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COMPARATIVE ANALYSIS OF CROPPING SYSTEMS: AN EXPLORATORY STUDY OF 14 RAINFED SITES IN THE PHILIPPINES

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ABSTRACT

Cropping systems adaptation to environment has been identified as an important study area in cropping systems research. A substantial body of supply response and adoption studies have analyzed changes in cropping and agricultural systems over time; however, comparative analyses using quantitative approaches are rare. This study discusses the application of a number of multivariate statistical techniques used to explore relationships between cropping systems and the biophysical and socioeconomic environment. Commonly used multivariate techniques such as single equation regression models are inadequate to analyze complex systems relationships involving interdependencies. Factor analysis and discriminant analysis can overcome some inadequacies. In future studies, careful specification of hypotheses by interdisciplinary teams regarding system x environment relationships would be desirable.

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Farms are systems. They also are subsystems of wider regional systems and are composed of subsystems, such as cropping systems and livestock systems. Cropping and livestock also may consist of subsystems. Farms differ from purely physical or biological systems because they are goal-oriented -- farmers strive to attain certain objectives within constraints imposed by resources, technology, and environmental factors (Ruthenberg 1976).

Adapting cropping systems to environment is a dynamic process rooted in the interaction of higher and lower order systems. Environment, technology, and farm resources all change over time, sometimes rapidly, and sometimes slowly. Where a state of relative environmental and farming system stability has persisted over long periods, we can observe complex farming and cropping systems that are highly adapted to the environment. However, recent history, particularly the last century, has seen tremendous external pressures on farming systems in all countries of the world. These pressures have caused major changes. In the humid tropics of Asia the impacts of colonization, plantation economies, cash cropping, and monetization of economies have made near self-subsistent village communities integral parts of national and international economies.

For researchers seeking to generate technology to develop more productive farming systems, a systematic analysis of these processes and an understanding of the principles underlying them are vital. A major research objective of the Asian Cropping Systems Network (ACSN) has been to develop this understanding by analyzing experiences at many sites (Zandstra 1977). The dimensions of the process are substantial and complex, and research studies involve biophysical, socioeconomic, and historic-cultural factors.

Two complementary approaches can define these principles and help identify the major determinants of farming and cropping systems. One approach is historical -- it analyzes changes in farming systems caused by factors over time. The response of small farmers to economic stimuli and the ways they have changed traditional systems and adopted new practices, crops, and market relationships have been extensively documented (for an early literature review, see Wharton 1969). Quantitative analysis has provided many supply response studies of farm products (see Lim 1975). These studies have demonstrated the economic rationality of small farmers -- they are shown to respond positively to opportunities for economic gains provided by new market forces and technologies. Many anthropological studies have analyzed and documented the complex processes involved when traditional systems are transformed and how transformation affects social, economic, and institutional structures at all levels (Berry 1975, Moulik 1974).

Such studies are limited because some environmental parameters do not change at a given site, making it difficult to understand or estimate the effects of factor changes and adaptations within a system.

The second approach, which complements the first, studies systems in different sites and environments and identifies major determinants and parameters of the adaptation process through comparative analysis. Such comparative analyses, with some exceptions (Ruthenberg 1976), are rare. Quantitative studies are almost nonexistent.

The scarcity of such studies has partially derived from the lack of adequate data sources and the problems of using quantitative methods when many interdependent and closely related factors, sometimes difficult to quantify, interact in complex ways.

However, if major relationships can be specified and quantified, researchers can further study system x environment relationships by using mathematical programming and computer simulation approaches. The latter enables the study of systems in simulated conditions by varying major environmental parameters in the models.

This study is an exploratory attempt to test and evaluate the feasibility of comparative analysis using quantitative techniques. This paper has two sections. The first outlines procedures we used to develop an agroeconomic profile of a site and describes major characteristics of farming and cropping systems. The second discusses multivariate statistical techniques we applied to analyze system relationships and how different statistical techniques enable researchers to analyze aspects and dimensions of multifaceted and complex systems.

Study areas

We chose 14 sites in 4 agroclimatic zones in the Philippines. The zones were chosen using the agroclimatic classification developed by Oldeman and Suardi (1977) which is based on the intensity and duration of annual rainfall. Months with less than 100 mm rainfall are dry months. Those with more than 200 mm are wet months. Sites are located in Laoag, Ilocos Norte (very dry); Iba, Zambales (dry); Tacloban, Leyte (very wet); and Aparri, Cagayan (wet) (Fig. 1). We chose sites where substantial wetland rainfed rice was grown and which

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were not served by major irrigation projects. Table 1 lists study sites and some of their characteristics.

Fifteen farmer respondents were randomly chosen from each site using a list provided by the village head or the Bureau of Agricultural Extension Office. Farmers were interviewed using a prepared questionnaire.

Data on farm characteristics such as farm size, number of parcels, cropping patterns, demographic information, and detailed input-output data for the largest or most important wetland rice parcel in the farm were gathered. We did not obtain detailed data for all parcels and farm activities because of time and other resource constraints. Data, where time specific, related to the survey period. Systems adjust to environmental changes, but we found that no major changes in the farming systems had occurred during the recent past.

On all sites, crop enterprises dominated the farming systems. However, livestock raising was common. Farmers usually had a work animal (carabao), some poultry, and sometimes a pig. Livestock raising was a major income-earning activity only in Sitio Bunga, Zambales, an isolated, hilly site.

Farms were generally small. The ratio of produce sold to total production, often an indicator of the degree of subsistence orientation, varied. Farms in Ilocos Norte and Leyte were more commercialized. They sold more than 40% of their produce. Farmers in Zambales and Cagayan sold less than 20%. Except in the Leyte site, the farms cultivated annual crops, predominantly rice. In Leyte, coconuts, planted on dryland, represented a major part of farm area and production value. Share tenancy was significant in most sites, except in Zambales.

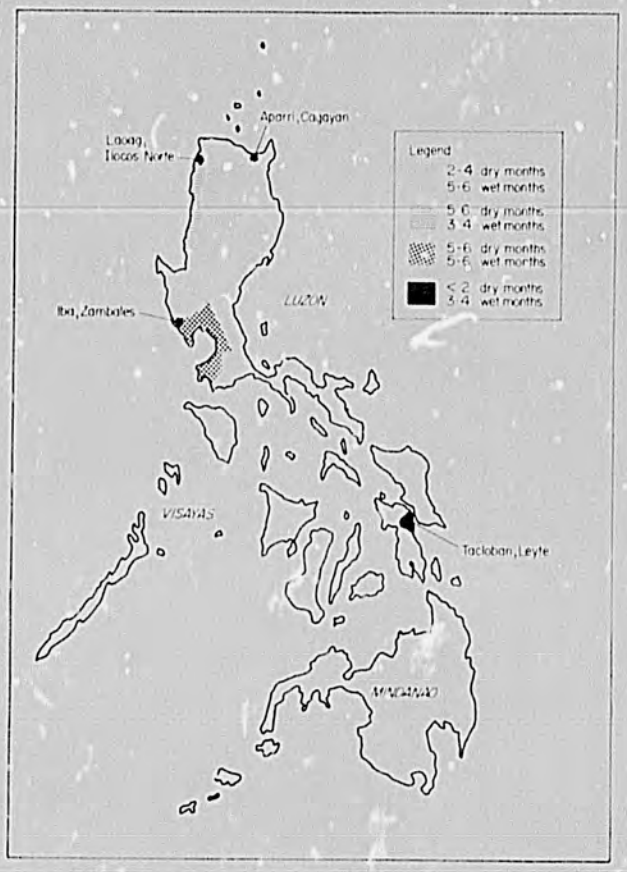

Fig. 1. Locations of research sites in the Philippines showing the number of wet and dry months.

