METHODS FOR THE EXTRAPOLATION OF CROPPING SYSTEMS TECHNOLOGIES

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Agricultural environments in the humid and subhumid tropics have very high spatial complexity. Efforts to classify this variability into homogeneous ecological units to facilitate the transfer of technologies across geographical areas, encounter serious constraints. It is not difficult to identify mappable criteria that will separate farm areas into distinct units. However, it is challenging to specify the relevant criteria that influence the adaptation of particular technologies, and to use the spatial data that is available to make efficient extrapolation judgements. This activity is often constrained by limited data and insufficient knowledge of how the data can be used.

The need for simple, reliable methods to extrapolate cropping systems technologies has been recognized for many years (IRRI, 1976; Morris and Zandstra, 1979). Magbanua and Morris (1980) observed that given the state of present extrapolation methododology, and the limitations of the potential users, the data will often be "soft", analytical procedures cannot be too complex, and judgement will be an important factor in the validity of the final product. Recognizing these constraints, they proposed a generalized routine for defining target areas for cropping systems projects (Figure 1), incorporating the steps of data inventory, criteria determination, spatial and temporal analysis, interpretation, and target area delineation. This was applied to the extrapolation of rainfed rice cropping pattern potential in Iloilo Province, Philippines.

Gomez and Gomez (1983) identified environmental classification as one of the three major research activities in cropping systems, the other two being the generation and verification of technologies. They estimated that large increases would result in the efficiency of technology generation and verification if a considerable investment were made in environmental classification research. In reality, it appears that the relative resource allocation to environmental analysis activities in most agricultural research institutions is a very small proportion of the whole.

<u>Scales of analysis</u>. The issue of mapping scale is one of major importance in environmental classification. Extrapolation questions need to be addressed at scales ranging from that of the field research site all the way up

to the international sphere. Therefore, environmental analysis for extrapolation may be carried out at four levels. Each level is unique in the specificity of information involved, and the types of questions that can be answered.

1) The mega level[1/]. This level includes studies across countries where "maga environments" are delineated at mapping scales of about 1: 5 million. Examples are the Agroclimatic Maps of SE Asia (Huke, 1982), the FAO agroecological studies, and the IRRI Rice Ecosystems Geographic Database (Garrity and Agustin, 1985, 1986; Garrity et al 1986).

2) The macro level. This includes extrapolation studies conducted at the level of an entire country. The mapping scales are generally about 1: 1 million. Examples are the extrapolation of double-crop rainfed rice in Bangladesh (Naseem et al 1987) and in the Philippines (Angus 1989).

3) The meso level. This includes work at the regional level within countries, with mapping scales of about 1:100,000 to 1: 250,000. This is the level of extrapolation from a research site to the surrounding agricultural areas, eg. Magbanua and Morris (1985).

4) The micro level. These studies characterize environmental variation at research sites, villages, or village clusters. Mapping scales may vary from 1: 5000 to 1: 25000.

Improved analytical tools. Microcomputers have now emerged as common equipment at agricultural experiment stations and extension offices in the developing world. Their appearance dramatically enhances the ability of agricultural scientists to analyze and interpret variation in the farm environments.

This paper discusses two methods of technology extrapolation which employ the microcomputer in contrasting ways. The first method uses an interactive simulation model of the water balance of rainfed fields and of the growth of rice to derive an estimate of the long-term production levels and stability of rice double-cropping in selected locations throughout an entire country (ie. macro level).

The second method employs the geographic database management capabilities of the microcomputer to assemble and

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[1/] The authors thank Dr. V.P. Singh for his contribution in distinguishing this level of analysis.

analyze landform, soils and climatic information for all mapping units in a rainfed rice growing region within a country (ie. meso level), and to assist in specifying the recommendation domains for more intensive rice-based cropping systems for each mapping unit.

ESTIMATING CROPPING PATTERN POTENTIAL ACROSS ENVIRONMENTS WITH SIMULATION MODELS

Simulation models are a recent tool in environmental analysis. The first work to apply the use of computer simulation to estimate the productivity and stability of Asian rice-based cropping systems was published in the mid-1970s (Paris, 1976). By the late 1970s modeling of the water balance of rainfed lowland rice became an active area of investigation at IRRI (Angus and Zandstra, 1978; Zandstra et al. 1982; Bolton and Zandstra, 1981a, 1981b).

Bolton and Zandstra demonstrated the practical utility of simulation in defining the extrapolation domain for double-crop rainfed rice. They determined the stability of rice-rice and rice-upland crop patterns for several locations in Iloilo Province.

