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Rainfed lowland rice-growing soils of Cambodia, Laos, and North-east Thailand

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Abstract

There has been little critical assessment of the similarities and differences between the lowland rainfed rice soils of Cambodia, Laos, and North-east Thailand and their implications for soil management. The purpose of this paper is to review the published literature on soil properties and their spatial distribution in Cambodia, Laos and North-east Thailand, the main soil and water related constraints identified for lowland rainfed rice, and the similarities and differences in soil management technologies that relate to water use. While rainfed rice is the dominant crop, rainfall and its seasonal distribution varies significantly across the region so that cropping patterns vary, especially those for pre-rice and post-rice cropping with field crops. However, for lowland rainfed rice, surface hydrology can vary with natural and artificial drainage patterns and subtle topographic variations to the extent that locally it may override the influence of rainfall. This can make it difficult to regionally assess the prevalent hydrological regimes. Cambodia has a higher prevalence of seasonally flooded, alluvial soils than North-east Thailand or Laos. Substantial areas of sandy, high permeability soils are used for lowland rice in the region, but especially in North-east Thailand. Standing rainwater drains quickly from the soils of these fields exposing the rice to drought and high rates of nutrient leaching. However, loss of soil-water saturation may limit rice yield by inhibiting nutrient uptake more often than drought, per se. The interaction between water supply and nutrient acquisition requires further investigation. Shallow ground water is a potential resource for supplementary irrigation but the scope for using it has not been adequately examined. In North-east Thailand and parts of Laos, salinity in the ground water may be the major limitation on its use. Prospects for growing field crops in the lowlands depend on the amounts and reliability of early wet season rainfall or on amounts of stored water after harvesting rice. Apart from drought, waterlogging and inundation are significant water-related hazards for growing field crops in the early wet season. In addition, soil-fertility constraints in the early wet season and dry season will likely differ from those encountered by rice due in part to the different soil-water regime they encounter.

Introduction

THE geographical proximity of Cambodia, Laos and North-east Thailand, and the prevalence of rainfed lowland rice as the major crop in their agro-ecosystems suggest that the cross-flow of research information among these regions should be helpful. Coordination and collaboration among these countries could minimise duplication of research, and maximise synergies in their collective research. Significant overlap in soil characteristics may facilitate the exchange of research information among these countries to their mutual advantage. This means there is no need for each country to try to maintain an elaborate soil management and agronomy research program. However, exchange needs to be based on a critical examination of the similarities and differences in their agro-ecological classifications, the prevalence of rainfed rice ecosystems, and in the soils used for rice and field crop production. Previously, there has been little critical assessment of the similarities and differences in soils of Laos, Cambodia and North-east Thailand and their response to soil management technologies. Since research on lowland rainfed rice (LRR) soils and rice growth on them is

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comparatively recent for Cambodia and Laos, such a detailed and critical analysis has not hitherto been feasible. The purpose of this paper will be to review the published literature on soil properties and their spatial distribution, the main soil-water- related constraints identified for Laos, Cambodia and North-east Thailand, and the similarities and differences in soil management technologies found to be effective. Areas of common strategic interest for research on soil management technologies will be identified and discussed. Most emphasis will be given to lowland rainfed rice.

Rainfall and surface hydrology

Total rainfall, and rainfall patterns vary across each of the regions (e.g. Limpinuntana 2001; Ouk et al. 2001; Schiller et al. 2001). In Cambodia, most rice growing areas have a mean annual rainfall of 1250–1750 mm but it increases up to 2500 mm in the south and east of the country. Annual rainfall in northern Laos is as low as 1200–1300 mm per annum, but other areas receive on average 1500–2000 mm (Inthavong et al. these proceedings). The extremes of rainfall in North-east Thailand are greater with most of the region receiving 1100–2100 mm annually. However, most of the south-west sector of the region receives 900–1100 mm annually making it the most drought-prone. The variations in annual average rainfall produce changes in cropping patterns, and options for pre-rice and post-rice cropping with field crops. For example, in the southern parts of North-east Thailand, reliable early season rainfall allows pre-rice cropping (Poltanee 2001) whereas in the central Khorat basin such cropping is less common. Similarly, the south-west and east of Cambodia have higher early wet season rainfall and may therefore be better areas for expanding field crops on lowlands. However, all parts of this region experience substantial year-to-year variation in total rainfall, and in the rainfall distribution pattern.