Table 1. General physical characteristics of the study sites.

Site	Wet months[a] (no.)	Dry months[b] (no.)	% clay	Dominant soil pH range	Organic matter (%)	Topography	Transportation accessibility[c]
Ilocos Norte							
Rayuray	3-4	5-6	60.7	7.6	.89	Flat	3
San Lorenzo	3-4	5-6	53.1	7.2-7.6	.81	Flat	2
Nanguyudan	3-4	5-6	30.2	6.2-7.0	.77	Gently sloping	3
Pasil	3-4	5-6	27.2	7.6-7.8	.67	Gently sloping	3
Zambales							
Amungan	5-6	5-6	21.9	6.4	.60	Flat	1
Inhobol	5-6	5-6	9.4	7.2	.40	Gently sloping	2
Santa Rita	5-6	5-6	37.0	6.8	.89	Flat	3
Sitio Bunga	5-6	5-6	38.4	6.2	.88	Gently sloping	4
Cagayan							
Camalaniugan	5-6	2-4	22.9	6.6-7.0	1.25	Flat	3
Gattaran	5-6	2-4	47.7	6.1-6.3	.93	Flat	1
Leyte							
Dacay	3-4	<2	26.9	7.0	.99	Flat	3
La Paz	3-4	<2	25.4	6.2-6.3	1.13	Flat	3
Cabacungan	3-4	<2	33.8	6.0-6.1	1.49	Flat	3
Mayorga	3-4	<2	28.1	6.0-6.1	1.77	Flat	2

[a]Months with more than 200 mm. [b]Months with less than 100 mm. [c]1 = farms are situated along the highway, 2 = farms are situated less than 4 km from the highway or market and are accessible, 3 = farms are more than 4 km from the highway or markets and are accessible, 4 = farms are more than 4 km from the highway and markets and are not accessible.

Cropping systems

Figure 2 shows dominant cropping patterns in the agroclimatic zones superimposed on the annual rainfall pattern.

There are four major patterns: rice - fallow (single rice crop), rice - rice, rice - garlic or tobacco (high-value cash crops), and rice - upland crops (legumes, vegetables, etc.) (Table 2).

These patterns have changed little in the recent past. In Ilocos Norte, areas planted to garlic and tobacco have changed in response to relative profitability over the last 2 decades. Double cropping in rice in the very wet Leyte is related to the introduction of short-maturing varieties (IR36 was commonly grown).

These annual crops are major sources of cash income for farmers, except in Leyte where coconut is the cash crop (Table 3). Where rice - fallow is the dominant pattern (Zambales and Cagayan), rice is the staple food crop and major cash crop. In Ilocos Norte, small farm sizes do not permit farmers to produce a marketable rice surplus. However, highly resource-intensive, high-value cash crops (garlic and tobacco) are grown using supplementary pump irrigation.

Table 4 shows the rice production technology at the sites. Technology used reflects the influence of many factors. For example, Ilocos Norte farmers use the rakem (ani-ani type knife) to cut panicles that are then tied into bundles. Here, the relationship between different systems and the resource flows between rice and nonrice subsystems are important. Straw is cut close to the ground, bundled, and stacked for use as mulch in nonrice crops. Revenue from nonrice crops is used to buy fertilizer (farmers apply about 90 kg N/ha) for the rice crop, which is fully consumed in the household.

Land preparation machinery is most common in Cagayan where average farm sizes are comparatively large. Threshing machines are common in Zambales.

Farmers do not have difficulty disposing marketable rice surpluses. Tobacco and garlic, high-value, relatively nonperishable crops, can be either transported to market or sold at the farm gate. Perishables, such as vegetables, were not grown widely by farmers in the study areas -- no established marketing channels existed for rapidly transporting them to distant urban centers.

Off-farm and nonfarm incomes were most important at the Zambales sites, except in remote Sitio Bunga. Wage rates for major rice production operations showed minor variation across sites, perhaps an indication of the relatively high labor mobility observed in the Philippines. Hired labor use in rice production was common at all sites, particularly for transplanting and harvesting/threshing. Exchange labor was significant only in Sitio Bunga. The unimportance of exchange labor in almost all sites indicates the extent to which farming systems have become monetized. Credit is usually obtained from informal sources. Arrangements and interest rates vary greatly.

Role of supplementary irrigation

On rainfed rice-based farms, water availability limits crop production during dry season. The major sources of water are rainfall, water pumps, wells, and overflows from canals and creeks. Rainfall distribution enables farmers to grow a single rice crop during the year in all sites. Crops grown after rice depend on the type of supplementary irrigation available. In Ilocos Norte, especially in San Lorenzo and Rayuray, the water table is high enough that farmers can tap groundwater with deep well pumps. Water pumps are expensive. They are used in small areas for high-value crops with low water requirements. In Ilocos Norte, it is typical to find rubber hoses attached to water pumps to facilitate irrigation of small fragmented farms planted to garlic or tobacco during dry season.

In Zambales, deep wells provide supplementary irrigation during dry season. A few farmers who have access to deep wells grow vegetables in limited areas. In Cagayan, farmers do not have access to supplementary irrigation during the dry season.

Table 2. Percentage of crop land in rainfed rice based patterns in 4 agroclimatic regions, 207 farmers, Philippines, 1979.[a]

Cropping patterns	Leyte				Ilocos Norte				Zambales				Cagayan	
	Dacay	La Paz	Cabacu-ngan	Mayorga	Mayu-ray	San Lo-renzo	Nangu-yudan	Pasil	Sitio Bunga	Santa Rita	Inhobol	Amu-ngan	Ca ala-niugan	Gat-taran
Rice - fallow	41.0	41.2	73.9*	35.9	6.0	1.0	7.0	28.0	98.1*	86.0*	76.0*	60.4	91.9*	68.7*
Rice - mungbean				8.5	1.0	1.0	1.0		1.9	10.9	16.4	37.0	8.1	20.6
Rice - vegetables							14.0			3.1	1.9	2.6		
Rice - watermelon											5.7			10.7
Rice - rice	50.2*	38.5	13.8	38.6*										
Rice - maize	5.6	16.9	7.9	10.6			19.0							
Rice - sweet potato		3.4												
Rice - garlic					53.0*	59.0*	32.0*	67.0*						
Rice - garlic - mung					18.0	5.0	6.0	1.0						
Rice - tobacco					22.0	27.0	18.0							
Rice - garlic - maize						6.0	3.0	4.0						
Others	3.2		4.4	6.4										
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a]An asterisk indicates dominant cropping pattern.

