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Distribution of Soils in Production Systems in India

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Abstract

Information on the distribution and attributes of soils is essential for proper resource utilization and for planning and execution of research in any production system In this communication, a brief description of the suborder classification of soils in Production Systems in India is provided The description is based on the delineation of soils in the production systems using the Geographic Information System and the soil map of India

Research projects at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) are based on 29 Production Systems (PS), defined by the key elements in their farming systems These include commodity production trends and key socioeconomic variables, environmental resources, geography, and important issues, or constraints to, and opportunities for improving productivity and sustainable agriculture Of the 12 ICRISAT Production Systems in Asia, 10 occur in India The 1985 National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), "Soils of India (suborder associates)" map based on soil taxonomy was developed using extrapolations from surveys of about 33% of India The objective of this Information Bulletin is to use this soil map to delineate the dominant soils of the Indian Production Systems, and to provide brief descriptions of their suborder classification It is hoped that the publication will be useful to researchers and technology exchange specialists particularly when identifying suitable locations for experimental work

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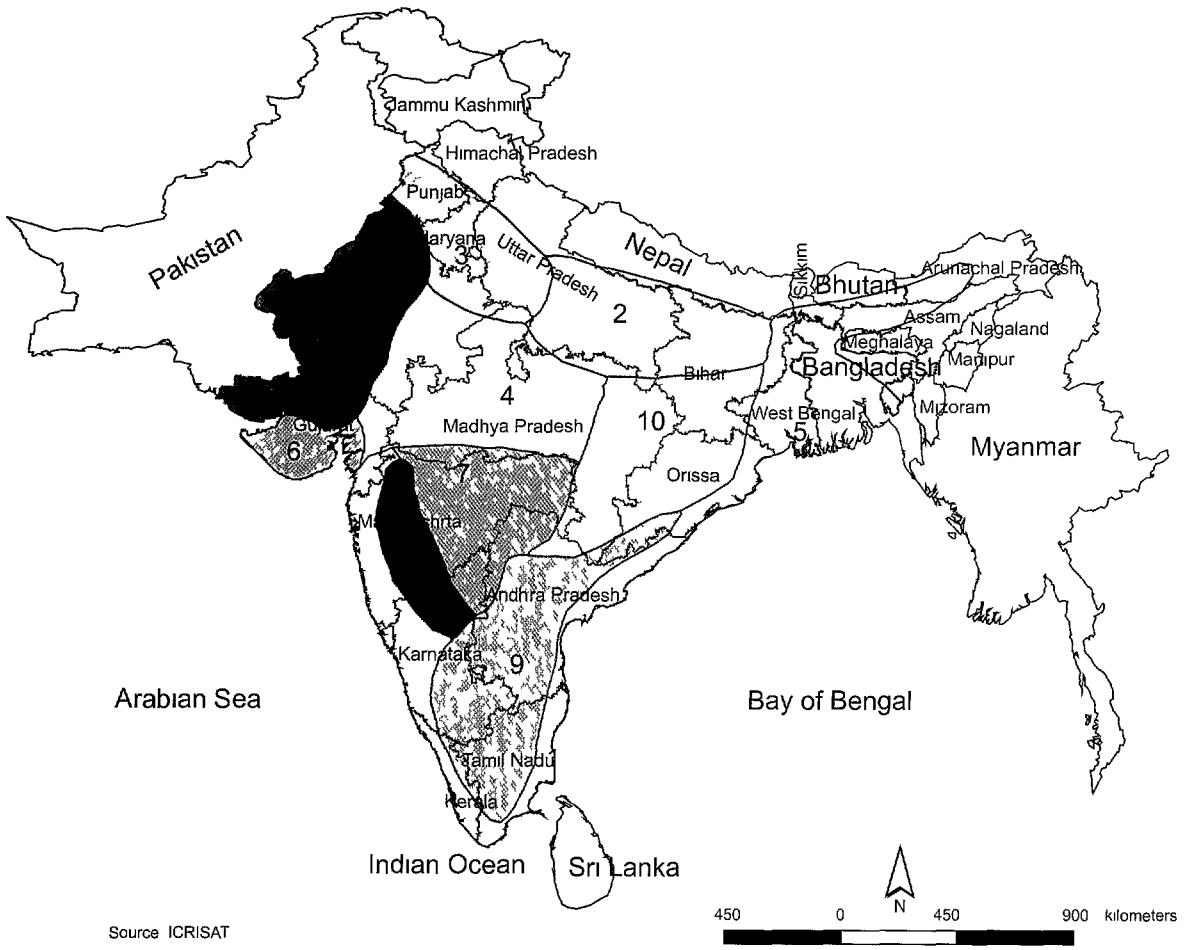

Figure 1 Production Systems in India

Introduction

Research projects at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are based on 29 Production Systems (PS) A Production System is defined by the key elements in its farming systems These include commodity production trends and key socioeconomic variables A Production System is also defined by environmental resources, geography, and important issues, or constraints to, and opportunities for improving productivity and sustainable agriculture (ICRISAT 1994) The Production System approach enables the use of computer-based geographic information systems (GIS) to identify and quantify the coexistence of climate, soil, socioeconomic, and other data that influence agricultural development This approach enables scientists and planners to identify and target priority outcomes and resource allocation during planning to achieve those outcomes in the most efficient and effective way Of the 12 ICRISAT Production Systems in Asia, 10 occur in India

Information on soil attributes is important to research activities in production systems In 1985, the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) of the Indian Council of Agricultural Research (ICAR) published a "Soils of India (suborder associates)" map based on the Soil Taxonomy of Soil Survey Staff (1978) The scale of this map is 1 7,000,000 (NBSS&LUP 1985) The original projection of the map is not indicated in the publication However, because maps produced at that scale by Survey Department of India are generally polyconic, it is assumed to be polyconic The map was developed using extrapolations from information from various surveys of about 33% of India by both the NBSS&LUP and State Soil Survey Organizations The objective of this Information Bulletin is to use this soil map of India that shows association of two or more soils to delineate the dominant soils of the different Production Systems, and to provide brief descriptions of their suborder classification

Order and suborder categories of soil taxonomy

Soil taxonomy has six categories, order (the broadest category), suborder, great group, subgroup, family, and series (the most specific category) The order category is based on soil-forming processes as indicated by the presence or absence of certain major features The names of the orders end in *sol* (Latin *solum* = soil) with *o* as the connecting vowel for Greek roots e g , Spod*o*sol Greek *spodos* = wood ash, or Hist*o*sol Greek *histos* = tissue, and *i* for other roots, e g , Vert*i*sol (Latin *verto* = turn), or Ult*i*sol (Latin *ultimus* = last), and Incept*i*sol (Latin *inceptum* = beginning) The name of each order contains a

Table 1 Soil orders and their formative elements

Order	Formative element	Derivation of formative element	Major characteristics
Alfisol	Alf	Meaningless syllable	Has a horizon of clay or sodium accumulation, high to medium base saturation
Aridisol	Id	Latin *aridus* = dry	Dry soil, light colored low organic matter surface horizon that sometimes contains clay or sodium
Entisol	Ent	Meaningless syllable	Little profile development, light-colored, low organic matter surface horizon
Histosol	Ist	Greek *histos* = tissue	Peat or bog > 30% organic matter
Inceptisol	Ept	Latin *inceptum* = beginning	Embryonic soils with few diagnostic features, may have light or dark-colored surface horizon
Mollisol	Oll	Latin *mollis* = soft	Thick, dark colored, high-base saturation, some have clay or sodium horizons, strong structure
Oxisol	Ox	French *oxide* = oxide	Highly weathered, with hydrated oxides of iron (Fe) and aluminium (Al), no clay accumulation
Spodosol	Od	Greek *spodos* = wood ash	Presence of active amorphous materials composed of organic matter and aluminium (Al) with or without iron (Fe)
Ultisol	Ult	Latin *ultimus* = last	Low base saturation and clay accumulating in a horizon below the surface
Vertisol	Ert	Latin *verto* = turn	High in swelling clays, form deep cracks when soil dries
Andisol	And	Modified from Ando	From volcanic ejecta, dominated by allophane or aluminium-humic complexes

Source Adapted from Brady (1990

formative element that begins with the consonant before the connecting vowel, and ends with the last consonant preceding the connecting vowel e g , in the order name Vertisol, the formative element is ert These formative elements are used as endings for the names of suborders, great groups, and subgroups Thus, the names of all categories above the series belonging to the Vertisol order end in ert and can be recognized as members of that order Table 1 presents names of the 11 orders in this classification and their formative letters

The suborders have two syllables The first denotes the diagnostic properties of the soil, and the second is the formative element from the name of the order Thus, an Aquent (Latin *aqua* = water) added to *ent* from Entisol is an Entisol that so wet that it is virtually free of dissolved oxygen and therefore shows a reducing rather than an oxidizing condition There are 47 suborders Table 2 presents the formative elements in names of suborders