The rice-growing environment may be identified by using the rice ecosystem and sub-ecosystem classification system developed at IRRI in 1984 (IRRI 1984). Using this system, it is possible to make broadscale identification of the rice growing environments in the study area. The dominant rice ecosystems in Laos, Cambodia and North-east Thailand are rainfed lowlands (Wade et al. 1999). Previously, the area of upland rice in Laos was greater than that of rainfed lowland, but the statistics for 1999 indicate that the upland rice area was reduced to 21% and irrigated and rainfed lowland rice areas increased (Schiller et al. 2001) (Table 1).

Table 1. Rice areas (%) for different ecosystems in North-east Thailand (IRRI 1997), Laos. (Schiller et al. 2001) and Cambodia (Ouk et al. 2001).

	North-east Thailand	Laos 1999	Cambodia 1999
Irrigated	6	12	11
Rainfed lowland	83	67	84
Deepwater	0	0	3
Upland	11	21	2

In the rainfed, shallow, favourable, sub-ecosystem, rainfall and water control are generally adequate for potential crop growth, and only short periods of drought stress or mild submergence may occur. Favourable rainfed lowlands are most prevalent in Laos and comparatively uncommon in Cambodia and North-east Thailand. Clear delineation of these areas in Laos could yield significant advances in being able to deliver technologies where drought and submergence rarely limit rice (Table 2).

Drought-prone sub-ecosystems are prevalent in all regions, especially in North-east Thailand (Table 2). The rain period is long and bimodal, but erratic in its continuity, and this sub-ecosystem is common in North-east Thailand and Laos. In this sub-ecosystem, there may not be standing water at the appropriate time for transplanting, which often corresponds to the trough between the two rainfall peaks of the bimodal distribution.

In the shallow, drought- and submergence-prone sub-ecosystem, drought and submergence may occur on a particular field within the same growing season or in different seasons. This sub-ecosystem is important in North-east Thailand and Laos but is the most widespread of the sub-ecosystems in Cambodia.

While the sub-ecosystem concept is useful in regional classifications of rice growing areas according to surface hydrology, in practice sub-ecosystems are not clearly separated and it is sometimes difficult to assign even a single farm to a particular sub-ecosystem (Singh et al. 2000). Locally, surface hydrology can vary by such an extent as to override the influence of rainfall. Within a single farm or among adjacent fields, the upper terraces may be classified into the drought-prone sub-ecosystem and

Table 2. Relative occurrence (as percentage of total area) of the main rainfed lowland rice sub-ecosystems in South and South-East Asia.

Country	Shallow soils (0–25 cm) and prone to:				Medium to deep soils (25–50 cm)	Total area ('000 ha)
	No water stress	Drought	Drought + submerg.	Submergence		
Laos	33	33	33	0	0	277
Cambodia	10	29	57	0	5	747
Thailand	9	52	24	12	3	6039
Total	20	36	15	16	13	35 907

Source: Wade et al. 1999

the lower terraces may belong to the submergence-prone, or drought- and submergence-prone, sub-ecosystem. Most farms in these countries are composed of a mixture of these different positions in the toposequence in varying proportions. Location of on-farm drains, and of road embankments and drains under roads can markedly affect where the run-off is directed. Lowland rice is uniquely dependent on surface hydrology and the duration of standing water in relation to crop-growth stages (Fukai et al. 2000). The surface water depth in paddies changes continuously during crop growth (e.g. Seng et al. 1996). There is relatively little data with continuous recording of surface hydrology and even less has been systematically assembled to allow better classification of agro-ecosystems (Boling et al. 2000).

Local surface hydrology of rice fields can be described by the water balance equation (Fukai et al. 2000). The change in soil-water content or free water level above or below the soil surface in rainfed lowlands is described by the equation:

$$\Delta S = R - (E + T + P + L + O)$$

where ΔS is the change in soil-water content, R the rainfall, E the evaporation from standing water surfaces or the soil surface, T the transpiration, P the deep percolation, L the net lateral water movement in the soil (positive means loss of water from the particular field), and O the runoff of water over the bund.

Commonly, the sum of evaporation + transpiration is 5–8 mm d^{-1} but it decreases sharply with soil drying and when the plant experiences drought. Deep percolation (drainage) rates were 1–6 mm d^{-1} at locations in North-east Thailand (Fukai et al. 1995). Model simulations for Ubon in North-east Thailand show about a 50% increase in yield if a percolation rate of 6.3 mm d^{-1} under puddled conditions can be reduced to 1.4–1.8 mm d^{-1} (Fukai et al. 2000). High percolation rates are a common problem in the sandy lowland rice soils of Cambodia (White et al. 1997), Laos and North-east Thailand (Fukai et al. 1995).