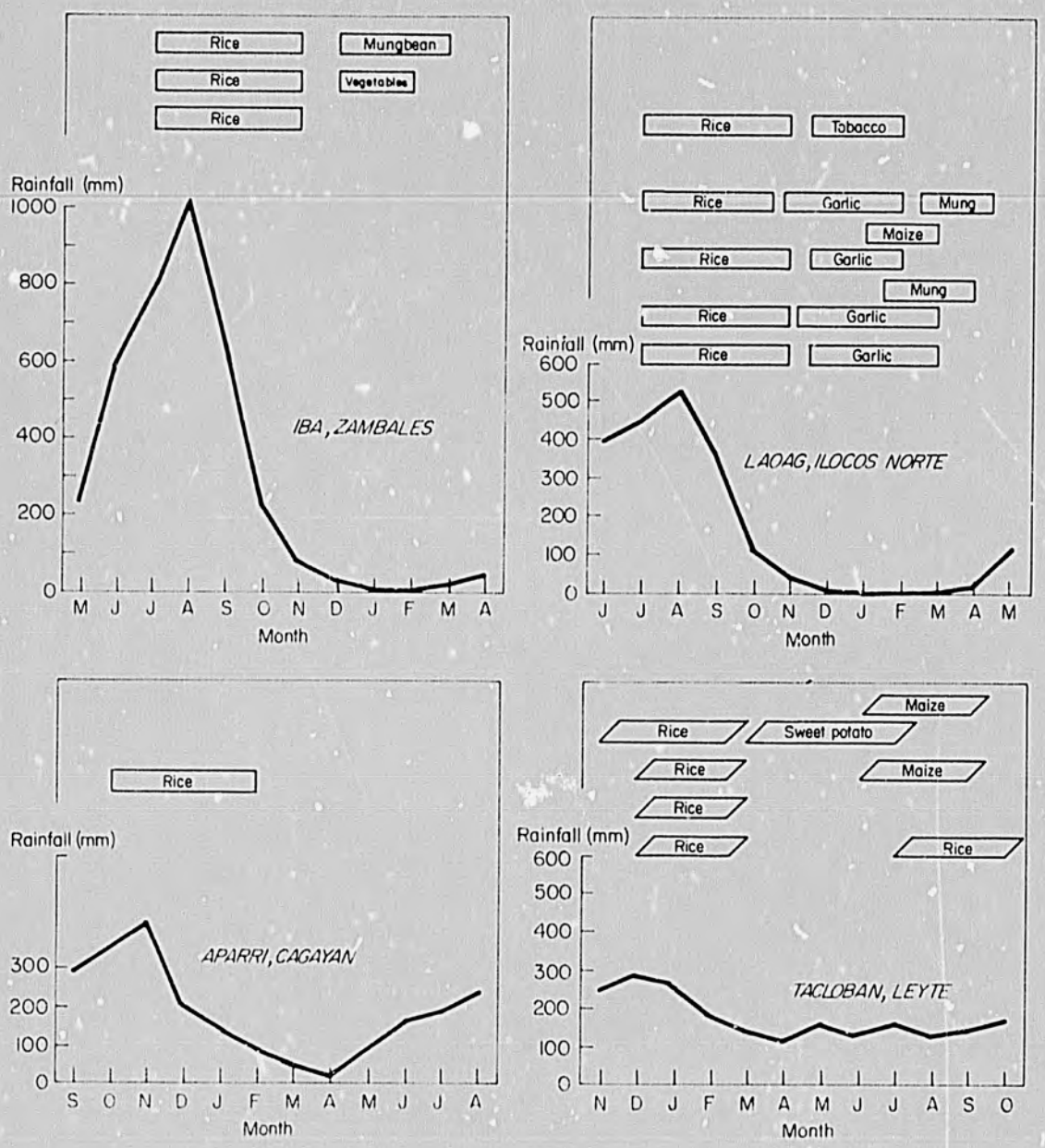

Fig. 2. Farmers' cropping patterns superimposed on the rainfall pattern in four agroclimatic zones, Philippines.

Farmers who have tried to tap water found it salty and unfit for crop production. Fields are left fallow during dry season. In Leyte, where monthly rainfall is greater than 100 mm, canals and creeks provide supplementary irrigation and enable some farmers to grow two rice crops. Water from canals and creeks costs little when fields are near.

Levels of credit use, sources, and interest rates varied substantially in the study areas. Most credit came from informal sources. Repayments were in produce, typically rough rice or palay. Generally, less credit was used in crop production than in other irrigated areas of the Philippines.

Quantitative analyses

The first methodological problem we faced in undertaking a quantitative analysis was the definition and quantification of major farming systems characteristics. For analytical purposes, we hypothesized that some cropping systems characteristics could be defined as descriptors and that biophysical and economic characteristics at site, farm and plot level could be determinants. Given systems interrelationships, including interdependencies between higher and lower order systems, such distinctions are somewhat arbitrary. Determinants are factors which, from the farmers' point of view, are often taken as given. Descriptors reflected farm-level resource allocation decisions.

Table 3. Sources of cash per farm across sites, 207 farmers, Philippines, 1979.

Site	Av farm size (ha)	Crop sales[a] (US$)		Total cash income from crops[a] (US$)	Off-farm income per year[a] (US$)	Cash income from livestock[a] (US$)	Total cash farm income[a] (US$)
		Rice	Nonrice crop				
Ilocos Norte							
Rayuray	.80	0	506	506	6	40	552
San Lorenzo	1.17	0	626	626	67	66	759
Nanguyudan	.65	0	37	37	98	65	200
Pasil	.47	0	144	144	29	83	256
Zambales							
Amungan	1.87	267	70	337	551	89	977
Inhobol	1.73	64	96	160	457	163	780
Santa Rita	1.45	37	0	37	256	8	301
Sitio Bunga	.65	0	3	3	96	6	105
Cagayan							
Camalaniugan	3.28	133	4	137	203	20	360
Gattaran	1.94	74	4	78	101	84	263
Leyte							
Dacay	1.80	111	529	640	41	31	712
La Paz	.95	54	408	462	98	0	560
Cabacungan	1.34	0	599	599	80	0	679
Mayorga	1.82	103	80	183	198	0	381

[a]US$1 = ₱7.35.

Table 4. Rice technology across sites, 207 farmers, Philippines, 1979.

