UPLAND RICE IN THE ANDEAN REGION

A PRELIMINARY AGRO-ECOLOGICAL INVENTORY

P. G. JONES

CIAT - AUGUST 1983

(PRESENTED IRTP, CIAT - AUGUST 1983)

SUMMARY

A study was made of upland rice growing regions in the Andean countries, Venezuela, Colombia, Ecuador, Peru and Bolivia. Rice growing areas were identified by available statistics and satellite imagery. Soil data was taken from FAO Soil Map of the World at 1:5,000,000 and climatic data from the CIAT climatic database. An agro-ecological inventory of rice production was produced.

Andean upland rice is produced on a range of soils from highly fertile fluvisols down to only moderately fertile soils. Very little is produced on the very infertile ferralsols soils. The majority of Andean upland rice is grown in regions with adequate season length, but rainfall variability, particularly on the poorer soils, may give rise the drought stress during the season.

RESUMEN

Se hizo un estudio de las regiones que siembran arroz de secano en los países andinos, Venezuela, Colombia, Ecuador, Perú y Bolivia. Las áreas de cultivo de arroz fueron identificadas por medio de datos estadísticos disponibles y por imágenes satélites. Los datos de suelos fueron tomados del Mapa Mundial de Suelos de la FAO a escala 1:5,000,000 y los datos climáticos de base de datos climáticos del CIAT. Un inventario agroecológico de producción de arroz fué presentado.

El arroz andino de secano es producido en suelos desde fluvisoles altamente fértiles hasta suelos ligeramente fértiles. Muy poco es producido sobre suelos ferrasoles muy infértiles. La mayoría del arroz andino de secano es sembrado en regiones con duración adecuada de estación húmeda, pero variabilidad de lluvia, particularmente en los suelos muy pobres pueden ocasionarse un alto stress de sequía durante la época de crecimiento.

INTRODUCTION

In this paper I will present the results of a preliminary agro-ecological study of upland rice growing areas in the Andean region. The southern Andean countries Chile and Argentina produce no upland rice and therefore are excluded from the study.

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.

By study of the distribution of a crop in its present distribution one would hope to obtain a description of the environments suitable for the production of the crop and to rank them in their suitability. This is evidently true for a crop with a long history of stable production and has been used with success in the case of *Phaseolus vulgaris*. It is to be hoped that this approach will hold with upland rice in the americas where it is an introduced crop. Rice has been established as an important crop in Colombia since at least 1580 (Leurquin 1967) and although changes have occurred in the distribution of upland rice in the last 50 years, see maps 1, 2 and 3, there are numerous stable areas of production.

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. Considerable 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, bounded 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 often be informed other sources (for instance agricultural credit statistics) 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

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.

Soil Data.

Cropping microregions were drawn on 1:1,000,000 overlay of the ONC (Operational Navigational 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 agriculturally 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. 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 aras to the correct mapping unit.

Subareas within individual mapping regions were assigned following the FAO method (FAO 1981). Associated soils were assigned progressively

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decreasing percentage 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. uplant 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.

Meteorological data.

CIAT now possesses a climatic data-base of long term mean climate records from over 4500 Latin America wide meteorological stations. Data recorded include rainfall and potential evaporation, temperatures (max, min and mean), solar radiation and windspeed. Not all of these are available for all stations. However, rainfall, the most spatially variable is always available so and the others may often be interpolated.

These 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

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rainfall within certain tropical climate types. More work is needed to generalize these relationships for varied climate types but within the Koppen Af and Aw classes which are those important for this study it is possible to obtain a rough estimate of the matrix of eight probabilities necessary for the model provided that the mean probability of rain is known.

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 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 estimable constant. Data from Rudloff (1981) gave an estimate for 'a' of $5.92 \pm .97$ 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.

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Distribution of upland Rice

Maps 5 to 8 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 plantings occur. Areas sown are shown, classified by FAO soil mapping unit and country, in Table 1.

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 2). 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. 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.

Table 3 summarizes the plantings by country and inherent fertility class.

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TABLE 1. 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 2. 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)

TABLE 3. 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

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 4 only 12% of Andean upland rice land falls out of this category. The vast majority has at least adequate or surplus season length.

Looking now to Table 5 we can see where this season restricted rice occurs. A large proportion is found in Bolivia, some (See Table 1 for the relevant areas) on gleysols which probably provide phreatic water. A considerable area (over 7000 ha) 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 1) these follow the trend of seasonal rainfall and produce a long subhumid period after a humid period sufficient for establisment.

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TABLE 4. 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 evapo-transpiration.

TABLE 5. Season length* of upland rice in the Andean region. (See Table 1 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				

