Soil degradation under long-term rice production in Northeast Thailand [1/]

Sawaeng Ruaysoongnern [2/] and Andrew D. Noble [3/]

Abstract

Soil degradation issues are assuming increasing importance in Northeast Thailand and are challenging the concept of sustainability of current land management systems. In this study, the impacts of land conversion from natural Dipterocarp forest and wetland to agricultural production on soil chemical properties are compared. Soil samples were collected at 10 cm increments to 1m from a Dipterocarp or wetland forest (forest) and adjacent paddy rice (cultivated) production system along a transect. Since conversion to agriculture production ranging from 40 to over 100 years, the cultivated site has undergone a significant decline in soil pH as a result of reduction in soil organic C leading to loss of exchangeable basic cations; especially Ca, Mg and K; and Al domination of the exchange complex. Consequently, the ability of the paddy soil to retain basic cations has been compromised. A significant component of the extracted cations from the surface soil of the cultivated site is in a form that was non-exchangeable and therefore subject to leaching at the onset of the wet season. The approach adopted in this study to assess soil degradation from a soil chemical perspective has demonstrated the fragility of these sandy soils after continuous rice production. This is evidenced by the degree of degradation as measured using an index that takes into account changes in the surface charge characteristics and basic cation retention capacity of a soil. It is suggested that the degradation index may assist in quantification of what is commonly referred to as 'soil health'. The long-term consequences of soil degradation are permanent and bring into question the sustainability of current production practices on this site. Soils that have a low buffering capacity (ie. low clay and organic matter content) are prone to acidification and cation depletion which has a dramatic effect on the productivity of these paddy soils.

Introduction

Sandy soils covers around 80% in the Northeast of Thailand and constitute an important economic resource for agricultural production despite their low inherent fertility (Panichapong, 1988, Ragland & Boonpuckdee, 1987) . They were originally dominated by climax Dipterocarp forests until recently; lowland areas has been cleared for rice production for more than 100 years ago, and until around 40 years ago the uplands were then extensively cleared for upland crop production. The continuous production of rice could have resulted in a decline in fertility, with

---

1/ Paper presented at the 2 [nd] Seminar on Technical National Agricultural System, Kosa Hotal, Khon Kaen Province, August 26 [th] - 27 [th], 2002.

2/ Department of Land Resource and Environment, Faculty of Agriculture, Khon Kaen University

3/ CSIRO Land and Water, Townsville, Australia (Currently : IWMI, Bangkok, Thailand)

an associated loss of productivity. To resource poor farmers of Northeast Thailand the soil is one of the major biophysical resources that they have at their disposal, but under the prevailing socio-economic conditions, it is one of the most fragile.

As a prerequisite to the rational management of these soils an understanding of the degree of degradation that these soils have undergone is needed. This will facilitate the development of appropriate management strategies for enhancing and rejuvenating the soil resource base. Whilst the concept of charge fingerprinting as described by Gillman and Abel (1986) and eloquently demonstrated by Menzies and Gillman (1997) was developed and refined on soils from the humid tropics, the technology has not been applied to soils in the semi-arid tropics. In the current study quantification of the degree of degradation subsequent to conversion from climax dry Dipterocarp forest to rice production is undertaken using the charge fingerprint technique on soils collected from paddy field with different land types. These sites could also form the core permanent monitoring sites that can be returned to in the future to assess chemical changes that may have occurred due to changed land use.

Materials and methods

Site

Three paired sites were selected from different rice production in the Northeast Thailand, and they have had comprehensive chemical and physical properties determined (Table 1.1 1.2 and 1.3) . The selection of sites was based on the following criteria: (1) the existence of an undisturbed Diterocarp forest in close proximity to an agricultural production system; (2) a well defined boundary separating the two production areas; (3) the same soil type in both areas; and (4) little topographical difference (ie slope) between the two areas. Samples were collected at five points in each area along a transect at right angles to the boundary separating the two systems. Sampling points were 10 m apart and at each point a single sample was collected from the 0-10, 10-20, 20-30, 30-50 and 50-70 cm.