Description of soils in the Production Systems

Production Systems PS 1 to PS 10 are described in Table 3 Figure 1 shows their location in India Out of the 11 soil orders of soil taxonomy (Brady 1990), seven occur in the 10 Production Systems in India (Figs 2–11, Table 4) The seven orders and their 14 suborders are shown in Table 5 The Entisols (suborder Orthents) are the most pervasive of all the soils, and occur in all the Production Systems (Table 4) Alfisols (suborder Ustalfs) and Vertisols (suborder Usterts) are found in eight of the 10 Productions Systems but Alfisols occupy a total area of 615016 km^2 and Vertisols 470148 km^2 in all the Production Systems A brief description of the seven soil orders that occur in the Production Systems is presented, followed by a description of their associated suborders

Alfisols

Mineral soils that often have gray to brown surface horizons They are commonly light-colored, have low organic matter content, may be hard, and may not have a structure when dry They normally have a soil horizon in which clays have accumulated by illuviation (Latin *il* = in and *lavere* = to wash) This clay horizon is called argillic (Latin *argilla* = white clay) if only silicate clays are present It is called natric, if in addition to the clay, it is more than 15% saturated with sodium ions (Na^+) and has either a prismatic [i e , structure with prism-like aggregates that have a vertical axis much longer than the horizontal axes and do not have rounded caps (Soil Science Society of America 1987)] or columnar (similar to prismatic but with rounded caps) The cation exchange capacity of the clay horizon is more than 35% saturated with base-forming cations Alfisols have

Table 2 Formative elements in names of suborders in soil taxonomy

Formative element	Derivation	Connotation of formative element
alb	Latin *albus* = white	Presence of albic horizon (a bleached eluvial horizon)
and	Modified from Ando	Ando like
aqu	Latin *aqua* = water	Characteristics associated with wetness
ar	Latin *arare* = to plow	Mixed horizons
arg	Latin *argilla* = white clay (a horizon with illuvial clay)	Presence of argillic horizon
bor	Greek *boreas* = northern	Cool
cry	Greek *kruos* = icy cold	Cold
ferr	Latin *ferrum* = iron	Presence of iron
fibr	Latin *fibra* = fiber	Least decomposed stage
fluv	Latin *fluvius* = river	Flood plains
fol	Latin *folia* = leaf	Mass of leaves
hem	Greek *hemi* = half	Intermediate stage of decomposition
hum	Latin *humus* = earth	Presence of organic matter
ochr	Greek *ochros* = pale	With a light surface
orth	Greek *orthos* = true	The common ones
perud	Continuously humid	Of year round humid climates
plagg	Modified from German *plaggen* = sod	Presence of plaggen epipedon
psamn	Greek *psammos* = sand	Sandy texture
rend	Modified from Rendzina	Rendzina–like
sapr	Greek *sapros* = rotten	Most decomposed stage
torr	Latin *torridus* = hot and dry	Usually dry
ud	Latin *udus* = humid	Of humid climates
umbr	Latin *umbra* = shade	With a dark surface
ust	Latin *ustus* = burnt	Of dry climates usually hot in summer
xer	Greek *xeros* = dry	Annual dry season

Source Brady (1990)

medium- to high-base status (i e , contain such base-forming cations as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) Of the five Alfisol suborders of soil taxonomy, three are frequently observed in the Production Systems in India These are Aqualfs, Udalfs, Ustalfs that are distinguishable by their soil water status

Aqualfs (Latin *aqua* = water) occur in wet environments, they therefore need to be drained artificially for crop production They are often gray and mottled in color, and may have iron or manganese concretions in their profiles In some Aqualfs, the groundwater may be near the surface at certain times of the year In others, the

Table 3 Description of the 10 Production Systems in India

Production System	Description
1	Transition zone from arid rangelands to rainfed, short-season millet/pulses/livestock *Eastern margins of the Thar desert*
2	Subtropical lowland rainy and postrainy season, rainfed, mixed cropping *Central/eastern Indo-Gangetic Plain*
3	Subtropical lowland rainy and postrainy season, rainfed *Western Indo-Gangetic Plain*
4	Tropical, high rainfall rainy plus postrainy season, rainfed, soybean/wheat/chickpea *Central India*
5	Tropical, lowland, rainfed/irrigated, rice-based *Eastern India*
6	Tropical, lowland, short rainy season, rainfed, groundnut/millet *Saurastra Peninsula*
7	Tropical, intermediate rainfall, rainy season, sorghum/cotton/pigeonpea *Eastern Deccan Plateau*
8	Tropical, low rainfall, primarily rainfed, postrainy season, sorghum/oilseed *Western Deccan Plateau*
9	Tropical, intermediate length rainy season, sorghum/oilseed/pigeonpea, interspersed with locally irrigated rice *Peninsular India*
10	Tropical, upland, rainfed, rice-based *Eastern India*

Source Adapted from ICRISAT (1994)

Table 4 Area of dominant suborders (> 10% of total area) in descending order of magnitude in the Production Systems in India

	Area of suborder in Production System ($10^4 km^2$)										
Suborder	PS 1	PS 2	PS 3	PS 4	PS 5	PS 6	PS 7	PS 8	PS 9	PS 10	Total
Ustalfs	0 14	4 30	0 61	2 17	7 48	-	1 99	-	22 54	22 28	61 50
Usterts	1 25		-	14 94	5 39	1 06	11 86	4 41	7 40	0 71	47 01
Orthents	0 78	2 94	0 28	8 27	8 50	2 34	11 26	6 53	3 32	2 58	46 80
Ochrepts	2 76	8 14	10 72	10 46	3 01	-	-	-	-	4 14	39 22
Psamments	10 95	0 87	3 39	1 37	2 40	-	-	-	0 00	-	18 98
Orthids	14 33	-	1 20	0 56	0 11	2 75	-	-	-	-	18 94
Aqualfs	-	2 24	-	-	1 75	-	-	-	0 79	3 22	7 10
Fluvents	0 58	2 72	0 14	-	2 20	-		-	0 04	0 51	6 18
Aquents	-	2 76	1 60		-	-	-	-	0 40	-	4 76
Tropepts	-	-	-	-	2 85	-	-	0 27	1 41	-	4 55
Aquepts	-	0 47	0 87	-	3 03	-	-			0 14	4 51
Udalfs	-	0 89	0 18	-	2 92	-	-		0 37	-	4 37
Aquolls	-	1 06	-	-	-	-		-	-	-	1 06
Udults	-	-	-	-	0 35	-	-	-	0 06	-	0 41

groundwater may be deep during most of the year, but the clay and other horizons with low water transmission characteristics may restrict water movement downwards, thus resulting in perched water tables Udalfs (Latin *udus* = humid) are found in humid areas They are often reddish or brownish and are freely drained, and occur in warmer temperatures Ustalfs (Latin *ustus* = burnt, implying dryness) are mostly reddish and occur in warm subhumid to semi-arid regions that have hot summers, with warm rainy seasons In most Ustalfs water percolates to deeper horizons during occasional years If there are carbonates in the parent materials, they tend to have a horizon with Ca^{2+} below that containing clay accumulation Droughts are common on Ustalfs because they tend to desiccate quickly after rainfall They are often used to grow annual crops, or for grazing Sorghum, cotton, groundnut, and castor are commonly grown on Ustalfs in India

Of the three suborders Ustalfs is the most dominant (Fig 2, Table 6) in the Production Systems of the Indian SAT, occurring extensively in PS 2 (16% of area), PS 5 (18%), PS 9 (61%), and PS 10 (66%) Ustalfs also occur to some extent in PS 1, PS 3, PS 4, and PS 7 Aqualfs or Udalfs occupy less than 10% of the production systems in which they occur

Vertisols

Soils in this order have high contents (>30%) of swelling and shrinking clays, particularly those of the smectite group (e g, montmorillonite, nontronite, saponite, and beidellite) to a depth of more than 1m This high clay content results in the development of deep, wide cracks when the soil dries When wet, Vertisols become sticky and plastic Therefore, cultivation of Vertisols in wet conditions results in puddling, that is detrimental to aeration and drainage It is difficult to use tillage implements on Vertisols in wet conditions When dry, most Vertisols become hard, and shatter when tilled In the SAT, there is a very narrow window of opportunity to cultivate Vertisols when their moisture contents are suitable Timeliness in farm operations on Vertisols is, therefore, extremely important Vertisol regions often (but not always) show a typical microrelief (gilgai) produced by swelling and shrinking as a result of changes in soil moisture content These microreliefs usually consist of a succession of microbasins and knolls in nearly level areas, or of microvalleys and ridges parallel to the direction of the slope Another characteristic feature is the presence at some depth (often between 0 25 – 1 0 m), of polished, often striated surfaces (slickensides) produced in the soil by movement of one mass sliding over another along a plane due to swelling and shrinking Of the

four Vertisol suborders in soil taxonomy, only Usterts occur to a large extent in the Production Systems in India As indicated in Tables 4 and 5, large (> 30% of the area) tracts of Usterts occur in PS 4 (40%), PS 7 (47%), and PS 8 (39%) They occupy between 10 to 20% of the areas of PS 5, PS 6, and PS 9 while PS 1 and PS 10 have less than 5% of their areas under this suborder Usterts normally have open cracks for 90 cumulative days or more in most years Such cracks are closed for 60 consecutive days or more in most years Because cracks open due to drying and the effect of temperature, soil temperatures at 0 5-m depth should be continuously higher than 8°C during the 60 consecutive days or more that the cracks are closed In most Usterts in India, calcium (Ca^{2+}) and magnesium (Mg^{2+}) are the dominant bases in the exchange complex

