AGROECOZONING FOR UPLAND RICE:

The CIAT Experience in Latin America

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Contents

SUMMARY

Agroecozoning may be approached from the standpoint of knowledge of the crop projected onto a map, or a crop distribution map interpreted as denoting crop requirements. If carried sufficiently far, both approaches should converge.

The approach of CIAT is basically that of analysing crop distribution. To produce an integrated information system three types of data are necessary: a) Climatic, b) Edaphic and c) Cropping System. CIAT is actively pursuing the collection of these data and is constructing a database to manage them. Initial studies of CIAT rice programs' definitions of Favored, Moderately Favored and Unfavored rice regimes showed that in Latin America season length was not an overriding factor but that rainfall variability was of great importance.

Subsequent studies in the Andean Region backed up this finding and demonstrated the range of soil types and moisture regimes presented. Almost no upland rice was found in the region on acid infertile Ferralsol type soils. This notwithstanding, the CIAT team have found that commercial yields can be possible on these soils in high rainfall areas.

The results of these studies point to the need to use a measure of possible stress during the growing season as well as season length as a classifying variable.

The merits of a complete agroecozone classification are discussed in relation to maintaining a database for consultation.

APPROACHES TO AGRO-ECOZONING

Many ecozoning studies to date assume a relatively complete knowledge of the physiology of the crop involved and attempt to put rational limits to the ranges of environmental factors. These limits are then used in a general way to map the regions of adaptation of the crop (See FAO 1981). This is a natural outgrowth of the crude agrozoning attempts of the past (ref. Holdridge, Thornthwaite). It has become apparent relatively recently that this approach has many limitations for practical application to help international agricultural research. For many of the crops involved, insufficient experimental data are available to determine the effects of environmental factors on crop growth and upon pest and disease relationships. Where sufficient information exists for a meaningful *a priori* ecozone definition for a crop then we are often faced with problems of differential varietal response to the zoning variables.

The almost exactly opposite approach is to proceed from the geographic distribution of the crop and determine the important differentiating variables and varietal reactions. At an International level there are few examples of these zoning attempts, but both IRRI and CIAT have opted at least in part for this approach. At IRRI the map of rice in Asia by Huke and Huke has been admirably used in an analysis of the status of rice cultivation by Garrity (1982). In CIAT we have for many years recognised the need for accurate description of crop distributions, and the Agroecological Studies Unit is actively pursuing this end.

The first type of study can be followed by an accurate crop inventory of the theoretically assigned areas. FAO is in process of publishing such a follow up to their Agroecozoning Studies (G. Higgins pers comm). The interpretation of a geographically based study should include the subsequent classification of subregions on the basis of observed varietal performance. If the studies proceed in this way then essentially the same end point may be reached.

Agroecozoning has a large range of potential end uses. Among these a number of important ones may be singled out.

a) Defining broad scale research priorities

b) Identifying areal homologues for technology transfer

c) Assisting in design and interpretation of extended trial networks

d) Identification of extension zones

e) Specific regional planning.

I would contend that these five uses constitute a spectrum in two senses: firstly, that of data type - running from generalized inventory of cropping areas and problems in a) to detailed mapping of crop potential in e). The second gradation is of the interest shown by types of organization. National programs are obviously concerned in all five, but IARCs are primarily interested in the upper part of the list and are rarely involved in regional mapping and planning at the level necessary for a national program. These considerations have considerable bearing on the system to be implemented.

CIAT'S AGRO-ECOLOGICAL STUDIES UNIT

SECTION OBJECTIVES

To be cost effective, CIAT's commodity programs require systematized information about their respective target areas in two main phases of their research activity: research strategy design and technology evaluation and transfer.

Research Strategy Design

Specific research goals and priorities must be initially defined and constantly evaluated in the light of knowledge of existing conditions in each program's target area. The development of adaptable seed based technology depends heavily on an undestanding of the land and climatic resources for agricultural production. This is particularly important for CIAT commodity programs, because of the variability in ecosystems in Latin America and the strong germplasm-ecosystem interactions in all CIAT commodities.

Technology Evaluation and Transfer

Target area analysis and evaluation appear also as critical components in the technology testing and validation stage. The availability of purposely collected and organized data on each program's target area not only helps in achieving the objective, but does so in the most cost-effective manner. Sites for regional trials, international nurseries and for the on-farm validation studies, should be selected so that they are representative of the various sub-ecosystems. The greater ability to extrapolate information to similar ecosystems will make network testing more useful. The greater ability to associate germplasm to a given type or range of ecosystems, will also significantly reduce the burden on cooperating national institutions and increase the confidence in networking with CIAT.

The purpose of the unit is to provide CIAT scientists with the information and analytic power to help in decisions in the above categories.

SECTION METHODOLOGY

Data collection and management

The gathering of necessary information by direct survey to describe all the possible cropping systems in the areas of interest would be prohibitively expensive. The Center is not prepared in terms of mandate, manpower or resources to tackle such a tremendous task. Instead, the system developed at CIAT relies on the use of prior surveys, census information and local knowledge of the situation. Information is gained on an opportunistic basis by CIAT personnel travelling in the field and from visitors and trainees coming to CIAT. In this way a highly cost effective system for the management, interpretation and analysis of existing information has been developed.

Agroecological analysis requires three distinct types of data; climatic and meteorological data, edaphic data and crop system data. These three types of data have distinctive attributes which call for different handling in their collection, maintenance and retrieval.

a) Climatic and Meteorological Data. Long term climatic normals in the form of monthly mean data, including temperatures, rainfall, radiation and humidity, have been collected and processed for more than 4600 meteorological stations throughout Latin America. These data are stored in a specially designed suite of computer files, with an associated data retrieval and maintenance system. This data base is being used to provide initial climatic stratification of the production zones of CIAT commodities. Long term climatic normals do not allow full analysis of varietal adaptation and stability. As will be described later in this paper it is planned to incorporate parameters for stochastic climate models in the database.

b) Edaphic Data. The data has a regionally based reference unit with a strict geographic boundary to the basic data element. The Land System approach of Christian and Stewart (1953) was modified for this section of the study. A landsystem was redefined as "an area or groups of areas throughout which there is a recurring pattern of climate, landscape and soils". The analysis relies on satellite and radar imagery, and occasionally aerial photography, to provide a geographical base. Existing information on soils is compiled and restructured to a common base for storage as descriptors of the landsystem. In a few cases where no information is available, limited field work must be undertaken.

The original work concentrated in delineating landsystems at the scale of 1:1000.000. As the study proceeds to more complex areas of small farmer cultivation, particularly in the tropical highland areas, it is envisaged that selected areas will be studied in more detail.

c) Cropping System Data. These data include information on the cultural practices and agronomic conditions for each of the cropping regions in the study. Data necessary include; sowing dates, harvest dates, cultivars used, incidence of disease, pests or weeds, yields, area sown, data on associated crop and cropping sequences. This is not intended to be an exhaustive study of each complete cropping system, but rather the data necessary to interpret the growth and development of the crop in question. The base reference units for these data are to a large extent geographical and for this reason it has been decided to call them 'Crop Production Microregions' and to define them in analogy to the landsystem as 'an area or group of areas with a relatively uniform pattern of climate, edaphic factors and cropping system'. This definition highlights the difference between the microregion and landsystem, in that the former now need no longer be geographically exclusive, in that microregions for different crops, or even for the same crop in different cropping systems or seasons, may now be superimposed.

AGRO-ECOLOGICAL STUDIES ON UPLAND RICE IN CIAT

INITIAL STUDIES FOR CIAT'S UPLAND RICE PROGRAM:

The CIAT rice program has developed a working classification of rice environments and three categories of upland rice ecosystems/production systems have been defined, i.e., favored-upland, moderately-favored upland and unfavored upland. Laing et al (1982) reported an initial survey of a set of 8 example sites for this working classification.

In general, soils at the favored-upland sites were all deep and heavy textured. These sites generally had soils with a high base status and moderately high fertility. Moisture holding potentials were generally high at all favored sites and since hydromorphic features were present, access to a water table within 50 cm was common.

Eutric fluvisols and mollic gleysols were present at two of the moderately-favored sites and in parts were associated with cambisols and kastanozems, all soils with high fertility, high base status and with good working properties and not inferior to the best favored sites. A vitric andosol in Panama had a deep profile but was inherently quite acid and low in fertility.

Both selected unfavored sites in Brazil were on a deep, loamy, well drained acric feralsol. These soils are highly acid and infertile with high aluminum saturation (70%) in most areas.