Site	Method of planting	Method of land preparation	Method of harvesting	Method of threshing	Fertilizer input use	Farmers using traditional varieties (%)
Ilocos Norte						
San Lorenzo	Transplant	Man/animal	Rakem[a]	Manual	High	80
Rayuray	Transplant	Man/animal	Rakem	Manual	High	27
Nanguyudan	Transplant	Man/animal	Rakem	Manual	High	75
Pasil	Transplant	Man/animal	Rakem	Manual	High	50
Zambales						
Amungan	Transplant	Man/animal	Sickle	Machine	Low	18
Inhobol	Transplant	Man/animal	Sickle	Machine	Low	38
Santa Rita	Transplant	Man/animal	Sickle	Machine	Low	25
Sitio Bunga	Transplant	Man/animal	Sickle	Machine	Low	67
Cagayan						
Gattaran	Transplant	Man/animal/tractor	Sickle	Manual	Zero	100
Camalaniugan	Transplant	Tractor	Sickle	Manual	Zero	100
Leyte						
Dacay	Transplant	Man/animal	Sickle	Manual	Low	13
La Paz	Transplant	Man/animal	Sickle	Manual	Low	7
Cabacungan	Transplant	Man/animal	Sickle	Manual	Low	13
Mayorga	Transplant	Man/animal	Sickle	Manual	Low	0

[a]Rakem = an ani-ani type knife.

We defined several descriptors because no single descriptor or measure could convey the many dimensions of a cropping system. The descriptors, as we used them, were not substitutes. Each represented a particular facet or attribute of the system. It is hoped that the selected descriptors adequately represented major system attributes. We classified descriptors as land use, labor use, capital use, and output descriptors.

1. Land use descriptors

a. Multiple cropping index (MCI) was the sum of areas planted to different crops harvested during the year, divided by total cultivated area and multiplied by 100.

b. Cropping intensity index (CII) was defined as

$$CII = \frac{\sum_{i=1}^{N_c} a_i t_i}{A_o T}$$

where:

$i = 1, 2, 3....., N_c$

a = total number of crops grown by a farmer during the time period T,

t = duration of ith crop (weeks that crop i occupies area a_i,

T = time period under study (52 weeks)

A_o = farm operator's total cultivated land area available for use during the entire time period T.

c. Another land use descriptor was area planted to rice and vegetables, as a proportion of the crop area. The vegetable category included eggplant, tomato, and garlic.

2. Labor use descriptors

a. Percent of hired labor use was the percent of man-days of hired labor in total labor used for rice production.

b. Labor use per hectare for rice and nonrice crops was measured in man-days.

3. Capital use descriptors

a. Cost of material inputs for rice, and

b. Cost of material inputs for nonrice crops. Material inputs include seeds, fertilizer, and chemicals.

4. Output descriptors

The output descriptors used were values of rice and nonrice produced and sold per hectare.

They were classified as plot-level, farm-level, and village (site)-level determinants. Table 5 presents these variables and their mean values across sites.

Multiple regression techniques were used in the first stage of the quantitative analyses. Additive linear single equation models were specified and we assumed that the hypothesized determinants could be treated as independent[2], exogenous variables to explain variations in the descriptors. That is, we assumed that determinants are not affected by the descriptors. Of course, as previously mentioned, this is unlikely However, it was possible that some descriptor in fluence on the determinants was small enough to b ignored, i.e. the determinants could be considere exogenously determined or given.

We hypothesized that the relationships between determinants and descriptors would vary with each descriptor and set of determinants. Parameters were estimated using the ordinary least squares method.

Twenty determinants were selected as independent variables and regressed on the descriptors. Determinants with statistically significant coefficients were identified. The hypothesized determinants were ranked according to the number of regressions in which coefficients were statistically significant from zero at 90% or higher probability. Nine of the highest ranked independent variables were again regressed on some of the descriptors, but, the resulting regression equations did not improve the explanatory power (for detailed results, see Paris 1981).

Results showed that some determinants were significantly related in most regressions, indicating that they were consistently related to the descriptors (Table 6). However, many of the estimated regression models showed poor explanatory power and relationships obtained were often untenable. Regression models with selected determinant subsets were also estimated, and rarely provided an improvement over the original models.

Multiple and cropping intensity indices

Two of the most widely used cropping systems descriptors are the multiple cropping index and the cropping intensity index; both relate to land use.

Although the regression equations are statistically significant, they do not explain much of the variation in these indices. Access to supplementary irrigation is highly significant in both cases. Duration of rainfall is not significant, however. Within the range of conditions in the study areas, the farmer's ability to grow more than one crop and/or the length of time land could be used depended on whether or not supplementary irrigation was available to extend the growing period. Cropping intensity is also higher in farms with heavy soils, probably because heavy soils retain more water.

Although it is not statistically significant, farm size has a positive coefficient. Family size and man-land ratio also are positive, which is significant in the cropping intensity index. The price of rice and of nitrogen are significant and positive, but implications are not clear (Table 7).

2/ Multicollinearity introduced by highly correlated independent variables was not a major problem in this particualr data set; except in a few cases, the degree of intercorrelation between the determinants was not high. But simultaneous equation bias as a result of determinants and descriptors mutually influencing each other was a possible source of biases in the regression results.

Table 5. Means of hypothesized determinants in 4 agroclimatic zones, 207 farmers.

Hypothesized determinants[a]	Ilocos Norte	Cagayan	Zambales	Leyte
Plot level - physical				
(topography) (0 = flat; 1 = rolling)	0.49	0	0.50	0
% clay	43.09	35.30	26.80	28.55
% organic carbon	0.79	1.09	0.69	1.35
Months of rainfall >100 mm	5.00	8.00	6.00	12.00
Access to supplementary irrigation (0 = no, 1 = yes)	0.65	0	0	0.35
Farm level - economic				
Farm size (ha)	0.86	2.68	1.50	1.61
Parcels (no.)	4.70	2.07	1.72	1.57
Family size	5.12	5.10	5.42	5.28
Livestock income (US$/year)	77.31	56.61	68.92	-
Off-farm income (US$/year)	78.11	152.20	270.94	101.43
Credit (US$/year)	58.73	95.24	77.46	78.57
Farm capital (US$)	1106.52	495.49	509.99	452.47
Farmers' age	48.54	48.20	53.58	48.00
Farming experience (years)	27.28	27.17	28.67	25.63
Farmers' years of schooling	5.35	4.97	5.23	5.55
Village level - economic				
Man-land ratio	7.98	2.42	5.15	4.72
Wage rate for transplanting (US$/day)	0.90	1.36	0.98	1.78
Price of rice (US$/cavan)	7.14	6.39	5.71	6.12
Price of N (US$/kg)	0.54	0.52	0.50	0.56
Transportation accessibility (0 = easy, 4 = difficult)	2.49	2.00	2.50	2.75

[a]US$1 = ₱7.35, 1 cavan = 50 kg.

Table 6. Importance ranking of determinants of cropping systems based on the number of relationships out of 14 regression equations in which their coefficients are statistically significant.

