and techniques can lead to a large array of cropping systems technologies. Good design should provide for testing at least those patterns and techniques which, among all possible combinations, are likely to have the greatest impact on food production. At the same time, the patterns should be designed with a view to reducing the total time, effort, and expense required to test and introduce them.

The design process consists of two steps: first, the selection of crops and techniques, and second, the assembly of those components into cropping patterns. The jobs are quite different. In the first step, a known population of crops and techniques is searched to find a subset of components that will be combined in numerous ways to form cropping patterns. In the second step, a population is, in effect, created; that is, a subset of the undefined universe of all possible patterns is identified for testing.

To digress, it is a long process of selection and assembly, in alternate steps, that leads to the eventual establishment of new cropping systems. First, elemental materials are selected, then assembled into new crop

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varieties, chemicals, and techniques. From a selection of those components we assemble cropping patterns. Then a portion of the patterns are selected through scientific testing and screening by farmers, before a small number of patterns are assembled on a farm to form a cropping system.

Specific procedures for selecting pattern components and for assembling the components into patterns are described in the second and third sections of this paper. The first section treats the overall design process in relation to other steps in pattern development and introduction.

THE DESIGN PROCESS

The universe of all possible crop combinations is, for practical purposes, infinite. Identifying a population containing all elements in the universe would be impossible; so would be the task of screening that population. In design, therefore, we construct a population of feasible patterns smaller than the universe. Since in cropping systems research our success is measured by the impact of the patterns we develop upon food production, it would be convenient if every pattern in the population identified for tests were likely to have more impact on food production than any unidentified pattern. But we know of no way of achieving that situation, for interactions between crops in untried combinations are somewhat unpredictable. It is likely that whatever design process we use, the universe will still contain unidentified patterns which would give higher yields than some of those chosen for testing.

Nevertheless, some progress can be made. I propose that potential profitability of new patterns be applied as the criterion for their construction, but that for practical purposes it not be applied directly. A way of separately applying the two parts of the profit formula—costs and returns—as criteria in the two-step design process—component selection and component assembly—will be described below. But first, I discuss how the profitability of patterns affects their impact upon aggregate food production, the ultimate target.

Success in pattern development is measured by how much more the newly developed patterns produce than those that farmers have been using. The increase in food production from a new pattern depends on:

1. the size of the area in which the new pattern is adopted,
2. the number of years that the new pattern is used, and
3. the yield advantage of the new pattern over those it replaces.

The size of the area in which a new pattern is adopted is a function of its profitability; so is the number of years it will be used. Hence the three factors reduce to two: pattern profitability and pattern productivity.

Consider how area of adoption relates to pattern profitability. Cropping systems researchers normally develop patterns for target zones—variously called agroclimatic zones or production complexes—that have particular combinations of physical and economic features that distinguish them from nearby areas. An agroclimatic zone, however, is not a homogeneous environment; it is made up of various "microenvironments" created by variations within the zone of such features as rainfall, slope, or access to markets. A crop activity will usually show different profits in different microenvironments. A particular location within a zone will be largely dedicated to the cropping pattern alternative that leads to the most profitable use of its resources. Moreover, the greater the margin of profitability of a pattern over that of competing patterns in one microenvironment, the more likely it is also to be the most profitable pattern elsewhere in the zone. The term "area of adoption" can be replaced by the term "profitability."

Consider how the number of years a cropping pattern is used relates to pattern profitability. The number of years of use of a new pattern is related to the lag time between design and adoption, and to the date the pattern is discontinued. Discounting future production at prevailing interest rates, one sees that the impact of a new pattern is largely determined by its earliest years of production. Long delays between pattern design and adoption seriously diminish the gains realized from the process of development and introduction. Since the speed with which a producer adjusts to new conditions—adopts a new pattern—depends on the size of the gain he expects from the adjustment, speed of adoption is a function of profitability.[1] Also, the more profitable a pattern is, the later it is likely to be supplanted by another. All in all, then, the number of years that a pattern is used is a function of its profitability.

The third factor that I have cited as contributing to the impact of new cropping systems on total food production—yield advantage of a new system—cannot be described solely in terms of profitability. Gross returns are precisely related to quantity of production, but costs are not, and profitability depends in part upon costs.

Hence the application of two criteria for cropping pattern design—pattern profitability and pattern productivity—are discussed below. Production and the gross-returns element in profitability are applied as criteria for selecting pattern components; the cost element in profitability is applied as a criterion for pattern assembly.

[1] The time between design and adoption is partly taken up by testing, which in turn is largely determined by the researcher through his choice of methods tor design and testing More effort spent on design can mean less needed for testing. We can assume the researcher wisely chooses a methodology, considering the tradeoff between design and testing. and between total research time and gains from early introduction.

The following steps are suggested as a simple procedure for cropping pattern design.

1. Select pattern components (techniques and crops), using a production-feasibility test.
2. Assemble new patterns according to resource use (cost) criteria.
3. In the field-testing phase, simultaneously apply the pattern cost and returns criteria (pattern-profitability criteria).

The method makes pattern assembly (the construction of a known subset of the universe of all possible patterns) a cost-based procedure.

I recommend such a procedure over several alternatives, including random generation, production-incrementing processes, and profit-incrementing processes. Random assembly of technically feasible patterns (by definition, a design process must deliver a crop combination *and* the technology for its execution) would likely provide so few successes among tested patterns as to be excessively costly. Cost criteria have the edge over production criteria because costs are more predictable than production; the specification of a technology for execution of a pattern automatically implies the levels of most costs, except harvest costs that are correlated with levels of production. In practice, a pattern is not field tested without a plan for its execution, and that largely sets the expected costs; production, on the other hand, is partly unpredictable, because of interactions between crops adjacent in time or space.

Finally, use of the profitability criterion as a basis for assembly, although theoretically a more direct approach, does not pay.[2] A profitability criterion would utilize more of the available information than the alternatives, and it is considered to be a sufficient condition for eventual acceptance by farmers, but when used at the design phase it is likely to be more costly than the value of the additional information obtained from the exercise. Indeed little new information is obtained, for the crop components of patterns have already been screened for production feasibility. Moreover, the margin of production above or below monoculture yield is somewhat unpredictable. In addition, profitability criteria can easily be applied at the testing phase when multiple-crop yield is no longer a matter of prediction but of observation. In other words, the gain from using yield information in the design decision of whether or not to test a pattern is less than the cost of obtaining and using the information.[3]

One can argue that design stops with the assembly of patterns, and that

[2]Actually there is no obvious profit-based mechanism for assembling cropping patterns. A way of applying profitability criteria is to generate patterns by some other process, randomly perhaps, then to test them through judgemental or quantitative simulation. The question then arises as to whether the simulation should be called a design or testing activity, as discussed in the following paragraph. But regardless of how the profitability criteria are used prior to field testing, or what it is called, the payoff argument applies.

screening of assembled patterns, judgmentally or quantitatively, is part of the testing phase of research. By definition, that makes cost criteria not only the mechanism for pattern assembly, but also the principal criteria for pattern design (since production feasibility is used only in component selection). Stated differently, no matter how arbitrary the choice of a cost-based mechanism for assembly, that mechanism is the principal basis for design if design activities are considered to stop after pattern assembly.

Ending design with pattern assembly is consonant with an economics methodology that says the ways of constructing a list of choices (assembly) are more similar to one another than to ways of eliminating patterns from a list. Extension of design into judgmental and simulation testing provides no terminological distinction between the two analytical processes.

Several points from the preceding discussion bear repeating before design methods are presented. Scientific pattern-development and extension may accelerate, shorten, or augment in wholly new ways the natural process of farmers' own experimentation and adoption. But adoption by farmers must be the final stage. The acceptability criteria which patterns must eventually meet, therefore, are the same regardless of how the patterns are assembled, tested, or communicated to farmers. If perfectly elucidated, the acceptability criteria applied in a scientific development of a pattern would precisely resemble those a farmer would use in choosing a cropping pattern.

Information on the availability of farm resources and the benefits farmers see in present patterns go into the design, testing, and introduction of new cropping patterns. Completeness and accuracy of that information strongly influence the effectiveness of subsequent research. More effort (cost) spent on observation and description can mean less effort spent on design, testing, and introduction.

Likewise, more effort on design can reduce the effort needed to test new cropping patterns. A designer might deliver a long list of all of the feasible crop combinations that are likely to show profit; it would surely include a far greater proportion of patterns that would show loss. Such a list would probably necessitate long testing (not to mention significant expense, which must also be considered). On the other hand, a designer might deliver a list made up exclusively of profitable patterns, few enough to be quickly tested; the danger then would be that many profitable patterns had been missed.

The benefits of a particular design process can be judged in roughly the

[3] The steps being outlined here are for a simple, general methodology. While proposing that gains from judgmental or quantitative simulation of profit patterns prior to field testing are low, it is not denied that such techniques may he warranted when scientists have extraordinary judgmental insight, or where costs for quantitative simulation are particularly low, or where the objectives of research are broader than developing suitable patterns for a given site.

same manner as the profitability of a new pattern. To compare design techniques, the costs of the research process must be subtracted from the margin of increased production. A design process leading to patterns that give a high margin of production and wide adoption can reduce the cost of testing.

In the following two sections, certain design methods are suggested.

ECONOMIC CRITERIA FOR SELECTING COMPONENTS OF NEW CROPPING PATTERNS

The set of possible pattern components is selected through the following steps:

a) Define the existing set of pattern components (the descriptive phase of research).

b) Assess the potential impact on food production of new combinations of elements in the present set.

c) If the potential impact on food production of recombinations of the present set appears to be satisfactory, proceed with design. If not, select additional components in the following additional steps.

d) Prepare a schedule of augmented sets of components together with costs of making the new components feasible choices.

e) Obtain commitment of policymakers to intervene in the economy as necessary to introduce one of the augmented sets.

f) Or choose an augmented set of components from which production-increasing patterns can be assembled; the set must be one that is likely to be supported by policymakers and accepted by farmers.

Since the objective at the International Rice Research Institute is to exploit those characteristics of new rice technology which can increase food production through crop intensification, a normal part of our approach is to augment the existing set of component choices with new rice technology that is suited to crop intensification. New components for one site may already exist at a different site. The set of possible components may consist of: (a) crops and techniques currently used by farmers in an area, (b) new crops and techniques resulting from scientific research, or (c) crops and techniques translocated from other areas.

Assessment of the potential impact of new combinations of the existing set of crops and techniques is a methodological problem with strong influence on the overall design process. Elsewhere I have said that productivity of patterns can be only very imprecisely estimated in advance of cropping pattern field trials because the effect of interactions between crops can be determined only by observation. Experience may suggest some of the favorable interactions that can be exploited in new patterns, but the possibility of unknown favorable interactions must also be considered. Food-increasing interactions can be assumed to occur randomly among all possible untried combinations. Therefore, the possibility of increasing food production through discovery of new favorable interactions between currently grown crops is directly related to the number of new and different ways that the crops can be juxtaposed in time and space. Adequacy of the present set of crops and techniques can therefore be judged partly by the number of untested intercrop, relay-crop, sequential-crop patterns, and other combinations that can be formed from it.

If farmers or scientists are already aware of a large number of favorable crop combinations in the existing set, then the chance of new discoveries is small. If the existing set has been available for a long time, the natural process of farmer experimentation and adoption may have largely completed the design process. If so, the favorable combinations remaining to be discovered are few, and the production gains to be realized from discovery are low. Opportunity for increased productivity then resides mainly in augmented sets of cropping pattern components.

The construction of a schedule of augmented sets of cropping pattern components is closely related to tasks in the descriptive phase of research. The schedule calls for a study of commodity demand, input supplies, farmers' skills, and other factors. Augmented sets of components may be chosen for the schedule according to the level and cost of intervention. (Table 1).

Costs of introduction may be predictable, but only very general assessments of the returns to new crops can be made. Cropping systems research in the Philippines is dotted with cases of new crops that have performed poorly as did early mung beans in Batangas pattern trials (Garrity et al. 1975), or spectacularly well, as did IR28 and IR30 in Iloilo (Palada, 1976).

Table 1. Schedule of cropping pattern component sets and their respective costs of introduction

Sets of added components for new patterns			
Crops	Techniques	Required change in economic environment	Public cost
IR30	Direct-seeding, drying	Early credit	50
Sorghum	Threshing	Threshers, seed suppliers	100
Soybeans		Exporter, transport	
Sorghum	Threshing	Threshers, seed suppliers	300
Water chestnuts	Culture, cleaning	Cannery. exporter	1000

On the other hand, necessary infrastructural changes have been relatively easy to predict. The need for sorghum threshing facilities in Batangas is a case in point (Nicolas et al., 1976).

Adequately considering the possible need for institutional changes, while selecting potential cropping pattern components can reduce waste in the research effort, and speed the introduction of new patterns. If certain types of intervention in the economy cannot be undertaken by government, the crops requiring such intervention need not be included among potential components. If policymakers are unwilling to commit the government to certain interventions without clear knowledge of the production gains—which can only be known after field tests—then researchers must assess the probable production gains as well as the probable attitude of policymakers toward intervention.

New patterns can be introduced faster when national agencies have been alerted to the kinds of institutional changes that the patterns may make necessary. Introduction is especially facilitated if exact configurations and operational requirements of new institutions, say, credit facilities, interest rates, or market margins, are foreseen at the time new pattern-development begins.

ASSEMBLY OF PATTERNS

The principal economic criterion suggested here for cropping pattern design is ability to stabilize the flow of inputs into the farm enterprise. Costs per unit of product can be reduced by higher use of inputs when they might be idle (and cheap) and reducing peaks of need (when they tend to become dear). Slack inputs (such as unused family labor, inactive machinery, and idle financial resources) can be considered to cost the farmer only the highest return they would bring from off-farm employment, less the cost of finding and holding that employment. Avoiding sharp peaks in the need for labor can mean hiring less outside labor, which usually costs more than family labor, considering the cost of finding, instructing, and supervising such labor. Reducing the peaks in credit needs can mean using less off-farm financing, which usually costs more than internal financing. The extra cost of off-farm financing is the cost of finding a loan, plus the interest paid on the borrowed money, minus interest that would be received on the same amount of money if put into savings.

The cost of fixed inputs (such as land and buildings) also can be lowered by stabilizing the use of variable resources, if production fluctuations decline along with input fluctuations. Suppose, for example, that a farm produces 100 units in 5 months and none in the other months. With more stable input and output, it might produce the same 100 units in 10 months, without using its fixed factors to capacity. The excess fixed factors could be liquidated, or used to expand total production. The cost of fixed factors per unit of product would be less.

It is assumed that new patterns will be introduced into an existing system that is composed of several cropping patterns. The existing system may be considered to comprise the patterns of an area containing many farms or the patterns of a single farm. If labor is highly mobile within an area, and the labor constraint facing a single farmer cannot be differentiated from that facing all farmers in the area, then the new patterns should consider the labor constraint in the larger environment. If farmers borrow freely from one another, it is the aggregate cropping system which should be considered. If, on the other hand, farms seldom provide labor or credit to other farms, the dominant crop system found on individual farms may be the more appropriate focus of designers.

The choice between design for farm-level or village-level systems is demonstrated in Manaoag, Pangasinan, where, as at all cropping systems research sites in the Philippines, labor is hired between neighboring farms. A farm family easily finds occasional work on other farms, and the weekly availability of labor is strongly influenced by the various patterns on all farms. It makes sense in Manaoag to design patterns suited to the levels of resource use and utilization in the larger environment. In doing so, the competing resource demands of more than 60 different patterns must be considered.

Among the 60 patterns, the dominant combination found on individual farms is a two-pattern system, rice-mung and rice-fallow. If in Manaoag labor were not a shared resource, then new patterns would need to be designed for introduction into this simpler system. In any case, the objective of the technique discussed here is to reduce variations in labor use in the area or on the farm through appropriate design of new patterns.

Initially, each pattern in an existing system, its weekly labor requirements and the proportion of land allocated to it are identified (Table 2). One pattern, called the "outgoing pattern," is selected as that most suitable for replacement. Patterns that reduce labor variance are then assembled. Alternatively, we sometimes assume that a new pattern would replace an identical proportion of all existing patterns, and thus do not have to identify every pattern in the existing system. I have never found such a pattern which could reduce labor variance.

As an initial step, the total labor use and variance of labor use over 52 weeks in the present cropping system are computed. (In Table 2, only 7 weeks are shown as an example.)

Table 2. Example of computation of variance of weekly labor use in existing system and system revised by 10 percent reallocation of labor from old pattern to new cropping pattern.

Weeks	Existing system labor requirement: Pattern A (h)	Pattern B[a] (h)	Pattern C (h)	Total (h)	Labor requirement of outgoing pattern (%)	Labor subtracted from existing system (h)	Labor requirement of new pattern: Amount (h)	%	Labor added to existing system (h)	Revised system total labor (h)
1	2	3	4	5	6	7	8	9	10	11
1	10	25	5	40	36	5	0	0	0	35
2	11	10	2	23	14	2	0	0	0	21
3	10	5	0	15	7	1	16	29	4	18
4	9	0	0	9	0	0	24	43	6	15
5	10	0	3	13	0	0	12	21	3	16
6	0	25	2	27	36	5	0	0	0	22
7	0	5	8	13	7	1	4	7	1	13
7-week total[b]	50	70	20	140	100	14[c]	56	100	14[c]	140
Variance				117						54

[a] Outgoing pattern. [b] Example shown for 7 weeks but normally 52 weeks would be used. [c] 10 percent of total labor in existing system.

Labor requirements may be expressed in various ways: as a total per week for a sample of farms, as an average per farm, or as an average per hectare. A level of adoption of the new pattern is assumed; 5, 10, or 15% say, of total current labor employment is assumed to be reallocated to the new pattern. To simulate 10% replacement of the outgoing pattern by a new pattern, the first 10% of all labor in the system is subtracted according to the weekly distribution of labor in the outgoing pattern (See columns 6 and 7, Table 2).

The same amount of labor is then added back to the system according to the weekly distribution of labor requirements in the new pattern. (See columns 9 and 10.)

To produce a design, the designer selects, for example, "early direct-seeded, early-maturing rice, under usual farmer management." Then he joins it with a crop that can feasibly be planted in the remainder of the crop year. Labor which was first removed from the existing system is then added back, but it is distributed according to the requirements of the new crop combination, and labor variance of the system is recomputed. New patterns which reduce the variance can then be field tested.

I have evaluated new patterns by examining variance of labor use at levels of adoption ranging from 0 to 100% at 5% intervals. With such a procedure one can examine (a) the rate at which labor variance in the system changes as new patterns are introduced, (b) the minimum level the variance reaches, and (c) the degree of adoption at which the minimum is attained. One might choose a pattern which reduces variance less than do other patterns but has more impact at low levels of adoption. Table 3 shows the results of recent tests of new patterns and demonstrates the way the procedure can be used for designing new patterns or system.

Patterns designed to reduce labor variance may subsequently be tested for their reduction of cash-flow variance, or the variance of other inputs. But the question of profitability remains a separate matter. Reduction of input variance, I have said, contributes to profit, particularly if the profitability measure adjusts for a cost differential between owned and hired inputs.

It is also likely that a reduction-of-variance strategy increases acceptability of patterns in ways that are not reflected in the usual measures of profit. Considering the cost of locating inputs for purchase and finding markets for products, each level of variance in input may be associated with a different level of input costs per unit, which cannot be easily reflected in cost and returns analysis. Also, stabilization of input flows may provide psychic returns that cannot be quantified.

The technique that has been described here for pattern design and

Table 3. Labor variance in cropping systems in relation to adoption of new patterns.

Labor in total system allocated to new pattern (%)	Weekly labor variance in old system expressed as a percentage of variance in revised system						
	Rice-soybeans	Rice-mung	Rice-cowpeas	Rice-sorghum	Rice-SP[a] + corn	Rice-SP	Rice-corn
0	100	100	100	100	100	100	100
5	105	110	110	110	108	115	104
10	108	120	119	119	115	130	105
15	108	130	126	126	122	142	103
20	105	139	131	131	126	148	100
25	100	145	132	133	130	146	94
30	93	150	130	131	130	138	88
35	85	150	124	126	129	125	80
40	76	148	116	119	126	110	73
50	61	135	97	100	114	82	59
60	48	116	78	80	98	59	47
70	38	96	62	64	83	44	38
100	21	52	32	33	48	20	21

[a] SP = sweet potato.

testing can be used in constructing hypothetical new systems. Choosing one pattern as a base, we may construct low-variance combinations of patterns in much the same way that we added different crops to systems in the above assembly of variance-reducing patterns.

Finally, we might test the hypothesis that an objective of farmers is to construct low-input-variance cropping systems. We could build hypothetical systems from the patterns being used in an area, and observe how closely the farmers' arrangements of patterns matched those in the lowest-variance versions of the hypothetical systems.

SUMMARY

I have attempted to show that the design phase of cropping systems research is distinguished from the testing phase by the fact that in design we must identify feasible patterns from an unknown universe of all possible crop combinations. Design is a creative activity. Testing, on the other hand, is screening a known population to find economically viable patterns. It is a selection activity.

A central proposition of multiple cropping research is that the productivity of different cultivars which are adjacent in time or space is different from that of the same plants in monoculture. We seek by scientific design and testing to capture the gains made possible by favorable interactions between adjacent crops. Since design creates novel crop combinations, the designer may treat crop interactions which increase production largely as random events. Design therefore cannot easily capture the productivity gains of crop interactions. The strength of design lies in its examination of the cost side of the profit formula. I argue that the best designing is that which takes resource utilization into account.

Selection of techniques and crops for possible inclusion in new patterns is the first step in design, and should take into account new infrastructural requirements. Policymakers should be consulted early in the design process so that the likelihood that needed infrastructure such as markets will be available can be considered as pattern components are chosen.

Stabilization of the rate of farm-input use is the appropriate measure of resource utilization for cropping pattern design. It can, I think, reduce input costs and increase satisfaction from farming. It also may result in the identification of a population of cropping patterns which, when developed, will result in maximum increase in food production for the effort expended in research.

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DISCUSSION

ZANDSTRA: (1) I wish to challenge the premise that given an adequate site description, researchers cannot arrive at reasonable estimates of performance of crops (including intercrops). The knowledge of crop adaptation and crop interactions in intercrops and relay cropping is sufficient to allow an estimate of productivity that will greatly aid in sorting out unacceptable combinations. (2) In addition, resource-input levels are a function of productivity and are very poorly defined without productivity estimates.

Price: (1) I do not argue that researchers cannot give reasonable estimates of performance of new intercrops. However, I think that an attempt to incorporate into design a prediction of the effect on yield of combining a number of crops in a pattern that has previously not been observed, is not practical for two reasons: a) Methodology for predicting yields of new, untested intercrops is beyond the scope of field-level research for which my proposed procedures are intended. b) The effort required for generating and incorporating into a profitability estimate information that goes beyond that already used for component selection is more than the gain. (2) Resources requirements are set largely by the management practices planned at the time of design. However, it is true that part of the actual resource use (for example, harvest requirements) will vary according to the actual level of production. But the percentage variation in costs caused by variation in production is less than the percentage variation in production itself. Therefore, I think one can still say costs are more predictable at the time of design than is the value of product.

HERDT: If you discard productivity (yield and price) from the criteria for the design stage and base all decisions on cost, you may direct your attention to low-cost, low-productivity crops.

Price: One *may* design low-cost, low-productivity systems, it is true; but that depends upon how one selects components during the first step of design and what cost criteria one uses and exactly how they are applied. I don't think our proposed method does this because in the first step of design we have selected pattern-components that, based on their presence in existing systems, promise to give acceptable levels of production.

Assembly of those components is then executed with a cost-reducing procedure. In effect, the first design-step is to assure production, and the second step is to reduce costs. The thrust of my argument is that the steps are best separated at the stage of design for practical reasons. Only at the subsequent testing stage can costs and production be usefully combined in the single criterion-profit.

HARWOOD: (1) I believe that you are placing too much emphasis on crop interaction in the design stage. In *most* patterns there are few biological interactions between crops. Interactions are economic (competition for resources). Legume-legume sequences are an exception, but we have avoided using them, and farmers don't use them either. (2) Intercrop combinations should be treated economically as *one crop* or one enterprise. In the design stage you should not separate the individual crops of a mixture. Don't overly complicate design by unnecessarily stressing interactions. They are *not* central to multiple cropping practices.

Price: (1) If interactions are not important in crop sequences, it may still be reasonable for field researchers to design patterns as I have suggested, simply to reduce computational requirements. But the limitations on knowledge which I have indicated as reasons for using the cost approach to assembly would clearly no longer apply. (2) I fully agree that intercrops should be treated as one crop after their combined value-product is known. However, before a new intercrop pattern is field-tested, and its value-product thereby learned, the economic analysis at the design stage would seem subject to the knowledge constraints I have mentioned, and the separable production/cost procedure I have suggested therefore should be followed.

KRANTZ: Before suggesting a new crop to the policymakers, would it not be helpful to do some "market-development research" in the area or country concerned?

Price: Yes, research into markets is required before policymakers are approached. Ideally, policy makers would be shown a full range of choices regarding market development, credit arrangement, and other infrastructural features.

A. GOMEZ: You have argued that profitability is a good basis for designing cropping patterns, but in the end you substituted cost or "resource allocation" for profitability. The two are quite different.

Price: That's right; production, cost, and profit are all different, and the last incorporates the other two. But my argument is not quite as you present it. While stating that greater profitability is the goal of design, I argue that the criterion cannot practically be applied at the design stage. Rather it is applied in parts: first, production is considered when components are selected, then costs are considered when components are assembled. This completes the design stage. Then at the testing stage, profitability as a single unified criterion is applied.

NURJADI: Assume a certain area in a particular agroclimatic zone—say 1,000 ha with 2,000 farmers. Suppose we introduce an improved cropping pattern which is technically and economically feasible. If some of the farmers adopt the improved cropping system, the result is still economically feasible, but if all 2,000 farmers do the same, that improved cropping system becomes uneconomical due to decrease of the price of the products. The question is whether a single farmer family or a whole area should be economically considered in order to meet the goal and farmer's need.

Price: The problem you mention is a serious one. We have taken the view that we cannot design patterns for their long-term impact, but let farmers make their own adjustments to the conditions that develop. On the other hand, we do avoid crops such as vegetables for which the planning horizon is very short. We are not very rigorous in such demand-analysis. One point is that even if the prices for a crop fall as more people grow it, at least we have introduced more flexibility into the system by giving farmers more choices.

NORMAN: When you calculate the percentage of total labor by week relative to peak-labor week, is the peak-labor week reference that for the cropping pattern under consideration, or is it for the farming system as a whole, including nonfarm activities, or for the cropping system only, If the latter, would not using the former be of value.

Price: The labor of the cropping system alone was used but, as you suggest, labor use in the farming system as a whole would be more appropriate. This is simply one aspect of the focus of our overall program, in which cropping systems are the main subject of study.

HOQUE: (1) If you recognize interaction between resource-use and productivity, which is quite likely to exist, how can you exclude productivity criteria for the design? (2) Agronomists tend to consider productivity as one of the major criteria for design; how do you tackle this conflict between yourself and the agronomist at the design phase?

Price: (1) The design process I suggest assumes that the only technological question under investigation is the economic viability of a crop combination, given that a set of recommended crop-management practices are followed in executing the pattern. That conforms to the IRRI field-research approach in which the economic analysis is restricted to pattern trials, and is generally *not* applied to tests of component technology, referred to as "superimposed trials." It means that crop-production responses to input-applications are generally not the principal subject of multiple cropping research. Resource-productivity interactions are assumed to have been largely taken care of already when recommended practices were selected based on monoculture research by other scientists.

The remaining resource-productivity interactions that are not considered are those which relate uniquely to multiple cropping regimes, and those, I have argued, are not sufficiently predictable on the production side to warrant consideration at the design phase as criteria for assembling new patterns. I say "on the production side" to emphasize that changes in input requirements (in contrast to yield) that result from switching from monoculture to a multiple-crop pattern can be planned. One can plan, for example, the deletion of a weeding operation, because one anticipates that weed growth should diminish during a preceding crop. (2) There is no conflict in the cases in which agronomists consider production as a basis for recommending practices for crops in a pattern on the basis of monoculture crop response. The implied conflict comes when the agronomist changes from recommending a practice for a given crop that is best under monocultural conditions to another practice that he thinks best, based on yield considerations, in a multiple cropping regime. Certainly the agronomist must make such judgments at the design phase, However, my point is that it is not practical for the economist at the design stage to apply a profitability test—on the basis of yield prediction—to the switch in practices. That is, he cannot apply it to the trade-off between the changing resource cost and the change in crop yield. This kind of economic information is more efficiently obtained later, at the time of field testing.

JODHA (comment): In my view, managing of "cost criteria" for testing new cropping patterns is quite difficult. That is because the term "cost" itself may have different meanings for researchers and farmers. Secondly, cost of a given pattern may change with the degree of complementarity it may have with other enterprises such as dairying.

Testing of cropping patterns

INTRODUCTION

M.Z. Hoque

The systems approach is gaining prominence in Asia for developing cropping patterns that utilize available farm resources more efficiently, and is gradually replacing the traditional single-crop-oriented research approach found at experiment stations. An integral part of this systems approach is testing and evaluating the performance of potential cropping patterns in the specific agroecological areas for which the patterns are designed. To determine their fit and viability within the farming system involved, as well as to ensure a better chance of acceptance by the farmers, potential cropping patterns are tested before they are entered into a production program.

The subject of cropping pattern testing has been dealt with quite elaborately at the third Cropping Systems Working Group meeting at Bangkok. This paper will briefly discuss the different aspects of such testing.

OBJECTIVES OF CROPPING PATTERN TESTING

A potential cropping pattern is tested to evaluate its agronomic performance, biological stability, land-use efficiency, resource and management requirements, and economic profitability.

The results of testing are eventually used in production programs or promotional activities and, therefore, become important in the

1. evaluation and modification of cropping patterns existing within a particular production complex,
2. determination of the potential of newly designed cropping patterns, and,
3. agroeconomic comparison of a set of alternative cropping patterns which can guide the farmers in making their choices.

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CRITERIA FOR TESTING CROPPING PATTERNS

Test criteria that are considered necessary to determine the performance of a cropping pattern include (1) agronomic productivity, (2) biological stability, (3) land-use efficiency, (4) resource requirements, (5) management requirements, and (6) economic profitability.

Agronomic productivity means the economic yield of the crops in a pattern. Accurate estimates of agronomic productivity can be obtained from crop cuts, using appropriate sampling procedures. That particular criterion should enable the research scientist to predict the production potential of the cropping pattern.

Several factors determine the biological stability of a cropping pattern. They include the effect of the cropping pattern on soil fertility, soil erosion or soil conservation, the changes in weed population, and the occurrence of insects and pests. It is very difficult to obtain reliable estimates of those factors and, consequently, to determine the biological stability of a cropping pattern without a testing program over a period of time. As researchers' time is generally limited, estimates of the biological stability of cropping patterns have to be obtained from general observations over several seasons.

Efficiency of land use ordinarily means the days of the year the land is utilized by the cropping pattern, as well as production per day of a land unit.

The resource and management requirements of a cropping pattern may be defined as that amount of resource allocation and management which exhibits the cropping pattern's maximum potential for economic profit. Under farmers' conditions, the determination of resource requirements is influenced by the availability of resources and also by the resource conflicts that may be brought about by the cropping pattern being tested.

The determination of economic profitability requires measurements of productivity, product prices, material and labor inputs, and the costs of inputs.

THE TEST ENVIRONMENT

Cropping patterns can be tested in any of the following environments: (1) research station, (2) research station simulating farmer's management, (3) farmer's field managed by the researcher, or (4) farmer's field under farmer's management.

The choice of test environment will depend on the immediate objectives of the researcher and the physical facilities at his disposal. The test environment, in turn, will influence the testing methodology and the measurements to be taken.

Testing cropping patterns at the research station enables the researcher to have considerable control over the testing process, but the environment does not provide a reasonable estimate of the performance of a cropping pattern in a farming system. Testing the pattern at a research station simulating farming situations may increase the reliability of the estimate of the pattern‘s performance on the farm but, again, the outcome will depend on the success of the researcher in the simulation act.

Testing cropping patterns on the farmer’s field managed by the researcher, on the other hand, appears to have advantages. The test environment provides considerable degree of control and more reliable estimates of the pattern’s performance on the farm; it enables the researcher to observe the effects of different site-variables on the pattern’s performance. Further, it can give an estimate of the pattern’s potential performance in a production complex with no constraints on the farmers.

Testing cropping patterns in the farmer’s field under his own management does not provide full control over the testing method, but it allows the researcher to study the pattern’s performance in different locations at varying levels of management and input. By accurately recording the farmer’s operations and input use in the test environment, the researcher can better understand the effect of the interaction of different factors in the farming system on the performance of the cropping pattern.

EXPERIMENTAL DESIGNS FOR CROPPING PATTERN TESTING

The experimental designs for testing cropping patterns will depend on the test environment and, to some extent, on the cropping pattern design and the measurements to be taken. However, the following designs can generally be used in evaluating the performance of a cropping pattern: (1) replicated small plot trials, (2) replicated large plot trials, and (3) production plot trials with replicates in different fields.

Replicated trials with small plots can be conducted at experiment stations and in farmers’ fields. They can provide accurate information on the agronomic performance of the pattern and the effect of site-variables on the pattern’s performance. However, it is difficult to have too many experimental units in the farmer’s field. Thus replicated trials on larger plots are needed when data on input requirements, farmer’s reaction to a cropping pattern, and the effect of special treatments such as tractors are to be collected. In most cases, replicated trials with larger plots in the farmer’s fields are not a problem if only a single cropping pattern is to be tested.

Valuable information on the performance and input requirements of a cropping pattern can be obtained by testing it in a production plot under farmer's management. To make the information statistically reliable, replicates will have to be placed in more or less similar production complexes. In production plots, superimposed treatments can be used without interfering with farmer's management, and new cropping patterns, with or without additional management requirements, thus can be tested.

CONSIDERATIONS FOR AN EFFICIENT TESTING PROGRAM

Success in modifying or developing a cropping pattern depends on the accuracy with which the cropping pattern's performance is tested, and on the success of the testing process itself. Several factors affect the success of the testing process. Some that merit consideration follow.

1. There should be a strong linkage between the design phase and the testing phase.
2. The pattern should preferably be tested in the agroecological environment for which it is intended or, at least, in a similar agroecological environment.
3. Appropriate experimental design should be used to meet the objectives and test criteria.
4. In work in a farmer's fields, clear understanding between the researcher and the farmer should be developed and maintained during the entire period of testing.

TESTING CROPPING PATTERNS FOR ASIAN RICE FARMS

Vast areas of the Southeast Asian countries are under rainfed and upland conditions. To increase total production in this region, immediate attention must be given to the improvement of cropping patterns under such conditions. However, cropping patterns will also have to be tested and developed for the more highly productive, irrigated areas to maximize crop production in the region.

Scientists have different opinions on the various aspects of cropping pattern testing in farmers' fields. Although the process is generally complicated, cropping pattern testing in farmers' fields has definite advantages, especially with regard to the quick generation of information necessary for urgent production programs.

In this session on "Testing of Cropping Patterns," we will present and discuss the results of cropping pattern testing under rainfed and upland conditions in Southeast Asia, and the methodologies for cropping pattern testing in farmers' fields.

TESTING CROPPING PATTERNS FOR RAINFED RICE AREAS

D. Chandrapanya

To be grown successfully in an area, crops must be modified to overcome agronomic and economic constraints and to fit into the agroclimatic and economic conditions of the particular area. Production inputs and their availability, and value of the crops and their marketability have to be considered. But limitations exist, especially when small farmers whose production resources are scarce or unobtainable are involved. Other natural conditions, such as the unproductivity of the soil or the unpredictability of rainfall, also lead to difficult decision making. However, through systematic research, means may be found to help small farmers to better their living conditions.

In this paper, the term "rainfed rice" refers to rice grown in lowland, bunded areas of Northeast Thailand which are entirely dependent on natural rainfall for crop production during the monsoon season. It occupies an area of about 2.5 M ha. In contrast to it are much of the floating rice of the Central Plain, which is rainfed for the first several months after seeding until floodwaters rise, and upland rice, which is generally grown on hillsides without standing water throughout the growing period. For the rainfed, lowland, bunded areas, the soil may vary from dry to moist for as much as 4 months, and high rainfall sometimes causes flooding.

The average cash income per household for the agricultural sector in Northeast Thailand is the lowest in the country—about US$105 in 1970 (Agricultural Statistics of Thailand, 1974). The soils of the Northeast in general are sandy, have low water-retention capacity, and are poor in essentially all major nutrients (Table 1). Erratic monsoon rainfall aggravates the difficult task of crop growing. At present, most subsist on a single

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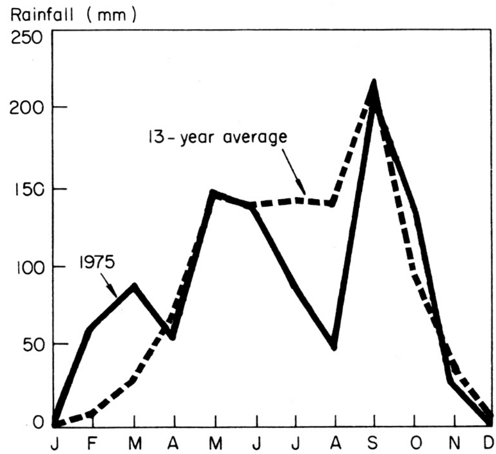
Table 1. Chemical analysis of soil types in farmers' fields in Thailand, 1972–74.[a]

Soil series	Location	pH	O.M. (%)	P (ppm)	K^+ (ppm)	Total N[b] (%)	Avail-able (ppm)	Ca^{++} (meq/100 g)	Mg^{++} (meq/100 g)	Na^+ (ppm)	Fe^{++} (ppm)	Al^{+++} (ppm)	Mn^{++} (ppm)	SO_4–S (ppm)	Cl^- (ppm)	CEC (meq/100 g)	EC (1 : 5) (mmho/cm)
Roi Et (Re)	Yasothon & Roi Et	4.6	0.71	4.6	14.3	0.04	126.3	0.72	0.26	106.5	42.8	70.0	3.2	6.7	34.6	2.4	0.1 08
Roi Et (Re)	Surin	4.8	0.69	2.2	17.1	0.03	105.9	1.28	0.29	69.0	38.0	59.6	18.7	1.7	Trace	4.1	0.031
Ubon (Ub)	Ubon & Roi Et	4.6	0.35	2.5	11.6	0.02	46.0	0.06	0.05	87.5	22.0	7.6	1.0	7.5	5.3	0.82	0.097
Northeastern region average		4.7	0.58	3.1	14.3	0.03	92.7	0.69	0.20	87.7	34.3	45.7	7.6	5.3	Trace to 20.0	2.4	0.079

[a]Source: Agricultural Chemistry Division, Department of Agriculture. Bangkok, Thailand. [b]% Total N = $\frac{\%O.M.}{20}$

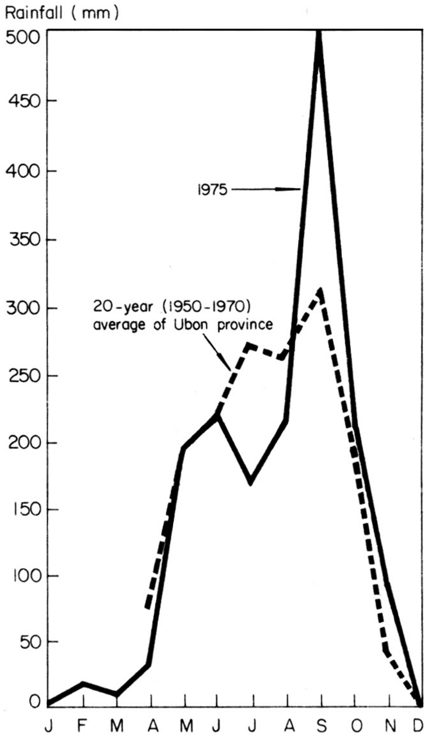


1. Monthly rainfall at Pimai Rice Experiment Station, Thailand.

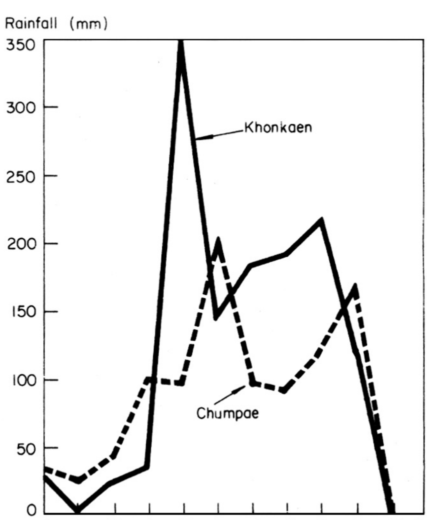
crop of rice which yields an average of 1.2 t/ha. The application of fertilizer, even at modest rates, is expensive compared to the price of paddy (cost of 1 kg of 16–20–0 fertilizer equals cost of 2 kg of paddy). Unfortunately, a great number of small farmers cannot afford to use fertilizer because of their limited cash inputs and the existing bureaucratic credit institutions. Moreover, the uncertainty of rainfall makes fertilizer application risky. Large numbers of farmers use manure and compost, but yields are not increased significantly.

One of the major environmental factors that limit grain yield is rainfall distribution. (Some of the rainfall data are presented in Fig. 1–4.) In 1974 and 1976, widespread drought occurred throughout the Northeast during the early monsoon season and delayed planting until near the end of the monsoon. The probability of getting good rain in a given year is 60%: in 3 of every 10 years, long, damaging drought periods can be expected, especially within the southernmost part of the region. Irrigation facilities are negligible. Soil moisture during the early monsoon season, which starts in April, is frequently not enough for transplanting the rice crop. Transplanting in some years may be near the end of the monsoon (as late as September); because of the short growing season, yields are low. Farmers plant photoperiod-sensitive types whose seedlings may be as much as 90 days old before transplanting. Rainfall distribution in the rainfed Northeast indicates two major patterns:

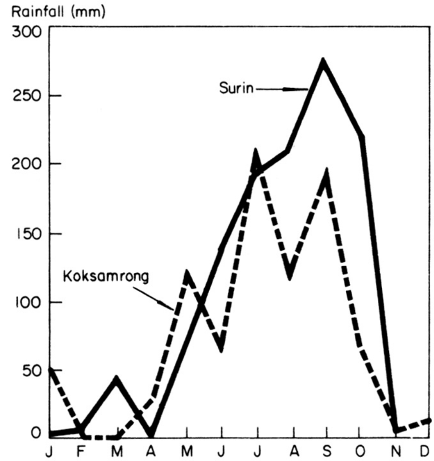
The Pimai area in the lower part of the Northeast is representative of one type of rainfed-rice area. The monsoon rainfall increases its intensity



2. Monthly rainfall at Ubon Rice Experiment Station, Thailand.



3. Monthly rainfall in 1975 at Chumpae and Khonkaen Rice Experiment Stations, Thailand.



4. Monthly rainfall in 1975 at Koksamrong and Surin Rice Experiment Stations, Thailand.

in late April and continues until November, with 2- to 3-week drought periods in early to mid-season. The probability of early-season drought periods is about 30%. Precipitation occurs in a characteristic bimodal pattern associated with the movement of the intertropical convergence zone.

The Ubon area in the upper eastern part of the Northeast represents areas which experience late drought periods at the end of the monsoon season. The probability of late seasonal drought at panicle formation, heading, and flowering of the rice crop is high. Quite often, monsoon rains end suddenly, leading to an insufficient amount of water for the maturation of the rice crop. In contrast to the Pimai area, the Ubon area has early season rains that are dependable in amount and regularity.

Experimental results suggest that to alleviate the problem in the Pimai-type area of insufficient moisture for transplanting, early direct-seeding methods may be useful. By dibbling the right varieties of rice seed into moist soil from the middle of June to the middle of July, it is possible to establish a rice crop which can withstand extended drought periods and produce reasonable yield (Table 2).

The data suggest that varieties play an important role under the alternating wet and dry conditions of fields at the experiment stations. The yields are also somewhat better than average for farmers in the Northeast, although that may be due partly to better conditions at the experiment stations. However, many problems are associated with the direct-seeded methods. They include small rats, mealy bugs, a kind of earthworm, other

Table 2. Yield of varieties and experimental lines (t/ha) after dibble planting (direct seeding) in June at 4 locations in Northeast Thailand, 1975 wet season.

Variety or line	Chumpae	Khonkaen	Pimai[a]	Surin	Average
Niew San Patong	2.3	1.6	0.6	2.1	1.65
Khao Dawk Mali 105	2.7	1.3	0.9	1.3	1.55
RD4	3.0	–	0.4	1.0	1.10
RD5	1.8	1.4	0.6	1.8	1.40
SPT 6012-134	3.5	1.2	1.4	2.2	2.07
KDML'65-G_2 U-68-254	1.9	1.6	1.6	1.7	1.70
KDML'65-G_1 U-45	1.9	1.5	1.3	1.7	1.60
MN 62'64-G_1 U-73	1.8	1.4	0.9	1.9	1.50
Av.	2.36	1.25	0.96	1.71	

[a]Low yields due to attack by mealy bugs.

insects, and weeds, especially during the submerged stage of plant growth. Those direct-seeding methods represented the first research work with the rainfed lowland paddy fields in the Northeast.

From the viewpoint of cropping systems research that includes upland crops with rice, it is possible to develop a program for rainfed lowland rice-field conditions by utilizing existing natural resources (rainfall, soil, and so on) and available production inputs. Such a system must use a simultaneous approach integrating different disciplines to cover the biological and economic aspects. Some recent agronomic research results in the Northeast are worth mention. The 1975 annual report of Khonkaen University shows that it is pursuing programs involving breeding, crop production, protection, and soil science with three crops—sorghum, soybeans and peanuts. The main emphasis is on cropping systems applicable to rainfed upland conditions. Some interesting research results were obtained from date-of-planting experiments. Planting sorghum during the rainy season between May 1 and October 1 at 15-day intervals increased yields as planting time was delayed. The highest yield was obtained from the August 1 planting. After that planting date, yields dropped markedly. On the other hand, soybeans and peanuts produced poor yields with all planting dates. Peanuts germinated poorly, and the soybeans were not inoculated with *Rhizobium* bacteria. Problems with stand establishment of the crops and soil heterogeneity prevented complete analysis of the results. However, sorghum appeared to be promising.

The Northeast Agricultural Center's 1974 annual report (1975) showed that mung-bean varieties MG-55-3 and MG-50-10A produced the highest yields (1.6 t/ha and 2.1 t/ha, respectively) in regional varietal trials at Pimai. Nine locations in the Northeast were involved in the trials, but Pimai was the most reliable. Six peanut varieties were also tested at nine

Table 3. Yield (t/ha) of eight rice varieties and experimental lines grown in farmers' field tests by direct seeding methods at three locations, Thailand 1975 wet season.

Variety or line	Type	Dibbling method				Row seeding method			
		Kok-samrong	Pimai	Amnart Charoen	Av.	Kok-samrong	Pimai	Amnart Charoen	Av.
Khao Dawk Mali 105	N.G.[a]	2.075	2.700	2.131	2.300	2.875	3.181	2.394	2.819
Nam Sagui 19	N.G.	2.475	1.675	1.681	1.944	1.500	1.306	1.150	1.319
Niew San Patong	G.[b]	2.419	2.694	2.037	2.175	2.144	2.319	0.881	1.781
RD5	N.G.	2.131	3.400	2.044	2.525	2.375	2.887	1.687	2.319
SPT 6012-134	N.G.	2.894	2.562	1.462	2.306	1.694	2.319	1.700	1.906
KDML 65-G_1 U-45	N.G.	2.125	2.337	2.100	2.187	2.612	2.837	0.987	2.144
Khao Hao (Upland)	G.	1.694	0.306	1.050	1.019	1.931	0.206	0.906	1.012
Khao Muser (Upland)	N.G.	1.206	0.469	0.306	0.662	1.056	0.706	0.550	0.769
Av.	–	2.125	2.019	1.600	1.912	2.025	1.969	1.281	1.756

[a]N.G. = nonglutinous. [b]G = glutinous.

locations. Lonyun 6103 produced the highest average dry pod yield of 1.4 t/ha; Tainan 6 followed, with an average of 1.3 t/ha.

To maximize use of the rainfall in the Northeast, timely direct-seeding of rice or planting of other crops in the early monsoon season shows great promise. Rice grown after harvesting the first crops seems best for rainfed lowland paddy-field agriculture. A first crop of rice followed by legumes or other crops toward the end of the season is another possibility. Experiments with direct seeding of rice in farmers' fields in 1975 at three locations (Table 3) indicated varieties and lines (Khao Dawk Mali 105, RD5 and KDML' 65-G_1U-45) that could tolerate early drought and produce an average yield of 2.5 t/ha. Those varieties and lines, with timely direct seeding, can be fitted into the cropping patterns of the Northeast rainfed areas. It should be pointed out that two upland forms among the entries performed very poorly under lowland rainfed conditions.

Data from the Ubon Rice Experiment Station (Table 4) suggest that a double crop of rice during the rainy season can be achieved. It was found that NTU 504-2, a nonglutinous Taiwanese line, and PMI 6643-4-15, a glutinous line, both photoperiod-insensitive types, could produce grain yields of 3.8 and 2.8 t/ha, respectively, if direct seeded in May. After harvest of those first crops in August, the plots were prepared for transplanting photoperiod-sensitive types, namely, two local recommended varieties, NS 19 and HY 71, and the experimental line KDML 65-G_1U-45. The three produced grain yields of 2.9, 2.0 and 3.1 t/ha, respectively, when harvested in mid-November. With this method, the yields of the two crops for one monsoon season approached 6 t/ha.

In 1975, for the first time, the Rice Division initiated a study on double

Table 4. Yield performance of rice cultivars in the double rice cropping experiment under rainfed conditions, Ubon Rice Experiment Station, Thailand. 1975 wet season.

Cultivar[a]	Type	Maturity	Yield (t/ha)
PMI 6643-4-15	G.[b]	116	2.8
PMI 6646-3-2-17	N.G.[c]	126	3.2
SPT 6624-66-18	N.G.	126	3.0
NTU 504-2	N.G.	116	3.8
NTU 504-5	N.G.	116	2.7
RD69 NFU-G_2-5	N.G.	135	3.2
IR26	N.G.	135	2.8
NS 19	N.G.	Nov. 4[d]	2.9
HY71	G.	Nov. 4[d]	2.0
KDML'65-G_1U-45	N.G.	Nov. 10[d]	3.1

[a]The first seven cultivars on this list were planted as first crop; the last three were planted as second crop. [b]G = glutinous. [c]N.G. = nonglutinous. [d]Harvesting date.

cropping patterns for the lowland paddy field under rainfed conditions at four locations. The experiment was started in May during the early monsoon season. Experimental results from the two most reliable locations are shown in Table 5. All rice plantings were direct seeded except the second rice crop in patterns 1, 2, and 4. All rice yield results indicated reasonable production except in the first crop of patterns 1 and 2 at Pimai, which experienced severe drought stress during the early growth stages. The second crop of rice in patterns 1 and 2 failed at both locations because of extremely late planting of a strongly photoperiod-sensitive variety. Mung beans planted before rice showed promise of being in the right pattern for both locations, even though the yields were low compared to the national average of about 1 t/ha. Mung beans after rice were essentially a failure because of late planting. Proper management of the crop in rainfed lowland paddy fields must be further studied if better yields are to be achieved. Such factors as lack of native *Rhizobium* bacteria in the soil have to be considered. Nevertheless, the growing of early maturing crops before rice in this agroclimate has considerable potential. The yields of grain legumes and sesame after rice were very low because of insufficient moisture and poor germination due to delayed planting after the monsoon rains ceased. That suggests that timing of the second crop is critical. More research is needed on selection of the second crop and on its planting date. It appears that such crops as sorghum and yam beans require more attention than others.

It should be noted that a cropping systems program in farmers' fields was started in the Northeast only in 1976. Nine farmer-cooperators were selected at the Pimai rainfed outreach site. Three plots were planted to

Table 5. Yield (t/ha) of eight cropping patterns planted under rainfed conditions in two experiment stations in Thailand, 1975 wet season.

Pattern[a]	Variety	Yield (t/ha)		Harvest date		Seeding date
		Koksamrong	Pimai	Koksamrong	Pimai	
1. Rice-rice	IR1561-288-3 and	3.4	0.619	Oct. 19	Oct. 27	*Koksamrong*
	KDML'65-G_1 U-45	–	–	–	–	*1st crop*
2. Rice-rice	RD9 and	3.1	1.3	Oct. 27	Oct. 27	
	KDML'65-G_1 U-45	–	–	–	–	Pattern 1–4: May 9
						Pattern 5–8: June 15
3. Rice-mung bean	RD5 and	4.7	2.3	Nov. 17	Nov. 27	
	SPR-1	0.126	0.004	–	–	
						2nd crop
4. Mung bean-rice	SPR-1 and	0.597	0.537	July 20, 28	July 18	
				Aug. 4	Aug. 1, 7	Pattern 4 transpl: Aug. 15
	KDML65-G_1 U-65	3.6	3.2	Nov. 28	Nov. 19	Pattern 3–8 planted: Dec. 23
5 Rice-sesame	RD5 and	4.5	3.2	Nov. 21	Nov. 27	*Pimai*
	local variety	0.021	–	–	–	
						1st crop
6. Rice-cowpea	KDML'65-G_1 U-45 and	3.9	3.4	Nov. 13	Nov. 17	
	local variety	0.055	0.045	–	–	Pattern 1–4: May 13, 14
						Pattern 5–8: June 9
7. Rice-soybeans	RD9 and	3.2	2.6	Nov. 6	Nov. 4	
	S.J.-2	0.006	0.091	–	–	
						2nd crop
8. Rice-peanuts	SPT 6012-134 and	3.7	3.2	Nov. 14	Nov. 14	
	local variety	0.046	0.002	–	–	Pattern 3, 5–8: Dec. 17
						Pattern 4 transpl.: Aug 19

[a] All direct seeded except the second rice crop in patterns 1, 2, and 4.

mung bean variety SPR-1 on May 4–7, 1976. The crop, which was harvested in July, had an average yield of 0.5 t/ha.

In conclusion, the design and testing of cropping patterns for rainfed areas requires an understanding of physical and socioeconomic parameters of the areas to be improved. Agronomic and economic situations are site-specific; thus, cropping pattern tests have to be conducted at the particular sites. A multidisciplinary approach is important. Variety trials and date-of-planting experiments are essential in selecting crop varieties for particular areas. Rainfall distribution seems to be the major factor in determining crops for Northeast Thailand. Sequential rice-based cropping patterns have good prospects of success. Relay-cropping research should also yield fruitful information, especially on the effective utilization of residual moisture immediately after the end of the monsoon. Direct-seeded rice promises to be a useful base on which to carry out a practicable Northeast cropping systems program. The techniques of direct-seeded-rice culture must be further tested and refined. Rice is the basic crop for the Northeast small farmers' subsistence, but crops in addition to rice must be added to increase farmers' income.

SUMMARY

A major part of Thailand's rice area, especially the northeastern region, is grown under lowland rainfed conditions. The northeastern area has gently rolling terrain interspersed with valleys. Soils tend to be sandy loam, and are low in all major plant nutrients and water retention. Monsoon rainfall is erratic, especially in about one half of the region during the early monsoon; thus, average yields are the lowest for the entire country (about 1 t/ha).

This paper describes preliminary cropping systems research in two major areas of the Northeast, namely, the Pimai and Ubon subregions. The two have different rainfall patterns but are representative of large areas. The Pimai subregion frequently experiences early monsoon droughts, whereas the Ubon area has dependable early rains that are frequently cut off sharply near the end of the season. Different cropping patterns must be devised for each subregion.

Preliminary research results suggest that we must focus our efforts on direct seeding of rice. At the Ubon Station it was possible to produce two crops of rice in the short monsoon season by direct seeding an early-maturing, photoperiod-insensitive variety at the beginning of the rains. That crop was followed by transplanting of an early photoperiod-sensitive variety. Upland crops such as mung beans and sorghum showed promise

either before or after rice. All indications point to the need for increased cooperative agro-socioeconomic research at each site.

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TESTING CROPPING PATTERNS FOR UPLAND CONDITIONS

J.L. McIntosh, S. Effendi, and A. Syarifuddin

The area available for increased production of lowland rice is limited. The lowland rice area in Indonesia covers approximately 5.8 M ha. About 4.1 M ha receive some irrigation (Biro Pusat Statistik, 1974). Recent World Bank surveys indicate that rehabilitation of present irrigation schemes and development of new ones in Indonesia could improve irrigation and drainage on 650,000 ha, upgrade another 650,000 ha from upland to lowland paddy, and provide supplemental water for dry-season irrigation through storage and ground water for another 210,000 ha (World Bank, Volume 11, Annex 2, 1974). Those are projected goals for the present 5-year plan. Much of this land is already in use (rainfed-upland and lowland rice), and yield increases that might result would come mostly from improved water control. The opportunity to bring new land under irrigation and increase dry-season irrigation is limited and expensive. The estimates are optimistic and no doubt will take several years to be realized.

On the other hand, in Indonesia and elsewhere, vast areas of arable land suitable only for upland cultivation are underused and in many instances are considered waste (Sanchez and Buol, 1975). That mistaken concept has arisen from the fact that stable societies have survived and even thrived on lowland rice culture. Meanwhile, their neighbors in upland areas have survived only with shifting cultivation and by living seminomadic existences. But some of the technology needed for increased production in lowland irrigated areas, such as fertilizer, insecticides, and the use of improved varieties, can give even higher return when applied to upland areas. In the past, those inputs, along with extension expertise and credit, have been almost exclusively reserved for lowland rice production. But an increased world supply of nitrogen fertilizers, in particular, has

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suggested possibilities for upland production. What was improbable even 2 years ago is highly feasible and perhaps even necessary today. It is estimated that between 15 and 20 M ha of level to gently undulating land, which has no permanent soil or terrain characteristics that restrict agriculture and is mostly unmanaged and free of forest concessions, could be developed for some kind of crop production in Indonesia at the present time (World Bank, 1974).

The most compelling reason for opening new lands and using more intensively those now in cultivation is to produce food to meet population increases. The food supply in some countries does not meet the need even now. In 1975, Indonesia imported rice, wheat, corn, and soybeans. Except for wheat, the situation should have been reversed; there should have been export, particularly of corn and soybeans. The production potential is available, but sustained production of exportable quantities has not taken place. Research on and implementation of viable and productive cropping systems for upland areas are needed to attain and maintain export markets. Such markets would absorb excess production and stabilize the domestic prices of the commodities. Ultimately, some capability would develop to process the crops into higher-valued products. The corn and soybean oil processing plants in Indonesia are good examples. Unfortunately, those facilities were developed before adequate production and storage facilities were available. Now it is necessary to import to keep the plants in operation during the off-season. In contrast, the demand for cassava for chips and pellets in Lampung has increased from about 150,000 t three years ago to 450,000 t at present. Excess production was available and the export market expanded accordingly.