From the above brief description of the soils and terrain characteristics of these sample locations it is clear that no one set of conditions uniquely classified sites as favored-upland. There was a greater preponderance of good soils at the more favored end of the upland spectrum. However, fertile soils were not necessarily indicative of a favored-upland ecosystem, because of possible climatic limitations. On the other hand, there was a definite tendency towards low fertility and highly acid soils in unfavored rice situations. Thus soil classification alone can not be sufficient to develop a useful quantitative classification of upland environments. Another difficulty encountered in classifying rice environments is illustrated by an analysis of data of crop climate for these locations.

Table 1 gives the range of climatic parameters for the eight selected upland locations. Growing season length is based on crop water balance evaluations using estimated mean weekly data for rainfall and potential evaporation. All locations appeared to have adequate growing season length (minimum 154 days) of contiguous days when soil water available was greater than 1/3 of potential under mean climatic conditions. Temperature and radiation were also adequate for rice at all locations. Even though mean growing season rainfall decreased from the favored to the unfavored sites (Table 2), calculations of water balances (using longterm mean rainfall) suggested that water supply would be in surplus over potential evapotranspiration even at the unfavored sites (Figures 1, 2, 3).

Using very approximate estimates of rainfall variability, Laing et al (1982) were able to show that the major climatic difference between the baseline sites was the probability of midseason stress and not necessarily the length of season. They assumed one month with only 50% of mean rainfall. The reduction in growing season days was then calculated as the number of days with available soil moisture at less

Table 1. Range[1] of agroclimatic parameters for typical selected upland sites. (See also Table 2).

Growing Season	Favored		Mod-favored		Unfavored	
Length days[2]	287	365	154	210	154	182
Mean temperature ºC	25.6	26.7	26.3	28.0	22.7	23.3
Mean E_t[3] mm day^{-1}	3.8	4.8	4.4	5.9	5.2	5.8
Radiation MJm^2 day^{-1}	15.9	19.3	19.6	21.0	20.5	21.6

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[1] Range noted in sample meteorological satation data.

[2] Length of growing season calculated from estimated daily soil water budgets as the number of contiguous days when available soil water is greater than 0.33 of potential available.

[3] Potential evapotranspiration (E_t)

Table 2. Effects of rainfall variability (simulated rainfall reduction by 50% mid season for one month) at selected upland rice sites.

	Reduced[1] GSD	Mild[2] Stress day	Days to[3] stress	Probability of dry[4] period	Yield[5] t ha^{-1}
Favored upland					
Site 1	0	0	23	Highly unlikely	4.50
Site 2	0	0	39	Nil	4.40
Site 3	0	0	34	Nil	3.50
Moderately favored-upland					
Site 1	0-35	28-35	22	Possible	3.00[i]
Site 2	0	21-35	26	Possible	1.92[c]
Site 3	0	0-14	22	Unlikely	2.59[c]
Unfavored-upland					
Site 1	98	14	9	Higly likely	1.10[c]
Site 2	64-98	14	9	Highly likely	1.20[c]

[1] Reduction in growing season (GSD) days (days with soil moisture available greater than 1/3 soil moisture holding potential) due to one mid-season month with half of normal mean rainfall.

[2] Mild stress days, days with soil water availability between 2/3 and 1/3 capacity, as induced by reduction in rainfall by 50% for one month.

[3] Days of growth available before 2/3 of available soil water is exhausted if no rain falls as in foot note 1.

[4] Subjective estimate of the probability of a dry spell as least as long as the figure in preceeding column.

[5] From census data where available (c) or from CIAT estimates from informed sources (i); yield estimates not including traditional subsistence areas.

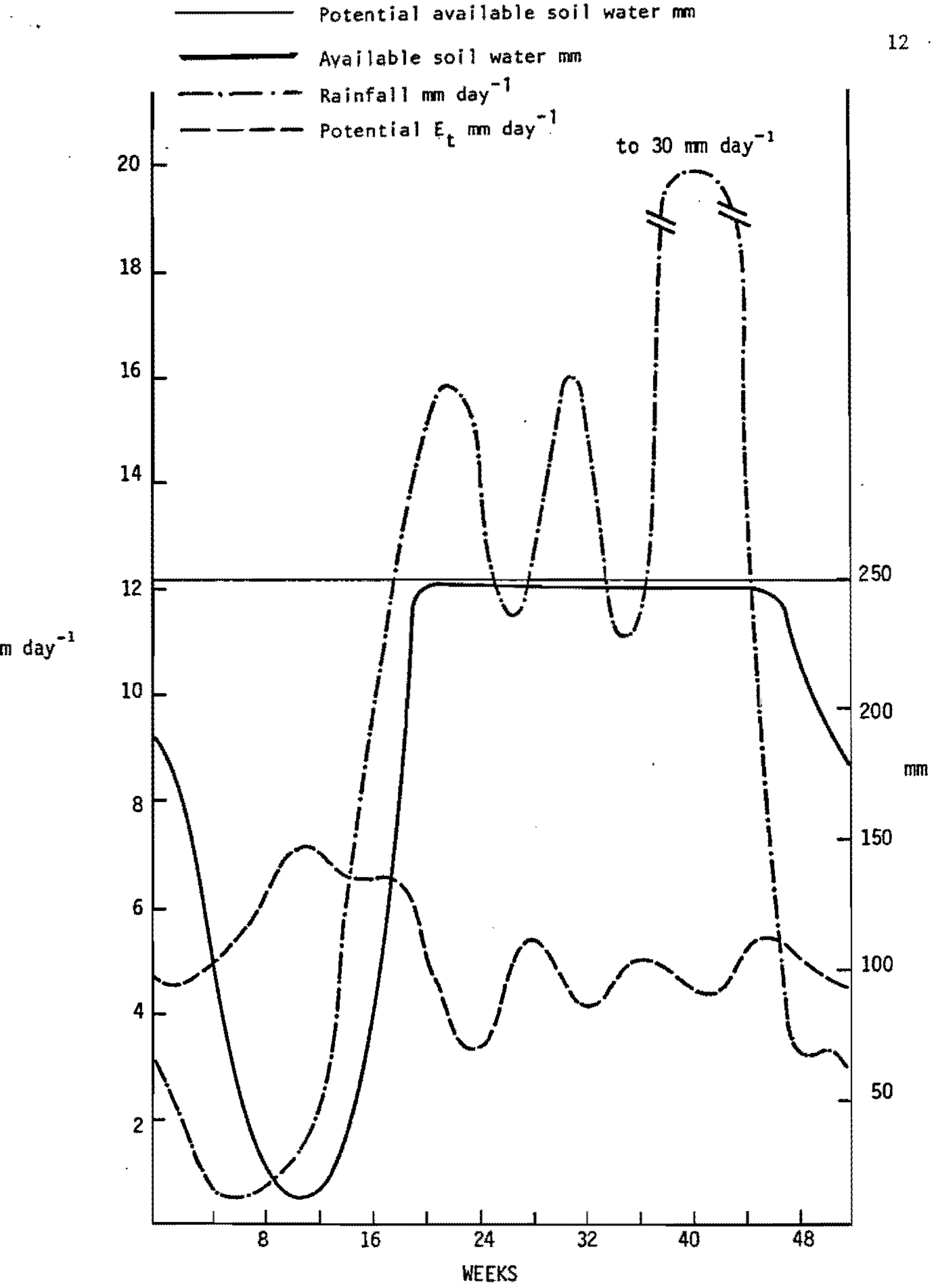

FIGURE 1: Representative precipitation, evapotranspiration and daily soil water balance for a favoured upland area, meterological station, Palmar Sur, Costa Rica.