Hypothesized determinants	Number of equations in which coefficient is significant	Rank of importance
Price of rice	10	1
Access to supplementary irrigation	9	2
Farm size	7	3
% clay	6	4
Value of farm capital and equipment	6	4
Farmer's years of schooling	5	5
Price of N	5	5
No. of parcels	4	6
Wage rate for transplanting	4	6
Months of rainfall >100 mm	4	6
Family size	3	7
% organic carbon	2	8
Topography	2	8
Transportation	2	8
Man-land ratio	2	8
Livestock income	2	8
Off-farm income	2	8
Credit	2	8
Farmer's age	0	9
Farming experience	0	9

Percentage of area planted to rice and other crops

The percentage of area planted to rice indicates the degree to which the farm operates a monocrop system. It relates positively to farm size and negatively to off-farm income, livestock income, education, and price of rice (Table 7).

Results obtained by Jodha (1976) in a study of six semiarid villages in India showed farm size and extent of grain crop cultivation did not have a consistent relationship. He attributed this to subsistence and risk considerations. Our results may arise from farmers' subsistence and cash income needs. Although larger farmers have a marketable rice surplus to generate cash income for essential requirements, smaller farmers may need to cultivate more resource-intensive, high-value crops. When noncrop income sources are important, the percentage of area planted to rice falls.

The apparent effects of high nitrogen prices on percentage of area planted to vegetables suggest that when faced with high material input costs, farmers shift to more labor-intensive and higher-value crops.

Larger farmers operate less diversified cropping systems. The percentage of area planted to rice is significantly positively related to farm size but the reverse is true with vegetables. Variations in percentage of area planted to grain legumes are poorly explained by the regression model.

Table 7. Regression models: land use descriptors.[a]

Determinants	MCI	CII[b]	% area planted to rice	% area planted to vegetables	% grain planted to legumes
Plot level-physical					
Topography	6.52	42.00	2.01	3.75	-3.73
% clay	0.70	2.80**	-0.13	0.11	-0.09
% organic carbon	-22.66	- 6.10	4.64	5.86	-3.95
Months of rainfall	0.68	- 6.0	1.64	-1.39***	-0.83
Access to supplementary irrigation	60.45***	150.0***	0.65	8.47***	0.45
Farm level - economics					
Farm size	6.32	40.0	3.16*	-1.30*	.98
No. of parcels	-1.59	- 5.7	-1.30	1.14**	-0.70
Family size	-1.78	-11.0**	-0.32	-0.56*	-0.30
Livestock income[b]	-0.19	-00.004	-2.9*	-1.10	2.40
Off-farm income[b]	1.2	00.004	-1.2***	0.20	-0.25
Credit[b]	-1.2	-00.009	-0.23	-0.53	-1.30***
Farm capital[b]	-0.06	00.004*	-0.27	-0.30**	0.36**
Farmers' age	0.14	00.29	0.03	-0.06	-0.06
Farming experience	-0.17	-00.54	-0.20	0.08	0.06
Education	1.43	00.80	-1.12**	-0.15	-0.56**
Village level - economics					
Man-land ratio	0.71	6.0*	0.33	0.19	-0.01
Wage rate	0.51	1.2	-0.70**	0.04	-0.25
Price of rice	2.21*	6.0*	-2.59***	1.22***	-0.18
Price of N	16.57**	38.0*	-4.77	3.56**	-0.58
Transportation	-5.70	-23.0	0.22	-0.89	-3.29***
Constant	-44.2	-86.9	221.9	-32.04	31.40
$\bar{R}^2$	.30	.36	.40	.62	.27

[a]* indicates that the coefficient is significantly different from zero at the 90% level of probability, ** indicates difference at 95% level, and *** indicates difference at 99% level. [b]Coefficient has been multiplied by 10^3.

We observed that months of rainfall relate negatively to percentage of area planted to vegetables (including garlic). This may have resulted from the complex interactions of rainfall, topography, soils, and access to supplementary irrigation which cannot be adequately captured in a linear relationship. The data showed vegetables are grown in dry areas that have supplementary irrigation (e.g. garlic in Ilocos Norte).

Rice price relates negatively to percentage of area planted to rice and positively to percentage of area planted to vegetables. This is contrary to expectations that higher rice prices cause more area to be planted to rice. Although this is probably true at a site over time, it need not be so across sites at a given time. The observed relationship probably reflects the fact that rice prices, as influenced by local supply levels, are higher in rice-deficit areas. If this is true, the postulated relationship between the determinant and descriptor does not hold. In this situation, the descriptor probably determines the level of the determinant.

Labor use descriptors

Labor use descriptors used in the final regression analysis were man-days per hectare in rice production, man-days per hectare in nonrice production, and hired labor as a percentage of total labor used in rice production (Table 8).

Where supplementary irrigation is available to increase potential crop returns farmers use more labor. The specified function explained little of the variation in rice labor use. Labor use in rice is higher when rice price is higher, but higher rice price also raises labor use in nonrice crops. The prices of the nonrice crops were not included in the analysis, therefore, it is not possible to draw firm inferences from this. However, we suspect that this is because farmers operated more labor-intensive and diversified cropping systems in rice-deficit areas where rice prices were higher.

Using a subset of the determinants we reestimated the model for labor use in rice. Results are in Table 9. Although the $\bar{R}^2$ is slightly lower than in the previous model, more of the variables are significant. Here, the inverse relationship between labor use intensity and farm size is statistically significant. Also, labor use intensity is higher on more fragmented farms.

As expected, larger farms encourage greater use of hired labor, although this is modified by mechanization of land preparation and/or threshing

Table 8. Regression models: labor use descriptors.[a]

Determinants	% of total hired labor	Rice labor (man-days/ha)	Labor on nonrice crop (man-days/ha)
Plot level - physical			
Topography	18.22***	33.64*	10.20
% clay	- 0.56***	- 1.07**	0.89
% organic carbon	30.84***	57.17**	13.13
Months of rainfall	- 0.96	1.00	- 3.64
Access to supplementary irrigation	5.29	50.81***	36.79**
Farm level - economics			
Farm size	4.41**	- 6.92	-11.29*
No. of parcels	- 2.84**	12.02***	6.84*
Family size	- 1.38	0.05	1.78
Livestock income[b]	1.30	- 7.50	12.00
Off-farm income[b]	0.54	- 1.20	0.37
Credit[b]	1.70	- 0.23	11.0**
Farm capital[b]	1.70	0.20	0.39
Farmers' age	0.13	0.59	0.20
Farming experience (years)	0.06	0.03	0.07
Education	0.72	3.80**	- 2.39
Village level - economics			
Man-land ratio	-0.16	2.11	- 4.23**
Wage rate	1.46	- 1.25	0.71
Price of rice	0.27	- 3.51**	7.42***
Price of N	-5.57	-13.36	13.90
Transportation	-1.60	-11.79	3.30
Constant	47.60	204.90	-378.90
R^2	0.55	0.17	0.34

[a]* indicates that the coefficient is significantly different from zero at the 90% level of probability, ** indicates difference at 95% level, *** indicates difference at 99% level. [b]Coefficient has been multiplied by 10^3.

operations. Results also show fragmented farms used less hired labor, probably because there are greater chances to stagger farm operations.