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

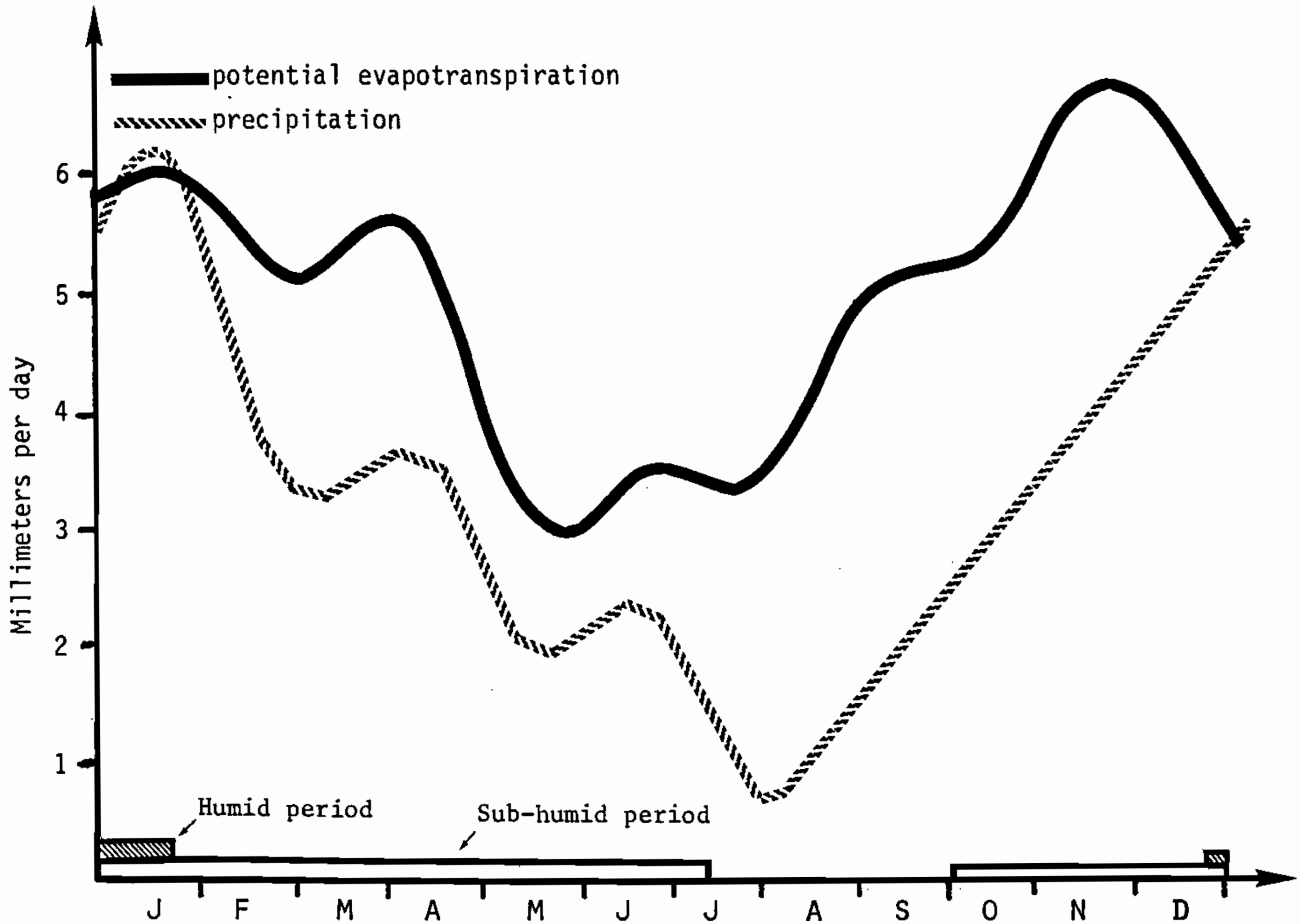

Fig.1. Daily precipitation and evaporation figures for Santa Cruz, Bolivia.

With few exceptions the above arguments point to the simple 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 is in rough agreement with the data presented by Garrity (1982) for Asia, and with common sense.

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? The hypothesis in this study is that it may be two fold. Physiological drought stress may be defined as occurring when the plant is unable to obtain sufficient water from the soil to maintain transpirational flow and results in stomatal closure and and loss of photosynthate. This will reduce yield in varying amounts depending on the phenological incidence of the stress. Usually the early reproductive phase is the most sensitive.

Many authors have proposed various stress/soil water relationships for a range of crops. These range from crude rules of thumb to precise measured 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 6 represents my inspired guesses. I will not argue with anyone who can produce experimental evidence to show that they are wrong, but agree to incorporate all such information in future extension of the study.

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TABLE 6. 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

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.

The periods were the second, third and fourth months of the crops growing season. These probabilities are available to anyone interested but 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 7 gives the results of this operation, to determine the areas involved please refer to Table 3. 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 physilogical stress.

TABLE 7. 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

Now we come to the second hypothesis of the effect of rainfall variability. Susceptibility to attack by *Piricularia* is undoubtedly linked with rainfall patterns, a susceptibility which is also affected by soil type (Jennings pers. comm.)

As a preliminary investigation of the extent of the preconditions of blast attack in the region studied, I have calculated the probabilities of a period of 7 dry days during the second month of the crop. Please note that the same was calculated by default for the third and fourth month and if required could be provided for any given length of dry days for any phenological period of the crop, space restricts a full rendering of the results but I will be happy to accommodate specific requests from the regions involved.

I do not pretend that Table 8 gives a definitive prediction of the probability of blast since many other factors must be accounted for. It does show the prime requisite; that a dry period exist. The main feature of the table is that a high proportion of the Andean zone rice crop is subject to the minimum requirements for blast epidemic. Soils in the lower fertility classes have on average a lower incidence of the dangerous dry periods, but this may only reflect the climate/soil interaction in that better crops on better deeper soils have a better chance.