CONSTRAINTS ON SUSTAINED CROP PRODUCTION IN UPLAND AREAS

The upland soils of South and Southeast Asia vary widely in natural fertility, physical properties, and topography. Those with high levels of bases are generally in areas with insufficient rainfall for more than one crop per year. In areas where rainfall is sufficient throughout the year, the soils tend to be highly leached and fragile. The organic fraction contains most of the nutrients required for crop production. That condition exists for about 46 M ha of red-yellow podzolic soils in Indonesia (Lembaga Penelitian Tanah, 1972). In Sumatra and Kalimantan, about 32 M ha of such soil are suitable for agriculture, but probably no more than 0.5 M ha are used for crop production. The average rainfall exceeds 200 mm for 8 months of the year and is less than 100 mm for only 2 months (Berlage, 1949). We feel that that area with its rainfall pattern and soil has tremendous potential for increased crop production. However, interacting physical and chemical constraints have inhibited crop production in the past. Those constraints, along with possible solutions, are briefly mentioned.

Rapid loss of fertility. Within 2 years after new land is opened, the soil loses its inherent fertility and productivity (North Carolina State University, 1976; Suryatna and McIntosh, 1976). The rapid oxidation of organic matter after cultivation and destruction of the vegetative cover permits leaching. The phenomenon is fast and certain for the sandy loam and silty soils that tend to predominate in upland areas. Soils with higher clay content remain productive longer, but within 5 years they usually are exhausted. Some areas may have unusual problems with trace element deficiencies and toxic substances. Fortunately those soils respond to fertilizer treatments. It is, therefore, absolutely necessary that farmers have credit for fertilizer inputs, and that the inputs be available. The recent decision in Indonesia to allow all farmers to buy fertilizer at one price has made it possible for crop production in the upland areas to compare favorably with that in lowlands.

Maintenance of soil fertility. Maintenance of inherent and amended soil fertility will determine a farmer's success. He can recycle residues as undecomposed plant materials into compost, or he can use manure. In some instances, incorporation of green manures provides striking response (North Carolina State University, 1976). Obviously, some fertilizers, particularly nitrogen, have to be used on a continuing basis, but phosphorus and potassium applications can be minimized. The increased organic component of the soil resulting from fertilization will keep nutrients from being leached, decrease the deleterious effects of toxic levels of aluminum in the soil, and improve the tilth. Three years of research in Lampung, Sumatra, indicate that the recycling of residues improves fertilizer efficiency and legume growth.

Erosion. Unless diversions or terraces are provided, land sloping more than 18% should not be cultivated and used for food crops. But erosion even on gentler slopes can be serious. We have observed that fertility management and maintenance of good ground cover throughout the year control erosion on these upland soils. The soil must never be left without crops to intercept the raindrops and bind the soil, particularly during the rainy season.

IDENTIFICATION AND SELECTION OF TARGET AREAS

The success of a cropping systems program can be measured only in terms of implementation. Great care must be used in selecting research areas.

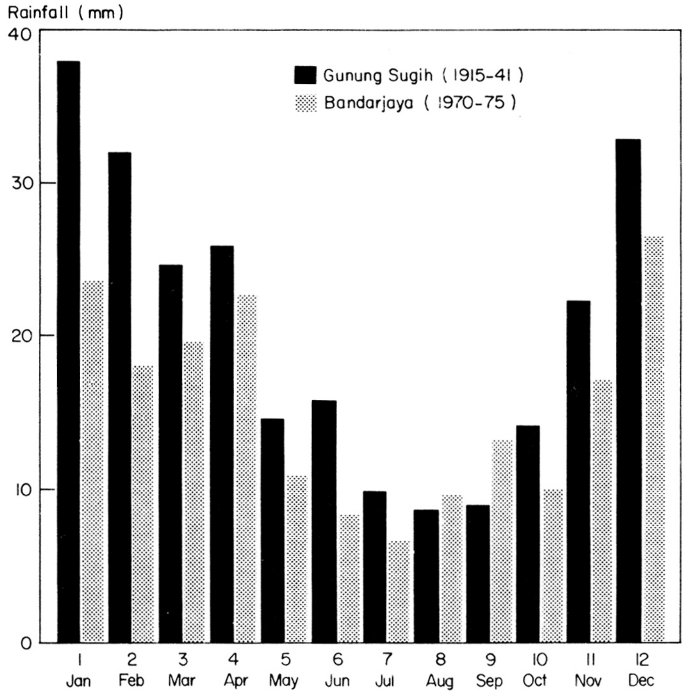
The criteria for selection will depend to a considerable extent upon government policy. Those used in Indonesia are probably suitable for most Asian countries where governmental participation in food production is common. The extent of this participation should probably determine the order of priority of the following criteria:

1. The area is designated by the government as one that has critical food shortages.
2. Uniform soil and climate characterize a large contiguous area.
3. Previous trials indicate the feasibility of intensifying present cropping patterns by adding at least one more crop per year.
4. Infrastructure and potential markets are available.

Central Lampung, in the south of Sumatra, was chosen as a target area for upland cropping systems research on the basis of the above criteria. The government had given the area high priority for agricultural development. Availability of open land and proximity to West Java also make it an ideal location for new transmigration schemes. The soil is classified as red-yellow podzolic and is similar to the soil of about 46 M ha, or approximately one-fourth of Indonesia's land (Lembaga Penelitian Tanah, 1972). Furthermore, the rainfall, which exceeds 200 mm for 9 months and falls below 100 mm for only 3 months (Berlage, 1949), is sufficient for year-round crop production, provided crops like cassava and cowpeas are grown during the driest period (Fig. 1). Unfortunately, the soil is low in inherent fertility and loses that contained in its organic component within 3 years. Fertilizer inputs have not been available. As a result, this large agroclimatic zone is agriculturally underdeveloped. Traditionally, farmers have used shifting cultivation and an extensive type of agriculture to circumvent the soil-fertility problem. The transmigration schemes, however, are committed to stationary agriculture. Farmers in older transmigration settlements have had difficulties in producing enough food to sustain their families. Before developing these areas further, we must develop cropping patterns and soil-management practices that will enable the farmers to produce food for their families and have some surplus to sell.

DESIGN OF CROPPING PATTERNS

This brief discussion will introduce the reasoning we have used in designing cropping patterns for testing in our selected target areas. Obviously, the priorities for different countries will depend upon prevailing social and economic conditions. Furthermore, we assume that sufficient research in the various disciplines (component technology) exists to allow the cropping systems personnel to choose from among a reasonably large selection of crops, techniques, and management practices.



1. Monthly average rainfall data for Central Lampung, Indonesia.

Selection of crops to be grown. Some crops are not useful for an area's cropping pattern, even though they might be agronomically suitable. For example, in Indonesia sorghum grows well during the dry season when planted after lowland rice. But it is difficult to market at the present time, and farmers will not eat it if they can get rice or corn.

Agronomic adaptation. Agronomic adaptation is obviously an important consideration in crop selection. In the tropics, the most decisive factor is rainfall and its distribution. In Indonesia, food crops almost always receive the highest priority. Of these, rice is the most highly valued crop and, consequently, is planted if the rainy season is long and dependable enough. Corn ranks next in terms of value and length of rainy season. Sweet potatoes are usually grown as a main food crop under conditions similar to those of corn in special areas where agriculture has not developed. Cassava will be the most stable crop in the drier regions or drier seasons. Legumes that depend upon available water can be grown as catch crops. Some can be retained for food and seed, but most can be sold.

Market and market potential. Most farmers grow food crops primarily for their families. Government policy keeps the consumer's price of rice low. Consequently, if farmers encounter production problems and have enough rice for their families, they are not always inclined to grow a second crop unless marketing prospects are good. Market prospects affect the prices and production of all food crops. If there is an export market for crops like cassava and corn, and processing for soybeans, mung beans, and peanuts, the greater market potential will help to raise and stabilize the selling prices of those commodities. If a crop is to be grown in a cropping pattern, a market for it must exist at harvest—not at some future time.

Arrangement of cropping sequences. The average farm in Indonesia is less than 1 ha. In the outer islands, the holdings tend to be larger. Formerly, transmigrants received 2 ha. They usually had enough labor to plant 0.5 ha to food crops. The rest of the land lay idle or grew alang-alang (*Imperata cylindrica*). Under such conditions, farmers intuitively consider certain things. We must therefore try to put ourselves in their shoes in order to design effective and applicable cropping patterns. We have used the following guidelines in designing new cropping patterns.

Maximize stability in production. The concept of maximizing stability in production is especially important in newly opened upland areas where the farmer must be self-sufficient. There, the farmer can often use complex cropping combinations, with crop species ranging from early-maturing legumes to cassava. For example, if there is doubt that rainfall may be enough for rice, perhaps early-maturing corn should be interplanted with drought-tolerant cassava; after corn harvest, the cassava should be interplanted with mung beans, cowpeas, or even cassava of an early maturing variety.

Minimize labor. The area that a farmer cultivates depends mostly upon the amount of labor or power he has for land preparation. Usually a farmer with only hand labor will prepare about 0.5 ha for planting at the beginning of the rainy season. During the cropping season, weed control becomes a constraint. Minimum tillage, relay planting, and continuous crop cover will enable the farmer to plant and manage a larger area with the same amount of labor than he can with monoculture and sequential plantings.

Distribute labor. The labor distribution that is inherent in multiple cropping is a useful attribute. Strip tillage and planting of intercrop combinations at intervals of 2 to 4 weeks enable a farmer to spread his labor for land preparation of a given area over a longer period of time. The harvest will also be spread out. However, the practice may not be practical if it greatly increases the labor requirement and obliges the farmer to hire labor. We can hope that with improved soil fertility the farmer will become prosperous enough to afford a cow for power.

Distribute capital inputs. It is difficult for a farmer to obtain credit. Without governmental asistance, he has difficulty in buying seeds, fertilizers, and insecticides. Lack of resources is one primary reason why farmers grow many kinds of crops in traditional mixed cropping combinations in upland agriculture in remote areas. They plant whatever is available. Multiple cropping techniques similar to the farmers' may be used to achieve the benefits of their systems. But those systems may have to be simplified to minimize the randomness and diversity that prevent the farmer from planting in rows, using specific fertilizers for higher valued crops, or planting second crops soon after first crops have been harvested.

Distribute harvest income. Frequent harvests mean the farmer has money more frequently and, consequently, is more likely to spend it for things he really needs. They minimize the need to borrow money for food and for production inputs. Again, the stability inherent in multiple cropping is useful. But there is a fine line between frequency of harvest and marketing efficiency. If the harvest is too small, it may not be profitable for the farmer to sell it.

EVALUATION AND TESTING OF CROPPING PATTERNS

In developed countries where farmers may be well educated and economically strong, the accumulated technology for multiple cropping may be sufficient to meet their needs. No further work by researchers is needed and farmers are able to adapt the technology to meet their own specific needs. In developing countries, however, where the farmers may be less educated, and financially weak, the governments have initiated production programs to implement the new technology. Those package programs include technology, credit, and inputs. The first programs, such as Masagana 99 in the Philippines and BIMAS in Indonesia, were for individual crops. Recently, provisions have been made to include additional crops and cropping systems.

Implementation of the programs for crop commodities and cropping systems should be preceded by research that approximates the physical conditions in the farmers' fields—ideally at the farmers' levels of management. Production programs are expensive; to minimize failures, they must be tailored to fit actual conditions.

Under the close supervision of researchers, we must design and test new cropping patterns in the target areas to get some idea of their agroeconomic potential and their probable problems (weeds, rats, insects, monkeys, birds, crabs, diseases, and so on). In the Indonesian program we start by trying to improve the farmer's existing pattern. This may simply mean introduction of new varieties, fertilizer and, perhaps, one extra crop into the cropping sequence.

The final evaluation before implementation should be made in multiple trials scattered over the target area and conducted as much as possible under farmer management. The trials would be conducted with and without removal of certain constraints such as credit, seed, fertilizer, pesticides, and markets. Objectives would be to establish a base line, to determine if farmers have the expertise to use inputs effectively if the inputs are available, and to get a measure of the benefits and of the probability of success.

Site-specific research in target areas by researchers. In 1973, site-specific research began near Bandarjaya, Central Lampung, on a red-yellow podzolic soil that had been abandoned for all practical purposes for crop production. The area had been settled by transmigrants from Java about 20 years earlier. The research aimed to see if the area could be made economically productive with moderate use of fertilizers and of other inputs, comparable with those made available to lowland rice farmers

Table 1. Cropping patterns and amounts of fertilizer used for full-treatment plots, Cropping Systems Experiment, Bandarjaya, Lampung. 1973–75.

Crops	Variety	Date of Planting	Date of Harvesting	Spacing[a] (cm)	Fertilizer (kg/ha) N	P_2O_5	K_2O
		Mixed cropping					
Corn	Metro	11/28/73	3/14/74	Uncertain	48	15	15
Upland rice	Cartuna	11/28/73	4/5/74	"	72	24	24
Cassava	Local	12/6/73	10/6/74	"	20	20	20
Sorghum	UPCA-S_1	31/7/74	7/14/74	"	24	8	8
Peanuts	Gajah	4/10/74	7/18/74		14	25	36
Rice beans	Local	7/22/74	10/4/74		14	25	36
		Intercropping					
Corn	Metro	11/18/73	3/4/74	150 × 20	48	15	15
Upland rice	Cartuna	11/28/73	4/5/74	25 × rows	72	24	24
Cassava	Local	12/6/74	10/6/74	300 × 60	20	20	40
Sorghum	UPCA-S_1	31/7/74	7/14/74	300 × 15	24	8	8
Peanuts	Gajah	4/10/74	7/18/74	30 × 10	14	25	36
Rice beans	Local	7/22/74	10/4/74	30 × 20	14	25	36
		Sequential planting					
Upland rice	Cartuna	11/28/73	4/5/74	25 × rows	90	30	30
Corn	Metro	4/10/74	7/22/74	100 × 20	90	25	25
Rice beans	Local	7/26/74	10/6/74	40 × 20	20	45	50

[a] The populations of corn, rice, peanuts, rice beans, and cassava in mixed cropping and intercropping were 53, 80, 71, 71 and 44.4% of those in sequential planting or solid planting, respectively. Sorghum was eliminated after the first year, and some modifications were made in planting and harvesting dates and in spacing.

Table 2. Fertilizer effect on average yields and approximate net returns from check and full-treatment plots. Cropping Systems Experiment, Bandarjaya, Lampung. 1973–75.

Fertilizer treatment	Dry grain (kg/ha)				Fresh roots cassava (t/ha)	Approximate net return	
	Corn	Upland rice	Peanuts	Rice beans		(Rp/ha) [a]	(US$/ha)
			Mixed cropping				
No lime + no NPK, + no mulch	467	690	161	55	12.7	65,000	156.62
Lime + NPK + mulch	165	1358	356	248	28.3	132,000	318.07
			Intercropping				
No lime + no NPK + no mulch	455	769	222	93	14.6	91,000	219.27
Lime + NPK + mulch	1350	2724	567	627	23.2	265,000	638.55
			Sequential planting				
No lime + no NPK + no mulch	606	850	–	153	–	–6,000	–14.45
Lime + NPK + mulch	2935	3536	–	723	–	74,000	178.31

[a] US$1 = Rp 415.

through the BIMAS program; and it sought preliminary data on cropping patterns, labor requirements, and economic returns. Six different fertilizer treatments and three cropping patterns were tested with and without insecticides. The cropping patterns, varieties, planting and harvesting dates, spacings, and amounts of N, P_2O_5, and K_2O used for all full-treatment plots were recorded (Table 1). The details of the experiment and preliminary data have been reported (Syarifuddin and McIntosh, 1975). The average yields for 2 years on the check and full-treatment plots are shown in Table 2. The third year's data are incomplete. Labor requirements and costs of inputs for the different operations were measured. From the data, we estimated the net returns for each cropping pattern, its total labor requirement, and its distribution of labor and capital inputs. Syarifuddin and McIntosh (1975) summarized the data in their preliminary report:

1. Poor red-yellow podzolic soils in Lampung, infested with alang-alang, were found to be highly responsive to fertilizer.
2. Intercrop combinations using drought-tolerant crops during the dry season permitted year-round cropping and gave the highest yields per year among the three cropping patterns used.
3. Total yields per year (in terms of rice equivalent) from those soils were comparable with yields from two rice crops on good, irrigated *padi sawah* in Java when comparable rates of fertilizer were used.
4. Improved vegetative growth, due to fertilizing and routine cultiva-

tion, effectively controlled weeds (alang-alang) and appeared to have reduced erosion.

5. The intercrop combination gave highest net returns of the three cropping patterns. Yield and net returns indicate that with fertilizers and suitable intercrop combinations, farmers could develop cropping systems that would enable them to produce enough food for their families, have surplus to sell, and maintain or improve the overall fertility and productivity of their soil.

TESTING CROPPING PATTERNS IN TARGET AREAS UNDER FARMERS' CONDITIONS

Under different circumstances, the data that have been presented and the experience gained by the authors would be ample to justify pushing on with some kind of implementation program. We asked the farmer who owned the land where the plots were located if he would continue our cropping patterns after we left the area. He said he would like to, but would not be able to get the seed, fertilizers, and other needed inputs. (At the time, subsidized insecticides and fertilizers were officially available only to lowland rice farmers.) Obviously, this is the reason Indonesia and other countries have production programs which supply credit and inputs. But how does a researcher convince himself that a production program would be successful? And if there is ample proof for him, how can the governmental agencies be convinced ?

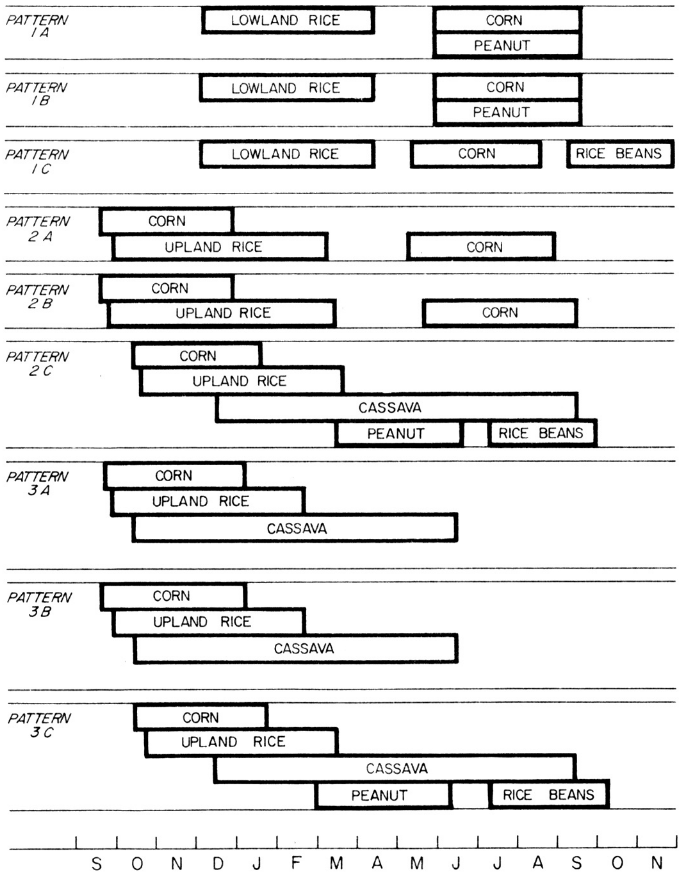
Need for further testing of new technology. Production programs have become more relevant in recent years with our growing experience with high yielding varieties (HYV) and the "green revolution." Farmers' use of HYV has not been as widespread as expected. Only 30 to 35% of the lowland rice fields in Indonesia are planted to HYV. Furthermore, the use of HYV along with the approved technological package many times have given lower yields than expected. Part of the reason is that the technology was developed for a high level of management like that practiced in the agricultural experiment stations (probably better water and insect control) rather than for the level practiced by farmers. A greater effort must be made to test and tailor technology to the farmer's needs and to his level of management. We must consider that the farmer is doing the best he can with the resources at his disposal. We must evaluate his system under actual conditions to understand the constraints he faces and to establish a base for comparison. Valid research can be done in the farmer's field at the farmer‘s level of management within a target area. We can study, as an intermediate step between the farmer‘s own pattern and an imposed "improved pattern," the farmer's response to the removal of certain constraints. Rather than impose a cropping pattern, we can determine the kind he will use if the agronomic inputs, credit, and markets are provided. Such an approach assumes that the farmer is not limited in technical know-how (human technology). On the other hand, if the farmer does not respond to the removal of constraints — continuing to use his present cropping pattern and misusing the agronomic inputs—we may conclude that he cannot successfully take part in a production program without a greater infusion of technical assistance by extension or, perhaps, without a simplified technology.

Methodology for testing cropping patterns. Cropping patterns were tested in two locations in Indonesia with the aim of developing improved methodology with which to establish a base line, and of pretesting packaged technology for production programs. Before the experiment, the cropping systems staff conducted a base-line survey in the Lampung target area to identify the most common cropping patterns used by farmers, and to accumulate as much physical, social, economic, and climatic data as possible before designing the trials. Previous trials had shown the potential for increased production if soil fertility constraints were removed. The area was divided into three categories based on the current conditions, caused by past management. Those conditions would necessitate modifications or completely different cropping patterns. The categories were :

Category I . . . .Area with 5-month irrigation.
Category II . . . . Old alang-alang fields, opened more than 3 years earlier.
Category III . . . .Newly opened alang-alang fields or secondary forest.

Three cropping patterns were tested within each category; each trial was replicated three times by different farmers. The cropping patterns for each category were not necessarily the same, but were selected on the basis of the same criterion. The criteria for selection and rationale for each criterion are as follows :

Criterion *A* . . . .Farmer's present cropping pattern.
Rationale . . . .To establish a base for comparison.
Criterion *B* . . . .Farmer's choice of cropping pattern with input and market constraints removed.
Rationale . . . .To evaluate the farmer's level of technical competence and managerial skill, and perhaps uncover hidden socioeconomic constraints.
Criterion *C* . . . .The recommended cropping pattern, with input and market constraints removed and technical assistance provided.
Rationale . . . .To determine production and economic potential within the farmer's environment.



2. Sequence of crops in cropping patterns trials. Central Lampung. 1975–76.

The cropping sequences for each cropping pattern are shown in Figure 2. The designation I*A,* for instance, indicates the cropping pattern used for category I (area with 5-month irrigation) with the design based on criterion *A* (farmer's present cropping pattern).

In addition to testing the cropping patterns already described, promising new varieties of the crops in the patterns were evaluated. The evaluation trials coincided with the growing of the particular crops in the sequence. Additional trials evaluated alternative cropping sequences, fertilizer rates, pest control and other components of the patterns. These have been called superimposed trials, but were actually parallel but separate experiments. Such research may be conducted for the various crops by agronomists, physiologists, economists, and multiple cropping agronomists. In that way,

Table 3. Average yield and cost and return analysis[a] for three cropping patterns in areas with 5-month irrigation (Category I). Nambahdadi, Lampung, 1975–76.

Cropping[b] pattern	Av yield (kg/ha)	Gross return		Labor cost		Material cost		Net return	
		Rp	US$	Rp	US$	Rp	US$	Rp	US$
I*A*									
L. Rice (Pelita I/1)	3828	229,680	553 44	92,269	222.33	19,605	47.24	117,806	283.86
Corn									
I*B*									
L. Rice (Pelita I/1)	4292	257,520	620.53	97,195	234 20	23,571	56.79	136,754	329.52
Corn									
I*C*									
L. Rice (Pelita I/1)	4895	293,520	707 27	11 0,100	265.30	37,710	90.86	145,710	351.10
Corn									
Rice beans									

[a]US$1 = Rp 415. [b]I*A* = farmer's choice, I*B* = farmer's choice when certain constraints were lifted; I*C* = researcher's choice.

the cropping systems program may benefit directly from the research without interfering with the special concerns of the various research disciplines. Rather, cropping systems may serve as the nucleus of a cooperative effort. The number of core cropping systems personnel may be quite small if an effective working group of scientists from other disciplines can be activated.

A site coordinator, an agronomist, and an economist were stationed in the Lampung target area. A technician was put in charge of the field work in each category and given the additional responsibility of collecting all input-output data. A system for collecting daily farm records for all buying and selling was carried out in cooperation with 36 farmers in the target area to get a broad base for socioeconomic evaluation.

Results. The data-collecting phase of the cropping systems program began in October 1975.[1] Because of the late start, the first crops were planted from 1 to 2 months after the beginning of the rainy season. The first crops in the cropping sequences have now been harvested. Yields and summarized cost and returns data for each cropping pattern tested are presented in Tables 3, 5, and 7. Tables 4, 6, and 8 show itemized time and cost data for labor in each category.

Unfortunately, we are unable to present more data and cannot make final evaluation of patterns until the end of the crop year. The most pro-

[1]Supplementary support for the expanded activities of the program has been generously provided by the International Development Research Centre through a cooperative project agreement between the CRIA and IRRI.

Table 4. Time and cost of several operations for three cropping patterns in areas with 5-month irrigation (Category I). Nambahdadi, Lampung, 1975–76.

Operation	Time (man-day/ha) and cost (Rp/ha)[a]					
	Pattern I*A*		Pattern I*B*		Pattern I*C*	
	Time	Cost	Time	cost	Time	cost
Plowing (2x)[b]	10	10,000	10	10,000	11	10,500
Seedbed preparation	11	3,800	11	3,800	13	4,500
Sowing	1	300	1	300	2	750
Clearing and bedding	9	3,000	5	1,750	7	2,420
Repair of bunds (2x)	15	6,000	18	6,400	9	3,170
Leveling and harrowing	19	9,500	8	6,000	20	10,920
Furrowing and layout	3	1,200	5	1,830	3	1,200
Transplanting and replanting	30	8,000	32	9,830	52	13,380
Weeding (twice)	29	10,050	28	9,430	32	10,630
Fertilizing (twice)	9	2,200	9	3,195	2	670
Spraying	3	1,150	5	1,740	9	3,010
Harvesting	128	35,069	129	42,920	93	48,950
Threshing						
Total	267	92,269	261	97,195	253	110,100

[a]One man-day = 7 hours; US$1 = Rp 415. [b]One man, a plow, and two cows.

fitable crop, cassava, and the legumes will not be harvested until late September. Because of that and because of the low yields of rice due to late plantings and pests, the net returns for all the upland farmers' patterns at this point in the sequences are negative. That has obvious implications that we hope to build upon when the data are complete. Nevertheless, our experience in the past months enables us to make some observations on methodology and on the prospects for implementation of production programs in the target area.

Time and cost data. The figures for labor requirements are included without modification and with little discussion. Obviously, the variations among the patterns in data on labor required for similar operations need further explanation. We will leave that task for another time. The cost figures appear to be comparable and within our range of expectations, but we have to refine the methodology for labor measurements if the figures obtained are to be meaningful outside the project.

Category 1—5-month irrigation. The data of Table 3 show that the farmers of Category I are doing a good job. No doubt they have benefited from participation in the BIMAS program for lowland rice. This year they received enough ammonium phosphate and urea to apply 68 kg N/ha and 48 kg P_2O_5/ha. Farmers in pattern I*B* applied equivalent amounts of nutrients with urea and triple superphosphate, but used 1 liter more of

Table 5. Average yield and cost and returns analysis[a] for three cropping patterns in old alang-alang fields (Category II). Bandar Agung, Lampung, 1975–76.

Cropping pattern[b]	Av. yield (kg/ha)	Gross return		Labor cost		Material cost		Net return	
		Rp	US $	Rp	US $	Rp	US $	Rp	US $
II*A*									
Corn +	235	14,100	33.98	57,381	138.27	2,520	6.07	–2,481	–5.98
Upland rice	722	43,320	104.39						
		57,420	138.37						
Corn									
II*B*									
Corn (DMR-5) +	541	32,460	78.22	71,785	172.98	24,935	60.08	–5,700	–13.74
Upland rice (Bicol)	976	58,560	141.11						
		91,020	219.33						
Corn									
II*C*									
Corn (DMR-5) +	1,798	107,880	259.95	106,390	256.36	56,440	136.00	10,690	25.75
Upland rlce (Bicol)	1,094	65,640	158.17						
Cassava + Peanuts - Rice beans		173,520	418.12						

[a] US$1 = Rp 415. [b] II*A* = farmer's choice; II*B* = farmer's choice when certain constraints were lifted; II*C* = researcher's choice.

Table 6. Time and cost for several operations for three cropping patterns in old alang-alang fields (Category II). Bandar Agung, Lampung, 1975–76.

Operation	Time (man-day/ha) and cost (Rp/ha)[a]					
	Pattern II*A*		Pattern II*B*		Pattern II*C*	
	Time	cost	Time	cost	Time	cost
Cutting alang-alang	23	5,635	29	7,105	26	6,370
Full cultivation for upland rice & corn[b]	90	22,050	114	27,930	–	–
Strip cultivation for corn (25-cm width)	–	–	–	–	68	16,660
Strip cultivation for upland rice (175-cm width)	–	–	–	–	138[c]	33,810
Planting corn			6	1,470	25	6,125
Planting upland rice	20	4,900	56	13,720	33	8,085
Weeding for corn & upland rice (twice)	54	13,281	38	9.310	47	11,575
Fertilizing upland rice (3 times)	–	–	–	–	26	6,370
Fertilizing corn (twice)	–	–	–	–	6	1,470
Spraying	–	–	5	1,225	9	2,205
Harvesting corn	8	1,960	4	980	7	1,715
Harvesting upland rice	39	9,555	41	10,045	49	12,005
Total	234	57,381	293	71,785	434	106,390

[a]One man-day = 7 hours; US$1 = Rp 415. [b] Plowed twice, rhizome-free. [c] More shrubs and dense alang-alang than in II*A* and II*B*.

insecticide per hectare. Since insects (stem borers and gall midges) were major problems, the additional insecticide may have contributed to the increased yield.

On the other hand, pattern I*C* yielded more than did I*B*. We are not sure if the difference was due to the addition of an extra 50 kg of urea and KCl, or of 1 liter insecticide per hectare. More research will be needed to determine the exact cause of these differences. In any case, it appears that the Extension Service and farmers are willing and able to adopt new technology. The superimposed trials indicated that considerable time could be gained by using IR28—enough time, it appears, for growing two rice crops in this category per year and an upland crop during the dry season.

Category II—old alang-alang fields. At the outset, it is obvious that strip tillage has its limitations (Table 6). Unfortunately, it is difficult to differentiate between research cost and a legitimate labor cost to the farmer. It seems that if a farmer has to contract labor, strip tillage may require so much extra labor that it may not be justified. For a new transmigrant using his own labor at odd times, the advantage of distributing labor would be most important.

Table 7. Average yield and cost and return analysis[a] for three cropping patterns in newly opened areas (Category III). Komering Putih, Lampung, 1975–76.

Cropping pattern[b]	Av yield (kg/ha)	Gross return		Labor cost		Material cost		Net return	
		Rp	US$	Rp	US$	Rp	US$	Rp	US$
III*A*									
Corn +	287	17,220	41.49	67,250	162.05	2,520	6.07	–24,890	–59.98
Upland rice	461	27,660	66.65						
		44,880	108.14						
Cassava									
III*B*									
Corn (DMR-5) +	412	24,720	99.57	81,500	196.39	23,360	56.29	–41,440	–99.86
Upland rice	645	38,700	93.25						
		63,420	192.82						
Cassava									
III*C*									
Corn (DMR-5) +	2,140	128.400	309.40	139,306	335.68	57,700	139.04	5,254	12.66
Upland rice (Bicol)	1,231	73,860	177.98						
		202,260	487.37						
Cassava + Peanuts – Rice beans									

[a]US$1 = Rp 415 [b]III*A* = farmer's choice; III*B* = farmer's choice when certain constraints were lifted; III*C* = researcher's choice; data for a cassava + peanut + rice bean pattern are not yet available.

Table 8. Time and cost of several operations for three cropping patterns in newly opened areas (Category III). Komering Putih, Lampung, 1975–76.

Operation	Time (man-day/ha) and cost (Rp/ha) [a]					
	Pattern III *A*		Pattern III *B*		Pattern III *C*	
	Time	cost	Time	Cost	Time	Cost
Cutting alang-alang	25	6,250	24	6,000	31	7,750
Full cultivation for upland rice	138[b]	34,500	202	50,500	–	–
Strip cultivation for corn (25-cm width)	–	–	–	–	71	17.737
Strip cultivation for upland rice (175-cm width)	–	–	–	–	137	34,250
Planting corn	–	–	7	1,750	33	8,332
Planting upland rice	26	6,500	27	6,785	69	17,262
Weeding for corn & upland rice (2x)	26	6,500	29	7,263	60	15,000
Fertilizing corn (2x)	–	–	–	–	6	1,500
Fertilizing upland rice (3x)	–	–.	–	–	31	7,750
Harvesting corn	10	2,500	3	750	6	1,500
Spraying (5x)	–	–	–	–	10	2,500
Harvesting upland rice	44	11,000	34	8,452	49	12,005
Threshing	–	–	–	–	56	13,720
Total	269	67,250	326	81,500	559	139,306

[a] One man-day = 7 hours; US$1 = Rp 415. [b] Dense, virgin alang-alang.

The yield data (Table 5) show that we know how to grow corn but that we do not know how to grow rice better than does the farmer. Rice yields were about the same for all treatments. That is somewhat misleading, for in addition to a lack of adapted new varieties, the constraints were late plantings, chickens, and birds. We had poor stand-establishment and, later, severe insect infestation. Earlier plantings would have helped considerably. For 3 years the researcher-managed plots at Bandarjaya have consistently yielded between 2 and 3 t/ha.

The farmers in pattern II*A* did not use fertilizer. The corn yields were low. In pattern II*B,* it appears that the farmers were unable to use their fertilizer inputs satisfactorily. They were to apply 150 kg urea/ha and 100 kg triple superphosphate (TSP)/ha to corn and rice, but the corn yields were only about one-third of those in pattern II*C.* Our first thought was that the farmers needed considerable technical assistance even though their rice yields were comparable with those in II*C.* Fortunately, we looked at the farmers' labor records. In Table 6 we see that farmers listed no labor for applying fertilizer to corn and rice. We doubt that that was an oversight. More than likely, they did not use the fertilizer for its intended purpose. However, this year we hope that earlier plantings at the beginning of

October and the use of furadan seed treatments to control ants and seedling-flies in this category will insure yields of rice comparable with those from researcher-managed plots in Bandarjaya.

Category III—newly opened areas. From the corn yields, it appears that the farmers need considerable technical assistance to use inputs successfully (Table 7). Application in pattern III*B* of 150 kg urea/ha and 100 kg TSP/ha gave little response compared with that in pattern III*A*. Again, from Table 8 we see no labor requirement listed. Either the farmers simply did not know how and when to apply the fertilizer and insecticide they received, or they felt a greater need to use the inputs for other purposes. In pattern III*C* under our supervision, the average corn yields were five times those in III*B*. Rice yields were double in spite of late planting and insects. Part of this increase, no doubt, could be due to the extra fertilizer (50 kg/ha of urea and of TSP plus 100 kg KCl/ha) applied in III*C*.

The yields in Category III were about the same as those from comparable Category II patterns. The soil differences between the two areas do not appear to be significant. Even though Category II was old alang-alang, it had become rejuvenated by being out of production for so long. The farmers in both categories are mostly retired police, and seem better organized than the average transmigrants. If convinced, they will probably accept the new technology.

Prospects for implementation. Lampung farmers who are indigenous to upland areas with red-yellow podzolic soils have survived by practicing shifting cultivation. Transmigrants, on the other hand, have been more or less restricted to a sedentary-type agriculture on 2-ha plots. Food production sufficient to sustain the family has been difficult. Cropping systems research has shown how improved soil fertility and year-round cropping patterns could provide a profitable farm economy. The authorities responsible for transmigration projects have seen the results of those trials and have agreed to provide funding for research at four new transmigration locations in Lampung and South Sumatra. The Cropping Systems Project will be responsible for the development of suitable cropping patterns; details as to crops, fertilizer treatments, and agronomic practices that can be fitted into a cropping calendar are to be given each transmigrant. Other agencies will be responsible for animal husbandry, industrial crops, and forages. All will be coordinated to provide integrated farming systems. After the transitory period and development of infrastructure, it is hoped that the settlements will be able to function more successfully within the usual governmental framework. Then the development activities may be moved to other locations.

SUMMARY

Much of the 46 M ha of red-yellow podzolic soils in Indonesia has no physical nor topographical characteristics that prevent their use for upland crop production. They receive ample rainfall with distribution suitable for year-round cropping patterns, provided drought-tolerant crops are grown during the drier months. It is estimated that between 15 and 20 M ha of level to gently undulating land with these conditions are unused and could be developed for crop production now. The area is four to five times as large as Indonesia's irrigated area.

Experiments managed by researchers were conducted in a selected target area to evaluate the crop production potential of the soils. The results showed that modest rates of fertilizer and other inputs, comparable with those used in package programs for lowland rice production, would be sufficient to make the soils productive. Good economic returns were obtained when the inputs were combined with adapted year-round cropping patterns.

An expanded program was begun to test cropping patterns in the target area under farmers' conditions as much as possible. The tests were considered the next step in the development of production programs for the target area. The objectives were to establish a base for comparison, to evaluate the farmers' ability to absorb and use new technology, and to determine production and economic potential for production in the farmers' physical setting

Preliminary data show that farmers who took part in the Indonesian production program for lowland rice (BIMAS) managed well the inputs made available to them and were able to absorb more. On the other hand, the upland crop farmers in our target area lost money on the first two crops in their cropping patterns when no technical assistance was provided. Under such conditions, production programs for the area should be accompanied by considerable assistance from the Extension Service or other sources if they are to be successful.

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DISCUSSION

VAN EMDEN: You referred to the crop-protection problems consequent on your introduced crop system as being more an "act of God" which "interfered" with your experiments than as much a "response" of the new environment as is increased yield. Are you seeking solutions through your cropping system or through more direct suppressive measures (such as plant resistance, insecticides) which would avoid major restructuring of your systems?

McIntosh: The insect problems exist under the farmers' conditions. I don't think at this point, at least, we intensified the problem. We are seeking repressive measures. For example: a) Seedling maggot—furadan; b) Shoot fly—furadan; c) Agromyza—furadan. For the podborer on legumes—we would like advice.

PRELIMINARY STUDY OF RICE-WHEAT CROPPING SYSTEMS IN THE MID-HILLS OF NORTHWESTERN HIMALAYAS

M.P. Singh and S.C. Modgal

Rice-wheat is the major crop rotation followed in the Kangra valley of Himachal Pradesh. The area represents the mid-hills of northwestern Himalayas. The total grain production of the cropping system, however, does not on the average exceed 3 t/ha. Although the availability of high yielding varieties has increased the chances for higher production, a simultaneous increase in price of fertilizers and their scarcity in the market have been obstacles to enthusiastic farmers. That has necessitated supplementing, if not entirely replacing, the commercial fertilizers with indigenous organic wastes. Hence an attempt has been made to compare the effect of recycling organic plant material and applying farmyard manure (FYM) with the effect of various levels of nitrogen applied as urea on crop productivity as well as on some soil properties. This paper presents preliminary observations. There have been earlier attempts to increase the productivity of rice-based cropping systems (Nair et al., 1973).

MATERIALS AND METHODS

A field experiment consisting of four FYM treatments, four nitrogen levels, and removal and burying of plant residues in rice-wheat rotation was conducted in 1974–75 at the University Experiment Station, Palampur, at 1,250 m above mean sea level in the northwestern Himalayan region of India (Himachal Pradesh). The annual average rainfall of the site is around 2,500 mm, with the major portion being received between July 1 and September 15. The later half of September and the whole of October usually remain dry, with intermittent winter rains from November through March. Hailstorms occur between March and May, and also in September and October,

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when wheat and rice crops are nearing maturity. Summers are comparatively mild and winters are severe. The overall climate is subtemperate.

The soils of the experimental site are deep clay loam, low in available phosphorus, and poor in nitrogen content. The pH of the surface soil is around 5.8. FYM treatments were applied to supply 100 kg nitrogen/ha 15 days before sowing. After grain harvest, the straw of each crop was chopped and buried in the soil according to treatment. Nitrogen was applied as urea in three equal parts to rice and two equal parts to wheat. A uniform basal application of P_2O_5 and K_2O was made at 50 kg/ha to each crop as single superphosphate and murate of potash, respectively.

Both the rice and the wheat were drilled in rows 20 cm apart on unpuddled soil. Rice was kept submerged throughout, and wheat was irrigated when necessary. Rice variety China-988 and *Sonalika* wheat, a high yielding variety, were used. The field experiment was laid out in a split-split plot design, replicated four times, with FYM treatments randomized in whole plots, residue-management treatments in subplots, and fertilizer-nitrogen treatments in sub-subplots. Further details of the treatments are given in Table 1 and 2.

RESULTS AND DISCUSSION

Yield. FYM when applied to both crops produced the highest wheat grain and straw yields as well as the highest total grain and straw yields of rice + wheat among FYM treatments (Table 1). The lowest yields were in the no-FYM treatment. The results could be explained by the increase in fertility with FYM addition. The effects of residue management could be ascertained on wheat yields only, as rice was the first crop. Burying rice straw seems to have depressed the wheat-grain yield, perhaps because of the partial immobilization of nitrogen. The decomposition of added residues is expected to be slow in a subtemperate climate. Increasing the levels of nitrogen increased the grain, straw, and total yields of grain + straw of rice and wheat. Such results are expected in nitrogen-deficient soils.

Soil studies. Adding FYM increased the infiltration rate and decreased resistance to the penetrometer needle (Table 2). FYM applications seem to have made the soil fluffy, hence these results. Residual-management treatments did not much influence the two soil properties. The effect of nitrogen levels on infiltration rate and penetrometer readings was less consistent. FYM additions increased total crop biomass production (Table 2). Little difference was observed, however, as a result of residue-management treatments. Increasing the levels of nitrogen increased the soil biomass, probably due to enhanced root and shoot growth.

Table 1. Effects of farmyard manure (FYM) treatments, residue management, and nitrogen levels on grain, straw, and total yields of rice, wheat, and rice + wheat, Palampur, Himachal Pradesh, India, 1974–75.

Treatment	Rice (kg/ha)			Wheat (kg/ha)			Rice + wheat (kg/ha)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
FYM treatment									
No FYM	2,905	4,351	7,256	2,987	5,352	8,339	5,892	9,703	15,595
FYM to rice	3,206	4,717	7,923	3,046	5,747	8,793	6,252	10,464	16,716
FYM to wheat	2,844	4,383	7,227	3,358	6,203	9,561	6,202	10,586	16,788
FYM to both crops	3,337	4,837	8,174	4,226	7,249	11,475	7,563	12,086	19,649
Residue management									
Removing residues	3,067	4,417	7,484	3,517	6,078	9,595	6,584	10,495	17,079
Burying residues	3,080	4,661	7,741	3,292	6,195	9,487	6,372	10,856	17,228
Nitrogen (kglha)									
N_0	1,593	2,046	3,639	1,564	3,544	5,108	3,157	5,590	8,747
N_{50}	2,941	3,837	6,778	3,273	6,053	9,326	6,214	9,890	16,104
N_{75}	3,724	5,410	9,134	3,791	6,820	10,611	7,515	12,230	19,745
N_{100}	4,035	6,783	10,818	4,989	7,975	12,964	9,024	14,758	23,782

Table 2. Effects of farmyard manure (FYM) treatments, residue management, and nitrogen levels on properties of soils at Northwestern Himalayas, 1974–75.

Treatment	Infiltration rate (cm/45 minutes)		Penetrometer reading (kg/sq cm)		Biomass (kg/ha)		
	After rice	After wheat	After rice	After wheat	After rice	After wheat	Total
FYM treatment							
No FYM	0.85	4.29	2.46	3.25	4,955	4,443	9,398
FYM to rice	1.14	4.45	2.24	2.41	6,910	5,124	12,034
FYM to wheat	0.85	4.33	2.50	2.66	5,416	5,957	11,373
FYM to both crops	1.15	4.77	2.27	2.16	8,232	6,690	14,922
Residue management							
Removing residues	1.01	4.59	2.44	2.75	6,235	5,746	11,981
Burying residues	1.02	4.51	231	2.73	6,389	5,359	11,748
Nitrogen (kg/ha)							
N_0	1.10	4.37	2.47	2.84	4,064	3,395	7,459
N_{50}	1.00	4.48	2.25	2.77	6,234	4,837	11,071
N_{75}	1.04	4.49	2.36	2.68	7,074	6,314	13,388
N_{100}	0.96	4.47	2.43	2.68	8,240	7,762	16,002

SUMMARY

The real treatment effects would be difficult to realize in only two crop-seasons. The results obtained for a rice-wheat system of cropping are summarized for the sake of the information they offer.

Applying FYM improved soil properties as well as crop yields. Burying residues, however, depressed the grain yield of wheat and had little effect on biomass additions. Increasing levels of nitrogen fertilizer up to 100 kg/ha increased the yields of rice and wheat substantially. Nitrogen additions through fertilizers also increased the biomass in the soil.

ACKNOWLEDGMENT

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ON-FARM TESTING OF CROPPING SYSTEMS

K.A. Gomez

Agricultural research in recent years has given more emphasis to understanding and possibly reducing the gap in crop productivity between experiment stations and farmers' fields. Researchers have become more aware that the impact of a new technology is measured, not by its excellence in experimental plots but rather by the extent to which it is adapted on the farms. The growing consensus among agricultural scientists is that the technology used on the farms is not catching up fast enough with that developed in experiment stations. The possible reasons are many. Farmers are unaware of the new technology. Farmers are anti-change. Farmers cannot afford the high input required by the new technology. The new technology was developed for "maximum productivity" rather than for maximum profit. The new technology does not work in actual farmers' environments.

While scientists have different opinions on the relative importance of the reasons for it, most agree on the urgency of studies that could characterize, quantify, and reduce the gap in crop productivity between experiment stations and farmers' fields.

The transfer of some research activities from the experiment station to farmers' fields has attracted much attention. Performing research in farmers' fields would, supposedly, eliminate the most serious reason for farmers' failure to adopt new technology, namely, the objection that the new technology developed in the experiment station does not work in farmers' fields.

In cropping systems research, two types of research could be conducted in farmers' fields. These are

1. **Technology-development research** (or research for designing or developing new technology). Its main objective is to understand and,

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possibly, quantify the effects of physical, biological, and economic factors on the performance of cropping systems. Examples are research on varietal screening, weed management, fertilizer trials, pest management, and crop interactions.

2. **Technology-adoption research.** Its main objective is to test the developed technology for its acceptability to farmers.

While the first type of research aims primarily at the gathering of information on the cropping systems' performance under varying environments, to be used as a basis for the design of cropping systems, the second evaluates the acceptability of the potential cropping systems to the farmers in the specific localities that the particular systems are designed for. Although the two activities can be conducted simultaneously, using some materials and facilities in common, it is important to remember that their objectives are distinctly different. For example, in the technology-development phase, tests in farmers' fields merely offer an opportunity to sample more environments, that is place an experiment in a "more realistic" environment than can be provided by the experiment station. In this type of research, the techniques used are the same as in the experiment station. The researcher conducts his on-farm experiments under conditions controlled to a certain degree and directly under his own supervision, as he would have done in the experiment station.

On the other hand, the technology-adoption phase demands not only that the tests be done in farmers' fields but that they be subject to some, if not all, of the constraints usually met on the farms. Appropriate modifications of research techniques are required.

Because technology-development research requires minimal modification of existing methodology, my discussion today will concentrate on techniques for on-farm testing in the technology-adoption phase. I shall first discuss some important considerations in doing on-farm research, then present specific procedures for conducting technology-adoption research.

IMPORTANT CONSIDERATIONS IN ON-FARM TESTING

As background for the procedures suggested in the next section of this paper, a few relevant issues will be discussed below.

1. **The need to test on several farms.**

Two major sources of variability in on-farm testing are (a) among farms, and (b) within a farm. While the number of replications within a test site (farm) is used to control variability within a farm, several test sites (farms) must be used to cope with variability among farms.

That is in contrast to the traditional experiment-station testing in which only the first source of variation is involved and, thus, only the number of replications is being considered.

The variation among farms is generally expected to be greater than that within a farm. Thus, using a large number of farms is usually more desirable than having a large number of replications within a farm. The number of farms needed for a particular problem depends greatly on the variation among farms within the target area. The larger the variation, the greater the number of farms needed.

2. **Selection of test sites.**

Test farms should cover, as much as possible, the total variation existing in an area. While both physical and socioeconomic conditions should be represented, the variation in the physical environments (mainly soil, water, topography and climatic conditions) should receive priority. The selection of test sites should be done as follows:

a) Stratify (or group) farms in the test area into a number of homogeneous physical environmental complexes (that is, the physical conditions should be more similar within a single physical environmental complex than among different complexes).

b) Select at random farms within a physical-environment complex.

3. **Precision of on-farm trials.**

Trials in farmers' fields may have fewer management controls than those in experiment stations. Hence, higher experimental error and probably a greater proportion of failures can be expected. Consequently, larger plots and more farms are usually used.

4. **The need to measure a minimum set of environmental factors.**

The measurement of environmental factors is needed, not only to relate biological performance to physical environment, but to ensure that sufficient variation among environments exists in the selected test sites. It is essential to prescribe the measurement of a standard set of minimum environmental parameters at all test sites.

5. **Technology to be tested: improved management vs. improved cropping patterns.**

Cropping systems technology that needs to be tested in farmers' fields may belong to one of two types.

Type I: Improved management of the currently used cropping pattern.

Type II: Improved cropping pattern. One or more crops are added to the farmer's cropping pattern, or crops in the original pattern are replaced by alternatives.

In the testing of Type I technology-change, interest is in the comparison of the farmer's management technique with the new technique. Since the crop sequence does not change, one or more management components within the system can be compared. The procedure for testing Type I technology-change is quite straightforward and follows closely the standard technique for single crops.

For Type 11, on the other hand, both the crops and the management components differ from those of the farmer. The basis of comparison is, therefore, not as clear-cut as for Type I. The conventional testing procedure is no longer applicable.

6. **Choice of factors to be tested.**

Factors influencing the adaptability of a given cropping system are innumerable. The major objective of on-farm testing in the technology-adoption phase is to identify major potential constraints to the adoption of the particular cropping systems so that appropriate schemes for their removal can be evolved. These constraints may be physical, biological, socioeconomic, or institutional. The constraints differ in degree of difficulty and in cost of removing them. The choice to remove does not always rest with the farmer; there may be for example, physical and institutional constraints.

Unless the objective is immediate adoption, different emphases can be placed on the different types of factor. A common procedure is to initially evaluate only the physical and biological factors (that is, the more-difficult-to-remove type) in first-stage testing. Cropping patterns that are found nonadaptable are discarded. Those that pass that test are further subjected to critical examination to determine if they fit readily into the existing socioeconomic and institutional conditions. If not, the specific constraints are identified, and the costs for their removal are examined and compared with the expected benefits.

7. **Test criteria.**

Two questions arise in determining test criteria for on-farm testing: (a) What is the comparison made against? and (b) What are the specific measures or indices to be used in making the comparison? For the first question, two possible alternatives are (i) to compare with the farmer's present system, and (ii) to compare with a predetermined "standard."

The first alternative is generally preferred.

For the second question, the answers are not as clear-cut. Some common criteria for on-farm testing are productivity, profit, stability, nutritional values, cash flow, and resource utilization. The appropriate index to be used for each criterion is not easily established. Take productivity, for example: Should the appropriate index be "production per day" or "production per hour of labor"? And how do we get a productivity index that can be compared across cropping patterns having different combinations?

Studies necessary to establish and standardize appropriate indices for use in on-farm testing of cropping systems are being carried out at The International Rice Research Institute (IRRI).

8. **Extent of farmer's participation in the trial.**
One of the important features of on-farm testing is the possible participation of farmers in the experimental process. It is generally claimed that by allowing the farmer to participate one can evaluate the degree of acceptability of the technology. On the other hand, farmer's participation can result in large losses in precision and, at times, even in total loss of the experiment.

It is my contention that the farmer's acceptance of a new technology should be determined on the basis of physical, biological, and socioeconomic constraints to adoption rather than simply on the basis of what the farmer thinks. The farmer works under a set of constraints that are generally beyond his ability to remove. His acceptance or rejection of a cropping system gives no clear indication of what he might have done had the constraints been removed. Moreover, the farmer's ability to manage a particular cropping pattern on his farm depends a great deal on how he allocates resources between his own crops and the crop assigned to him for testing. We can probably expect that whenever there is any conflict over resource allocation, the farmer will give priority to his own crops. Thus his failure to properly implement an experimental cropping system is not conclusive evidence of the unsuitability of that system. The farmer's participation in on-farm trials should not be taken for granted; it should be evaluated critically.

9. **Data to be collected: agronomic vs. economic.**
Data to be collected from on-farm testing of cropping systems can be classified, based on the unit of measurement as follows: (a) physical environment of the farm, such as soil, water, topography, climate, etc; (b) socioeconomic conditions of the farm household, such as number and age of household members, farm power, etc; (c) agronomic data from test plots, such as yield and other agronomic characters; and (d) resource requirements of the test pattern, such as labor requirement and input requirement, and so on.

The first two data types are not affected by the experimental technique used in the test plot since their measurement units are farm and farm household, respectively. On the other hand, the collection of agronomic and resource requirement data is greatly affected by the technique employed. In addition, agronomic data require methods of collection very different from those of resource-requirement data; it may be necessary to modify the experimental technique to satisfy the requirements of both groups. Two major differences in the requirements of agronomic and resource-requirement data are the following:

a) Data on resource requirements cannot be adequately estimated from the small plots generally used for agronomic data. Preliminary work at IRRI, for example, has indicated that the labor requirement should be estimated from plots that are about 800 to 1,000 sq m. That is much larger than the normal plot size (20 to 60 sq m) for measuring agronomic data.

b) Data on resource requirements of a cropping pattern are not as variable as most agronomic data. For example, data on labor use or power requirement do not vary much, especially within a single farm. There is probably little need for replication in measuring resource requirements of a pattern for one farm. On the other hand, agronomic data are more variable and replication may be needed.

TECHNIQUES FOR ON-FARM TESTING

In this section, a suggested procedure for on-farm testing of cropping systems in a technology-adoption research phase will be described. The presentation will be made as a step-by-step process under five headings, namely, (a) selection of test sites, (b) designs and plot layout, (c) plot management, (d) collection of data, and (e) data analyses.

A. **Selection of test sites.**

1. Using information on the variation in physical conditions within the test area obtained in the description phase of data-gathering[1] divide the area into two to eight subgroups. The major criterion for grouping is similarity in the expected agronomic performance within a subgroup. The decision on the number of subgroups is important: too few can lead to incomplete information, and too many can result in unnecessary expense.

2. For each subgroup, select two to five farms. As much as possible, select at random. While the problem of getting the close cooperation of the farmer concerned needs to be taken into consideration, it should not be the dominant factor. Otherwise, bias may result.

B. **Experimental design and plot layout.**

3. Determine whether the cropping system to be tested is Type I or Type II (see page 229).

4. For Type I (improved management of the currently used cropping pattern) the steps involved are:

   a) Determine the specific component technology that differs from the farmer's.

[1]Described in the report of the Cropping Systems Working Group, Third Cropping Systems Working Group Meeting, February 16–18, 1976, Thailand.

b) Identify sets of components that are closely related to each other and classify them as a single component. For example, since both herbicide-application and cultivation are related to the control of weeds, and one greatly influences the effects of the other, it is desirable to consider the two as a single factor.

c) Make the number of treatments two more than the number of components. For example, if there are four components to be tested, namely, variety, insect management, tillage and weed management, and fertility, the number of treatments for testing should be six.

Treatment 1: Recommended technology, that is, recommended variety, recommended insect management, recommended tillage and weed management, and recommended fertilizer application.

Treatment 2: Farmer's technology, that is, farmer's variety, farmer's insect management, farmer's tillage and weed management, and farmer's fertilizer application.

Treatment 3: Farmer's variety, recommended insect management, recommended tillage and weed management, and recommended fertilizer application.

Treatment 4: Recommended variety, farmer's insect management, recommended tillage and weed management, and recommended fertilizer application.

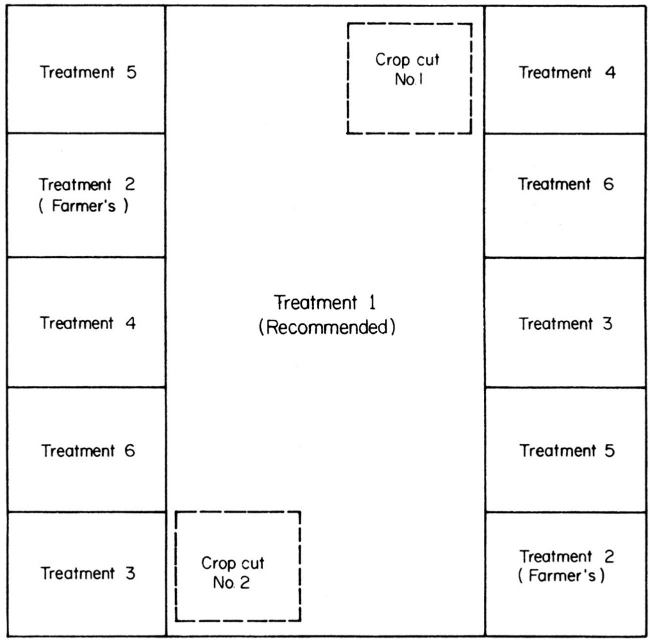
Treatment 5: Recommended variety, recommended insect management, farmer's tillage and weed management, and recommended fertilizer application.

Treatment 6: Recommended variety, recommended insect management, recommended tillage and weed management, and farmer's fertilizer application.

d) The plot layout provides two plot sizes: small plots for agronomic data and large plots for resource-requirement data. A sample layout is suggested by Figure 1. The required total test area is about 1,000 sq m. Five small plots on each side of the test area form one of the two replications. All treatments except the first are randomly allocated to the five plots of each replication. The first treatment (the recommended technology) is tested in the center area. The size of the small plots can be between 20 to 60 sq m. The consideration for choosing the specific plot size for the specific crop (or crops) and treatment involved is similar to that for the conventional field experiments in an experiment station. A slightly larger plot size, however, should be used in farmers' fields than in an experiment station (See item no. 3, p. 229).

5. For Type II (improved cropping pattern) the steps involved are:

a) Determine whether the new cropping pattern adds one or more



1. Sample plot for on-farm testing of a cropping pattern involving technology change in four components. Total area is about 1,000 sq m, and a small-plot size is about 20 sq m.

crops to the farmer's existing crops (Type IIa), or replaces farmer's crops with alternative crops (Type IIb).

b) For Type IIa, the choice of a particular crop (or set of crops) to be added defines one cropping system to be tested. For each cropping system, determine whether the growing of additional crops requires changes in management of existing crops. If so, the changes can be incorporated into the treatments to be tested. Plot layout could follow the scheme outlined for the testing of Type I cropping systems.

For example, adding a crop of sorghum to an existing rice crop may require changes in the management of the rice crop, such as changing the variety to one with a different growth duration, changing from transplanting to direct-seeding, changing planting time, or changing fertilizer application. In testing the rice-sorghum cropping pattern, the design and plot layout for the rice crop can follow that described in item 4, above, with the recommended management of the rice crop in the center area (the large plot) and the five treatments involving different levels of the four components (variety, method of planting, time of planting, and fertilizer application) in small plots on each side of the test area (see Fig. 1). A crop of sorghum with a prescribed management level can then be grown in all plots as the succeeding crop.

c) For Type IIb, since the cropping pattern structure differs entirely from that of the farmer's pattern, the consideration for component changes that was necessary in type I and type IIa is no longer valid.

The recommended cropping pattern will be evaluated and compared with that of the farmer, based on some appropriate test criteria (see page 230). The comparison will be made for the cropping pattern as a whole, and not component by component.

C. **Plot management**

6. All management practices except the specific components under test should be managed by the farmer. Those pertaining to the components should be managed by the researcher. If, on the other hand, it is deemed essential for the farmer to totally manage the recommended technology the farmer's management can be done in the large plot.