Entisols

Soils in this order have slightly or recently developed subsurface horizons Most of them have the beginnings of horizon development Entisols occur under a variety of environmental conditions in the Production Systems in India Of the five suborders in soil taxonomy, Aquents, Fluvents, Orthents, and Psamments occur in the Production Systems in India Shallow, medium-to fine-textured Entisols (Orthents) found over hard rocks are present in all 10 Indian Production Systems, while deep Orthents occupy large areas in India Orthents normally have very fine sand or finer textures They may have a coarse fragment content of 35% or more, and an organic

Table 5 Soil taxonomy soil orders and suborders in the Production Systems in India

Order	Suborder	Order	Suborder
Alfisols	Aqualfs	Inceptisols	Aquepts
	Udalfs		Ochrepts
	Ustalfs		Tropepts
Aridisols	Orthids	Mollisols	Aquolls
Entisols	Aquents	Ultisols	Udults
	Fluvents		
	Orthents		
	Psamments	Vertisols	Usterts

Table 6 Proportion of area of Production System occupied by each soil taxonomy soil order and suborder in India

Order	Suborder	Percentage area of Production System									
		PS 1	PS 2	PS 3	PS 4	PS 5	PS 6	PS 7	PS 8	PS 9	PS 10
Alfisol	Ustalf	0 47	16 28	3 20	5 74	17 51	-	7 93		60 59	66 21
	Aqualfs	-	8 49			4 10		-		2 13	9 56
	Udalfs	-	3 36	0 95	-	6 85		-	-		-
Vertisol	Usterts	4 02	-	-	39 57	12 62	16 45	47 24	39 34	19 89	2 12
Entisol	Orthents	2 54	11 14	1 45	21 89	19 90	36 41	44 83	58 24	8 92	7 67
	Psamments	35 57	3 28	17 83	3 63	5 62	-				-
	Fluvents	1 88	10 31	0 74	-	5 14				0 10	1 52
	Aquents	-	10 46	8 44	-					1 07	-
Inceptisol	Ochrepts	8 97	30 87	56 45	27 69	7 04	-				-
	Tropepts	-	-	-	-	6 67	-	-	2 42	3 80	-
	Aquepts	-	1 79	4 59	-	7 09		-	-		0 41
Aridisol	Orthids	46 55	-	6 34	1 40	0 25	42 76				-
Mollisol	Aquolls	-	4 02	-	-			-	-		-
Ultisol	Udults	-	-	-	-	0 82	-			0 15	-

carbon content that decreases regularly with depth (Soil Science Society of America 1984) They do not become saturated with water for periods long enough to limit their use for most crops Figures 6, 7, and 8 indicate that large areas of this suborder occur in PS 6 (36%), PS 7 (45%), and PS 8 (58%) Orthents occupy considerable proportions (10 – 22%) of PS 2, PS 4, and PS 5 (Table 6) In terms of area, Orthents are the third largest suborder (468,000 km^2) after Ustalfs and Usterts, when all the 10 Production Systems in India are considered together

Psamments are the next most widely distributed Entisol suborder in Indian Production Systems after Orthents Psamments have loamy fine sand or coarser textures, have <35% by volume of gravel or coarse fragments in all subhorizons, and are not saturated with water for periods long enough to limit their use for most crops (Soil Science Society of America 1984) Below the plowed layer, or 25 cm below the surface, they often have a sandy particle-size class in all subhorizons, either to a depth of 1 m, or to the rocky parent material Large tracts of Psamments found in PS 1 (109,500 km^2 or 36% of the area) are sands of shifting or stabilized sand dunes (Fig 2) About 18% of PS 3 (Fig 4) is occupied by Psamments PS 2, PS 4, and PS 5 have 3–6% of their areas under this suborder (Table 6) Psamments have low water-holding capacities, they tend to blow and drift when dry and bare, and do not adequately support most wheeled vehicles This results in traction difficulties when they are mechanically cultivated

Except for PS 2 that has about 10% of Fluvents and 11% Aquents (Table 6, Fig 3), the remaining Production Systems have very small areas or none of these two suborders PS 1, PS 3, PS 5, PS 9, and PS 10 have about 0 1 – 5% of Fluvents, while Aquents occupy 8% of PS 3 and 1% of PS 9 Fluvents are brownish to reddish soils formed in recent water-deposited sediments mainly on flood plains or deltas of rivers and streams (Soil Survey Staff 1975) They are frequently flooded if not protected by dams, embarkments, or levees Aquents are wet Entisols, found along the margins of lakes, in flood plains of streams, or in tidal marshes and deltas where they are continually saturated with water at some times in the year They show the mottling and gray colors symptomatic of periodically reduced soil conditions

Inceptisols

Soils in this order have one or more horizons in which mineral materials other than carbonates or amorphous silica have been altered or removed, but not accumulated to a significant degree during soil formation and development (pedogenesis) (Soil Science Society of America 1984) Under certain conditions Inceptisols may either have surface

horizons (epipedon, Greek *epi* = over or upon, and *pedon* = soil) that are too light in color (ochric, Greek *ochrus* = pale), may have a low organic carbon content, and harden upon drying, or have a relatively thick surface horizon that is dark colored and contains at least 5 8 g kg ^{1} organic carbon, is not massive or hard when dry (mollic, Latin *mollis* = soft) and has a base saturation greater than 50% when measured at pH 7, has less than 110 mg P kg ^{1} soluble in 1% citric acid and is dominantly saturated with bivalent cations Inceptisols may, apart from being ochric or mollic, be umbric (Latin *umbra* = shade), histic (Greek *histos* = tissue), with high organic matter contents and wet during some part of the year, or plaggen (German *plaggen* = sod) i e , with a man-made sod-like horizon resulting from years of manuring Of the six Inceptisol suborders of soil taxonomy (Soil Survey Staff 1978), Ochrepts, the light-colored, brownish, more or less freely drained soils, occur to some extent in PS 2 (31%), PS 3 (57%), and PS 4 (28%) (Table 6, Figs 3, 4, and 5) PS 1 and PS 5 have about 7 – 9% of this suborder Tropepts and Aquepts occur to a lesser extent Tropepts (0 4 to 7%) in PS 5, PS 8, and PS 9 and Aquepts 0 4 – 7% in PS 2, PS 3, and PS 5

Most of the Ochrepts in India occur in the cooler subtropical and tempe-rate climates (e g , the subtropical low-lying regions of central, eastern, and western Indo-Gangetic Plains where PS 2 and PS 3 are located) Some of them have an umbric or a mollic surface layer less than 0 25-m thick, an accumulation of calcium ($CaCO_3$) or $CaCO_3$ $MgCO_3$ (calcic), a hard pan (duripan) that is strongly cemented by silica, or a weakly cemented brittle pan (fragipan) in the soil profile Ochrepts are usually not saturated with water long enough to limit their use for most crops Unless they are artificially drained, the Aquepts on the other hand, are saturated with water long enough to limit their use for most crops They have either histic or umbric surface soil (epipedon) and are gray in color 0 5 m below the surface Alternatively, Aquepts may have an ochric epipedon that is underlain by a gray horizon that has been altered by physical movement or chemical processes, i e , a cambic (Latin *cambiare* = to exchange) horizon They may have a sodium saturation of 15% or more Tropepts *(trop* modified from Greek *tropikos* = of the solstice — implying humid and continually warm), are brownish to reddish freely drained soils They do not have man-made sod-like horizons (*plaggen*) and are not normally saturated with water for periods long enough to limit their use for crop production Most Tropepts have light-colored, low organic carbon content surface soils (ochric) and a horizon altered by physical or chemical processes (cambic)

Aridisols

These soils are mostly found in dry desert regions They are light in color and low in organic carbon content They may have a horizon with accumulations of $CaCO_3$ (calcic),

gypsum (gypsic), soluble salts (salic), or sodium (natric) Soils in this order have profiles that are moist for short periods during the year These short moist periods may be sufficient to grow such drought-tolerant crops as millets and some desert shrubs The suborder Orthids, that are Aridisols without silicate clay (argillic) or sodium accumulation (natric) are found in PS 1 (143,300 km^2 or 47%) and PS 6 (27,500 km^2 or 43%) They occur to a lesser extent in PS 3 (6%), PS 4 (1%), and PS 5 (0 3%) Orthids commonly have horizons of accumulations of soluble salts and carbonates