Fields in the high or upper terraces of the lowlands lose much water, particularly after heavy rainfall, through surface runoff and subsurface lateral water movement, while those in the lower terraces may intercept the flows from the upper paddies (Fukai et al. 2000). Lateral redistribution of water results in water availability and rice growth duration varying by 30 days or more, within quite small areas. Experimentally, it is difficult to separate the lateral flow and drainage components of water balance. Accordingly, Fukai and colleagues used simulation models to estimate the sensitivity of yield to the effect of variation in one parameter while all others are held constant (Table 3). At Ubon in North-east Thailand, the influence of run-on to the lower terrace diminished as the deep percolation rate was reduced from 6 to 1 mm d^{-1}. With 1 mm d^{-1}, there was almost no water stress throughout the growth period and hence the effect of water movement was small. However, with 4–6 mm d^{-1}, there were periods with standing water interspersed with periods of water stress. In this case, simulated grain yield was strongly influenced by variation in lateral water movement.

Homma (2002) conducted a detailed study of variation in soil properties, water regimes, and rice growth and yield, across a toposequence in North-east Thailand with elevation differences of 1.5–6 m along 150–500 m transects. The study area, south-west of Ubon Ratchathani, occupied 9.3 ha and comprised 10 farms. During the wet season, the duration of flooding varied inversely with elevation (Table 4). The number of days of flooding was positively related to yield. However, the low elevation sites also had higher organic matter and clay content sug-

Table 3. Simulated grain yield (t ha^{-1}) for rice cv. KDML105 under different degrees of lateral movement of water and deep percolation rate at Ubon, North-east Thailand. C_L<1 indicates net run-off, and C_L>1 indicates net run-on of water.

Deep percolation rate (mm day^{-1})	Coefficient for lateral movement of water (C_L)				
	0.5	0.75	1.0	1.25	1.50
1	2.28	2.46	2.46	2.46	2.46
4	1.78	1.85	2.15	2.37	2.41
6	1.56	1.73	1.79	1.88	2.12

Source: Fukai et al. 2000

gesting that the lower elevations benefit not only from run-on of water from higher elevations (Fukai et al. 2000), but that their soil properties would aid soil-water retention. Oberthur and Kam (2000) also report that soils in North-east Thailand are often much higher in clay and organic matter content in the low terraces than mid and upper terraces.

Table 4. Rice dry matter and grain yield at sites along a toposequence in North-east Thailand in relation to flooding regime, and soil organic matter and clay.

	Lower	Middle	Upper
Total dry matter (t/ha)	8.4 ± 2.4	7.2 ± 2.3	4.1 ± 2.4
Grain yield (t/ha)	2.6 ± 0.6	2.5 ± 0.9	1.1 ± 1.0
Flooded days	88 ± 3 3	66 ± 29	7 ± 15
Organic C (g/kg)	13.1 ± 4.9	6.7 ± 2.4	3.9 ± 2.2
Clay (g/kg)	26 ± 13.3	10 ± 12.0	3 ± 0.9

Source: Homma 2002

Surface geology and soil distribution

Whereas the Mesozoic sandstone and its weathering products dominate most of the surface geology of North-east Thailand, in Cambodia their influence is attenuated by Tertiary and Pleistocene igneous geology and by Pleistocene and Holocene sediments that mantle a considerable proportion of the major rice growing parts of the country (Workman 1972). Recent and Pleistocene alluvial/colluvial sediments that now form the parent material for most of the agricultural soils of Cambodia are substantially derived from the weathering and erosional products of the Mesozoic sandstone (White et al. 1997). However, low hills from felsic igneous intrusions particularly in south and south-east Cambodia have also supplied siliceous sediments for the recent and older alluvial/colluvial terraces. In the north-east and west of Cambodia, basaltic lava flows of the Pleistocene cover significant areas of older alluvial terraces. The soils formed on weathered basalt and on the alluvial/colluvial sediments derived from basalt differ markedly from those of the siliceous parent materials that dominate most other soils (White et al. 1997). Basaltic parent rocks are prevalent on the Bolovens Plain of Southern Laos, but uncommon in North-east Thailand. Finally, the sediments deposited by the Mekong River along its flood plain and in the basin of the Tonle Sap means that much of central Cambodia is dominated by recent alluvial/lacustrine sediments derived in part from the Mekong River basin and in part from the immediate basin of the Tonle Sap (Oberthur et al. 2000b).