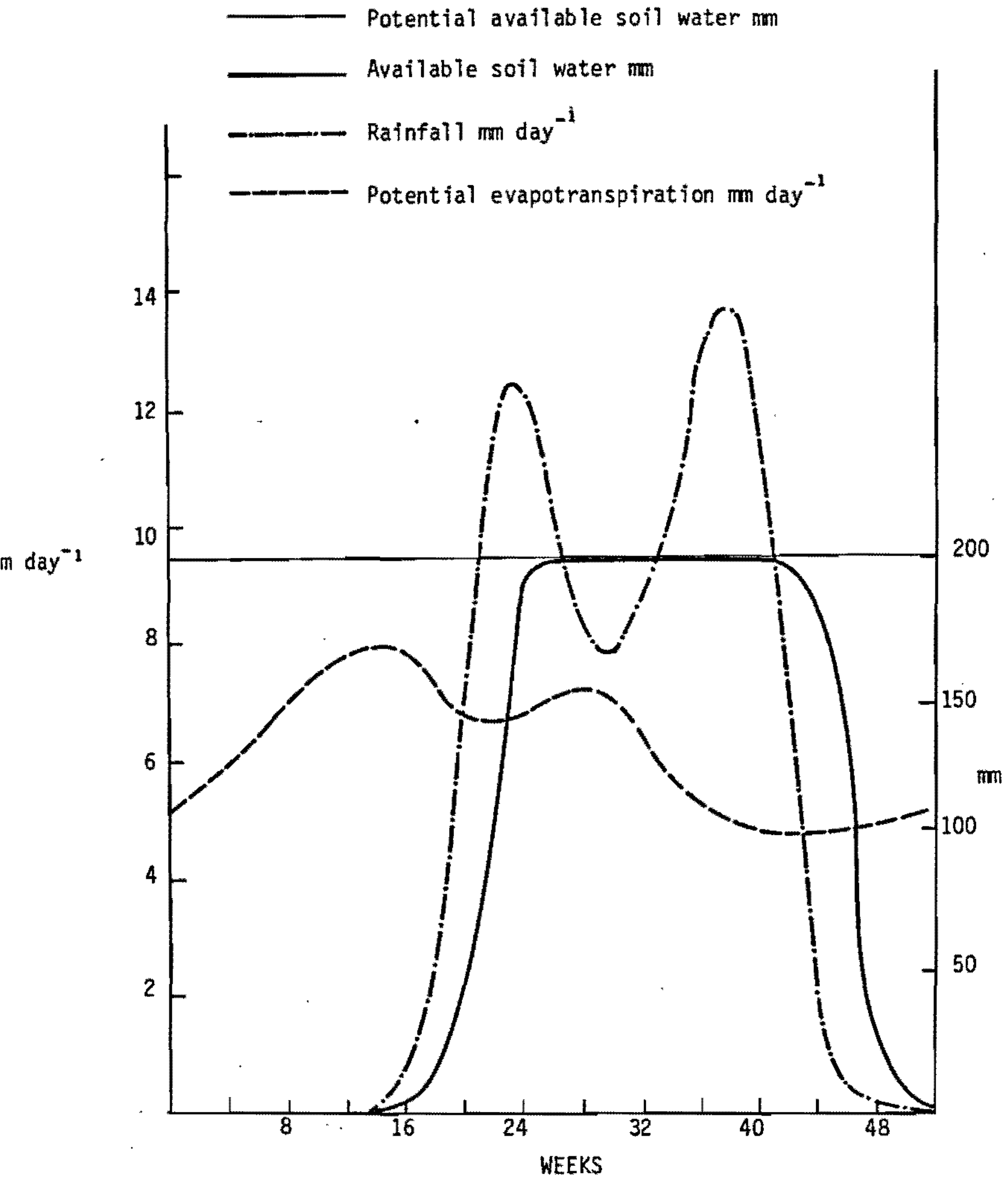

FIGURE 2 : Representative precipitation, evapotranspiration and soil water balance for a moderately favoured area Station Usulatan.

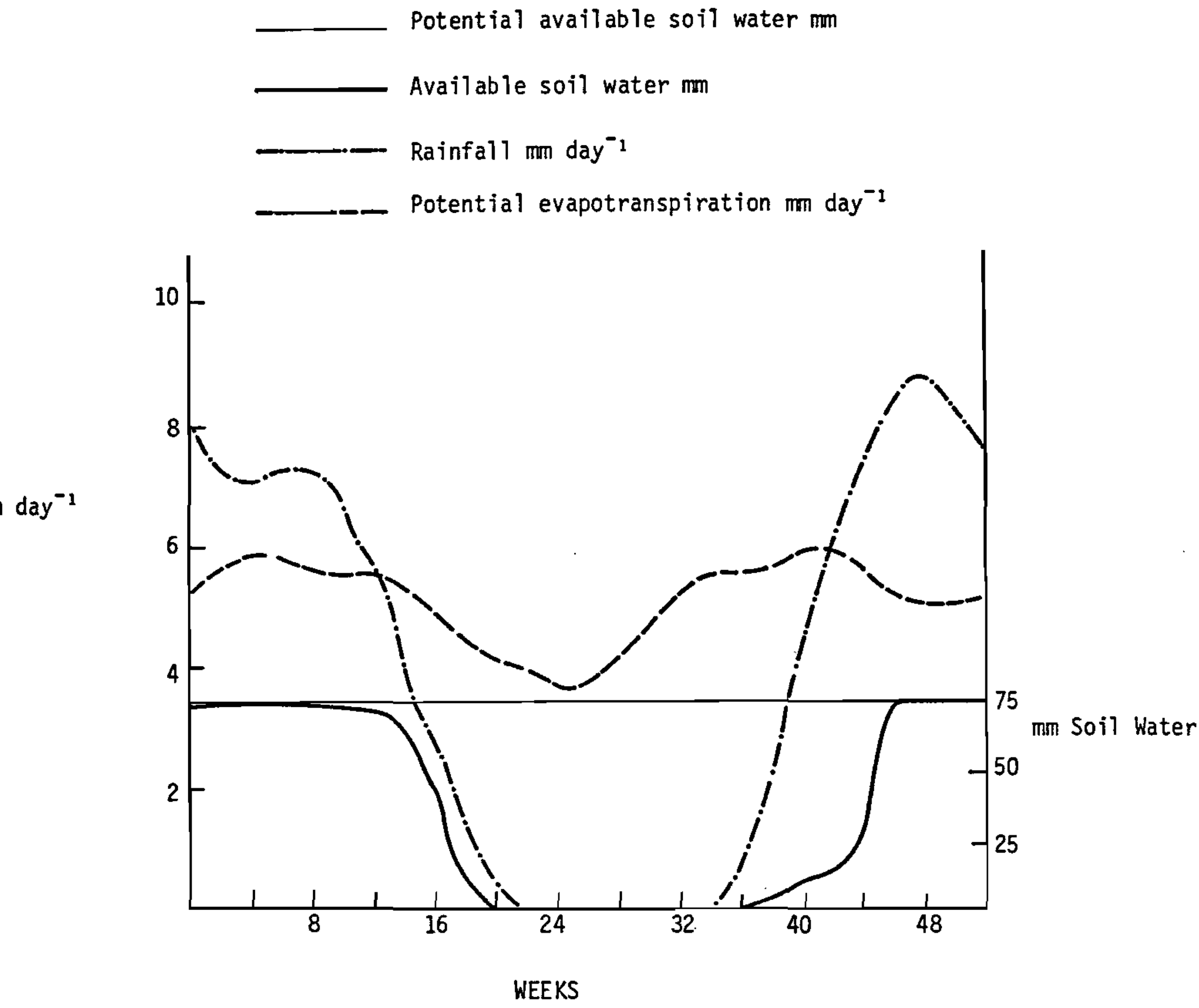

FIGURE 3: Representative precipitation, evapotranspiration and daily soil water balance for an unfavoured upland area, meterological station Goiania,Brasil.

than 1/3 of potential plus that part of the season rendered unusable due to too short a growth cycle. The results of this exercise (Table 2) clearly distinguished the unfavored locations. Mild stress days induced by reduced rainfall, were defined as those days with soil water between 1/3 and 2/3 of potential. At favored sites no mild stress days were encountered with a simulated 50% reduction rainfall. At almost all moderately-favored sites a considerable number of mild stress days was experienced. Stress was predicted to be severe at the unfavored sites. The probability of a reduction in monthly rainfall by 50% differs across the locations. There would be a higher probability of reduced rainfall at the moderately-favored and particularly at the unfavored sites, as noted in Table 2.

PRESENT STATUS OF ECOZONES DEFINED BY CIAT'S TEAM:

As studies have not advanced to the stage of defining and mapping exact ecozones for upland rice in Latin America the CIAT Team have maintained their provisional groupings of favored, moderately favored (or less favored) and unfavored, but have added the classification (perhaps specific in nomenclature to Colombia) of savanna. This last denotes a region of rainfall completely adequate for upland rice, but with adverse soil conditions. These soil conditions include low base status, low ph and more or less aluminium saturation. Table 3 gives the present situation of major CIAT testing stations for upland rice.

Table 3. Constraints to rice production and its severity found in four different testing sites[a].