The point worthy of note is that the only crops on class 8 soils have a very low probability of a week of dry weather. This would not be the case for many areas of other soils of this class. If upland rice is to be extended to these areas then piricularice resistance is obviously of paramount importance. No one would disagree with this obvious statement but if we look back at Table 7 then it is apparent that in the lesser favoured soils physiological drought stress is liable to play a much greater part in breeding requirements.

TABLE 8. 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

Conclusions

1) This study has been disadvantaged greatly by lack of sufficient statistics. I would urge that:

   a/ All countries attempt to provide at least decenial published agricultural censures at the municipal level.

   b/ That local agencies undertake surveys of rice growing that clearly differentiate irrigated, mechanized upland, traditional hand cultivated upland and rainfed rice culture.

   c/ A series of trials be initiated to determine the rooting capacity of a range of rice cultivars in upland conditions on soils prevalent throughout potential upland rice regions of Latin America.

2) *Piricularia* will undoubtedly be a problem in all observed and probably all future potential region.

3) Breeding for specific physiological tolerance to water stress will depend much on the soil type involved. At present it is not the major constraint, but if rice production is extended to the poorer soil classes then studies should be made to determine it's severity.

4) Upland rice is grown across a range of soils of varying fertility, but in general rainfall is observed to be more reliable on the lower fertility areas.