Simulation methods have continued to evolve in recent years. We will discuss two new developments that expand the practical utility of water balance/crop growth models for extrapolation:

1) The development of user-friendly interactive microcomputer programs that enable researchers or production technicians to conveniently estimate cropping pattern productivity.

2) The use of simulation to map the rainfed rice double-cropping potential on a nationwide basis.

POLYCROP: An interactive water balance simulation model

In rainfed wetlands the productivity of different cropping systems is primarily determined by the water supply. The development of short-duration crops enables multiple cropping to be extended to areas where it has not previously been practiced, but in rainfed conditions more intensive cropping systems entail a greater risk of drought stress than do single-crop systems. The risk of drought must be evaluated in relation to the additional production normally expected from double-cropping. Such an evaluation cannot be conducted on the basis of only a few years of experiments because each year only provides one observation.

The longterm opportunities for multiple cropping can be evaluated by a simulation model of crop growth in relation to the water balance. The POLYCROP model, developed by Angus, Garcia, and Stein (1987), is a user-friendly interactive microcomputer program to calculate the water-limited yield of rainfed crops grown in sequence. It was adapted to enable researchers and production technicians in the Philippines to test the productivity of rice-based cropping patterns in relation to changes in the number and types of crops grown, and in relation to changes in management factors, eg. crop turn-around time (Garcia 1987).

The model is a tool to estimate the number of crops and the arrangement of crops which can be grown per year, and the stability of crop yield in relation to weather. The core of the model is a simulation of the water balance and growth of a rainfed rice crop (Figure 2). The parameters of the model were calibrated with data from Bolton's (1980) studies in Iloilo, and validated against independent data from the PHARLAP project in Antique.

Data requirements. The model can be applied to both upland and lowland rainfed fields. It requires five types of input data: 1) daily rainfall, 2) weekly potential evapotranspiration, 3) soil characteristics, 4) cropping sequence, and 5) crop characteristics. Input variables include the number and types of crops to be planted within a crop year, and the crop phasic development (days to anthesis and maturity), maximum root depth, maximum percentage foliage cover, and crop water use efficiency.

The model has built-in data files that contain daily rainfall data for 104 stations in the Philippines. Evaporation data was obtained for 29 locations from estimates by Tamisin (1977) based on the Penman equation. Since measured evaporation data is not widely available, the method of Wahba (1979), as applied by Hutchison et al (1983, 1984) was used for the remaining 75 rainfall locations where there were no previous estimates. Weekly mean rates of evaporation were calculated from the monthly values (Boor, 1978). The soil characteristics that need to be specified are the infiltration and seepage rates, the percent soil water at the saturation point, field capacity, and wilting point.

User output. The model output consists of the crop yields, estimated evapotranspiration, sowing date, and harvest date. A printout of the interactive dialog of a simulation session is shown in Attachment A, along with an example of the input data and results. On page 5 of the Attachment the productivity of the crops in a 3-crop pattern are given for a three year simulation experiment in Iloilo Province. The test pattern was Direct-Seeded Rice-Transplanted Rice-Mungbean (DSR-TPR-Mung).

The 3-crop pattern was possible only during 1976-77 and 1978-79. During the 1977-78 crop year, the rainy season ended early and the only crop that could be grown was a single crop of rice.

Nationwide Extrapolation of Rainfed Rice Double-Cropping Potential

Angus (1989) has applied the POLYCROP model to assess of the longterm productivity of single and double-crop rice in rainfed conditions throughout the entire Philippines. The model was run on longterm rainfall data for 103 locations, simulating the hydrology of a plain toposequence position. Simulated yields for a single crop of wet-seeded rice were similar over much of the Philippines (Figure 3). This reflected the fact that water supply is usually not limiting during the the middle of the rainy season. However, the potential for successfully producing double-crop rainfed rice varied greatly from region to region (Figure 4). The percentage of years in which two wet-seeded rice crops could be simulated varied from less than 10 percent to greater than 80 percent of the years simulated among the locations. In most major rice-growing areas rainfed double-cropping was successful 60 to 80 percent of the time. Simulated yields for the total production of a double-crop pattern were estimated to range from less than one to over eight tons per hectare (Figure 5). Total yields were frequently 5 to 6 t/ha, reflecting the significant proportion of years in which two crops were not possible.

These simulation experiments raise many practical hypotheses concerning future research and extension efforts on rainfed double-cropping in the Philippines. They assist in building a scientific understanding of rainfed double-crop potential on a nation-wide basis. When the model is further refined, and evaluated against field experimental data at sites throughout the country, it can be used in many additional types of studies. It adds a considerable degree of refinement to the extrapolation of rainfed cropperformance compared to that done solely on the basis of general soil and climate maps.