	DISEASES							PESTS		SOILS PROBLEMS		OTHERS	
Sites	P. oryzae	R. Oryzae	H. oryzae	Grain discoloration	HBV	Acrocy-lindrium	Entyloma oryzae	Sogatodes oryzicola	Rice Weevil	Al Toxicity	Fertility	Water stress	Weed infestation
Santa Rosa (Favored)	***	***	**	**	***	*	*	***	**	—	High	—	***
La Libertad (Savanna)	***	***	**	***	***	*	—	***	**	***	Very low	—	***
Tocumen Panama (Favored)	**	***	*	*	*	**	***	*	—	—	High	*	**
Rio Hato Panama (Less favored)	*	*	*	*	*	*	*	*	—	—	Low	***	**

a.
- = Absent
* = Low severity
** = Moderate severity
*** = High severity

SURVEY OF UPLAND RICE IN THE ANDEAN COUNTRIES:

In this section I will present the results of a preliminary agro-ecological study of upland rice growing areas in the Andean region.

The study involved various stages of activity; description of the crop distribution, derivation of homogeneous cropping microregions from these distributions, collation of edaphic and climatic data with these microregions.

The definition of upland rice quoted by Garrity (1982) as: "rice grown in fields that are not bunded, are prepared and seeded under dry conditions, and depend on rainfall for moisture", has been chosen for this study. Considerably ingenuity has been required to estimate the production of this rice from the varied statistics of the Andean countries, and it is inevitable that some confounding, especially with non irrigated, bunded rainfed rice may still exist. Future studies of the microregions will clarify this.

Many countries fail to differentiate between irrigated, mechanized upland or traditional manual upland in their reported statistics. While the areas sown to irrigated or upland rice may be reported, other sources (for instance agricultural credit statistics) were often needed. It was often impossible to estimate yields. Thus yields are not reported here and I have been unable to use the current CIAT classification of favoured, moderately favoured and unfavoured areas which depend closely on a knowledge of achieved or potential yields.

Methods

a) Crop Distribution. Cropping areas were defined wherever possible at the municipio level from agricultural census data. This was not frequently possible and various more aggregated data sources were of necessity used. Within the broadly delimited statistical areas, cropping regions were identified from satellite imagery and, where available, land use maps. Irrigation areas were identified and discounted. An inventory of cropping microregions was formed, recording the area sown for each microregion. These data are not necessarily contemporaneous from microregion to microregion and must be used only as a guide to the relative importance of the region.

b) Soil Data. Cropping microregions were drawn on 1:1,000,000 overlay of the ONC (Operational Navigation Charts). The relevant region for each microregion was transferred from the FAO soil map of the world at 1:5,000,000 and overlaid on the microregion. Areal extents of each soil association was measured. Areas of agriculturallly unsuitable soils were ignored. It is unsatisfactory to work from 1:5,000,000 soil mapping back to the more accurate 1:1,000,000 scale, but lack of detailed soil maps for many countries gave no alternative. Wherever possible and where doubt existed the soil mapping boundaries were checked against recognizable topographic and vegetation pattern in the satellite images. This greatly increased the probability of allocating production areas to the correct mapping unit.

Subareas within individual mapping regions were assigned following the FAO method (FAO 1981). Associated soils were assigned progressively decreasing percentages of the area as the number of associated soils increased. A similar technique was used for inclusions. Known non-agricultural soils were discounted immediately and the sown area allocated to the remaining soil types in the following manner: if prior knowledge of the distribution of rice in the area existed (eg. upland rice being concentrated on the vega soils in the Colombian Llanos) then the sown area was allocated to that soil type or types; if no prior knowledge existed but cultivated areas could be unequivocally identified from satellite image, then production was assigned to the identified facet (ie. dominant or inferred associate soil); if neither of the above held then production was divided on an area proportional basis.

c) Meteorological data. CIAT climatic database data are long term monthly means and as such are of use only as an average guide. They do not reflect the short term fluctuation observed and hence say little about varietal stability or crop risk.

In certain areas, studies of directly estimated probabilities of rainfall or runs of rainfree days are available from compilations of long term daily rainfall data. These studies are scarce and expensive.

Markov models of rainfall have been used by many authors. (See Stern 1982 Garbutt et al 1981), but until now have required that a long run of daily rainfall data was necessary for the estimation of the model parameters. Recent work at CIAT, (Jones in preparation) has shown that there are recognizable patterns in the coefficients for third order Markov models of daily rainfall within certain tropical climate types.

Third order Markov coefficients are a set of eight conditional probabilities. The set of eight can be viewed as a 2^3 factorial arrangement of factors taking value 1 if rain fell and 0 if not. The three factors denote days -1, -2 and -3 respectively. Using generalized least squares analysis (Baker and Nelder 1978), the main effects and interactions of these factors can be analysed. The data are analysed as counts of rain days with a binomial distribution and probit link function. The resultant analysis of deviance (which can be regarded as CHI squared) is analogous to the normal analysis of variance and can be readily used to determine the significance of an extra fitted term.

In no case, in nearly 20 data series from Latin American stations, have there been significant terms in the model higher than the factor main effects. This means that a third order Markov model may be reduced from eight probability coefficient to a mere 3 probit coefficients.

With further research it is hoped that these three coefficients may be estimated by either Kriging, or a model based on climate type to eliminate the necessity of storing vast files of daily rainfall data. The present study included only Kopen Af and Aw climates and it was possible to estimate the matrix of probabilities to a reasonable approximation from the number of rain days per month. Unfortunately, the value of mean rain days per month is not always published and so had to be estimated. In tropical climates, rain arrives in rainstorms with characteristic intensity and duration distributions which are roughly similar within climate classes. There is therefore a general functional relationship between total monthly rainfall and long term average rain days per month. The function is restricted to the origin and is asymptotic to the full number of days per month with increasing monthly total rainfall. For simplicity we assume 31 days per month and write:

$$D = \frac{R}{a + .0323\ R}$$

Where D is mean rain days per month and R is the average monthly total rainfall in millimeters, and'a' is an estimatable constant. Data from Rudloff (1981) gave an estimate for 'a' of 5.92±.97 over a wide range of Koppen A class climates throughout the Americas. This estimates rain days per month with the estimates accounting for approximately 70% of the squared deviations from the observed mean.

This relationship was applied to monthly rainfall means for each meteorological station representative of a rice growing microregion. The matrix of probabilities was estimated for each month and each probability interpolated to a 365 daily series by Fourier transform.

Thus it was possible to estimate the probability of series of dry days within any chosen cropping period.

For full simulation of rainfall sequences the amount of rainfall per day must be estimated. This is readily done using incomplete gamma distributions as are common in the literature (Stern 1982 etc.). It is to be hoped that the parameters of these distributions prove to be interpolable as do the Markov probit coefficients.

Distribution of Upland Rice

Maps 1 to 5 show the locations of microregions identified for the study. The areas as shown on the maps do not necessarily represent the area planted but the area over which planting occur. Areas sown are shown, classified by FAO soil mapping unit and country, in Table 4.

Although in each country one or two soil types predominate, there is no clear cross correlation between countries. Thus gleysols and fluvisols are the preferred soils in Colombia, whereas ferric luvisols account for the majority of Venezuelan plantings and Vertisols for those of Ecuador.

Following Garrity (1982), the soil mapping units were classified into a subjective fertility capability scale. (See Table 5). Certain areas of the Andean fluvisols on the FAO map are undesignated as to fertility status due to lack of information. I have placed these in a lower fertility class than the Eutric fluvisols although many in reality may be better soils than this would indicate.

Although substantial areas are sown on the inherently good soils, the fluvisols and vertisols of class 3, there is a general distribution down to the luvisols of class 7. While those are probably the poorest soils represented in the body of the area distribution, it should be noted that they are considerably better than the ferralsols of group 8.

TABLE 4. Areas[+] sown to upland rice in the Andean region.

FAO Soil Mapping Unit	COUNTRY				
	BOL	COL	ECU	PER	VEN
Ao[*]	7060	-	100	-	6080
Bd	21800				
Be					20
Fo					75
Fx					110
Ge	12340	15030	360	4770	50
Gh	500			7120	
Gm					50
J	12240			7730	430
Je	7320	36460			1090
Lf	6880				62700
Lo		522			
Lp	11040				
Nd		1250	1270		2050
Ne				1100	
Vc				6870	2580
Vp			10940		
We	3900	2500			1000
Vm	1000				

[*] For full names of the mapping units see Table 2.

[+] Hectares: estimates are not necessarily contemporaneous although every effort has been made at standardization.