Mollisols

These are mineral soils that have thick, dark-colored surface soils with a base saturation of 50% or more when measured at pH 7 (Soil Science Society of America 1984) They may have either a silicate clay accumulation (argillic) horizon high in sodium, with a columnar or prismatic structure, an albic (Latin *albus* = white), cambic (horizon altered by physical or chemical processes), gypsic, or a histic horizon with a very high content of organic matter They do not normally possess a horizon that is highly weathered and contains a mixture of iron (Fe), and aluminium (Al) oxides (oxic) or ore with an accumulation of organic matter, Fe and Al oxides (spodic) Their surface horizons usually have granular or crumb structures as a result of their organic matter content Of the seven suborders in soil taxonomy, only a small area of Aquolls (10605 km^2) occur in PS 2 Aquolls are naturally wet, they develop in low places where water stagnates They may be artificially drained, have high organic matter contents, sodium saturations of 15% or more in the upper part of the soil and a decreasing sodium absorption ratio (SAR)[1] or decreasing sodium saturation at an increasing depth below 0 5 m (Soil Survey Staff 1978)

Ultisols

Soils in this order have an argillic horizon and a low base status (i e , less than 35% of the exchange capacity is satisfied with metallic cations) Their mean annual temperatures at 0 5 m depth are above 8°C They are highly weathered and are acidic Udults, the moist, well-drained Ultisol suborder is the only one that occurs to a small extent (0 8%) in PS 5 Udults are freely drained, humus-deficient soils that occur in humid climates with well-distributed rainfall Most of them have light-colored upper horizons, commonly a grayish horizon that rests on a yellowish brown to reddish argillic horizon A few Udults

1 $SAR = Na^+/[0\ 5(Ca^{2+} + Mg^{2+})]^{0\ 5}$ in moles per liter

that developed from rocks containing dark-colored minerals have dark brown or reddish brown surface horizons that rest on a dark or husky red argillic horizons

Summary

The dominant suborders in PS 1 (Fig 2) are Orthids (47%) and Psamments (36%) Both suborders have low water-holding capacities and low organic carbon contents They are susceptible to wind erosion and because they occur in dry environments, water and nutrient management is important for sustainable agricultural production

PS 2 (Fig 3) is a mixture of five suborders, three of which are Entisols that together constitute 32% of the area Entisols and the Inceptisols together constitute about 63% of PS 2 The five suborders are Ochrepts (31%), Ustalfs (16%), Orthents (11%), Aquents (11%), and Fluvents (10%) The Ochrepts are cultivated to wheat, rice, pigeonpea, and sugarcane (Lal et al , 1994) The Aquents have an aquic moisture regime, and are saturated by groundwater or water of the capillary fringe during part of the year During these periods of the year the saturated soil limits crop growth Its management should include adequate drainage and crops that tolerate waterlogging The Ustalfs in PS 2 are cultivated to such rainfed crops as maize

In PS 3 (Fig 4), Ochrepts (57%), and Psamments (18%) are the major suborders The Ochrepts are often cultivated to sorghum, maize, black gram, barley, wheat, cotton, and sugarcane under irrigation The Psamments are used for the cultivation of pearl millet and cluster beans during the rainy season, and wheat, barley, and gram with irrigation during the postrainy season (Lal et al , 1994)

Three suborders, Usterts, Ochrepts, and Orthents are dominant in PS 4 (Fig 5) The Usterts (40%) are usually cultivated to cotton, sorghum, and chilli The Ochrepts are cultivated to groundnut, cotton, wheat, and sorghum The Orthents are often cultivated to *Ziziphus jujuba* (ber) and such grasses as *Cynodon dactylon* and *Saccharum spontaneum* (Lal et al , 1994)

In PS 5, (Fig 6) Orthents (20%), Ustalfs (18%), and Usterts (13%) are the major suborders They border the coastal fringe of the eastern and the western parts of India The Orthents are occasionally cultivated to sorghum and pearl millet The Ustalfs are normally cultivated during the rainy season to rice, and in the postrainy season to rice, green gram, black gram, and sesame

The dominant suborders in PS 6 (Fig 7) are the Orthids (43%), Orthents (36%), and Usterts (17%) The Orthids are usually not cultivated, but *Prosopis juliflora* often grows wild on this suborder When used for agriculture, cotton and pearl

millet are grown The Orthents in PS 6 are often cultivated to groundnut, pearl millet, and fodder sorghum The Usterts are cultivated to cotton, rice, sugarcane, wheat, and sorghum (Lal et al , 1994)

In PS 7 and PS 8 (Figs 8 and 9), Usterts and Orthents are the dominant suborders Usterts occupy 47% and Orthents 45% in PS 7, while Orthents occupy 58% and Usterts 39% in PS 8 Usterts are normally cultivated in these Production Systems to rice, wheat, gram, linseed, pigeonpea, and lentil Most Orthents are under forest vegetation with such trees as *Butea frondosa*, *Acacia arabica*, *Madhuca indica*, and *Diospyros* spp and shrubs like *Ziziphus jujuba* (Lal et al , 1994)

Both PS 9 and PS 10 (Figs 10 and 11) have large areas of Ustalfs, 61% of PS 9 and 66% of PS 10 In addition, PS 9 has about 20% Usterts, that are normally cultivated to rainfed sorghum, maize, castor, groundnut, and pulses The Usterts in these Production Systems are normally cultivated to chickpea, pigeonpea, sorghum, and safflower (Lal et al , 1994)

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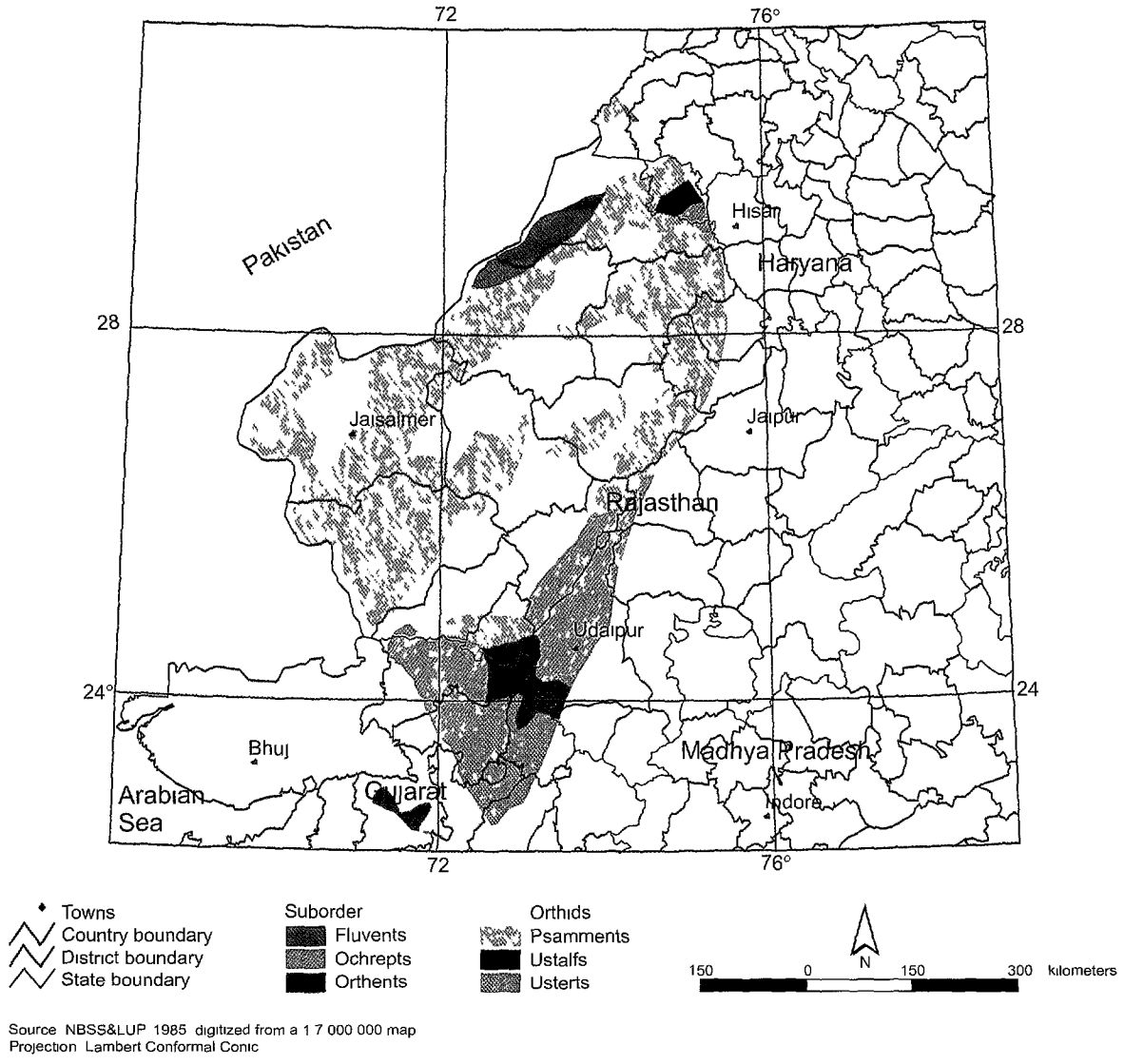

Figure 2 Production System PS 1 Eastern margins of the Thar desert Transition zone from arid rangelands to rainfed, short season millet/pulses/livestock