Wage rate is positively related to hired labor use, probably because of the interaction between farm level labor demand and regional wage rates. Higher labor demand caused by farm-level factors may increase regional wage rates. The real determinant-descriptor relationship is more complex than hypothesized in the regression model.

The effects of plot-level physical variables on hired labor use are difficult to interpret and, in practice, are complex. No appealing interpretations of the results can be made.

Material input use

The specified regression model explains less than 30% of the variation in material input use in rice. It is significantly positively related to farm size and irrigation and livestock income and wage rate. It relates negatively to rice price and rainfall duration. The model suggests fewer material inputs are used in clay soils. Intuitively reasonable interpretations cannot be made for many

Table 9. Labor use in rice - regression models with subset of determinants.[a]

Hypothesized determinants of systems	Man-days/ha rice
Plot level - physical	
% clay	-8.77**
Access to supplementary irrigation	41.44***
Months of rainfall >100 mm	3.31
Farm - level economic	
Farm size	-11.81***
No. of parcels	11.41***
Value of workstock and equipment	-.0002
Years in school completed by operator	2.83*
Village level - economic	
Price of rice	2.83*
Wage rate	-1.54
Constant	175.76
R^2	0.16
F	5.33

[a]*indicates that coefficient is significantly different from zero at the 90% level of probability, ** indicates difference at 95% level, *** indicates difference at 99% level.

of the significant coefficients. Indeed, the observation that rice price negatively influences material input use is contrary to general economic theory but perhaps reflects the influence of an unspecified marketing or transport parameter -- high rice prices occur in rice-deficit areas with poor access to markets, and under such conditions inputs are likely to be more costly and therefore less used.

The model explains a larger proportion of observed variability in nonrice input material use. Nevertheless, similar problems can be observed. Some results (negative coefficient of rainfall duration and positive coefficient of access to supplementary irrigation) are compatible with observations. Farmers in dry areas (Ilocos Norte and Zambales) who have access to supplementary irrigation spend substantial amounts for nonrice crop material inputs. The model suggests, in contrast to the rice analysis, that more material inputs are applied for clay soils (Table 10).

Table 10. Regression models: material input use descriptors.[a]

Determinants	Cost of material inputs on rice (US$/ha)	Cost of material inputs on other crops (US$/ha)
Plot level - physical		
Topography	-19.22	16.38
% clay	- 2.60**	5.10***
% organic carbon	-34.41	10.07
Months of rainfall	-23.71***	-33.01***
Access to supplementary irrigation	79.59***	152.58***
Farm level - economic		
Farm size	30.46***	-18.08
No. of parcels	- 4.90	3.79
Family size	7.49	11.08*
Livestock income[b]	0.03	- 0.70
Off-farm income[b]	- 1.00	- 7.80**
Credit[b]	- 1.10	- 5.80
Farm capital[b]	- 1.10	4.70*
Farmers' age	1.28	- 1.30
Farming experience (years)	- 0.09	0.82
Education	3.28	- 3.65
Village level - economic		
Man-land ratio	- 2.07	- 9.78
Wage rate	5.05**	6.05**
Price of rice	- 8.09**	18.57***
Price of N	- 8.92	-23.74
Transportation	4.51	- 1.75
Constant	719.30	-594.40
Adjusted R^{-2}	0.26	0.61

[a]* indicates that coefficient is significantly different from zero at the 90% level of probability, ** indicates difference at 95% level, *** indicates difference at 99% level. [b]Coefficient has been multiplied by 10^3.

Output descriptors

The models poorly explain variations in rice yields, value of rice produced, and value of rice sold; R^2 values were low (Table 11).

The models explain substantially more of the variations in nonrice output descriptors; R^2 values were higher.

Farm size has a negative coefficient which probably reflects the diminished importance of nonrice crops on larger farms. The positive coefficient of supplementary irrigation was anticipated. As described previously in Ilocos Norte, farmers who grow high-value crops often own water pumps, etc. This regression model confirms earlier indications that smaller farms grow more nonrice crops. The relationships of value of nonrice crops with wage rate and rice price are similar to those with percentage of nonrice areas and probably are caused by the same factors. Relationships for value of nonrice crops sold are broadly similar.

An examination of regression results shows they were generally unsatisfactory. We reestimated models using the determinants that were most often significant in these regressions. The results obtained were not much better. More clearly defined hypotheses about the relationships would certainly be helpful in future studies. They should be developed in close interaction with biological scientists. However, given system interdependencies and interactions some of the estimational problems are likely to persist.

Application of factor analysis

In contrast to regression analysis, which is a study of dependence, factor analysis is a study of mutual interdependence because all variables are dependent and independent in turn (Kendall 1950). The technique is described in many publications (see Harman 1960 for a comprehensive exposition) and is widely used in quantitative analysis of social phenomena.

Factor analysis techniques show underlying relationship patterns that exist among a large number of variables and allow data to be rearranged or reduced to a number of clusters known as factors. Sometimes these factors do not lend themselves to straightforward interpretations. In factor analysis, the coefficients that relate observed variables to common factors are determined. These coefficients, called factor loadings, play the same role in factor analysis as do regression coefficients in correlation analysis. Since the squared factor loadings represent the relative contribution of each factor to the total standardized variance of a variable, the sum of squared factor loadings for each variable (known as the communality) shows the extent to which common factors account for total unit variance of the variable. Therefore, the role of communality in factor analysis is analogous to the role of the coefficient of multiple determination, R^2, in regression analysis.

Table 11. Regression models: output descriptors.[a]

Determinants	Value of nonrice produced (US$/ha)	Value of nonrice sold (US$/ha)	Value of rice produced (US$/ha)	Value of rice sold (US$/ha)	Rice yield per hectare
Plot - level physical					
Topography	-491.86	288.64	-209.78	31.40	- 6.37
% clay	19.49	45.70**	- 2.69	2.50	-00.06
% organic carbon	632.18	260.20	-395.38	-342.21	-10.12
Months of rainfall	-246.65	- 87.47***	- 5.81	27.99	-00.02
Access to supplementary irrigation	2433.17***	1729.31	684.78**	- 53.73	-13.67*
Farm - level economic					
Farm size	-680.30**	-349.44*	55.23	51.76	1.05
No. of parcels	163.32	-113.58	42.30	-18.74	0.84
Family size	-115.18	- 8.49	15.45	7.09	-0.21
Livestock income[b]	- 0.21	0.03	-04.31	15.70	-0.12
Off-farm income[b]	0.041	0.04	15.1	-11.00	0.39
Credit[b]	- 0.13	- 0.09	-95.0	34.70	-1.95
Farm capital[b]	0.19***	0.16***	13.5	-10.80	0.30
Farmers' age	14.04	- 3.00	7.47*	- 3.27	0.12
Farming experience (years)	- 20.87	- 14.86	-10.95	3.22	-0.20
Education	16.89	- 20.52	72.48**	34.58**	1.45**
Village - level economic					
Man-land ratio	13.61	- 35.52	30.12	- 7.54	0.55
Wage rate	45.58	15.12	8.18	1.15	0.19
Price of rice	450.65***	381.62***	18.16	- 7.21	-0.60
Price of N	-1312.05**	-922.23**	17.46	86.37	1.03
Transportation	204.82	148.21	67.65	-150.15*	1.80
Constant	11354.11	-13058.31	820.02	576.28	63.30
Adjusted R^{-2}	0.50	0.57	0.06	0.01	0.01