D. **Collection of data.**

7. Physical environment[2]: Decide on the standard minimum set of parameters of physical environment to be measured for each test farm. The parameters to be included in the minimum set should depend on its influence on the agronomic performance of the cropping patterns being tested. The more commonly used parameters for this purpose are

- rainfall,
- solar radiation,
- soil texture,
- topographic position, and
- depth of water table.

8. Socioeconomic condition[3]: Decide on the standard minimum set of parameters for the socioeconomic conditions of the farmer. The criterion for choosing the parameters that are to be included is the magnitude of their influence on the adaptability of the cropping pattern by the farmer. The more commonly measured parameters are

- labor availability,
- power availability,
- land condition, and
- management capability.

9. Agronomic data: Decide on the agronomic data to be collected for each cropping pattern tested. Some of these are

- economic yield,

[2] Additional information can he found in the papers of Scharpenseel, Oldeman, and Brammer presented in this Symposium.

[3] Additional information can he found in the papers of Jodha, Seetisarn, Banta, and Price presented in this Symposium.

- insect and disease incidence, and
- weeds.

Data are collected from each of the small plots as well as from the subareas in the large plot identified in Figure 1 as crop cut no. 1 and crop cut no. 2.

10. Resource-requirement data: Decide on the resource-requirement data to be collected for each cropping pattern tested. Some of these are

- labor requirement,
- power requirement,
- land requirement, and
- management requirement.

Data pertaining to the recommended technology are collected from the large trial plot and those of the farmer are collected from his field. Information on other treatments that are of intermediate level is simply obtained through direct computation.

11. Establish appropriate techniques for measuring the four sets of parameters mentioned in items 7 to 10. It is worth pointing out that standard techniques for measuring most of these parameters have not been established. While the collection of agronomic data for describing the performance of a cropping pattern can follow more closely the established standard procedures, collection of data to describe resource requirement does not.

While proper indices for some of these parameters are still being developed, raw data can be collected. For example, data on labor requirements can be collected as the man-hours required by each operation of the cropping pattern, including the specific time each operation is performed. From such data the labor profile, or other indices that may be deemed appropriate in the future, can be easily assessed.

E. **Data analyses.**

12. Compare agronomic performance of the test pattern with that of the farmer. This is straightforward for Type I cropping systems but not for Type II.

13. Compare resource utilization of the test pattern with that of the farmer. Here, the lack of proper indices for resource utilization creates a problem; a clearly defined goal is necessary. For example, how does one compare labor utilization of the test pattern and that of the farmer? In one case, labor that is relatively more evenly distributed over time may be a desirable goal. In another case, uniform distribution may not be as important as reduction of the labor requirement.

14. In a case in which component technology is tested individually, as for Type I cropping systems, assess the contribution of individual components to the success (or failure) of the new cropping systems and compare

each with its counterpart in the farmer's system. Such assessment enables the researcher to determine whether modification of the specific structure of the systems being tested is required and, if so, what the modification is. It also allows computation of the relative costs of and benefits from the farmer's adoption of the different components and, thus, provides him with better means of evaluation.

15. Combine agronomic and resource-requirement data to estimate the various indices that are deemed important for comparing the test pattern with the farmer's, for example, profit and nutritional values.

16. Combine data on resource-requirement and agronomic data for all farms. Such analysis can provide not only information on the stability of the cropping systems but also information on (a) the effectiveness of the present criterion for subdividing the area into different physical-environment complexes, and (b) the effects on the performance of the cropping patterns of certain environmental factors measured during the technology-development phase.

17. Compare the resource requirements of the test cropping pattern with the resources available to the farmer. This step helps to identify constraints on resource utilization, if any exist.

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DISCUSSION

VAN EMDEN: Your examples included systematic variation of varieties and fertilizer, where the technology-development stage ought to have reached the point that such main effects are of considerably less interest than interactions. Do you see no merit in replicating such main effects at a lower level than the other aspects of the experiment?

K. Gomez: The number of replications in the proposed design is only two. Further reduction is not justifiable. It should be pointed out that the main effects here are measured with the individual farmer's level as base and may differ from that measured in the technology-development stage.

MORRIS: Could you briefly discuss how the test designs should be allocated over farms or fields to better evaluate the "stability level" factor. What data analysis methods might be employed to estimate or compare stability levels?

K. Gomez: As stated in the paper, the test farms should be selected to cover, as much as possible, the total variation existing in the test area. This will provide a good basis for the evaluation of the stability level of cropping systems under test. The stability level referred to here is different from the traditional one which is measured from varietal tests at different locations. Hence, a different approach is required.

PRICE: (1) You said experimental patterns were to be compared with the existing system. Which data contain information on a farmer's pattern? Which contain socioeconomic information? (2) One must compare new patterns with one another as well as with the farmer's pattern. Please comment on when comparisons of recommended treatments are appropriate, and when comparisons of farmer's treatments are appropriate in evaluating new patterns?

K. Gomez: Agronomic data on a farmer's pattern could be obtained either from the test plot with treatment 2 (that is, farmer's pattern), from the farmer's field, or from both. If both sources are used, the ability of the researcher to simulate the farmer's practices can also be evaluated. The socioeconomic or resource-requirement data on the farmer's pattern are obtained from the farmer's field. (2) Comparisons among recommended cropping patterns as well as between each recommended cropping pattern and the farmer's pattern should be made.

LOHANI: The layout that you presented for comparing various test components may be valid if there is no influence of one treatment upon another in the adjacent plot and thus there is no interaction. However, for a treatment like the use of insecticide for insect control, effect of minor nutrients, and so on, a different layout with large plot-size may he necessary.

K. Gomez: With the proposed design, plot size can he increased from 20 sq m to 60 or 80 sq m for testing of such component as insecticide application. In addition, other measures such as the use of plastic sheets between plots to prevent spray drift when insecticide is applied should he employed.

NURJADI: Assume that the same level of management in similar agroclimatic zones gives the same yield in plots with the same treatment. Suppose there is a series of five trials, each located in a different province but within a similar agroclimatic zone (with 5 replications/trial). How does one analyze yield data coming from such trials in order to obtain a recommendation (recommended technology) for that agroclimatic zone in five provinces? As you know, it is very important to make national recommendations of technology.
Please help me with a more detailed procedure for analyzing such data. Can I analyze the data by treating the five trials each with 5 replications as one single trial with 25 replications?

K. Gomez: Obtain a combined analysis of variance of yield data over trials, providing the following sources of variation : trials, replications within trials, treatments, trial × treatment interaction, and pooled error. If there are no trial × treatment interactions, then results can he pooled and applied to the whole agroclimatic zone under study. Otherwise, the nature of the interaction should he critically investigated, and further subgrouping of the area into two or more agroclimatic zones (where technology recommendations could vary) is likely.

ECONOMIC METHODOLOGY FOR ASSESSINGCROPPINGSYSTEMS

D.W. Norman and R.W. Palmer-Jones

The study of cropping systems has in the past heavily emphasized the technology of production. It has looked at the interaction of physical and biological factors with management. Such study can tell us the necessary conditions for crop growth—what crops it is technically possible to grow, and how. But it ignores one of the crucial elements of the cropping system—the sufficient condition—the human being.

Cropping systems are harnessed by men seeking certain goals. No matter how broad the range of technical possibilities may be, it is the individual human who ultimately decides what is used in practice.

In this paper we shall look at that individual.

The human element in the cropping system can, for study, be divided conveniently into two sets of factors.

First are exogenous factors, such as the social environment, that are largely outside the control of the individual farmer. The farmer sees these as infrastructural elements that encourage or discourage his adoption of a system. They may convince him of the system's viability (extension staff inputs, explicit provision of markets through setting up of market boards, minimum prices, and so on). They may ensure that he has the financial resources he needs when he needs them to pay for the improved technology. They may reassure him that he will receive necessary new inputs at the right places and at the right times. In the developing world these elements are often provided by government funds and personnel.

Second are endogenous factors that are under the influence of individual farmers. Depending upon circumstances and the farmer's wishes, the factors of production (land, labor, capital, and management) that he initially has access to may be complemented and supplemented quantita-

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tively or qualitatively, or both. The farmer's problem then lies in allocating the factors of production he has at his disposal to the technically feasible crop enterprises (cropping systems), livestock enterprises and off-farm enterprises and activities in deriving a farming system' which satisfies him, by, for example, increasing his chances of (social) survival-taking one year with another—maximizing net income for a given mean level and variance of subsistence output, and so on.

The cropping and, ultimately, the farming systems that tend to evolve are therefore very complex, and the necessary and sufficient conditions for their existence and adoption go far beyond the physical and biological elements to encompass also those of an economic, social (Harwood, 1974; Charreau, 1975), political, and historical nature.

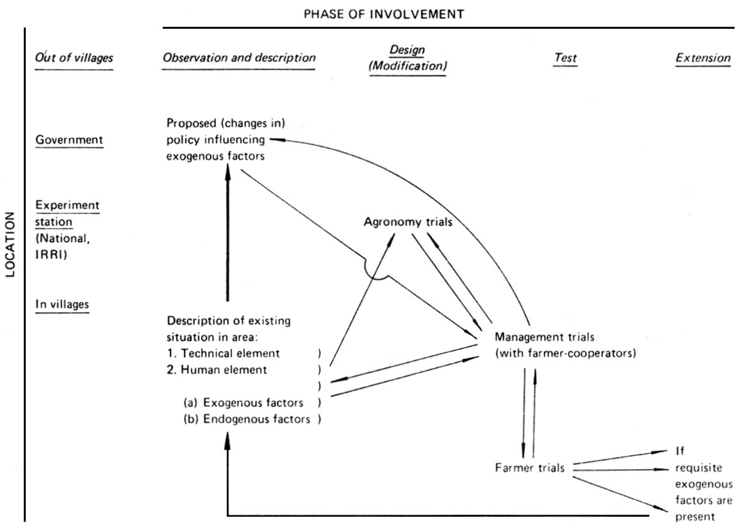
REQUIREMENTS OF CROPPING SYSTEMS RESEARCH

Since it is apparent that the farmers' existing cropping system reflects a complicated interaction of variables, the delineation of the most efficient program for developing, designing, testing and extending improved cropping systems that will be adopted by farmers to their benefit is, under the most ideal situation, a daunting task. Limitations on finance and manpower also must be taken into account in organizing a realistic research system. The research system must ensure as far as possible the collection and analysis of adequate relevant data for (1) describing the existing "total" environment (technical and human), (2) using information from that description to design and test improved cropping systems, and (3) documenting and evaluating the improved cropping systems in such a way that they may be applied in areas other than where they were developed and tested.

Some standardization of the research system, data collection, and analytical procedures may achieve economies in operation and in later transfer of the pattern to other areas by increasing the scale on which it is possible to collect reliable data and to compare them. This paper is a discussion of the possibility of such standardization.

The research process. The process outlined in Figure 1, which is almost the same as that which prevails between cooperating countries and the International Rice Research Institute (IRRI) (Carangal, 1975 ; Harwood,

[1] The term "cropping system" is used to refer to the systematic, even systematically irregular arrangement of economic plants in a field over time, and the sequence of crop husbandry operations employed in this area. The rotation is a part of the cropping system. The term "farmmg system" is used to mean the allocation of resources to agricultural activities. In peasant farming systems it may be helpful to talk in terms of own-farm and non-own farm activities.



1. A scheme for cropping systems research

1975), is one approach to the development of improved cropping systems. A discussion of the outline follows.

1. An environmental description includes both technical and human elements; it needs input from both technical and social scientists, from extension workers and other government officials. Since the adoption of changes by farmers is purely voluntary in most parts of the developing world, and since input supplies and product disposal will be largely unmodified in extension programs, the study must adequately describe both the social system and the individual situation if the improved cropping system is to appeal to farmers who will implement them.

2. Complementing the environmental description should be some idea of changes in government policy that might influence the exogenous or endogenous factors, and hence the type of improved cropping systems that could be relevant to farmers in the area. For example, a weak infrastructural support system (exogenous) would imply that the most relevant improved cropping pattern (a) would usually emphasize dependable (stable) returns rather than spectacular but very variable returns (Harwood, 1974); (b) would be easy to adopt and would not involve radical changes by the farmer; (c) would need only low levels of, and be productive in the absence of certain new inputs; and (d) would not involve a high cash investment.

In contrast, a strong infrastructural support system could stimulate the development of more radical changes. It could (a) emphasize large increases in gross return; (b) use large quantities of improved inputs, given a good input distribution system and the availability of institutional sources of credit; (c) accommodate a relatively complex improved cropping system and potentially a relatively high variability in returns, although minimum net return would be greater than current minima. Both complexity and variability could be relieved to some extent by an extension staff. Such staff will be more common when infrastructural systems are strong.

The information on proposed changes in policy can be obtained by the social scientist from government.

3. In conducting agronomic trials, technical scientists should consider the environment and government policy. The economist then can play an *ex ante* role in the development of relevant improved cropping systems in contrast to his usual *ex post* role of evaluating already developed technology. Typically the social scientist will be concerned with the farming system itself and with variables that may not be of immediate interest to the technical scientist.

4. Information on the environment, government policy, and the agronomic trials is fed into the designing of improved cropping systems and testing them in management trials carried out on farmers' fields with farmer-cooperators. Although the control under such conditions is not as great as at research stations, and fewer alternatives can be compared, it is believed that the conditions more closely reflect practical farming conditions (Collinson, 1972), in particular with respect to other inputs and the farming system employed. In addition, work in farmers' fields tends to keep interdisciplinary research teams practically oriented, and their direct involvement in design, implementation and evaluation prevents tension building up between designers and evaluators. The trials need careful supervision and evaluation. Once again, technical and social scientists and the extension specialists need to be involved, receiving feedback from the agronomic trials, from the existing farming system, and from the exogenous factors potentially under government control that effect adoptability of systems.

5. At present, the main involvement of IRRI, in cooperation with national agencies, is with environmental description, agronomic trials, and design and testing. Farmers' trials[2] and extension appear to be generally the concern of the national agency. Although extension will obviously play the major function in farmers' trials, there appear to be two roles for the social scientist. First, he will evaluate the impact of adjustments made during the trials. The management trials are heavily supervised and the

[2] Farmers' trials are the initial stages of an extension program and are undertaken without the direct involvement of full-time researchers. Their form will be variable.

compliance of the farmer is likely to be fairly good; this is not necessarily the case with farmers' trials, especially if low infrastructural support systems are envisaged. Modification of the package developed in the management trials is likely to take place to suit individual farmers' conditions. Over time, further changes are likely to take place. The evaluation of such adjustments and why they have occurred could be important in assessing what might happen if the improved cropping systems were introduced elsewhere; indeed such evaluation may have implications for earlier stages of the research process (See Fig. 1.).

Second, he may need, under some circumstances, to assess the implications that the impact of particular improved cropping systems on total production, income distribution, and so forth, have for governmental policy. Policy implications can usually be understood only at the extension stage, because of the poor understanding by social scientists of the macro-level effects of technological innovations.

There is, we suggest, a role for the social scientist in all the five stages discussed above. Without his collaborative input, it is unlikely that relevant improved cropping systems will be developed, tested, evaluated, and adopted; the consequences for support of agricultural research are obvious.

Problems of collecting socioeconomic data. Data collection costs money. Technical scientists make direct measurements within controlled environments; social scientists must collect much of their data indirectly through respondents who are each unique, independent, and self-interested participants. The conflict between a desire for broad relevance of results, requiring large samples, and a desire for detailed, precise observation and understanding, obtainable from small samples, becomes critical for the social scientist. The data required and the accuracy needed will partially determine the collection method. Direct observation and interview methods are often used. Lower measurement errors can be obtained through direct observation (for instance, measuring fields oneself rather than relying on farmers' estimates), but the approach is expensive and time consuming. All else being equal, it implies small samples[3], with relatively large sampling errors. Thus, for many types of data, the interview method is used.

The type of data required will influence the number of interviews needed to achieve a particular degree of accuracy. In this respect, Lipton and Moore (1972) have drawn a useful distinction between single point

[3]It must be noted that in most circumstances direct observation of some relevant data is not feasible without very small samples. Combination of direct observation. interviews, and cross-checks helps, but the full benefit from such an approach requires complete enumeration of, for example, a village, which of course reduces the number of villages that can be sampled.

Table 1. Classification of data for economic analysis of a cropping system.[a]

	Inputs		Products	
	Single-point	Continuous	Single-point	Continuous
Registered	Inorganic fertilizer	Money for hired labor	a) Cash crop sales b) Harvest of major food and cash crops which are harvested at one point in time	Sale of food crops
Nonregistered	Seed	a) Family labor use. b) Quantity of hired labor used c) Organic fertilizer	Harvest of minor crops	a) Harvest of crops that occur in small amounts over a long period of time b) Consumption of farm-produced products

[a] This breakdown is based on a concept developed by Lipton and Moore (1972). This continuum ranging from registered to nonregistered refers to the extent to which circumstances influence the respondent's ability to remember the quantities involved in an activity, while that from single point to continuous refers to whether the event occurred once or frequently.

and continuous data, and between registered and nonregistered data (Table 1). The continuum ranging from single point to continuous data discriminates among activities according to how often they are repeated. The continuum ranging from registered to nonregistered refers to the extent to which circumstances influence the respondent's ability to remember the quantities of an activity.

Measurement of single-point, registered data should, all else being equal, be fairly error-free even if the information is requested at infrequent intervals.[4] For data in the continuous, nonregistered class, there is no substitute for frequent interviewing.[5] It is particularly unfortunate that labor use, especially family labor, falls into the latter category.[6] Collinson (1972), attempting to reduce costs and circumvent the labor data problem, conducted detailed questioning of each respondent in one interview; he obtained labor profiles by month and by operation for crop enterprises, and for the farm business as a whole for an average year. Under certain circumstances that may be sufficient.

[4]However, frequency of interview is definitely not the only variable affecting accuracy, although it is the one given most consideration. Just as Important are the quality of the enumerators, and the trust and involvement of the farmers. which again can only be obtained at a cost, both in terms of quantity and quality of resources, time. quantity and type of data collected.

[5]Costs can be cut drastically if farmers are sufficiently literate and can be trusted to keep then own records, as they are doing in the Philippines work. Such a possibility is likely to he the exception, rather than the rule in most of Southeast Asia.

[6]Single-point and registered data may not he as well remembered as Lipton and Moore suggest, if they apply to more than one field. Also in order to check for continuous, registered data (for example, hired labor) it may be necessary to ask about corresponding nonregistered data.

The relation of cost to the degree of accuracy required in the analytical stages needs to be borne in mind constantly by the social scientist undertaking work on improved cropping systems.

DESCRIBING THE EXISTING SITUATION

The description of the existing situation should, as emphasized earlier, provide a major input into both agronomic and management trials. It should include the following information:

1. A general description of the area in terms of major physical parameters, such as temperature, water availability by the shortest possible period a day, for instance, evapotranspiration, and so on.
2. A general description of the area in terms of local variations in physical parameters, such as topography, rainfall, soil type, weed or disease infestation, and so on.
3. A description of the economies of different farming households in the area in terms of the stock and flow of resources (such as land, labor, and capital), and the output and hence, income throughout the year for both farm and off-farm activities.
4. A detailed description of the major cropping systems used by farmers in the area in terms of the stock and flow of resources, the management practices, yields, profitability, dependability, and so on.
5. A list of prices and availability of products and inputs in the area by period.
6. An assessment of the farmer's viewpoint, including his ideas of what is desirable, the problems he faces, the ways that are available to him for achieving what he wants, and the ways in which he either deals with or expects to deal with his life and the problems that may face him.
7. An assessment of the likely effectiveness of the infrastructural support system and an evaluation of the possible impact of any proposed changes.[7]

Data listed under point 1 are presumably at least partially available from those used in defining agroclimatic zones (Carangal, 1975). Technical scientists must be able to supplement them with locally available data which presumably are also available for items under point 2.

Data involved in points 3 to 7 come mainly under the purview of social scientists although, particularly with 3 and 4, cooperative, multidisciplinary work is highly desirable. For the data required in 6 and 7 and for parts of 3 to 5, frequent interviewing is unnecessary, provided all the other factors

[7] This would arise from work mentioned under point 2 on page 243.

mentioned are satisfactory (see footnote 4). However, cash flow and labor utilization are liable to large measurement errors if interviewing takes place only at infrequent intervals.

Using samples of two sizes appears to be justified: a fairly large sample to collect data that exhibit little sensitivity to the frequency of interviewing, and a smaller sample to collect data at frequent intervals; the latter can be used both for variables that are sensitive to interview frequency and for those that are not. Another way to cut the cost of collecting data to describe the existing situation might be to use Collinson's (1972) approach for constructing profiles of labor and perhaps cash flow[8], and supplementing it with information on all the enterprises undertaken by the farmer who is cooperating in the management trials could then be collected. The data are obtainable because of the intensive contact required by the trial, and because of the offer of something in return for the data. However, there are major methodological problems connected with the relevance of data obtained by such intervention; they include problems of sampling bias and of stamina of cooperating farmers. The resources required for a satisfactory single, frequently-interviewed sample may preclude its use where resources are limited. It cannot be too strongly emphasized that collecting data from a panel is not just a matter of designing and administering a survey; it is an interactive process in which the researchers learn gradually about the farmers as the latter come to understand, trust, and like the researchers. Survey designs seldom come off the shelf.

MANAGEMENT TRIALS

The management trials or experimental site trials use relatively few sites and farmer-cooperators. This means that certain special precautions must be taken.

1. The trials must be carefully selected on the basis of the agronomic trials, and of the description of what the situation is now and what it might be after policy changes.
2. Farmer-cooperators must be carefully selected to represent different resource classes. Even when that is the case, the fact that they have to cooperate in the highly supervised trial may mean that they are more compliant with instructions than "average" farmers. However, that compliance is not really under investigation in the trials.
3. Because of the overhead costs of mounting an interdisciplinary team for such trials, it is essential that utilization of the results be maximized. Usefulness of trial results can be expanded by the standardizing design,

[8] This is being suggested by the authors and may not be feasible.

execution and reporting with the help of a “cookbook” of improved cropping systems. The cookbook describes cropping systems in such a way that their relevance to and potential success in other areas can be assessed. A basic cookbook could be designed at IRRI and be continuously modified and updated locally.

Three other points should be considered in undertaking management trials.

1. Since the research team discusses with the farmer the management trial he will undertake, the economist can collect data on the cropping system that the farmer is using on his own initiative and with which he will, inevitably, compare the improved cropping system.[9]

2. There may be a temptation if existing and proposed infrastructural systems are promising, to test only improved cropping systems that require high levels of support. That will be especially true if the trials are conducted in areas where a better-than-average support structure already exists, or if there is a class of especially cooperative farmers to whom the necessary support can be easily made available. We plead here for management trials also of strategies that require only minimal levels of infrastructural support. Individual results are not likely to be nearly as spectacular as for other trials, but the applicability of such systems may be much wider and their aggregate effects much greater. Many developing areas have poor support systems, and even where good support systems are available some farmers are not able or willing to take advantage of them. Improved cropping systems need to be developed for a wide range of social circumstances.

3. Care should be taken not to eliminate improved cropping systems simply because, while they appear to be technically sound, they are not suitable for the conditions prevailing in the area. Criteria for evaluating the relevance of improved cropping systems will differ from area to area due to differences in resource levels and qualities, incomes, infrastructural support systems, and so on, and may change over time. Also, slight modification of a technology may result in improved acceptability.

A cookbook for a particular improved cropping system should contain the information discussed briefly in the following sections.

Description of the cropping system. A description of the cropping system would include a specification of the original plan, and a description of the scheme that was actually followed in terms of:

1. crops (varieties) involved;
2. quantities and types of material inputs involved;
3. specification of timing (in relation to exogenous events if necessary),

[9] This should usually he simply updating knowledge about the existing situation.

methods and rates of application of all inputs;

4. specification of any special cultural practices and equipment introduced;

5. indication of expected yields; and

6. indication of other anticipated changes in the farmer's system implied or necessitated by adoption of the new system.

Description of the physical environment. A description of the physical environment would include

1. location (latitude, longitude, altitude);

2. the distribution between years, by 5- to 10-day intervals, of the actual daily levels of:

   a) water availability (rainfall, supplementary irrigation),

   b) temperature (maximum and minimum), and

   c) potential evapotranspiration;

3. specification of soil type, including physical and chemical properties as they are likely to affect tillage, nutrient and water characteristics, erosion, and so on.

Economic specifications. Estimate the following:

1. Labor profiles by labor category and operation[10] in 1- or 2-week periods, referenced to the exogenous events. Reference to events such as rain, irrigation, or tractor cultivation is essential because of the timeliness limitations for many operations. For example, planting may *have* to occur 1 or at most 2 days after rain or irrigation; or weeding may not be feasible or desirable more than 4 or 5 days after rain.

2. Power profile by machine, operation period, and events.

3. Profile of cash income and outgo by season and period.

4. Measurement of other items specified in input and output sections of Table 2.

Evaluation. It is obvious from the preceding discussion that the evaluation of an improved cropping system must be based on far more than mere profitability. A number of criteria for evaluating the systems are considered in the following subsections.

1. **Level of returns.** The most commonly used criterion is level of returns. To relate inputs and product or products it is necessary to move away from purely physical indices, such as land-equivalent ratios, to some kind of common denominator—usually money (Menegay, 1975). Table 2 summarizes the process of calculating the net return per hectare. However, a farmer who is interested in profit maximization will achieve that goal by

[10] The widespread use of labor equivalents for different categories of labor must be avoided where possible, since relative productivity is hard to generalize, and varies with operation, etc.

Table 2. Suggested layout for assessment of profitability (per ha).

		Crop 1	Crop 2	Crop3	Crop 4	Crop 5	Crop 6	Total
output	(1) Yield (kg/ha)[a]							
	(2) Price ($/kg)							
	(3) Gross value [(1) x (2)]							
		Quantitative description		Actual payment		Cash equivalent	Subtotal	
Inputs	(4) Land rent							
	(5) Labor. (a) Hired							
	(b) Other nonfamily							
	(c) Family							
	(6) "Capital[b]:							
	(a) Seed							
	(b) Seed dressing							
	(c) Inorganic and organic fertilizer							
	(d) Other, specify[c]							
	Costs of production:							
	(7) Cash and direct kind cost[d]							
	(8) Including all inputs at Imputed costs							
Profit	Net return:							
	(9) Including costs as in (7) [(3)–(7)]							
	(10) Including all costs [(3)–(8)]							

[a] Farm gate if possible. If not give location and transport methods, availability and cost. Give form (threshed, unthreshed, etc) and grade if necessary. Also give date of price fixing, preferably at harvesting to avoid ambiguity about storage costs [b]Capital is a loosely defined category including working and fixed capital. Consideration should be given to Including actual or Imputed interest or opportunity costs of resources to pay for land or labor Depreciation should also be included [c]Includes owned, hired and borrowed inputs of animal or mechanical power, sprays, water, and interest [d]Other statistics may be suitable depending on how actual payments are made.

Table 3. Returns to factors of production.

	Factor	Specific return	Method of calculation[a]
(11)	Land	$/ha	(10) + (4)
		$/$ land	[(10) + (4)1/(4)
(12)	Labor	All labor	[(10) + (5) (a) (b) (c)]/total man-hours[b]
		Family labor	[(10) + (5) (c)]/family man-hours
		Peak tabor	(10)/total man-hours in period[c]
(13)	Cash	All cash	[(10) + all cash costs]/all cash costs
		Excluding labor	[(10) + (5) (a) (b)l/[all cash-(5) (a) (b)]
		Cash constraint [d]	(10) /total cash costs in period

[a] Line numbers refer to Table 2. [b] Weighting of different types of family labor to be stated. [c] There may be more than one period in which labor limits output. Total hours per period may not reflect this if, for example, some activities are particularly arduous, or have a rigid time constraint. [d] Cash constraint by supply or demand.

maximizing the return to his most limiting factor. If land is not, in fact, his most limiting factor, net return per unit of land will not be the most relevant criterion. The plan of Table 3 provides a tool for evaluating an improved cropping system in terms of different factors of production, both as annual total inputs and as the flow of some inputs. That permits assessing suitability of the cropping system to wide variations in factor supplies. For example, an appropriate cropping system[11] in an area with a marked shortage of labor at a certain time of year will be one that increases the return per unit of labor at that time. It may be a completely different system from that appropriate where land is the most limiting factor.

2. **Variability of returns.** Differences between yields, input levels and economic returns[12] of different farmers will be available from earlier analysis. If the test sites are dispersed, weather variation may account for some variance, but generally year-to-year variations in yield caused by weather will be very much greater than within-year variation.[13] The effect of weather on input levels and timing should be borne in mind. For example, very high temperatures may limit the productivity of labor and thus constrain output; planting or tillage operations may be feasible only under certain soil moisture conditions of limited duration.

In practice, a very large amount of variance in yields from management

[11] Assuming that the other criteria discussed later are satisfactorily met.

[12] Economic return can he defined in terms of net returns, or returns to factors as in Table 3.

[13] Indirect methods of assessment of interyear variability will have to he used, as resource constraints will preclude extended management trials. Ideally we would like to simulate yields and returns using crop (cropping system) growth models and either historical weather data or a weather model. Yield-weather models must he based on sound theory and properly estimated (Palmer-Jones, 1976). The implications of the technology for individual strategies in the face of major decreases in standard of living of the individual or community should be considered. At least it is necessary to think through the implications of various weather patterns or other exogenous events for the cropping system and its relation to the rest of the farming system, taking into account whole income variation. Flexibility and well developed and documented fall-back strategies should he an integral part of a cropping system.

trials will remain unexplained, and for assessment will have to be regarded as an inherent characteristic of the technology. Depending on the size and distribution of the unexplained variance, different types of data and analysis will be applicable. Ultimately, management trials are only a stage in the exploration of the production surface (the determinants of yield), and continuous and sequential assessment of the technology is necessary to building up a satisfactory picture of its variability.

A number of methods have been used to look at variability. Mean and variance have been the main tools although, more recently, stochastic dominance, that is, a greater probability of a higher yield at all yield levels (Anderson, 1971), reduced expected loss (Zandstra et al., 1976), and other variants have been suggested. While all such statistics have intuitive appeal, they are to some extent arbitrary and may be misleading. The problem of which decision rules should be used in risky low-income situations in different social systems remains unsolved.

Although in the light of the above it is recognized that there are limitations to their use, it is suggested that the following should be calculated from the management trials:

a) the probability distribution of economic returns,
b) mean and variance of economic returns,
c) the probability distribution of economic loss, and
d) the expected value of a loss.

The probability distribution of economic returns[14] should be presented graphically as a frequency distribution; extreme or unexpected values should be discussed, as some may be irrelevant and unnecessarily distort the subsequent statistics.[15] Some attempt can be made to describe the distribution if it is normal.[16] Ultimately, intuitive judgment has to be used about the true distribution and significance of the variability of returns, and that judgment should not be hidden behind such statistics as the mean or moments.

As has already been suggested, a desirable feature of a technology is that it should be stochastically dominant. The dominance can be shown by drawing cumulative frequency distributions on a single graph. If only one technology is being evaluated, it should be compared with the existing situation. However, stochastic dominance is unlikely to be a discriminating criterion, since the cumulative distributions will probably cross one or

[14] Since return will be mainly, hut not totally, dependent on yields, it may be simpler to work with yields than returns

[15] If possible, a regression model should he fitted to the yield data so that residual variance for specified levels of inputs can he discussed. Examination of economic returns presents the point of view of society; the individual would be more concerned with variability for his chosen level of inputs and management skill.

[16] See Day (1965) for the use of probability distributions to describe yields.

more times.

Under such circumstances, one has resort to other criteria, all of which will be derived from the probability distribution of returns. If the distribution can be normalized, then at least a higher (or no lower) mean and no greater (or smaller) standard error are sufficient criteria for improvement. But again it will not be possible to show for most technologies that they fulfill these criteria; other criteria must be employed. Under low-income situations, it is intuitively plausible that higher lower-returns, or at least no lower ones, and a higher expected return are generally sufficient conditions for acceptability.[17] In *reality,* the term "higher lower-returns" is difficult to define since, again, one is likely to be dealing with poorly defined and nondominant distributions. A lower probability of a loss (Sp (R|R £ 0, where R is net returns and *P* is the probability of *R*), and a lower expected value of a loss ($SP_i{\cdot}R_i|R_i$ £ 0, where P_i is the probability of a return in the interval *i,* and R_i^l is the mean value of returns in *i*) possibly are necessary conditions, but because they neglect the "worst" outcomes they are not entirely intuitively acceptable. In any case, it is desirable to present the actual frequency distribution of poor returns (which will probably not include the worst outcomes) rather than simply make arbitrary assumptions about what is the worst outcome (or worst distribution of outcomes) and base evaluation or analysis of decision-making strategies on that (Low, 1975). It has to be acknowledged that societies provide numerous social strategies and mechanisms for dealing with exceptionally low returns, and one might do better to consider the effect of the technology and its support on these mechanisms, rather than search for dominant technologies.

3. **Infrastructural support.** The basic aim is to understand how to obtain farmer adoption. While more general policy affairs have implications for the suitability of technology (for example land tenure, taxation, and so on), the infrastructural elements mentioned at the beginning of this paper are of more direct relevance.

Management trials do not usually compare alternate levels and sources of direct support, nor are they intended to do so. A potential major weakness of reports of the trials is that the support provided and the social situation within which the trials operate go unreported. One may obtain an idea about the technology, but very little about the means and costs used to obtain its implementation; one can predict the results of implementation but not how to obtain it. At best, if the support and social systems are adequately described, one may know how to obtain the results, but not

[17] Other conditions might be a minimum increase for given size and type of changes, and what is often termed "social acceptability."

what happens if various components of the support are altered.

For an adequate description of the support, the following should be made explicit.

a) Extension efforts, [18] including details of contacts, and individual control over technology implementation.

b) Financial arrangements for inputs and outputs.

c) Biases in the access of the selected farmers to the support system.

Data for such a description are already available in part from the description of the technology, and from comparing the original specifications with what actually happened.

Collinson (1972) has also indicated how a technology can be analyzed to indicate the conditions, including infrastructural support, required for adoption.

4. **Farmer assessment.** Several times the point has been made that, for the circumstances with which we are concerned, the farmer ultimately decides what to do, and therefore his opinion is relevant. But it may be very difficult to get a direct statement of his attitude. He has a self-conscious interest in the results of expressing his opinion. Since he is likely to perceive that his private interest is in conflict with the society's welfare, his answers to such questions as: "Was it a good thing?", "Would you grow it?" or "What would make it better?" are unlikely to be straightforward. The notorious unwillingness of farmers to express negative opinions about government initiatives, especially when facing government employees or those who are identified with government, would hardly need mention were it not that the expression of a few negative attitudes is often taken as proof of frankness. Farmers are likely to say that shortage of labor restricts their output. However, they are unlikely to say that they would probably not adopt a technology dependent on new scarce inputs because of doubt that a system that could deliver them would allow farmers to benefit from them. Also, giving too much attention to farmers' attitudes is likely to give undue weight to the most articulate. Finally, the use of certain methods of public opinion assessment (such as, public meetings to choose the most suitable varieties) may have unpredictable results because of the lack of experience with such techniques in the social system of an area.

This is not to say that attention should not be paid to farmers' attitudes; but we feel that any quantification without in-depth sociological evaluation is likely to be pointless. Any such investigation would be too location-specific to warrant any attempt at "cookbooking".

5. **Farm planning.** What has been suggested so far is a partial approach

[18] Extension effects on farmers' knowledge can be assessed by questionnaire although the questionnaire would seem difficult to design.

to the testing and evaluation of cropping systems; a field using the system is grown, and the inputs and outputs are recorded, together with some ancillary data (prices, for instance). But no attempt is made to look at the whole farming system for the following reasons:

a) Such an exercise requires very many more research resources (or does it?).

b) Given the level of intervention (that is, considerable control of farmer compliance and limitation on his freedom of adaptation), it is of limited interest to observe his adaptation strategy since it probably bears little relation to what he would do in other, more normal, institutional circumstances.

c) A satisfactory preliminary study of the existing situation should have provided the necessary data for initial planning of the role of the new technology, given the input-output coefficients derived from the trial.

However those reasons neglect obvious facts:

a) Adoption at the "optimal" level found by a farm-planning exercise probably would not be immediate, since the farmer would want to experiment for himself with the technology, or at least adopt it by stages.

b) The "optimal" level given by the point on the production surface employed in the trial may unfortunately be different from the optimal level when the farmer is free to vary inputs and activities so that other points become available to him. Within the framework of cropping systems research laid out above, this problem is probably inevitable and unavoidable. While acknowledging this and other deficiencies, we have stayed with the framework because we think it has other benefits over a methodology which would provide a fuller specification of the production function. Perhaps the two most important benefits are, first, that better use of scarce resources is made, particularly of farm planning personnel,[19] and second, the farmer's management trials are an ideal vehicle for cooperative research, involving technical scientists in field work with farmers and thoroughly acquainting social scientists with the technical aspects of the technology.

As with the problem of data to estimate interyear variations, there are ways of approaching this area indirectly. Without elaboration we would like to emphasize these points:

a) The calculation technique used in a farm-planning exercise, such as hand budgeting, linear programming, and so on, must reflect the underlying decision-making process.

b) Simple methods are usually sufficient to identify the only systems that have any real chance of successful adoption.

[19] Realistic farm planning for our clients looks like an inexhaustible area of research.

c) Whatever method is used, a sound data base is a prerequisite for useful and responsible work.

POSTMANAGEMENT TRIAL MONITORING AND APPRAISAL

A cropping system that has passed through the management trial will be well understood and documented, as well as profitable, reliable, and so on. However, it now enters a very different system, the extension and farming system. It would be valuable to see what adoption takes place. It may be necessary to stimulate feedback in order to improve understanding of the farming system; also, feedback to the agronomy researchers will assist in the extension and adoption process. Monitoring of adoption in practice may reveal problems not realized through the previous research process, or technical problems may occur for which previous research has provided answers not explicitly included in the package.

Initially, extension should operate on a small scale (in farmers' trials, for instance) and, if necessary, encourage high feedback. The basic purpose of monitoring should be to update documentation of the cropping system. Initial documentation based on the cookbook would include detailed description of the physical prerequisites, inputs used (including sources and prices), husbandry operations, labor and power inputs, yield expectations, extension methods and support requirements. Some variants of the basic system can be given. The extension monitoring service should, on the basis of experience, update the initial documentation and, where deviation from the blueprint, or unexpected outcomes or other problems occur, should refer to the research system for assistance. While for a successful innovation this can be carried out by the extension system, the study of major problems would be a matter for researchers, since it implies a research failure in either the study of the existing situation, the agronomic trials, or the management trials.

It is suggested, then, that the cookbook form the basis of a system documentation which can be localized and updated by the extension network, and sometimes by the research center. The process would be intensive in the first years after release. Large disconformities in the documentation should activate the research feedback.

CONCLUSIONS

An attempt has been made to outline and explicate an economic and feasible methodology for testing and evaluating new cropping systems for small, poor farmers. The current institutional and political situation as outlined in Figure 1 has been accepted, together with the challenge of working within it. We clearly have many doubts about what we have proposed, and it is possible that changing circumstances and the passage of time will lead us to reconsider the organization and content of this type of research. We have tried to keep both the proposals and the exposition simple and free from technicalities.

It is proposed that technical scientists, extension workers, and social scientists be involved in the planning and implementation of a farmer's management trial; we suggest the range of data to be collected, and their analysis and presentation for wide relevance. Technologies may be compared on the basis of the probability distribution of net returns, of losses, and of returns to factors of production, particularly time-specific constraints, which are usually either cash or labor. Attention is drawn to the inadequate incorporation of between-year variability in returns, to the narrow range of variants of the technology explored, to the unsuitability of the data for appraisal of support requirements or for elaborate farm planning exercises. Any extension program based on the conclusions of this type of research system should allow for monitoring and feedback so that new research requirements may be assessed.

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DISCUSSION

SEETISARN: If I understand correctly, what you have described in your presentation on methodology for assessing cropping systems deals primarily with the farm level. Do you have any suggestions for evaluating at the aggregate level?

Norman: Sorry I have very few. I think it is very important and needs much more consideration.

MCINTOSH: I agree that when developing cropping systems we must consider the situation where infrastructure is lacking and is not likely to be forthcoming. But with limited personnel and funds, we have to be selective. Even in the poorest country, there are situations with greater potential for and higher probabilities of success. A larger number of people in the long run may be benefited if we are successful in developing improved cropping patterns for these areas. In Indonesia, the criteria for selecting target areas include the stipulation that the areas that have high production potential levels also have food deficiencies, and that they be classified as critical areas by the government.

Norman: As long as it is a priority of government I see no problem. I would be concerned if the proposed infrastructural support system for the area were not taken into account in designing the cropping systems or if researchers refused to work in areas of less promise if the government requested them.

TWO ALTERNATIVES IN EVALUATING CROPPING SYSTEMS

F. Librero

An increasingly more productive system of agriculture is needed to respond to the expanding needs of a rapidly growing human population. As a production system, agriculture must organize and utilize farm resources to take advantage of the impinging environmental factors. This is the basic context of a cropping system as "the sequence of crops and its interactions with the physical, biological, and social environments" (IRRI, 1975).

In practice, cropping systems have been viewed primarily as approaches to land-use intensification. Conceptually, however, that is only partly true, because alternative single-resource-use approaches might be argued and proposed for the same purpose. Cropping systems aim to achieve higher levels of total resource use, and no single-resource-use treatment can suffice to rationalize a particular cropping system.

The rationalization of cropping systems is the general objective of evaluating such systems. A well-defined framework is required within which to examine the intent and content of various cropping systems. The value of a cropping system extends beyond its intensification of land use to something more basic: efficiency in generating desired products and quality of products through the use of a set of farm resources.

This paper aims to examine two approaches to evaluating cropping systems. The two approaches will be conceptually differentiated, using as an example the records of the University of the Philippines at Los Baños (UPLB) multicropping extension pilot project (UPLB, 1973–75), which has been supported by the International Development Research Centre (IDRC).

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Cropping systems may be viewed as mechanisms for integrating production resources to generate composite outputs. The transformation from a unit set of resource inputs to a unit set of product outputs implies a system of aggregation. That system qualitatively and quantitatively represents and describes the biophysical and socioeconomic processes involved in any cropping system. Hence, an evaluation has to utilize a particular system of aggregation.

The aggregation process using a monetary unit has been developed by economists. It has, however, basic problems in valuation of items that do not go through the market channels, and in the externalities of price determination. The money approach will be examined further with an alternative energetics approach.

The economics approach. The economics approach utilizes a system of monetary quantification to provide a common measure for all the various input resources and product outputs. Input resources conventionally include land, labor, capital, and management; the product outputs generally include sale, home consumption, and other noncash product disposal. Operationally, the approach becomes the cost and returns analysis of farm business or commodity enterprises usually done by agricultural economists.

As an approach to evaluation, it assumes the existence of input resource as well as output product markets; prices and value of resources and products are usually those prevailing in the local or general markets. The assumption is important, because it explains the basic difference in results obtained by an accountant and by an economist when they analyze the same farm business.

While the accountant is primarily concerned with trade in the markets, that is, sales, the economist extends his analysis to the total flow of goods and services in the operational unit, for example, the farm business or farm household. As a result, the economist usually includes the untraded portions of the farm produce used for home consumption which the accountant normally excludes. The untraded portion of the farm production is significant in analyzing the farm business of small farmers in which a substantial portion of production is consumed at home.

Because cropping systems aim at total resource-use intensification, the usual cost and returns analysis may be extended to obtain strategic but simple indicators. For this purpose, I propose three simple indicators: the index of monetization, the index of commercialization, and the economic efficiency index.

The index of monetization measures the magnitude of cash transactions on the input side. It is derived by determining the ratio of the cash cost to the total cost of obtaining goods and services needed in the farm production process. The small scale of farm business, together with the relatively high cost of its credit, makes the intensity of cash requirements and utilization very important.

The index of commercialization measures the magnitude of sales on the output side. It is obtained by computing the ratio of sales to total value of production. The magnitude of sales reflects, of course, the portion of production that goes into trade channels. It also indicates the rate at which cash income is generated to obtain the various farm and household needs.

Finally, the economic efficiency index measures the rate at which a composite of farm resources generates a set of products. It is basically the cost-benefit ratio.

The energetics approach. The energetics approach utilizes a system of calorific quantification of both the input materials and forces and the product outputs. It has not been widely used, but the recent oil crisis has generated new interest in it.

The approach claims that what really matters is the intrinsic value of the things given up or obtained, or both. Intrinsic value is hardly quantified by marketplace pricing systems. Calorific quantification is an attempt to indicate the intrinsic values of goods and efforts by a process that is not seriously influenced by the vagaries of the existing market systems.

Operationally, it involves converting into energy units (calories) all input materials and efforts and all output goods. Essentially, it achieves results equivalent to those obtained by monetary quantification in economics. In both cases, inputs and outputs are reduced to common units.

In farming, energy inputs come principally from mechanical, biochemical, animal, human, and solar sources. On the output side, energy is stored in the crop and its byproducts.

Mechanical energy on the farm is provided principally by farm machinery, which characterizes western agriculture. Biochemical energy, on the other hand, comes from the use of agrochemicals—fertilizers, insecticides, pesticides, and other chemicals—characteristic of modern agriculture.

Primitive cropping systems have utilized much human labor for the various farming operations. In New Guinea, it has been estimated, an acre of "swiden" farm involved about 561,313 kilocalories of human energy to produce a variety of crops (Spedding and Walsingham, 1975). More developed agriculture has increasingly replaced or complemented human power with animal power in such farming operations as plowing, harrowing, cultivation, and hauling.

Solar radiation provides the basic energy for the photosynthetic activity of plants in both primitive and modern cropping systems. Strictly speaking, much biochemical energy, including that in tractor fuel, is stored solar energy, transformed through geologic action and manufacturing processes.

Energy outputs of cropping systems may be categorized according to the use of the crops and by-products, for instance, for direct human consumption, animal feed, raw materials for industrial processing, and waste materials which may be recycled. In the primitive New Guinea cropping system, the total biomass of crop yield was estimated to be about 9,779 megacalories, about 63% of which was for direct home consumption; the rest was animal feed.

To indicate energy use and energy yields, a total-resource accounting comparable to cost and returns analysis may easily be done. To measure the intensity of total energy use, however, the process has to be extended. For that purpose, four basic energy indicators are proposed: the pro-modernity index, the pro-industry index, the energy-efficiency index and the output-parity index.

The promodernity index measures the extent to which input energy to the farm production process comes from goods developed through the use of modern technology or manufacturing processes, such as machinery, manufactured fertilizer, insecticides, and other agrochemicals. Since manufactured goods are normally those which farmers have to purchase, the index is comparable to the index of monetization.

The proindustry index (or its corollary prosubsistence index) measures the magnitude of output used as raw materials for industrial processing or to support industrial workers (or used for direct home consumption). It is comparable to the index of commercialization.

The energy-efficiency index measures the rate at which the use of energy inputs generates energy outputs. It is comparable to the economic-efficiency index.

Finally, the output-parity index measures the parity of energy output to energy input. It combines the economics and energetics approaches. Operationally, it is the ratio of the price per unit of energy output to the price per unit of energy input.

APPLICATION

Both the economics approach and the energetics approach can be used to evaluate a given cropping system. The existing records of the UPLB multicropping project may provide a basis for comparing results. It should

Table 1. Estimated monetary values[a] of inputs and outputs, 28 rice farmers, Santa Cruz, Laguna, 1974–75 crop year.

Item	Per farmer		Per hectare	
	Pesos	US $	Pesos	US $
Input				
Labor costs				
Cash	942	127	437	59
All	2996	405	1390	188
Material costs				
Cash	678	92	314	42
All	877	118	407	55
Other costs				
Cash	9	1	4	–[a]
All	1372	185	637	86
Total costs				
Cash	1628	220	755	102
All	5245	709	2434	329
Output				
Sales	4978	673	2310	312
Total	8114	1096	3765	509
Net return				
Cash	3352	453	1555	210
Total	2873	388	1331	180

[a]Less than US$1.

be pointed out, however, that the project was not really planned in an energetics context and may not provide completely adequate data.

Evaluation of cropping systems should be addressed to a particular level of aggregation. Initially, the two approaches will be applied at the commodity, the firm (or farm), and the community levels.

At the commodity level. Project records of 28 rice farmers from Santa Cruz, Laguna, show that the farmers cultivated an aggregate of 60.34 ha planted mainly to lowland rice. On the average, a cost of about ₱2,434 US$329) generated a total output of about 83,765 (US$509), giving a net return of about 81,33l/ha (Table 1). This meant about 82,873 (US$388) net return per farmer with a total landholding of about 2.2 ha. Farmers here had about the same net return as rice farmers in the other project areas. In 1975, the net return of all 159 cooperating rice farmers in Laguna and Batangas was about ₱1,310/ha (US$177) (UPLB, 1973–75).

Comparable results from the two approaches were obtained by translating the labor and material inputs, and the grain and straw yields, using conversion factors derived from various sources (Table 2). In general, about 1,097 Mcal of support energy inputs generated a total output of about 47,574 Mcal. About 30% was for grain yield (Table 3), that is, about 13,175 Mcal of net yield for rice grains alone.

Table 2. Conversion factors of support energy inputs and outputs.

Item	Conversion factor	Source
Human labor	1.4 Mcal/man-day	Heichel, 1973
Carabao labor	19.2 Mcal/animal-day	FAO, 1973
Fuel (gasoline/diesel)	8.45 Mcal/1	Heichel, 1973, and Pimentel, et al.. 1973
Fertilizer		
N	12.34 Mcal/kg	Blowin, 1974
P_2O_5	2.90 Mcal/kg	Hawthorn, 1975
K_2O	1.90 Mcal/kg	Hawthorn, 1975
Herbides/insecticides	28.68 Mcal/a.i.[a]	Jones, 1975
Grain yield	4.4 Mcal/TDN[b]	Castillo and Gerpacio, 1976
Straw yield[c]	4.4 Mcal/TDN[b]	Castillo and Gerpacio, 1976

[a] a.i. = active ingredient. [b]TDN = total digestible nutrients, [c]Straw yield of rice is approximately about 23 times the grain yield.

Resource-use intensity indices derived from the two summary tables appear in Table 4. The two sets of indices showed distinct differences. The promodernity index of 0.59 was about double the comparable index of monetization of 0.31. The fact is that the promodernity index reflected two basic factors. First, it captured the relatively high energy equivalence

Table 3. Estimated energy values of support energy inputs and outputs, 28 rice farmers, Santa Cruz, Laguna, 1974–75 crop year.

Item	Energy value (Mcal)	
	Per farmer	Per hectare
Input		
Labor:	401	186
Man	157	73
Animal	123	57
Machine	121	56
Materials:	1,963	911
Seeds	689	320
Fertilizer	1,224	568
Ag. chemicals	50	23
Subtotal	2,365	1,097
Output		
Consumer goods	30,757	14,272
Grain sold	18,871	8,757
Straw	71,766	33,302
Subtotal	102,523	47,574
Net yield		
Consumer goods	28,392	13,175
Total	100,158	46,477

Table 4. Comparative indices of achievement, 28 rice farmers, Santa Cruz, Laguna, 1974–75 crop year.

Indicator	Index
Economics	
Monetization	0.31
Commercialization	0.61
Economic efficiency	1.55
Energetics	
Promodernity	0.59
Proindustry	0.18
Energy efficiency	43.37
Output parity	0.26[a]

[a]Based on grain energy price only.

of the fertilizer, agrochemicals, and machinery inputs; and second, it reflected the use of self-provided farm machinery. The monetization index only partially reflected the second because it considered only the cash cost of fuel and oil.

The difference between the proindustry and commercialization indices was more marked; the value of the former was less than one-third the value of the latter. That was primarily because it included the energy equivalent of the straw yield as a potential raw material for industry. In this particular case, the proindustry index emphasized the potential forward linkage of the enterprise that needed to be developed. Hence, the difference signified undeveloped markets for both product and byproducts of the crop enterprise.

For the same reason, the energy-efficiency index (1:43) differed greatly from the comparable economic-efficiency index (1:2). The difference signified the underutilization of the total output of production. Incidentally, Heichel's (1973) earlier estimate of the energy efficiency for rice in the Philippines (about 1:40) indicates some stability in the energy efficiency of rice production.

Finally, the output-parity index showed that a unit of energy output was valued at only about one-fourth of what it cost to obtain the equivalent unit of energy input. This showed a distinct disparity in pricing systems in the input and output markets (Table 4).

Similar analysis could be extended to the other commodities, but existing data were not as adequate as those for rice. Hence, only the economic indicators could be meaningfully derived (Table 5). In general, they showed high market orientation, with the more labor-intensive crops showing comparatively lower indices of monetization.

Energy-efficiency estimates have generally shown that the more tradi-

Table 5. Economic indices of achievement at the commodity level, multicropping project in Batangas and Laguna, 1975.

Commodity	Economic index		
	Commercialization	Monetization	Efficiency
Tomatoes	0.90	0.34	2.85
Eggplant	0.81	0.81	1.10
Bush sitao	0.97	0.75	1.46
Watermelons	0.95	0.59	1.76
Gourds (upo)	0.65	0.66	1.92
Mung beans	0.74	0.54	1.68
Ginger	0.97	0.80	0.95
Cassava	0.70	0.64	2.09
Gabi	0.60	0.72	2.05

Table 6. Efficiency of use of support energy in different agricultural systems. (Adapted in part from Nguyen, 1970, and Spedding and Walsingham, 1975)

Commodity	Country	Agricultural system	Efficiency
Maize	USA	modern	2.8
Maize	Zambia	traditional	40.0
Wheat	USA	modern	2.2
Sugar beets	USA and Western Europe	modern	1.8
Sweet potatoes	Zambia	traditional	4–9
Sweet potatoes	African rain forest	primitive	16
Rice	Fiji	traditional	20
Rice	Philippines	traditional	40
Sugarcane	Mauritius	traditional	11
Cowpeas	Zambia	traditional	9
Cassava	Fiji	traditional	71
Bananas	Fiji	traditional	130

tional production systems in less-developed agriculture had comparatively higher energy-efficiency conversions than the developed systems. Nguyen (1970) estimated the cultural energy-input efficiencies of rice for the "modern cultivating system"[1] at 1 : 8.5 in the dry season and 1: 6 in the wet season. For the "traditional cultivating system"[2], the values were about 1 : 10.4 in the dry season and 1 : 7.1 in the wet season. Data on energy efficiencies of various crops elsewhere are given in Table 6.

Basically, the developed agricultural systems have come to depend largely on the proindustrial inputs such as fossil fuel, machinery, and

[1]Modern cultivating system involves (a) human labor and agricultural machinery for land preparation, (b) herbicides for weed control, and (c) insecticides for insect pest control.

[2]Traditional cultivating system involves (a) human labor and draft animal for land preparation, (b) weed control done with hand and simple tools, and (c) insecticides applied whenever needed.

Table 7. Comparative indices of achievement at the farm-business level on case farm, Laguna, 1974–75 crop year.

Indicator	Index
Economics	
Monetization	0.81
Commercialization	0.92
Economic efficiency	3.37
Energetics	
Promodernity	0.90
Proindustry	0.32
Energy efficiency	17.65
Output parity	0.19

manufactured fertilizers and agrochemicals. Such inputs have become necessary because the production period in the west is relatively shorter. Energy efficiency has been sacrificed for speed. Indeed, Summers (1971) has generalized that the energy required to do a job varies with the square of the working speed.

The evidence, however, does not necessarily argue for primitive or traditional cropping systems. Rather, it should indicate the opportunities that have to be fully utilized in the less-developed agricultural production systems because manufactured energy inputs are expensive.

At the farm level. In a cropping system, the crop enterprises do not exist and operate independently; neither do their individual monoculture performances directly add up in a straightforward way when the crops are cultivated in combination with each other on a given piece of land.

Records of a farmer-cooperator during the crop year 1974–75 were analyzed to provide some bases for evaluating cropping systems at the farm level. The cooperator planted his first crop of rice on a 1.2–ha farm in mid-August 1974. After harvest in early December, he planted watermelons on about 0.5 ha and tomatoes on another 0.25 ha. Both crops were harvested at the end of April 1975. The next rice crop was planted the following month on the entire 1.2 ha and harvested in early September. Meanwhile, the farmer had also rented another 0.8 ha of lowland area where he planted another rice crop in mid-October 1974, and harvested in late January.

The aggregate indices of achievement showed high rates of monetization, commercialization, and promodernity orientation (Table 7). Economic- and energy-efficiency indices were about 1:3.37 and 1:17.65, respectively. However, the proindustry index remained low. The output parity showed that what the farmer got from his energy output was less than one-fifth of what he paid for his energy inputs.

More detailed examination of the weekly economic and energy indicators (Tables 8 and 9) led to three major observations. First, there was maldistribution in the production inputs and product outputs translated into either monetary or energy terms. Production activities, material inputs, and yields were governed by both biological processes and crop scheduling.

Second, the relatively high solar radiation throughout the year offered opportunities to utilize photosynthetically efficient crops and to follow better crop scheduling. Norcio (1970) earlier reported a mean photosynthetic efficiency of 3.36% for rice. Other crops may be similarly examined to identify those which approach the theoretical maximum of 20% efficiency.

Actual solar-radiation readings at the University of the Philippines at Los Baños during the period of study showed a weekly average of about 2,685 Mcal/ha. The radiation varied from about 1,383 Mcal in a rainy August week to a high of about 3,942 Mcal during a sunny April week.

Third, the cash crops in the cropping system increased both labor and material inputs. That was dramatically shown by the results of a separate survey of 127 multicroppers in the same project. Labor inputs and cash costs increased by 27% and 97%, respectively.

At the farm level, the problem of resource allocation to achieve high resource-use intensification seemed to be more pronounced. The operational procedures to arrive at optimum cropping systems, however, may vary in their sophistication. Already, a procedure to optimize crop production on small farms has been developed with the use of data from the same UPLB multicropping project (Gomez, 1975). Possibly, the procedure can be adapted using energy rather than monetary units.

At the community level. The community forms the social environment of a cropping system. A particular farming community may be viewed as an outsized farm implementing a particular cropping system. Thus, total resource-use intensification at the community level may be undertaken and the achievements evaluated. Problems of resource allocation would become apparent. Indeed, except for the many more complications involved because of more diverse interests, the community may be regarded operationally as a farm unit.

The additional complications come partly because, while the individual farm deals principally with allocational problems among various crops in the cropping system, resource allocation at the community level also considers the various individual farm units, which independently decide on their respective allocational problems. Optimization at the individual farm unit may not necessarily add up to the optimum at the community level.

Table 8. Weekly economic indicators and labor inputs, case farmer. Laguna, 1974-75 crop year.