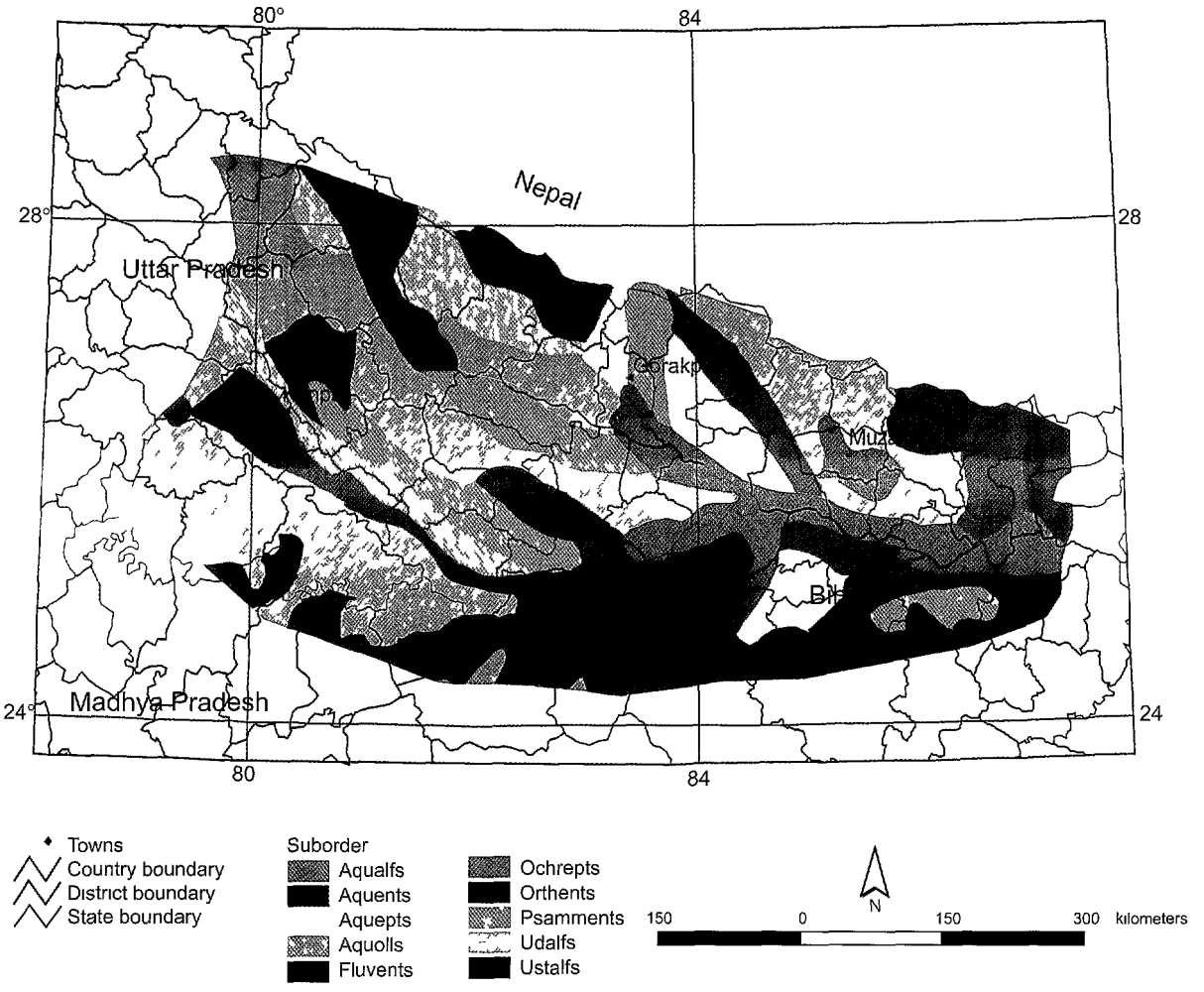

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Figure 3 Production System PS 2 Central/eastern Indo Gangetic Plain Subtropical lowland rainy and postrainy season, rainfed, mixed cropping

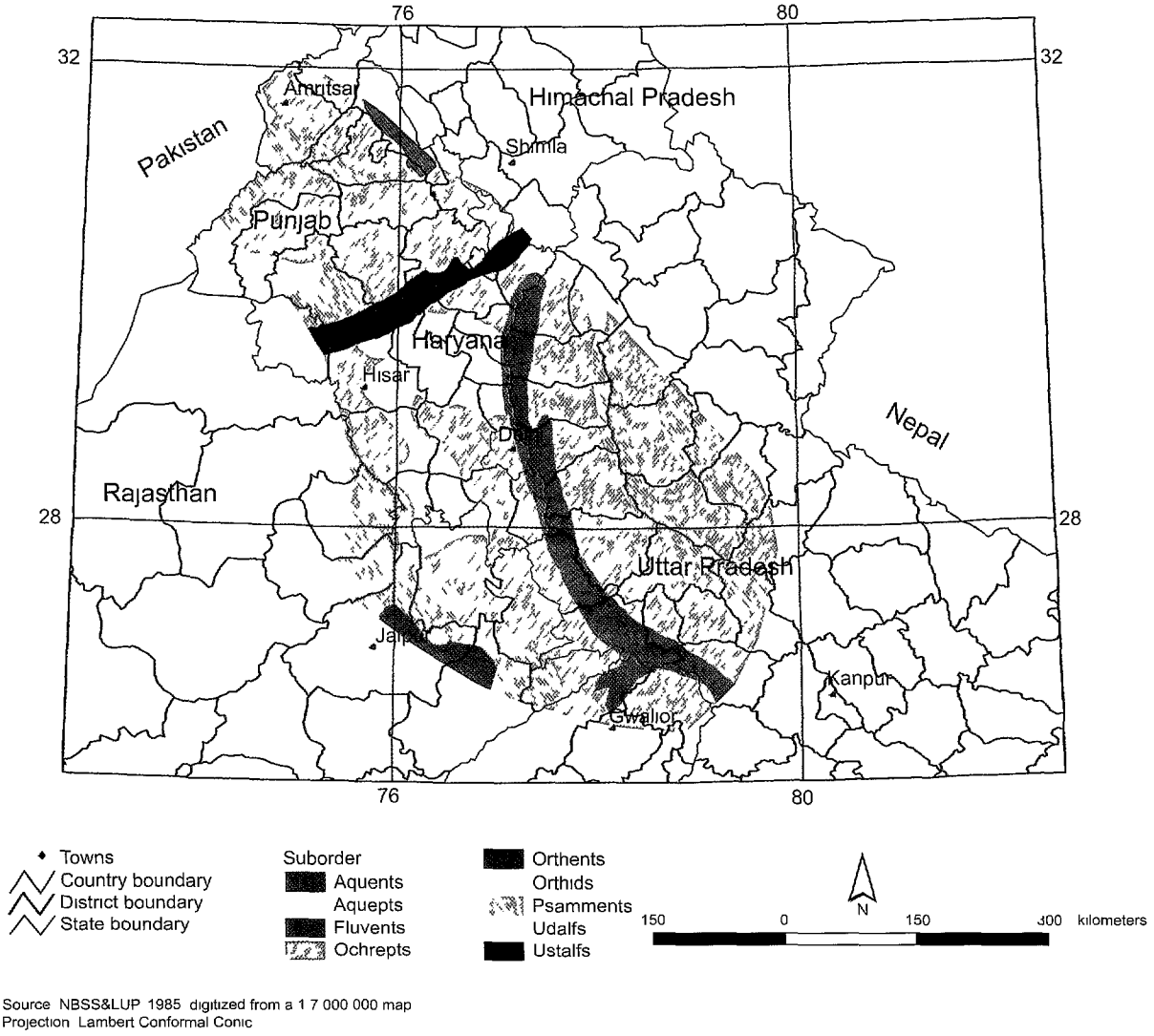

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Figure 4 Production System PS 3 Western Indo Gangetic Plain Subtropical lowland rainy and postrainy season, rainfed