A soil map (1: 250,000) based on the FAO World Soils Map (1988) was recently compiled for the lower Mekong Basin (MRC, 2002). Apart from Laos, this map was based on limited new soil surveying. Only North-east Thailand has complete soil survey and soil map coverage. In Cambodia the rice growing soils have been mapped (Oberthur et al. 2000b) based in part on an old, small-scale map (1:900,000) of soils in the whole country. Detailed 1:50,000 maps exist for three provinces of south-east Cambodia. Soil mapping is continuing in Laos, but the Mekong River Commission (MRC) map ensures that there is coverage of the entire lower Mekong Basin using a consistent classification.

Even at the level of soil groups, significant differences are evident between soils of the three regions (Table 5). In Cambodia the most prevalent soils are Acrisols, Leptosols, Cambisols and Gleysols. Cambodia has the highest proportion of Gleysols, and significant areas of Plinthosols, Planosols, Ferralsols and Vertisols. The latter are not important in Laos or North-east Thailand. Laos has the highest proportion of Acrisols, and Cambisols, but the lowest proportion of Gleysols, Planosols, Arenosols, Fluvisols and Vertisols. By contrast Cambisols are not important in North-east Thailand and Gleysols are not important in Laos. Fluvisols are not common in Laos, but are common and important in North-east Thailand and Cambodia for rice. North-east Thailand has the highest proportion of Luvisols, Arenosols, Solonetz and Lixisols, but the lowest proportions of Cambisols, Ferralsols, and Plinthosols. North-east Thailand has a large area of

Arenosols and Solonetz, whereas these are much less prevalent in Laos and Cambodia.

Table 5. Relative abundance (percentage land coverage within country) of soil groups within the countries of the Lower Mekong Basin (Mekong River Commission 2002). Soil groups based on FAO World Soil Resources map (FAO, 1988).

Soil groups	Cambodia	Laos	North-east Thailand
Acrisols	48.8	61.4	60.9
Leptosols	12.5	10.3	16.1[a]
Cambisols	11.2	20.9	0.5
Gleysols	9.5	0.1	4.1
Ferralsols	3.7	0.8	0.4
Planosols	2.8	0	0
Luvisols	2.5	2.5	6.3
Plinthosols	1.8	0.4	0
Vertisols	1.6	0	0.2
Arenosols	1.6	0.1	5.9
Fluvisols	0.8	0.2	1.0
Solonetz	0	0.1	1.1
Lixisols	0	0.3	1.7
Water	3.1	0.8	1.3
Rock/slope complex	-	2.1	

[a] mapped as slope complex

Even where there are apparent similarities in abundance of soil groups, at the level of soil units, there can be large differences. For example, in Laos and North-east Thailand Haplic Acrisols are the most abundant soil unit, whereas in Cambodia Gleyic Acrisols are more prevalent. Moreover, since the map covers the whole region, it may give a misleading impression of the prevalence of lowland soils. In Cambodia, the prevalence of Fluvisols in rice-growing areas is not evident in Table 5. Similarly in Laos, Linquist et al. (1998) reports that Alisols are the most prevalent rice soils in southern and central Laos whereas Luvisols are most prevalent in the north.

Soil properties

Rice growing soils in Cambodia exhibit varied properties (Table 6). Two-thirds of them are derived from old (Pleistocene) alluvial/colluvial deposits and 28% from recent alluvial deposits (White et al. 1997). Of the former, Prey Khmer and Prateah Lang which comprise 39% of the rice-growing soils have very sandy surface horizons, and the Prey Khmer is sandy in both the surface and sub-soil. One-third of the rice growing soils are strongly acidic in oxic conditions. Apart from the recent alluvial soils which have >23% clay and the highest CEC, exchangeable potassium (K) and Olsen phosphorus (P), all other soils have very low levels of exchangeable K and Olsen P. In field trials in Cambodia, strong responses to nitrogen (N) are generally reported in most rice soils (Seng et al. 2001b). However, only the recent alluvial soils belonging to the Krakor group respond to N alone. On Koktrap soils, on the sandy Prey Khmer, and on Prateah Lang soils, N alone either has no effect on yield or decreases it (White et al. 1997, Seng et al. 2001b). On all soils, apart from Krakor, responses to P alone may be obtained although the strongest responses generally require N and P, and on the lower fertility soils K and S (sulfur) fertilisers are also required. Soil physical properties are often limiting for tillage (Table 7), and several profile types have sub-soil features that limit root growth.