Item	Total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cash costs (₱)	5525	150	445	–	410	30	110		12	80	240	165	320	10	63	22	5	–	140
Total costs (₱)	6834	168	457	–	416	124	113		16	89	267	174	325	12	66	24	7	90	144
Sales (₱)	21310																	3750	
Total output (₱)	23060																	4250	
Human labor (man-days)	292.3	11 0	24 0	–	10	18 5	155		0.5	65	9.5	5.5	2.8	0.4	8.5	24	0.4	150	08
		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Cash costs (₱)		10	150	–	10	24	24	50	27	93	104	117	244	362	404	246	–	–	–
Total costs (₱)		12	153	9	78	141	150	92	61	145	149	153	282	400	434	279	42	21	6
Sales (₱)							3500										1408		9152
Total output (₱)							4000										1408		9152
Human labor (man-days)		0.3	0.5	15	11 2	19.5	21.0	70	5.6	86	7.5	6.0	6.4	6.4	5.0	5.5	7.0	3.5	1.0
		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52		
Cash costs (₱)			–	340	300	–	280	210						180	44	59	44		
Total costs (₱)		6	3	340	300	27	295	230	14	63	57	6	3	191	48	66	80		
Sales (₱)																	3500		
Total output (₱)																	4250		
Human labor (man-days)		1.0	0.5	05	1.0	4.5	2.5	3.2	2.2	10.5	9.5	1.0	0.5	1.9	0.6	0.6	6.5		

Table 9. Weekly energy indicators (Mcal), case farmer, Laguna, 1974–75 crop year.

Item	Total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Labor (man and animal)	964.9	226.6	33.6	–	1.4	25.9	21.7	–	0.7	9.1	186.1	7.7	3.8	0.5	11.9	3.0	0.5	21.0	1.0
Total labor and materials	9530.6	226.6	506.6	–	812.8	26.0	21.9	–	0.8	55.0	602.9	777.8	4.1	0.6	12.1	3.1	0.6	21.0	279.1
Traded product	54076																	14190	
Total produce	168227																	53607	
Solar radiation[a]	139622	1411	2842	3132	3047	2911	2553	2787	2211	2013	1662	2132	1930	2010	1608	1864	2167	2239	1785

Item	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Labor (man and animal)	0.5	0.7	2.1	15.8	27.3	29.4	9.8	7.9	12.1	10.5	8.4	8.9	8.9	7.0	7.7	9.8	4.9	1.4
Total labor and materials	0.6	278.9	2.1	15.9	82.9	85.0	93.2	24.6	223.3	205.2	230.9	520.4	837.0	885.4	519.3	9.8	4.9	1.4
Traded product						13244										1408		9152
Total produce						50453										1408		9152
Solar radiation[a]	1866	2150	1677	1968	2084	2466	2679	2811	3013	2302	3411	3070	3714	3624	3381	2629	3671	3715

Item	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Labor (man and animal)	1.4	0.7	10.3	20.6	92.7	32.3	33.4	3.2	14.7	13.3	1.4	0.7	2.6	0.9	0.7	8.4
Total labor and materials	1.4	4.5	14.1	20.6	92.7	599.9	683.8	3.2	14.7	13.3	1.4	0.7	588.4	1.4	0.9	147.8
Traded product																16092
Total produce																53607
Solar radiation[a]	2624	3942	3463	3739	3853	2803	3563	2725	2780	3106	3254	2414	3258	3446	2734	1383

[a]Per hectare (actual data at UPLB, College, Laguna).

Another aspect related to social and economic services becomes obvious at the community level. Health, education, and other services become more important and must enter the evaluation process. In the UPLB multicropping project, the children of the cooperating families in the Laguna and Batangas sites show more rationalized food nutrient intake and lower levels of malnutrition. Energy food intake in 1973 and 1975 were 107% and 105%, respectively, of the daily allowance recommended by the Philippine Nutrition Council. During the same periods, protein food intake was 121% and 109%, respectively. Malnutrition among children decreased from about 81% in 1973 to about 70% in 1975.

The need for economic services, particularly credit, was also shown by the sixfold increase in the number of borrowers as well as the ninefold increase in the amount borrowed from the credit support services initiated by the project. In 1972, 36 farmers borrowed an aggregate amount of about ₱13,700 (US$l,851). In 1975, 222 borrowed about ₱125,000 (US$16,892).

Other economic services, such as marketing, and the establishment of local organizations also became necessary.

GENERALIZATIONS

The basic concept of a cropping system as a total resource-use intensification in the context of its biophysical and socioeconomic environment necessarily makes the system complex. The impinging factors, forces, and processes are many and just as complex.

To deal with this complex system, the economics approach for evaluating cropping systems was examined. This approach translates factors and services into monetary units to examine the operational processes in a particular cropping system. The approach has a number of fundamental problems, such as those relating to the valuation process and the externalities of the pricing system. Economics might have conditioned us to think and act mainly in its world of scarcity rather than in an alternative world of plenty.

The energetics approach was also examined. The approach reduces the various factors and forces involved in a cropping system to energy units and describes the production process as energy transformation. It does not involve the vagaries of the market pricing system, and presumes stability of the energy units and of their relationships within and across commodities and communities.

Use of the two approaches requires explicitness on the level of application. At the commodity level, the problems tend to be biophysical; at the farm level, they tend to be allocational or economic; and at the community level, they tend to be socioeconomic. There is a need to plan projects which would explicitly obtain more adequate data for further developing the energetics approach.

While adoption of either the economics or energetics approach may be convincingly argued, the complex problems of cropping systems may not necessarily favor any single approach. Alternative approaches might be developed and examined.

Whatever approach is used, however, one basic frame of reference has become apparent. It has become necessary to think in terms of the whole biophysical system of agriculture and relate this to the socioeconomic system of a human community. The key approach to the problem might be to use the methodology of economics with the calorie units of energetics.

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DISCUSSION

VILLAREAL: It seems to me that by using the energetics approach, there is a bias toward crops that produce a lot of calories, like cereals and root crops, since legumes produce more protein than calories; although vegetables in general are not good calorie producers, they are especially rich in minerals and vitamins. Please comment.

Librero: That is not so. In fact, the energetics approach will favor protein-rich crops over the carbohydrate-rich cereals. The specific energy liberated by burning a unit dry weight of carbohydrates such as starch, sugar, and so on, is between 16 and 18 megajoules/kg (about 3.84 to 4.32 Mcal/kg), while the specific energy liberated by proteins and lignins is about 25 megajoules/kg (about 6.00 Mcal/kg).

Component technology weed science

INTRODUCTION

B.L. Mercado

Weed scientists in Southeast Asia face a twofold problem. They seek proper control of weeds under particular situations; in addition they have to make small farmers realize that weeds are serious pests in crop production, and demand immediate attention.

The damage caused by weeds does not become apparent until it is irreparable. Most farmers ignore weeds unless the density is very high. Some believe that weeds are easy to handle because of their immobility. They think they can pull out weeds any time it is convenient to do so.

Hand weeding is the most common method used by small farmers. It often means merely cutting off the aboveground parts without taking out the roots or any of the underground portion. Regrowth is fast, and the full advantage of weeding is not realized.

Multiple cropping is designed to increase food production. Some people think that intensified crop production can reduce weed problems. Although the idea is not entirely wrong, neither is it entirely correct. Weed infestation can be severe or light, depending upon the cultural practices employed. As will be pointed out by Dr. Keith Moody, some crop combinations or sequences can reduce weed infestation, whereas others do the opposite.

In general, weed control problems are more serious in multicrop systems than in single-crop schemes. Sequential cropping usually results in a different weed problem with every season, demanding a different weed-control approach. It is perhaps in multiple cropping that problems of herbicide selectivity and residual toxicity are most critical.

Research on herbicides for all established or promising cropping systems is still inadequate. That is true even for single-crop schemes. In upland rice, for instance, we still have to come up with a very selective, very effective, and inexpensive herbicide.

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Another problem in weed control is with undesirable shifts in weed populations. Shifts are bound to occur in any cropping system. The weed problem never remains the same, whether or not a crop is grown continuously, or whether or not it is grown with another crop. Even if cultural practices do not change, the weed population will certainly do so. In irrigated, transplanted rice, where water management can effect good control of grasses, the possible emergence of floating, aquatic weeds can present a more serious control problem.

Even if we had a ready answer to every weed problem, we would still have to consider a second aspect of the situation. Acceptance at the farmer's level will be possible only if returns can warrant the additional input. That will be true of any control method that might be developed. Even if control is through the use of a competitive crop, the crop itself should be one with a good market.

The two papers that will be presented this morning will deal with some weed control problems, the solutions that have been proposed to meet them, and possible approaches to the solution of present and future weed problems in different cropping systems. The two papers will expose the many gaps that weed scientists are expected to fill in the future.

WEED CONTROL IN MULTIPLE CROPPING

K. Moody

What will intensification of agriculture mean with respect to weeds and their control? Will there be more problems or fewer? Will the weed population change? In what way? How will weed-control practices used in one crop affect the weeds in the next crop? How can the effects be researched? Those and many more questions arise when the subject of weed control in multiple cropping is discussed. Many of the questions can be answered only with an educated guess based on experience, intuition, or observation.

In many countries of tropical Asia, little research has been done on weed control in the crops that are being used as components of the cropping system. Should we even consider weed control in multiple cropping when we do not even know the answers for individual crops? The best approach is probably to research both areas, placing initial emphasis on the individual crops and later, as more information becomes available, stressing how the crops interact with one another for weed control. It is imperative that we know how such things as land preparation, fertilizer application, weed control methods, and so forth, affect not only the weeds in one crop but also those in subsequent crops. If we lack such knowledge, weeds will continue to be a major factor limiting the increased crop production that is possible with multiple cropping.

Each of the ways in which crop production per unit area can be increased through weed control will be discussed separately. Research in these areas is reviewed, problems that have been encountered are discussed, and possible areas of future research are suggested.

SEQUENTIAL CROPPING

By plowing at the end of the wet season before the soil became too hard for penetration by the tillage implement and by keeping the soil tilled

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during the dry season, Bolton (personal communication) was able to dry seed rice 2 weeks earlier than when land preparation was commenced at the start of the rainy season. However, no advantage is gained from this method unless the germinating rains fall soon after planting. Cultivating the soil during the dry season may conserve soil moisture; it also reduces the weed population in subsequent crops because it kills weeds, particularly perennials. Curfs (1976) observed a difference in weed weight and in the weed flora between plots that were plowed at the end of the wet season and those that were left undisturbed (Table 1). Bolton (personal communication) noted a lower weed weight and markedly fewer perennials growing with rice in plots that had been plowed at the end of the wet season than in those that had been plowed at the start of the rainy season.

Mahyuddin and Soeharsono (1976) suggested that farmers should grow upland crops instead of merely tilling the soil during the dry season. The land preparation for an upland crop and tillage for weed control during the crop's growth would result in the same benefits as continuous tillage throughout the dry season. In addition, the farmer would have the yield of the upland crop.

Herrera et al. (1976) reported that thorough land preparation following lowland rice resulted in planting1 month later than with no tillage, the soil being too wet to prepare by conventional tillage techniques. Yields were not affected by the delay. The weed flora, however, appeared to be different. In one field, in particular, I observed that the predominant weeds in the no-tillage plots were grasses; those in conventionally tilled plots were almost exclusively sedges, primarily *Cyperus rotundus* L.

In research plots in farmers' fields in the Philippines and Indonesia, weed growth in upland crops following rice did not seem to be particularly heavy, suggesting that yield depression due to these weeds was probably

Table 1. Effect of tillage at end of rainy season on weed species and weed weight measured at the end of the dry season (adapted from Curfs, 1976).[a]

Weed species	Weed (g/sq m)	
	Plowed at end of rainy season	Not plowed
Croton lobatus	185	0
Spigelia anthelmia	9	0
Talinum triangulare	36	143
Others (mainly grasses)	50	356
Total	280	499

[a]Land not cropped during dry season.

low. However, that needs further investigation. Generally, when an upland crop is rotated with a lowland crop, the total number of weeds in either will be lower than under continuous lowland or upland culture.

In the Punjab in India, however, in an endeavor to increase crop production, transplanted rice followed by dwarf varieties of wheat is becoming an important crop rotation, particularly on heavy soils. Under such conditions, *Phalaris minor* L., a relatively minor weed when tall, traditional varieties of wheat are grown alone, thrives and is increasing at alarming rates (Gill and Brar, 1972).

Even though yield depression may be slight, some weed control is recommended to prevent weeds' seeding and to help prepare the soil for the crop that will be planted at the start of the rains.

Elimination of tillage gains no time for planting at the start of the rainy season; the soil is too hard after the harvest of the upland crop and land preparation has to be delayed until the rains have started. The low yields currently obtained from the dry-season crop may not warrant the use of herbicides for weed control; thus, the only means of achieving weed suppression is the use of highly competitive crops or varieties. The only advantage, thus, of using no tillage is the possibility of higher yields in areas where water is limiting, and possibly higher prices because of earlier harvest.

Even if yields are increased substantially, the currently available herbicides are not satisfactory. Preemergence herbicides have limited usage when the crop is growing on residual moisture, because water to activate the herbicide is limited. Suitable selective, postemergence herbicides have yet to be found for use in those upland crops that show the greatest potential for cropping systems in Asia.

In many areas throughout Asia, to grow two crops of rice where one was grown previously may require sowing the first crop dry. The rice starts its life cycle as an upland crop but finishes as a lowland crop. Weeds are a major problem in such culture, a problem that will have to be solved before the method can be recommended as a general practice.

In addition to preparing the land during the dry season, the following weed control practices are suggested as possibilities:

1. *Stale-seedbed technique.* Following land preparation, weeds are allowed to germinate at the onset of rains and then controlled either by another tillage operation or by herbicides applied prior to planting. The rice is then planted with as little soil disturbance as possible. There may be no advantage in this method. The 2 weeks that one gains by tilling during the dry season are lost. Moreover, it seems that the earlier one plants after the start of the rains, the fewer are the weed problems. Delay in planting

results in more weeds and more control difficulties.

Further research is needed to clarify the situation.

2. *Herbicides.* Nearly all herbicides that have been used for weed control in upland rice or in rice that has been direct-seeded on puddled soil either are phytotoxic or have failed to give adequate control. To reduce phytotoxicity, the herbicide can be applied after the first heavy rain following planting has soaked into the soil, and prior to rice emergence. Unfortunately, along with the reduction in phytotoxicity a reduction in weed control may occur.

In trials now being conducted at Pangasinan, Philippines, an average stand reduction of 15% has occurred with all herbicides being tested. Because seeding rates have been high, no loss of yield is expected. Weed control has been less than adequate. Over 250 man-hours/ha of hand weeding in addition to the herbicide were required to achieve satisfactory control. A farmer in the area who had used no herbicide was forced to abandon his field.

It seems unlikely that weed control with that type of rice cultivation will succeed unless herbicides are used. However, we have a long way to go in determining suitable herbicides and rates. A major research effort in the area is obviously needed.

3. *Water control.* Better weed control will result if flooding of the soil occurs as soon as possible after stand establishment. Unfortunately, flooding cannot be accomplished in most rainfed rice areas. If a guaranteed supply of water were available, the farmer would not plant dry-seeded rice.

Occasionally, heavy rains fall at the start of the rainy season. Instead of dry seeding, the farmer may puddle the soil and sow pregerminated seed. Seeding rates in the Philippines are generally high to help control weeds. Rates of 150 kg/ha are not uncommon, and rates as high as 400 kg/ha have been used. Even so, a major portion of the farmer's time during crop growth may be spent weeding.

Puddling reduces the number of weeds, and seems to produce change in the weed flora. Grasses appear to be dominant with dry seeding; with puddling, broadleaf weeds predominate.

Herbicidal compounds are available that are suitable if they are applied as granules in standing water 6 days after sowing. In rainfed areas, standing water may not be present at the time it is needed. If that is the case, it may be wiser to plow up the field and replant with transplanted rice than to try to remove the weeds by hand; no suitable herbicides have been found except those for use in standing water about 6 days after seeding.

It may be that direct seeding on puddled soil should be used only where good water control exists or supplementary water is available, until herbicides are found that will work under the conditions described above. The possibility of using preplant or preemergence herbicides should be investigated.

No major problems are seen for weed control in the second rice crop, provided that it is transplanted and provided that water is available when the weed-control method is being applied. If water is not available at the time of the second crop planting, the crop may have to be direct-seeded wet, or even dry. If such is the case, then the control problems that have already been described are likely to occur.

Reduction of turnaround time between crops is also desirable. Hammerton (1974) has noted that the fallow period can lead to an intense weed problem in the following crop due to seed shedding or the development of vegetative propagules. Shortening the fallow period reduces the problems. The use of minimum or zero tillage to reduce turnaround time should be investigated thoroughly.

Under certain conditions, however, fallow can be useful. Care should be taken that growing of successive crops of rice does not lead to a buildup of certain weed species, particularly perennials. Interrupting the lowland crop cycle with an upland crop (Table 2) or a cultivated fallow will help appreciably to reduce or prevent the problem.

MIXED CROPPING

Numerous reasons are given for farmer's practice of mixed cropping or intercropping, or both. One is weed control. If a number of crops are grown in such close proximity that plant density is greater than in sole cropping, there would be greater competition against weeds, and less need for weeding. If the density of the mixed crops or intercrops is the same as that of the component crops when grown alone, or if the crops are planted at their optimal densities, there may be little improvement in weed control with mixed cropping.

Weeds are often said to be a lesser problem in mixed cropping with its multistoried, multicrop associations than in crops that are grown alone. There is little experimental evidence to support the contention. The few experiments that have been conducted on this subject are summarized below.

Arny et al. (1 929) said that the chief advantage of mixed cropping is weed control. Mixing wheat (*Triticum aestivurn* L.) or oats (*Avena sativa* L.) with flax (*Linum usitatissimum* L.) made it possible to grow flax on land which was too weedy for flax alone.

Over a 5-year period, the yearly average weight of weeds growing in

Table 2. Effect of crop rotation on weeds growing with lowland and dry-seeded, rainfed, bunded rice (adapted from Jereza and De Datta, 1976).

Treatment	Weed count (no./sq m)		
	Scirpus maritimus	*Cyperus rotundus*	Other weeds
Continuous lowland rice			
Bentazon	3	0	292
Rotary weeding	25	0	20
No weeding	325	0	340
Lowland rice–upland crop rotation			
Bentazon	15	0	434
Rotary weeding	5	0	26
No weeding	167	0	364
Dry-seeded rice–upland crop rotation			
Oxadiazon	23	110	153
Hand weeding	17	22	164
No weeding	20	33	1463

association with flax was 2,625 kg/ha (Table 3). Wheat, which has a heavier foliage and is thus more competitive against weeds, had only 624 kg/ha of weeds growing in association with it. Oats were almost as competitive. Weed weights in different mixtures varied from 1,996 kg/ha when flax and wheat were combined at 17 and 11 kg/ha, respectively, to 914 kg/ha when flax sown at the standard rate of 28 kg/ha was mixed with wheat sown at half the standard rate of 34 kg/ha. The number and weight of weeds decreased as the seeding rate of the mixture increased.

Table 3. Yearly average number and weight of weeds growing with flax and cereals either sole-cropped or as mix-crops (adapted from Arny et al., 1929).

Crop	Seeding rate (kg/ha)	Weeds	
		No. (thousands/ha)	Wt (kg/ha)
Flax	28	2467	2625
Wheat	67	1644	624
Oats	54	1205	640
Flax + wheat	17 + 11	2652	1996
Flax + wheat	17 + 22	2491	1298
Flax + wheat	17 + 34	2116	1028
Flax + wheat	28 + 11	2146	1520
Flax + wheat	28 + 22	1911	1127
Flax + wheat	28 + 34	1877	914
Flax + oats	22 + 9	1578	1232
Flax + oats	22 + 18	1407	1039

Even though the mixture had fewer weeds than did flax as a sole crop, it had more weeds than either wheat or oats grown alone. Thus mixing the crops gave effective weed suppression only for flax.

In northern Nigeria, crop mixtures required 62% more labor than sole crops, but the difference was reduced to only 29% when labor was limiting (Baker and Norman, 1975). Crop mixtures thus helped to alleviate the labor problem, probably by reducing the time required for land preparation and for weeding.

In Indonesia, however, more time was needed to weed crops that were randomly mixed than to weed those that were sole cropped or intercropped (Syarifuddin et al., 1975). I have noted (Moody, 1975) that weeding was more difficult when crops were sown in scattered or staggered patterns on mounds or on the flat, while Tiley (1970) stated that weeding could be reduced substantially if all crops were sown in rows.

INTERCROPPING

A common practice in Nigeria is to sow cowpeas [*Vigna unguiculata* (L.) Walp.] into established sorghum [*Sorghum bicolor* (L.) Moench], millet [*Pennisetum glaucum* (L.) R. Br.], or corn (*Zea mays* L.) during weeding about a month after the cereals have emerged. According to Summerfield et al. (1974), the spreading canopy of the cowpeas competes effectively with weeds, and makes further weeding unnecessary. It is highly unlikely that additional weeding would be required in the sole-cropped corn in any event because weeds that emerge after the first month of crop growth are poorly competitive and have almost no effect on yield. Nonetheless, the presence of the cowpeas would probably result in fewer weeds, and fewer weed problems in subsequent crops.

In Iloilo, Philippines, farmers intercrop Mexican yam beans (*Pachyrrhizus erosus* Rich.) with corn, sowing them at the same time. The farmers say that the Mexican yam beans cause no reduction in corn yield, but Palada (personal communication) observed that corn sown at approximately the same populations (only 1,500 plants/ha fewer in the intercrop) yielded 48% less in the intercrop than in the sole crop. Weed growth was greatly reduced in the intercrop, however, and weeding was minimal or unnecessary. If weeding had not been carried out in sole-cropped corn, considerable yield reductions would have resulted.

It has also been reported from the Philippines that intercropping corn and mung beans [*Vigna radiata* (L.) Wilczek] under coconut (*Cocos nucifera* L.) trees reduced the natural weed vegetation to the point that weeding was unnecessary (Paner, 1975). In the Congo basin, the reason given for growing

Table 4. Dry weight of weeds sampled 60 days after planting in unweeded sole-cropped or intercropped corn and mung beans (adapted from Bantilan et al., 1974).

Crop	Dry wt of weeds (kg/ha)
Corn	1394
Mung beans	1534
Corn + mung beans (CES 14)	501
Corn + mung beans [MG50-10A (Y)]	72

Table 5. Average weight of weeds growing with sole-cropped and intercropped corn and mung beans (adapted from Bantilan and Harwood, 1973).

Treatment	Weed wt (t/ha)		
	Corn	Mung beans	Corn + mung beans
Unweeded	2.06	0.85	0.28
Interrow cultivation	1.96	0.78	0.42
Butachlor (0.6 kg a.i./ha)	1.26	0.15	0.15
Butachlor (1.2 kg a.i./ha)	0.71	0.31	0.08
Butachlor (2.4 kg a.i./ha)	0.35	0.03	0.04
Hand weeded	0.06	0.02	0.03

cucurbits with corn is that the companion crop shades out the weeds and thus helps to conserve moisture (Miracle, 1967). Syarifuddin et al. (1975) reported that it took less time to weed crops grown in intercrop combinations than the same crops grown sequentially.

Corn and mung beans are an excellent combination for reducing weed growth, yield losses, and weeding time. In trials carried out in the Philippines (Castin et al., 1976; Table 4, 5) and Indonesia (Mahyuddin et al., 1976), the weight of weeds growing with the intercrop has been as low as or lower than that of those growing with the sole crops. Bantilan et al. (1974) and Mahyuddin et al. (1976) reported that the yield of corn was greater in the intercrop than in the sole crop, and land equivalent ratios were highest under unweeded conditions. Castin et al. (1976), however, observed the opposite.

Other crop combinations that have been tried in the Philippines are corn and sweet potatoes [*Ipomoea batatas* (L.) Lam] (Bantilan and Harwood, 1973) and corn and peanuts (*Arachis hypogaea* L.) (Bantilan and Harwood, 1973). In these combinations, weed growth in the intercrops was less than in the sole crop of sweet potatoes or peanuts but greater than in the sole crop of corn (Table 6). The difference between mung beans and peanuts appeared

Table 6. Effect on weed growth of various crops grown alone and in combination (Bantilan and Harwood, 1973).

Crop	Weed wt (kg/ha)
Corn	1065
Mung beans	1172
Sweet potatoes	1793
Peanuts	2354
Corn + mung beans	617
Corn + sweet potatoes	1107
Corn + peanuts	1362

to be due to the more rapid early growth of the mung beans and to differences in leaf canopy (Bantilan et al., 1974).

Another common combination in parts of Asia is corn and rice grown under upland or dry-seeded lowland conditions. There appears to be no weed suppression benefit from this combination. In fact, the corn may interfere with the diagonal mechanical weeding that is carried out in upland rice in the Batangas area of the Philippines. In Indonesia, the corn is harvested green and provides money to pay for the large amount of labor needed to weed the rice (McIntosh, personal communication).

The intercrop combination need not necessarily lead to a reduction of weed weight to less than that in the crops grown separately. Morales (1975) observed more broadleaf weeds growing in a corn-bean (*Phaseolus vulgaris* L.) intercrop and in sole-cropped corn than in sole-cropped beans, the beans being more effective competitors. However, in all crop combinations, only one weeding was needed to produce optimum yields.

Central American data indicate that corn + beans, corn + cassava (*Manihot esculenta* Crantz.), and corn + cassava + beans are poor combinations for suppressing weeds, especially with heavy fertilization. Bantilan et al. (1974) observed that intercrops of corn + peanuts and corn + sweet potatoes became less competitive as soil fertility increased, but corn + mung beans are more competitive.

Thus it appears that whether weed weight decreases with intercropping depends on the component crops, their density, and the soil's fertility. The farmer who intercrops or mixes his crops in areas where soil fertility is generally low has probably selected his crops (or varieties) and combined them in such a way that they are more competitive against weeds than are the components when grown alone.

The major methods of controlling weeds in crop combinations are manual and mechanical. Because there are fewer weeds in certain crop combinations, weeding time is probably less or fewer weedings are required. However, other crop combinations may require as much or even more weeding time because they have not reduced weed growth.

Herbicides have been tested for possible use in mixed cropping or intercropping. Encouraging results have been obtained with some, but those which have proven to be most promising are not used by the farmer because of expense, unreliability, unavailability, application difficulties, or the supposed availability of inexpensive labor.

As the number of crops that tolerate a herbicide increases, so must the number of weeds. Success will be achieved if most of the weeds that are present are controlled. Those remaining should be removed by alternative methods.

Some people feel that if a crop combination has fewer weeds, less herbicide than was used in the sole crops will be needed to achieve the same degree of control. That is not necessarily true. A certain rate of herbicide is needed for weed control, regardless of the number of weeds that are present. Below such a level, weed control is greatly reduced or not achieved.

RELAY CROPPING

Relay cropping of grain legumes (soybeans [*Glycine max* (L.) Merr.], cowpeas, mung beans) by broadcasting seed into rice before its harvest is common in certain parts of Asia. Yields are low because inputs are minimal or nonexistent. Ratoon rice, volunteer rice, and such weeds as *Echinochloa colona* (L.) Link, which thrive well in both lowland and upland conditions, compete vigorously with the legumes when the soil is saturated at planting, or rains are frequent during the dry season, or both. Yield reductions due to weeds under these conditions are likely to be of the order of 50 or 60%.

Weed weights and yield losses can be reduced substantially if the straw from the harvested rice is used as a mulch in the legume crop (Moody, 1976).

When soil at planting is relatively dry, and little rain falls during the dry season, and crop growth is dependent upon residual soil moisture, weeds do not seem to thrive as well, and it appears that they may cause only small losses.

A relay-cropping combination that could have considerable potential is corn and cassava. The cassava could be planted in corn rows about a month before corn harvest. Earlier planting would cause the cassava to become too etiolated, with resulting lodging and loss of yield. Any weeds in the corn when the cassava is planted can be removed manually or sprayed with a contact herbicide. Ridging of the cassava soon after corn harvest may eliminate the need for further weed control in the cassava, or reduce it to a minimum.

Grain legumes might be relayed into corn in much the same way. To ensure that competition from the corn does not result in decreased legume yields, planting of the legumes probably should be delayed until 1 or 2 weeks before corn harvest.

If a herbicide is used for weed control in the first crop in the combination, care should be taken that it is not toxic to the second crop, or that toxic residues have disappeared by the time the second crop is planted. I believe (Litsinger and Moody, 1976) that the problem is less likely to occur in the tropics than in the temperate regions, and have cited several examples in support of that position. To avoid the problem, it may be advisable to use a herbicide that is safe for both crops. That could lead to less weed control, but successful establishment of the second crop would be guaranteed.

RATOON CROPPING

When high-yielding, short-duration rices are grown after harvest, the field may be too wet to plant an upland crop, and at the same time insufficient water will be available to support another rice crop. Ratooning of the rice may be the logical answer. Bahar (personal communication) reported yields as high as 1.9 t/ha from a ratoon crop of rice.

Plucknett et al. (1970) noted that weed control may be the key to successful ratooning of some crops. Buildup of weeds is likely to occur if the same weed control practices used in the planted crop are used in the ratoon crop. The ratoon crop is also less competitive against weeds because of the reduced plant stand and reduced growth. Weeds can also be well established by the time the original crop is harvested, and therefore can be more competitive with the ratoon crop than they were with the planted crop.

It is not known if or to what extent weeds reduce yields in ratoon rice. If they do cause appreciable reduction, the best means of control is unknown. Further research on weed control in ratoon crops, especially in rice, is obviously needed.

CONCLUSIONS

The study of weeds and their control in multiple cropping is in its infancy. It is obvious that a promising start has been made in trying to solve a complex problem. Research results have probably raised more questions than they have answered. At least they show where new research is needed, either because that which has been done needs further clarification or because no research has been conducted.

The task ahead of the weed scientist is great but not insurmountable. With a concerted research effort, the problem can be solved, and an understanding of the implications of weeds in multiple cropping should be achievable within the next decade. Without solutions, multiple cropping may be a dream rather than a reality.

SUMMARY

Weeds are a major factor limiting crop production throughout the world. The losses caused by and the cost of control of weeds are among the most expensive items in crop production. In most crops, the farmer spends more of his time fighting these agricultural misfits than doing any other farm operation.

Research on weed control in the various crops suitable for incorporation into multiple cropping programs in tropical Asia is in most instances sadly lacking. Even in rice (*Oryza sativa* L.) very little information is available except, perhaps, in transplanted rice. It is difficult to study weed control in multiple cropping unless weed control practices for the component crops are known and understood.

In this paper, each of the possible means of intensifying crop production on a given area of land is discussed separately with regard to weed control. The present status is reviewed and future areas of research are suggested.

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DISCUSSION

HOQUE: When you recommended ratooning of early-maturing rice varieties in fields where direct-seeding cannot be done due to standing water, how seriously are you concerned about the yield of the crop or the total production from the pattern?

Tinsley: The field potential of rice ratoon, at present, does not justify including ratooning in cropping pattern design. The ratoon takes only 45 to 60 days, harvest to harvest, but yields only 1.0 t/ha. We have allowed ratooning to take place when it was a natural fit to the environment (microenvironment). The rice-ratoon provides flexibility in the system to account for a topographic position or *normal* variation in decline of the monsoon rains. The ratoon occurs when the individual paddy remains flooded for a prolonged period after rice harvest. During this wet fallow period, the ratooning process occurs naturally. In our work, we do not add any input to the ratoon, but evaluate the field as it dries up. Once the field is dry enough to work and plant the upland crop, we evaluate the individual paddy and estimate whether the total productivity of the pattern will be greater if we allow the ratoon to go to maturity, or if we plow it under for a better chance with the following upland crop. This has to be an individual evaluation, aimed at each individual paddy.

MODCAL: Establishment of an optimum or higher-than-optimum crop stand provides one of the cheapest and easiest means to control weeds in rice fields. Therefore, why should the Asian farmer not be encouraged to use a higher seed rate to establish an early good crop stand and to replace costly herbicide, at least in part, to control weeds? Such a practice would suit a cropping system where rice is followed by a legume crop. The use of herbicide in rice may not be favorable for the following crop.

Moody: Herbicide carryover from one crop to the following crop is probably minimal in the tropics. I agree that we should use optimum plant populations. In fact, there is no substitute for good cultural practices. We have done some studies on plant populations and weed control in rice. For example, at a 25- × 25-cm plant spacing, yield losses due to weeds were over 50%. At a spacing of 15- × 15-cm, losses were less than 20%. However, we also have to take into consideration such factors as economics, disease, insects, and lodging.

Varieties also vary greatly in the ability to compete with weeds. There is a tremendous variation in the germ plasm available to us. For example, in the International Rice Observational Nursery currently planted under upland conditions, the height of plants 1 week after emergence varied from 11.3 cm for the shortest variety to 22.7 cm for the tallest. We must take advantage of factors such as this when we select crop varieties. Not only should we select them for yield and for disease and insect resistance, but we should select them for their ability to compete against weeds.

SCHARPENSEEL: In the temperate climate, one observes sometimes a drastic reduction in the earthworm population even in the very fertile loessic soils. In parallel, one recognizes bad decomposition of straw and other vegetation relics. Many people associate this phenomenon with increasing application of herbicides. How do you judge similar effects on tropical soils? Are there observations, and what are they?

Moody: No observations that I know of. Other weed scientists at the meeting also know of no example for the tropics.

HARWOOD (comment): 1 would like to point to the opportunity presented, through weed control, for coordination of scientists in our systems research programs. Weed management has provided "point of coordination" in the overall program, since, as Dr. Moody pointed out, weed management transects all aspects of the system. It concerns soil and water management, tillage, crop sequence, variety, plant population, insect management, crop-residue management, and fertility, and is perhaps the most important area of labor, power, and cash inputs. Weed management, then, can serve as a practical "vehicle" for field-research team coordination, as well as have one of the greatest potentials of any discipline for improving systems.

APPROACHES TO WEED CONTROL IN CROPPING SYSTEMS

D.L. Plucknett, E.J. Rice, L.C. Burrill, and H.H. Fisher

Interest in cropping systems has increased significantly during the past five years. Several international agricultural research centers, as well as national and regional institutions, have initiated cropping systems research programs.

The International Rice Research Institute (IRRI) can claim credit for some of the current interest. Other factors or ideas have also stimulated investigation; they include (1) increasing awareness that agricultural research results are generally ignored by small farmers; (2) a better understanding of the small producer and his production system, making it possible to identify appropriate intermediate technology; (3) a concern that the small farmer in the tropics has been bypassed or overlooked in traditional agricultural research and development programs, coupled with the realization that very little is known about the farmer, his household, or his management problems; (4) an increased awareness that world food needs can best be met by intensifying production on existing lands, some of which are marginal and will not receive all the inputs that high yielding varieties may require; (5) the fact that small farmers around the world produce more food per unit area of land than larger producers; and (6) an increased awareness of the need for an overall management approach to pest control within the dynamic crop environment.

To deal effectively with any of these six factors, research on farming systems is needed urgently. To be most effective, most of that research should be conducted on the farm and not at experiment stations (Navarro and Moreno, 1976). The following comments address the task of obtaining satisfactory weed control in various cropping systems. They not only

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concern the practices which could be used, but also present a philosophy and approach aimed at improved understanding and management of the weed problems which each farmer must confront.

A common misconception exists concerning weed problems and cropping systems: that somehow, intensive cropping systems will reduce weed problems and farmers will experience minimal difficulty with weeds by simply maximizing production. It is true that some intensive cropping patterns will help reduce weed problems because of more vigorous crops, more extensive shading, more frequent tillage, crop rotation, better water management, or other factors. However, it is a truism that "each cropping or farming system has its own weed problems." The important questions pivot on the nature and effect of the weed species present.

In one study, six upland crops — corn, rice, sorghum, soybeans, mung beans, and cowpeas — grown at different row spacings varied considerably in their ability to compete with weeds (IRRI, 1975). Weed flora changed little as spacing increased, but differed greatly among the six crops. In corn and legumes, 50% of the weeds were broadleaves, 30% grasses, and 20% sedges; in sorghum, 75% were broadleaves, 20% grasses, and only 5% sedges; the respective percentages' for rice were 30, 50, and 20. The type of crop affects the composition of weed flora.

DIFFERENT CONCEPT OF WEED CONTROL NEEDED

Weed control in cropping systems needs to be considered on a different basis from that in monoculture agriculture. Too many agriculturists consider weeds a stable mixture of familiar, but unwanted, plants that can be controlled by several conventional methods (including herbicides). Many fail to recognize the tremendously dynamic nature of weed populations, especially the rapid shift in species that may accompany changes in cultural practices.

The need to recognize and understand shifts in weed populations in various cropping systems is important. Between-crop weeds that complete growth cycles during turnaround time will greatly influence composition and effect of the succeeding weed community. However, under intensive cropping, the weed community is the result both of the crop-weed association and of the crop management (Bantilan et al., 1974). Another study demonstrated that various management practices can reduce the populations of many problem grasses and sedges over time in an intensive cropping system (Harwood and Bantilan, 1974); the most effective method employed butachlor herbicide at a low rate, and one hand-weeding coupled with high plant-population and rotation of lowland and upland crops. Similar favorable weed-species shifts have occurred under purely upland conditions (personal communication with R.R. Harwood, IRRI, 1976). It is significant that small farmers can afford this type of weed management. The important point is that constant vigilance must be maintained to enable growers to keep one step ahead of an undesirable weed-species buildup.

Each cropping system provides many ecological niches for the weed community. How, then, can the ecological balance be shifted to favor the crop over the weeds? How can niches be filled? That is the underlying principle of weed management.

Ecological niches may be thought of as maximum utilization of the resources of the environment—especially solar radiation, water, and nutrients. No one plant species—crop or weed—is able to fully exploit all the resources (National Academy of Sciences, 1968). However, through use of optimal planting times, plant densities and spacings, crop combinations, rotations, and sequences, environmental resources can be utilized more fully throughout the year. For example, intercropping has been practiced for centuries in various parts of Asia. By growing two or more crops together, farmers often achieve income maximization and insurance against crop failure (Faris et al., 1975; Soria et al., 1975). Vertical and horizontal crop combinations such as corn-mung beans (personal communication with K. Moody, IRRI, 1976) and sugarcane-tomatoes or sugarcane-peanuts (personal communication with R.D. William, Asian Vegetable Research and Development Center, Taiwan, 1976) are common. Such combinations allow crops to effectively compete against weeds by becoming established rapidly and subsequently shading the weeds.

Competitive ability against weeds is not sufficient. A highly competitive mung-bean cultivar may produce less than a poor competitor simply because it is not an inherently high yielding variety (IRRI, 1975; personal communication, Moody, 1976).

While the need for a weed-management approach is recognized, there is too little basic information on the plants and the systems involved to make it possible to conduct effective programs. Weed control might best be regarded as applying ecological pressure against weeds.

THREAT FROM PERENNIALS

Currently, cropping systems changes appear to be bringing about rapid changes in weed flora, with an accompanying, ominous increase in perennial weeds. At the 5th Asian Pacific Weed Science Conference in Tokyo in October 1975, several scientists reported the alarming increase and spread of perennial sedges and other weeds in flooded rice in temperate Japan and

Korea, as well as in tropical countries such as Indonesia and the Philippines (Ahn et al., 1975; Duc Chao and Mercado, 1975; Ryang and Han, 1975; Soerjani et al., 1975; Ueki and Kobayashi, 1975). The appearance of the perennial sedge *Scirpus maritimus* as a recent problem in Asian rice fields is but one example (De Datta, 1974; Kim and De Datta, 1974). Other perennials that pose threats elsewhere in the tropical world are *Sorghum halepense, Cynodon dactylon,* and *Cyperus rotundus* in many situations; *Panicum maximum* in many sugarcane areas; and *Imperata cylindrica, Panicum* spp., and *Paspalum* spp., which are serious in plantation crops (Parker and Fryer, 1975). Many are acquiring tolerance for chemicals under intensive herbicide use.

Why the shifts? What changes in the cropping system have taken place to allow those perennial weeds to become dominant? What changes will be necessary to control them? Could the problem have been predicted? If not, why not? What are the requirements of an "early warning" system that spots weeds which are not now, but which could become, serious problems?

PROBLEM OF ANNUALS

Many of the developing nations' problem weeds are annuals which have been building up in certain crops because of their tolerance for less expensive herbicides such as 2,4-D, atrazine, and paraquat.

Phalaris spp. has increased rapidly in 2,4-D-treated wheat in areas of Northern India (Parker and Fryer, 1975). *Rottboellia exaltata* has become a serious problem in maize, upland rice, and sugarcane in many Latin American and Asian nations (Labrada, 1975; Arevalo, 1976; personal communication with A. Gonzalez, Bolivia, 1976, and with B.L. Mercado, University of the Philippines at Los Baños, Philippines, 1976). Again the development of tolerance for herbicides (especially atrazine) and the ability to produce tremendous numbers of viable seeds continuously throughout the year has resulted in its dominance.

Extensive use ,of paraquat in banana, citrus, and coffee has led to dominance of *Parthenium hysterophorus* in Cuba (Labrada, 1975). Seedlings can often be controlled by paraquat, but established plants are resistant (Hammerton, 1974; Dhanaraj and Mittra, 1976). *Parthenium* not only reduces crop yields, but is quite serious in parts of India and other regions as a cause of dermatitis in man (Dhanaraj and Mittra, 1976).

CONCEPT OF WEED ECOLOGY

Each weed is a biologically unique entity and should be understood as such. Each species has its own life cycle, morphology, and physiology. For that reason it is difficult to chemically or mechanically control all weeds in a given setting for any extended period. Some are simply more resistant than others to herbicides or tillage practices and will become dominant due to lack of competition from weeds that are controlled. Not all plants that are likely to be weeds need to be studied in detail. However, the life cycles, environmental requirements, and basic biology of certain plants which are now, or which might become, troublesome should be better understood. Such plants can be chosen by studying their incidence and behavior in existing, important cropping systems.

How can weed ecology be studied? There is a commonsense, straightforward :approach. When a new cropping systems research program is undertaken, or when a weed scientist is added to a program, some of the following questions should be answered:

1. What are the key weed problems of the area's existing farming systems?
2. Which weeds cause major losses or problems in various cropping systems?
3. Are there physical or biological factors operating in the system which affect the way a particular weed or weeds behave?
4. Are some weeds increasing and others decreasing under different management practices? Which management factors affect which weeds?
5. How can the present management system be altered to control certain weeds?
6. Which management practices employed by the farmer appear to be designed primarily to control weeds?
7. What is an acceptable level of weed competition in the system? Is clean weeding essential or desirable? What is the cost of perfect control? In other words, what levels of weed infestation can be tolerated without leading to later, severer problems?
8. Which plants in or near present fields are likely to become problems?

Weed management may be thought of as part of total vegetation management. Through a program utilizing cultural, manual, mechanical, chemical, biological, or ecological methods, or various combinations of these, an attempt is made to create an environment that is detrimental to weeds and favorable to the crop. Because weed populations are extremely dynamic, farming practices, such as tillage or use of herbicides, may cause the buildup of particular species. Or a certain weed may have a life cycle very similar to that of the crop it infests, and thus escape control and increase in severity.

Weed species may be purposefully shifted toward more easily-controlled species through such practices as growing a competitive and high yielding variety of a crop, planting at optimum crop density, using crop rotation, varying the type and rate of application of herbicides, and changing tillage methods.

As to specific weeding operations, answers are needed for the following :

- How, when, for how long, and how many times should weeding be performed?
- Which weeds can be controlled and which cannot?
- Which weeds can be ignored?

HOW CAN THE WEED MANAGEMENT APPROACH BE IMPLEMENTED IN CROPPING SYSTEMS ?

The weed-management approach must be incorporated into cropping systems practice if measuring or forecasting the impact of change in a farming system is to improve. Most agriculturists recognize, in a general way, that certain cropping systems beget certain weed problems. People speak of sugarcane weeds, weeds of wheat, and so forth. However, the focus needs to be made even sharper for effective evaluation of any situation's present condition and its direction of evolution. One method of attack is "to know the enemy." What mechanisms does each weed species possess that enable it to establish and spread? When does it spread and for how long? How long are seeds or propagules viable? What is man's role in aiding dissemination and establishment through his cultural practices, and how can he eliminate or reduce offending practices? What are the favorable conditions within crop production programs that encourage growth and dominance of certain species and how can they be neutralized?

Weed researchers must seek information concerning new varieties of weeds, resistance of weeds to herbicides, and weed hybridization. Emphases in weed research programs may have to shift, with more attention devoted to identifying and predicting future problems.

In a recent symposium on pest problems, Parker (1976) cited four possible sources of new weed problems:

1. sudden genetic change,
2. introduction,
3. chemical selection, and
4. cultural selection.

New weed ecotypes and varieties arise from time to time as a result of genetic changes. They may show some variability in herbicide response. McWhorter and Jordan (1976) studied the morphological development of six *Sorghum halepense* (L.) Pers. ecotypes from different regions in the

United States; some were more resistant to dalapon than others. Bell et al. (1973) made interspecific crosses between the perennial *Sonchus arvensis* L. and the annual *Sonchus oleraceus* L. The annual and backcrosses to it were more tolerant of 2,4-D and dicamba than were the perennial or its backcrosses. Schreiber and Oliver (1971) reported two new varieties of *Setaria viridis,* with differences in flowering date and seedling vigor which obviously could effect control. Ryan (1970) showed differential response of biotypes of *Senecio vulgaris* L. to simazine and atrazine. Hence, continued use of a particular herbicide can allow a shift in weeds from susceptible to more tolerant species.

As man searches for new crops and better varieties, he commonly transports weed seeds and rootstocks into new areas. *Rottboellia exaltata* is a serious annual grass weed in the Santa Cruz, Bolivia, area. It infests corn, sorghum, upland rice, and sugarcane on thousands of hectares. No one in the region remembers seeing it more than 10 years ago. It probably was imported in contaminated grain (personal communication, Gonzalez, 1976). In Arabia, Parker (1973) found that at least 50% of the newly imported citrus and mango trees at one research station were contaminated with the perennials *Cyperus rotundus, Oxalis latifolia* and *O. corymbosa.* Grapefruit trees at another station were surrounded by *Sorghum halepense* to a 3-m radius. With the many crops employed in various cropping systems it goes without saying that introduction of new weeds will occur. Everything possible should be done to prevent that.

The industries producing tree crops have used the term "cover management" in their research programs and production systems. The concept is especially useful, for it recognizes two facts:

1. Some cover on the soil is essential to provide soil protection and to prevent erosion;
2. Covers can be bare fallow, cover crops, catch crops, or combinations of these; or they can be naturally occurring weeds which provide valuable soil cover but give little competition to the crop. Cover management can be especially useful in such cropping systems as those in Taiwan where vegetables and legumes are intercropped with fruit trees (personal communication, William, 1976).

Parka (1976) recently identified seven divisions of weed biology that cover 36 subjects. His survey revealed an increase in the number of United States scientific publications dealing with weed biology and a marked decrease in those treating only chemical weed control. Within the division *Genetic Aspects and Evolution,* the subject "Weed Population Shifts" has been enjoying by far the greatest recent attention. Integrated programs have been receiving much more emphasis than other weed control methods.

TRAINING IN WEED ECOLOGY AND BIOLOGY

More weed biologists and weed ecologists are urgently needed. How can they be trained? Students may place special emphasis on the subjects within the desciplines of botany, plant ecology, agronomy, horticulture, and forestry. Graduate students may work under recognized scientists, on special problems emphasizing the ecology of individual weed species.

Older scientists will have to give themselves as much self-education as new conditions demand. Short courses, workshops, and the literature can help them.

Another useful tool for keeping up to date is cooperative studies by scientists working on similar problems. Parka (1976) has suggested that weed biology research be conducted on a regional basis. Data obtained from uniform trials for a period of 2 or 3 years would be comparable throughout a region of similar environments, and would become useful for growers.

EXAMPLES OF WEED PROBLEMS WHICH NEED A WEED ECOLOGY APPROACH

Because of their aggressive characteristics, most perennial cropland weeds in the tropics need much more ecological study. In spite of the many excellent studies on *Cyperus rotundus,* control of that pernicious weed leaves much to be desired. We need continuous investigation of *Cyperus* as well as of *Cynodon dactylon, Imperata cylindrica, Paspalum conjugatum, Sorghum halepense,* and *Scirpus maritimus,* to name a few.

Annual grasses, including *Digitaria sanguinalis, Eleusine indica,* and *Rottboellia exaltata;* various species of *Setaria;* and several species of *Echinochloa* have become more serious as problems in crops in recent years than annual broadleaves. Many of these grasses produce large numbers of seeds all through the year. Often, as with *Setaria* spp., several sets of seed may be produced (personal communication with L. Holm, University of Wisconsin, USA). Some Bolivian sugarcane may have as many as 7 or 8 germination flushes of *Rottboellia exaltata* per calendar year (Gonzalez, personal communication, 1976). Obviously, there are times when weed seeds germinate after the effects of a herbicide have dissipated.

The annual broadleaf *Portulaca oleracea* not only can produce hundreds of thousands of seeds per plant, but often sets seed very early, assuring survival (personal communication, L. Holm, 1976). Its seed dormancy also varies considerably (Egley, 1974).

The parasitic weeds *Orobanche* and *Striga* cause serious losses in many regions of Africa and Asia. Pitifully little is known of their biology or ecology.

Further studies are needed of the physiology of weed seeds and vegetative propagules for all groups. More will have to be learned about their dormancy, germination, soil longevity, populations, production, and dissemination. Weed growth and development will need to be better understood ; so will the development of resistance to herbicides and the complex reasons behind weed population shifts.

BENEFITS OF ON-FARM RESEARCH IN NORTHEAST BRAZIL

The International Plant Protection Center at Oregon State University, USA; the Brazilian Enterprise for Agricultural Research; and the US Agency for International Development recently conducted a weed research program near Recife, Northwest Brazil. The efforts were directed toward weed control systems in dry beans, maize, cassava, and sorghum. Most of the work was performed in farmers' fields; the philosophy and approach behind the investigation may be of interest.

Its basic research goal was twofold:

1. to develop effective and economical weed-control systems for small and medium-size farms of the semiarid Agreste region; and,
2. to evaluate those systems in terms of such socioeconomic criteria as economic efficiency, income distribution, seasonal availability of labor, and possibility of labor displacement.

The agricultural, social, and economic conditions in any research area must be thoroughly understood before an agronomically and economically appropriate weed control technology can be chosen (Young and Miller, 1976). Those conditions were explored in 71 interviews with local farmers, mostly producers with small and medium-size farms, and their families. Additional surveys and literature searches were carried out as needed. Six basic types of agro-socioeconomic field experiments were then designed and executed to study:

1. trade-off between labor (number of hoeings) and capital (rates of herbicides);
2. herbicide selectivity for monocrop and intercrop systems;
3. interaction between manual (number of hoeings) and cultural (crop-density and fertilizer-level) methods;
4. relation of various control methods (hoes, cultivators, herbicides) to labor availability during the year;
5. comparison of cultural, manual, mechanical, chemical, and integrated methods; and,

6. preplant methods for removal of weed flushes.

The experiments were carried out during two crop years with both traditional and modern land preparation, in monoculture and intercrop situations and, in most instances, on farmers' properties.

Traditional cropping systems throughout the world are the final result of a series of adaptations made by farmers to conditions within their immediate environments (Navarro and Moreno, 1976). The systems are complex and dynamic. They evolve constantly, adapting to such changes as improved roads, better storage facilities, guaranteed prices, and modern inputs (including better seed, fertilizer, irrigation, and pest and weed control) if the risk factor is acceptable and the incentive is positive.

After observing the Brazilian Agreste farmer, his family situation, his cultural practices, and the complexities of each of his cropping systems with their varying cultural practices, we found it possible to design research that improved his weed control practices. The improvements were small, but substantial, increasing crop production and enhancing the quality of the farmer's life by providing an intermediate technology that he understood, helped develop, and could afford.

The principal characteristic of the on-farm research was its practicality :

1. The primary goal was to improve the living standard of the rural Northeast Brazilian. The farmer was made an integral part of the information-developing process. His folk wisdom (derived from centuries of survival of his predecessors in a harsh environment) was considered valuable and was used in planning and executing the investigations.

2. Experiments were conducted on the farmer's property where the weed problems were his own and not those of a remote experiment station—not products of differing cultural practices and weed-seed or propagule importations. For example, the usual experiment station practice was to leave alternate fields in weed fallow for 1 to 3 years to prevent water erosion. That obviously allowed a tremendous buildup in annual weeds and some perennials. On the other hand, some of the better growers had most or all of their land in crops throughout the year. After bean harvest, they had sufficient soil moisture to establish cassava, which developed slowly during the dry season. As they weeded the cassava, they reduced the general weed-seed buildup and kept perennials in check.

3. On the farmers' lands it was much easier to practice traditional methods. Plant spacing; method, time, and depth of planting; thinning; pest management; and other cultural practices were those of the farmer, or his with some modifications. Availability of men for manual weeding and draft animals for cultivation was greater than at the one available experiment station.

4. Through on-farm research, it was also possible to test the various weed-control systems on several soil types that the experiment station lacked. That proved invaluable in providing information on herbicide selectivity. For instance, on one light soil, dry beans were severely damaged by a herbicide combination that yielded excellent results on a heavier soil. Experiment station soils didn‘t provide that information. Soils appropriate for cassava production were found only off-station.

SOME DISADVANTAGES OF ON-FARM RESEARCH

Probably the most serious disadvantage of on-farm research is the loss of control of the experiments. A complete understanding by the farmer and his workers of the importance of the research is fundamental. A year's research, or more, can be quickly lost if control plots are weeded because "they looked so terrible, I never would have gotten a crop there," or if they are "harvested" by an animal or by someone needing animal feed. The farmer may not understand the need for uniformity, and may carry out certain cultural practices differently than would the researcher.

The distance to suitable farmers' lands may be a problem; the experiment station is often close by. Weed growth can be considerable in only a few days under certain conditions. If treatments are many and involved, their timely execution may be difficult at an off-station location.

Agricultural technology employed at the experiment station is usually different from that practiced by the farmer, and the researcher occasionally may need more sophisticated information than can be obtained from work with the small producer. Detailed information about soil conditions and previous cropping history is often more readily available from the station than from the farmer. Certain cultural practices such as irrigation, special land preparation, or more advanced pest control may not be available off the station.

A vast amount of information remains to be developed on the ecology and biology of each weed if we are to be able to predict its possible future seriousness. With greater understanding of each species' life cycle, morphology, physiology, and association with surrounding plants, man will be able to more effectively manage weed/crop populations in various cropping systems.

The researcher must also work more closely with the small farmer, blending the farmer's innate wisdom and knowledge of cropping systems with modern agricultural technology to develop an intermediate technology that is based upon scientific principles and socioeconomics and that is realistic in terms of risk and cost.

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DISCUSSION

HOQUE: Dr. Marcos Vega showed the presence of 800 million viable weed seeds per hectare of lowland rice. I found 214 million viable weed seeds per hectare in 1 year's time under upland conditions in Bangladesh. How can you consider preventive weed control the most important control measure?

Fisher: When I emphasized preventive weed control as being the most important method I was speaking in a general sense about all weeds in all situations around the world. There are many pernicious weeds (mostly perennials) that are not found in certain localities but which could be introduced very easily through crop seed, contaminated nursery stock, irrigation water, and so on. We can also prevent the buildup of existing weed populations by preventing weed-seed set, for example, by reducing the turnaround time in a crop sequence.

In your particular case, however, preventive weed control would not be the most effective method. It has taken time to build up to these weed-seed levels. Likewise, it will take some time to reduce them. But it can be done.

MERCADO: I consider weed management as employing all the known and perhaps the "still unknown" methods of weed control, physical, chemical, ecological, and so on. In other words, it is an all-embracing approach rather than a separate chemical, physical, and so on, approach.

Fisher: Yes, I agree. Weed management should include all methods of weed control. However, since we are dealing with living organisms, it is imperative that weed management be based on weed ecology and weed biology principles.

KRANTZ: Since weed shifts can be rapid, is it possible to develop crop rotations or sequences which could keep weed populations within reasonable levels?

Fisher: Yes. Dr. Richard Harwood just showed me the results of some of his research, recently completed at IRRI, indicating that even in a purely upland rotation sequence, the serious problem weed *Cyperus rotundus* was almost entirely replaced by a population consisting mainly of annual grasses. This rapid shift was accomplished by the use of *low* rates of the herbicide butachlor and crops with a high leaf-area index. That is extremely significant, since the means represent something that the small farmer can afford.

In addition, the annual grasses which resulted from the shift were rather easily controlled by hoeing or low rates of a suitable herbicide—the important thing is that we see an example of a difficult-to-control perennial replaced by an easy-to-control annual, and *quickly.*

Rotations from a lowland crop to an upland planting (or vice versa) also permit the same beneficial population shift.

VINCENT: With reference to your description of the initial survey, you said you learned what farmers did and *why* they did it. Can you offer any methodology to assure that the researcher learns the true reasons why the farmer does something?

Fisher: During our research effort in Northeast Brazil to develop effective and economical weed control systems for small farmers in staple food crops and to evaluate these systems in terms of labor availability, labor displacement employment, unemployment, and income levels, we also conducted three socioeconomic surveys of the local farmers and landholdings. A pretest questionnaire was completed on 10 farms of different sizes. From that an improved questionnaire was made and used in 71 additional interviews. In the second year, about 60 more interviews were utilized. In all of these, only native Northeast Brazilians actually asked the questions. This was to ensure the best communication possible. Also, the questions were always asked so that discussion was prompted. All “yes-no” answers were avoided. An informal, friendly atmosphere was maintained, and comparisons among all answers were constantly made.

In addition, the farmers’ cultural practices, yields, and so on, were compared. The results of these various comparisons were surprisingly uniform. For these reasons we feel that the methodology employed got at the basic reasons behind farmers‘ practices.

Component technology insect–pest management

INTRODUCTION

T. Wongsiri

It is an honor to be selected as Chairman of this subsession. Although I have been an administrator for the past few years, I will attempt to draw on my experience and that of my colleagues, which I hope will be of value to you.

The proposed and active cropping systems in Northeast Thailand will be used in my introductory remarks today as a base for references to some of the entomological problems that might result from new cropping systems introduced into the region. No doubt many other examples could be presented and the possibilities are almost limitless, but if these few remarks serve to stimulate other ideas, my purpose will have been served.

The agricultural sector of the northeast region of Thailand is based primarily on a single crop of rainfed rice grown during the monsoon season. Soils tend to be sandy to silt loam, with poor water retention and low natural fertility. Major insect problems of rice at present include the rice gall midge, stem borer, and brown planthopper, depending on the region and the year.

The first example I wish to have you consider is a rice-rice system in which the first crop is directly planted in late April or early May and harvested in early September, when a second crop of an early photoperiod-sensitive variety is immediately transplanted into the same field. The most encouraging results obtained thus far from such a system have been at the Ubol Station in an area where the rice gall midge is indigenous. The system if practiced on a wide scale could result in a devastating buildup of the rice gall midge. Work at Pan Station in the North suggests that the rice gall midge can carry over from one season to another by feeding on certain weeds and wild rice. Given the opportunity to multiply on cultivated rice, it could produce serious effects. The point is that very little research

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has been done on such cropping systems, and any promotion of them should contain an entomological research component to warn against the insect dangers.

The second example concerns the attempt to seed rice directly into moist soil in the Korat area and establish sufficient growth under aerobic conditions that the plants do not die even when exposed to drought for 2 to 3 weeks.

In 1975, we obtained excellent stands of rice that showed good tolerance for prolonged drought through the supposed height of the monsoon in September; then suddenly what promised to be an excellent rice crop (no rice was planted in adjacent farmer fields since no standing water was present) became a total failure. The reason was invasion by mealy bugs. No doubt some of the local farmers considered the experiment a failure, but we had learned that the project needed an alert entomologist as well as plant breeders and agronomists. The agronomists had not anticipated the problem, but that was because work on cropping systems had just been initiated, and we had never grown rice without standing water.

In the last example that I wish to mention, we have begun to encounter problems with brown planthoppers in the Ubol area where none had been reported before. That may be due to the continuous cropping of rice initiated by the experiment station; the basic causes deserve attention.