TABLE 5. Areas sown to upland rice the Andean region grouped by inherent fertility status*

Inherent fertility status rating	Soil Mapping Unit		Area sown hectares
2	Be	Eutric Cambisols	20
3	Je	Eutric Fluvisols	44900
	Lo	Orthic Luvisols	520
	Vp	Pellic Vertisols	10940
	Ve	Chromic Vertisols	9450
4	Ne	Eutric Nitosols	1100
	J	unspecified fluvisols	20400
5	Gm	Mollic Gleysols	50
	Ge	Eutric Gleysols	39600
	We	Eutric Planosols	8400
6	Bd	Dystric Cambisols	21800
	Ao	Orthic Acrisols	13240
7	Lf	Ferric Luvisols	69580
	Nd	Dystric Nitosols	4570
	Lp	Plinthic Luvisols	11040
	Gh	Humic gleysols	7620
8	Fo	Orthic Ferralsols	75
	Fx	Xanthic Ferralsols	110

* Modified after Garrity (1982)

Little upland rice is sown in this lowest group even though the group of ferralsols and poorer acrisols (almost equivalent to the oxisols of US Soil Taxonomy) are by far the most extensive in the potential agricultural lands of the region. It is a subset of these soils with high rainfall that have been denoted 'Savanna' ecozone. Although practically no upland rice is presently sown in the Andean regions in this ecozone, a potential for commercially acceptable yields has been determined.

Table 6 summarizes the plantings by country and inherent fertility class.

Climate and growing season.

A conservative estimate of growing season length is that continuous period during which precipitation exceeds potential evapotranspiration (E_t). Some studies, (ie. FAO 1981) include periods where precipitation is less than potential E_t but greater than half of it. Also counted should be an allowance for residual soil moisture at the end of the season. Future studies at CIAT will incorporate a more sophisticated approach and attempt to estimate growing season from simulated soil water budgets, but due to the preliminary nature of this study only the simplest estimates will be presented.

Allowing subjectively for subhumid periods at either end of the season (those with rainfall approaching but not exceeding evapotranspiration) and residual soil moisture use, it is reasonable to say that 100 days should normally be sufficient to produce an upland rice crop without the shortness of the season seriously impeding crop growth. As can be seen from Table 7, only 12% of Andean upland rice

TABLE 6. Area sown to upland rice in the Andean region classified by inherent fertility class and by country.

Inherent Fertility class	COUNTRY				
	BOL	COL	ECU	PER	VEN
2					20
3	18,360	37,000	10,900	6,900	3,700
4	12,200			8,800	400
5	16,900	17,500	260	4,800	1,100
6	28,900				6,080
7	7,400	1,200	1,300	7,100	64,700
8					200

TABLE 7. Areas (hectares and proportion) of upland rice in Andean region classified by growing season length.

Humid days*	Hectares	Percentage
Less than 50	21900	9
50 - 100	8090	3
100 - 150	136900	57
150 - 200	44700	19
200 plus	29600	12

* Number of consecutive days on which precipitation exceeds potential evapotranspiration.

land falls out of this category. The vast majority has at least adequate or surplus season length. This to a large extent vindicaties the initial survey described above.

Looking now to Table 8 we can see where this season restricted rice occurs. A large proportion is found in Bolivia, on gleysols which probably provide phreatic water. A further considerable area (over 7000 ha) is on eutric fluvisols and 4900 ha on planosols, either of which could suffer season inundation or could unbeknownst to this study be bunded. Another factor with the Bolivian production is that the low number of humid days is due, in part, to very high seasonal evaporation levels (See Fig 4). These follow the trend of seasonal rainfall and produce a long subhumid period after a humid period sufficient for establishment.

With few exceptions the above arguments point to the fact that in the Andean region of Latin America few people attempt to grow upland rice in a season that is demonstrably too short. This does not exactly agree with the data presented by Garrity (1982) for Asia. It may reflect a regional difference, or merely the restricted scope of this study.

Nevertheless, rainfall and its variability is a deciding factor in the viability of an upland rice growing region even within the constraints of season length. The latter part of the analysis of this study is taken up with a discussion of rainfall variability and its effect on the rice crop.

How does rainfall variability determine rice yields? Many authors have proposed various stress/soil water relationships for a range of crops. These range from crude rules of thumb to precise measure

TABLE 8. Season length* of upland rice in the Andean region. (See Table 4 for relevant areas of each class).

FAO Soil Mapping Unit	COUNTRY				
	BOL	COL	ECU	PER	VEN
Ao	127		155		147
Bd	122				
Be					147
Fo					133
Fx					133
Ge	133	273	365	245	210
Gh	35			365	
Gm					210
J	146	157		226	126
Je	21				54
Lf	26				136
Lo		98			
Lp	21				
Nd		217	182		122
Ne				211	
Vc				165	70
Vp			109		
We	63	42			126
Wm	35				

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* Number of consecutive days on which mean precipitation exceeds potential evapotranspiration.

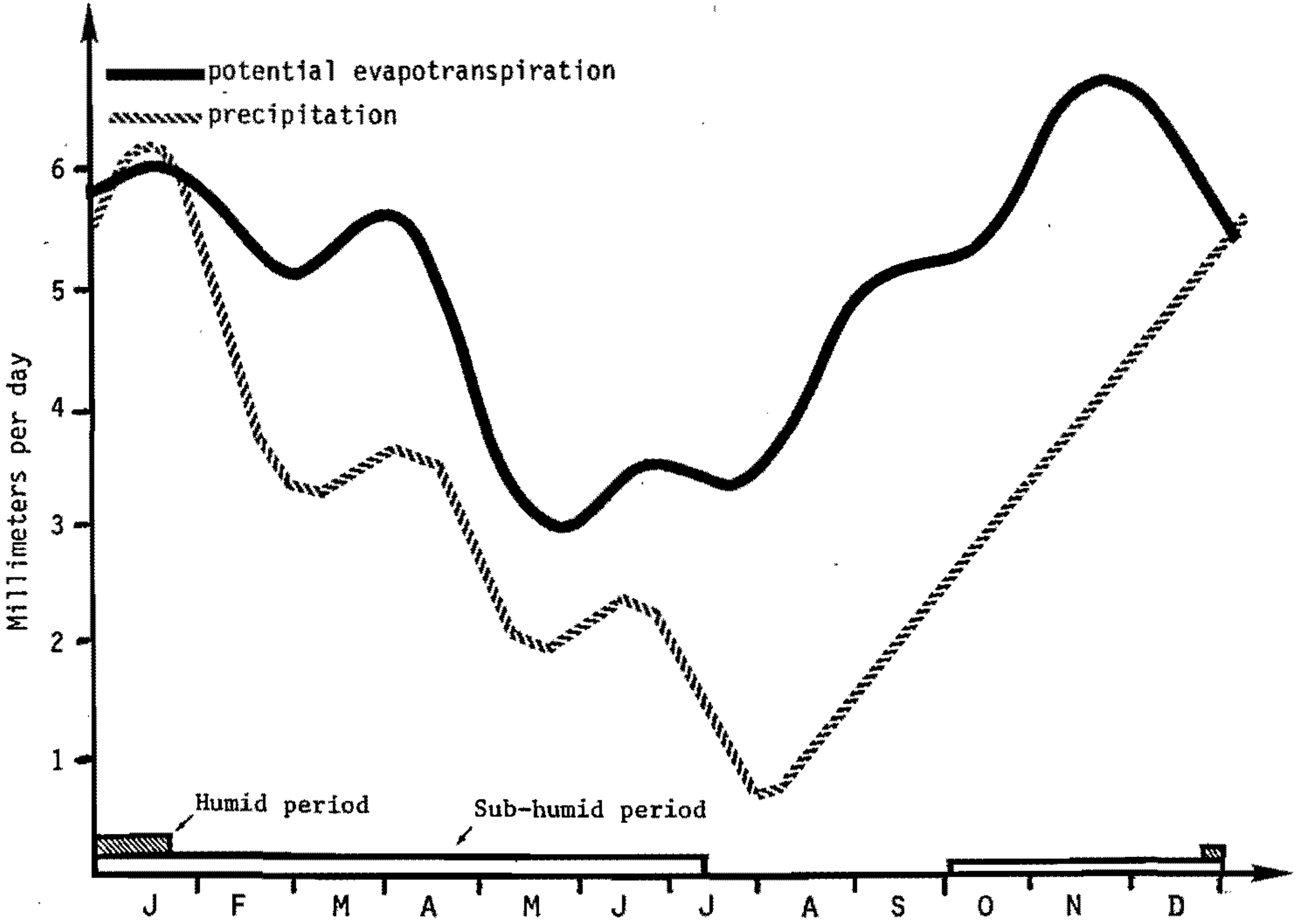

Fig.4. Daily precipitation and evaporation figures for Santa Cruz, Bolivia.

functional relationships. I have chosen to take a very conservative but simple estimate. Let us say that when available soil water has fallen to half of its potential value then, on average, soil water potential will have fallen to such a level that yield will start to suffer due to lack of assimilated carbon. Let us gloss over some obvious anomalies by pointing out that in this study all soils are of fine texture, and thus soil water holding capacity, in my view, is related to rooting depth rather than texture. The first step is to assign soil water holding capacities to the various soil mapping units encountered in the study. Since no literature exists on the ability of upland rice to extract water in these Latin American soils, Table 9 represents my inspired guesses.