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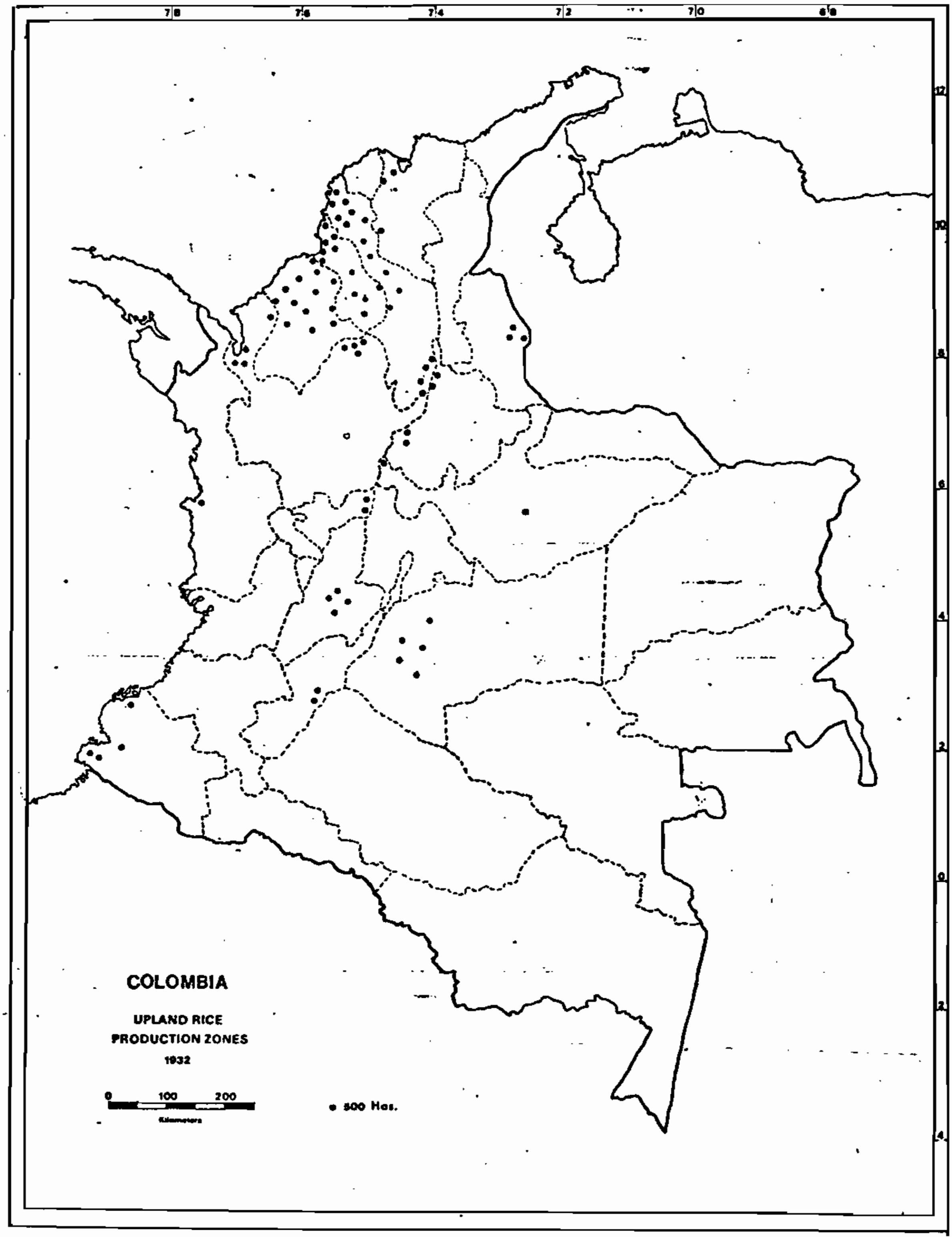