In summary, I wish to emphasize that while new cropping systems may be of great value to a country, there exist dangers of creating heavy populations of insect pests, and our research, therefore, must proceed along with that of the agronomists; we must not wait to close the gate until after the horses are gone.

My colleagues, Dr. J.A. Litsinger and Dr. H.F. van Emden, in formal papers following these introductory remarks, will give more details and formulate theories for entomological research. We must keep in mind that today we have very little of the much-needed information on which to base recommendations.

PEST-MANAGEMENT RESEARCH METHODOLOGY ON FARMERS' FIELDS IN A CROPPING SYSTEMS PROGRAM

J.A. Litsinger

The traditional system for the development and implementation of pest control technology involves a flow of information from research laboratories, to research plots at experiment stations, to extension demonstrations, and finally to farmers' fields for testing. News of adoption eventually filters back to the researcher. The process involves many individuals working independently on isolated problems in government research stations, universities, and private corporations.

The Cropping Systems Program (CSP) of the International Rice Research Institute (IRRI) offers a format to shorten the time for information flow from the researcher to the farmer and back, because the farmer becomes involved from the beginning in the research and testing process.

The program involves an interdisciplinary team approach to the solving of problems and to the testing of new crop production technology to make possible its early adoption by farmers. The feasibility of adoption is determined early in the testing process, as the farmer in effect becomes a part of the research team. A farmer, after all, is himself a one-man "team". He is an integrator—a composite of agronomist, economist, soil scientist, weed scientist, entomologist, and plant pathologist. He is also close to the land, and his everyday experiences can reshape researchers' ideas in the early stages of technology development, saving time and research expense.

The Cropping Systems Program focuses research on specific sites; it is regional. Pest incidence varies from region to region. Pest control methods must suit the specific problems of each region. They require testing; the methodology of that testing is the subject of this paper.

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New cropping patterns, which are the basic units of study, are designed by members of a multidisciplinary research team, tested by team agronomists and become accepted or rejected. A new cropping pattern may increase or decrease pest problems (Litsinger and Moody, 1976). The changes are difficult to predict and are site specific. Since new cropping patterns mean new pest patterns, the input from entomologists and plant pathologists is needed at each site. The associated pest populations will influence decisions on the adoptability of each cropping pattern. If the cost of pest control is too high, a cropping pattern cannot be recommended. If in time, more effective pest control methods such as new pest-resistant varieties are developed, the cropping pattern will be reassessed.

At the outset of a cropping pattern trial, standardized pest control recommendations are needed. If the researcher lacks first-hand experience with the pests of the test area, he should interview farmers at the site to indicate dominant problems. He should also consult local extension workers. If new crops are being introduced, information from other regions will be needed to use in predicting probable pests and recommending general control methods.

Team members will require that pests be controlled in all cropping pattern trials. Recommendations for first-year trials are based on currently available technology. They usually call for a relatively high level of pest management, especially if the composition of the pest complex is unknown. Recommendations can be revised as the results of the first year's tests become apparent. A researcher's recommendations for cropping pattern trials throughout the first several years of testing are subject to change; they are not ready to be disseminated to all farmers in the region. Extension workers will do that later.

Choices exist among the several methods and levels within a method of pest control. It should be remembered that cost and return analyses will be carried out for all inputs into the cropping pattern trials. Control recommendations have to be very practical in terms both of costs and the farmers' ability to execute them. The main input of crop protection technology involves adapting control methods that have already been developed. That restricts the set of choices of pest control methods.

Any recommendation must take into account the present methods used by farmers. A benchmark survey carried out by economist team members at each site will reveal currently used pesticides. Additional detailed interviews may be necessary to discover other methods of pest control, such as cultural control, that farmers currently practice. Many new cropping patterns will involve planting-time changes. The farmers probably already know whether pest incidence will be high or low if a certain crop is planted in a certain month. It is difficult to know, however, if that is true seasonal effect, or the consequence of pest buildup from neighboring fields. Such information will form a basis for choosing the types of trials to be carried out.

PESTICIDES

At the current level of technology, with the notable exception of that for lowland rice, pesticides will be the mainstay of crop protection technology. The standard chemicals have been screened at experiment stations and much is already known about their performance. Undoubtedly, pesticide recomendations are available for all the crops that will be tested in each cropping pattern trial. What needs to be done then is to choose the pesticides to recommend for local testing. A good guide is to find out which pesticides are locally available. One should visit all the pesticide dealers in the area and compile a list of chemicals and their prices. The prices are important for cost and return analyses. Pesticide dealers are also a good source of information on the pesticides currently used by farmers of the area. In addition, it is important to know if farmers have access to mechanized sprayers. It is futile to recommend sprayers if farmers do not have them. In the absence of sprayers, the pesticides will have to be tested using the farmers' current methods.

The basic screening of new pesticides should continue at experiment stations, not in farmers' fields. Cropping pattern trials should emphasize frequency and timing of application. Farmers tend to have problems in calculating dosages, and frequently underdose. They do not retain untreated plots in their fields, and therefore remain unsure of pesticide effectiveness. They are also unsure of the effectiveness of each kind of pesticide; they tend to think one is as good as another, and opt for the cheapest. The situation of course varies from region to region, as some farmers have more experience and apply more pesticides than do others.

The basic cropping pattern trial covers about 1000 sq m in farmers' fields (Zandstra, 1977). Pesticide trials can be superimposed on these fields; if one allows 100 to 150 sq m per plot, up to eight unreplicated treatments per field can be compared. Replicates can be between fields. One treatment should be that recommended for pest control in the cropping pattern. The recommended pest control practice for the first year probably is intensive; some treatments can compare more or less intensive pesticide applications to protect plants at various stages of growth. If economic threshold values are known for pests, one treatment could incorporate these. Another should be the farmers' current method if they normally use pesticides. One plot should be left untreated for control. The yield differences between plots with highest level of pesticides and the control will indicate the scope of economic benefits to be realized from pesticide application. In the second and succeeding years, trials should focus on determining optimal timing, frequency, and lower dosages, as well as methods of application which offer the most effective results at the lowest cost.

Insecticides and fungicides may be tested on the same crop. The number of treatments is thereby increased but the treatments can be conducted in the same fields. The interaction of the fungicides and insecticides provides useful information. For purposes of comparison, one needs a control plot with neither insecticide nor fungicide treatments, an insecticide plot with no fungicide, and a fungicide plot with no insecticide. The other treatments constitute combinations of insecticides and fungicides.

The treatment of seeds with insecticides or fungicides can be tested in smaller plots and may be entirely research-managed at one end of a farmer's field. Application of pesticides to intercropping patterns is more complicated because of spray drift. Because of the several crops involved, one has to be careful of phytotoxicity. If two crops in the pattern have pest problems, the best choice is a pesticide recommended for both. Costs and returns can be calculated on an area basis. For example, in corn-peanut intercropping with one row of corn after four rows of peanuts, one-fifth of the cost is charged to the corn.

Because of the small plot-size, spray drift should be controlled even on windless days. Plastic sheeting, a meter or so wide and 5 meters long, can serve as a barrier. The plastic can be weighted by fixing bamboo stakes to its bottom. Two assistants carry the sheet, and follow the sprayer operator downwind between plots. The plastic sheet can be rolled up afterwards for easy transport from field to field.

Dosages for sprayables can be calibrated in either of two ways. The more accurate consists of the following steps: (1) Determine the volume of water necessary to spray one treatment. (2) Put a known volume of water into the sprayer with the chemical. (3) Walk, spraying the plot. The operator's walking speed is determined by observing the spray coverage. If the spray runs off the plants, the operator walks faster. The walking speed and spray volume vary with the height and growth stage of crop, and the spray volume must be recalculated for each growth stage. Once the spray volume is known, one can calculate the amount of pesticides to be added to give the desired dosage.

Another method, which is quicker, is to use a predetermined concentration of pesticide and water. To determine the dosage that has been applied, the unsprayed volume is measured after spraying, and actual amount of active ingredient used is calculated. As each person tends to spray in a particular manner, it is best to use one person for all spray operations to keep pesticide application uniform in all fields.

To mix emulsifiable concentrates more accurately in the field, a pipette can be used. A suction bulb draws out the pesticide from the bottle. The pipette can be cleaned with acetone from a wash bottle. For wettable powders, the same measuring spoon should be used each time. To calculate dosages, one should weigh the powder in an analytical balance.

Pesticide recommendations are either prophylactic or based on pest thresholds. Prophylactic treatments are warranted for seed and seedling pests if they are known to be endemic to the site. They are also recommended if it is known that major pests appear in most years and pesticide timing is critical. Otherwise it is best to determine thresholds based either on percentage of infected plants or number of pests per plant or area. These methods require pest recognition on the part of the farmer and increase his decision-making activities.

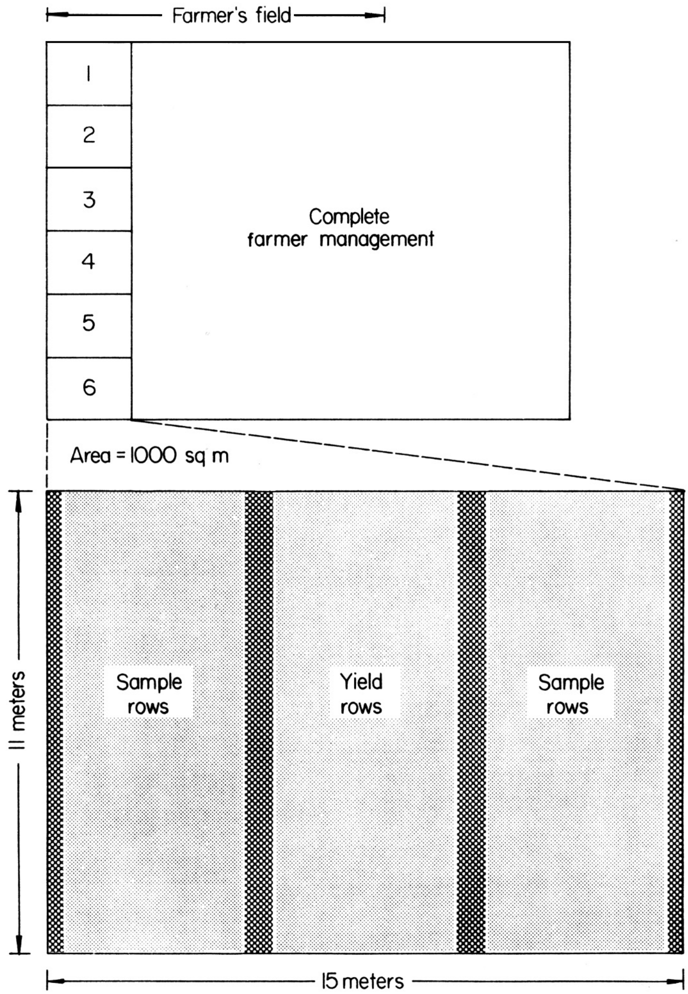
SAMPLING PEST POPULATIONS

Populations of each pest are determined by sampling. Sampling methods for most situations have already been developed. During the first year, one should sample extensively to determine what pest species are present or absent. Determining a pest's absence is often as important as determining its presence.

In addition to sampling in the test fields, it is useful to determine what pests are attacking traditional varieties in nearby fields that are entirely under farmer management. A significant pest incidence will have a direct bearing on farmers' adoption of crop protection practices.

Most sampling procedures are destructive. Plots should therefore be larger than 100 sq m. It is necessary to determine beforehand the subplot areas where yield cuts will be made. Sampling can then be done in areas adjacent to the yield areas (Fig. 1). The use of a pesticide spray barrier to catch drift will allow a fuller utilization of each plot for sampling.

It is best not to sample border rows. Sampling can be done on a per-plant basis for relatively immobile insects. The plants can be removed for later dissection. A sweep net is useful in sampling active insects. Because many insects feed at night, it is necessary to visit the fields at night several times during the growth period of the crop. Night sweeping should begin no sooner than one hour after sunset. With a flashlight, walk through the fields and observe the insects. Wear boots for protection against snakes.



1. Experimental design for six plant protection plots superimposed on a basic cropping pattern trial within a farmer's field.

Other sampling tools are beating cloths, pitfall traps for catching ground insects, sticky board traps, and light traps.

Disease incidence and defoliation by insects can be calculated by observing whole plots. It is better to first express pest incidence as a percentage of leaf area infested rather than by complicated subjective rating scales. Data can later be converted to a rating scale if desired.

Pest damage to reproductive plant parts is useful data. Harvest samples can be taken to the site headquarters for thorough observation. Basic agronomic data such as plant stand, plant height, and number of pods per plant, for example, will aid in later analysis of yield as affected by pests.

As pest incidence varies from year to year, extensive sampling should be carried out over several years to substantiate the incidence of major and minor pests.

PLANT RESISTANCE TO PESTS

The introduction of new high yielding varieties may alter the pest patterns associated with traditional varieties. Although new pest-resistant varieties have some degree of resistance to a set of pests, the reaction of the local pests to them should be monitored. The varieties may turn out to be very susceptible to some pests, and potential gains may be offset.

Variety trials are carried out in farmers' fields by the CSP team agronomist. Periodic examination of the varieties by the crop protection specialists at the site provides an invaluable input to the program. The entomologist and the plant pathologist are best trained to carry out this part of the job, as they are the persons most familiar with pests and know the best sampling techniques.

Resistance to pests is receiving more attention in plant breeding programs in the tropics. Cropping systems research sites offer opportunities to broaden evaluations and study plants' resistance to local pests. After the first year of trials, as local pests become better understood, trained staff at the site may also provide unique assistance to the breeder in developing pest-resistant varieties. The entomologist or plant pathologist can plant small plots at the site to test the parent materials from research station breeding programs. Lines that have been identified as pest resistant can be evaluated at the site against local pest populations. Extensive evaluation should not be the role of the cropping systems program, but on a small-plot basis it can provide useful feedback to the breeder about the uniformity of resistance. If a site harbors high populations of a certain pest that is not common at the experiment station, the breeder may wish to plant many lines for field evaluation. His staff should help in the more extensive testing effort.

CULTURAL CONTROL

As one crop may be planted at various times in different cropping patterns, seasonal effects on pest incidence can be studied. The planting of successive crops of rice, for example, extends the time the host plant is available.

However, interpretation of pest incidence in two rice crops may be difficult, because the trials are carried out in small fields. If the dominant pattern of an area is one rice crop, pests may unnaturally concentrate on the isolated fields that are planted to a second rice crop. Any decrease in pests in the second crop can be interpreted as a seasonal effect. But interpretation becomes difficult if the number of pests increases. Another problem is rats and birds that may overwhelm isolated, late-planted fields; they would not be as injurious if the second rice crop were more widely planted. The dominant cropping patterns, then, are influential in determining pest incidence.

Accurate prediction of the outcome of introducing a new and more extensive cropping pattern into a region cannot be made on the basis of small field trials. One needs to evaluate the pest incidence in a region where the more intensive cropping pattern is dominant.

The situation is reversed when a new crop is introduced into a region. Very few pests would be expected to occur initially, especially if the crop is botanically unrelated to the existing ones. However, as a crop becomes more widely planted, the pest incidence is bound to rise with time.

BIOLOGICAL CONTROL

Many insect pests are controlled by naturally occurring parasites, predators, or pathogens, especially on crops where little insecticide is used. Because farmers tend to use low insecticide dosages, these organisms may be spared and consequently may play an important role in pest control.

It is desirable to measure the extent of natural control in farmers' fields at each site. Insights can be obtained from the record of predators collected in sweep-net sampling, or from pests reared for parasite emergence. In the beginning, one should concentrate on major pests in the egg and larval stages. Pests can be reared at the site with minimum expense and effort. Rearing cages should be simple. Local assistants can be trained to construct and use them. A bench with legs immersed in oil or kerosene to keep away ants can hold the cages. Insect pests can also be intensively collected from untreated control plots or from adjacent farmers' fields.

If natural control is strong, measures such as timing and application of pesticide should be taken to conserve it. Pesticides that harm natural enemies should be avoided if possible. Detailed basic studies of the effect of pesticides on biological control agents should be done at the experiment station, but results may be confirmed at the test site. Information on the presence or absence of parasites and predators may lead to more in-depth research and introduction of biological control agents.

TRIALS SUPERIMPOSED ON CROPPING PATTERNS

The CSP agronomy section normally plants 4 to 12 fields in a single cropping pattern. The initial pest control trials are conveniently carried out by superimposing treatments, most commonly pesticides, on the agronomy cropping pattern fields. Such an arrangement not only permits cost savings in seed, fertilizer, and other inputs but also provides greater opportunity for interaction among members of different disciplines. All trials should be jointly planned before the cropping season to make sure team members are aware of each other's intentions.

The pesticide plots, by nature of their small size, will restrict the area for the basic measurements that interest the agronomists. One pesticide treatment can serve as the recommended crop protection practice for the pattern as a whole; it is best if two plots within each field are set aside for the purpose. To measure the recommended cropping pattern's performance, plant stand and yield data will come from these plots; hence, a larger area is desirable.

The CSP economics section records input costs for each cropping pattern. Its data should likewise be taken only from the plots that have the recommended crop protection. The costs can then be extrapolated over the field as a whole, with the other pesticide treatments disregarded in the economic analysis. One of the economic inputs—time spent spraying—is rather standardized and can be estimated from past data.

The basic CSP arrangement with a farmer-cooperator provides that he should receive the necessary inputs for growing each crop and then receive the yield. As yields of the pesticide plots may differ, the yield is determined for the plots with recommended crop protection, and that figure is extrapolated to the entire field.

Farmers are basically experimenters themselves and are curious to see trial results. We have found them extremely cooperative. Constant communication with the farmers before and during the trials ensures their continued cooperation in the next season.

The trials superimposed on cropping pattern fields are good for comparing simple pesticide treatments. More complicated trials such as intercropping experiments and evaluation of resistant varieties should be carried out on other fields at the site. They can be entirely researcher-managed on rented land, with the farmer hired as a laborer.

EFFECTIVENESS OF PLANT-PROTECTION RECOMMENDATIONS

A 3-year limitation is usually imposed for cropping pattern testing at each site. Within that time frame, the plant-protection specialists are given the task of developing the most economically feasible pest-control package for the best-fitting cropping patterns. As economic cost and return analyses will be made for each cropping pattern, the plant-protection specialists should continually strive to reduce the cost of pest control, while at the same time maintaining optimum yields. A measure of the degree of success of the plant-protection component could be the increasing ability to do this over the 3-year period, continually making more cropping patterns economical. Due to the large number of cropping pattern trials, not all can be included for detailed trials by the plant-protection specialists. Some ordering of priorities must be made so as to concentrate on the more promising patterns for the area, particularly those where pests are likely to be significant. If a pattern is low yielding for reasons other than pests, there is less potential for plant-protection measures to pay for themselves. First-year trials should concentrate on the crops most widely planted in the areas, for those would have the highest probability of achieving the best fit. Second-year trials could pick up some patterns involving other promising crops. Third-year trials should confirm the results found in the first 2 years of testing. If time and manpower allow, researcher-managed trials may be run to explore the feasibility of designing new pest-suppressive cropping patterns which may prove attractive. That may be only a matter of cropping sequence.

The rapidity with which the plant-protection specialists can determine the optimal control measures for the greatest number of cropping patterns is a reflection of the extent of technology already generated at national research institutions. The more this technology is lacking, the greater is the number of cropping patterns that are bound to fail. The cropping systems specialists may feel the need to test new technology themselves or to influence others at research centers to intensify or expand their studies into the new areas.

Another measure of the soundness of plant-protection recommendations would be to compare 2 or 3 years' data on cropping patterns in which superimposed or researcher-managed trials involving several levels of pest control had been tested. If the recommended control consistently performed optimally in terms of cost and return analyses compared to other levels of control, that would give great assurance of the reliability of the recommendations, particularly if they had been practiced by the farmers themselves in cropping pattern trials.

After several years' data have been gathered, the researcher can further test the feasibility of his recommendations by providing the farmer with several options, say a range of pesticides, and letting him choose the ones he wants. That would test the farmers' ability to recognize pest problems.

It would also tell whether the farmer has the time to perform the pest-control operations in large fields. With free inputs provided, such testing will show whether the farmer has learned to control his pests but cannot afford the inputs or does not have the time to apply them, or whether he does not understand the method of control.

COOPERATION WITH OTHER TEAM MEMBERS

Crop protection technology cannot be developed in a vacuum. It is extremely important for every researcher to visit the experiments of his team members. By doing so, he can observe pest incidence in more crops and fields and obtain deeper insights into pest problems and the relation of their solutions to the overall activities of farmers.

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DISCUSSION

PATHAK: It should be helpful to have data from controlled experiments on the effectiveness of pesticides against potential pests and on the population levels of those insects that are capable of causing economic losses. Data based on paddy field populations may take too long to provide standardized recommendations.

Litsinger: In our recommendations we recognize two situations. The first recommendation is prophylactic treatments for pests that seem to appear year after year at a location. Prophylactic treatments are necessary to protect the plant at the seedling stage against such pests as the rice whorl maggot, the corn seedling maggot, and soil-borne pathogens attacking the seeds. The second type of recommendation depends on field surveillance where we use economic thresholds as much as they are known. We recommend, then, that if a certain pest reaches a specified population level, the farmer must treat his field. As you know, many pests achieve economic level only 1 year in 5. We must be ready for them as well. That is more difficult in practice, as it requires more decision making on the part of the farmer or the local pest-control officer. Many times pests, such as cutworms, attack only a few fields and the damage is localized.

VIGNARAJAH: Rainfall patterns have a dominating influence on cropping systems in Asian countries. Are you involved in any studies of insect pest populations in relation to rainfall patterns?

Litsinger: We are not looking at the rainfall patterns between sites as they affect pest populations. However, the rainfall within sites is very important to many pests. Knowledge of the seasonal effect on pest populations is very helpful to the pest manager, as pests can be avoided by shifting the planting time by as little as two weeks.

VIGNARAJAH: You indicated that in farmers' field test plots you use the commonly available pesticides. With a large number of new pesticides coming into the market, this may not be quite advisable. It will be better to try some new pesticides also.

Litsinger: Our philosophy is to test those pesticides that are locally available at first. They no doubt are the cheaper ones, as they have been marketed for many years. In the Philippines, we have found them most adequate. If the locally available pesticides are not adequate, then I would test others available in the country. In other words, we are talking of early adoption of component technology in this year 1976. In some countries, the government is responsible for purchase and distribution of pesticides and fertilizer. If the government subsidizes the inputs to new cropping patterns, then the government can purchase overseas, in which case present local availability may not be important.

VIGNARAJAH: Control of weeds by selected crop sequences seems to be a possibility. Is this possible for insect pests?

Litsinger: Soil-inhabiting insects, diseases, and nematodes lend themselves readily to crop rotation management. The air-dispersed organisms, however, are more difficult to deal with. It is also noted that many weed species are dispersed in the air and, in fact, the development of the *r* and *K* concepts of pest type was derived by weed scientists.

REJESUS: I wonder why pest management is rather loosely used to describe insecticidal control. Would it be, perhaps, more appropriate to specify chemical control as an initial approach at the farmers' level?

Litsinger: You are correct in stating that the term pest management implies more than chemical control. However, this paper deals with varietal resistance, biocontrol, and cultural control methods as well.

INSECT-PEST MANAGEMENT IN MULTIPLE CROPPING SYSTEMS - A STRATEGY

H.F. van Emden

Pest management has been defined (Rabb, 1970) as "the reduction of pest problems by actions selected after the life systems of the pests are understood and the ecological as well as the economic consequences of these actions have been predicted, as accurately as possible, to be in the best interest of mankind."

The emphasis in that definition on the biology of pests as a foundation for predictions argues for a systems approach. I aim to show that the complexity of outcomes inherent in the flexibility of multiple cropping casts grave doubt on the practical profitability of a modeling approach and that empiricism is not only feasible but is sound on the basis of ecological principles.

ECOLOGICAL BACKGROUND

Life-systems of pests. Southwood (1975) has proposed a synoptic scheme, based on the relationship between population growth and population density (Fig. 1), for grading animal life-systems. The variations in this relationship can be arranged along an axis of habitat stability (defined as the length of time the habitat remains suitable for food harvesting divided by the length of a generation of the species). The three-dimensional surface so produced (Fig. 2) demonstrates, at the "stable" end, the relationship for animals that are extreme *K* strategists (MacArthur and Wilson, 1967). K strategists are insects whose populations are tightly regulated by the limited sources of the habitat (by intraspecific competition). At the other end lie the extreme *r* strategists, vagile, multivoltine exploiters whose role in nature is to colonize new habitats, modify them, and then move on. In between are the "intermediate" species (Southwood, 1977). "In the

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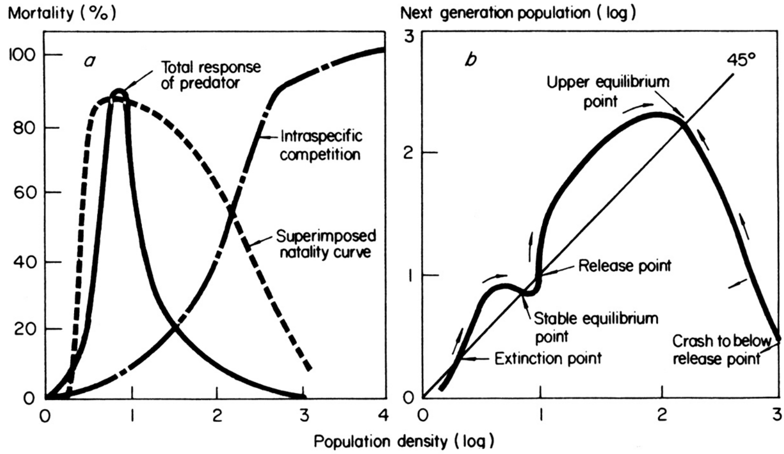
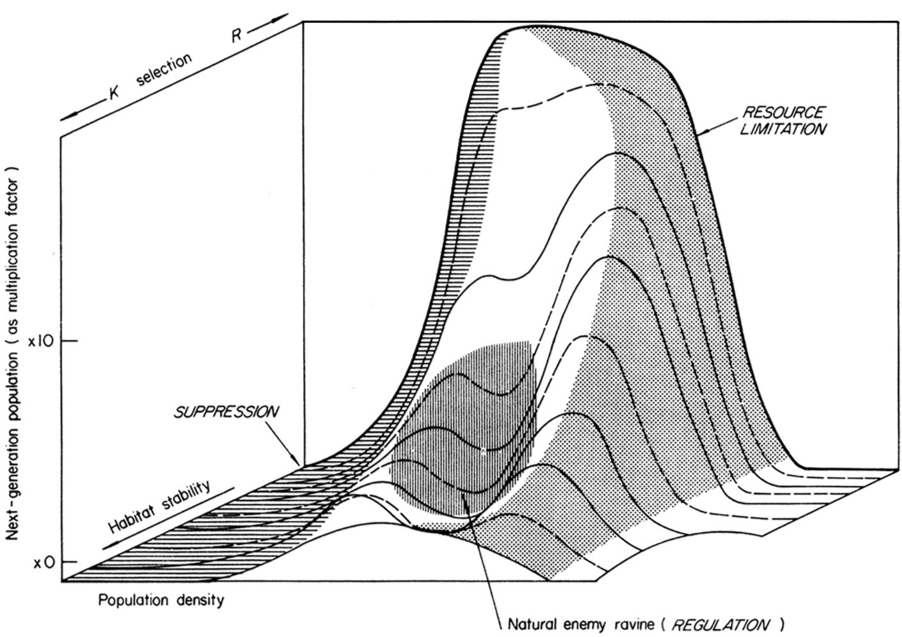


1a. Mortality-density relationships with natality-density curve superimposed (after Southwood, 1975). Units of natality curve represent an adjustment of and compensation for the associated mortality. **1b.** Curves of la combined as a population-growth relationship (after Southwood, 1975).



2. Synoptic model of population-growth relationships with pest management strategies superimposed (modified from Southwood, 1977).

area of the natural enemy ravine of the model . . . they are generally held at a level lower than the carrying capacity of their habitat by the action of natural enemies."

The three-dimensional surface suggests three ways in which manipulation could prevent successive generations from increasing in density (Fig. 2).

1. *Suppression.* Prevent the population from climbing up the population curve from its origin.
2. *Regulation.* Prevent the population from exceeding its release point from the natural enemy ravine.
3. *Resource limitation.* Make the population crash from its peak density.

Agroecosystems can be arranged in a descending order of vegetational diversity and increasing isolation (Table 1; Southwood and Way, 1970). Both diversity and isolation affect the ability of invaders to enter and multiply on a crop. However, as weapons of control, both are double-edged; their effects are not limited to pests, but may apply equally to beneficial species (van Emden and Williams, 1974). Southwood and Way (1970) describe some of the pest management characteristics of a number of ecosystems. For multiple cropping systems these characteristics are as follows.

1. The opportunity to "mimic nature" is high; many of the natural constraints on increase of animal populations can be encouraged.
2. The risk that pesticides may upset natural biological control is particularly high.

Table 1. Characteristics particularly relevant in the pest management program of some agroecosystems (modified from Southwood and Way, 1970).

Agroecosystem	Vegetational diversity	Permanence of crops	Stability of climate	Isolation
Modified rain forest	High	High	High	Low
Mixed cropping in tropics	Fairly high	Some crops generally present	Fairly high	Rather low
Irrigated agriculture	Medium	Crops present most of the year	Medium	Medium
Developed agriculture	Medium	Crops present most of the year	Rather low	Medium
Extreme monoculture	Low	Low	Low	Rather high

3. The reduced isolation of crop areas hampers the efficiency of cultural measures such as varying planting dates.

PEST MANAGEMENT STRATEGIES AVAILABLE IN MULTIPLE CROPPING

The ecosystem characteristics just described can be related to the pest management areas derived from Southwood:s (1975) synoptic population-dynamics model. The literature that offers examples of the effect of crop diversity on pest problems has been reviewed by Southwood and Way (1970), van Emden and Williams (1974), and Litsinger and Moody (1975); reference should be made to their papers for individual case histories.

Suppression. A number of pest control approaches aim to prevent low populations from swinging back to equilibrium. Pest reduction may involve promoting instability, the converse of "mimicking nature." Promoting instability is the conventional role of pesticides, crop rotation, crop residue destruction, change in the sowing date of a crop, and some other cultural controls. Multiple cropping tends to make the use of those strategies more difficult except in certain instances when, for example, a farmer is forced to destroy crop residues quickly because he needs the land for the next crop, or when he can include a fallow in the cropping sequence. Intercropping is likely to lead to allowing the residues of an earlier maturing crop in a pattern to remain in the field. There is clearly some pest-management advantage in combining crops that have similar maturation times.

Multiple cropping in time or space also poses problems for pest suppression with toxic chemicals. In a mixed stand, it is clearly difficult to prevent drift from reaching the crop not being sprayed. Moreover, Litsinger and Moody (1975) give examples of the carryover of residues from one crop to succeeding crops. Sometimes that is beneficial. Suppression with pesticides is clearly to be minimized in mixed cropping—it ignores and is potentially antagonistic to the pest control that mixed cropping can itself provide. Nonetheless, some insecticide use on the mixed farm would seem inevitable, especially as new varieties bred under insecticide protection are introduced and fertilizer applications become more common.

Furthermore, multiple cropping can easily escalate pest problems by providing alternative host plants either in space or in time; in the latter case, the breeding season for a pest is extended, and dangerous buildup of its population can occur. Overlap of pest incidence is almost bound to occur among crops in a multiple cropping sequence. Hill (1974) lists the insect and mite pests of various crops, and allows one to estimate the pest overlaps among rice, maize, legumes, and cotton as an example (Table 2).

Table 2. Number of shared pests of cotton, legumes, maize, and rice (tabulated from Hill, 1974).

Crops	Pests (no.) shared among			
	Cotton	Legumes	Maize	Rice
Legumes	18			
Maize	9	5		
Rice	7	7	18	
Total pest complex	64	63	52	12

Where overlapping occurs, there are pest repercussions beyond the straightforward increase in direct damage to crops. Pest control by crop rotation becomes less effective, and disease transmission may increase, especially between such related crops as rice and maize. Moreover, different diets may cause some quite unexpected changes in insects (van Emden, 1970), with the result that the same pest reared on different crops may vary considerably in fecundity or susceptibility to pesticides or pathogens. Such varying susceptibility can present a serious problem in intercropping, especially if phytotoxicity problems with one crop make it inadvisable to use the same chemical dose over the entire crop area.

It follows that, in general, a pest suppression strategy is easier to carry out in monoculture than in mixed cropping, especially against the mobile, exploiting, r-selected organisms. The more an organism tends to K selection, with increasing adaptation to specific habitat characteristics (including microclimate), the greater the likelihood that its pest status is due to some environmental change resulting from cropping (Southwood, 1977). The manipulation of intercropping to alter humidity and shade is an experimental strategy worth evaluating. The generalizations just made are oversimplications, for intercropping provides three possibilities for suppressing even *r*-selected pests. One possibility is related to the initial attraction of the crop surface, the others to movement within the crop stand.

First, there is evidence that bare ground in a crop area is an important element in the attraction crops have for pests. The phenomenon has been identified several times in temperate monocultures (Jepson et al., 1960; Dempster, 1969; Jones, 1969) but has never been studied in relation to intercropping. It might prove to be a very important component of intercropping strategy to include a prostrate ground cover crop, such as many of the legumes.

Second, one crop can act as a useful trap for another. Often the taller of two crops filters flying insects out of the airstream (Lewis, 1965); in other cases, more specialized relationships also exist. For example, maize attracts the moth *Heliothis* away from cotton if the emergence of the attractive maize tassels coincides with bud formation on the cotton crop. *Heliothis* fails to develop as a serious maize pest, because the several larvae per cob cannibalize each other. That is an interesting example, for in other situations the inclusion of maize and cotton together in a multiple cropping system can lead to a severe *Heliothis* problem on cotton (Reed, 1965).

Third, although intercropping with a nonattractive plant will not prevent a pest from infesting its host crop at the invasion flight, subsequent spread within the crop may well be hindered, especially if strip cropping is used. Unfortunately, some pests (such as the grasshopper *Melanoplus bivittatus*) lay eggs at the edges of crops and can become serious problems when, as with strip farming, the edge forms a large proportion of each cropping unit (York, 1951). Additionally, the strip-cropping philosophy can be extended to maximize crop heterogeneity in terms of individual plants. This may work even with a single crop species. S.R. Singh (personal communication) has observed that highly susceptible cowpea varieties can be protected from pests by sowing them among more resistant cultivars. The idea of monoculture mixtures of seeds with differing pest-resistance characteristics would appear to represent the ultimate sophistication in pest management by creating spatial diversity within a crop (van Emden and Williams, 1974), but it has yet to be explored experimentally.

Regulation. The correlation which, many ecologists have proposed, exists between environmental diversity and population stability (reviewed by van Emden and Williams, 1974), lies behind the appeal of multiple cropping as a device for copying natural ecological processes in the agroecosystem. Indeed, the potential of increased crop diversity for conserving and maximizing the action of natural enemies is, without doubt, the prime contribution that multiple cropping can make to reducing pests intermediate between the *r*- and *K*-selected types.

The *r* strategists achieve their stability on a regional level (Mackauer and Way, 1976), with little contribution to stability from the individual, local, "exploit and crash" population cycles. This makes them poor targets for management by regulation. They escalate across Southwood's (1975) natural-enemy ravine, and our control strategy cannot be one of stabilizing their populations unless we can first influence their life styles. That may in fact be possible where sizable populations are tolerable, as in many heading cereals or in leafy crops whose leaf areas are larger than needed for optimum yield (many legumes, for example). In such cases, the introduction of resistant varieties may restrict the pests to uncharacteristically low multiplication rates. In monoculture, that would merely delay the occurrence of economic damage, but tropical multiple cropping provides the additional dimension of less insecticide interference as well as the conservation of beneficial insects. The beneficial insects may well give us economic control of a pest on a resistant variety even if not on a susceptible variety (van Emden and Wearing, 1965; Starks et al., 1972).

The Cañete valley of Peru (Smith and van den Bosch, 1967) offers perhaps the classic example of the way that crop diversity can help control "intermediate" pests by improving the conditions for beneficial insects. Here, broad-spectrum insecticides and a large irrigated area of monoculture cotton had induced a yield crisis. The beneficial insect fauna had virtually vanished, and pesticide-tolerant strains of pests, as well as new pests, had appeared. An important part of the program, which so spectacularly reduced the problems, was the repopulation of the area with beneficial insects, and their conservation by the use of mixed cropping and more selective insecticides. Clearly, mixed cropping provides an excellent background for the practice of the original Californian ideal of integrated control—"applied pest control which combines and integrates biological and chemical control" (Stern et al., 1959).

Crop diversity is likely to promote the activity of beneficial insects for several reasons although, like "suppression," "regulation" depends more on the choice and sequence of crops in the multiple cropping program than merely on the decision to increase crop diversity.

Microclimate. Ground cover, by increasing humidity and shade (Taylor, 1940) near the soil, can increase the population of beneficial insects, especially of such general predators as ground beetles (Dempster, 1969).

Crop background. Occasionally, as with some predatory syrphid species (Smith, 1969), oviposition is enhanced on plants which have a lower storey plant background.

Beneficial insect reservoir. Two crops adjacent in space or time may maintain the population equilibrium of prey-predator systems in a way which monoculture followed by fallow cannot do. Alternative prey in one crop may maintain a reservoir of beneficial insects when the other crop is cleared of prey by harvest, maturation of the plants, or use of insecticides. That principle was behind the introduction of strip-harvesting of alfalfa into California (Smith and van den Bosch, 1967). The aphid-parasite balance in unharvested strips allows the parasite population to respond rapidly to steep rises in aphid numbers on the strips that are re-growing after harvest. Where enemies of major pests are polyphagous, it is even possible for their alternative prey to be nonpest or minor pest species on another crop. Györfi (1951) found that the gypsy moth *Lymantria dispar* attained stability in oak woods (at a subeconomic damage level) in the presence of noneconomic *Lepidoptera* living in the forest undergrowth and providing half the secondary hosts of *L. dispar* parasites. Similarly, strawberries grown as the ground crop for peaches in New Jersey support alternative hosts of an important parasite *Macrocentrus ancylivorus* of the oriental fruit moth *Laspeyresia molesta,* a serious pest of the tree crop (Allen, 1932).

Alternate hosts (obligatory). Occasionally, "secondary"prey species are essential *alternate* hosts that provide life-cycle continuity for beneficial insects, and not merely alternative prey on which parasites or predators can maintain themselves should their principal prey become scarce. Here, the example always quoted is the success in California (Doutt and Nakata, 1965) of a specific and purposeful crop diversification—the planting of blackberries near vineyards for the control of the grape leafhopper *Erythroneura elegantula.* The effective egg parasite *Anagrus epos* cannot overwinter in *E. elegantula* because the leafhopper overwinters as an adult. Adjacent blackberries, however, carry a second leafhopper, *Dikrella cruentata,* that overwinters in the egg stage and can therefore support the parasite. The way this example crops up in the literature would suggest it is unique, but there is in fact a rather similar case in Britain (van Emden, 1965). The parasite *Horogenes* sp. of the diamond-back moth *Plutella maculipennis,* a pest of brassicas, emerges from the cocooned larva in the autumn and depends on another caterpillar, *Swammerdamia* sp., for overwintering on hawthorn *Crataegus.* Similar stories are likely to be revealed only when one of the necessary hosts has been destroyed by man or added by chance. That provides one reason why we should experiment with the possibilities that multiple cropping offers rather than guess the outcomes.

Flowers. Flowers are important sources of adult food for many insects (both beneficial and harmful, though predominantly beneficial). Females of some species need to feed on flowers before they can deposit viable eggs with adequate yolk (van Emden, 1965). Indeed, biological-control projects have failed in the absence of suitable flowers (Wolcott, 1941a,b, 1942). In Russia, high levels of parasitization of caterpillars have been achieved by sowing plots of umbellifers to flower near vegetable fields (Kopvillem, 1960). Multiple cropping in space provides the opportunity to include a crop that at the appropriate time bears flowers attractive to parasites and predators. Unfortunately, that is likely to limit choice of crops to an extent that is uneconomic within the overall strategy of multiple cropping.

A comment needs to be added about the role of insecticides when we seek to use multiple cropping systems to increase the impact of beneficial insects. The advent of hand-held ultra-low-volume application equipment used with special formulations for the tropics is increasing the number of pesticide treatments of farmers' fields. There is a danger, though by no means immediate, that the cultural controls and mixed farming which at present provide such valuable pest suppression and regulation in the tropics will collapse if spraying is escalated (to perhaps 15 or 16 sprays on a single crop), leaving no entomological reason for retaining multiple cropping. From the very start, it is thus vital that in choosing toxic compounds and developing application procedures, the need to kill the target organism be given lower priority than the need to retain a reservoir of beneficial insects.

Four major principles are relevant to the use of pesticides in the multiple cropping systems.

Selective pesticides. Financial constraints on pesticide development companies (van Emden, 1974) prevent the marketing of highly selective compounds except those for a few pests (such as aphids), or for crops (such as cotton) that command adequate markets. If we accept the fact that a pesticide will kill both pests and beneficial insects, we must seek a favorable balance of kill rather than absolute selectivity. That aim can be achieved with spatially or temporally selective use of pesticides, but "relative" selectivity can often be achieved from fairly broad-spectrum compounds by juggling the dose or formulation applied, or both. Moreover, there is a potential for selectivity in the fact that we are often seeking to kill sedentary, flightless pests (such as caterpillars, or nymphs of sucking insects) while most anxious to conserve the beneficial species in their adult, flight-active forms. Even with a residual poison, ingenuity will sometimes suggest ways of differentiating the chances of contact with the residue by the two types of insects. That was the thinking behind the ingenious banding of coffee trunks with DDT combined with a nonlethal "knockdown" spray of pyrethrum to control caterpillars. The caterpillars, after knockdown, had to crawl across the DDT on their way back up the tree, whereas the parasites could fly (Wheatley, 1963). It may seem paradoxical, but I suspect that in multiple cropping it is better to use ingenuity with one broad-spectrum spray aimed at a pest complex than to apply a number of sprays, even though each is highly selective for a particular target.

Selectivity in space. Partial treatment of a crop area—parts of plants, spot treatment, or alternating strips—is a generally applicable technique for preserving a reservoir of natural enemies on the crop. In the future, insecticidal species-specific baits (such as those with sex attractants) may prove a very simple way of imparting selectivity to a broad-spectrum poison.

Selectivity in time. For short periods, a proportion of a beneficial species population may have protection against a spray. It may be in the endoparasitic stage (as egg parasites, for example), or it may be outside the treated area (adults feeding on weed flowers, for example).

Low density pests. Even low density pests (such as virus vectors) may well require nearly complete elimination to avoid economic damage. We need not worry too much about selectivity of pesticides between such pests and their enemies because, by the definition of the problem, we cannot expect to use those enemies in our control strategy. Nonetheless, in multiple cropping, a selective-poisoning philosophy should still apply, but its goal is selectivity between a particular pest and the natural enemies of the many other pests and potential pests in the cropping pattern or sequence.

Resource limitation. The reduction in population growth due to intensification of intraspecific competition sets a limit to the populations of all species. The *r* strategists seem to be inherently unsuitable targets for any approach to pest control based on resource limitation. Although some research at Reading University is testing how much lower the carrying capacity for pests is on resistant than on susceptible plants, it is unlikely that peak densities of *r* pests can be brought below the economic threshold by plant resistance. For pests nearer the *K* end of the spectrum, however, such resistance may lower the insect-carrying capacity of a crop to an economic level.

More practical for *r* pests is the possibility, inherent in intercropping, of wider spacing of a crop, with the undercrop acting as a barrier to limit dispersal of pests from overcrowded plants. There may be "exploit and crash" pest cycles on individual plants (infested at immigration) that do not significantly reduce yield per hectare. Some crops have a naturally lower carrying capacity for a particular pest than have others, for example, maize which, because of intense *Heliothis* competition (cannibalism in the cob), supports lower populations of the pest than does cotton.

Multiple cropping offers a further opportunity for control that relates more to the carrying capacity for pests in terms of crop yield than to pest-population dynamics. Varieties that yield well in spite of pest attack (tolerant varieties) are probably not as uncommon as is often supposed. In cowpeas, Raman (1975) has found tolerance for sucking insects in quite small samples of the available germ plasm. Tolerance is sometimes based on unusual physiological properties (van Emden, 1974). A widespread tolerance for leaf-chewing insects and some sucking insects accompanies the high leaf area index of many crop cultivars, particularly those used as undercrops in intercropping systems. It should not surprise us that the peasant farmer, having had only limited pest control weaponry for centuries, has selected leafy varieties for many crops. Removing quite considerable quantities of leaf area from those varieties does little harm to yields; it may even raise yields by reducing mutual shading of leaves and by lowering respiration of leaf areas that in any event would contribute little to photosynthesis. Under the insecticide umbrella of the plant breeders in crop improvement programs, such varieties may fail to attain their potential yield; automatically, the extremely nontolerant plants with low leaf area indices are the ones registered and distributed from such programs.

Problems in developing a general pest management strategy. The main manipulative possibilities that the multiple cropping philosophy offers pest managers all contribute to a deepening of the "natural enemy ravine" and thus to stabilizing the species intermediate between *r* and *K* life-styles—at below epidemic proportions. To deal with the mobile, multivoltine, *r*-type pest, techniques such as plant resistance (for lowering reproductive rates) and, especially, insecticides will need to be "borrowed" from the technology of monoculture. The true K strategist is rarely a pest in multiple cropping; if so, plant resistance or tolerance is an appropriate countermeasure.

An attempt has been made (Table 3) to see how pest life-styles are distributed across four crops commonly involved in multiple cropping systems in the tropics. At least two-thirds of the arthropod pests of each crop are subject to the "natural enemy ravine," and that should encourage us to make full use of the regulative opportunities that mixed cropping provides.

It is clear that suppression, regulation, and resource limitation, as control strategies for multiple cropping, apply in different ways to different kinds of pests. In the simpler conditions of monoculture, the usual pest management approach is a synthesis of separate controls for a number of individual

Table 3. Distribution by life style of arthropod pests of various crops (from lists of pests compiled by Hill, 1974).

Group[a]	Cotton	Legumes	Maize	Rice
r type	13	21	8	22
Intermediate type most subject to natural enemy ravine	23	34	29	33
Intermediate type near *K* end of natural enemy ravine	28	8	15	17

[a]See Figure 2.

pests with the controls, as far as possible, mutually noninteracting. For example, the sorghum program in the USA consists of early planting against sorghum midge, resistant varieties against aphid and sugarcane borer, rotation against soil larvae, granular insecticides against corn borer, and a half-dose of organophosphate insecticides for further aphid control (Watson et al., 1976).

The strategy of synthesis seems unlikely to succeed with the far greater number of interactions possible in multiple cropping. Litsinger and Moody (1975) point out the pest implications of the various possible inputs (Table 4) into multiple cropping, and confirm that contrasting effects can often result. This unpredictability echoes the conclusion that has come from general surveys on the relationship between diversity (the main ecological feature of multiple cropping) and stability (Southwood and Way, 1970; van Emden and Williams, 1974), which I have previously (1975) summed up as follows:

Table 4. Decisions with pest management implications involved in devising a multiple cropping program (modified from Litsinger and Moody, 1975).

Choice of crops
Crop species
Annual or perennial
Height, shade, ground cover
Maturation period
Flowering or nonflowering
Pest spectra
Crop varieties
Susceptible, resistant or tolerant
Height, shade, ground cover
Maturation period
Crop arrangement in time
Sequence of rotation
Continuous or discontinuous
Asynchronous or synchronous in area
Seasonal position of each crop
Crop arrangement in space
Pure stand, seed mixtures, intercrops, or strip crops
Planting density
Large or small fields
Regional host crop area
Distribution of host crop fields
Pesticides
Choice of material
Number of applications
Type of application
Partial or complete treatment of crop area
Time of application

"Diversity and stability do not appear to be causatively correlated; diversity merely creates a wide range of possibilities (the average of which tends to decreased stability) from which natural selection can select for stability."

We cannot expect to mimic the evolved diversity (and stability) of mature systems in crop systems (however complex) that have entirely different productivity characteristics (van Emden and Williams, 1974). We will probably have to use the suppressive as well as the stabilizing (regulative) forces of multiple cropping for some pest problems, with the result that the radiation of possibilities created by any management decision increases geometrically. A conservative estimate based on the nonpesticidal inputs of Table 4 suggests that, with four defined crops involved in a successional cropping system, there are already more than seven million possible combinations.

In agriculture it is man, and not "natural selection," that has to select the combination best suited to his purpose of maximizing the productivity: biomass ratio, and thereby (by definition) preventing the evolution of the agroecosystem to maturity and increased stability (van Emden and Williams, 1974).

A STRATEGY

I suggest that a breakthrough in developing a pest management strategy for the multiple cropping system may lie in an approach that may seem totally heretical to many pest managers who lay stress on the biology of the pests, the monitoring of their populations, and the estimating of economic damage levels. The usual approach is pest oriented rather than crop oriented.

I visualize a totally contrasting approach, with experimental variation of crop management rather than of pest-control possibilities, and data on crop characteristics rather than on pest populations.

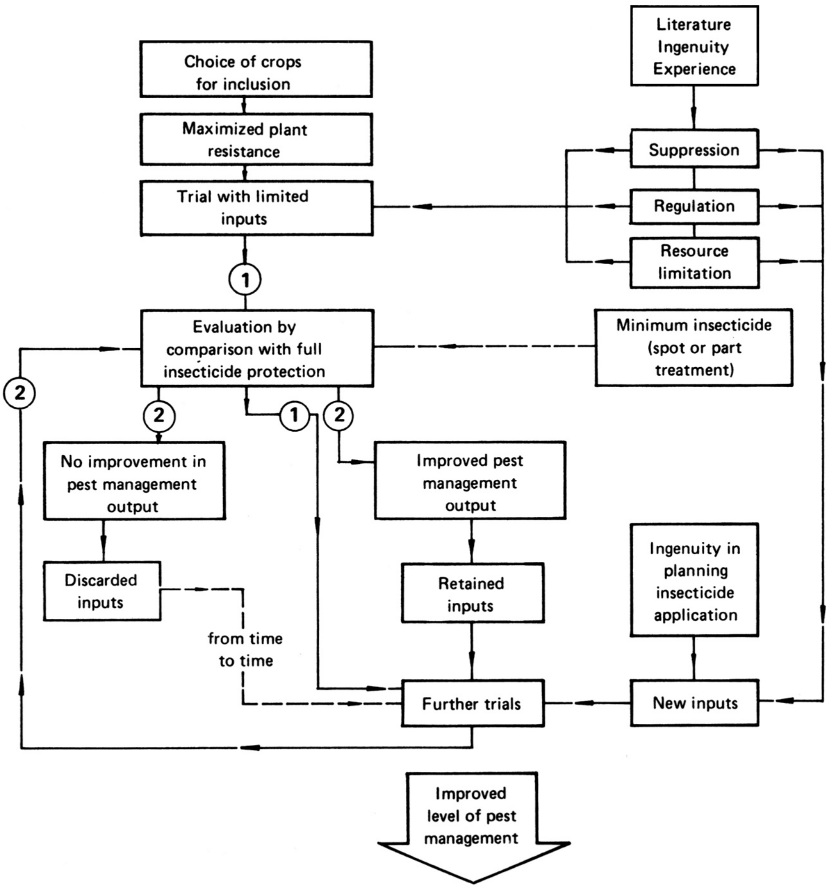
Variation of crop management will aim to create a radiation of possibilities. The sheer wealth of possibilities (*vide* the seven million mentioned earlier) means that, as in an evolving natural system, we must work from the simple to the complex. Some decisions will be obvious. We can safely decide, as a general policy, to maximize the plant resistance available to us—that resistance will almost invariably synergize with all three approaches of suppression, regulation, and resource limitation. By maximizing resistance I mean maximizing the use of resistance rather than its degree. There is no merit in using nearly immune varieties if, with background biological control, a 12% resistant variety would be adequate (van Emden, 1972). Varieties with enough resistance to be useful in multiple cropping are probably already in seed collections, and no further breeding is needed.

For some other decisions we can, at least in early trials, follow our experience and intuition by considering, for example, the number of pests shared by crops that could be intercropped or follow one another successively. Many decisions will be arbitrary; unpredictable interactions are involved. Painstakingly unraveling them is the academically most satisfying approach. For practical purposes, however, a much more rapid empirical approach comparable to that of Griffiths et al. (1975) in developing an artificial diet for laboratory insects may be useful. The diet is developed in complexity on the basis of whether the next step increases or decreases acceptance by the insects, that is, creating new possibilities and developing a selection criterion so that the system evolves as rapidly as possible in the desired direction.

In this repeated process of radiating new possibilities and selecting from them, we should be prepared to find, at times, that pest problems have been intensified by some diversification from which we expected a converse result. Similarly, we should periodically (at a high stage of complexity) reevaluate some inputs that we discarded at an earlier stage (as did Griffiths et al., 1975, in their diet work).

The suggested program needs a screening process to select those components that are to be retained as a contribution to the multiple cropping system. The screen could consist simply of an assessment of the yields (preferably per crop as well as per unit area) over the whole cropping cycle of each tested combination of inputs, and of the difference between these yields and those of the same combinations under full insecticide protection. Field experiments in the tropics suggest that the test plots themselves will probably require some minimum pesticide treatments. It is essential that the yields of all plots should be quantifiable; they should not approach zero; otherwise, the test plots may not be distinguishable in spite of considerable variations in pest management potential. The development of an optimal multiple cropping system will progress more and more toward eventual minimal use of insecticides, and it is only early on that there is any danger of having to use so much pesticide as to obliterate the discrimination between tests and fully protected treatments. It is suggested that restricting the pesticide on the test plots to spot or part (strip) treatments will preserve the comparison, yet allow a base-line yield to show on which to build further improvements.

I believe that approach (Fig. 3) represents an immediate practical step toward coping with the biological and physical complexity of multiple



3. Conceptual framework of strategy for developing pest management in multiple cropping systems.

cropping systems. The criterion for "improvement" is valid for the pathologist, the weed scientist, and the agronomist, as well as for the entomologist. It offers a fully integrated improvement program, for no step will be retained if it proves unacceptable in terms of another worker's discipline. Litsinger and Moody (1975) state: "The complex nature of multiple cropping demands that cropping patterns and systems be modeled. . . . Much more basic work needs to be done before models of pest ecologies and management systems can be formulated for multiple cropping patterns and systems." The "radiation and selection strategy" is not really at variance with this statement; the strategy may well provide a focus on the most necessary basic work, and the choice of radiations to be tested will come, especially initially, from a conceptual model. The accuracy of its predictions is perhaps of secondary importance, for it can be refined more rapidly by the repeated testing of its field predictions than by accumulating more basic knowledge. Perhaps there is a valuable analogy here in the technology of programming computers to play games — the computer must contain a model of at least some rules before it can begin to play chess, but in the end it is what it "learns" from playing games rather than the initial model that teaches it how to win!

SUMMARY

Pest management has emphasized systems analysis of basic information on pest damage and biology. The pests of multiple cropping systems can be grouped according to "life style," and only some life styles can be managed by the biological control that can be conserved in multiple cropping. Moreover, nearly every increase in diversity in the system has the potential for escalating some pest problems although reducing others, and a choice of four crops for a system already presents seven million such possibilities. Natural ecosystems show parallel evolution of stability and diversity; that is due to natural selection among the new possibilities created by diversity and not to diversity itself. With so many possibilities of multiple cropping, man also has a selection to make; the selection is complicated by the need to select for instability (suppression) of some pest species while selecting for stability (regulation) of others. In designing multiple cropping systems, that "selection" of diversity for agricultural rather than ecological ends can probably be achieved more economically by successive field testing of systems that are progressively increasing in complexity, than by looking to a model.

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DISCUSSION

KASMO: Do you stress that the selectivity of pesticides should be viewed from the application point of view rather than from the nature of the pesticide to be used? I need further clarification.

van Emden: As selective pesticides would normally be an uneconomic proposition for a manufacturer, we will have to settle for ingenious use of formulation and application techniques. This perhaps has one big advantage—we may develop our techniques for the pest complex rather than think in terms of single pests.

REJESUS: Could you express your view on the use of weed management for pest regulation? There has been a lot said on weed management per se.

van Emden: There is a long list of pros and cons; can I merely underline my generalized opinion that your own weeds are a pest nuisance whereas your neighbor's may be your salvation?

PATHAK: (1) Do you have information on population buildup of resistant varieties alone, susceptible varieties alone, and on 50:50 mixtures of resistant and susceptible varieties? (2) The system of strip-harvesting that you mentioned is frequently cited as an aid to pest management. However in the equiclimatic tropics, rice is being grown throughout the year, but biocontrol has not been generally efficient. Would you like to comment?

van Emden: (1) We know something about buildup on varieties alone. As yet the visual appearance of the mixtures is our only guide. (2) You probably don't have parasite populations of rice pests large enough to make this technique worth trying. Perhaps the pests have been largely introduced.

KRANTZ: In the semiarid tropics we are very much interested in intercropping. What are the best principles to follow in choosing from the insect management standpoint?

van Emden: Some principles are: 1) Cover ground as quickly as possible. 2) Aim for a height differential. 3) Use crops which carry natural enemies. This may mean going for shared pests; in this case the crops should have similar harvesting dates.

VILLAREAL: Could you explain how you got the total pest complex data presented in Table 2?

van Emden: I used Hill's (1974) catalogue of pests of tropical crops and used experience, taxonomic position, life history, distribution in aerial trapping samples, and so on, to judge position in *"r-K"* selection.

FREEMAN: In maximizing resistance, how could selection be made for intermediate resistance and what would be the genetic composition of this type of resistance?

van Emden: Genetic composition is probably most often polygenetic, but that is likely to be an overgeneralization. Selection is by normal procedures, provided insect counts are added to less precise visual-damage rating, and so on.

Component technology: varietal requirements

INTRODUCTION

N. Vignarajah

The objective of this Symposium is to review, discuss, and develop strategies for conducting research and for planning and implementing production programs, not only to help the small rice farmers of Asia increase their income but to improve the quality of their life. Not only the farmers' well-being but that of mankind is dependent upon the prosperity of crops, because crops are the ultimate source of food as well as of other necessities of life. Crop species have been endowed with variability and diversity in order to thrive and meet mankind's need. The void between the existing and the potential performance of a crop, and the changes in natural environment as well in man's needs have caused crop variability and diversity to be maintained in a dynamic state by genetic manipulation.

A plant breeder's role is to make possible the optimum exploitation of a particular environment and to meet man's needs by genetically manipulating the morphological and physiological traits of crops and evolving new varieties. However, if a new, tailored variety, is to realize its potential, the agronomist, the extension worker, and the farmer must be quick to adopt the management practices that are best suited to the variety.

The need for a strong interdisciplinary approach to meet the varietal requirements of multiple cropping systems cannot be overemphasized. Existing varieties have to be matched to particular environments (including farmer inputs and pest problems), and to market and consumer demands. Both before commencement of a breeding program and during its course, scientists from other disciplines have to exert a strong influence in formulating breeding objectives, screening selections and, ultimately, testing in farmers' fields to determine a variety's attributes and capabilities.

In multiple cropping systems a variety's daily yield per unit area becomes of paramount importance; that is not quite so in cropping systems where only one or two crops are cultivated per year.