The surface soils of North-east Thailand contrast with those of Cambodia in that almost all the major soil series contain >60% sand (Table 8). This has led to the conclusion that soils of North-east Thailand are almost universally infertile (Ragland and Boonpukdee 1987). However, Oberthur and Kam (2000) challenge the previous generalisations about the sandy and infertile nature of soils in North-east Thailand. They report that short-range variation in texture is substantially greater than previous reports have suggested and that the lower elevations of toposequences, that comprise up to 25% of landscapes, have loam or heavier textures that are suited to rice production. This notion of variation in soil texture along a toposequence is consistent with the results from Homma (2002). The Phimai series which occurs on the recent alluvial plains of North-east Thailand is an exception to the general pattern of North-east Thailand soils. It has properties relatively similar to the recent alluvial soils in Cambodia, apart from higher exchangeable sodium (Na). However, the prevalence of Phimai series in North-east Thailand is low. Thirty-two per cent of the soils of North-east Thailand are strongly acidic (pH KCl <4.2) in their oxic state, and most of the soils were low in exchangeable K. There is a high incidence of B (boron) deficiency in soils of the uplands of North-east Thailand (Bell et al. 1990), but it has not been reported as a problem for rice in the lowlands.

Table 6. Chemical properties of major rice soils in Cambodia and the percentage of the rice area they occupy.

Soil type[a]	Landscape	Area (%)	Sand (%)	Silt (%)	Clay (%)	pH[b] (1:1 H2O)	Organic C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Exch K	Exch Na	Exch Ca	CEC[c]	Olsen P ($mg\ kg^{-1}$)
									[cmol(+)kg^{-1}]				
Prateah Lang (Plinthustalfs)	Old colluvial/ alluvial	28	50	37	13	4.0	2.9	0.3	0.08	0.55	1.20	3.71	0.4
Krakor and Kbal Po (Entisol/Inceptisol)	Active floodplain	28	18	34	48	5.9	9.1	1.0	0.24	0.62	6.68	15.1	4.6
Bakan (Alfisol/ Ultisol)	Old colluvial/ alluvial	13	35	49	16	5.8	6.6	0.6	0.09	0.51	1.75	4.84	1.0
Prey Khmer (Psamments)	Old colluvial/ alluvial	11	73	22	5	5.6	4.7	0.5	0.04	0.05	0.61	1.45	1.3
Toul Samroung (Vertisol/Alfisol)	Old colluvial/ alluvial	10	28	29	42	5.5	8.8	0.9	0.17	0.29	7.10	16.0	3.1
Koktrap (Kandic Plinthaquualt)	Old colluvial/ alluvial	5	36	41	23	4.0	10.9	1.1	0.10	0.25	1.13	8.09	2.6

[a] Local name according to White et al. (1997). Names in parentheses refer to the *Key to Soil Taxonomy*.
[b] 1:1, soil to water, except for values in italics, which were obtained from 1:5, soil to $CaCl_2$.
[c] CEC = cation-exchange capacity.
Data source: Oberthur et al. 2000a; White et al. 2000 and Seng et al. 2001b

Table 7. Rice soils of Cambodia—constraints and opportunities for rice.

Soil[A]	Parent material	Profile	Main constraints	Opportunities
Prey Khmer	Old alluvial/colluvial from sandstone, granitic detritus	Sandy to 40–100 cm	NPKS deficiency, S, Fe toxicity, Low water holding capacity, leaching, transplanting difficulties as sand settles, coarse sandy phase	Compaction at depth, fertiliser in small doses, deep rooted cultivars, direct seeding, Clay layer at depth Use high tannin green manures that break down slowly, N placement an depth
Prateah Lang	Old alluvial/colluvial from sandstone and other mixed detritus	Sandy to 10–25 cm on clay sub-soil	NPKS (Mg, B) deficiency, S, Fe toxicity, Low WHC, leaching, hard setting, shallow phase, ironstone, transplanting difficulties as sand settles	Upland crops on loamy phase, drainage, direct seeding, post-rice crops, supplementary irrigation, split fertiliser, deeper cultivation Use high tannin green manures that break down slowly, N placement at depth
Bakan	Old alluvial/colluvial	Clay-loamy topsoil over clay or loam	Dispersive, poor structure, surface sealing, N, P, K, deficiency, S, Fe toxicity	Deeper ploughing, supplementary irrigation, land levelling, ratooning? Direct sowing, N placement at depth
Koktrap	Old (and recent?) lacustrine, tidal sediments	Black clay or loam (0–20 cm) over grey clay	Very low P, shallow hardpan, Fe toxicity, NK deficiency	Deeper ploughing Liming
Toul Samrong	Mixed alluvial/colluvial sediments of mafic origin	Well structured brown or grey cracking clay or loam over clay	Shallow root depth, tillage when dry, NP(K) deficiency.	Deeper tillage, level fields, supplementary irrigation
Orung	Recent or old alluvium	Loamy or clay over sand	NPKS deficiency, leaching, tillage, dispersive, hard setting, Fe toxicity	Supplementary irrigation
Labansiek	In situ weathered basalt	Deep, well structured reddish clay	NP(KS) deficiency, Root depth on petroferric hardpan in places,	Upland rice
Kompong Siem	Colluvial/alluvial outwash from basalt, marl, limestone or in situ basalt	Dark cracking clay (with stones and boulders in profile)	N(P) deficiency, Sticky when wet, Fe toxicity, cracks when dry, Zn deficiency	Supplementary irrigation, direct seedling. Drainage Dry season irrigation
Kein Svay	Recent alluvium with annual sediment additions	Deep brown loamy to clay texture	N(P) deficiency, submergence	Dry season irrigation
Kbal Po	Recent alluvium	Deep dark clay over lighter coloured clay	N(P) deficiency, potential acid sulfate in some places, sticky and low load bearing when wet, deep cracks	Supplementary dry season irrigation
Krakor	Recent alluvium	Deep loam—clay over lighter coloured sand, loam or clay	N(P) deficiency, potential acid sulfate in some places, sticky and low load bearing when wet	Supplementary dry season irrigation