Simulation Networking

The application of simulation modeling to rice-based cropping systems has recently expanded to many countries in Asia. The Centre for Agrobiological Research (Netherlands) and IRRI are cooperating in the development of detailed models for rice and legume crops, and their application to a number of research problems (Penning de Vries et al, 1987). Fourteen teams of scientists from seven countries have trained in the use of these models. A network of national program teams is now developing (Penning de Vries et al 1988).

USING LANDFORM CLASSIFICATION AND GEOGRAPHIC DATABASES TO IDENTIFY EXTRAPOLATION DOMAINS

New tools to organize, manipulate, and interpret geographic data onòagricultural ecosystems are also emerging. These methods will facilitate the communication of spatial data among researchers and extension specialists. This section discusses our recent experience in developing and applying a geographic database for rainfed ricelands using landform classification as the basis.

IRRI and the Department of Agriculture of the Philippines began collaborative research in 1980 to develop more intensive cropping systems for rainfed drought and submergence-prone ricelands in northern Luzon island (figure 6). In these unfavorable rice-growing conditions the surface hydrology is highly variable.

<u>Landform analysis</u>. Within the domain of a relatively homogeneous rainfall regime, the landscape and soil characteristics determine the variation in surface hydrology, and consequently the type and productivity of the agricultural enterprises. Recognizing the importance of landform in understanding cropping pattern potential across a diverse landscape in the Cagayan River Valley, Bruce and Morris (1981) proposed a land classification system to be used in extrapolating research results within the valley.

The classification was initially used by the research team to target research on the major landscape units, and to help interpret experimental results. For example, Lara (1984) and Kim (1985) used landform analysis in their research site stratification.

The classification was structured into four hierarchical levels: The Land System, Land Subsystems, Landform Unit, and Land Surface Unit, in order of increasing specificity. Figure 7 illustrates several landform units and their spatial relationships. Lowland rice is grown on 17 of the landform units within the four land systems. Three of these landform units,viz. alluvial terraces, interhill miniplains, and interhill basins comprise about 95 percent of the 175,650 ha in the alluvial land system. These three landform units have been nearly fully developed for rainfed or irrigated rice production.

<u>Results of on-farm systems research</u>. Cropping pattern research was conducted for five years at on-farm research site located on the most common landform unit in the valley, the alluvial terrace (Morris 1987). This landform unit was

subdivided into three specific land surface units. These correspond to relatively small areas having common relief and a high degree of homogeneity in the factors related to crop performance.

The predominant cropping pattern in the rainfed portion of the alluvial terrace (about-two thirds of the total areas) was a single transplanted crop of a tall traditional photoperiod sensitive rice variety (Gines et al. 1984). Double cropping of rainfed rice with modern cultivars was found to be infeasible due to the highly unstable rainfall pattern during the early months of the monsoon, and the frequent correct of crop submergence during the high rainfall months of September and November.

Medium-maturing improved cultivars have now been identified which can increase the productive potential of the single crop system (Agustin and Garrity 1988; Pernito et al. 1988). Recent work has also developed a more stable pre-rice management system for mungbeans using simple ridges for surface drainage to prevent waterlogging (Pernito and Garrity (1988).

Pre-rice mungbean cropping, however, is limited to the higher elevation land surface unit (facet 1) of the alluvial terrace landform, where drainage is better. In the lower elevation land surface units, the only pre-rice crop with potential is a waterlogging tolerant green manure, Sesbania rostrata (Baquiran and Garrity 1988).

Recently, cropping pattern research has been extended to four other landform units on which rainfed rice is important. The current rive varieties, cropping patterns, and crop management practices used by farmers have been determined, and tentative recommendations developed for further crop intensification.

Extrapolation analysis. To explore the utility of the land classification in extrapolating rainfed cropping pattern recommendations from the research sites to the surrounding lands of the valley, Agustin and Garrity (1987, 1988) characterized the hydrology of two representative locations in each of the five main landform units cultivated to rice. We identified typical land surface units (which we term land facets, after Thomas 1969) within each landform, and obtained hydrographs of the surface water regime to compare and classify them.

Based on the above studies, IRRI and the Department of Agriculture initiated in 1987 a study to define the extrapolation domains for rainfed rice cropping systems technology in the northern Cagayan Valley. The major objectives were to develop: (1) a set of maps whose mapping units correspond to Rainfed Land Types, unique combinations of landform/hydrology/soils that define cropping pattern extrapolation zones and (2) a geographic database on a microcomputer that contains all the available environmental data for each mapping unit. Computerization of the database is not essential, but it adds flexibility and speed in analysis, interpretation, and updating.