N. Vignarajah. Research Officer (Grain Legumes), Department of Agriculture, Agricultural Research Station, Sri Lanka.

In developing varieties for multiple cropping systems, it is inevitable that we can meet the requirements satisfactorily only by local research. For example, in a small country like Sri Lanka (approximately 6.6 M ha), three main agroclimatic zones and, within these, 24 agroecological regions have been identified. The classification has been based on rainfall, vegetation, soils, and present land-use patterns. Besides climate, edaphic factors, and land-use patterns that dominate these regions, a strong influence is exerted by market and consumer demands, pest problems, and farmer inputs on the varieties that could be adopted to suit a particular region; it is *sine qua non* that research to meet a region's need be carried out in that region. I would like to illustrate the point by referring to Sri Lanka's experience with rice. Before 1960, the nation had a few introductions and selections from local varieties being cultivated in large areas. Since that time its rice research programs have been intensified. IR8 and other varieties have been released from the International Rice Research Institute and other institutions outside Sri Lanka, but none of these varieties ever became popular in Sri Lanka. The nation now has a range of rice varieties to suit several regional requirements—and all of them had been bred in Sri Lanka.

This afternoon, we have three leading scientists who will discuss the philosophies, objectives, research findings, and accomplishments and strategies relating to rice, field crops, and vegetable crops. Certainly, their presentations and the discussions to follow will contribute immensely to the realization of the objectives of this Symposium.

FIELD CROPS BREEDING FOR MULTIPLE CROPPING PATTERNS

R.M. Lantican

My topic will be confined to our work on a few field crops which have possibilities as alternate crops in association with paddy rice cultivation, or as intercrops in mixed cropping systems.

At the University of the Philippines at Los Baños (UPLB), breeding programs for upland field crops have so far been geared to a monocropping system under idealized upland conditions. With the current emphasis on intensive cultivation and use of land, it has been thought wise to extend the scope of the work to include the various mixed cropping systems and the paddy rice-based cultivation system.

It is believed that the added dimension is necessary for a number of reasons. First, while information to date has shown that most of UPLB's variety releases have done well in mixed cropping with sugarcane or as follow-crops in paddy fields, a few have shown erratic performance. Second, there are new strains of crops that have not officially been released owing to mediocre performance or lack of appeal under monoculture, but have shown consistently good performance in tests and in actual production on paddy fields. For example, two hybrid mung beans, CES 28 and CES 14, have never made it as officially recommended upland varieties but have repeatedly shown superior performance under rice paddy cultivation. Third, differential variety performance are expected once the adaptation of crops is extended over a wide range of such conditions as shading, moisture stress, soil aeration and compaction, and level of management care. A review of variety performance under varying cropping system environments has shown substantial interaction of variety with cropping system.[1]

[1] C A. Francis et al , "Adapting Varieties lor Intercropped Systems in the Tropics". Paper presented in the Multiple Cropping Symposium, American Society of Agronomy Annual Meeting, Knoxville, Tennessee, 1975.

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SYSTEMS OF APPROACHES IN VARIETY SCREENING

In breeding for cropping systems, certain lines of approach in screening have been chosen. They are as follows:

Breeding and screening for paddy field cultivation. Such an approach presupposes that the rice crop in the system is raised using prevailing soil-puddling practices.

Post-rice harvest screening. We have chosen a cultivation system based on zero tillage, with complete reliance on residual moisture. The practice is already in use in many parts of Southeast Asia and applies in strictly rainfed and partially irrigated areas, and where tillage after rice is impractical. With this screening system, seeds are dibbled into the ground at the base of the rice stubble. Fertilizer is applied on the ground surface. For legumes that do not provide much ground cover, mulching has been introduced to conserve soil moisture and minimize heating of the soil.

Pre-rice cultivation screening. The aim is to screen for tolerance for "wet feet" or excessive moisture during the monsoon rains that normally occur before the rice transplanting season. Tillage is zero. Seeds are dibbled into the ground; fertilizer is applied.

Breeding and screening for shade tolerance. Shade-tolerant plants are intended for a mixed or intercropping system in which short-statured crops become disadvantaged and shaded by the taller crop. Varieties are sought that can be planted under coconut, rubber, and palm oil trees, or between rows of sugarcane and other crops. An 8-foot (about 2.44 m) elevated structure has been built in which bamboo slats cut the sunlight reaching the ground by about 40%. Normal tillage operations are practiced. Whenever possible, duplicate experiments are planted synchronously in the open and without shading, for comparisons.

PRELIMINARY RESULTS

UPLB has undertaken initial replicated yield experiments for a number of chosen elite varieties of sorghum, maize, sweet potatoes, soybeans, and mung beans under paddy conditions following a rice crop, and partial shade. At zero tillage and without supplemental irrigation, very encouraging yields have been obtained. The data are preliminary and the characteristics associated with or responsible for increased yields are not yet fully understood. Such associated characteristics would be useful as selection indices in the breeding and selection programs.

I will present some of the initial findings and hypothesize later.

Table 1. Grain yields of sorghum grown on lowland paddy soil and in shade, College, Laguna, Philippines, 1975–76 dry season.

Variety or entry	Grain yield (t/ha)	
	Lowland paddy	Shade
D # 67-4	4.71	2.40
CS 100 (UPLB SG-5)	4.66	2.30
CS 107	4.23	1.93
D #67-1	4.04	2.30
CS 108	3.71	2.44
CS 102	3.42	2.84
CS 106	3.42	1.91
CS 99	3.42	1.57
CS 105	3.33	1.65
CS 103	3.28	1.63
COSOR 3	3.23	1.26
IS 2940	3.04	2.54
139024	2.95	1.69
CS 104	2.90	2.12
498003	2.42	1.44
BPI SOR 1	1.66	1.66
Average	3.40	1.98
CV	18%	14%
LSD –.05	1.06	0.57

Source of data: International Development Research Centre experiments of Dr. A.A. Gomez and A.A. Evangelista.

Rice paddy experiments. *Sorghum.* No tillage. Seeds were dibbled into the ground close to rice stubble to provide 320,000 plants to a hectare. Fertilizer was applied at 45 kg each of nitrogen, phosphorus, and potassium. Gramoxone was applied after planting to reduce weed population. The crop was subjected to waterlogging for 2 weeks because of heavy rains immediately after planting and to water stress before harvesting.

Each plot was 4.5 m long and 2.25 m or 9 rows wide. Sixteen varieties were planted in three replications in RCB design.

Average yield of 16 varieties was 3.4 t/ha. Four varieties yielded more than 4 t/ha (Table 1).

Soybeans. No tillage. Seeds were dibbled near the base of rice stubble to produce 500,000 plants/ha. Fertilizer was applied at 45 kg each of nitrogen, phosphorus, and potassium. No supplemental irrigation was used.

Twenty varieties were planted in four replications. Each plot was 5 m long and 0.8 m or 4 rows wide. Two replications were mulched with straw; the other two were not.

The 20 varieties averaged 1.568 t/ha when mulched and 0.783 t/ha when unmulched.

Highest yielders with mulch were Clark 63 at 2.135 t/ha, Williams at 2.020 t/ha, and Multivar 80 at 1.830 t/ha (Table 2). Highest yielders unmulched were Lincoln at 1.395 t/ha and KE 32 at 1.100 t/ha.

Mung beans. Treatments were the same as those of the soybean experiments, including plant populations.

Twenty varieties were used in four replications; two were mulched, two unmulched.

Table 2. Bean yields of 16 soybean varieties grown under four conditions, College, Laguna, Philippines, 1975–76 dry season.

Variety or entry	Yield (t/ha)				
	Lowland paddy				
	Mulched	Unmulched	Upland open	Upland shaded	Mean
TK-5	1.645	0.780	1.019	0.743	1.046
Clark 63	2.135	0.910	0.956	0.860	1.215
UPL-SY2	1.495	3.845	1.356	1.020	1.552
L-114	1.760	0.735	–	–	1.247
CES 434	1.580	0.570	–	–	1.075
I. Pelican	1.615	0.750	1.209	0.523	1.024
Wayne	1.240	0.785	0.845	0.673	0.885
# 29	1.655	0.660	1.199	0.741	1.063
Americana	0.990	0.480	–	–	0.735
SJ-1	1.525	0.985	0.813	0.643	0.991
SJ-2	1.390	0.630	0.926	0.514	0.865
KE 32	1.675	1.100	0.724	0.759	1.064
I-346	1.390	0.730	0.526	0.579	0.806
Bethel	1.535	0.595	1.241	0.986	1.089
Lincoln	1.795	1.395	1.428	0.769	1.346
Tainung 3	1.500	0.790	0.986	0.414	0.922
Tainung 4	1.305	0.920	0.903	0.489	0.904
Williams	2.020	0.845	0.809	0.689	1.090
Multivar 80	1.830	0.300	1.373	1.023	1.131
1248 (DAVROS)	1.275	0.875	–	–	1.075
Mean	1.568	0.783	1.019	0.714	1.021
CV (%)	15.02	25.50	24.40	17.34	
LSD .05	0.086	.069	0.423	0.217	0.247

Pooled statistical analysis of data

SV	DF	MS	F
Total	127	–	–
Conditions (A)	3	5.11126	21.96**
Reps within conditions	4	0.23271	–
Varieties (B)	15	0.16007	4.77**
A × B	45	0.10908	3.25**
Error	60	0.03357	

CV (%) = 17.02
Source of data: International Development Research Centre experiments of I.G. Catedral and R.M. Lantican.

The 20 varieties averaged 0.986 t/ha with mulching, 0.550 t/ha with no mulching, or about 100% increase in yields with mulching.

The highest yielders with mulching were Bhacti at 1.188 t/ha, CES 55 at 1.177 t/ha, and CES 28 at 1.141 t/ha (Table 3).

Sweet potatoes. No tillage. Cuttings were planted in dug-out hills at the rate of 45,000 plants/ha. Fertilizer was applied at 60-90-90 kg of nitrogen, phosphorus, and potassium per hectare. Single hills were watered once

Table 3. Bean yields of 20 mung bean varieties grown under four conditions, College, Laguna, Philippines, 1975–76 dry season.

Variety or entry	Yield (t/ha)				
	Lowland mulched	Lowland unmulched	Upland open	Upland shaded	Mean
CES 14	1.048	0.677	1.510	0.433	0.917
CES 28	1.141	0.482	1.214	0.348	0.796
CES 55	1.177	0.670	0.918	0.442	0.801
CES 87	1.030	0.523	1.321	0.374	0.812
MG 50-10A (G)	0.994	0.412	0.958	0.273	0.659
MG 50-10A (Y)	0.936	0.506	1.131	0.348	0.730
EG Glabrous #3	0.853	0.595	1.165	0.351	0.741
Dau Mo	1.116	0.583	1.136	0.400	0.808
Bhacti	1.188	0.549	1.156	0.323	0.804
CES Q-1	1.025	0.449	0.569	0.259	0.575
CES U-1	1.067	0.660	1.513	0.328	0.892
CES U-2	0.813	0.331	0.963	0.239	0.586
CES X-10	0.908	0.499	0.863	0.399	0.667
CES Z-10	0.872	0.328	1.176	0.403	0.694
CES 1D-1	0.838	0.553	1.191	0.399	0.745
CES 1D-21	0.963	0.507	1.376	0.456	0.825
CES 1 blk-6	0.897	0.611	1.160	0.388	0.764
CES 1E-1	0.846	0.432	0.885	0.313	0.619
CES N-6 (Y)	0.976	0.722	1.471	0.408	0.894
CES 1F-5	0.941	0.563	1.323	0.472	0.824
Mean	0.986	0.550	1.149	0.368	0.763
CV (%)	14.74	17.10	24.40	17.34	–
LSD .05	.034	N.S.	0.423	0.217	0.043

Pooled statistical analysis of data

SV	DF	MS	F
Total	159	–	–
Conditions (A)	3	5.282	142 75**
Reps within conditions	4	0.037	–
Varieties (B)	19	0.035	1.40 NS
A × B	57	0.048	1.92*
Error	76	0.025	–

CV (%) = 20.70

Source of data: International Development Research Centre experiments of I.G. Catedral and R.M. Lantican

Table 4. Yield of marketable tubers of sweet potatoes grown on lowland paddy soil, College, Laguna, Philippines, 1975–76 dry season.

Variety entry	Yield[a] (t/ha)
Bangued	14.8[b]
Binasayon	11.9[b]
BNAS 51	10.6
Centennial	2.3
Cx	3.5
C16-1	3.9
C28-5	5.6
C35-1	15.0
Daja	7.4
Jewel	3.8
Kaogbon	4.3
Katalo	5.4
San Carlos 2	1.2
Sweet Potato 45	5.2

[a]Av. of 2 replications. [b]Av. of 1 replication only.
Source of data: International Development Research Centre experiments of Dr. A.L. Carpena

immediately after planting. No further watering or irrigation was employed.

Fourteen varieties were grown in 6-m-long plots, 2 rows wide, in two replications.

Only one variety, C35-1, gave a respectable yield, 15 t marketable roots/ha. That yield was beyond all expectations, considering the extreme hardness of the paddy soil. BNAS#51 yielded 10.6 t/ha. The other varieties had miserable yields (Table 4).

Corn. No tillage. Seeds were directly planted at the rate of 80,000 plants/ha. Fertilizer was applied at 120-60-60 kg of nitrogen, phosphorus, and potassium per hectare.

Twenty-five varieties were grown in 5-m-long single rows spaced 60 cm apart.

The corn experiment needed at least one application of irrigation water at early seedling stage for better establishment, and another at the tasseling stage. Nutrient deficiency symptoms were much evident.

The highest yielding variety gave a yield of 3 t/ha. Complete data were not available at the time this report was written.

Shade experiments. At the time of writing, data were available early on sorghum, soybean, and mung bean experiments.

Sorghum. The sorghum shade experiment included 16 varieties and was replicated 2 times. Each entry was grown in 5-m-long plots, 2 rows wide, at a row spacing of 75 cm and plant density of 250,000/ha. Normal tillage was used. Fertilizer was applied at 45 kg/ha each of nitrogen, phosphorus, and potassium. Since the experiment was conducted in summer, overhead irrigation was undertaken once at the seedling stage. There was no duplicate planting in the open.

Average yield of the 16 varieties was 1.98 t/ha. Seven varieties yielded more than 2 t/ha, the highest being CS 102 at 2.84 t/ha, followed by IS 2940 at 2.54 t/ha (Table 1).

Soybeans. In duplicate experiments, each with two replications, 20 varieties were grown under shade and in the open. Each entry was grown in 2-m-long plots, 3 rows wide, at row spacing of 50 cm and at a plant population of 400,000 plants/ha. Fertilizer was applied at 45 kg each of nitrogen, phosphorus, and potassium.

Normal tillage operations were employed before planting. Since both experiments were planted in summer, overhead irrigation was used three times, once after planting and twice during the pod-filling stage.

The average yield of the 20 varieties grown in the shade was 0.714 t/ha (1.019 t/ha was average yield for the same varieties grown in the open), showing a decrease of 32%. In shade, Multivar 80 and UPL-SY2 yielded the highest, 1.023 and 1.020 t/ha, respectively (Table 2).

Mung beans. The experiments were laid out and managed like those with soybeans. Duplicate experiments were grown, one in shade, one in the open.

The 20 varieties in shade averaged only 0.368 t/ha, compared with 1.149 t/ha in the open, showing a yield reduction of 68%. The highest yield in shade was 0.472 t/ha (Table 3).

IMPLICATIONS OF THE PRELIMINARY FINDINGS FOR BREEDING APPROACHES

1. First, UPLB researchers were quite surprised at the high yields obtained from sorghum, mung beans, soybeans, and even sweet potatoes, which grew normally in plantings after the harvest of rice, even without the benefit of soil tillage or supplemental irrigation. Those yields indicate that breeding of crops for paddy soil cultivation after rice is worthwhile and will make an impact.

For soybeans and mung beans, mulching becomes a must, since they do not provide enough ground cover. That gives sorghum a great advantage over both, since with it mulching can be ignored and labor cost reduced.

2. The high yields of sorghum, mung beans, and soybeans were due partly to the large plant populations.

3. Good seed viability is important under paddy stress during early seedling establishment, especially for a crop like soybeans. Varieties of

temperate-zone origin usually have poor germinability, and establishment of good stands is difficult. The tropical varieties are easier to handle under paddy conditions. No problem was encountered in germination and seedling establishment of sorghum or mung beans.

4. Earliness is specially important for a crop that is sustained by residual moisture alone. Late-maturing varieties are prone to suffer from moisture stress late in the growing season. Highly indeterminate types among soybeans, which flower and produce pods over long periods beyond the blooming stage, are undesirable.

5. UPLB researchers have observed that varieties of soybeans and sorghum that have a faster rate of seed-filling do better than others under stress conditions. Sweet potato varieties that produce roundish tubers and develop at the upper layer of the ground surface fit better in highly compacted clay paddy soils than the subterranean types which have elongated tubers and burrow deeper into the ground. We hope to look further into the matter of seed filling and tuber development.

6. In shade, a 20% and 44% reduction, respectively, were observed in the number of pods that set for mung beans and soybeans. While seed size did not look much affected, the seed weight or density of soybeans, mung beans, and sorghum were much reduced, apparently due to lack of adequate supply of assimilates from the starved leaves.

7. Disease problems associated with powdery mildew and *Cercospora* in mung beans were magnified in shade. Disease resistance should be an important "plus" factor for shaded crops.

8. Statistical analysis revealed statistically significant interactions of varieties with open, shaded, and paddy cultivation in both soybeans and mung beans (Table 2, 3). Separate breeding and selection programs must be geared to the requirements of each cropping system.

It is hoped that the entire UPLB germ plasm collections and all of its segregating populations of crops (including cowpeas) will be screened for response to post-rice and pre-rice planting conditions and to partial shade. Experiments that have also been designed, I hope, can help in developing selection indices and criteria for each of the specialized situations.

DISCUSSION

PATHAK: Are you doing any work on black gram and chick peas?

Lantican: Yes, black gram is our source of resistance to diseases; we cross it with green gram and with chick-peas. We have started a germ plasm collection which we will screen under cool and hot climates (at Baguio and UPLB).

PATANOTHAI: Did you observe any correlation between performance of varieties of the crops you tested with certain characteristics of the plants? Take sorghum, for example. Was there a correlation between earliness and yield in lowland paddy?

Lantican: We are still looking at these various correlations; we hope to come up with selection indices. For one thing, earliness in maturity and increased rate of seed development are very important, especially where there is moisture stress.

RICE VARIETAL DEVELOPMENT FOR CROPPING SYSTEMS AT IRRI

W.R. Coffman

Varietal development is of crucial concern to scientists involved in cropping systems research. Of the many factors to be considered in the study and design of cropping systems, the characteristics of available crop varieties are of major importance. They determine the scientist's options in designing systems, and affect the ability of the farmer operating within a given system to adjust to the vagaries of the weather and the market.

Rice is the focal point of cropping systems research at the International Rice Research Institute (IRRI). This paper will discuss the philosophy, objectives, accomplishments, and future plans for rice varietal development work at IRRI. The program involves many scientists.

Few crops are cultivated under more diverse conditions than is rice. It is found at latitudes from 0° to at least 48° and at elevations ranging from sea level to at least 2,400 m. It grows in a continuous gradient of water regimes ranging from upland to a maximum depth of about 6 m. Rice is produced on a wide array of soils and under a wide range of solar energy regimes. Disease and insect pests are numerous and of major importance in most rice-growing environments. The properties of the grain that affect nutritive value, milling and eating quality, and consumer preference provide an added dimension of complexity. The increasing and appropriate emphasis on cropping systems research to maximize food production has created awareness of the fact that rice must be viewed in relation to other crops.

Common sense dictates that rice varieties should be tailor-made for specific locations, conditions, and systems. So-called widely adapted varieties are probably nothing more than a reflection of the fact that local research has not met the challenge of providing optimum varieties. At

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IRRI, we have designed a Genetic Evaluation and Utilization (GEU) program with the ultimate objective of making available, for every location and condition, its best possible variety of rice. GEU is an interdisciplinary program that focuses on the following problems : agronomic characteristics, grain quality, disease resistance, insect resistance, protein content, drought tolerance, adverse-soil tolerance, deep-water and flood tolerance, and temperature tolerance.

The program has several interrelated components or activities:

• *Germ plasm* collection and preservation, which is critically important to the improvement of rice.

• *Research* in the various problem areas, to identify the best genetic sources of resistance, tolerance, or other desirable characteristics, and to support the development of rapid, effective screening techniques.

• *Development* of superior, improved germ plasm which combines appropriate, desirable characteristics in a single genotype.

• *Distribution* and evaluation of the improved germ plasm from IRRI and national programs through the International Rice Testing Program (IRTP). The 14 international nurseries of this program assure the regular exchange of improved germ plasm between IRRI and local programs where it can be further selected or hybridized to fit local conditions. The nurseries also provide feedback to IRRI and other programs in the form of data on reactions to pests and adverse soils, yield potential and stability, and other important factors. The information provides the base for further breeding work.

• *Training* of young scientists in the methods and techniques of rice improvement. The training stresses a multidisciplinary approach and prepares scientists at the local level to utilize the products of the GEU Program and to develop or strengthen their own programs, which are essential to the development of varieties suited to specific locations, conditions, and systems.

The several problem areas of the GEU Program are discussed below, with emphasis on those that are of critical importance to cropping systems.

AGRONOMIC CHARACTERISTICS

The yield potential of a variety depends upon a set of plant characteristics that are grouped under the general term "plant type." The ideal plant type varies from one growing condition to another; each growing condition has particular optimums of growth duration, photoperiod sensitivity, threshability, and grain dormancy. Traditional cultural practices and methods of harvesting must also be considered.

Plant type. The characteristics and history of the IR8 plant type are well known. It is short and sturdy, highly responsive to nitrogen fertilizer, and has erect leaves that make efficient use of light. On farms with relatively high levels of management and good water control, it has been accepted and is now demanded. The IR5 plant type, which is somewhat taller and more competitive, is popular in areas of less dependable water control, or lower levels of management or soil fertility, or both. It is also popular in areas where harvesting practices discriminate against shorter types. IRRI's past breeding efforts have focused on these two types, which now occupy roughly 25 percent of the world's rice land. In those efforts, however, some advantages of the IR8 type have been sacrificed to incorporate essential disease and insect resistance. The output of the IRRI program also has probably failed to reflect the demand for the IR5 type of intermediate height. However, a shift in emphasis has begun and the 1976 IRTP nurseries include a number of lines that combine resistance to major diseases and insects with very high yield-potentials and various heights and maturities (Table 1).

Growth duration. Early varieties (105 days or less) are in great demand in the expanding rice area under irrigation. They are also particularly suitable for multiple cropping systems that involve either several crops of rice per year or one or two crops of rice in rotation with other crops. For rainfed areas where only one crop is possible, varieties of medium duration (130 days) seem to be preferred, probably because they usually yield more on a per-crop basis than do earlier types. Most varieties and advanced lines that have been distributed have been of medium duration, but the recent material (Table 1) represents a complete range of maturities.

In certain areas where heavy rains occur in 4- to 5-month periods, varieties with longer growth (150 days or more) or with photoperiod sensitivity are required. In the vast river deltas of Thailand, Burma, Bangladesh, and India, rice is planted in May or June before the onset of heavy rains. Photoperiod-insensitive types planted in those areas would mature in September or October, a period of heavy rains and standing water. Large areas could not be harvested during those months because there are no drying facilities. We have begun to emphasize photosensitive types suitable for such areas, but they are still early generation. The single-seed descent method has been adopted to shorten generation time and speed up breeding work in that area.

The performance and popularity of existing varieties available to farmers will be carefully monitored, and the breeding strategy altered for agronomic characteristics as necessary. I believe that a wide variety of types, representing a continuous range from the high input (HIP) to the

Table 1. Characteristics of some outstanding varieties and advanced lines that are resistant to most major diseases and insect pests of the Philippines, including blast, bacterial blight, tongro, grassy stunt, green leafhopper, and brown planthopper. IRRI, 1976 dry season.

Designation	Cross	Maturity [a] (days)	Height (cm)	Amylose content	Gel consistency	Yield (t/ha)	Special attribute
IR26	IR24/TKM 6	133	96	High	Medium	6.6	
IR28	IR833-6/IR1561-149//IRl737	111	97	High	Hard	6.3	
IR30	IR24/TKM 6//1 R24^4/*O. nivara*	111	90	High	Medium	6.0	
IR32	IR20^2/*O. nivara*//CR 94-13	136	100	High	Soft	6.0	
IR34	IR833-6/IR1561-149//IR1737	123	115	High	Hard	6.5	
IR2070-414-3-9	IR20^2/*O. nivara*//CR 94-13	114	93	High	Hard	5.1	Resistance to whorl maggot
IR2070-423-2-5 [b]		125	95	High	Medium	6.2	
IR2071-586-5-6-3	IR1561-228/IR1737//CR 94-13	133	103	High	Hard	6.7	
IR2071-625-1-252 [c]		111	79	High	Medium	6.3	
IR2153-26-3-5-6	IR24/TKM 6//IR24^4/*O. nivara*	125	100	High	Medium	6.2	Tolerance to salinity
IR2153-338-3		114	89	High	Hard	5.6	High protein
IR2307-217-2-3	CR 94-1 3/IR1561-228	108	84	High	Medium	6.3	
IR2823-399-5-6	CR 94-13/IR1529-680///IR24^3/ *O. nivara* //IR1416-131	126	101	High	Medium	6.9	
IR2863-38-1-2	IR1529-680/CR 94-13//IR480-5-9-3	128	90	High	Medium	7.6	Stable performance, Resistance to gall midge
IR3464-126-1-3	IR1628-68-3/IR841-67//IR2061-213	126	110	High	Medium	7.0	
IR3941-25-1	CR 126-42-3/IR2061-213	108	93	High	Medium	6.4	Cold tolerance
IR4215-4-3-1	IR2061-213/C4-63	128	130	High	Soft	5.1	
IR4227-28-3-2	IR2061-213/IR1820-17-1	128	119	High	Medium	7.5	
IR4422-164-3-6	IR2049-134-2/IR2061-125-37	133	103	High	Soft	7.5	
IR4427-58-5-2	IR2055-451-2/IR2061-464-4	126	93	Waxy	-	6.8	
IR4427-315-2-3		128	102	Inter-mediate	Soft	6.6	

continued on opposite page

table 1 continued

Designation	Cross	Maturity[a] (days)	Height (cm)	Amylose content	Gel consistency	Yield (t/ha)	Special attribute
IR4432-52-6-4	IR2061-125-37/CR 94-13	129	94	High	Medium	7.9	
IR4442-45-2-1	IR2061-464-2/1R1820-52-2	126	109	High	Medium	8.1	Resistance to stem borer
IR4608-6-2	IR1544-340/1R442-2-58//IR2061-213/C4-63	126	120	High	Hard	7.2	
IR4613-54-5	IR1702-74/1R1544-340//1R1545-339/IR1721-11	128	118	High	Medium	6.6	
IR4683-54-2	IR1545-339/1R1721-11//IR2035-290	126	122	High	Medium	7.2	
IR4712-208-1	IR1905-72/IR5//IR2061-213-2	118	124	High	Medium	6.5	
IR4816-70-1	IR1737-19///BRJ1-13-B-10//IR1103-15/IR1514A-E588	118	104	High	Hard	7.1	
LSD (.05)		–	–	–	–	0.9	
CV (%)		–	–	–	–	9.3	

[a] Maturity was about 1 week later than normal because of unusually low temperature in the early part of the season. [b] IR38 in the Philippines. [c] IR36 in the Philippines.

nearly zero input (ZIP) type will be required. I use the term "input" to describe the level of fertilizer use, degree of water control, and quality of management. The greatest gains can probably be made in the intermediate range, for which I use the general term "low input" (LIP).

These three types are described below as examples rather than as specific objectives. The tremendous diversity of the rice germ plasm and the fact that crop improvement is still to a certain degree an art must be kept in mind.

• High input (HIP)—essentially the IR8 type with short to moderately short (80–110 cm), sturdy stems, and short, thick, tough, glabrous, upright leaves. It will be highly responsive to nitrogen fertilizer, and highly resistant to lodging. The short, erect leaves will make efficient use of the low light intensity during the monsoon season. The type will have excellent early vegetative vigor and a relatively high tillering capacity, and will be suitable for both direct seeding and transplanting.

Very early maturity will be emphasized for this plant type, but the medium and late categories will not be ignored. The type will be insensitive to photoperiod. Threshability will be ”medium hard” to minimize losses during typhoons, and dormancy will be adequate to prevent sprouting when maturity is reached during rainy weather.

• Low input (LIP)—a modified IR5 type. It will have very sturdy stems of intermediate height (115–130 cm) and will respond to moderate amounts of nitrogen fertilizer. The leaves will be less erect than those of the HIP type, but much wider and somewhat longer. They will also be thick and tough (stormproof). The type will have excellent early vegetative vigor and high tillering capacity. It will be competitive with weeds. It will tiller under the waterlogged conditions prevalent throughout the monsoon tropics and have sufficient seedling size to allow transplanting under such conditions.

Medium and late maturity will be emphasized, but early types and photoperiod-sensitive types will also be developed. Threshability will be "firm" to minimize storm losses and to be compatible with the bundle harvest and storage methods often employed by farmers favoring this type.

• Zero input (ZIP)—There is no plan to place emphasis on this type immediately, but it is envisioned as a highly competitive plant that can essentially take care of itself. Its appearance would not differ greatly from that of many of the best traditional varieties still cultivated on most rice land in Asia. It would have stronger straw and such stormproof characteristics as thick, tough leaves, and hard threshability. The ZIP type would concede that very little improvement is possible in agronomic type *per se* for some rice-growing areas. It is envisioned as a carrier of major genes from other areas of GEU, such as resistance to disease and insects, flood tolerance, tolerance for adverse soils, drought tolerance, and improved nutritional and eating quality.

GRAIN QUALITY

The market price of a variety is determined largely by its grain quality. Grain quality characteristics affect production in terms of the amount of milled rice recovered from paddy. Local preferences in grain shape and in eating quality are often the major determining factors in the acceptance of new improved varieties for cultivation.

The grains of tropical rices are very divergent in physical properties, such as size and shape, and in the physicochemical properties of the starch. Starch, a polymer of glucose, is the major constituent of milled rice. The amount of its linear fraction (amylose) and of its branched fraction (amylopectin), and its gel consistency are major influences on eating quality.

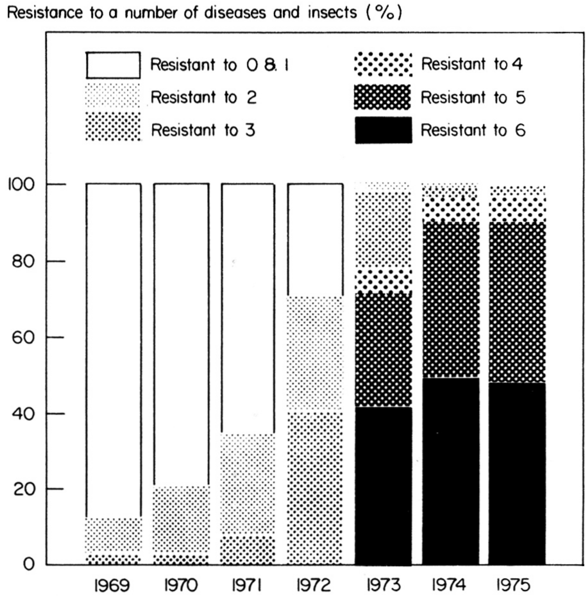
IRRI's objective is to specifically define the grain quality preferred by most consumers in each of the major rice-producing countries, and then to develop simple, rapid, and reliable tests to identify desirable types. Using past findings, IRRI workers are now seeking varieties with intermediate amylose content, or with high amylose content and soft gel consistency. They strive for high yield of head rice (whole grain milled rice) and total milled rice (low hull content). Translucency is also considered desirable, as are medium-long grains. These general objectives do not apply to waxy rice, which is a special case.

Many of the advanced lines (Table 1) have intermediate amylose content and are highly desirable in terms of the other characteristics that affect grain quality.

DISEASE AND INSECT RESISTANCE

Diseases and insect pests of major importance in rice include blast, sheath blight, bacterial blight, tungro virus, grassy stunt virus, stem borers, leafhoppers and planthoppers, whorl maggots, and gall midges. Incorporating varietal resistance is the only practical way of controlling rice diseases in the tropics, and such resistance is an essential component of any effective insect control program. Disease and insect problems will probably intensify in proportion to cropping intensity, especially in systems involving sequential crops of rice.

Resistance to diseases and insects has been a major thrust of the IRRI



1. Proportion of advanced IRRI breeding lines resistant to one or more diseases and insects in the Philippines. IRRI, 1975.

program. Most of its advanced lines carry resistance to five or more pests important in the Philippines (Fig. 1). In some cases, the resistance holds in other countries, but there is increasing evidence of biotype or strain differences. That further emphasizes the need for strong, local GEU programs. The pest-resistant lines (examples in Table 1) are distributed to local programs through a series of IRTP nurseries.

PROTEIN

Rice protein is one of the most nutritious cereal proteins (about 4% lysine), but the protein content of milled rice is the lowest among all cereals (about 7% at 14% moisture). Screening a major portion of the cultivars in IRRI's germ plasm bank has revealed a variation of one-half of one percentage point in lysine content. Some cultivars show a consistent advantage of about two percentage points in protein content over currently cultivated varieties at comparative yield levels. Therefore, IRRI's research has focused on the improvement of protein content while maintaining the nutritional quality and other essential traits of modern, improved rice varieties. To date, IR2153-338-3 is the best breeding line to have apparent improved protein content combined with other traits essential to modern varieties (Table 1). However, it lacks certain essential traits, and its possible advantage in protein requires further study.

DROUGHT

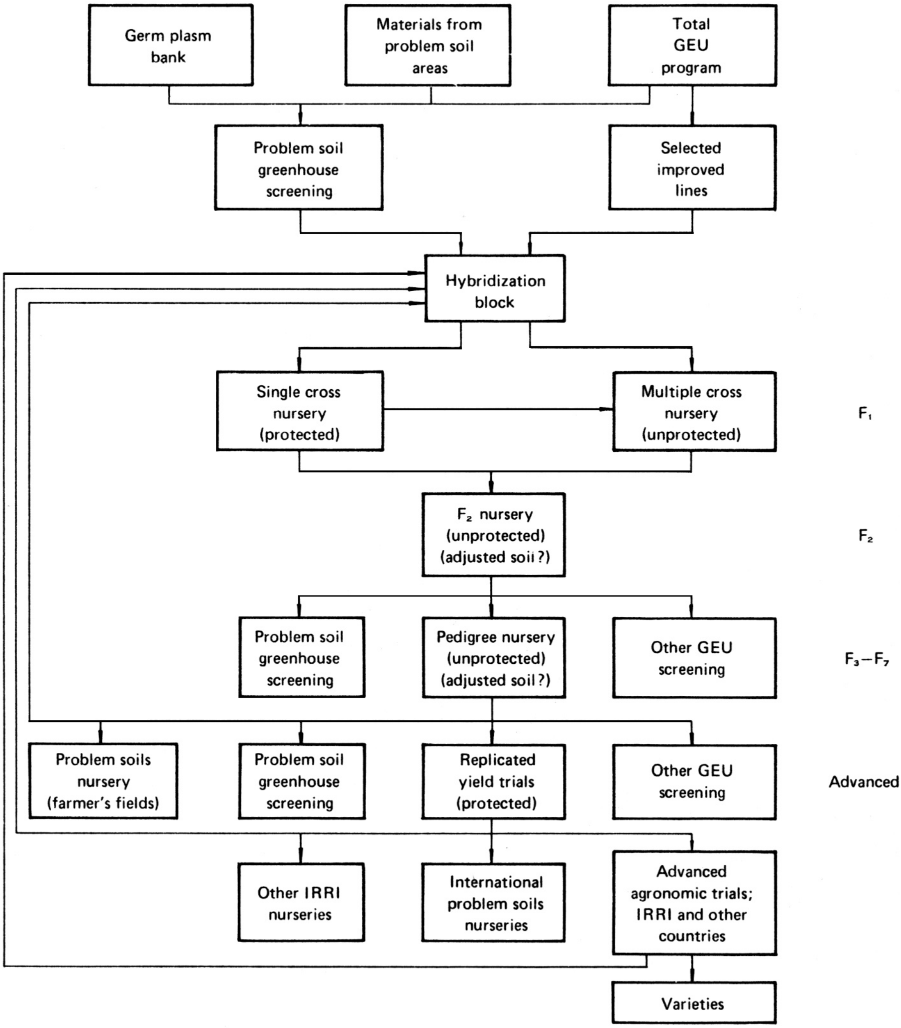
Drought resistance is essential for stable yields in nearly all rice-growing areas that are not dependably irrigated. IRRI scientists have demonstrated major differences in drought resistance among varieties and are now perfecting screening techniques. There are significant differences in drought resistance among our improved lines but, at present, those considered to have adequate resistance lack one or more traits essential to modern varieties. IR2071-625-1-252 (IR36 in the Philippines) is perhaps the best drought-resistant line among those considered adequate for other essential traits.

ADVERSE-SOILS TOLERANCE

Salinity, alkalinity, iron toxicity, phosphorus deficiency, zinc deficiency, iron deficiency, manganese toxicity, and aluminum toxicity limit rice yields in vast areas. Genetically conditioned tolerance for each of those adverse soil conditions has been identified. IRRI scientists are now developing rapid screening techniques for use in breeding work, and have organized a comprehensive program (Fig. 2) emphasizing salinity because it is considered the most important of the problems. Advanced lines are evaluated in as many of the soils as possible, and many have been found tolerant of one or more adverse conditions.

DEEP-WATER AND FLOOD TOLERANCE

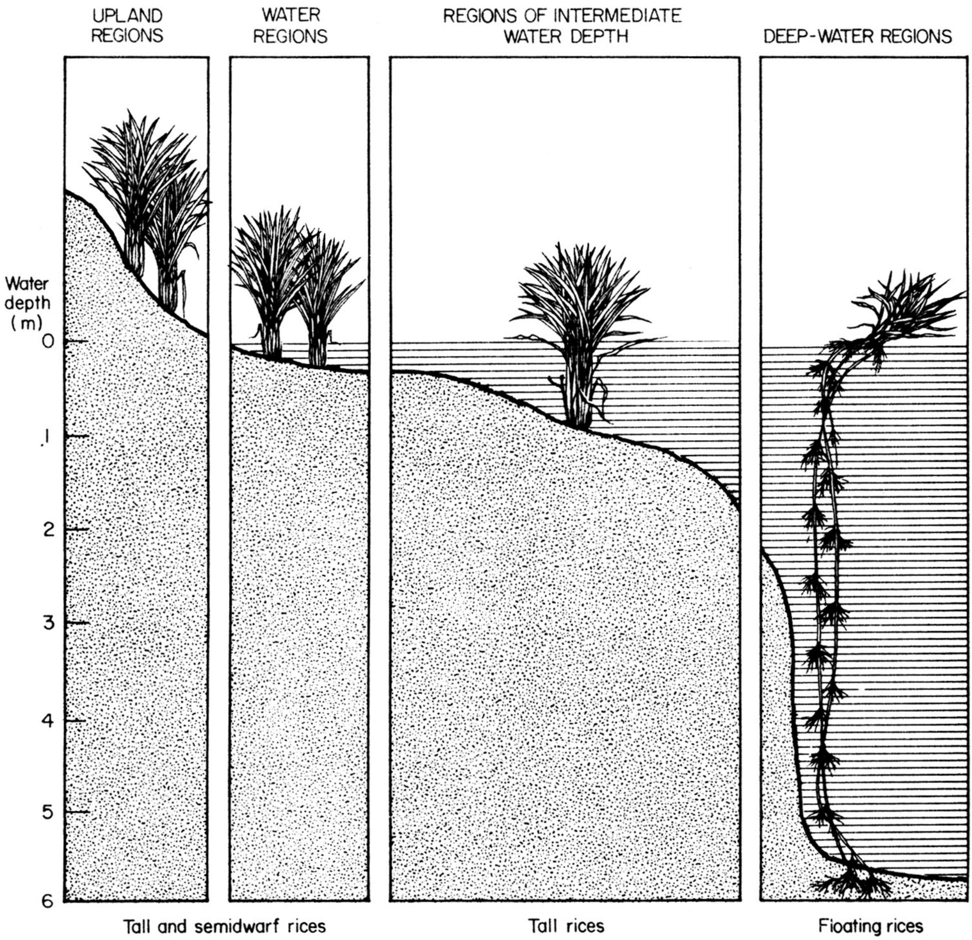
Farmers grow improved rice varieties extensively in the world's shallow-water regions, where water depth ranges from 5 to about 90 cm. But the new rice technology has bypassed other areas, including the vast regions where water is not controlled and may become too deep during the monsoon season for the semidwarf varieties (Fig. 3). Estimates of such areas range from 25 to 40% of the world's rice land. IRRI scientists, collaborating with Thai scientists, have developed prototype selections for such areas. The selections are intermediate in stature and carry elongation genes from floating rice which allow them to respond to water depth. Also, preliminary screening of the germ plasm bank material has shown dramatic variation in tolerance for submergence. In the future, I expect this research to greatly increase the stability and potential of yield in areas of uncontrolled water.



2. Flow of material for the evolvement of varieties adapted to problem soil conditions.

TEMPERATURE TOLERANCE

Low temperature tolerance has always been important in rice-growing areas at high elevations or high latitudes. In the past, the importance of high temperature tolerance was undetermined. However, as traditional cropping systems are displaced by new and more intensive systems, temperature tolerance in rice has become much more important. In new

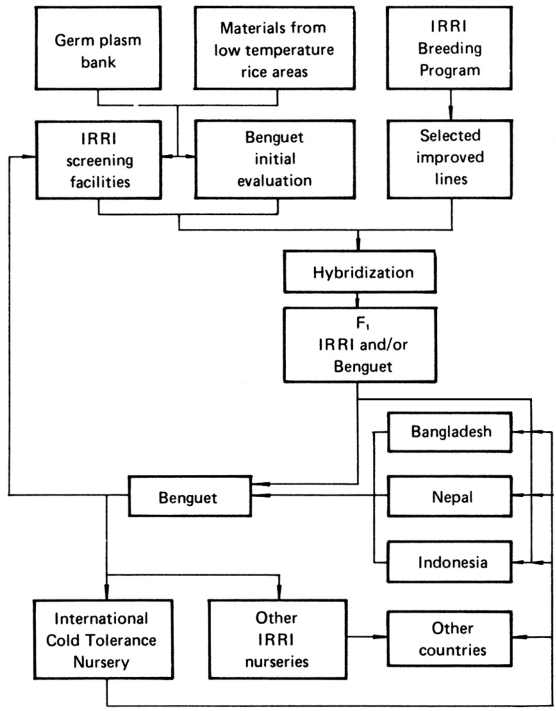


3. The world's rice land classified by water regimes and predominant rice types.

systems, planting dates are altered, and the crop may reach a critical stage of growth during periods of adverse temperature.

IRRI has a well-organized program to improve low temperature tolerance (Fig. 4), and several promising lines have been distributed through the International Rice Cold Tolerance Nursery. Among the best lines are Kn-1b-361 selections from Indonesia and IR3941 selections from IRRI.

Major differences have been found in tolerance for high temperatures. Advanced lines are being evaluated in the phytotron. We are ascertaining the relative importance of high temperature in limiting production before the possible initiation of breeding efforts.



4. Flow of materials for cold tolerance improvement program.

SUMMARY

IRRI's ultimate objective is to develop an international GEU network for rice improvement composed of strong national programs cooperating with IRRI to develop the many diverse varieties needed for the world's rice farmers. The network will provide national programs with the resources (germ plasm, screening facilities, training, manpower, and so on) on which they can draw to supplement and strengthen their rice improvement programs. I feel that interdisciplinary teams of scientists from national programs and IRRI can take the lead in accelerating the utilization of the genetic potential of the rice plant to overcome many yield-limiting constraints. The result should be new varieties specifically suited for the many and varied locations, conditions, and cropping systems throughout the rice-growing world.

DISCUSSION

ZANDSTRA: In both dry-seeded and wet-seeded rice, a common damaging factor is early flooding of the field. Do you know if genetic material is available that can tolerate the covering of seed by water and some soil?

Coffman: I was taught that rice can germinate in soil or in water, but not in both. I have never seen any exception, but some may exist.

HARWOOD: With direct seeding on dry soil (either upland or bunded paddy), present weed-control methods can hold weeds only for 30 to 40 days, after which the crop itself must take over. Some lines, like the otherwise unsuited IR442, have superior competitive ability. The short, erect types are almost impossible to grow because of weeds. Is there any effort planned to select broad, semidrooping leaves, or types that will compete better?

Coffman: Yes. We are developing a wide range of heights and leaf types. We are working closely with Dr. Keith Moody, cropping systems agronomist, to identify the height and degree of leaf droopiness that would offer maximum competitiveness with weeds with the least sacrifice in yield.

DEVELOPING VEGETABLE CROP VARIETIES FOR INTENSIVE CROPPING SYSTEMS

R. Villareal and S.H. Lai

In Asia, farmers use many cropping systems. The systems include crop-animal combinations (rice-duck, fish-vegetable) and a variety of crop combinations (rice-vegetable-vegetable-rice, sugarcane-sweet potato-vegetable, and so forth). In more general terms, such systems include mixed cropping, intercropping, relay cropping, planting after harvest, and so forth. Development of varieties for such intensive cropping systems is complex. In this paper, we shall discuss the possibility of developing vegetable crop varieties for intercropping with other horticultural crops or with field crops, for relay cropping with field crops, and for immediate planting after harvest of a rainfed rice crop. We are limiting ourselves to vegetable crops for the following reasons:

1. Vegetable crops have been and always will be used in intensive cropping systems because of their high cash and nutritional values and high production rates;
2. Most vegetable crops can be raised efficiently as seedlings, then transplanted, thereby shortening their growing period in the main field and minimizing competition with the principal crop ;
3. Vegetable crops can be grown in open spaces between rows of horticultural crops such as papaya, coconut, rubber, and so on;
4. Field crops such as rice, corn, and sugarcane are often the principal crops with which vegetable crops can be either intercropped or relay cropped; and
5. In numerous rainfed rice areas in Asia, the present cropping intensity is low and there is potential for increased land utilization (IRRI, 1975).

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DEFINITIONS

For more complete definitions of multiple cropping terminology, the reader is referred to Strout (1975). In this paper, however, the working definitions are as follows. Intercropping is planting two or more crops together on a given piece of land. It offers a means of maximizing water use and avoiding the land preparation associated with a second-season crop (ICRISAT, 1974). In contrast, relay cropping is planting a second crop when the main crop is already mature or almost ready for harvest, to minimize competition which may reduce the yields of both the main crop and the relay crop. Relay cropping is a means of maximizing the use of land and residual soil moisture. Planting is done immediately after harvesting a rainfed rice crop to take advantage of the residual moisture in the soil, as in intercropping and relay cropping. The growing of a crop in such a system may be done with or without tillage.

Theoretically, competition for nutrients, water, and light should be more severe in intercropping than in relay cropping, because in the former the intercrops and the principal crop are together on the same land for a much longer time. Such competition, of course, is absent when a crop is planted after the harvest of rainfed rice.

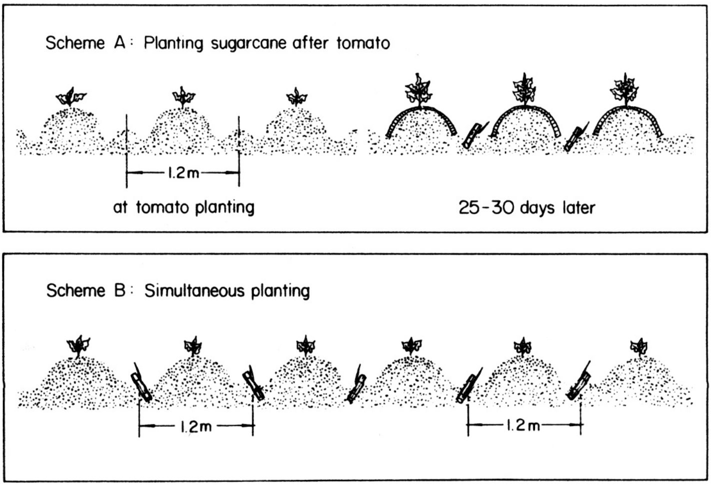
PLANT TYPES FOR INTENSIVE CROPPING SYSTEMS

In Taiwan, many vegetable crops have been interplanted with sugarcane. However, it was observed that they caused a yield loss of about 2 to 11% in the sugarcane (FFTC, 1974). No explanation was given. But we suspect

Table 1. Yield loss and gain in sugarcane due to interplanting of some vegetable crops. [a]

Intercrops	Scientific name	Yield loss (%)	Yield gain (%)	Yield of intercrops (t/ha)
Rape seed	*Brassica napus*	2.4		0.6–1.2
Pickling & yellow melons	*Cucumis melo*	5		10–20
Sugar beets	*Beta vulgaris*	5.5		30–50
Pigeon beans	*Cajanus cajan*	7		1.4
Sweet potatoes	*Ipomoea batatas*	7.5		17
Tomatoes (processing)	*Lycopersicon esculentum*	11		4–10
Broad beans	*Vicia faba*		2.0	0.2–0.5
Radishes	*Raphanus brassica*		7.0	15

[a] Adapted from Food and Fertilizer Technology Center (1974).



1. Intercropping tomato with sugarcane (adapted from chart of Kagome Co. Inc., Tainan, Taiwan).

that it was mainly due to competition for food and water, particularly when the intercrop was tomatoes (Table 1). In farmers' fields at the time of tomato harvest,[1] a colleague and one of us observed no difference in the amount of solar radiation that the two crops received. In other words, tomatoes did not interfere with the light needed by the sugarcane, or vice versa.

In Taiwan, tomatoes are intercropped with sugarcane in autumn (September to November) when temperatures are milder; regardless of whether the tomato seedlings and sugarcane seedpieces are planted simultaneously, or the sugarcane seedpieces are planted 25 to 30 days after the tomato seedlings are transplanted (Fig. 1). the crop canopies fail to overlap even after 4 months. In the Philippines, overlapping of cane canopies can occur in less than 3 months. In Taiwan, spacing between sugarcane rows is 1.2 m, and the mild winter probably slows growth. In the Philippines, the spacing between cane rows is 1 m and the weather is generally warm.

Examination of a few random plants showed that the root systems of the tomato plants were much more developed than those of the cane; the tomatoes probably used up some of the food and water that would have otherwise gone to the sugarcane. The root systems of some vegetable crops probably compete with sugarcane for water and nutrients. Exceptions, perhaps, are such shallow-rooted vegetables as radish, cabbage, Chinese

[1]Dr. George C. Kuo, AVRDC plant physiologist, and the senior author made light measurements above the canopies of both tomato and sugarcane using Lambda LI-185 (tomato at harvest, sugarcane 4 months after planting).

Table 2. Marketable ears of sweet corn relay planted with vegetables 20, 10. and 0 days before harvest [a]

Relay crop	Marketable ears (thousand/ha) 20 days [b]	10 days [b]	0 day [b]	Mean [c]
Tomatoes	45.4	45.7	44.5	45 2
Cabbages	48.0	46.7	44.2	46.3
Bush sitao	40.0	45.6	42.1	42.6
Sweet potatoes	46.4	46.0	42.1	44.9
Mean [c]	44.9	46.0	43.2	

[a] Adapted from Aycardo (1974). [b] Number of days before harvest of main crop when relay crop planted. [c] No significant differences among means of relay crop and among means of time of relay planting.

cabbage, and water convolvulus; the bulk of their roots are spread within the upper 30 cm of the soil.

Ideally the principal crop and the relayed crop should grow together without reducing the yield of either. Aycardo (1974) demonstrated that relay planting of tomatoes, cabbages, bush sitao, and sweet potatoes as early as 20 days before harvest did not reduce yield (Table 2). or alter the other horticultural characters of sweet corn, the main crop. In general, the yields of the relay crops were not affected, but the crops matured later than their corresponding monocrops (Table 3). The delay in maturation was attributed to shading of the young relay crops by the main crop. The relay crops received about 35% of the prevailing solar radiation.

The examples clearly suggest that shallow root-systems and ability to tolerate some shading are two horticultural traits that may be used in developing varieties for intercropping and relay cropping. These traits should be combined with such favorable characteristics of improved varieties as earliness, resistance to pests and diseases, eating quality, and high yielding ability.

Table 3. Yield and maturity of different vegetables relay planted with sweet corn and as monocrops. [a]

Vegetable crop	Yield (t/ha)		Days to maturation	
	Relay crop	Monocrop	Relay crop	Monocrop
Tomatoes	20.1	21.0 ns	78.8	74.5*
Cabbages	22.5	18.6*	82.0	72.5*
Bush sitao (fresh pods)	11.9	11.4 ns	65.8	60.5*
Sweet potatoes	16.2	13.8 ns	110	107 ns

[a] = Adapted from Aycardo (1974). ns = difference between relay crop and monocrop is not significant. * = difference between relay crop and monocrop is significant at 5% level.

In other cropping systems, a vegetable crop that can be planted immediately after the rice harvest should be drought-tolerant (with ability to establish quickly after planting and to withstand water stress), and be a minimum-input plant type (with ability to yield sufficiently well with little fertilizer use and no pesticides). The justification for this prototype of a vegetable crop variety is the fact that 80% of the arable land in Asia and the Far East is rainfed (FAO, 1974). In addition, fertilizers in the developing countries are either costly or scarce; many hectares of paddy fields remain idle after the rice crop because farmers are unable to obtain the needed inputs for a second crop.

To our knowledge, there is yet no specific breeding program that is primarily concerned with developing vegetable varieties for intensive cropping systems. Even at the Asian Vegetable Research and Development Centre (AVRDC), we have just begun to look at some characteristics of the tomato and the sweet potato that have potential for such systems (AVRDC, 1975). Our initial observations have been encouraging, and we believe that considerable varietal improvement for intensive cropping systems can be achieved.

SCREENING METHODS

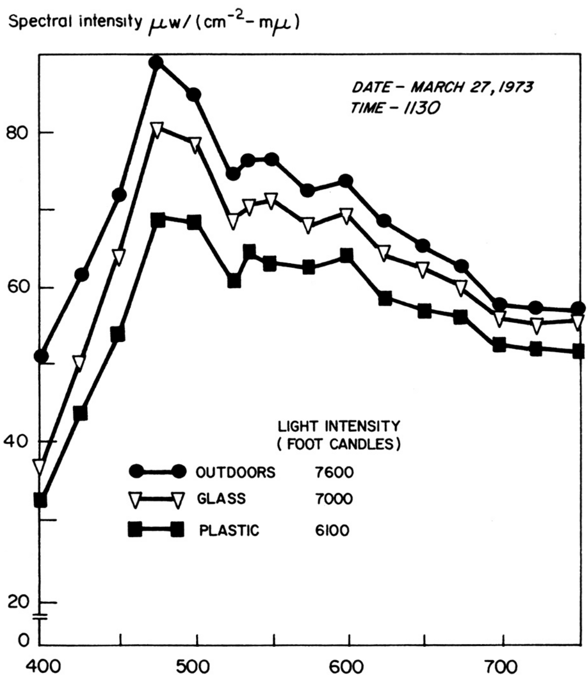
Essential to success in developing the desired varieties is an effective method of screening for the traits we are seeking.

Shallow root-systems. The search for shallow root-systems is not easy because it is difficult to sample the roots directly. Hermano (1972) described the method he used in gathering samples of cabbage root: "The soil around the plants was dug and loosened. An excess amount of pressurized water from a hose was directed toward the roots. The roots were then individually traced and uprooted with extra care." Unless a rapid and reliable technique of screening can be devised, or some aboveground parts of the plant can be associated with shallow roots, we cannot efficiently screen for the trait.

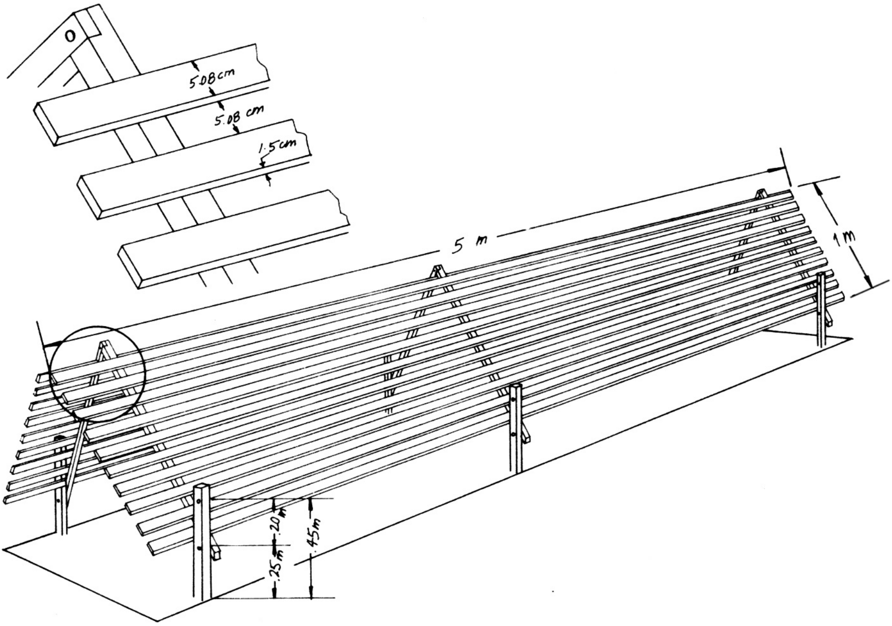
An alternative is to classify vegetable crops according to root distribution, calling them "shallow-rooted" when the roots are thickly spread near the surface of the soil (10–30 cm), and "deep-rooted" when the root spread reaches below 30 cm. Such a technique will indicate which vegetable crops may be intercropped with less danger of destructive competition with the main crop. But, the technique cannot be used to screen for a more shallow-rooted genotype in segregating populations of a given vegetable crop.

From a practical breeding standpoint, however, segregating materials may be intercropped with a main crop to compare the individual yield performance of the intercrop with the average yield of its corresponding monocrop. The yield levels of the main crop as intercrop and as monocrop should also be compared. The genotypes that yield well and do not compete with the main crop for food, light, and water, as evidenced by comparing yields of the main crop grown as intercrop and as monocrop, can then be studied more intensively for root characteristics and other traits.

Shade tolerance. The traditional way of studying the effect of light on crops is to grow the crops under greenhouse conditions, using glass- or fiberglass-reinforced polyester resin panels (reinforced plastics). Hasselkus and Beck (1963) reported 64.2% and 42.5% average visible light transmission over a year in glass and reinforced plastics, respectively. When the experimental materials were placed on the lower shelves of the greenhouse, the average visible transmission was only 14.2%. With aging and the exposure of plastics to sunlight, a 14.6% reduction in light transmission occurred in a 5-year period. Under greenhouse conditions, then, reduction in light intensity and in quality of light occurs (Fig. 2). We would, therefore, give greenhouse conditions low priority in screening for shade tolerance.



2. Comparisons of light intensity outdoors, through glass, and through plastic (adapted from McLaughlin and Sheldrake, 1973).



3. Wooden frame with 50 percent light penetration (adapted from Aclan, 1973).

Some other techniques of studying the effect of shading on plants have been reported by Marr and Hillyer (1968), Aclan (1973), and AVRDC (1975).