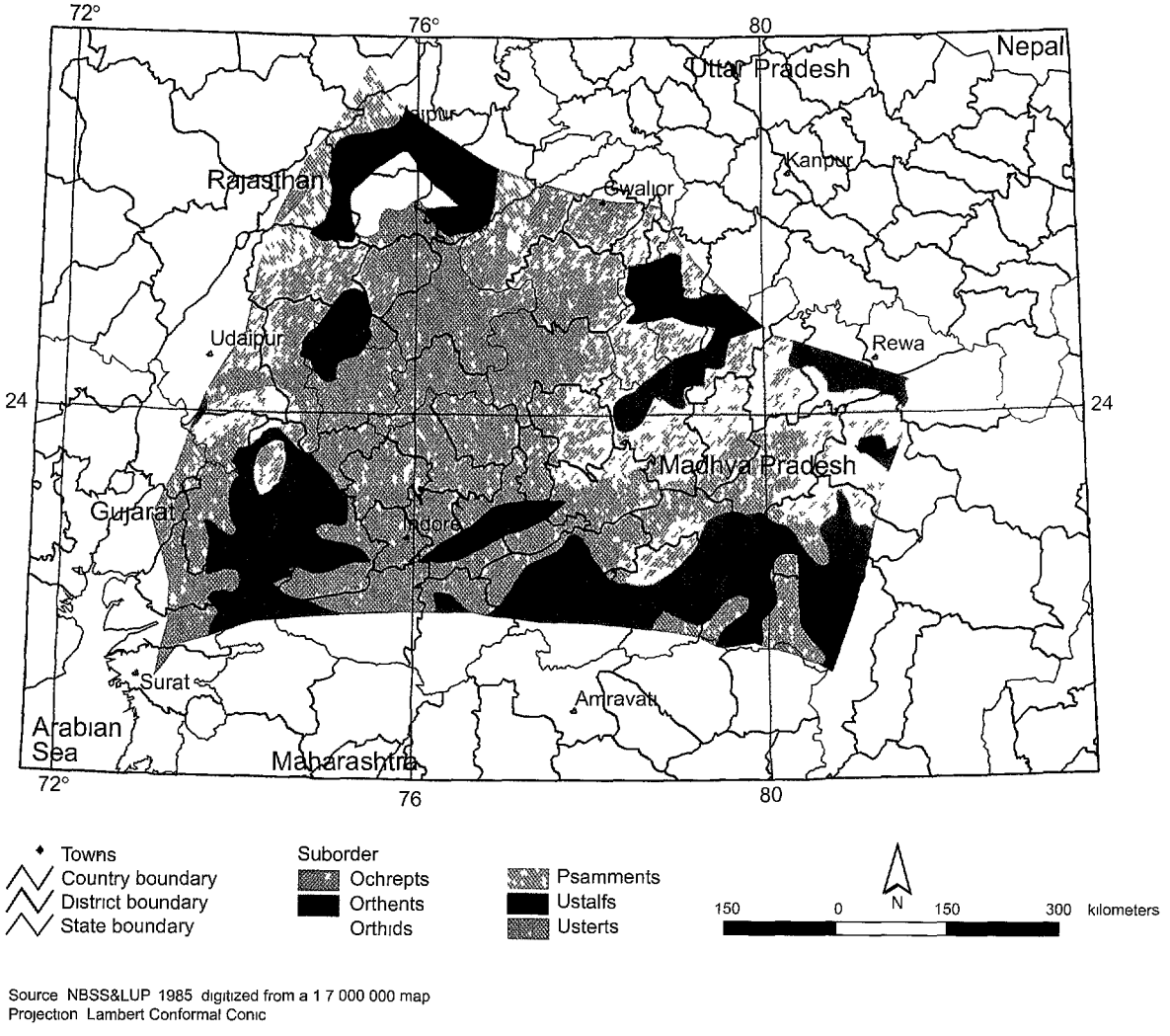

Figure 5 Production System PS 4 Central India Tropical, high rainfall rainy plus postrainy season, rainfed, soybean/wheat/chickpea

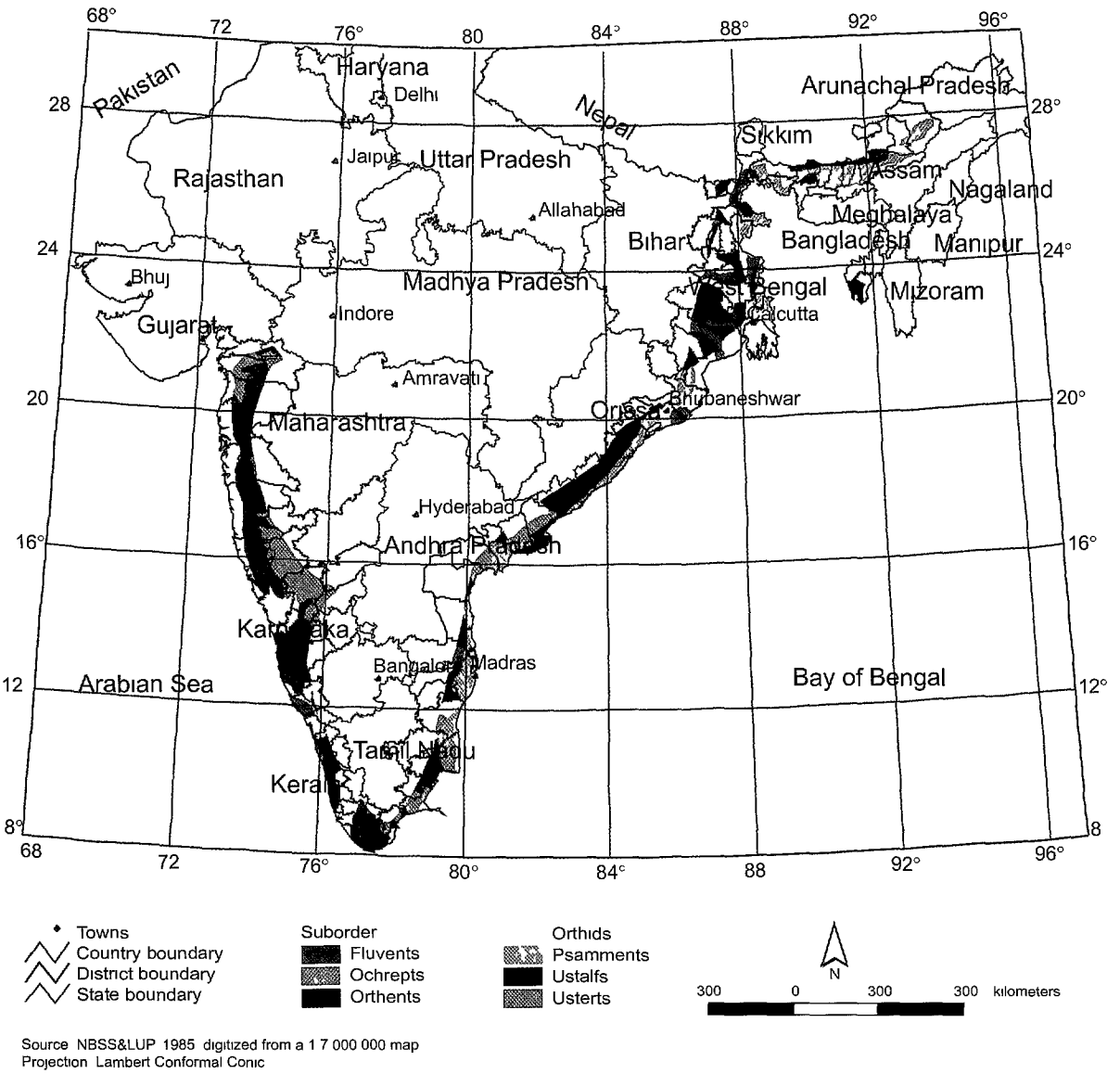

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Figure 6 Production System PS 5 Eastern India Tropical, lowland, rainfed/irrigated, rice based