[a]* indicates that the coefficient is significantly different from zero at the 90% level of probability, ** indicates difference at 95% level, *** indicates difference at 99% level. [b]Coefficient has been multiplied by 10^3.

We applied factor analysis to our study in two ways. In one, we used factor analysis to develop three factors each from selected hypothesized descriptors and determinants (Table 12). Then we ran three regression models relating the set of three determinant factors to each descriptor factor.

For the descriptors, factor one represents nonrice descriptors such as percentage of area planted to vegetables, man-days per hectare for nonrice crops, cash per hectare for nonrice, nonrice produced per hectare, and nonrice sold per hectare. Factor two includes land use descriptors such as multiple cropping intensity index, cropping intensity index, percentage of area planted to rice, and percentage of area planted to legumes. Factor three includes labor use descriptors such as percentage of hired labor and man-days per hectare for rice, and nitrogen used per hectare.

For the determinants, factor one consists of physical and economic variables such as topography, percentage of organic carbon, rainfall duration, farm size, and wage rates. Factor two represents physical variables such as percentage of clay, access to supplementary irrigation, and number of parcels. It also includes farm capital. Factor three represents social variables such as farming experience, farmer's age, and man-land ratio.

The regression results relating the factors extracted from the 3 determinants (D variables) to each of the factors estimated from the descriptors (F variables) are:

$$F_1 = -.0006 - .196D_1^{***} + .817D_2^{***} + .0087D_3, \quad \bar{R}^2 = .59$$

$$F_2 = -.0002 + .017D_1 + .488D_2^{***} + .028D_3, \quad \bar{R}^2 = .18$$

$$F_3 = -.001 - .397D_1^{***} + .383D_2^{***} + .020D_3, \quad \bar{R}^2 = .28$$

*** indicates that coefficient is significantly different from zero at the 99% level of probability.

In both cases, the factors are hybrids of physical and economic variables and are not easily interpreted. Regression results show that a substantial proportion of the variations in the nonrice component of the cropping systems are explained by the first and second determinant factors (R^2 = .59). However, the explanatory power of the other two models is poor.

Table 12. Varimax rotated factor matrix of hypothesized determinants and descriptors of cropping systems.

Hypothesized determinants	Factor loadings[a] D_1	D_2	D_3	h_i^2 (R^2)
Topography	-.843	-.182	-.018	.744
% organic carbon	.762	-.151	-.200	.644
Rainfall duration	.772	-.383	-.103	.753
Farm size	.405	.083	.359	.300
Wage rates	.754	.091	.112	.589
% clay	.135	.726	-.183	.726
Access to supplementary irrigation	.080	.713	-.193	.713
Farm capital	-.107	.617	.155	.617
No. of parcels	-.244	.721	.090	.721
Farming experience	-.084	.045	.815	.815
Farmers' age	-.117	-.054	.826	.826
Man-land ratio	-.416	.066	.533	.462
Descriptors	**Factor loadings[b] F_1**	**F_2**	**F_3**	**h_i^2 (R^2)**
% area planted to vegetable	.831	.112	.267	.774
Man-days/ha nonrice	.676	.280	.015	.536
Cash/ha nonrice	.832	.321	.049	.797
Nonrice produced/ha	.878	.071	.161	.785
Nonrice sold/ha	.892	.139	.080	.821
MCI	.287	.861	.056	.826
CII	.888	.727	-.016	.680
% area planted to rice	.275	.625	-.116	.480
% area planted to legumes	-.072	.709	-.001	.508
% hired labor	-.255	.211	-.450	.312
Man-days/ha rice	-.079	.142	.855	.757
Nitrogen/ha	.216	.131	.816	.729

[a]In subsequent analysis D_1, D_2, and D_3 refer to the boxed determinants. In subsequent analysis F_1, F_2, and F_3 refer to the boxed descriptors.

The approach used by Adelman and Morris (1967) to study factors associated with economic development is helpful in focusing on how the determinants affect selected descriptors. This approach is better than the single equation regression model because problems of multicollinearity among determinants appearing as explanatory variables are greatly reduced. Because of time limitations we used this approach in only 1 application to study how the cropping intensity index related to 11 hypothesized determinants (Table 13). Cropping intensity index and the 11 hypothesized determinants are arranged in 3 factor dimensions. Factor loading entries show the net correlation between each factor and the observed variables.

The first factor includes two plot-level physical variables: percentage of clay and access to supplementary irrigation, and two farm-level economic variables: number of parcels and farm capital. Factor two consists of physical variables: topography and duration of rainfall, and socioeconomic variables: farm size, wage rates, and man-land ratio. Factor three represents sociodemographic variables such as farmer's age and farming experience, two highly correlated variables, and man-land ratio.

Table 13. Varimax rotated factor matrix for cropping intensity index together with eleven hypothesized determinants of cropping systems.

	Rotated factor loadings F_1	F_2	F_3	h_i^2 (R^2)
CII	.714	.018	-.089	.519
% clay	.678	.068	-.156	.489
Access to supplementary irrigation	.744	.043	-.170	.584
No. of parcels	.694	-.222	.150	.554
Farm capital	.602	.069	.183	.401
Topography	-.149	-.835	.131	.736
Rainfall duration	-.354	.682	-.212	.635
Farm size	-.055	.520	.221	.323
Wage rates	.058	.798	-.048	.642
Man-land ratio	.088	-.563	-.396	.481
Farming experience	.023	.020	.860	.741
Operator's age	-.070	-.002	.867	.756

About 52% of cropping intensity variations are associated with the 3 common factors extracted from the 11 hypothesized determinants. The first factor contributes almost all the explanatory power of the model.

Discriminant analysis

Cropping systems can also be described in qualitative fashion and can sometimes provide information about the systems which is not conveyed by quantitative descriptors. However, many of the commonly used statistical tools are of limited analytical value when qualitative descriptors are used. Discriminant function analysis is a multivariate statistical technique that can be used in such cases. It is discussed in many publications (Morrison 1969) and has often been used in studies of new technology adoption [illegible] economists (Flinn et al 1980).