Marr and Hillyer (1968) used four densities of Saran plastic shade cloth— 0, 30, 45, and 63%—in 60-cm-high canopies over tomato rows. Aclan (1973) used wooden slats 5.08 cm × 5 m, mounted on wooden frames. The distances between slats were as follows :

100% sunlight — no slats
25% light attenuation—slats were 15.24 cm apart
50% light attenuation—slats were 5.08 cm apart
75% light attenuation—slats were 1.68 cm apart

Each treatment was a pair of wooden frames joined by three iron bolts (Fig. 3). The frames, oriented north to south, covered the four rows of each plot completely so that sunlight was attenuated uniformly throughout the day. The frames were raised as the plants grew. The techniques used by Marr and Hillyer and Aclan seem adequate, except that more shade cloth and bigger frames would be needed to screen a larger population of segregating materials. Under tropical conditions (generally rainy with strong winds), however, the setup of Aclan would be preferable, because it is sturdier.

Table 4. Light transmission of nylon nets of different colors.

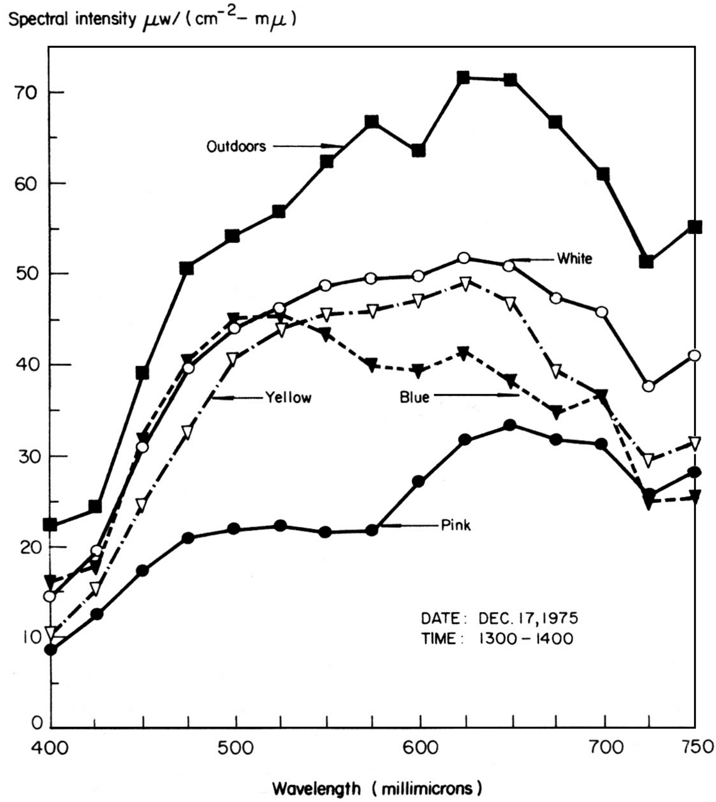
Color of net	Light transmission [b] (%)
Yellow	68.6
White	64.7
Blue	59.8
Pink	58.8
Green	45.5
Light green	38.1
Black	18.6

[a] Measurements were made by AVRDC Plant Physiology Department using Lambda LI-185. [b] Percentage light transmission of prevailing solar radiation.

Scientists at the Institute of Plant Breeding (IPB) in the Philippines built frames of bamboo slats that allowed 50% light penetration (personal communication with Dr. L.T. Empig, IPB, College, Laguna, Philippines). Frame height could be adjusted according to the height of the experimental materials. The setup is comparable to the orchid houses that are popular in the Philippines, except that all sides are open. We would consider it useful for preliminary screening of breeding materials for shade tolerance. Net houses can also be tested for use in screening for shade tolerance. Net houses of varying sizes, designs and colors have been used in Taiwan in summer to protect leafy vegetables from strong winds, rain, and insects (Lu, 1974). As in the greenhouse, however, both the quantity and quality of light are reduced, depending on the color of the net (Table 4; Fig. 4).

The technique used by scientists at AVRDC and the Philippine Sugar Research Institute (AVRDC, 1975) merits attention. We have intercropped segregating populations of soybeans, mung beans, tomatoes, and sweet potatoes with sugarcane to select genotypes to be grown in partial shade. We believe that is an efficient technique of screening not only for shade tolerance but also for other traits useful in intercropping, since the selection for a specific crop is done on genotypes that are grown under natural conditions with the main crop. By comparing the yield of the intercrops with their corresponding monocrops, we may find genotypes that do not compete with the main crop for nutrients, light, and water. We give this technique high priority in screening materials for intensive cropping systems.

Drought tolerance. Establishing an upland crop such as tomatoes, sweet potatoes, soybeans, mung beans, and so on in a flooded or saturated paddy field following rice harvest is a major problem in multiple cropping



4. Comparison of light spectrum of different color nylon nets (adapted from Plant Physiology Department, AVRDC, 1975).

(Villareal, 1976). Some degree of drought tolerance should be possessed by genotypes of vegetable crops that establish quickly in the paddy field and provide adequate yield with only the residual moisture in the soil and natural precipitation. In contrast with the shallow root-systems desired in varieties for intercropping and relay cropping, a deep, wide-spreading, and much-branched root-system is needed for drought-tolerant varieties. At the beginning of the dry season, we screen for the trait by planting our experimental materials immediately after the rice harvest. We believe that the genotypes selected this way will have an advantage over those selected under ideal growing conditions. Although the ultimate measure of drought tolerance is yield, it would surely be a big plus, if an alternative index of drought tolerance could be devised for identifying potential drought-tolerant genotypes.

At AVRDC, we observed that heat-tolerant varieties[2] of Chinese cabbage are susceptible to bolting under cool conditions. That trait was then used in screening for heat-tolerant genotypes (AVRDC, 1976). The exposure of germinating seedlings to continuous light at 5°C for 20 days was sufficient to induce bolting in most heat-tolerant varieties but not in heat-sensitive varieties. Furthermore, we noted that Chinese cabbage seeds treated with 5 ppm of gibberellin $A\frac{4}{7}$ for 24 hours before being placed on an agar medium for germination also provided a criterion for identifying heat-tolerant varieties; following treatment, they had significantly longer hypocotyls than heat-sensitive varieties. If criteria for drought tolerance similar to the aforementioned parameters could be discovered for other vegetable crops, then screening for drought tolerance would be more rapid and efficient.

Rasco (1974) found differences in the effect of hardening on the drought resistance and on the free proline content of four tomato varieties. His data on leaf proline accumulation during water stress demonstrated that it is possible to refine the use of the proline index in screening for drought resistance in the tomato. He suggested two promising methods of evaluating drought resistance. They are germination in a medium of low osmotic pressure (Gautreau, 1966; Williams et al., 1967; Flores-Reyes and Creech, 1968; and Tsai and Tang, 1970), and analysis of free proline accumulation in the leaves during water stress. Germination tests involve simple and rapid procedures, and allow simultaneous testing of a large number of genotypes. Proline accumulation, on the other hand, appears to be closer to a molecular mechanism of drought resistance than any other parameter. From a practical, breeding standpoint, however, we would explore the possibility of germination tests because the analysis of free proline accumulation in the leaves is time consuming and expensive, and therefore would be more suitable to basic studies of drought tolerance. There should be a direct relationship between the results of germination tests and drought tolerance.

Minimum-input plant types. Scientists at the International Rice Research Institute have found some striking differences among varieties and genetic lines of rice in tolerance for low levels of phosphorus, zinc, and other elements, as well as to low pH and toxic levels of elements such as iron and aluminum (IRRI, 1971, 1972, 1973, 1974). In vegetable crops, several studies were conducted to demonstrate genetic control of some nutrients (Harvey, 1939; Pope and Munger, 1953a,b; Whitaker, 1972; O'Sullivan et al., 1974). The reports suggest interesting possibilities in the

[2] Heat tolerance is defined as the ability of Chinese cabbage to form firm heads during summer when night temperatures are above 21°C.

breeding of crop varieties that can yield adequately in the face of either excesses or deficiencies of different elements. The study of O'Sullivan et al. (1974), for example, showed that variations in the efficiency of nitrogen utilization exist in *Lycopersicon esculentum.* Under severe N stress (35 mg N/plant) in nutrient solutions, efficient strains produced as much as 45% more dry weight than inefficient strains.

It seems to us that a modified (lacking a given element) Hoagland's nutrient solution of major essential elements is so far the best screening technique for minimum-input plant types. After screening with that technique, however, promising materials should also be grown in problem soils (low N, low P_2O_5, and so forth).

CURRENT STATUS

Some preliminary work has been initiated at AVRDC to develop tomato and sweet potato varieties for intensive cropping systems (AVRDC, 1975; Villareal, 1976). Some exploratory studies have also been conducted at IPB in the Philippines (personal communication with Dr. L.T. Empig).

Tomatoes. In September 1974, a limited number of tomato seedlings were planted immediately after the rice harvest. The first evaluation showed a wide range of variation in their ability to establish quickly and survive (Villareal, 1976). Inspired by these observations, we grew about 200 cultivars and 50 breeding lines after rice harvest in August 1975. However, the experiment was abandoned because the plots were flooded several times and all entries drowned.

Two experiments were conducted to compare the fruit-setting ability of various heat-tolerant, moisture-tolerant, and traditional (neither heat- nor moisture-tolerant) tomato cultivars grown in the field and in the greenhouse. The plants in the field experiment received 1,385 mm of water (about 126 mm/week). The beds were covered with rice straw to prevent soil erosion. Three heat-tolerant cultivars, three moisture-tolerant, and three traditional were used for the field and two of each for the greenhouse experiment.

In both experiments, highly significant differences were obtained in fruit-setting scores and rates. In general, the heat-tolerant cultivars had higher fruit-setting ability than the moisture-tolerant or traditional tomato cultivars.

It is interesting to note, however, that fruit setting of the first 10 clusters of all cultivars, except Nagcarlan, appeared to be higher in the field than in the greenhouse (Table 5). Stylar exsertion was observed more often in the greenhouse than in the field experiment. It could account for the fruit-

Table 5. Summary of fruit-setting rates of heat-tolerant, moisture-tolerant, and traditional cultivars under greenhouse and field conditions. [a]

AVRDC Acc. No.	Cultivar	Fruit-setting rate (%)	
		Greenhouse	Field
Heat-tolerant			
L 245	KL 2	27.4	54.5
L 232	Nagcarlan	51.6	54.4
L 125	Divisoria 2	–	47.4
Means		39.5	52.1
Moisture-tolerant			
L 166	LA 1421	0	19.7
L 133	LA 1231	6.3	28.7
L 146	LA 1291	–	55.5
Means		3.2	34.6
Traditional			
L 97	Healani	–	0
L 388	Green Fruit	4.1	10.0
L 203	Floradel	–	25.9
Means		4.1	10.1

[a] Mean range of minimum temperatures during fruit set was 22 to 27°C for both conditions.

setting differential. Wind action in the field probably permitted movement of the flowers and agitation of the pollen, and allowed more pollen to reach the stigmas. Such wind action was absent in the greenhouse, and the tomato flowers were not tapped. Previous studies showed that more pollinations occurred following tapping (Verkerk, 1956 ; Charles and Harris, 1972). It is also possible that the limited amount of solar radiation in the greenhouse (50% of the prevailing solar radiation) could have affected fruit setting. Nagcarlan, whose fruit setting was unaffected, seems to possess not only heat tolerance and moisture tolerance, but also shade tolerance.

We are repeating those greenhouse and field experiments using heat-tolerant cultivars of *Lycopersicon esculentum* and *L. pimpinellifolium* to find out if other heat-tolerant cultivars possess shade tolerance.

This season we are comparing the yield and other horticultural traits of 10 tomato cultivars grown as a monocrop and as a relay crop with sweet corn (relayed 40 days before harvesting sweet corn). We hope to confirm preliminary observations of the shade tolerance of some tomato cultivars, particularly Nagcarlan and UPCA 1169, when grown as intercrops.

In the Philippine Sugar Research Institute (PHILSUGIN), La Carlota City, Philippines, eight AVRDC breeding lines that were intercropped with sugarcane withstood the rainy season, and produced satisfactory numbers of fruits without being sprayed against pests and diseases. Those lines have been turned over to Dr. Laures T. Empig for use in the breeding program of the IPB.

The exploratory experiments of Dr. Empig and his group to select tomato varieties for intensive cropping systems are encouraging (personal communication with Dr. L.T. Empig). For example, their shading experiment showed extremes of variability in shade tolerance. Five varieties had higher fruit setting rates in the shade, four varieties were unaffected, and 13 had higher fruit setting rates in the open.

Seeds of 54 tomato lines were directly seeded in a lowland rice field without tillage. Wide variations in their germination and yielding ability were observed. Germination varied from 50 to 80%; yield varied from about 0.3 to 1.5 kg per plant.

Sweet potato. Cropping intensity in Asia and the Far East is low because about 80% of the area's arable land is rainfed. After the rainy season, the residual moisture may be just enough to germinate a seed but not sufficient to bring a crop to maturity. Besides, many farmers cannot afford the high cost of chemical inputs for high yields. A drought-tolerant and minimum-input variety could raise the present low cropping intensity in these areas.

We have relied solely on the field performance of our sweet potato materials to see if we can develop minimum-input varieties for planting immediately after a rice harvest. We grew 194 cultivars and 495 breeding lines in a field previously planted to rice to select genotypes that would give good yield with low soil-fertility levels, low management, and water stress (Trial I). After the rice harvest, the field was rotovated, bedded, and planted. No irrigation, pesticide, or fertilizer was applied. The materials with the best yields at this screening were further evaluated (Trial 11) following the procedure used in Trial I.

In Trial I, yields ranged from 0 to 17.8 t/ha for the cultivars (Table 6) and 0 to 19.5 t/ha for the selections (Table 7). In Trial II, the yields ranged from 0 to 12.9 t/ha for the cultivars (Table 6) and 0 to 8.4 t/ha for the selections (Table 7). The yield differences between Trial I and Trial II could be attributed to colder weather and excessive weed competition (*Chenopodium album*) for nutrients, water, and light in Trial II. The weeds grew to about 1.5 m and probably reduced drastically the solar radiation that the sweet potatoes received. The experimental plots, however, were weeded 3 weeks before harvesting for ease in gathering yield data.

The yields were impressive, considering that the only inputs were minimal land preparation, and planting of the sweet potato cuttings. Average yield in most tropical Asian countries is about 6 t/ha (AVRDC, 1975). In both trials, the crops depended on residual moisture and natural precipitation for water. In Trial I, natural precipitation was 97 mm during

Table 6. Highest yielding sweet potato cultivars under minimum input conditions, AVRDC, Tainan, Taiwan, 1974–76.

AVRDC accession no.	Variety	Marketable yield (t/ha)			Flesh color	Flowering habit [c]
		Trial I [a]	Trial II [b]	Mean		
I 6	Tainung 31	18	7	12	white	F
I 18	Taiwan 2	17	9	13	white	NF
I 93	PI 31 5342	14	5	10	white	F
I 117	PI 3441 29	14	14	14	white	NF
I 54	PI 31 8548	14	4	9	yellow	F
I 154	Tainung 10	14	9	11	yellow	NF
I 58	Tainan 14	13	5	9	white	NF
I 115	PI 3441 23	13	13	13	yellow	NF
I 106	PI 31 8859	12	–	12	yellow	F
I 5	Tainung New 10	12	9	10	white	NF
I 171	Tainung 63 (check)	4	2	3	orange	NF
I 57	Tainung 57 (check)	11	4	8	white	F

[a] Planted November 15, 1974, and harvested April 19, 1975 (155 days); basid on yields from 10 hills. [b] Planted November 19, 1975, and harvested April 21, 1976 (153 days); based on yields from 20 hills. [c] F = flowering; NF = nonflowering.

the cropping season, with 604 mm of evaporation; in Trial II, it was 128 mm, with 646 mm of evaporation. Optimum yield is generally obtained with 530 to 660 mm of precipitation during the growing season.

Most of the minimum-input selections were yellow- or white-fleshed. We are looking for orange-fleshed lines, which are richer in β-carotene. The flowering selections can facilitate our breeding program, since non-

Table 7. Highest yielding sweet potato selections under minimum input conditions, AVRDC, Tainan, Taiwan, 1974–76.

AVRDC selection no.	Marketable yield (t/ha)			Flesh color	Flowering habit [c]
	Trial I [a]	Trial II [b]	Mean		
AIS 278-1	20	8	14	yellow	NF
AIS 277-1	18	5	12	yellow	F
AIS 276-1	17	4	11	white	F
AIS 0122-2	16	8	12	orange	F
AIS 272-8	15	2	8	yellow	NF
AIS 015-10	15	2	8	orange	NF
AIS 010-2	14	4	9	yellow	NF
AIS 272-2	13	8	11	yellow	F
AIS 137-1	12	7	10	white	F
AIS 272-4	12	7	10	white	NF
I 171 (check)	4	2	3	orange	NF
I 57 (check)	11	4	8	white	F

[a] Planted November 15, 1974, and harvested April 19, 1975 (155 days); based on yields from 10 hills. [b] Planted November 19, 1975, and harvested April 21, 1976 (153 days); based on yields from 20 hills. [c] NF = nonflowering; F = flowering.

Table 8. Highest yielding cultivars under minimum input cultivation, [a]AVRDC, Tainan, Taiwan, 1975.

AVRDC acc. no.	Cultivar name	Yield (t/ha) Market-able	Cull	Total	Culls (no./ha)	Top-to-root ratio	Flesh color
I 89	PI 3081 96	8	4	12	78	1.04	yellow
I 98	PI 318861	5	4	9	72	1.68	yellow
I 36	Copper Skin Goldrush	5	7	12	67	3.00	orange
I 5	Tainung New 10	4	2	6	37	3.18	white
I 118	PI 344134	4	3	7	33	2.70	white
I 60	Tainung 6	4	5	9	240	1.63	orange
I 152	Red Tuber Tail (check)	2	4	6	140	1.44	yellow
I 57	Tainung 57 (check)	2	4	6	139	2.00	white

[a] Planted August 8, 1975, and harvested December 15, 1975 (131 days); based on yields from 10 hills.

flowering types may fail to flower even with appropriate treatments.

During the rainy season of 1975, we planted 302 cultivars and 100 breeding lines in a field where rice had been the previous crop. This time, however, no land preparation was undertaken. A hoe was used to dig a hole in which an eight-node sweet potato cutting was planted. About a month later, soil was hilled up around established plants with a small hand tractor. Hilling up was repeated after about the second month to eliminate weeds. As in the previous screening, no pesticide was applied. But unlike the previous screening, the experimental plots were flooded several times.

We terminated the experiment after 131 days rather than after 100 days as originally planned, because of flooding. The total yields ranged from 0 to 12 t/ha for the cultivars (Table 8) and 0 to 17 t/ha for the selections (Table 9). The highest marketable yields for both experiments, however, were quite low, although higher than those of the check varieties. Most of the culls in these experiments were results of the large number of small fleshy roots that failed to enlarge (Tables 8 and 9). It was observed that plants with lower top-to-root ratios gave the best root yields. It is interesting to note that Tainung New 10 and AIS 0122-2 were selected in both screenings, showing a wide range of adaptability.

The two screenings for minimum-input cultivation gave different outstanding genotypes. That is understandable, since in the first screening (planted November 15, 1974), the genotypes encountered a water shortage, while the second screening (planted August 8) had excessive moisture. The preliminary observations suggest the importance of season in evaluat-

Table 9. Highest yielding selections under minimum input cultivation, [a]AVRDC, Tainan, Taiwan, 1975.

AVRDC selection no.	Yield (t/ha)			Culls (no./ ha)	Top-to-root ratio	Flesh color
	Market-able	Cull	Total			
AIS 471	7	10	17	236	0.71	yellow
AIS 468	4	7	11	193	0.73	orange
AIS 0157-2	4	11	15	353	1.00	yellow
AIS 0122-2	4	5	9	142	1.12	orange
AIS 466	4	5	9	67	0.05	white
AIS 486	3	11	14	307	0.64	white
Red Tuber Tail (check)	2	4	6	140	1.44	yellow
Tainung 57 (check)	2	4	6	139	2.00	white

[a] Planted August 8, 1975, and harvested December 15, 1975 (131 days); based on yields from 10 hills.

ing the performance of materials, especially under minimum-input cultivation. Variation exists in the ability of genotypes to withstand extreme moisture conditions.

The highest-yielding selections from our minimum-input screening that will flower readily will be planted in a polycross nursery to allow intercrossing. That should widen the genetic base and further increase yield potentials under minimum-input conditions. The five best selections from the aforementioned screenings will be planted in a single experiment to compare their yields. In addition we will study the morphological basis underlying minimum-input plant type.

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DISCUSSION

PANTASTICO: Do you intend to separate the critical environmental elements for evaluating vegetables suitable for effective intensive cropping, for instance, critical light, critical temperature, critical water?

Villareal: Our plant physiologist and soil scientist at AVRDC are cooperating with us in trying to establish the critical environmental elements for effective intensive cropping systems.

Cropping Systems approach to adaptive research

INTRODUCTION

E.B. Pantastico

The topic at hand is cropping systems. The tool is adaptive research. The final goal: a national production program.

This session will be devoted to the elaboration of those topics with the aim of determining how research can help the food production programs of governments in Asia.

Our commodity—our product—is cropping systems. We should fully understand cropping systems if we are to sell them. As shown in Figure 1, a cropping system is a complicated product composed of physicochemical and socioeconomic resources, and all the technologies involved in crop production. To integrate these into a unified system calls for skill and a lot of understanding. Perhaps more attention should be given to the system itself than to the crops within the system.

Before one can introduce a crop or crops into farmers' fields, he finds himself involved in five areas of knowledge: crop variety, production technology, processing/utilization technology, marketing technology, and extension technology (Fig. 2).

Those five areas of concern in development of a crop industry can be summarized in the following manner :

1. *Crop Variety.* For a given crop commodity, there should be an existing variety with yield potential comparable to or better than that in a competitive country growing the same crop. Some studies under this broad problem area are breeding for high yield; for pest and disease resistance, quality, climatic adaptation, stress conditions (waterlogged or saline soils, or drought); and to suit various utilities, products, and processing systems; and adaptability trials.

2. *Production Technology.* The existing variety must already have a cultural management package which can be used to realize its optimum

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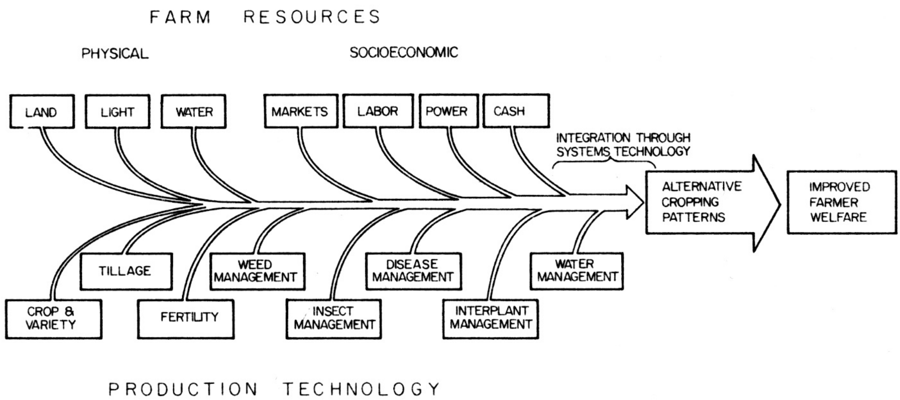
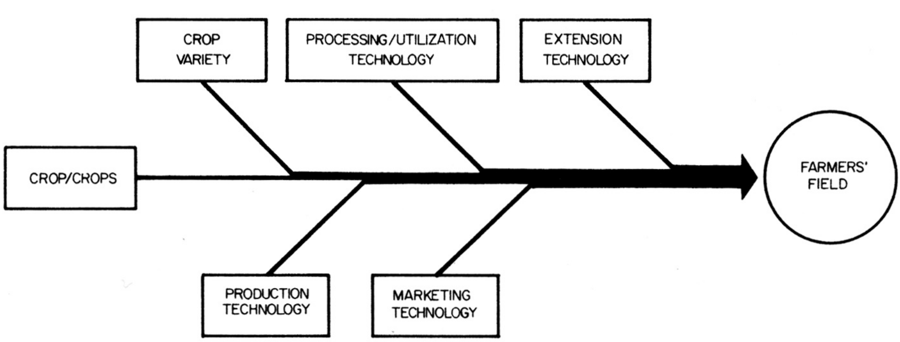


1. Conceptual outline of the cropping systems approach.

yield potential (for instance, seed production technique; planting system; fertilization; soil and water management; crop protection against insects, diseases, weeds and other pests; and harvesting).

3. *Processing/Utilization Technology.* The basic processing (postharvest) requirements of the crop must be known and must be suitable for local conditions. Among the studies which can be included here are those on product and byproduct utilization, processing tools and equipment, machinery development, storage requirements, waste utilization, drying efficiency, and bulk handling.

4. *Marketing Technology.* The market structure for the crop must be developed for either local consumption or export. Important studies along this line are those of the supply and demand system, financing scheme



2. Areas of concern in the development of the crop industry.

and repayment structure, packaging and transport, commodity flow, consumer preferences, and marketing systems.

5. *Extension Technology.* There should be effective technology transfer from the experiment station to the farmers' fields, shown by farmers' acceptance of the commodity.

Research in those areas can be packaged; it should disclose whether or not the package is good enough for implementation under farmers' conditions.

Adaptive research, as implied here, is a means of bridging the gap between research institutions and farmers' fields. It is not the extension worker's demonstration plot, but the end of a series of basic and applied researches to see if the technology will work. Here, adaptive researchers can try their hand on extension activities, since the research is usually done in farmers' fields, or the extension workers may assume the role of researchers, as the work also involves some amount of package-deal experimental design for easy interpretation.

Moving the cropping systems technology into the government's national program calls for consideration of some basic concerns. The move must be dictated by national policy and properly backed by national capability. For instance, are the crops being considered market oriented or are they meant for home consumption? Granting that they are market oriented, is the government prepared to distribute them to the consuming areas? Processing technology and storage capacity in a given locality must also be looked into before any national cropping systems program is launched.

The high cost of farm inputs and the uncertainty of the market are risks of nationalizing a cropping systems program. If those become threats, step-by-step, gradual implementation may prove successful.

In the Philippines, the credit policy of the Central Bank is currently being structured for agricultural crops. In most cases, loans are given for predetermined farm operations on a monocrop basis. The suggestion for multiple cropping has been to give loans on a year-to-year basis according to the area planted. In this way, pressure is put on the farmer to make good his farm-keeping records and to budget his resources. Too often, the farmers cannot do these tasks. They need more education on the activities. The researchers, on the other hand, have also to do more serious study.

Finally, if adaptive research is to become an effective tool in a cropping systems national program, it must be based on interdisciplinary, interagency cooperation. It should provide a clearinghouse for research and extension. Cropping systems are catching the attention of many agencies; an attempt by one agency to move on its own to implement a system in farmers' fields may duplicate similar activities in another agency. Such can confuse the farmer and eventually lead to his failure to adopt the technology.

To counteract that possibility, the National Agriculture and Resources Research Systems has adopted a way of determining priority areas with interagency participation. Goals for a specific commodity, for example rice, have been determined, and any specific constraints to attaining the goals have been considered priority problem areas. Such a system has been followed in the Philippine Council for Agriculture and Resources Research for the national commodities, including farming systems.

I hope the points I have brought out in this introductory paper will be covered by our speakers and elaborated on by our discussants.

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ADAPTIVE TRIALS TO DETERMINE PRODUCTION PROGRAM FEASIBILITY

L.D. Haws

Scientists of the world are producing about 60 M pages of research results every year. Not all of their work is in agriculture, of course. However, a great deal may have implications for agriculture to one who reviews the mountain of work with the question of how it may help the world in producing more food (Escarpit, 1966).

At the International Rice Research Institute (IRRI) each year, about 10,000 pages of new information are produced primarily on rice. IRRI also publishes an annual bibliography of rice research. The 1974 supplement contains 385 pages of titles on rice research or work closely related to rice.

Today, change in techno-societies is so swift and relentless that yesterday's truths become today's fiction, and the most highly skilled and intelligent members of society admit difficulty in keeping up with the deluge of new knowledge—even in extremely narrow fields. "You can't possibly keep in touch with all you want to," complains Dr. Rudolph Stohler, a zoologist at the University of California at Berkeley. "I spend 25 to 50% of my working time trying to keep up with what's going on." Dr. Arthur Stump admits: "I don't really know the answer unless we declare a moratorium on publication for 10 years."

New knowledge either extends or outmodes the old. In either case, it compels those for whom it is relevant to reorganize their store of images. It forces us to relearn today what we thought we knew yesterday.

Technology makes more technology possible, as we can see if we look for a moment at the process of innovation. Technological innovations in industry go through three stages, linked in a self-reenforcing cycle. First, basic research produces the creative, feasible idea. Second, applied and adaptive research determines the idea's practical implications. Third, national programs cause its diffusion through society.

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The process is complete, the loop is closed, when the technology embodying the new idea has been accepted and used. Generally, new creative ideas—spin-offs—occur and create need for new research; thus a new cycle begins (Lesher and Howick, 1965). Think of your own institution; compare the number of scientists producing research results with the number trying to adapt those results to farmers' conditions. I don't mean extension personnel, but applied researchers.

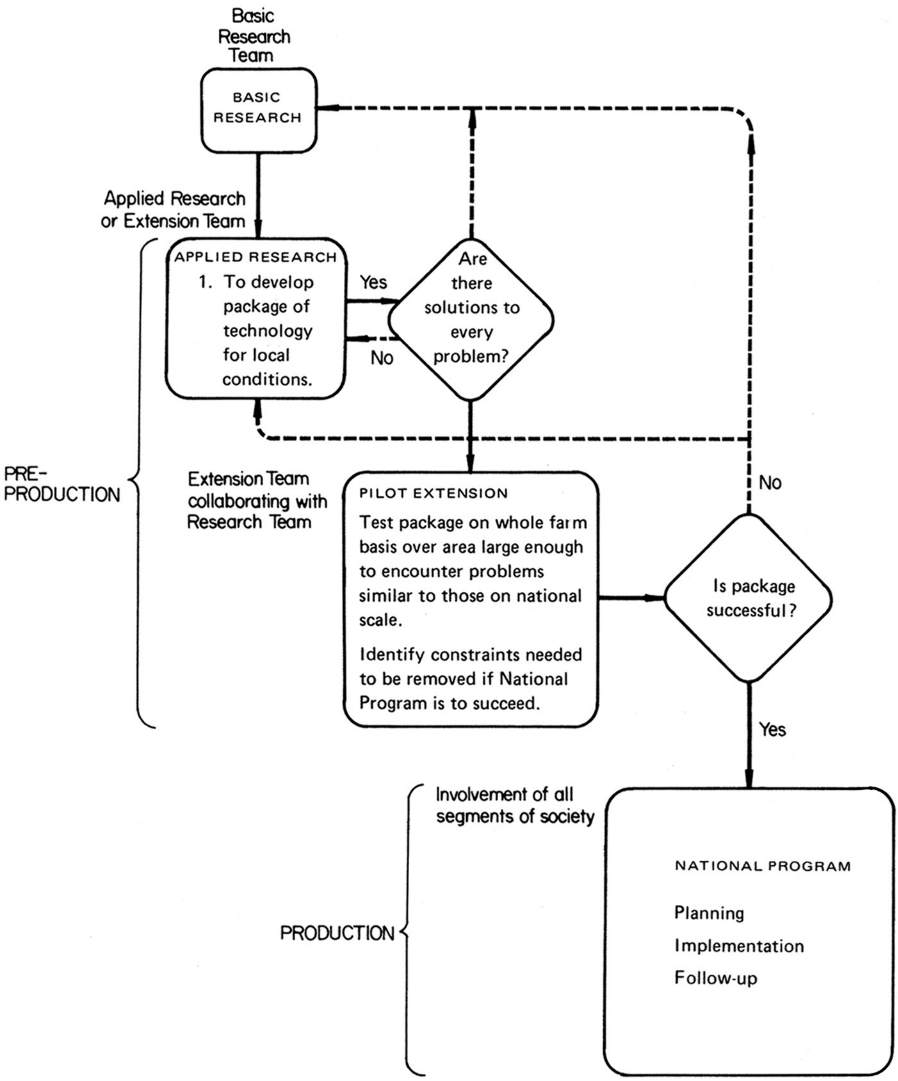
A great challenge is placed on the shoulders of those of us who are given the responsibility of making the research results from this vast literature available to farmers in usable form.

We have sufficient technological information, crop varieties, and inputs to overcome the world's food deficit *today.* This important knowledge is not being used by the farmers for whom it is intended. This is not to say that research needs to be reduced, but rather that we must make better use of the research results we already have.

That brings us to the topic of our discussion today. How do we adapt the results of our research to benefit, in the best and fastest way, the farmers for whom we all are working? Are our research activities oriented to solve real problems? Do researchers and extension personnel work together? Or do scientists go their own way, do the work they are interested in, and let those responsible for the diffusion of new technology gather what they can from where they can find the information? Unfortunately, it is the latter situation that generally exists.

To overcome these problems, you work with your basic scientists until you arrive at an understanding of the best technology available to grow a certain crop (Fig. 1). In addition, you reserve the right to evaluate and solve problems noted in the field that are constraints to production. In many cases, those are not problems of production, but of marketing, etc. Once a pertinent technology has been chosen, it is tested under diverse conditions in farmers' fields or predefined areas. If the applied research result? are satisfactory, the technology is expanded to a pilot program where the number of farmers using it is greatly increased. Problems that arise in both the applied research and the pilot program phases may be referred to research scientists, or experiments can be designed for quick answers. Finally, when the applied research results prove practical in the pilot program, a final phase, regional or national, can be organized. The four-step procedure has this advantage: a program can be stopped or continued after a very short time (4–6 months), depending on results. Uneconomical or unworkable applied research results or implications can be replaced.

Let me quickly review the Masagana 99 program, which grew out of an applied research program at IRRI, then conclude with a description of an


Basic Research Team
BASIC RESEARCH
Applied Research or Extension Team
APPLIED RESEARCH
1. To develop package of technology for local conditions.
Yes
No
Are there solutions to every problem?
PRE-PRODUCTION
Extension Team collaborating with Research Team
PILOT EXTENSION
Test package on whole farm basis over area large enough to encounter problems similar to those on national scale.
Identify constraints needed to be removed if National Program is to succeed.
Is package successful?
No
Yes
Involvement of all segments of society
PRODUCTION
NATIONAL PROGRAM
Planning
Implementation
Follow-up

applied research program now under way on direct-seeded rainfed rice followed by upland crops.

Masagana means abundant, and a yield of 99 cavans (1 cavan = 44 kg) of paddy rice per hectare is the program's target.

The year 1973 was a year of food crisis for the Philippines. It was a year of large production deficits. Six countries in Asia alone had grain shortages totaling about 8.6 M t. Japan's rice inventories dropped from 7 M t to 1.6 M t. The traditional rice-exporting countries in Southeast Asia had little to offer. Rice prices rose to unprecedented levels—$400 to $500/t—at least five times higher than 1971 prices. And even if a country had the foreign exchange with which to buy rice, there was little supply.

The rice shortage of the Philippines was estimated to be about 700,000 t, and all indications were that less than 30% of that amount could be harvested before July, August, and September, the months when little rice is harvested.

In February 1971, IRRI and several Philippine agencies agreed to establish an applied research program to test current research results in farmers' fields in selected areas to develop a "package of practices" for use by Philippine farmers.

One element of the rationale behind the proposal was the fact that about 74% of the rice land in the Philippines is under rainfed and upland conditions (47% rainfed lowland and 28% upland). If technology could be brought to bear on this area, it would surely have a significant impact on rice production.

The applied research effort sought answers to 12 questions. I will recite some of them quickly and state the major findings from some 400 trials covering different types of experiments in two provinces in Bulacan and Nueva Ecija.

1. What is the optimum nitrogen application for short-statured, high yielding varieties?

Responses of the two tested varieties were similar. The optimum nitrogen level was 90 kg/ha.

2. Which of the available herbicides control weeds best in upland areas?

Butachlor controlled weeds best in upland rice. Research conducted in 1973 indicated that other chemicals (C288, A-820, and US-3153) might be more effective and should further be tested.

3. Which of three levels of crop management (fertilization, weed control, or insect control) is most economical under existing conditions?

The more sophisticated management increased yields five times that of low-level management treatments.

4. Which of the currently available insecticides perform best under rainfed conditions?

Insecticide applications significantly increased yields at all locations in the 1971 and 1972 tests. Carbofuran, a broad-spectrum insecticide, was found effective against most insects, particularly the green leafhopper, the vector for the tungro virus.

5. What are some crops with economic potential that may be grown after rainfed and upland rice?

Mungo, sweet corn, sorghum, soybeans, and sweet potatoes can follow upland rice.

Although the field tests to develop a package of cultural practices were originally planned for 5 years, the results after 2 years convinced researchers and extension agents that a package was ready to be recommended to farmers. Masagana 99 was ready (Drilon, 1975). Since that time, work has continued in the same direction and manner to discover the major constraints to production, to investigate those constraints, and to make results available to national programs. A description of that applied research program follows.

The program was organized as a cooperative effort of IRRI and the Philippine Council for Agriculture and Resources Research (PCARR), to evaluate the usefulness in a national cropping system program of the research on direct-seeded rice. The proposed system would call for two crops of rice and an upland crop on heavy soils; on light soils, it would evaluate the potential of one rice crop plus one or two upland crops.

METHODS

Many steps must be considered in planning an applied research project (Ross, 1970). Some of them are:

1. defining the general objectives and setting forth the problems to be solved,
2. involving the various agencies concerned and delineating the role each is to play,
3. determining training needs,
4. planning for lead time to adequately prepare the project,
5. conducting the actual work,
6. developing plans to use the applied research findings in national programs,
7. selecting the project area, and
8. collecting, analyzing, and interpreting data.

Perhaps an actual experience at IRRI in using this methodology will illustrate the procedure. To the project description, I will add occasional comments and suggestions to future workers.

In recent research, success with direct-seeded, rainfed rice has created a good possibility that multiple cropping could become an important means of increasing agricultural output in the Philippines and in the humid tropics. The variable climate and soils found throughout those areas have made it imperative that research be conducted to determine the performance of various crops; the information was needed so that farmers could make intelligent decisions in choosing the kind of cropping systems that would be most economical. The IRRI-PCARR project was designed to help achieve the following objectives:

1. to determine the best method of establishing direct-seeded rice under rainfed conditions.
2. to determine varietal differences between two early maturing rice selections when direct-seeded in dry-to-moist soils, and
3. to evaluate the potential of raising a crop of rice followed by another crop of rice or by various upland crops (depending upon soil and moisture conditions) under rainfed conditions.

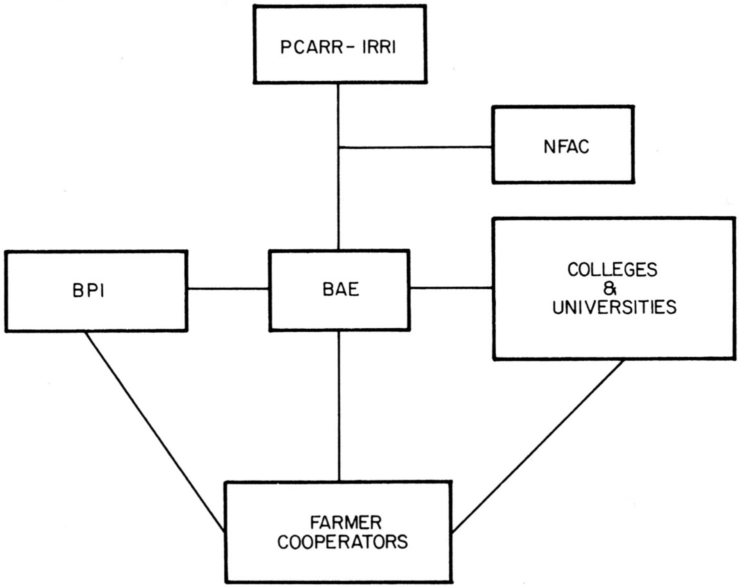
Involving various agencies. Two main considerations were noted here: (1) It was impossible for IRRI to do all the work necessary to meet the objectives of the project. It was necessary to rely on existing research organizations for help. The main organizations conducting agricultural research are the Bureau of Agricultural Extension (BAE), the Bureau of Plant Industry (BPI), and national and private colleges and universities. (2) Since the ultimate objective of the program was to apply the results to a national program, PCARR was the obvious organization to work with because it is responsible for the country's agricultural research and is in direct contact with all agencies of the government, especially the National Food and Agriculture Council (NFAC) that is responsible for national food production.

Under such an arrangement, results obtained from the research work could immediately be fed into the existing organization for a National Production Program for Philippine farmers.

An organizational chart shows the agencies involved in the program (Fig. 2).

Determining training needs and selecting cooperators. Selecting and training cooperative researchers from participating institutions constituted a critical operation. The importance of trained people cannot be overemphasized.

Not all cooperators were effective in conducting experiments. Results were obtained from 28 of the 32 locations selected to carry out the research.



2. Organizational chart of the PCARR-IRRI Applied Research Project, 1976.

Reports ranged from excellent to unreliable. It appeared that about 50% of the cooperators returned reliable data.

All cooperators were trained in experimental procedures in a 2-week period at IRRI. Every part of the program, from plot layout to sampling, was described to them. Each cooperator was required to establish plots at IRRI before doing so in his own area. Even with this rather extensive training, not all plots were established correctly.

If major errors are to be avoided, it may be necessary to have someone from your own institution help establish research plots.

Conducting the actual work and collecting data. After the 2-week training period in which participating researchers were instructed in all experimental procedures, the cooperating researchers returned to their homes. They carried all inputs with them. Delay in shipment of supplies is a worldwide problem, and any method of avoiding it will expedite a project.

As before, not all plots were established in a completely satisfactory manner. If you are trying something similar, it may be necessary to assign someone from your own office to the experimental site when the plots are established and also when they are harvested. Travel costs should, of course, be included in your budget.

Detailed schedules of the samples that should be taken and methods of sampling should be included in the plan.

Develop plans to use results of applied research. A major purpose of the cooperative applied research venture between IRRI and PCARR was to provide linkage with a government agency interested in disseminating research results as soon as those results are shown to have some value to farmers. It is essential to *institutionalize* your activities with government agencies so that results can be put into the extension channels.

Selection of project area. As mentioned earlier, the research work would evaluate the possibilities of growing two crops on light or heavy soils in the various rainfall areas of the country. On heavy soils, two crops of rice would be grown, but on light soils only one rice crop would be grown, followed by upland crops. Therefore, two very important physical factors were taken into consideration when selecting sites for this project. They were:

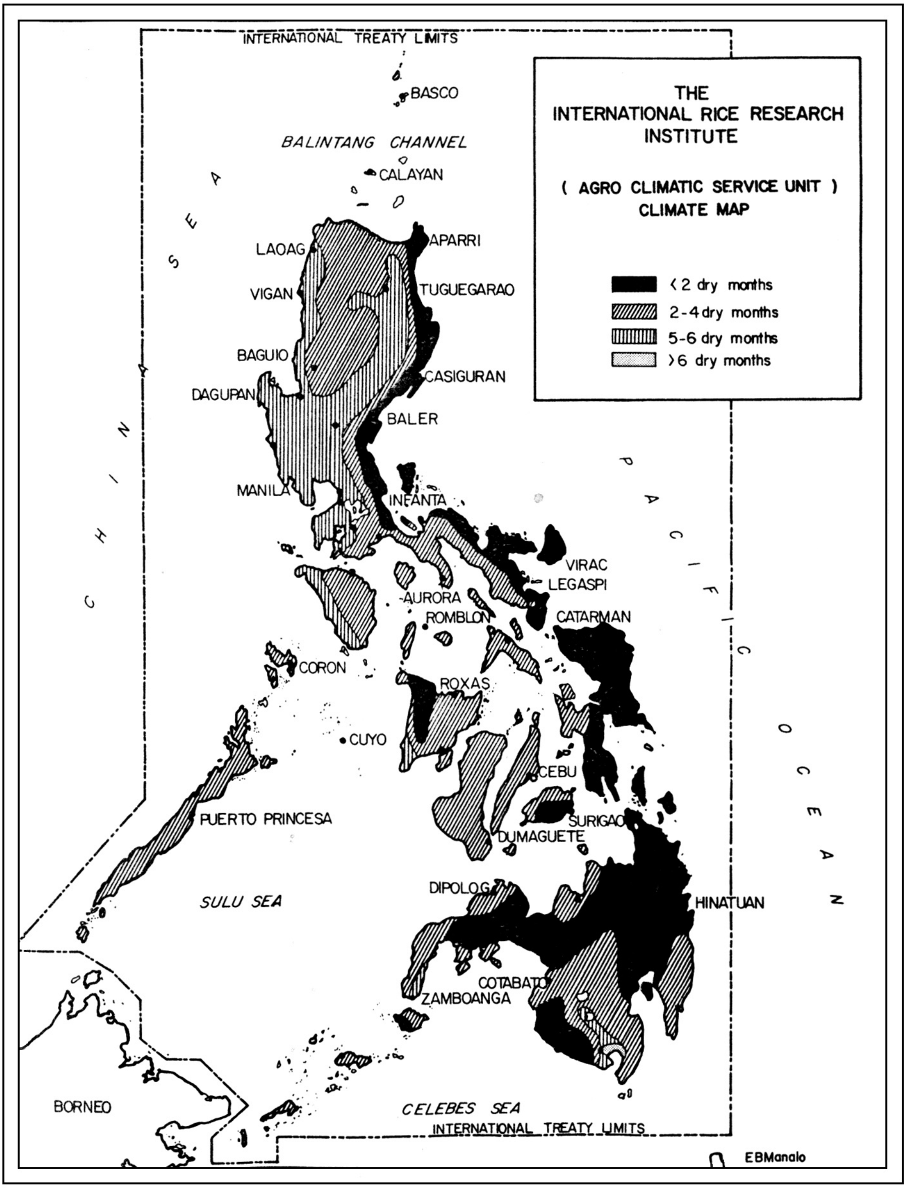
1. *Rainfall.* Of the various factors that affect upland and rainfed rice, low soil moisture is generally the most serious (De Datta, 1975). For the purpose of this paper, *upland rice* is that rice grown on light soils that will not allow rain water to accumulate and remain in the bunded paddy for over 2 days. *Rainfed rice* is that rice grown in paddies on heavy soils that allow rain water to accumulate and remain in the bunded paddy. Thus, sites for the work throughout the Philippines were selected on the basis of the number of months of rain in a year (Fig. 3).

2. *Soil texture.* Soil texture was classified in two broad categories—heavy and light. Heavy soils have a high clay content. They allow water to be impounded in a bunded paddy. Light soils have a high sand content and do not allow rain water to remain in a bunded paddy for more than 2 days. soils at each site were analyzed, and a more detailed description of the soil characteristics of each site is being made.

RESULTS

The second year of the 5-year program is now under way. Results from the first year are in. Some procedural adjustments have been made for the second year's work. Additional experiments have been included where results of the first year's work showed deficiencies that must be overcome to meet objectives.

Objectives 1 (to determine the best method of establishing direct-seeded rice) and 2 (to determine varietal differences) were achieved during the



3. Agroclimatic map of the Philippines based on the number of months during the year when average rainfall is less than 100 mm/mo.

Table 1. Grain yields of IR1561-228-3 and IR30 as affected by two methods of stand establishment of direct-seeded rice under different rainfall patterns.

Method of stand establishment[a]	Rainfall (no. dry mo.)[b]							Mean yield (t/ha)
	A	B	C	D	E	F	G	
				IRI567-228-3				
DSL	3.75 (12)[c]	1.90 (9)	4.43 (9)	2.35 (8)	3.25 (8)	5.07 (9)	4.50 (3)	3.61
DSB	3.75 (12)	1.98	4.00 (9)	2.40 (8)	3.25 (8)	5.40 (9)	4.60 (3)	3.62
				IR30				
DSL	2.67 (13)	1.85 (11)	3.92 (8)	1.94 (8)	2.45 (9)	5.46 (8)	4.07 (8)	3.14
DSB	2.78 (13)	1.88 (11)	3.57 (8)	1.67 (8)	2.47 (9)	5.60 (8)	3.92 (8)	3.12

[a]DSL = direct-seeded, *lithao:* DSB = direct-seeded broadcast. [b]A = long dry season during low-sun period, very pronounced wet season. Has a high-sun maximum rainfall of over 61 mm for 7 months. Dry season lasting 5 months. B = shorter dry season and less severe drought than Type A, lasting only 4 months. C = short dry season 1 to 3 months during the low-sun period. D = short dry season 1 to 3 months during the high-sun period. E = marked by a rainfall at dry months with a marked seasonal period of heavy rainfall which occurs after the autumnal equinox during the low-sun period. F = the same as Type E except that it has its heavy rainfall during the high-sun period following the vernal equinox. G = even distribution of rainfall with no marked seasonality. [c]Numerals in parentheses indicate the number of locations where experiments were conducted.

first year. The two methods of planting rice under dry conditions did not differ significantly (Table 1). IR1561-228-3 produced from 0.46 t/ha to 0.5 t/ha more than did IR30, a difference of less than 0.1 t/ha.

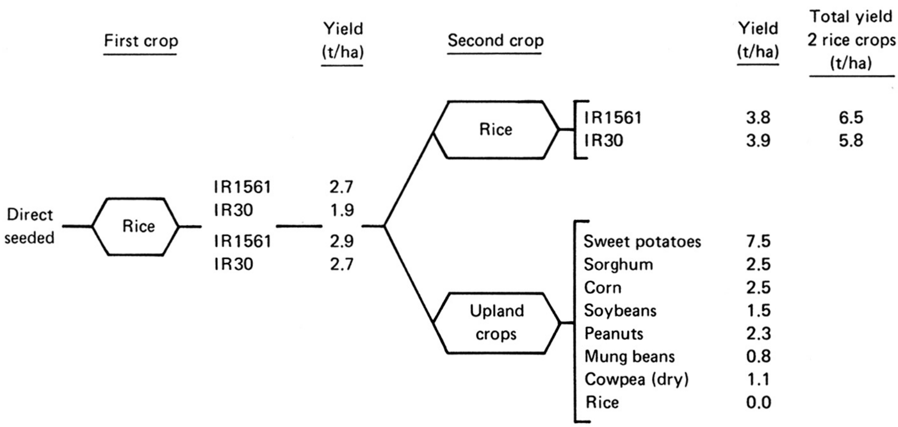
The work has had great impact in two areas of the project in Iloilo and Mindanao. In those areas, farmers have saved time by broadcasting seed instead of transplanting. Because labor is scarce and expensive, farmers have been quick to adopt the new method of seeding. IR1561-228-3 has an overall production advantage of about 0.25 t/ha. However, IR30 has resistance to tungro virus, and that may prove an advantage. In fact, IR30 was planted in 100% of the area planted under the new method in Iloilo (about 100 ha).

Additional research work was necessary to arrive at a definitive solution for objective No. 3 (two or three crops raised on the same land). First-year results are extremely promising.

To see the significance of the results presented in Figure 4, one must realize that the average yields of rainfed rice in the Philippines are only 1.4 t/ha and generally, only one crop per year is grown.

An additional significant finding is that soil texture is an important consideration when deciding what crop to grow and when. The figure shows that 6.5 t/ha of rice can be grown with two crops on heavy soils. It also shows that rice failed in every location where planted in light soils.

Applied research has shown that combined yields of IR30 and IR1561



4. Comparison of production potential for growing two crops of rice, or one rice and one of seven upland crops on light and heavy soils under rainfed conditions in areas with 5 dry months.

from two crops of rice ranged from 4.7 to 12.4 t/ha, with an average yield of 7.5 t/ha from the 11 sites in the test (Table 2).

The data on the success or failure of crop establishment and yields are encouraging (Table 3). Soybeans and sorghum were successfully grown on 88 and 85%, respectively, of the plots planted. Yields were satisfactory at 1.5 t/ha for soybeans and 2.5 t/ha for sorghum.[1] Production costs for those crops are about ₱708 for sorghum and P896 for soybeans, with a resulting net profit of about 12,796 for soybeans and ₱1,570 for sorghum.

Table 2. Rice yields from 11 provinces in the Philippines growing two crops of rainfed rice, 1975.

Location	Yield (t/ha)		
	1st crop	2nd crop	Total
San Fernando, La Union	2.6	4.9	7.5
Santa Cruz, Zambales	3.0	3.8	6.8
Santa Maria, Bulacan	3.3	2.8	6.1
Santa Maria, Pangasinan	1.5	3.9	5.4
Iloilo (Central Philippines University)	2.9	3.9	6.8
Iloilo (Sta. Barbara)	5.0	4.5	9.5
Puerto Princesa, Palawan	3.4	3.7	7.1
Aborlan, Palawan	2.2	2.5	4.7
Cagayan de Oro City	5.6	2.4	8.0
Tacloban City	2.1	6.0	8.1
Kabacan, North Cotabato	8.2	4.2	12.4

[1] Sorghum at ₱0.90/kg and soybean at ₱2.50/kg.

Table 3. Plots successfully established and harvested, and yields of 7 upland crops harvested from 33 plots in 11 provinces of the Philippines, 1975-76.

Crop	Plots (of 33 planted successfully) established (no.)	Plots (of 33 planted successfully) harvested (%)	Mean yield (t/ha)
Soybeans	29	88	1.5
Sorghum	28	85	2.5
Cowpea	27	82	1.1
Sweet potatoes	26	79	7.5
Corn	24	73	2.5
Peanuts	17	52	2.3
Mung	15	45	0.75

The effects of the dry period that developed along the west coast of Luzon during the last half of the wet season in 1975 can be seen in Table 4. Ilocos Norte, Zambales, and Tarlac harvested less than 50% of the plots planted. In Tarlac, only sorghum survived the drought. The dry period also shows up in the data presented in Table 5. Here, mung beans were less successful than other crops planted. They failed four times out of seven. Table 5 also shows that all other crops were fairly stable in all locations except Tarlac and Ilocos Norte. The failures in Tarlac are due to the dry weather in 1975. In Ilocos Norte, however, management was an important factor in the failure of the crops.

Table 4. Number and percentage of plots that were successfully grown in each of 11 provinces in the Philippines, 1975-76.

Location	Plots successfully Established (no.)	Plots successfully Harvested (%)
Curareng	14 (14)[a]	100
Parnpanga	7 (7)	100
Cavite	26 (28)	93
EPAC	26 (28)	93
La Union	23 (28)	82
Santa Maria, Bulacan	22 (28)	79
Capiz	20 (28)	71
Central Philippines University	8 (14)	57
Ilocos Norte	6 (14)	43
Zambales	6 (14)	43
Tarlac	2 (28)	07

[a] Figures in parentheses indicate number of plots planted.

Table 5. The success (S) or failure (F) of crops in each of 11 provinces. F indicates that the crop was not harvested because of drought or management problems.

Location	Crop						
	Corn	Sorghum	Mung	Soybeans	Peanuts	Cowpeas	S. potato
EPAC	S	S	S	S	S	S	S
Curareng	S	S	S	S	S	S	S
Zambales	F	S	F	S	S	S	S
La Union	S	S	F	S	S	S	S
Cavite	S	S	S	S	S	S	S
Pampanga	S	S	S	S	S	S	S
Ilocos Norte	S	F	F	S	S	F	F
Santa Maria, Bulacan	S	S	S	S	F	S	S
Camillng, Tarlac	F	S	F	F	F	F	F
Capiz	S	S	S	S	S	S	S
Central Philippines University	S	S	S	S	S	S	S

This work has demonstrated that the two-crop rice system developed over the last 2 years fits fairly well into the environmental conditions of the experimental areas of Iloilo and Cotabato. A two-crop system of rainfed rice in those two areas has produced 9.5 and 12.4 t/ha, respectively. The yields are high enough to excite the imagination of farmers. The third step of the plan or of the pilot program will now be initiated in the two areas. It is expected that by December 1977, a regional program will be fairly easy to establish and will be successful. Also, the economic feasibility of growing sorghum, soybeans, or peanuts as a third crop in the previously one-crop area will be established this year.

In most of the areas of Central Luzon, additional problems need to be overcome before the two-crop rice system is widely accepted. Risk from drought or dry periods during the growing season (May to December) seems to be the major limiting factor preventing farmers from enthusiastically accepting the pattern.

It appears that there is sufficient ground water in that area to allow timely irrigation to start, protect, or finish a crop of rice that may be in danger of reduced yields because of the failure of rain. Also, irrigation for sorghum or soybeans during the dry months from ground-water sources seems feasible at the present time. These adaptations are being included in the plans for future applied research.

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DISCUSSION

HIDAJAT: You have presented a very concise picture of the problems and proper ways to solve them. I would like to focus attention on the crucial item not explicitly mentioned in your paper: The men behind the gun and their skill, tools, knowledge, attitude, organization.

Haws: I assume you mean our own people who help conduct the research, As mentioned, we cannot do all the work ourselves at IRRI. Therefore, we select people from one of three agencies in the area where the research is being conducted. They are extension service people, plant industry people, or staff from the various agricultural colleges. We give them training to provide them skills and technical knowledge. We also give the tools that are necessary to conduct the work.

Attitude is a different matter. We "select" people with this very important characteristic, but I must admit we have not always been successful.

HOQUE: In your adaptive research in farmers' fields, how much value do you attach to the methodologies and precision of data gathering and feedback collection to help the cropping systems research scientists in redesigning their experiments?

Haws: That is a question that up to now has not been answered satisfactorily to my thinking. You are really asking two questions. The first is not hard to answer, that is, how much of a role do we give to methodologies and precision in gathering data. Of course we use every effort to make sure the research plan is sound and we can correctly measure the responses of crops to environment and management. However, we are successful only about 50% of the time. This year, we have reduced the number of locations where we do the research in an effort to give more attention to the work in each site, with the hope that our results will be exact. The second question is difficult. Even here at IRRI, we do not have any arrangement for planning our basic and applied research to complement each other, as we should. It is a serious problem. Basic research people generally plan their work according to criteria different from those of applied researchers. I believe in fact, that if it worked as it should, basic research would be organized around findings of applied research. It doesn't and probably never will be organized this way, but I think it should.

FREEMAN: Were your packages for all the upland crops of an equal level of potential or perfection? If not, how far can an extension program of multiple cropping be pursued?

Haws: Packages for each crop were based on optimum conditions for the crop variety involved. We were looking for stability of the crop, more than anything else, under rainfed conditions. I think the most important element is risk in producing a crop. This implies an economic return. In our study, sorghum and soybeans were more stable than any other crops tested under the same environmental conditions. Markets were the major limiting factors preventing production. We now have a pilot program on sorghum in Batangas where we have an assured market, and the farmers are enthusiastic about the program.

CARANDANG: Is the classification of the climate zones helpful in the choice and performance of the crop during the period of the study?

Haws: Very much so. It tells when we can plant and, to a certain extent, what crop will have a chance there—for example, where you have good rain throughout the year and no typhoon. In Mindanao, flexibility is much greater than in Central Luzon which has high-intensity rains for short periods and has 2½ typhoons per month for 6 months. This is the major reason why President Marcos is moving food production to the south, I think.

VIGNARAJAH: In your trials, did you try out more than one variety of crop, and if so, did you notice any interaction between plant types (erect or spreading) of groundnut varieties and regions?

Haws: Only one variety of the same crop was used in all sites. However, seven different crops—corn, sorghum, peanuts, mung beans, soybeans, cowpeas, sweet potatoes—were planted in each.

SIKURAJAPATHY: Butachlor is effective only when wet soil conditions are encountered in dry sowing. What alternatives would you suggest for weed control when soil conditions are not wet?