Source: Based on White et al. 1997.

Table 8. Typical soil properties of the main soil series of North-east Thailand (NET).

	Landscape	% of NET	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (KCl)	Org C (g/kg)	Exch K (cmol/kg)	Exch Ca (cmol/kg)	Exch Na (cmol/kg)	Bray II P (mg/kg)
Korat	Middle	21	0–19	65	18	17	3.9	5.3	0.03	1.3	0.2	5
Roi Et (R)	Low	21	0–19	68	12	21	4.6	3.3	0.2	1.6	0.2	16
Phon Phisai	Middle	9.4	0–14	41	32	27	4.8	36	0.3	2.4	0.3	15
Nam Phong	Middle	3.1	0–18	87	11	2	3.5	2.4	0.1	0.4	0.3	4
Ubon (R)	Low-middle	2.5	0–23	87	11	3	3.8	2.5	0.04	0.6	0.2	5
Warin	Middle-high	2	0–26	54	27	19	3.7	6.6	0.1	0.4	0.2	7
Satuk	Middle-high	1.8	0–26	74	22	5	4.0	2.7	0.1	0.8	0.2	18
Borabu	Middle-high	1.6	0–15	86	11	3	4.3	4.2	0.1	0.7	0.1	3
Phen (R)	Low	1.3	0–13	63	20	17	4.2	5.6	0.1	0.3	0.1	3
Phimai (R)	Flood-plain	1.3	0–18	7	28	66	4.1	14.5	0.5	15.3	3.7	3
Yasothon	High	1.2	0–11	61	33	6	5.3	8.0	0.1	4.3	0.2	3
Tha Thum (R)	Low	1	0–11	44	48	8	3.7	6.7	0.03	1.0	0.6	3
Kula Ronghai (R)	Low	0.7	0–19	45	43	13	4.1	3.0	0.03	0.6	0.2	3

Source: Mitsuchi et al. 1986

There is limited analytical data available on rice soils of Laos. Most of the present knowledge about the properties of these soils is inferred from rice yield and yield responses to fertiliser. Rice growing soils in Laos show a gradient in properties from the northern regions where 80% are loamy in texture to the southern region where only 25% are loams (Linquist et al. 1998). In Laos, 85% of rainfed lowland rice crops in the northern region and 100% of those in the central and southern regions responded to NPK fertiliser (Linquist et al. 1998). Nitrogen deficiency was the most prevalent, with 40–50% of crops responding to N alone and another 30% when P also was applied. Some evidence suggests S deficiency for rice in Laos, and leaf analysis suggests that magnesium (Mg) levels may also be too low for rice.

Water-related soil constraints and soil management technologies

Based on rainfall, its distribution and variability, it would be presumed that drought was the main water-related constraint affecting soil used for growing rice in the region. However, the more common effect of low soil-water may be to limit nutrient availability and uptake rather than to cause drought per se. Variations in soil-water saturation interact with nutrient availability (Bell et al. 2001). Fluctuating soil-water regimes will have major effects on the forms and availability of N (Seng 2000), P (Seng et al. 1999) and on iron (Fe) and Al toxicities (Willett and Intrawech 1988).

In the rainfed lowlands, significant periods of loss of soil-water saturation occur intermittently throughout the growing season (e.g. Seng et al. 1996; Fukai et al. 2000; Homma 2002). The implications of the temporary periods of loss of soil-water saturation for nutrient availability are not fully understood, although growth may be depressed as nutrient availability decreases (Fukai et al. 1999). Intermittent flooding of soils results in a significant loss of soil N (Seng 2000) and decreased P availability (Seng et al. 1999).