Soil analysis

Samples were air dried and sieved to pass a 2 mm mesh before composite sub-samples were made for each depth and production system. These samples were returned to Australia for chemical and physical analysis. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M BaCl2-NH4Cl as recommended by Gillman & Sumpter (1986). Acidic cations were extracted with 1 M KCl and the extractant titrated to pH 8.0 as described by Rayment & Higginson (1992). The effective cation exchange capacity (ECEC) was calculated as the sum of basic and acidic cations (Ca2++Mg2++K++Na++Al3++H+). Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment & Higginson (1992) and particle size as described by Coventry & Fett (1979).

Charge Fingerprints were determined on the composite samples from each site using the methodology described by Gillman & Sumpter (1986). The CECB is a measure of the maximum amount of exchangeable basic cations that can be retained in exchangeable form, and is therefore of agricultural significance. In brief, soils were saturated with Ca2+ and brought to equilibrium in a 0.002 M CaCl2 matrix. The pH of the suspension was adjusted to six values ranging from approximately 4.0 to 7.5, and exchangeable Ca2+, Al3+ and Cl- were displaced with NH4NO3. The Al3+ content in solution was determined using the pyrocatechol-violet method (Bartlett et al., 1987). Amounts adsorbed were calculated taking into account the amounts present in the entrained solutes. The CECB is operationally defined as the Ca2+ adsorbed and CECT as the Ca2+ and Al3+ adsorbed. During the equilibration period, pH0.002 was determined in a 1:10 soil:0.002 M CaCl2 suspension following Ca2+ saturation. This value is operationally defined as the soil pH. Records of the amounts of acid or base added to the tubes during the equilibration phase were kept and these converted to cmolc H+/OH- added /kg of soil. These values were plotted against the equilibrium pH for each tube and the inverse of the slope of this relationship was taken to be the pH buffering capacity (pHBC) of the soil.

The regression analysis routine of Genstat (Genstat 5 Committee, 1993) was used to investigate relationships between pHBC and selected soil properties to establish a pedotransfer function that could be used to estimate this parameter. Curves associated with the charge fingerprints were fitted using the curve fitting function of SigmaPlot 4.0 for Windows.

Estimation of net acid addition rate

The net acid addition rate (NAAR, kmol H+/ha. year) to the agricultural production system was calculated relative to the adjacent undeveloped Diptercarp forest at each site for the 0-15 and 15-30 cm depth interval using the following equation (Helyar,1991) :

$$NAAR = [((pH_U \times pHBC_U) - (pH_D \times pHBC_D)) \times BD \times V] / T \qquad (1)$$

where the subscripts U and D refer to the undeveloped Diterocarp forest and developed agricultural production system respectively; pHBC is the pH buffering capacity for each of the (kmol H+. kg-1. pH unit-1) of the developed and undeveloped areas; BD is soil bulk density which was taken to be 1300 kg m-3; V is the soil volume in the depth interval under consideration (m3 ha-1) ; and T is time (years) since the change in land use system. The net acid addition due to the change in land use was estimated from the sum of two depth intervals.

As will be seen below, management practices often fundamentally affect surface charge characteristics of a soil. As this attribute influences the ability of soils to hold nutrients and buffer changes in soil reactivity, it should therefore form the basis of a degradation index. Menzies and Gillman (1997) suggested that a more satisfactory estimate of degradation can be achieved by comparing the actual basic cation content with an 'ideal' situation where pH is sufficiently high for Al^{3+} to be eliminated from the system. They recommended that at a pH of 5.5, Al^{3+} is effectively eliminated from the exchange complex and that this should form the foundation of an index. They proposed the following Degradation Index (*D*) :

$$D = 100 \times (C_{5.5} - \sum) / C_{5.5} \qquad (2)$$

pHBC and acid addition

Associated with changes in soil organic matter, the pHBC declined with declining OC (Table 1.2). pHBC ranged from 1.321 to 0.205 cmol H+/kg.unit pH over the depth intervals studied. Using a generalized linear model and over all depth intervals, a highly significant relationship between pHBC, and the attributes organic carbon and clay content was observed:

$$pHBC = 0.184\ (\pm 0.037) + 1.004\ (\pm 0.05)\ OC\ (\%) + 0.009\ (\pm 0.004)\ Clay\ (\%)\ ;\ r^2 = 0.916 \qquad (4)$$

A comparison of the measured and predicted pHBC using equation 4 is presented in Figure 1.1. It is of note that the slope of the line is 0.92, which is not markedly different from 1. The use of this pedotransfer function in estimating the buffering capacity of these light textured soils using commonly determined soil attributes (i.e. OC and clay content) will assist in the development of an acidity risk map for Northeast Thailand using existing soil databases.