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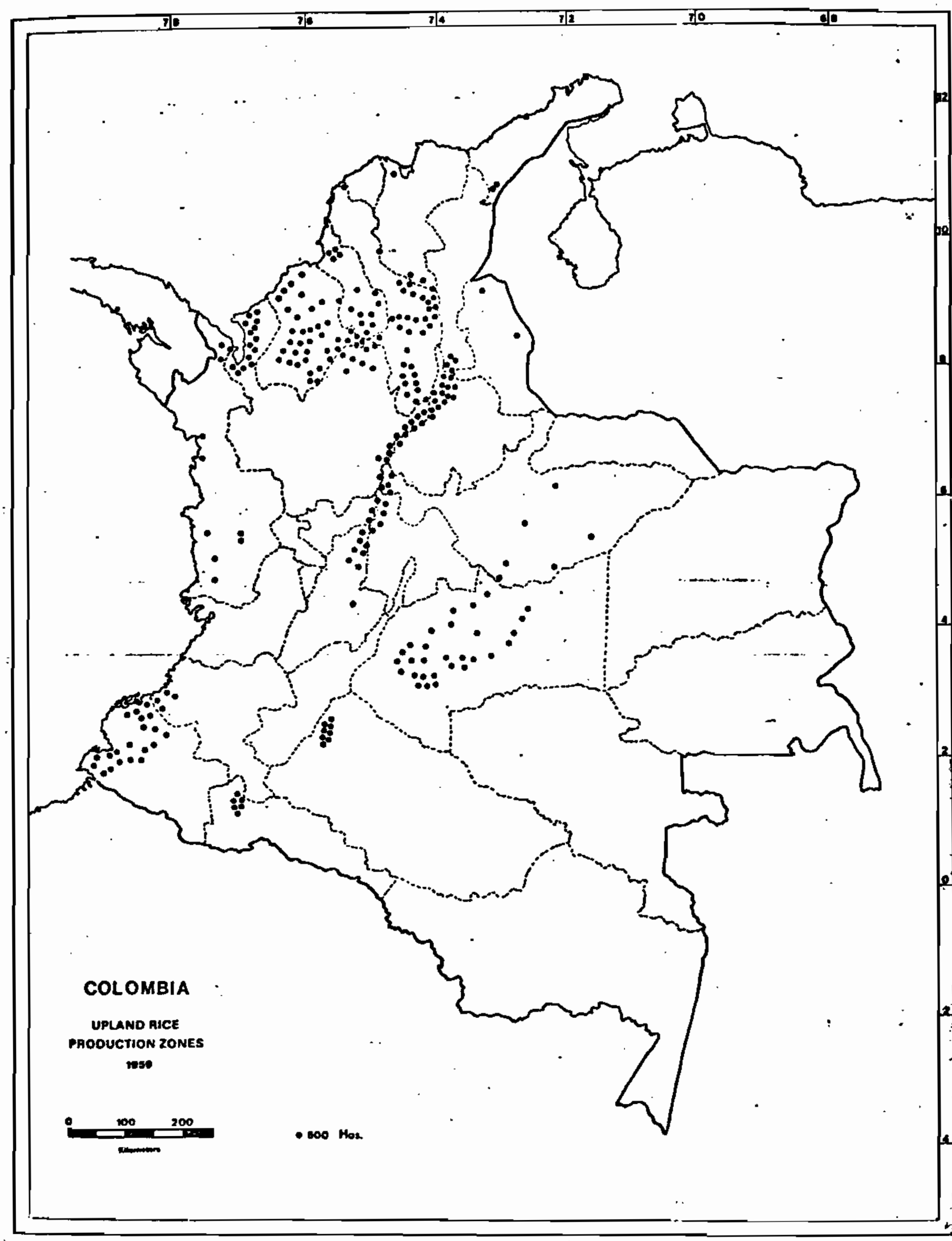
MAP 1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