The end product envisioned is a set of large-scale maps in booklet form for the convenient reference of agricultural extension technicians. The maps, each at a scale of 1:25,000 and covering the approximate area served by each technician, will relate each mapping unit in his service area to the most up-to-date recommendations concerning rice cultivars, crop management practices, and cropping patterns. A copy of the computer database will be included in the extension manual to make all data on soil fertility status, drainage characteristics, landform classification, and climatic data available for quick reference in a standard format. This will enable convenient detailed comparison of the characteristic of different mapping units.

The first phase of the project was targeted to five contiguous municipalities where the major research site is located (Figure 8). The rice-growing areas were identified on recent large-scale topographic maps. Rainfed and irrigated land classes were differentiated using current maps from the National Irrigation Administration. The comparative distribution of rainfed and irrigated land is given in Figure 9.

The administrative boundaries for all barangays in the five municipalities were then placed on the maps. For convenience in database development the real extent of individual mapping units were confined within barangay boundaries. The soil series (Bureau of Soils, 1982) were then mapped onto copies of the topo maps. Soil fertility class (NPK status) and drainage class were specified and mapped. Sites for which soil analytical information was available were placed on the map. Using the topographic information contained on the 1:25,000 scale maps, and field observation, the landform units and land facets were delineated.

The overlay of all the above factors onto the same map enabled the identification of several hundred unique mapping units. Each mapping unit contained a contiguous area with the same values for all the determinants. A computer database was then assembled, containing all of the data from the overlay maps and site characteristics (Table 1).

A set of seven characteristic Rainfed Land Types were identified by correlating the landforms, soils, and hydrology with crop adaptation from research at 12 research sites. These land types are characterized in Table 2. The land types are arranged in a general order from relatively favorable to unfavorable surface hydrology. The predominant cropping pattern in each land type was identified, and a suggested cropping pattern was determined on the basis of current knowledge. The area distribution of the respective land types is shown in Figure 10.

The most favorable rainfed land type was composed of alluvial fans and interhill miniplains with large watersheds. These land units have relatively long hydrological years due to extended surface water flow and interflow from the elevated catchment areas above them (Figure 10). Land type II has an extended hydrological year but experiences periodic short-term crop submergence. These are the only rainfed land types with the potential for the double-cropping of rainfed rice.

Land types III through VI are unfavorable rainfed, with variation in the type and degree of hydrological stresses. The cropping pattern is composed of a single crop of a traditional photoperiod sensitive rice cultivar.

A short hydrological year, and frequent severe drought stress during the rice growing season, are similar characteristics of land types III and IV (Figure 10). A cropping pattern composed of a pre-rice upland crop followed by transplanted rice is feasible in most years. Mungbean is currently the most appropriate upland crop for this pattern, since very early duration (60 d) is essential. Waterlogging is a serious threat to upland crop production because of limitations in surface and internal drainage. Therefore, the ridge planting technology is needed to ensure yield stability (Pernito and Garrity, 1988). The appropriate rice cultivar for land types III and IV is an intermediate height, medium maturity improved variety. Land Type IV differs from III in experiencing periodic submergence and rarely, deep flooding.

Land types V and VI are highly prone to severe crop submergence and prolonged flooding. Crop intensification will be difficult for rice or upland crops. Tall, photoperiod sensitive rices continue to demonstrate advantages in production stability over improved insensitive types. Five of the six rainfed land types are observed within the municipality of Solana (Figure 11). The map in Figure 11. The map in Figure 12 shows their spatial distribution.

<u>Future work</u>. The classification of rainfed land types, and their correlation with on-farm cropping systems research, has enabled the development of a microcomputer database and maps of the extrapolation domains for current cropping pattern technology. We are currently verifying the classification over a wider area in five municipalities,

with a view to eventual extension to the entire lower Cagayan Valley. One present challenge is to develop practical extension products for effective use of this information.

A number of methodological problems were identified. The delineation of the boundaries of land facets if often gradual. Differentiation of landforms can sometimes be difficult because there are no simple quantitative boundary distinctions specified in the classification. Judgement and experience are needed and these vary among practitioners.

Climatic differences and socio-economic variation will need to be incorporated in the delineation of mapping units, particularly as the geographic coverage expands. Objective methods for characterizing the relevant aspects of the spatial differentiation of rainfall patterns are needed.

<u>The practicability of landform analysis</u>. From our experience in integrating the concepts and terminology of land classification into the on-farm research program, we observed that site-based agronomists who have limited training in geomorphology or soil survey can still productively utilize them. By employing the land classification as a tool in interpreting landscapes we found that the precision of communication among site researchers concerning rice varietal and cropping pattern adaptation to the diverse rainfed environments in the Cagayan Valley, increased substantially.

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