Evidently the water availability for the gleysols may be much underestimated depending on the level and permanence of the water table. The water holding capacity of the vertisols is evidently great, but depends on rooting depth and I have been conservative.

To determine when the crop will reach the critical level of half soil water available really should be determined by a soil water balance. This was not possible in this preliminary study and so another very conservative approach was used. The current potential evapotranspiration was calculated for each day at each site and simply summed to yield half the potential soil water holding. The number of days required for this was recorded and from the Markov models the probability of this occurrence was calculated.

The probability of this event happening in each of three periods of the crop growth was calculated.

TABLE 9. Estimates of soil water availabilities for soils in the Andean zone study.

mm available water	Soil classes
45	Fx
50	Ao,Fo,Nd
60	Lp
70	Lf,Ne
80	Lo,Bd
100	Be
120	Vc,Vp
150	W,We,Wm,Gh,Gm,J,Je
180	Ge

The periods were the second, third and fourth months of the crops growing season. These probabilities, for the purpose of this paper, have been combined to yield the overall probability of a crop being stressed during its latter three months. Note that probabilities are combined as

$$p_1 V p_2 V p_3 = 1 - (1-p_1).(1-p_2).(1-p_3)$$

When the end is to evaluate the probability of the event occurring during <u>any</u> of the three periods. This should therefore yield a value much greater than any of the individual probabilities. Table 10 gives the results of this operation. To determine the areas involved please refer to Table 11. General observations are that Bolivia is the more susceptible country and that drought stress is negligible in the middle range of fertility. Poorer soils are more likely to be stressed but also the good soils (the fluvisols, vertisols and orthic luvisols) are not necessarily exempt. The probability of catastrophic crop failure is not what is being measured here; merely that the crop will at some stage undergo physiological stress.

What does this mean for classification of Upland Rice ecozones? It shows that in addition to season length, a rainfall reliability factor must be incorporated into the classification. Apparently the season length is important in Asia and, although I minimised it in this paper, certain restricted areas in the Andean region. Must we use both? This raises two very important questions:

What are the essential environmental variables for a usable classification?

How many classes does the classification needs?

TABLE 10. Probability that upland rice sown in the various inherent fertility classes will suffer at least one period of physiological water stress.

Inherent fertility class	COUNTRY				
	BOL	COL	ECU	PER	VEN
2	-	-	-	-	1.0
3	.79	.12	.35	.48	.43
4	.22	-	-	.20	.02
5	.15	.04	.00	.01	.02
6	.95	-	-	-	.99
7	.96	.99	.62	.07	.72
8	-	-	-	-	.96

TABLE 11. Areas sown to upland rice in the Andean zone classified by fertility class and probability of 7 dry days in the second month of the cropping season.

Inherent fertility class	Probability				
	0-.4	.4-.6	.6-.8	.8-1.0	TOTAL
	Hectares				
2 + 3	8820	16100	20000	20300	65300
4	3000	9400	5900	3300	21500
5	3000	10100	28000	4300	45000
6	0	10500	7200	17400	35100
7	58000	7500	27000	800	93000
8	200				
	Percentage				
2 + 3	13	25	31	31	100
4	14	44	27	15	100
5	7	22	62	9	100
6	0	30	20	50	100
7	62	8	29	1	100
8	100	0	0	0	100

TOWARDS AN HEIRARCHIC AGRO-ECOZONING AND BEYOND

It is absolutely incontrovertible that International Research and National Programs need a broad simple classification to aid in conceptualizing the problem. If nothing else, a simple diagram and map that can be made into a readily interpretable slide is nowadays considered essential for research presentations to donors and boards of trustees.

We must not be lulled into the complacency of thinking that a simple ecozone classification describes the world for all aspects of the crop. There still exists detail beneath this superficial level which is of vital importance in some discipline or other. For example what have we said about temperature? About dew persistence for fungal spore germination? What is the effect of diurnal temperature range?

With care, all these factors and many more of specific interest can be built into a heirarchic ecozone classification system that the scientist or administrator may use at whatever level he feels to be appropriate. What we end up with is a taxonomy of ecozones.

Classifications are a necessary tool of science and are used extensively to clarify thought in many complex situations. They are often, however, artificial and overly rigid. Take an example from our experience at CIAT. Cassava has a marked change in growth response at about 20-21°C. It would be useful to trace that change using one of the well known climate classifications which are already mapped. Obvious choices would be Koppen or Papadakis. Neither of these classifications divide temperature regimes at this point, but at 18°C and at 24°C. They are therefore too rigid to use for our purpose.

What is the alternative to a rigid classification? One answer is the database. Sophisticated database technology used to be restricted to those who owned a large expensive mainframe computer. This is no longer the case. Most IARCs now have the computing capacity and, as described above, CIAT is working towards implimenting a database. For those of more limited means, the microcomputer is fast becoming a realistic alternative for small but extremely useful databases. With the data immediately on hand, specific questions may be answered directly without recourse to a restricting classification.

We will always need at least the highest level of the classification system given explicity and named, to allow for easy discourse on the subject. Whether we need explicit definitions for the lower levels depends on the implementation of the databases. I feel that we should all be working to give greater access to the basic data for the scientists who need it, and not forcing them into a system which may not fit their needs. This is not an easy option. Precise definition of data structure is a difficult task and is something that I hope we may fruitfully discuss during the rest of this workshop.