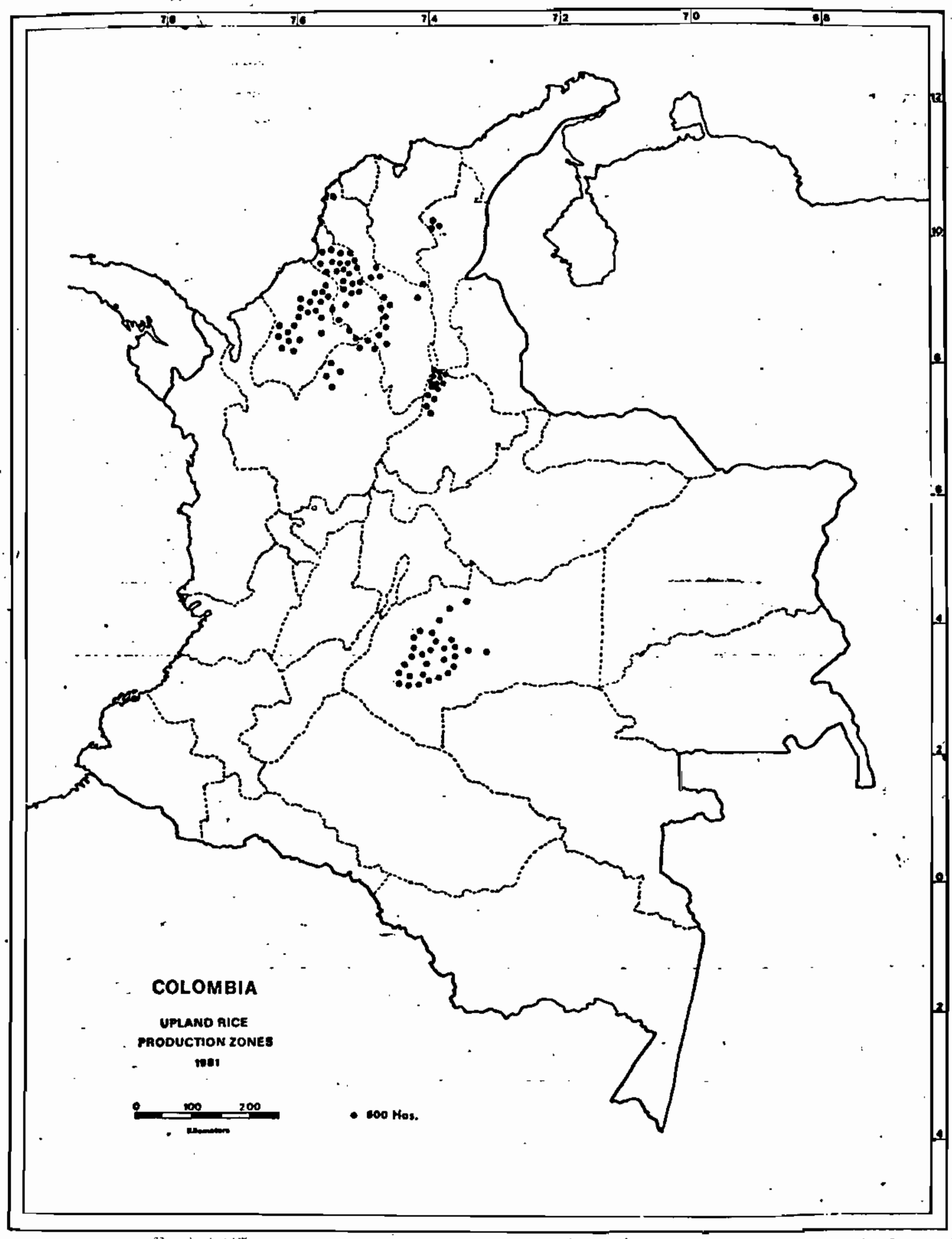
MAP 2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