Willett and Intrawech (1988) and Seng (2000) suggested that the increase in soluble Al after re-oxidation of the soil was a possible additional factor limiting P uptake during periods of loss of soil-water saturation. Hence, while flooding rice soils in Cambodia and North-east Thailand has been shown to increase pH to >6 (Willett and Intrawech 1988; Seng et al. 2001a), there are concerns that periodic losses of soil-water saturation during the growing season will see toxic levels of Al return to impair root growth and P uptake of rice (Willett and Intrawech 1988; Seng et al. 1999; Seng 2000).

If P uptake is restricted by loss of soil-water saturation, particularly at transplanting, growth and final yield will be impaired (Seng et al. 1999; Seng 2000). However, the relative sensitivity of yield to P deficiency at different stages of crop growth is poorly understood. Improved understanding would permit better tactical decisions on correction during the growing season. The effect of periods of loss of soil-water saturation can be minimised by using cultivars that are efficient in P uptake and use, and presumably best able to cope with a temporary decline in P availability (Fukai et al. 1999); or by treating soil with straw (Seng et al. 1999). Straw keeps the redox potential lower during the period of soil-water saturation loss, thus apparently decreasing the extent of Fe^{2+}oxidation and minimising losses in P availability due to reaction with Fe oxides. Other forms of organic matter added to the soil at planting, including cow manure, or residues from pre-rice pulse crops or green manures like sesbania, can all help minimise losses of P during periods of soil-water saturation loss. The minimum amount of organic matter needed to make a difference is not known, but Seng et al. (1999) had applied the equivalent of 5 t of straw per hectare. Seng et al. (2004a) has also suggested that lime application may be useful on some acid soils to minimise the formation of toxic Al levels in soils when loss of soil-water saturation occurs. However, Seng et al. (2004b) also found that over-liming of the acid sandy soils could occur.

The high percolation rates of the deep sands (Arenosols) are a major limiting factor for rainfed rice. Loss of standing water and drought are the most important consequences. However, leaching of N and other nutrients may also limit productivity of these soils even when water is not limiting. The Prey Khmer soil in Cambodia has lower potential productivity even with fertiliser application than the other major sandy lowland soil, Prateah Lang (White et al. 1997).

Sandy soils that occupy a significant proportion of the region represent a continuing challenge for water and nutrient management. Productivity on these soils tends to be low, even when recommended agronomic practices are followed. Application of clay to these soils has been suggested as a semi-permanent treat-

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ment to enhance water and nutrient retention (Noble et al. these proceedings). Initial research on the sandy soils of North-east Thailand suggests very strong responses in growth can be achieved by clay amelioration. Work to show the benefits of adding clay is continuing. The use of claying presumes a ready local supply of clay. North-east Thailand has numerous deposits of high activity clay in lacustrine sediments (S. Ruaysoongnern, pers. comm.). The relevance of this technology for other parts of the region, particularly for the Prey Khmer (Arenosols) and Prateah Lang (Acrisols) of Cambodia, warrants further research.

Shallow rooting is a major constraint on productivity for rainfed lowland rice (Table 7). Alleviating soil physical constraints to root penetration may therefore increase rice productivity by increasing access to stored water and nutrients in the deeper layers of the soil profile. If roots can penetrate the shallow plough pan, then rice crops can extract significant amounts of N from below 20 cm (Ventura and Watanabe 1984). Kundu and Ladha (1999) reported that deep cultivation increases rice yields. In Korea, increasing cultivation depth from 14 to 19 cm increased root depth from 27 to 36 cm and rice yield from 4.5 to 8.1 t ha^{-1}. Increasing cultivation depth from 15 to 40 cm on a soil with a hardpan at 15 cm increased both N uptake and grain yield (Kundu et al. 1996). The scope for increasing cultivation depth with draught animals is limited. In Cambodia, a pair of working animals can achieve a cultivation depth of 7–10 cm (Rickman et al. 1997). However, increasing availability of tractors for primary cultivation is making deeper cultivation possible on rainfed lowland soils with shallow hardpans.