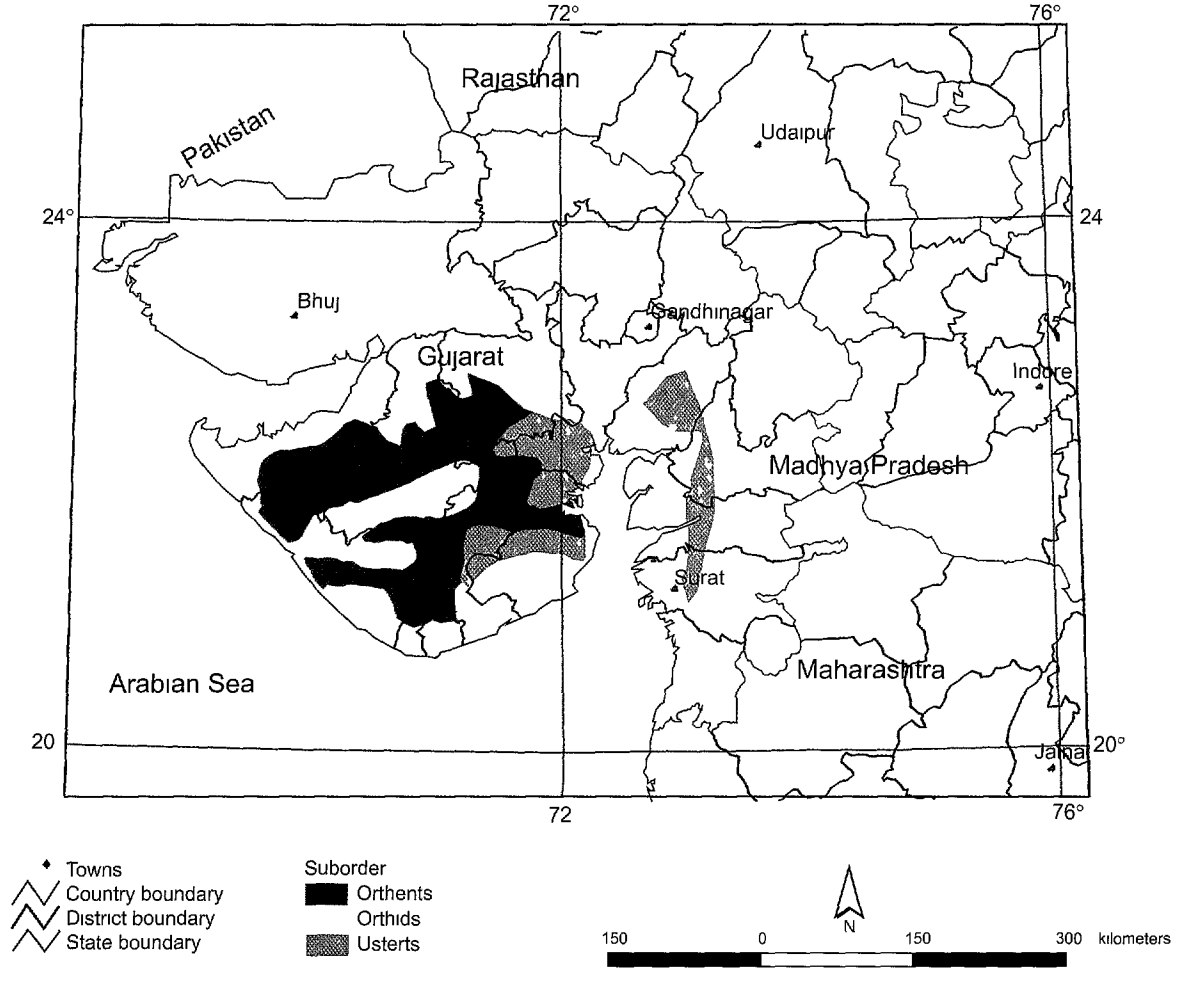

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Figure 7 Production System PS 6 Saurastra Peninsula Tropical, lowland, short rainy season, rainfed, groundnut/millet

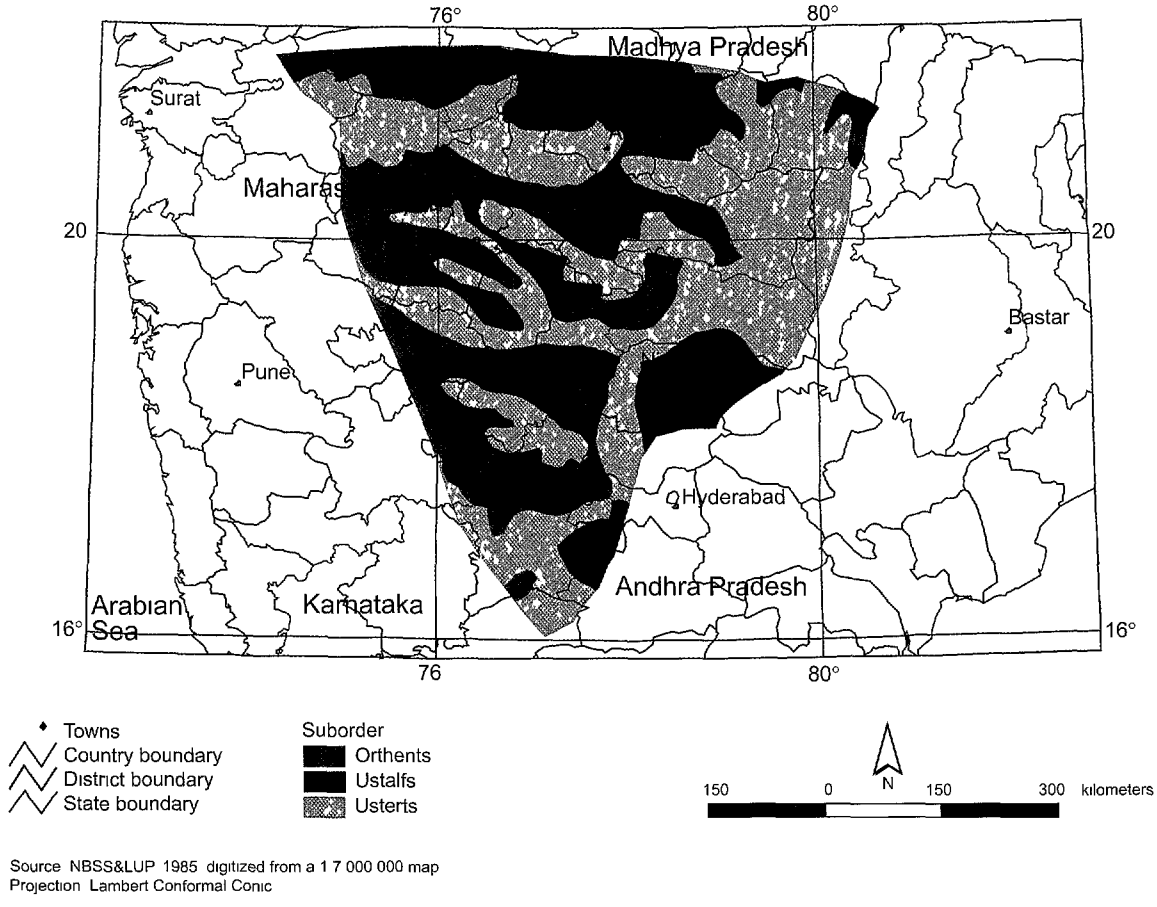

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Figure 8 Production System PS 7 Eastern Deccan Plateau Tropical, intermediate rainfall, rainy season, sorghum/cotton/pigeonpea

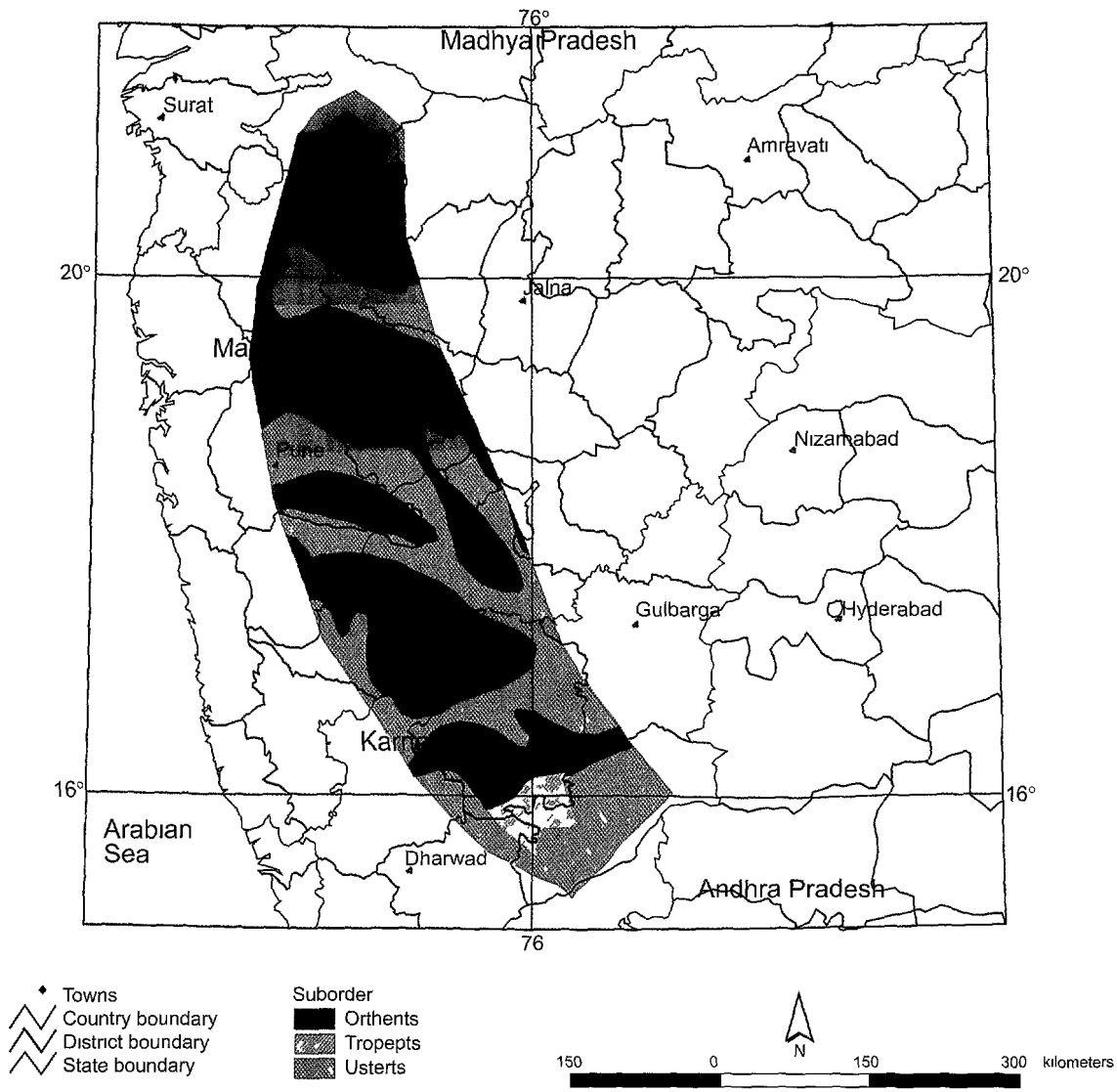

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Figure 9 Production System PS 8 Western Deccan Plateau Tropical, low rainfall, primarily rainfed, postrainy season, sorghum/oilseed