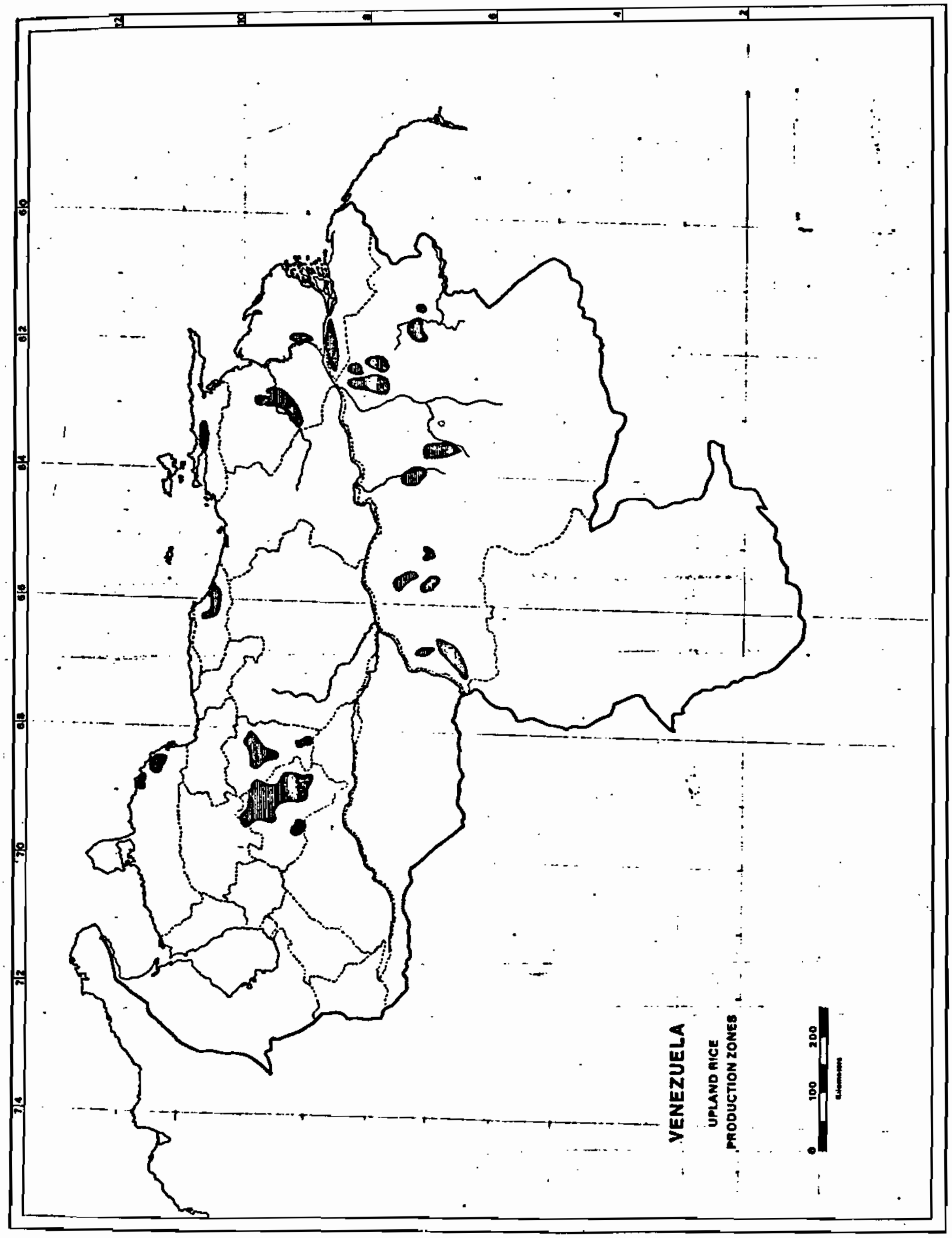
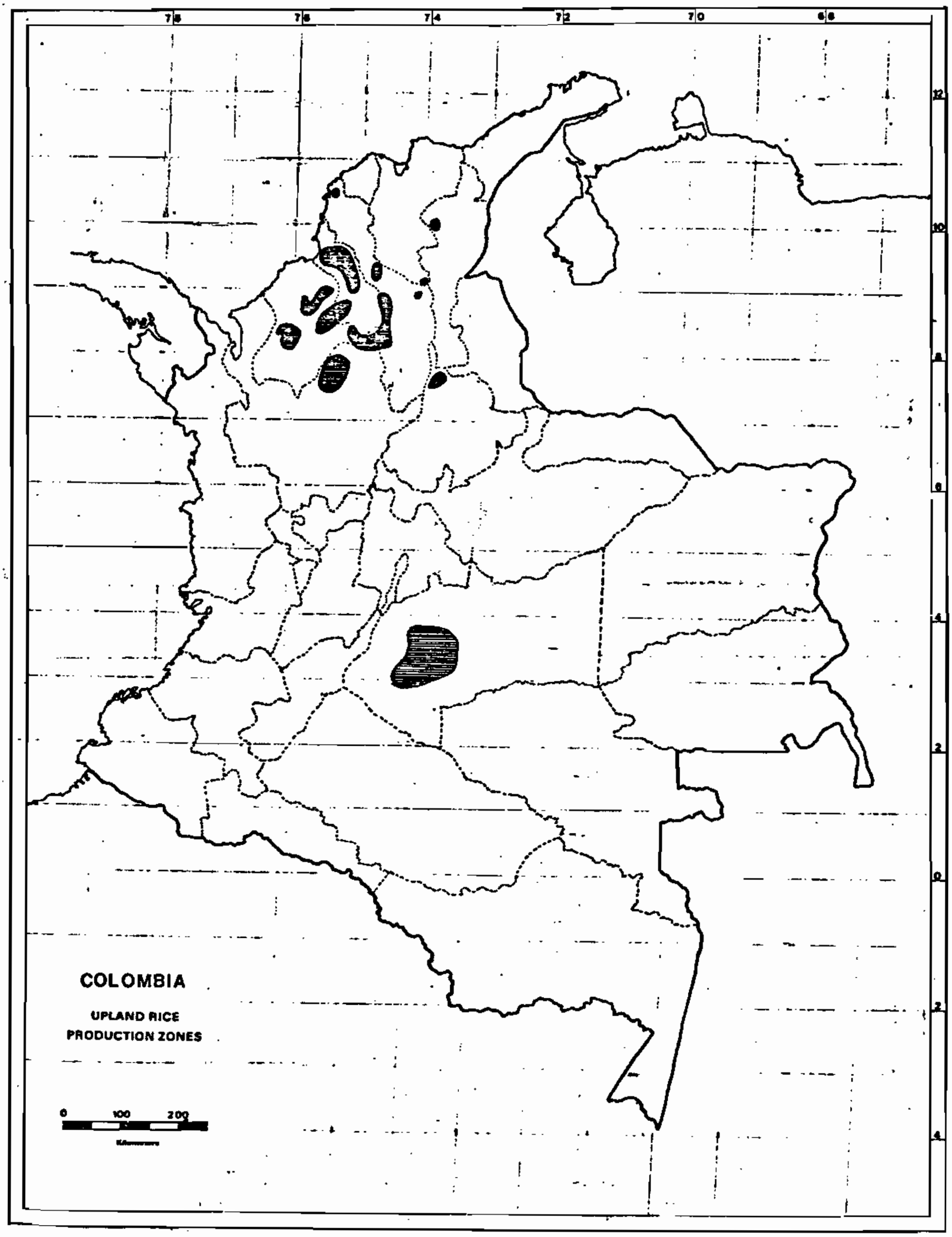
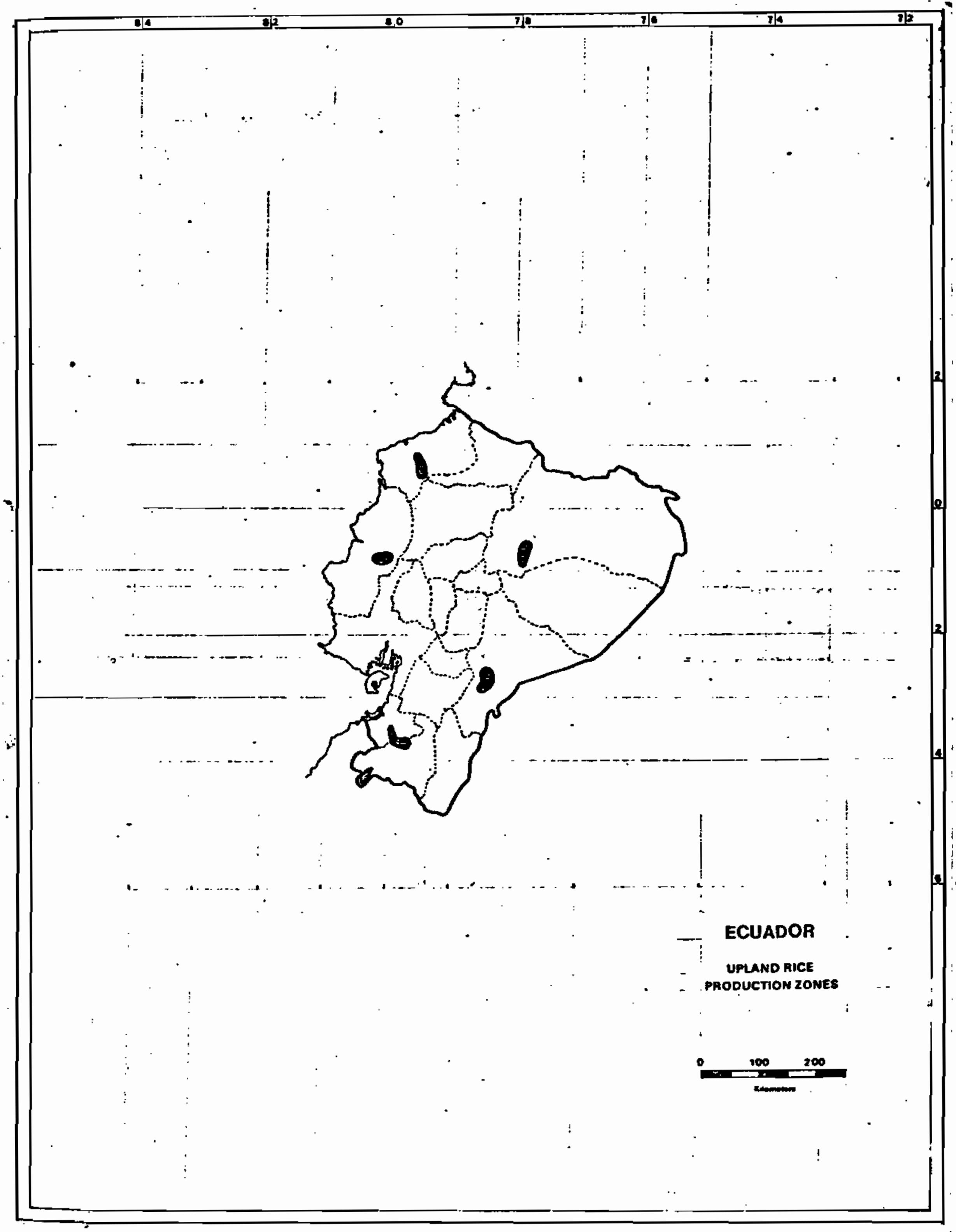
MAP 3