Salinity currently affects about 12% of the lowland soils in North-east Thailand but is predicted to spread to cover about 30% (Yuvaniyama, 2001). The cause of salinity appears to be related to a change in the landscape water balance after clearing of the forest for agriculture (Williamson et al. 1989). Rapid clearing in North-east Thailand occurred in the 1960s (Ruaysoongnern and Suphanchaimart, 2001). Before that the salt stored in the halite strata of the near-surface Mahasarakham formation was not mobilised because the vegetation used most of the rainfall allowing little to recharge to ground water. However, under rice-based and upland farming significant recharge of the ground water occurs annually and this has caused watertables to rise regionally. Where ground water reaches the soil surface or is within 2 m of the surface, discharge of salt occurs. The gentle relief of the North-east Thailand and the widespread shallow Mahasarakham formation place large areas of North-east Thailand at risk of salinity. The potential risk of salinity in Laos has not been reported although salinised soils are occasionally reported (MRC, 2002). In Cambodia the salinity reported is in coastal soils (White et al. 1997).

As the development of salinity in North-east Thailand is essentially a water balance problem (Williamson et al. 1989), its solution will most likely come from changes in land use that decrease recharge to regional ground water. Given the current prevalence of lowland rice cultivation, this will prove a challenge. Tree planting or revegetation with perennial vegetation across a significant portion of the landscape may be needed to restore water balance, but the minimum amount needed to be effective is not known. Currently, upland areas are mostly targeted for tree planting. Agroforestry planting in lowlands may also be needed to help restore water balance. However, the present research emphasis appears to be on selecting for salt-tolerant plants to grow in salt-affected soils rather than on finding effective ways to restore water balance (Yuvaniyama, 2001).

In the region, there is a significant shift away from traditional transplanted rainfed rice. Shortages of labour are driving the development of direct seedling technologies for rice establishment. The increased demand for cash income is driving moves towards crop diversification (Ruaysoongnern and Suphanchaimart 2001). For much of the rainfed lowlands, the frequent uncontrolled inundation of land makes rice the only feasible wet season crop. However, there are opportunities to adopt double cropping by planting the early wet season crops, or planting post-rice crops (Polthanee 2001). The productivity of these systems depends on the reliability and amount of early wet season rainfall, and on access to supplementary irrigation from either stored surface water or shallow ground water. Where shallow ground water persists after the wet season, productive field cropping systems have also been developed (Polthanee 2001). Double cropping obviously increases the potential for negative nutrient balances, exacerbating what is already a relatively common scenario in North-east Thailand (Lefroy and Konboon 1998).

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Environmental sustainability

At present, fertiliser rates in rainfed lowlands are generally still low, leading Crosson (1995) to suggest that the negative environmental impact of fertiliser use on rice production is probably minimal. However, nutrient deficiencies are prevalent and farmers are increasing their fertiliser use and application rates (e.g. Ieng et al. 2002). In rainfed lowlands with access to supplementary irrigation, dry-season cropping is becoming more common (Pandey 1998). The environmental impact of these systems is under examination and may be a precursor of more widespread concern for agrochemical use in rainfed lowlands (Shrestra and Ladha 1999). Because these problems generally have not yet arisen in most rainfed lowland rice environments, now is an opportune time to develop strategies to prevent them becoming a concern. Periodic monitoring of water quality and identifying areas in catchment basins that contribute most to nutrient enrichment of water bodies should be implemented.

Shallow ground water is prevalent across the lowlands of Cambodia (Briese 1996) and North-east Thailand. In North-east Thailand much of this is unsuitable for irrigation because of its salinity and over half of the production wells drilled have low yields (Srisuk et al. 2001). There is a risk of over exploitation of the shallow ground water for irrigation. Villagers commonly rely on this resource for domestic water supplies, hence any loss of access to this resource, or compromise in its quality, would have serious implications.

Conclusions

Despite their close proximity and the prevalence of rainfed lowland rice ecosystems in Cambodia, Laos and North-east Thailand, there are significant differences between these three countries, and between areas within them in use of land resources. Rainfall patterns and soils differ sufficiently between them so that the proportions of rice sub-ecosystems and types of double cropping systems vary to suit each country. Lowland rainfed rice surface hydrology can vary because of natural and artificial drainage patterns and of subtle topographic variations to the extent that locally it may override the influence of rainfall, and make it difficult to regionally assess the prevalent hydrological regime. Cambodia has a higher prevalence of seasonally flooded, alluvial soils than North-east Thailand or Laos. Substantial areas of sandy, high permeability soils are used for lowland rice in the region, but especially in North-east Thailand. Standing water in rice fields of these soils drains quickly after rainfall exposing rice crops to drought and high rates of nutrient leaching. However, loss of soil-water saturation may limit rice yield by inhibiting nutrient uptake more often than drought, per se. Shallow ground water is a potential resource for supplementary irrigation but the scope for using it has not been adequately examined. In North-east Thailand and parts of Laos, salinity in the ground water may be the major limitation on its use.

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