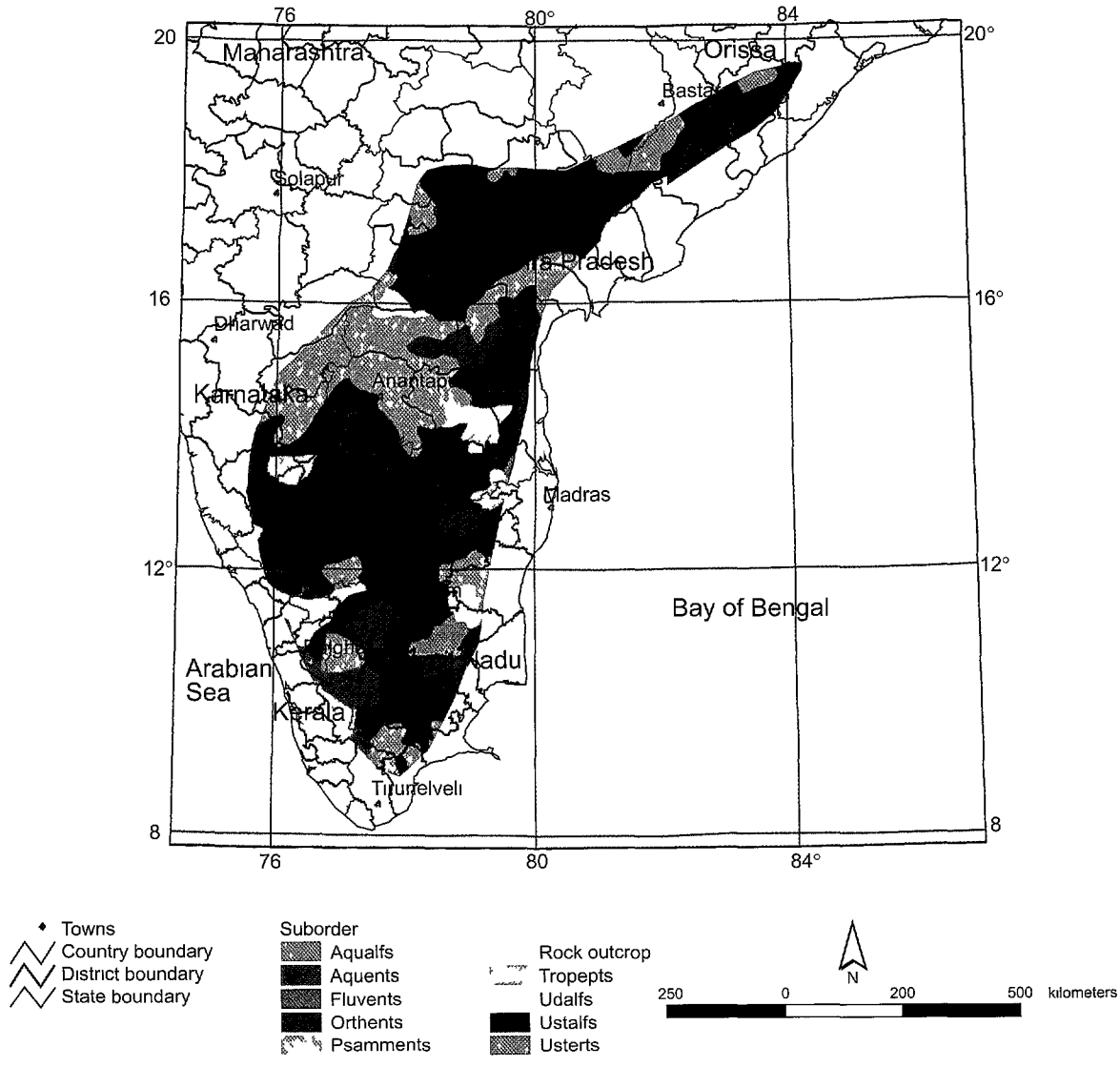

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Figure 10 Production System PS 9 Peninsular India Tropical, intermediate length rainy season, sorghum/oilseed/pigeonpea, interspersed with locally irrigated rice

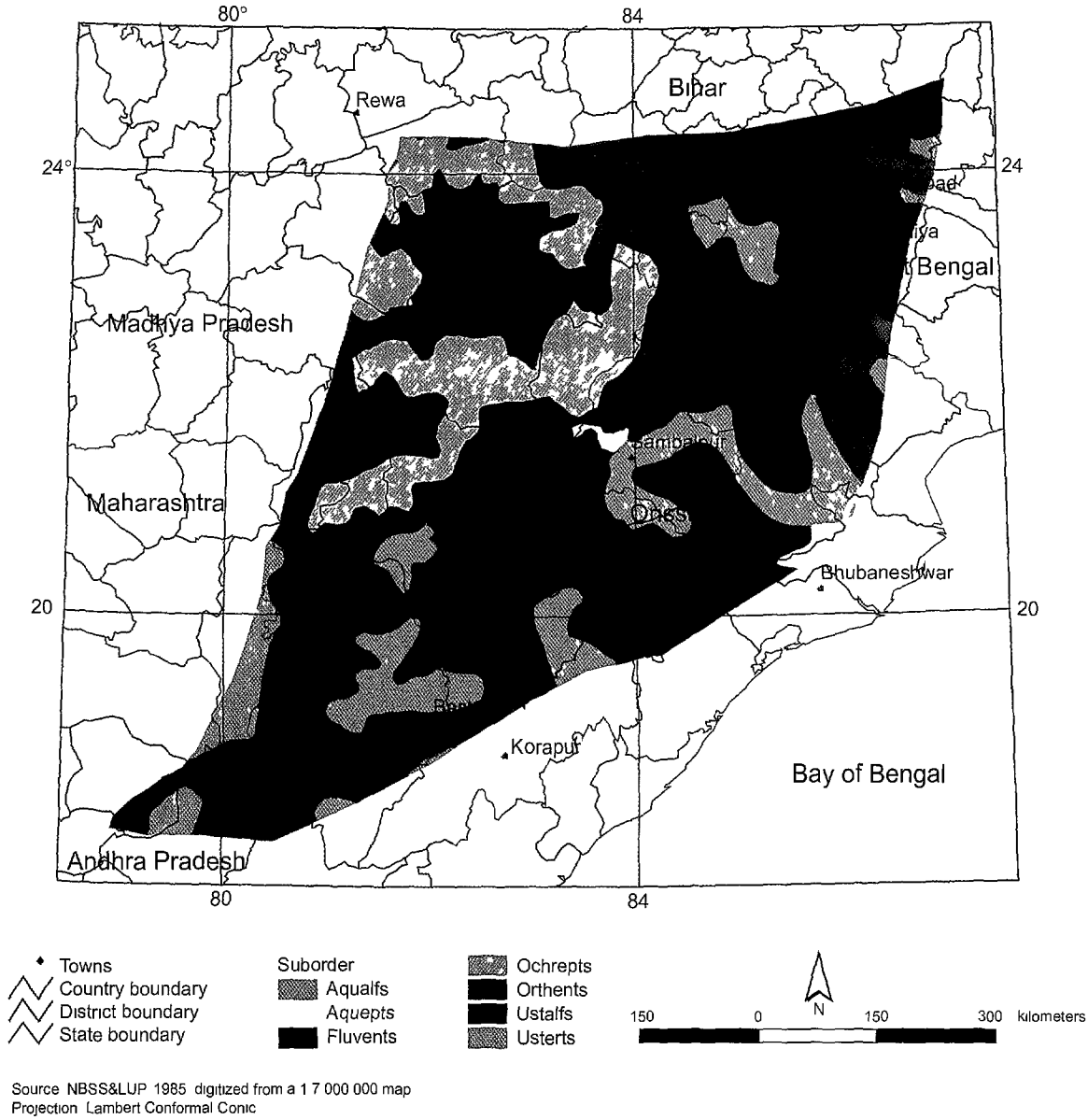

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Figure 11 Eastern India Production System PS 10 Tropical, upland, rainfed, rice based

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia a swathe across sub Saharan Africa, much of southern and eastern Africa and parts of Latin America Many of these countries are among the poorest in the world Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather limited and erratic rainfall and nutrient-poor soils

ICRISAT s mandate crops are sorghum pearl millet finger millet chickpea pigeonpea and groundnut, these six crops are vital to life for the ever-increasing populations of the semi-arid tropics ICRISAT s mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT ICRISAT communicates information on technologies as they are developed through workshops networks training library services, and publishing

ICRISAT was established in 1972 It is one of 16 nonprofit research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR) The CGIAR is an informal association of approximately 50 public and private sector donors it is co sponsored by the Food and Agriculture Organization of the United Nations (FAO) the United Nations Development Programme (UNDP) the United Nations Environment Programme (UNEP) and the World Bank