Haws: A major factor in weed control in rainfed areas is early land preparation (in December when rice is to be planted in May). This procedure prevents weeds from producing more seeds. Also, weeds that are hard to control with chemicals can be killed by several weedings during the dry season. Mechanical control is the only method that remains if herbicides cannot be used.

FREEMAN: Do you feel that an 80% chance of success is sufficient for the small farmer to utilize the crop or crops advocated ?

Haws: When compared with the percentage for rice on light soils where no rice was harvested, I think 80% (88% for soybeans, 85% for sorghum) is sufficient. Better odds than one gets at Las Vegas.

VIGNARAJAH: It is recognized that rainfall pattern is one of the dominating factors that determine agroclimatic regions. Crop varieties show distinct regional adaptation. Moisture and fertilizer regimes have a strong bearing on the performance of grain-legume varieties. Therefore, I would suggest that it would be best to determine which varieties are best suited to a region and then incorporate them in trials. rather than use one standard variety to represent a crop in all regions.

ZAN: (1) Please distinguish a bit more between basic research and applied research. (2) If farmers are involved in applied research, how are they remunerated or rewarded for taking part in such research?

Haws: (1) My definitions of basic and applied research may be a little different from those of others, but I like to think of basic research as methods used to derive facts that may be used to establish verifiable laws, chiefly by hypothesis but based on recent facts. Applied research is the initial utilization of fundamental or basic knowledge to solve practical problems. We often say applied research is farming. (2) We do most of our work on farmers' fields. There are two major ways in which farmers benefit from cooperation with IRRI researchers: a) They gain knowledge from the research findings; b) IRRI pays for all input for the research, but the farmer-cooperator keeps all production from the plots.

COMMENTS ON ADAPTIVE TRIALS TO DETERMINE PRODUCTION PROGRAM FEASIBILITY

S. Bangliang

The presentation of Dr. L.D. Haws is useful to me in determining production program feasibility. Looking at his Figure 1 on the Path of Agricultural Development, I agree that the national food production program will be effective if it follows such a path.

Applied research, one of the components of the pathway, seems to be very important. As Dr. Haws points out, "Once a pertinent technology has been chosen, it is tested under diverse conditions in farmers' fields or predefined areas. If the applied research results are satisfactory, the technology is expanded to a pilot program where the number of farmers using it is greatly increased." Generally, the management of applied or adaptive research should be done by farmers. The research objectives should be simple and clear to the farmers (the farmers should see what they will have or how they will benefit after getting the results), the management should be uncomplicated and practical for them to work with. If an experiment is complicated or the level of management is too high, either it should be done in the experiment station close to the problem area or by farmers who have proven their ability to do the required work.

Applied research done in the Agronomic Management Branch, Technical Division, today consists of the following:

1. Determining the yield of rice that results from applying packaged technology (high yielding varieties, fertilizers, insect control), and measuring the benefits after extra inputs have been added.
2. Determining the best cropping systems for lowland rice that fit the economic conditions of the farmers in a certain area.

Will the new technology be adopted by farmers or not? In my opinion, adoption will depend on the level of management and socioeconomic conditions of the farmers.

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DISCUSSION OF ADAPTIVE TRIALS TO DETERMINE PRODUCTION PROGRAM FEASIBILITY

Nurjadi

Considering Dr. L.D. Haws' wide experience in many countries, his seniority, and his profession, I can almost be sure that his paper presents some important basic solutions for conducting the adaptive trials to determine production program feasibility.

I am also of the opinion that the problems farmers face are not only production problems, but also marketing problems. Since both types of problems are closely related at the farmer's level, it is understandable that any recommended new technology that considers only production is not always adopted by the farmer.

There are constraints to be overcome in facilitating adoption by farmers of the needed new technology, and problems in determining the objectives and the methodology of activities to ensure fulfillment of farmers' requirements.

Dr. Haws' paper gives me the impression that he is trying to pinpoint the possible clues to the solution of the question I have put forward. But still I feel it necessary to make some comments and suggestions requested by Dr. Haws, not to improve, but only to enrich his idea.

I agree with the methodology and project outline Dr. Haws suggests to achieve the objectives. But using the methodology and procedure within the project outline seem to raise some difficulties in conducting applied research and in making recommendations. To overcome these difficulties, we ought to establish the criteria for basic research, applied research, pilot project, and production development in the process of disseminating new technology. Table 1 tells much about the proposed criteria with respect to design, treatment, replication, plot size, location, characteristics,

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Table 1. Proposed criteria for basic research, applied research, pilot project, and production development.[a]

Item	Basic research	Applied research	Pilot project	Production development
1. Design	Relatively complicated	Simple	Test for compatibility with farming systems	Mass guidance
2. Treatments	More	Less	One-package technology	Package technology
3. Replications	Not dispersed	Dispersed	None	None
4. Plot size	Smaller	Larger	Farm size	Similar agro-climatic zones
5. Location	Any land	Representative area	Area sample	Project area
6. Characteristics	Basic	Applied	Adopted	Farmer use
7. Farmer involvement	None	Partly	Wholly	Farmer's responsibility
8. Result	Source of technology	Adaptive technology	Adopted technology	Used technology

[a] To be discussed further.

farmer involvement and results. Dr. Haws has defined them previously (Haws, 1975), but the table gives a clearer description.

Priority and concentration principles will give us more efficiency in using limited resources (funds, facilities, and manpower).

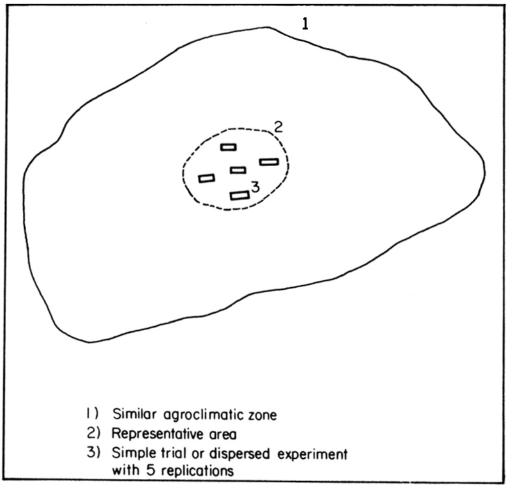
Further we ought to consider the farmers' basic way of thinking in selecting new technology for increasing production and improving farmers' welfare.

Returning to the topic, let us discuss the applied research trials. The important item is the distribution of replications, because the applied research result will be recommended to the farmers within similar "agroclimatic zones." In this case I assume that the same level of management in the similar agroclimatic zones will produce the same yields, and the yields in different agroclimatic zones will be different. So we should classify the project area of production development into similar agroclimatic zones (with the same type of soil and rainfall pattern).

The outlining of such agroclimatic zones is essential to the eventual development of the design capability for improved systems. Because cropping systems are so dependent upon environment, the environmental parameters that affect them must be identified.

The parameters specifically referred to include:

1. climatological factors;
2. soil factors;
3. topographical factors;



1. Location of applied research trial.

4. irrigation potential; and
5. economic factors.

Those key parameters must be mapped for areas of interest to cropping systems programs. It was recommended last year that the International Rice Research Institute (IRRI) coordinate these efforts on a region-wide basis to permit

1. selection of research sites in key zones;
2. extrapolation of results across each zone; and
3. use of the research data from a zone in one country in similar zones elsewhere in the region (Anonymous, 1975). Dr. V.R. Carangal coordinates these efforts. Applied research trials are the follow-up to those efforts.

The map of agroclimatic zones in the Philippines is available in the report *An agroclimatic classification for evaluating cropping systems potential in South Asian rice-growing regions* (Herrera and Harwood, 1974). I am sure that Dr. Haws used it.

Each similar agroclimatic zone needs a set of trials to cope with its production problems. The trials should be dispersed within a representative area. Figure 1 shows the dispersed experiment for a certain agroclimatic zone. The dispersed experiment is named “simple trials”; any farmer, supervised by a researcher, can easily carry it out.

The goal is to obtain a package of new technology that is feasible for larger, similar agroclimatic zones.

The farmers always think of and try to find ways to provide for their needs and to improve their welfare. They will select new technology carefully, based on the constraints on their resources. According to this consideration the new technology will be selected by the farmers only if it offers no significant risk. The innovation must be technically and economically feasible, socially acceptable, and educationally attainable (Dacanay, 1975). As we intensify cropping, the limit will be reached when one or more farm resources become limiting. In general, a balanced use of all farm resources will probably have the greater benefit for the farmer. The easiest things should be done first:

1. Increase productivity of existing crops.
2. Shift to more productive crops.
3. Intensify the sequence.
4. Intercrop.
5. Relay crop.

Usually, the last named (5) has the last priority (Harwood, 1973). According to both statements mentioned above, we need a test for compatibility with farming system, namely a pilot project or production-development (test) unit. The procedures follow the framework for cropping systems research and extension outlined by participants in the 1975 Cropping Systems Workshop held at IRRI.

The results of the pilot project could be recommended as an adopted new technology to be developed in the similar agroclimatic zones of the national production program, like the Masagana 99 in the Philippines.

I would like to extend my gratitude to Dr. Nyle C. Brady, Dr. Virgilio R. Carañgal, Dr. L.D. Haws, Dr. Jerry L. McIntosh, Dr. R.A. Morris, and the International Rice Research Institute for the honor given me to participate in this Symposium as a discussant.

DISCUSSION

OLDEMAN: Do you feel from your experience that the farmers in Indonesia have by tradition already chosen the best possible cropping pattern with regard to their environment (climate, soil)? If so, should we then not give highest priority to improving their existing cropping patterns (varieties, fertilizer management, and so on)?

Nurjadi: Anyone will select the best, but not everyone can get the best if there is only one best. I think there is no best cropping pattern at the farmers' level, so farmers use more than one cropping pattern. Everything that affects their life will be considered, especially environment.

Now, as to the approach of improving or increasing production: the easiest things should be done first. To increase productivity of existing crops is easier than to improve cropping patterns. So the higher priority goes to the easier one. This approach depends upon many factors, including environment. Maybe in areas where farmers use the highest level of management for any crop and already get superior yields, only a cropping-pattern change will increase their income by arranging the harvest at the period when prices are high. Improving the existing cropping pattern must have first priority. So the priorities depend on physical resources, economic and social development, and so on.

Cropping systems approach to production programs

INTRODUCTION

Kasmo

It is said that what counts today, as far as the world's economic condition is concerned, is the need for a redistribution of wealth. That would certainly be easier to accomplish if the wealth available for redistribution and the wealth the world needs were more nearly equal. That implies that the present level of world production should be increased.

There seem to be two principal approaches to agriculture production: one based on a "comparative advantage principle" and one based on a "diversification principle."

The first approach is usually adopted by large commercial farms, that are generally equipped with high skills in technology and management, and are provided with sufficient capital to apply heavy inputs; those farms aim at high profits. The second approach is that commonly adopted—in many cases unconsciously—by small farmers with relatively poor skill, for whom capital is always a constraint. Its emphasis is not on profit, but rather on sharing of risk and on distributing income evenly throughout the year. It is widely used in Indonesia. In such a context, we have to deal with the cropping system.

The two approaches to agricultural production are not necessarily incompatible. Large commercial farms often adopt the first approach, while some developing countries, in their efforts to improve the welfare of small farmers, prefer the second.

No matter which approach is adopted, the important thing is to select the most efficient production techniques that promise to meet the goal.

Although there are already significant experimental and research achievements in agricultural technology, there are still problems in disseminating those results. And even if the dissemination is considered successful, there may be many discrepancies between the results of experiment and research and the results coming from practice. So, discovery of

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the most efficient way to disseminate the most appropriate technology, and elimination of discrepancies between experimental and practical results are the two main aspects to be taken into account in putting any production program into practice.

It is also evident (again with special reference to Indonesia) that the comparative advantage principle, which leads to a commodity approach to the production program, cannot cope with the small farmer's problems.

In spite of the relatively high benefit-to-cost ratios for fertilizers (as revealed by Indonesia's BIMAS Program), the operating surplus (net farm income minus family living allowance) is likely to be negative for the smallest farms. The approach emphasizes profitability, but it is rather the farmer's liquidity position which ultimately determines his fertilizer use. I wonder if the cropping systems approach could be better than the commodity approach in a production program for small farmers, bearing in mind that such an approach will also invite new institutional problems.

Those are the issues that I can pinpoint. I am sure there are still more that will come from the participants, and especially from the papers that will be presented by Prof. Eldon D. Smith and Prof. Arturo A. Gomez, which, it is hoped, can also put forward some possible solutions.

ASSESSMENTOF THE CAPACITY OF NATIONAL INSTITUTIONS TO INTRODUCE AND SERVICE NEW TECHNOLOGY

E.D. Smith

The concept *institution* is exceedingly broad and variously defined. So is *technology*! In this paper it will be necessary to sharply define the concepts *institution* and *institutional* capacity, and to limit discussion to a few classes of institutions and technology.

Since this is a symposium on cropping systems research, I will attempt (1) to conceptualize some specific issues related to the capacity of institutions to support new cropping systems technologies, and (2) to provisionally assess the skimpy evidence about that capacity and some specific types of deficiencies that may be encountered in introducing those technologies. This necessarily general assessment will emphasize problems related to the introduction of commercially oriented, multiple cropping systems into single-crop, staples-producing areas, particularly rainfed rice-growing areas. For brevity, discussion will be limited primarily to land tenure, credit, and marketing.

Unfortunately, scarcely any research literature is specific to institutional performance in the introduction of multiple cropping systems technologies. Therefore, I shall reason primarily from analogy. I shall also refer to the research on the introduction of new single crops and to new technologies for traditional single crops such as the high yielding variety (HYV) cereals.

WHAT IS INSTITUTIONAL CAPACITY?

Institutions are units of collective action coordinating individual action. That is, they are made up of individuals acting (willingly or not) in concert to achieve purposes not attainable by uncoordinated individual action.

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The effective implementation of a set of rules binds those individual actions. The rules define individual rights or discretionary actions, the types of behavior required, and the types not tolerated. Implementation requires that there be sanctions *against* undesired behavior and effective inducements *for* desired behavior.

Institutional capacity, then, is simply the ability of those rules and applied sanctions or incentives to elicit coordinated behavior that achieves the desired results—in this case to effect the utilization of adapted technology by a target population or group.[1]

While multiple objectives in technology design are recognized, I shall consider adapted technology to be simply *that which is profitable or potentially profitable to the farmers for whom it is designed.*[2] I shall evaluate institutional capacity in terms of

1. the ability of the institutions to provide full opportunity to cultivators to profit from the productivity of the available technology, and
2. user awareness of the potential profits.

Essentially, the problem is to exploit the economic potential of appropriate adapted technologies. Practical questions that must be addressed in introducing such technologies are: Does institutional capacity limit the profitability and opportunity for utilization of the technology? May it become limitational? May its limiting effects, if any, be removed by institutional adaptation or innovation?

Institutions in many cases represent societal responses to anticipated economic opportunities (Ruttan, 1973; Schultz, 1968; Hayami and Ruttan, 1971). The response is not always something deliberate, but may be a product of more or less vaguely recognized economic circumstances. It may be inappropriate, even at the level of a simple transaction or action by a small group, if the knowledge of those belonging to the group is inadequate. But if the consequences of collective action (institutional response) are diffuse, indirect, and difficult to observe, there is need for systematic institutional engineering based on scientific evidence.

[1] Note here that we bypass the whole issue of how "good" technology is identified, that is, the selection of general criteria against which it can he evaluated. Such criteria include employment levels, income distribution, productivity and so on.

[2] In nonmarket economies, institutional capacity would presumably be evaluated against ability to achieve established production quotas or targets. Hence, this analysis is more or less inapplicable to socialized countries.

The reference to "target user clientele" is intentionally unspecific. It allows for the possibility of specific designs that are intended for use by small-scale cultivators and which tend to neutralize such things as (1) scale diseconomies that disadvantage those with limited resources, (2) labor-displacing characteristics, (3) heavy demands on technical or managerial skills that disadvantage those without the advantages of education or relevant experience. The reference could also he to a particular region.

"Potentially profitable" in this context means a technology which would he profitable if the following existed (1) efficient markets for products and production inputs and/or publicly operated marketing and distribution systems. and (2) levels of management that are attainable by the farmers for whom it was designed.

Of course, economic institutions are not always completely responsible for the failure of farmers to utilize adapted technology. Conflicts between the use of technology and other goals, or a lack of the knowledge or of the managerial skill to utilize complex or sophisticated technology may result either from inadequate design of the technology or from institutional failure.

Moreover, there are degrees of profitability, and high potential profits can compensate for managerial inadequacies, conflicting goals, or institutional failures. The existence of drug traffic in areas where violations of laws against it are punishable by death is evidence to this point. I am inclined to believe, for example, that much of the early success in diffusing the HYV food grains technology is explained by its very large profit potential. Its slower diffusion in recent years results, in part, from combinations of goal conflicts, management deficiencies, and institutional impediments to adoption in areas to which the technology is less well adapted.

To summarize, the failure to introduce an adapted technology can result from

1. conflict between the adoption of the technology and other goals;
2. lack of adequate knowledge or managerial skill of intended users;
3. incapacity of the institutional system to deliver full profit incentives and knowledge of them to intended users;
4. profit potentials insufficient to overcome value conflicts, managerial weakness or institutional deficiencies;
5. profit potentials insufficient to induce institutional innovation or adaptation when existing institutional capacities are inadequate to support the technology;
6. incapacity of the political and social institutions to respond to the economic potentials of technologies by economic institutional innovations, or lack of the knowledge needed for designing the required institutional innovations; and
7. combinations of the above.

With the foregoing definitions and typology of adoption failures as background, I turn to a general analysis of sources of institutional incapacity to use adapted cropping systems technology. Based on that framework, using analogies to the experience with single-crop technologies, and considering the distinctive features of multiple cropping systems technologies, I will try to isolate some specific deficiencies in institutional capacity to support those technologies. First, however, I will assess the general importance of institutional capacity as a potential constraint on use of the technologies.

GENERAL IMPORTANCE OF INSTITUTIONAL CAPACITY TO SUPPORT MULTIPLE CROPPING

The fact that multiple cropping systems cover several crops besides off-season rice suggests a higher probability that some element of each cropping systems package would encounter institutional-capacity constraints than would a single-crop system. But beyond that, there are at least three important reasons for hypothesizing that institutional capacity will be more important in the introduction of a multiple cropping systems package than in the introduction of new single crops or single-crop-technology packages. First, personnel of the International Rice Research Institute have observed that multiple cropping technologies are considerably more complex than single-crop technologies and demand a much higher quality of management (Harwood and Price, 1975). Second, I have found no indication in the publications here that anyone believes that it is realistic to expect multiple cropping to double or triple productivity potentials on the wide scale effected by HYV rice technology. Profit inducements are likely to be somewhat less spectacular. Institutional malfunctions probably more often will reduce profits below an adoption threshold if active attempts to improve institutional capacity do not complement technology development. Finally, because of the delicate interactions between crops in the "package," an institutional failure affecting the crop, such as late delivery of seeds, may have a profound influence on the yield or even on the feasibility of other crops in the system.

But what types of institutional capacity will become important? What institutional impediments to adoption can be expected, and which will require remedial action? Obviously, that will vary from area to area and from crop to crop. The remainder of this paper will attempt to isolate some fairly generally important impediments.

LAND TENURE INSTITUTIONS

Tenure systems must be rigorously distinguished from tenure institutions, just as pricing patterns or marketing practices must be distinguished from market institutions. Tenure systems comprise the general terms of tenure transactions, but those transactions are made within a set of rules and sanctions defined by tenure institutions.[3] The issue before us is whether

[3]For example, most land laws (institutions) *permit* many types of tenancy arrangements and, except where land reforms are carried out, do not require owner cultivatorship. Usually the tenure system consists of a mix of owner- and tenant-operated farms of varying size under various combinations of leasehold and share tenancy plus owner-cultivatorship. But if land reform laws (institutions) so require, the land tenure system is characterized by owner-cultivatorship alone.

the tenure system already adequately meets the demands of new cropping systems or will accommodate them without change in the basic institutions.

When the existing system is an owner-cultivator system, the principal questions seem to be related to whether ownership has been acquired by depleting operating capital, and whether lumpy factor inputs are required by the technology and cause diseconomies in small-scale farms with limited resources (or fragmented holdings, or both). Many diseconomies resulting from lumpy factors can be avoided by joint ownership of factors (such as tobacco flue-curing facilities) or by custom-hire arrangements. If operating capital shortages are imposed by private lenders, they can presumably be removed by effective credit programs, although the difficulties of designing such programs are considerable.[4]

When tenancy, especially share tenancy, pervades the existing system, much knottier issues arise. Even with fixed rents (leasehold), there is the problem of insecurity of tenure and its possible effects, especially on what Raup has called "accretionary" capital formation. That is notably true of nonmonetized "investments of family labor time in productive undertakings'' (Raup, 1967). Such nonmonetized investments may become important when land improvements, structures, and so on, are required by the technology.

Share tenancy arrangements have been traditionally regarded as likely impediments to technological change. The traditional theoretical argument has been that for maximum efficiency, such arrangements require a proportionate sharing by tenant and landlord of incremental input costs and incremental output *over the life of an input.* Such a condition often is unfulfilled.

Assume, for example, that for the rice crop a 50–50 sharing of output is normal and that a second crop is introduced following rice.[5] Obviously, except for possible sharing of added fertilizer and other variable cash costs, the landlords' "land service" contribution remains essentially the same; it is merely used more intensively. If, then, the landlord shares 50–50 in the output of the second crop, he obtains a reward disproportionate to incremental contributions and the incentive for the tenant to produce such a crop is, accordingly, reduced.

Both this example and the Raup argument regarding internal capital formation appear to be based on a premise that has been challenged by

[4] The general difficulties of upgrading productivity of smallholder rubber production are suggestive of potential difficulties in this regard. i e.. the problems of designing suitable Institutional credit systems for particular crops such as long-maturing perennials.

[5] It is recognized that interplanting may be a part of a cropping system and that this will present somewhat different demands on institutional capacitiees than does sequential multiple cropping In the interest of brevity, interplanting will be Ignored. However, most of the discussion will he relevant to either.

several authors—that the lease terms are fixed by custom or other nonmarket factors. If those critics of the traditional argument are correct, changes in landlord-tenant agreements would be expected to quickly follow the introduction of adapted new cropping systems as a result of competition among tenants and landlords.[6] That would follow logically if no externally imposed rules precluded such adjustments, and if tenants and landlords had perfect foresight and profit maximization objectives in making their decisions.

Unfortunately, those assumptions seem to be somewhat tenuous, especially in the short run. The complexities of new cropping systems may require extended experimentation before the required accommodations can be worked out. A variety of personal considerations may intervene in landlord-tenant relations, and may result in tenure uncertainties regardless of managerial performance levels. The difficulty of measuring nonmonetized family-labor contributions to the fixed assets of the farm may make those contributions ineffectual as a basis for competing for access to land; the right to evict tenants at the end of each year may retard adoption of cropping systems that require new structures or land improvements.

A further potential retardant to adoption is the *de facto* participation in enterprise selection by landlords, especially absentee landlords. Fixed rent specified in units of a particular crop, or share agreements specified for a particular crop, are cases in point. In such cases, the agreement would have to be renegotiated if a change were made. Renegotiation may be difficult with absentee owners.

As a minimum, it seems likely that new informational and technical assistance services may be required to facilitate adjustments of rental agreements in some cases. Otherwise, tenure arrangements may retard adoption even though tenure institutions are sufficiently permissive to allow necessary adjustments.[7]

However, what I have said indicates nothing about whether landlords or tenants would be the primary beneficiaries of the technology. If, for example, large numbers of potential tenants bid for a very limited and

[6] Newberry (1975) and Cheung (1969) have presented convincing theoretical arguments that if the market for land services is competitive, those terms would be modified to reflect the marginal contributions of landlord and tenant to to the value of output. Mangahas (1975) has a generally similar formulation and provides supporting evidence that there are no important differences between share tenants and owner-cultivators in rates of adoption of HYV technology.

[7] Chaudhari et al. (1975) provide an example of failure to adjust terms for fodder crops as HYV rice and wheat technology became available, apparently diminishing incentives for use of land in the most productive way.

That education and technical assistance are needed by peasant farm tenants and their landlords is not surprising since extension programs in the United States will provide assistance on such matters and the related matter of production contracts in vertically integrated industries. Absentee ownership. in particular, may complicate adjustments, since information will be somewhat less perfect and delegation processes of management more inefficient than with resident ownership. Agreements requiring nonmonetized investments of tenant labor would probably be diffcult to enforce.

relatively fixed supply of land, the result may be contract terms that are relatively unfavorable to tenants. Thus, a large part of the income stream created by the technology will go to landlords, and further inequalities of income and wealth may result from technological changes, especially in tenancy dominated areas (Parthasarathy, 1975).

CREDIT INSTITUTIONS

Local moneylender credit terms presumably reflect demand and supply conditions in an area. If the technologies are sufficiently profitable to more than cover costs of credit at current moneylender rates, it seems likely that there would be no great difficulty in adapting terms of loans to the new cropping patterns. Lines of communication are short in the villages. In fact, by smoothing out demand for production credit over the year, multiple crops may reduce interest costs for individual crops by increasing total returns per unit of saving.

For moneylender credit to suffice, the capital requirements of new crops will have to be very modest or the productivity of new crops very high, or both. Interest charges are ordinarily very high by developed-country standards! Therefore, in the event that added crops require large quantities of purchased inputs, especially durable assets such as machines and storage facilities, the capacities of lending institutions to provide credit on appropriate terms may be critical.[8] United States farm credit history indicates that commercial lenders seem to be less capable than governmental systems of adapting their lending systems to agricultural needs. The 1973 AID Spring Review of Small Farmer Credit Programs supported this general view of private lenders. But it is instructive to note that only two countries (Korea and Taiwan) of 16 evaluated had supplied more than 25% of small farmer credit through national credit institutions (Gayoso, 1973).[9] Six of 14 countries reporting at a 1975 IRRI conference on adoption of HYV rice technology mentioned lack of credit as a constraint to adoption (IRRI, 1975a). Nonrepayment and delinquency, high administrative costs, untimely release of funds, lack of coordination with technical assistance agencies, and complex loan application and approval procedures which are difficult for farmers to understand all have been mentioned in connection with the programs. That being the case, caution seems to be dictated

[8]C.B. Baker (1973) says. "Even Important improvements in technology may not generate payoffs that reach 50 percent to 100 percent levels." He goes on to say that, "The money lender is ill-equipped and uninterested in making loans over a period of time that allows much of the increase in small farm income to serve as a basis for repaying loans."

[9]Several important Asian countries were not included in the review: Indonesia, India, Malaysia, the philippines, Nepal, and Afghanistan.

with regard to the current capacity of national credit institutions to support technologies requiring large supplies of credit.

Even more caution is possibly dictated with regard to the present ability of the credit organizations to modify institutional procedures to accommodate changed patterns of demand and radically different repayment schedules from those used with traditional crops. For example, it is somewhat difficult to conceive of anything such as the United States Production Credit Association "line of credit" or "budgeted loan" being administered by a system that has been unable to disburse loans on time in traditional monocultural systems. Thus introduction of new systems will probably require careful analysis of

1. magnitude and timing of capital needs,
2. compatibility of these needs with existing systems,
3. present institutional latitude in modifying loan terms, and
4. feasible adjustments of credit institution rules to accommodate the new systems.

Timely disbursement is especially critical in multiple cropping systems, since most farmers depend on more complete utilization of seasonally variable supplies of water and solar radiation. Advance consultations and assistance in the engineering of institutionally feasible and appropriate lending systems may be as important as designing agronomic practices suited to cropping systems in some cases.

MARKETS AND MARKET INSTITUTIONS

It is extremely difficult to encapsulate in a few paragraphs the multitudinous ways in which the performance of markets may influence the utilization of new cropping systems technologies. It is still more difficult to identify a few specific sources of probable deficiency, considering the wide variety of institutions that influence the performance of markets. That, perhaps, explains why, as Schutjer and Van der Veen (1976) observed recently, the literature on technological change reveals that "markets and prices have received minor attention," although "the literature is replete with references regarding the importance of assuring profitability of new technology."

Any of the functions performed by marketing systems—assembly, transportation, processing, distribution and pricing—may, if inefficiently conducted, cause difficulties. Moreover, these difficulties may occur at widely separated points in space, literally worldwide. They may relate to enforcement of contracts and agreements, standardization of quality categories and weights and measures, information diffusion, equalization of bargaining power, establishment of rules of trading, and provision of physical facilities—all to expedite private competitive transactions. In addition, a wide variety of institutions, such as the various price stabilization schemes as well as direct public performance of marketing functions, directly regulate private transactions. Yet, to this vast array of product markets and institutions must be added a parallel and equally important set of markets for improved seeds, fertilizers, machines, chemicals, and so on, the purchased input markets.[10]

That markets may limit the utilization of new technology is amply illustrated by the failures of input delivery systems, and the inadequacies of transportation and storage to support the introduction of early HYV grains. It seems highly probable that deficiencies in the capacities of marketing systems will be more common in multiple cropping introductions.

There are two reasons for expecting those differences. First, staple food grains markets have been commercially important in most countries for decades or even centuries. The rapid increase in their importance in the last decade or so has allowed an intricate pattern of communication and trade to develop more or less incrementally. Despite short-run dislocations during the early Green Revolution experience, product markets appear to have worked well in most respects (Lele, 1967; Ruttan, 1969). While not as highly formalized and sophisticated as the grain markets of some of the North American and European countries, they have a functioning information network and a variety of institutional means created by the trade itself to expedite transactions. In addition, staple food-grain markets and the major export commodity markets have been important enough to be subjected to a variety of formal institutional supports and controls, such as official quality standards, market information diffusion, and export quality inspections.

In contrast, no comparable market system has developed for the so-called minor crops except in regions of specialized production. Lacking an important profit inducement, neither public agencies nor private marketing agents have felt the need to invest heavily of time, energy, or resources in developing institutions, personal managerial or entrepreneurial capability, or physical facilities for minor-crop markets. Even when potentially profitable cropping technologies are developed, it seems unlikely that an adequately functioning marketing system will spring up spontaneously. In some cases the rapid introductions of new export crops appear to have taken place as a result of extraordinary profit potentials sufficient to

[10] For more complete analysis of marketing institutions, see Smith (1974)

overcome serious malfunctions that continue to reduce the crops' economic contribution (Smith, 1969; Tongpan, 1970). Therefore, specific investigations and governmental action will be required to develop markets for many of the "new" crops. Indeed, experience with the early introductions already indicates that significant market problems will be encountered (Syarifuddin et al., 1975; personal communication with A. Gomez, University of the Philippines at Los Baños, 1976).

While efficient markets are important, indeed essential to such technological development, they can easily become a scapegoat for other program deficiencies. At best, marketing institutions can elicit efficient performance of marketing services and efficient pricing of commodities. The real costs of resources employed in marketing are no more avoidable than the costs of land, labor, and materials used in farming operations. Efficient marketing cannot make an economically ill-adapted cropping system profitable; but unavoidable input cost, marketing cost, and supply-and-demand realities can easily be mistaken for badly functioning markets and deficient institutional capacity. Hence, a provisional assessment of final demand, achievable minimum costs of marketing, and achievable costs of inputs is an important step in the selection of crops for inclusion in the systems to be introduced.

Input markets. Input markets as an important factor in agriculture are relatively new in developing nations. Many input market problems are similar to those of minor or new crops. A specialized trade with expertise in anticipating demand and coordinating advance ordering, inventory, financing, and so on, has only begun to develop in many areas. Despite a decade or more of increased demand and a significant amount of attention in development programs, the markets for nontraditional inputs still appear to be an important bottleneck to technological change—even to the profitable HYV technology (Ruttan, 1969; Sidhu, 1974; IRRI, 1975a,b,c; Schutjer and Van der Veen, 1976).

Two problems, however, are unique to the input markets: the inadequacy of direct inspection for discerning chemical, physical, and genetic characteristics of items being exchanged; and the undeveloped or latent demand. Without technical understanding of the biological, chemical, and economic processes involved, farmers can depend only on direct experience to become effective demanders of the inputs. Input suppliers cannot fully capture the benefits of their investments if they undertake to develop the understanding required by farmers to make them effective demanders of the inputs.

Those problems are common to all classes of modern inputs, not only to those required for multiple crop technology. The progress that has been made in developing farmer organizations, cooperatives, public distribution agencies, and improved institutional supports for the private trade will unquestionably be applicable to new fertilizers, chemicals, and seeds. The principal exception may be in the policing of the purity of improved seeds.

Institutions and institutional alternatives. Obviously, market problems may be experienced in areas where new crops are introduced or where commercial production of subsistence crops is profitable. "Second best" systems that avoid the more serious of the market problems may have to suffice unless those problems are solved. Whether it is possible to develop the institutional capacity to effect their removal becomes the fundamental issue. However, it is important to determine whether genuine malfunctions in input or product markets really exist. For example, despite some problems in the fertilizer distribution system of Thailand, it was found that the farm price of ammonium phosphate in northeastern Thailand was approximately equal to that reported in the United States, plus shipping costs from West Coast US ports (Smith and Berry, 1968).

If an adequately developed private trade in the crops being considered or in the inputs required to produce these crops does not exist within an area, several strategies requiring somewhat different types of institutional capacities present themselves as alternatives. The first is information and technical assistance.

Information and technical assistance institutions can provide the private trade and farmers with

1. realistic estimates of farm prices for various levels of output,
2. meaningful quality classifications that are understood by local tradesmen and farmers and that serve as bases for price reporting,
3. current market prices in relevant market areas,
4. marketing margins (adjusted for differences in transportation costs) in commercial producing areas,
5. information on functional quality standards, on probable price differentials among quality categories, on the handling and processing methods required to minimize losses due to damage or spoilage, and on methods for increasing salability, and
6. information about channels of trade and available outlets.

Such services may enable local merchants and tradesmen to enter new trading enterprises, especially if they are assured of adequate supplies to make trade in the product profitable. They may enable processors, wholesalers, or even exporters, by vertical integration of marketing functions, to bypass normal marketing channels that are dysfunctional.

Contract integration arrangements may be made so that input-supply and product-marketing functions will be coordinated. Contractual arrangements with farmers will reduce uncertainty regarding quality and quantity of available product supplies.

Such contract-integration arrangements have become widespread in developed countries and are apparently becoming more common in Asia, as the comments of Harwood and Price (1975), and my own observations, and those of Van (1975) indicate. Such integrative contract arrangements were operated under carefully designed licensing and controls in the early stages of a project reported by Van. Input-supply bottlenecks were avoided by provision of inputs by the integrator company; production was carefully supervised until managerial capacity was developed to satisfactory levels; gradual acquisition of processing facilities (flue-curing houses) by farmers was provided. The company had an assured supply of products of the desired quality, and the farmers had a guaranteed market.

While probably fairly effective in introducing technology, integrative arrangements, especially those providing credit and input supplies, require careful surveillance to avoid possible exploitation of farmers and exclusion of competitors once the crop is fully established. They demand an institutional capacity which is in fairly short supply except in a few countries. However, only a relatively limited institutional capacity is demanded to support (as distinguished from control) the system if interested firms are available. Markets, technical assistance to farmers, and input supplies are coordinated within a single managerial unit. Information on and training in cultural practices and handling methods may be the maximum required of institutional supports.

A second approach is the integration of supply, product market, and production operations through farmers' organizations. In principle, the institutional structure of farmers' associations or cooperatives can accomplish the same objectives as vertical contract integration by proprietary marketing organizations, or input suppliers. The much-copied model of the Taiwanese Farmers Associations is a case in point. By gaining direct control over both product and input markets, such an organization can provide the same coordinative functions without the uncertainties inherent in a market coordinative mechanism. However, the situation appears to remain about as when Ruttan (1969) remarked almost a decade ago that there was scarcely a single successful system of cooperatives in the region. While quasi-cooperative Taiwanese organizations provide a notable success story, attempts to transfer the idea to different political, cultural, and economic climates have been far less than completely successful. Nevertheless, experience in the United States, Taiwan, Korea, Japan and elsewhere seems to suggest that local farmers' organizations can be extremely useful, especially in supplying modern inputs under government subsidies. They minimize the need for government personnel to operate the services directly and may constitute the initial steps toward institutional capability for complete self-management.

The message in this experience seems to be that if farmer organizations to supply inputs or marketing services or both are to be developed, they will have to be engineered for specific social, political, and economic "microclimates." That probably means building incrementally upon workable components of going organizations designed for other purposes, as in Taiwan.

Finally, governmental institutions directly performing marketing and supply functions are, perhaps, overpopular as instruments for dealing with market deficiencies. They range from government corporations to marketing boards of various types and to normal administrative units that are mandated to perform direct services ranging from storage and price stabilization to processing, assembly and contracting with overseas importers.

It seems apparent that governmental institutions must undertake some direct services for new cropping systems. However, among the cases in which their activity completely displaced normal, private, marketing channels, one is hard put to find an outstanding success story. The activity puts extreme demands on typically over-committed governmental institutions. The more useful strategy appears to be careful, selective intervention at points in which the private trade, with adequate supporting services, cannot adequately function. Examples of such intervention are providing educational programs and subsidies to develop the demand for modern inputs, developing transportation, providing standby price guarantees until reliable markets are established, or giving technical assistance in establishing marketing enterprises. If those analytical resources are mobilized, most Asian countries can use their own stocks of basic analytical capacity to identify strategically limiting elements.

What has been said about the role of market institutions is necessarily general and nondefinitive, because the types of institutional capacity required to provide adequate markets in support of new cropping systems cannot be specified without investigating the specifics of a particular situation. What can be said specifically is that careful attention to the engineering of marketing institutions may be as essential as the engineering of the technology itself. That engineering probably must be done by indigenous professionals and administrators rather than by personnel from regional institutes.

SUMMARY

In general, institutional impediments to the introduction of improved cropping systems are likely to be much more serious than those that were found in the less complex, high yielding variety grains technology. There are delicate interactions between cropping enterprises, and there are large numbers of crops that might be included in one or more of the systems. Those considerations and the dominance of rice in defining tenure, credit and market institutions all suggest that institutional malfunctions may more seriously affect those technologies than new single-crop technologies. Moreover, such malfunctions may be more damaging, because the productivity gains are likely to be less spectacular than in the HYV grains technology.

Credit systems will require modifications to meet the changed timing of capital needs and repayment capability. That, in turn, may require revamping of credit institutions to allow flexibility in working out loan terms suited to modified cropping patterns in particular areas.

Marketing systems and input-supply systems will undoubtedly require modification. Product markets are likely to be serious problems, since both entrepreneurial capability and institutions will not have been highly developed for minor crops or newly introduced commercial crops. Institutional innovations will in some cases be required to provide direct marketing services. However, experience in the region suggests that such services should be used only as a last resort, only after possibilities of developing facilitating institutions and services for private transactions are investigated and found wanting. The demand on governmental institutions to directly operate marketing facilities has, in most cases, exceeded their capabilities.

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CROPPING SYSTEMS APPROACH TO PRODUCTION PROGRAM: THE PHILIPPINE EXPERIENCE

A.A. Gomez

BACKGROUND INFORMATION

Approaches to crop production programs. There are at least two approaches to crop production programs: the commodity approach, in which the main objective is to increase production in a commodity, and the cropping systems approach, in which the main objective is to increase farm profit through efficient use of farm resources. Crop production in the Philippines and in most other Asian countries has, in the last decade, primarily followed the commodity approach. Typical examples are the rice programs of the Philippines and of Indonesia.

There are two important advantages in a commodity approach. First, the improved technology of a single crop like rice is easy to transmit to farmers. Second, limited resources can be concentrated on a single crop, maximizing the chance of success. Because of those advantages, and because of the initial success in rice, the commodity approach has been applied to other crops. Thus, in the Philippines two other commodity programs, namely Masaganang Maisan for corn and Gulayan sa Kalusugan for vegetables, are being implemented simultaneously with Masagana 99 for rice. Each program has its own extension technicians and its own administrative setup. Yet all three programs are directed to the same farmers. Obviously, the efficiency of the commodity approach is reduced as more commodities are involved. On the other hand, the cropping systems approach, by virtue of its ability to include many crops under one program, becomes more efficient as more crops are included.

Initial evaluation of the cropping systems approach. Since 1972, the University of the Philippines at Los Baños (UPLB), in cooperation with the International Rice Research Institute (IRRI) and with financial support

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from the International Development Research Centre (IDRC), has evaluated the effectiveness of the cropping systems approach in Laguna and Batangas. The important features of the current program are these:

1. Six accessible barrios[1] in Laguna and Batangas were selected as pilot areas.
2. One extension technician (a BSA graduate) was assigned to each barrio to advise on improving crop production for the community.
3. Credit was liberalized and market outlets were improved.

After 4 years, tangible improvement in the pilot communities was shown by

1. increase in the multicropped area from less than 15% to 40%;
2. increase in the use of credit from a negligible amount to approximately ₱250,000 per barrio; and
3. existence in each barrio of a farmer organization which assists its members in jointly securing credit, procuring farm inputs, and selling farm products.

NATIONAL MULTIPLE CROPPING PRODUCTION PROGRAM OF THE PHILIPPINES

The advantages of the cropping systems approach, together with its success in the initial evaluation phase, have prompted the Philippine Government to try the approach in a wider area. In late 1975 the national government appropriated funds for a National Multiple Cropping Production Program that will evaluate the applicability of the cropping systems approach to the different regions of the country. While the procedures for implementing the program will be patterned after those used in the initial pilot barrios, several important differences should be noted. First, the area covered will be approximately 100 times larger. Second, the area will be widely distributed over the archipelago, providing samples of both the favorable and the less favorable communities. Third, available government technicians will be used. In the succeeding section, I shall discuss in detail the strategy for implementing the program, and its status on 31 August 1976.

Strategy of implementation. I mentioned in the previous sections that the Philippines is currently implementing three crop production programs: Masagana 99 for rice, Masaganang Maisan for corn, and Gulayan sa Kalusugan for vegetables. The Multiple Cropping Production Program is essentially an integration of those three programs. Integration was achieved through

[1] A barrio is the smallest unit of government. It covers an area of about 200 ha and is inhabited by about 150 or more households.

1. crop production—introduction of multiple cropping which emphasizes the integration and intensification of farm production;

2. credit—changing the lending scheme from the previous single-crop loan to one which covers all crops grown for 1 year; and

3. extension technicians—making the production technician responsible not only for a single crop but for all crops grown by his farmer-cooperators.

Target areas. The program will concentrate its effort on some selected areas in order to monitor performance closely. There will be two types of pilot communities: a province where the modified extension organizational setup can be evaluated, and 18 pilot municipalities where the productivity of the multiple cropping technology can be studied over a wide range of environmental conditions. Pampanga, the pilot province, was chosen for its

1. high rate of repayment of previous loans,
2. active and highly motivated extension staff, and
3. good market outlets.

The 18 pilot municipalities were selected on the basis of the following criteria:

1. Rice and corn are the major crops.
2. The rate of repayment of loans is high.
3. Good market outlets are available.
4. Good production technicians are on hand.
5. The different geographical areas of the country are represented.

The 18 pilot municipalities are in 11 provinces :

a) La Union . . . . Rosario and Balaoan
b) Pangasinan . . . . . . Urdaneta and Magaldan
c) Nueva Ecija . . . . . Sto. Domingo and Gapan
d) Bulacan . . . . Baliwag, Sta.Maria, and Pandi
e) Batangas . . . . Tanauan
f) Camarines Sur . . . Iriga City and Nabua
g) Laguna . . . . Cabuyao
h) Iloilo . . . . San Miguel and Tigbauan
i) Misamis Oriental . Cagayan de Oro
j) South Cotabato . . Koronadal
k) Davao del Sur . . . Digos

Extension technicians. All rice, corn, and vegetable technicians in the selected pilot areas were converted to multiple cropping technicians. All were brought to Los Baños for a short training that covered such topics as multiple cropping technology, techniques for introducing to farmers the multiple cropping technology, and integrated credit and marketing schemes.

Credit. Farm credit in the Philippines comes essentially from two sources: the Philippine National Bank, a government-controlled corporation which operates many branches all over the country; and the rural banks, which are small private banks. For participating in the crop production programs, the banking institutions, especially the rural banks, are heavily subsidized by the government.

Two credit schemes were implemented in the multiple cropping pilot areas. The first is the same as that in the existing commodity program, in which the farmer applies for a separate loan for every crop. All farmers borrowing from the Phillippine National Bank use that credit scheme.

The second scheme involves rural banks which the Central Bank has authorized to implement the integrated agricultural financing scheme (IAF). Farmer borrowers are granted a credit line for 1 year for the production of a duly approved cropping pattern. A farmer borrows only once for all the crops he will grow in a 1-year period.

To familiarize rural bankers with their role in the new credit scheme, the top administrators of each bank in the pilot communities were brought to Los Baños for a week of training in the multiple cropping technology and the integrated agricultural financing scheme.

Markets. One of the most important requirements for increasing farmers' income is a market for additional farm products. Such a market is insured in two ways. First, the production technician sees to it that only crops with a good chance of being marketed are included in the farmers' plan. For example, on farms far from roads and market outlets, the nonperishable grain crops are suitable. In the more accessible areas, more vegetables may be grown. Second, marketing schemes are prearranged with the Food Terminal Market (FTI) and the National Grains Authority (NGA). NGA is the primary buyer of rice, corn, sorghum, soybeans, and mungo, and FTI is the primary buyer of other agricultural products.

Monitoring system. An efficient reporting system to monitor the status of the program at any given time is essential to any national program. It is more so in the present case because of the program's experimental status. The monitoring system for the project is divided into three parts:

1. A listing of farmer-cooperators. Each technician is required to assist 75 farmers in his area. His first task, therefore, is to list each cooperator, and to describe the area of the cooperator's farm, his tenure status, and his projected cropping pattern.

2. A monthly report. Each technician is required to submit a monthly record of crops planted or harvested and money borrowed or paid by each cooperator.

Table 1. Characteristics of 341 extension technicians trained in multiple cropping in early 1976.

Characteristic	Pilot municipality				Average
	Pampanga	Central Luzon	Bicol and Southern Luzon	Visayas and Mindanao	
Trainees (no.)	189	76	31	45	–
Female (%)	24	28	55	27	28
BS degree holder (%)	92	89	90	96	92
Years in service					
< 1 year (%)	15	27	6	26	19
1–5 years (%)	28	41	38	43	34
> 5 years (%)	57	32	56	32	47
Barrios (no./technician)					
Before training	3.79	3.89	5.67	2 73	3.84
After training	1.05	2.44	2.35	2.28	1 60
Cooperators (no./technician)					
Before training	133	91	75	127	116
After training	80	69	66	83	76

3. A benchmark survey. A 10% random sample of the listed farmer-cooperators were interviewed by the project staff. Information was sought on family size, land area, household and farm equipment, and crops grown in previous years. The survey provides benchmark information and a random check of the technician's list of farmer-cooperators.

Program status on 31 August 1976. *Extension technicians.* Between January and April 1976, 341 technicians were trained at UPLB. Table 1 shows their profile.

Farmer-cooperators and cropping patterns. After training, the technicians must identify their farmer-cooperators and decide on cropping patterns for the coming year. Their reports by region are summarized in Tables 2 and 3.

Table 2. Workload of technicians in the Multiple Cropping Program.

Pilot municipality	Technicians (no.)	Barrios per technician (av no.)	Cooperators per technician (av. no.)	Supervised area (ha)
Pampanga	258	1.05	80	46,925
Central Luzon	102	2.44	69	8,740
Bicol and Southern Luzon	34	2.35	66	3,137
Visayas and Mindanao	47	2 28	83	8,055
Total	441	1.60	76	66,857

Table 3. Proposed cropping patterns in the program areas.

Cropping season	Projected area (ha) by crop				
	Rice	Corn	Other grain crops	Other crops	Total
			Visayas and Mindanao		
May to August	3,690	2,100	28	17	5,835
September to December	1,790	2,600	716	85	5,101
January to April	600	2,100	400	198	3,298
Total	6,080	6,800	1,144	300	14,234
			Southern Luzon		
May to September	2,200	500	–	81	2,781
October to March	1,700	500	45	600	2,845
Total	3,900	1,000	45	681	5,626
			Central and Northern Luzon		
June to October	8,200	60	65	90	8,415
November to February	5,000	250	830	1,120	7,200
March to May	500	400	200	320	1,420
Total	13,700	710	1,095	1,530	17,035
			Pampanga		
June to September	41,325	794	309	153	42,581
October to January	29,190	1,590	4,122	2,485	37,387
February to May	13,050	4,302	1,340	2,890	21,582
Total	83,565	6,686	5,771	5,528	101,550
Grand total	107,245	15,196	8,055	8,039	138,445

Benchmark information. Interviews with sample farmers from Visayas and Mindanao have just been completed. The interviewer team is now in Central and Northern Luzon. Benchmark data should be completed before the end of September 1976. In March 1977 the sample farmers will be revisited and asked the same questions. It is hoped that the differences between their current responses and those of next year will indicate the impact of the program.

Monitoring and data management. Each technician is required to submit a monthly report of the status of his farmer-cooperators on the third day of the succeeding month. That report is summarized at the computer center of the Department of Agriculture. As determined through that reporting system, the areas planted as of 31 August 1976 are shown in Table 4.

SUMMARY

To intensify land use and to rationalize the organization of her extension system, the Philippines in late 1975 initiated a national program for multiple cropping in selected municipalities. The main feature of the program is the integration of existing production programs in three directions. First, crop

Table 4. Status of crop production in the Multiple Cropping Project, 31 August 1976.

Region	Area planted (ha)				
	Rice	Corn	Other grain crops	Other crops	Total
Visayas and Mindanao	2,510	2.613	11	10	5,144
Southern Tagalog	2,680	581	–	99	3,360
Central and Northern Luzon	8,856	98	23	38	9,015
Pampanga	23,203	–	–	4	23,207
Total	37,249	3,292	34	151	40,726

production technology was converted from a single-crop approach to one that emphasizes cropping system technology. Second, credit was modified from its single-crop orientation to one that covers all crops to be grown within a single year. Third, the responsibility of each extension technician was modified to cover not only a single crop but all crops to be grown by his farmer-cooperators.

On 31 August 1976, the program had 441 technicians working with 33,700 farmer-cooperators on 66,800 ha. By the end of May 1977, we should be able to evaluate the program in terms of

1. productivity and income of, and intensity of land use by farmer-cooperators;
2. repayment of crop loans; and
3. reaction of technicians and farmers to the new extension setup.

DISCUSSION

BANTA: You helped the market system in the six barrios. Could you define what the most important factors are that have been carried over to the expanded program, or what changes were made?

A. Gomez: In the original pilot barrios, the market was improved in two ways. First, we tried to expand demand for agricultural products by motivating large food-manufacturing companies in Manila to buy from our pilot barrios. Second, we tried to produce products with available markets. We have followed essentially the same guideline in the expanded program. That is made easy by the existence of a minimum price for grain crops such as corn, sorghum, soybean, rice, and mungo. For those crops, the government has guaranteed the farmer a minimum price for any amount of the product. Consequently, our instructions to our technicians are these: When market outlets are difficult, grow the grain crops: produce crops without guaranteed price only if a reliable market has been identified.

GINES: I am very interested in knowing how you were able to liberalize credit for your farmer-cooperators. Will you please tell us how you accomplished this and what degree of success you had.

A. Gomez: In the original pilot communities (six barrios in Laguna and Batangas), we deposited in the local banks under the name of the project a given amount of money which was used as collateral for loans granted to farmer-cooperators. We executed a contract with the local banks which allows them to deduct from our savings deposit an amount equivalent to unpaid loans. For the larger project, a similar procedure is followed, except that the guarantee is now handled by the Central Bank of the Philippines.

ZAN: Is there any relationship of the planned cropping system and cropping intensity to irrigation or rainfall patterns?

A. Gomez: Most rules that we prescribe to our technicians in identifying cropping patterns are directly related to water supply either from irrigation or rainfall. For places with a short rainy period, only two crops per year are prescribed. For areas with longer rainfall or with supplementary irrigation, the recommended cropping pattern usually involves three crops.

SIKURAJAPATHY and SMITH: How does the production program relate the existing realities, in terms of the institutions and personnel in other areas (that is, in those areas which do not come under the production program)?

A. Gomez: There are a little more than 34,000 barrios in the whole country. There are approximately 7,000 production technicians that are actively participating in our crop production programs. Thus, we can figure on an approximate ratio of about 1:5 technicians to barrios. In addition, most of these production technicians have about the same level of education as those in the program areas. We are, therefore, quite confident that the expansion of the present program area will not unduly tax the capability of the government.

HOQUE: What happens to your production program if you remove the credit component from it?

A. Gomez: At least 25% of our farmer-cooperators are currently without credit. They are cooperators who have not completely liquidated their previous loans, and are therefore using their own resources to implement an improved pattern. My feeling is that if a farmer is convinced of the merits of a new technology, he will try his best to satisfy its requirements. Thus, to answer your question directly, the program would probably be harder to implement without credit, but I do not think it would be impossible.

RIKKEN: In your multiple cropping program research, are you also evaluating program impact on employment and income distribution?

A. Gomez: We are looking into the effect on employment in terms of the labor requirement of some cropping patterns. In terms of income distribution, we feel that we are working with the low-income group and that an increase in income among them would improve income distribution. At the end of the program, there should be enough data to look into this aspect in greater detail.

MAGBANUA: Inasmuch as your national multiple cropping program went directly into the production phase without preliminary testing of a cropping pattern, how do you formulate the patterns in areas where previously no stable research results have been evolved ?

A. Gomez: Very definitely the patterns we are using in the program areas have gone through adequate testing. As you know, the International Rice Research Institute has been testing cropping patterns for the last decade. The University of the Philippines at Los Baños has been doing the same kind of work, and government research agencies such as the Bureau of Plant Industry and Bureau of Soils have been doing extensive testing of new cropping patterns in farmers' fields. We have also done the same in our pilot barrios. We have definitely used these results in formulating cropping patterns in the project areas.

PRICE: If you have not already stated them, what factors will be examined 2 years from now when you evaluate the program?

A. Gomez: As I have mentioned, we will examine our six pilot barrios two years from now. The evaluation will be based on income and nutritional status. Those are the two criteria we have used in the baseline survey and in the second and fourth years of evaluation.

SEETISARN: What is good for one farmer is not necessarily good for the whole group of farmers. Your statement is similar to what is often said: What is good for General Motors is good for the United States. In most cases, when production increases, price will decrease. Without a price-support program, your program will not get the same result. The price-support scheme amounts to a measure which redistributes income to farmers in the program but at a cost to society.

A. Gomez: It is true that the benefits to a farmer do not necessarily coincide with those to society. We feel, however, that the initial social cost of subsidized market and credit will be easily repaid by increased purchasing power and improved income distribution if the production program succeeds.

VILLAREAL: In your original pilot area of six barrios, you mentioned that credit to a barrio was increased from 0 to ₱250,000/barrio. The questions are 1) Who provided the credit? 2) With credit given to a farm enterprise rather than to a commodity, how long does it take for a cooperator to get his loan? Is the loan in kind or in pesos?

A. Gomez: Credit was primarily provided by the local rural banks. About one-fifth of the loans were guaranteed by our deposit (as mentioned in previous answers), while the others were granted on the strength of guarantees from other sources.

One objective of giving a single loan to the whole farm enterprise is to reduce paper work. One loan will take from 2 days to 1 week to complete. Since the farmer applies for a single loan for all the crops he grows within a year, this time is not too long. Note further that the proceeds of the loan are given to the farmer on a staggered basis at the time when the crops need the input. A large fraction of the loan is received by the farmer in the form of material input instead of cash.

VILLAREAL: I think even with proper motivation of your technicians and good follow-up of your program it will not be as successful if you don‘t give your technicians adequate financial support.

A. Gomez: Indeed it is true that financial benefits are a very good source of motivation. Our production technicians are now probably among the highest paid government employees in their area of assignment. This is so because technicians get additional income on top of their basic salaries. The additional income comes from the following: a) incentive allowance directly from the government, b) incentive pay for every borrower a technician successfully delivers to a local bank, and c) transportation allowance. In addition, many technicians have motorcycles which they have purchased on very easy credit terms, arranged for them by the government.

ZANDSTRA: (1) What level of flexibility do technicians have in specifying patterns and input level? How do you achieve sufficient flexibility without losing guidance towards a desired type of production technology. (2) On motivation: Can technicians identify with their zone of responsibility?

A. Gomez; We are handling in this program 17 species of annual crops. For every planting season, we specify a subset of these 17 species that can be grown in a given geographical area. This rule eliminates from the technician’s choice all patterns that are not suited for his area. On the other hand, there are usually about 15 or more allowable patterns from which the technician can choose. We have instructed all our technicians that the choice of the final pattern to be used on a given farm should be made in close consultation with his farmer-cooperator.

While most of the technicians’ areas of assignment have undergone some degree of modification, we have exerted effort to see to it that their new areas are within the vicinity of their previous assignments. Consequently, familiarity with people and places, which they have developed in previous years, is not totally lost. In fact, we feel that the reduction in the areas of their assignment will redound to an intensification of their feelings of identity with given groups of farmers.

NORMAN: I was intrigued by the criteria you are using in evaluating the success of your project. You are using, among others, land intensity index, profit, and production per unit area. Four sample questions: 1) Are you looking primarily at success for the farmer rather than for society? 2) Two criteria relate to land. Is the population density in the area such that land is more limiting than labor? 3) Is there always consistency in your conclusions concerning success with the criteria you are using? 4) Do you consider low variability in profit an important criterion for success? Is this implicitly being taken into account in your criteria for success?

A. Gomez: We are looking primarily at the success of the farmer, for his success will eventually result in a better society. We feel that the cost to society of such features as price support and subsidized credit will be more than compensated for by the benefits from improvements in farm-family incomes due to increased farm output.

The population density in most of the project area is high and land, not labor, is the more limiting resource.

One purpose for using different performance criteria is to bring out possible conflicts among different program objectives. We feel that subsequent policies will be greatly enriched by recognizing these inconsistencies rather than by ignoring them.

Low variability in profit is, indeed, an important criterion for evaluating new production technology. We have not used it as a major performance criterion because of certain operational difficulties, such as very variable prices and nonrepetition of certain cropping patterns over time.

SAMSON: Don't you think a year is a short time in which to evaluate the project in this national multiple cropping programs. Cropping potentials might be affected by climatological factors such as drought, flood, etc. within this 1-year period.

A. Gomez: Indeed, 1 year might be short. On the other hand, we had 5 years of experience in a small area before going into the expanded program. Nevertheless, we shall carefully evaluate the performance after 1 year, and if there is pressing need for extension, we shall probably extend the period.

PATANOTHAI: What are the main problems you encountered in implementing the program?

A. Gomez: While I have not talked about problems in my paper, there are indeed compelling problems in a program of this type, Our biggest problem is related to people rather than to technology. How can we motivate more than 400 technicians to do the job that is expected of them? As you know, many of these technicians, by virtue of the location of their areas of assignment, must operate on their own initiative. Their effectiveness therefore, greatly depends upon their personal motivation. Because of the importance of motivation, we are currently trying, on a small scale, to put our technicians through a training course that puts more emphasis on motivation than on technology.

Another closely related problem is a system of monitoring and follow-up. Any national program worth the name must be able to follow field performance closely both in production accomplishments and in personnel efficiency. The best source of motivation among government workers is a reward system that identifies the most deserving workers. This can be done only through an efficient monitoring system. For this project we have hired five full-time supervisors whose main task is to visit and confer with all project personnel at least once a month. They also collect reports on farm activities which are fed into a computer in Manila for quick summarization.

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