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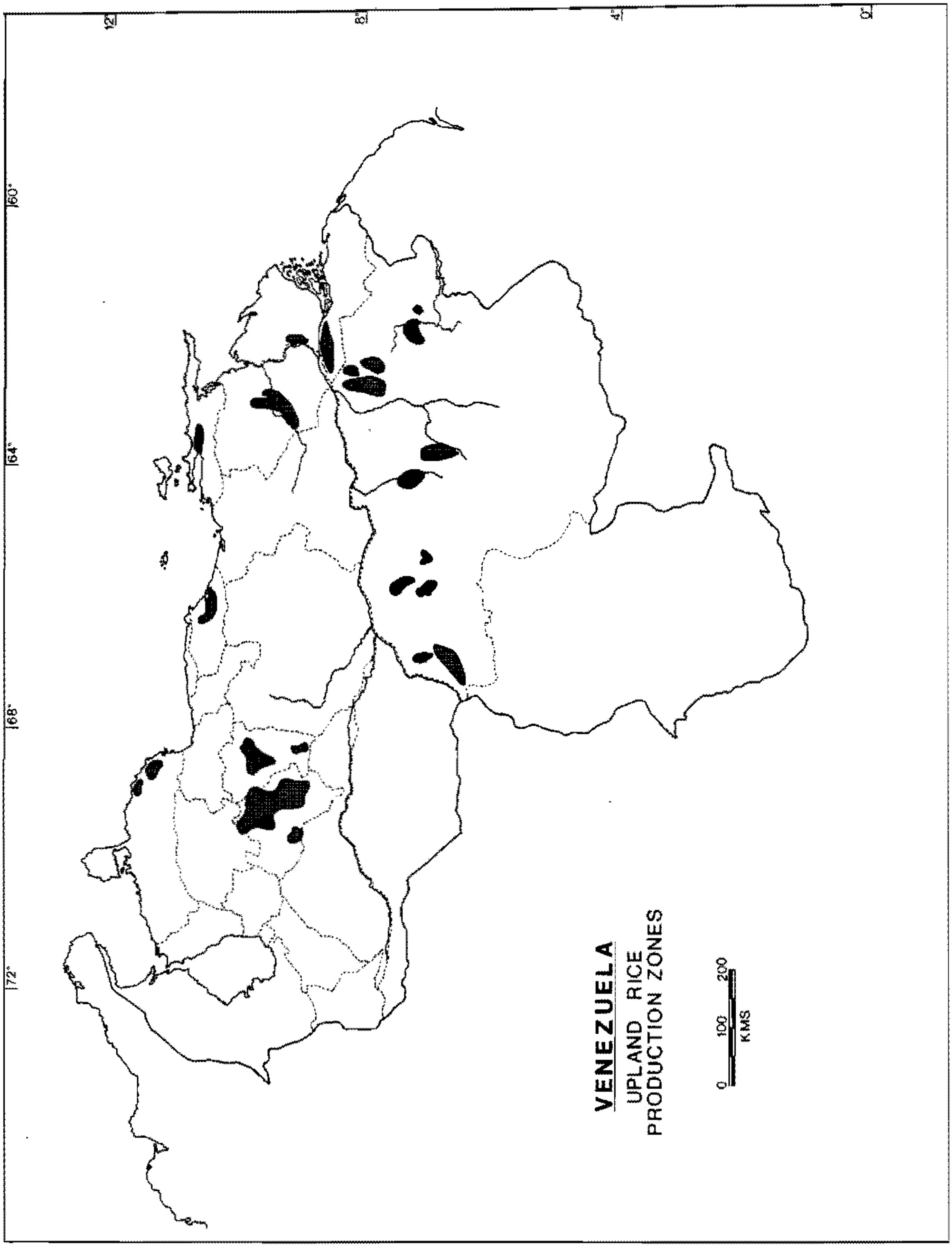
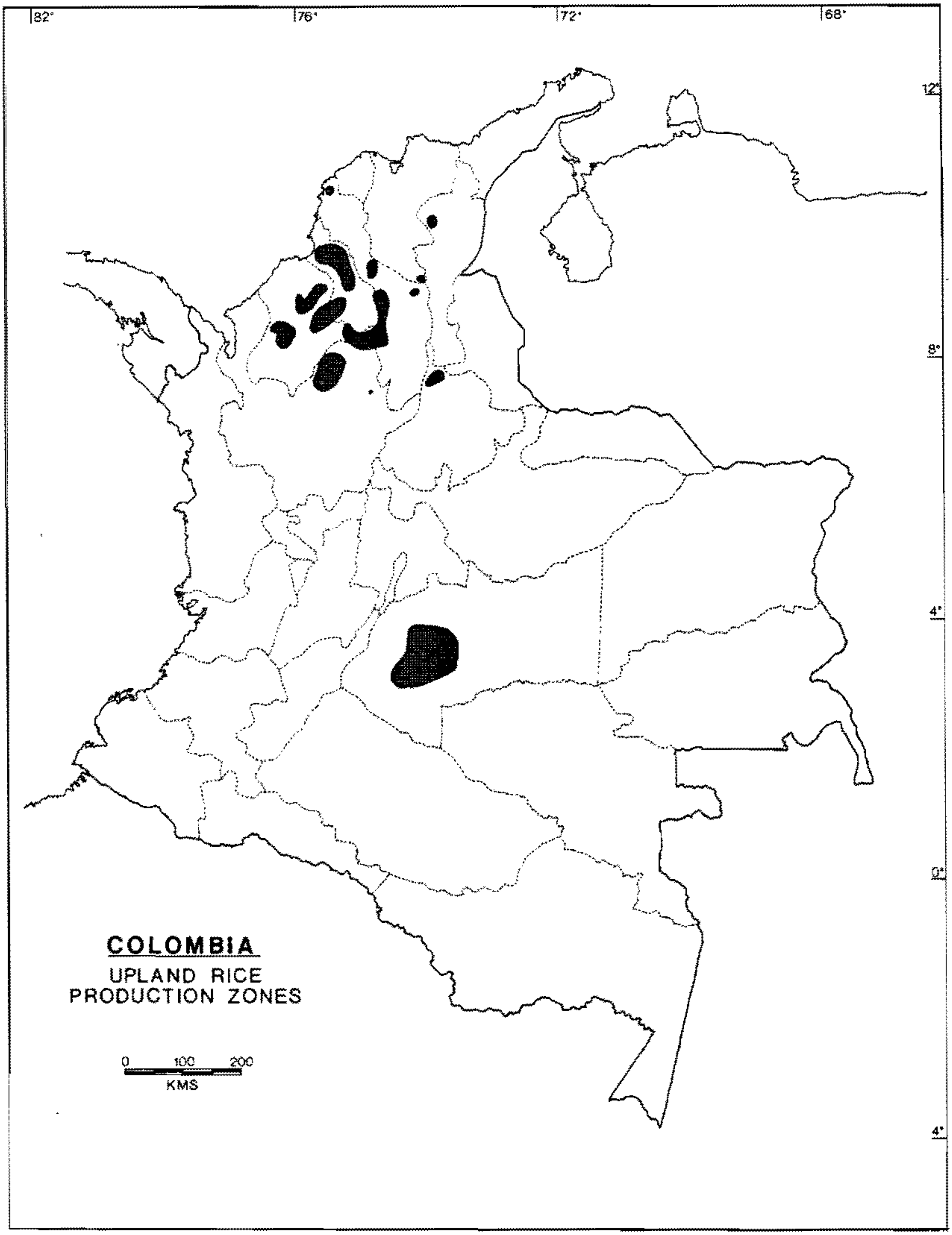
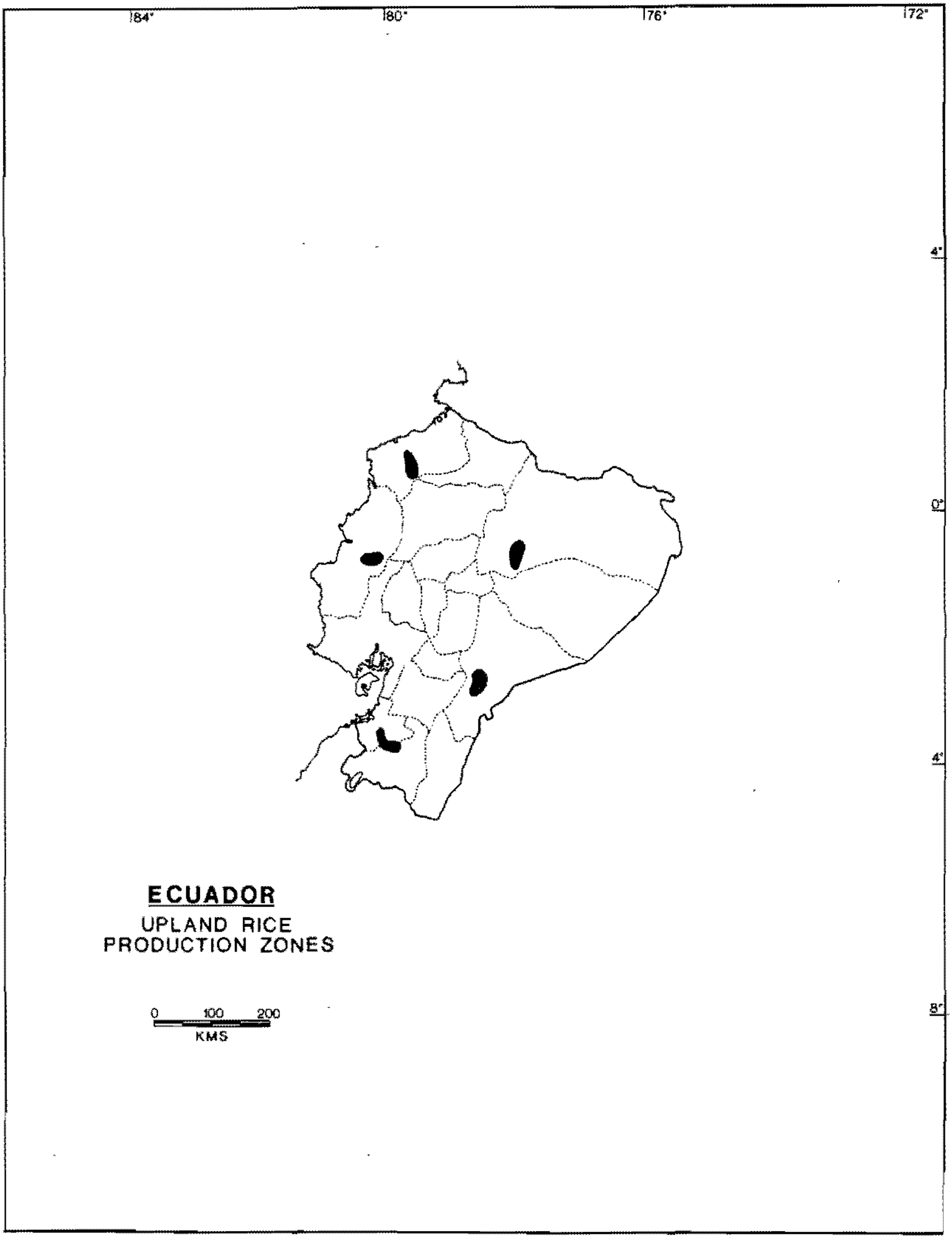