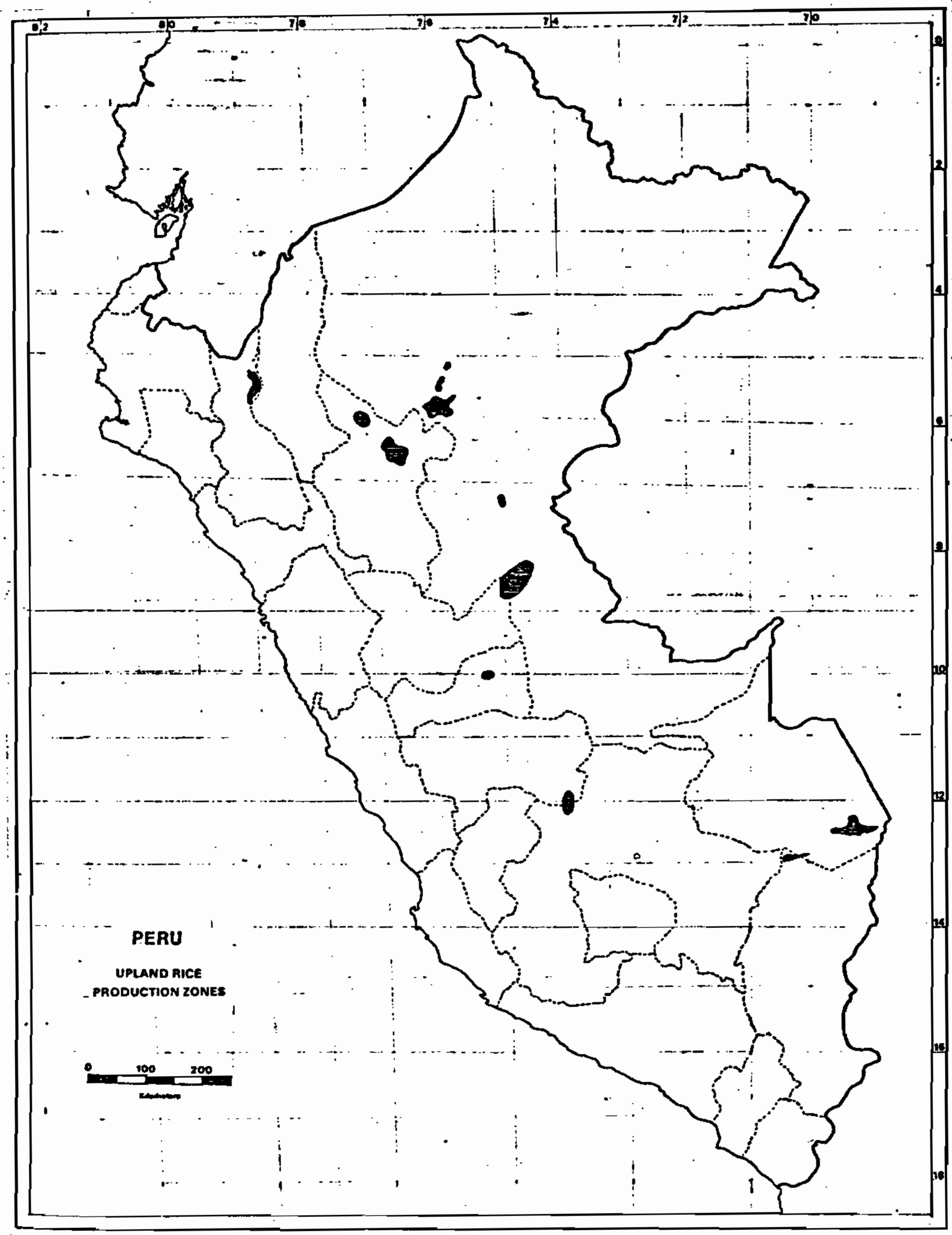
MAP 4



MAP 5



MAP 6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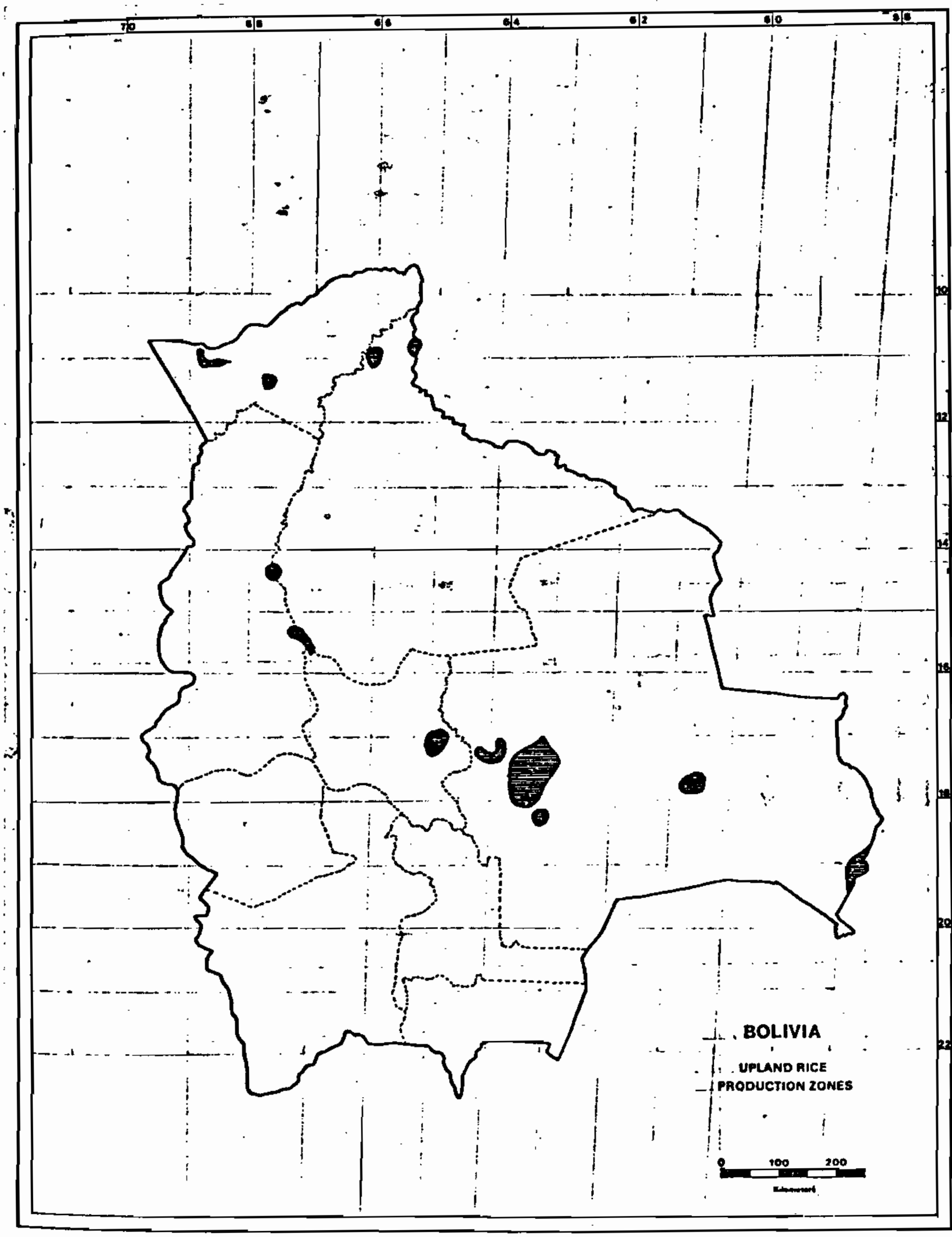
MAP 7



MAP 8