Discriminant funct[illegible]ysis enables a researcher to identify the su[illegible] of attributes that most successfully discrim[illegible]tween members of distinct groups when data [illegible]mber of members' attributes are available. [illegible]thematical objective of this technique is to w[illegible] and linearly combine the hypothesized discriminating variables so groups become statistically distinct. The resulting discriminant functions help identify the relative contribution of each variable. The model assumes that variables have multivariate normal distributions, therefore using dummy variables poses problems. Fortunately, the technique is robust to departures from this assumption (Morrison 1969) and the use of dummy variables is common.

In our study, we distinguished four major types of cropping systems:

1. Rice - fallow. One rainfed rice crop is grown each year. After it is harvested fields are idle and are commonly used for pasture.

2. Rice - rice. One rainfed rice crop is grown during wet season followed by another during dry season.

3. Rice - garlic or rice - tobacco. One rainfed rice crop is grown during wet season followed by high-value crops such as garlic or tobacco during dry season.

4. Rice - other crops. One rainfed rice crop is grown during wet season followed by other crops, mostly upland crops.

Table 14 shows the estimated discriminant functions when all farmers were included in these four groups, based on their major cropping patterns. The seven variables used in this analysis were selected by examining the variability of the determinants from the four groups.

Although three functions were estimated, the second and third functions added little to the discriminating power of the first. In the latter, variables that contributed most to the classification were access to and type of supplementary irrigation followed by soil characteristics. The classification analysis shows an average 75% of farmers were correctly classified, given the discriminating variables (Table 15). Site-related physical variables were usually dominant determinants of cropping patterns within the site.

Discriminant analysis can also be used to examine factors contributing to within-site variation in systems. Using the technique to study farmers from Leyte showed that access to canal irrigation, followed by soil factors, was crucial in differentiating between double rice cropping farmers and others (Paris 1981).

Table 14. Standardized canonical discriminant function coefficients for different cropping systems, 207 farmers, 14 Philippines sites.

Variable	$Function_1$	$Function_2$	$Function_3$	F-ratio
Topography	-.088	-.337	.324	2.69
% clay	-.332	-.170	.415	32.12
% organic carbon	.253	-.064	1.021	17.57
Rainfall duration	-.061	.061	-.093	26.51
Access to canals	.550	-.883	-.069	139.10
Access to pumps	-.614	-.616	-.039	121.50
Man-land ratio	-.139	-.093	-.026	4.90

SUMMARY AND CONCLUSIONS

The study analyzed cropping systems adaptation to the environment through a cross-site comparison. It evaluated 14 sites in the Philippines that fall under 4 agroclimatic zones. Data collected from 207 farmers were analyzed using tabular analysis, multiple regression, factor analysis, and discriminant analysis techniques.

Several cropping systems descriptors were used. To capture different attributes of cropping systems quantitative and qualitative descriptors are needed. The often complex, interactive relationships between cropping systems attributes and postulated determinants required the use of several multivariate analytical techniques. Overlapping results generally agreed and other findings were complementary.

All analytical techniques showed that biophysical factors are the dominant influence determining the number of crops grown in sequence (MCI) and the duration of land use by crops (CII). Soil texture and the presence (or absence) and type of supplementary irrigation were highly important. They determine the feasible period for crop growth by their influence on soil moisture.

Table 15. Prediction results of the discriminant function in 14 Philippine sites, 207 farmers, 1979.

Actual farm groups	Cases (no.)	Rice - fallow	Rice - rice	Rice - garlic/ rice - tobacco	Rice - others
Rice - fallow	91	74 (81.3%)	1 (1.1%)	0 (0.0%)	16 (17.6%)
Rice - rice	22	1 (4.5%)	18 (81.8%)	1 (4.5%)	2 (9.1%)
Rice - garlic/rice - tobacco	47	4 (8.5%)	0 (0.0%)	35 (74.5%)	8 (17.0%)
Rice - others	47	16 (34.0%)	2 (4.3%)	1 (2.1%)	28 (59.6%)

(Percent of "grouped" cases correctly classified: 74.88%).

In the analysis, rainfall distribution alone was not a critical determinant. At first thought, this is surprising, however, supplementary irrigation can modify natural soil moisture regimes. The most important cropping systems differences were linked to this. This does not, of course, imply that rainfall pattern is unimportant. The supply and costs of supplementary irrigation depend substantially on the level and duration of rainfall.

Among farm-level socioeconomic variables, farm size is a major influence on cropping system characteristics, particularly on those related to input use. Smaller farms operate more diversified cropping systems.

There was no direct link between farm size and cropping intensity as measured by number of crops (MCI) or duration of land use by crops (CII). However, regression results showed small farms were more labor intensive. Also, small farms used higher levels of material inputs, particularly urea fertilizer.

As expected, farm size influenced the use of hired labor and machinery. Larger farms used more hired labor and tended to be more mechanized.

Generally, sociodemographic variables such as farmer's age, farming experience, and education were not important cropping systems determinants. This was particularly evident in factor analysis results. Subject to confirmation through future research, this indicates that this type of data may be of little use when designing new cropping technologies for specific locations. Because such data are often more difficult to obtain than biophysical data at site research initial stages, this may reduce the burden of data collection at that stage.

From a methodological point of view the study showed that the complexity of interrelated components within farming systems makes it necessary to use multivariate statistical techniques to understand underlying relationships. Commonly used single equation multiple regression models are by themselves inadequate. Estimated relationships between dependent and explanatory variables were difficult to explain and/or did not conform with a priori expectations. R^2 values were usually low, indicating that many important variables had been left out. Assumptions of linear, unidirectional relationships between hypothesized determinants and descriptors did not always hold.

When interpreted with care, single equation models, despite their specification limitations, can be used to understand how site-level factors are combined with farm-level system characteristics. The unexpected signs of some of the coefficients, for example, can be used to develop hypotheses regarding system interdependencies and the real direction of relationships.

Significant developments in the application of multivariate statistical techniques to the study of complex systems during the last two decades have enabled us to make a systematic analysis of the complex, interdependent relationships involved in adapting a cropping system to an environment. In our study, factor and discriminant analysis helped overcome some of the limitations of single equation multiple regression models. However, our results should be carefully interpreted because the assumption that all variables are normally distributed is not always sustained, particularly when dummy variables are used for qualitative or categorical data.

Our experience shows stronger hypothesis regarding the nature of the system relationships needs to be carefully developed before undertaking quantitative analyses. Because biophysical systems and environmental factors are so closely interwoven with the socioeconomic variables, such hypotheses are best formulated by interdisciplinary teams.

Because of time and other constraints this study was confined to 14 Philippine sites. The degree of variability of many major variables (biophysical as well as socioeconomic) was small, which made estimation difficult. Data obtained from a wider range of environmental complexes may provide a more reliable foundation for an extended study, and ACSN sites may provide a more extended data base for further research and analysis.

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