VENEZUELA
UPLAND RICE
PRODUCTION ZONES
0
100
200
KMS
12°
8°
4°
0°
60°
64°
68°
72°

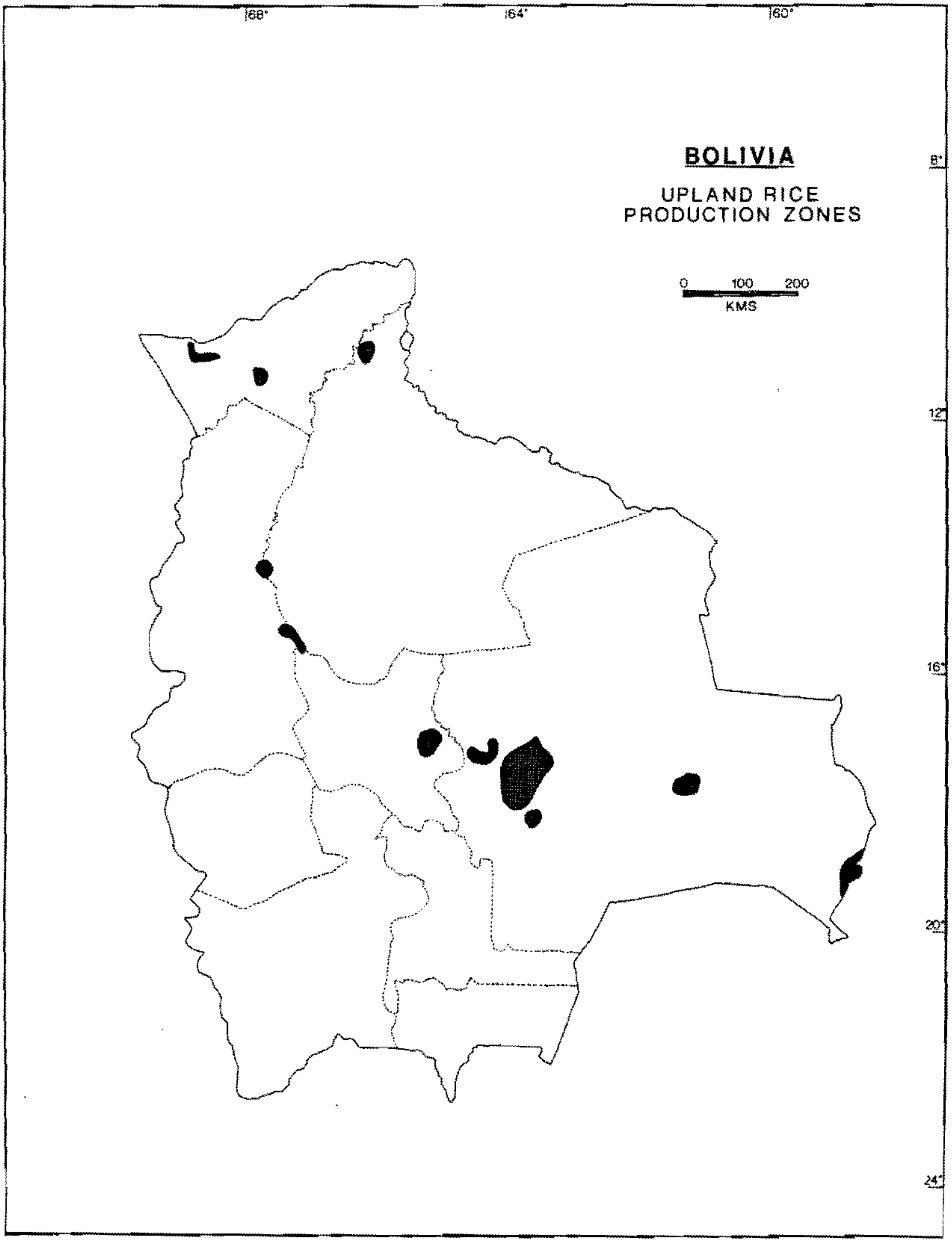
MAP 1


82°
76°
72°
68°
12°
8°
4°
0°
4°
COLOMBIA
UPLAND RICE
PRODUCTION ZONES
0 100 200
KMS

MAP 2


84°
80°
76°
72°
4°
0°
4°
8°
ECUADOR
UPLAND RICE
PRODUCTION ZONES
0
100
200
KMS

MAP 3


68°
64°
60°
BOLIVIA
UPLAND RICE
PRODUCTION ZONES
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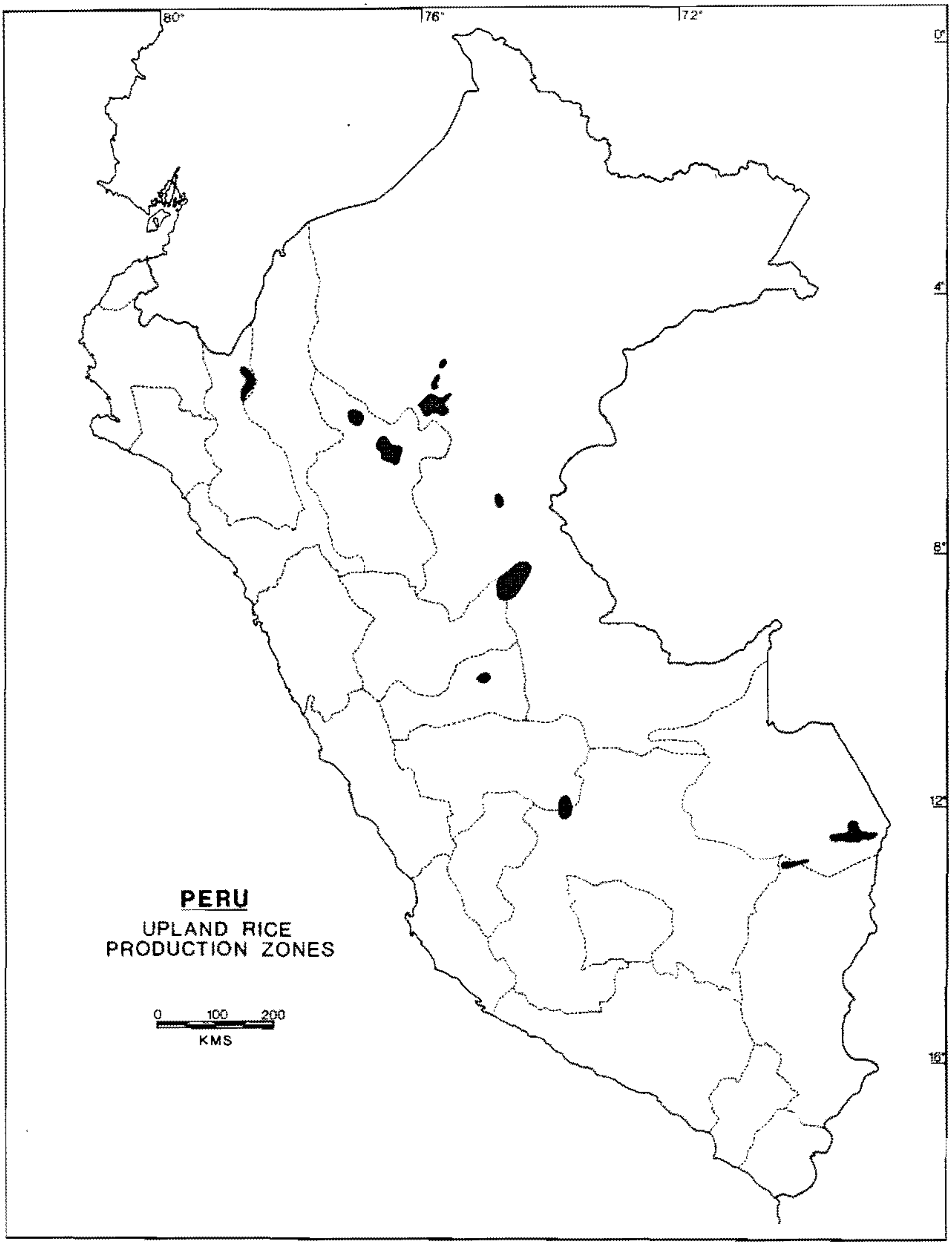
100
200
KMS
8°
12°
16°
20°
24°

MAP 4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76°
72°
0°
4°
8°
12°
16°
PERU
UPLAND RICE
PRODUCTION ZONES
0
100
200
KMS

MAP 5