Surface charge fingerprints

The charge fingerprints for each of the paired sites and depth intervals are presented in Figure 1.2 to 1.10. The general trend exhibited for each site is that the greatest degree of charge diminution occurred in the surface 0-10 cm depth interval. This decline in charge diminished with depth and in most cases was not evident at 70 cm. Clearly the greatest degree of charge decline is associated with a decline in soil organic matter which was highest in the surface 10 cm. The fact that the greatest degree of degradation occurs in the surface layers is somewhat heartening since remediation of this charge decline is possible through either soil organic matter conservation or through other engineering solutions. The regression curves for the charge curves are presented in Tables 1.4. It is of note that when regressing CECt against ECEC for all of the depth intervals there are in some cases a deviation from the 1:1 line (Figure 1.11) . This would suggest that there is an over estimation of cation exchange capacity when using ECEC, this being associated with the presence of soluble cations that are not held on the exchange complex. It is therefore suggested that caution should be taken when using ECEC as an indicator of CEC.

Table 1.1. Selected site information of paddy field sites in Northeast Thailand.

Sample No.	Province	Soil Form	Production system	GPS location	Parent material	Land form	Vegetation	Years under production system.	Comments
F1-5 (R 3)	Yasothon	Roi-et	Forest	15° 35' 59" N 104° 10' 38"E	Alluvium	Low terrace	DDF	Unknown	National Reserved forest
F6-10	Yasothon		Low land rice	15° 35' 59" N 104° 10' 38"E	Alluvium	Low terrace	DDF	37	Upper paddy
G1-5 (R 4)	Roi-et	Roi-et	Forest	15° 47' 36" N 103° 57' 04"E	Alluvium	Low terrace	DDF	Unknown	Spiritual forest
G6-10	Roi-et		Low land rice	15° 47' 36" N 103° 57' 04"E	Alluvium	Low terrace	DDF	50+	Middle paddy
H1-5 (R 5)	Roi-et	Roi-et	Forest	15° 49' 29" N 103° 55' 51"E	Alluvium	Flood plain	Swamp forest	Unknown	Spiritual forest
H6-10	Roi-et		Low land rice	15° 49' 29" N 103° 55' 51"E	Alluvium	Flood plain	Swamp forest	100+	Lower paddy

Table 1.2. Selected chemical and physical properties of composite samples from the 0-10, 20-30 and 50-70 cm depth intervals from Northeast Thailand. All samples collected from rice cropping systems.

Site No.	Depth	Vegetation	$pH_{0.002}$	OC	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Exch. acidity	ECEC	$CEC_{B5.5}$	CEC_T	pHBC	C sand	F Sand	Silt	Clay
	(cm)			(%)	($cmol_c$/kg)								($cmol_c$/kg.pH)	(%)			
R3	0-10	Forest	4.72	0.963	0.246	0.192	0.092	0.019	0.873	1.421	1.674	1.309	1.321	42.9	43.2	8.4	5.4
R3	20-30	Forest	4.89	0.346	0.056	0.081	0.032	0.011	0.695	0.875	1.035	0.826	0.683	44.7	43.3	8.1	3.8
R3	50-70	Forest	5.21	0.133	0.040	0.046	0.014	0.008	0.434	0.541	1.054	0.535	0.324	44.2	44.5	7.7	3.5
R3	0-10	Rice	5.09	0.668	0.601	0.110	0.040	0.036	0.212	1.000	1.210	1.072	0.759	52.2	37.7	6.7	3.5
R3	20-30	Rice	5.12	0.156	0.184	0.085	0.028	0.017	0.525	0.839	0.809	0.795	0.387	48.5	37.6	8.8	5.1
R3	50-70	Rice	4.95	0.103	0.319	0.120	0.044	0.016	0.897	1.395	1.070	1.028	0.342	45.2	40.6	7.7	6.6
R4	0-10	Forest	4.87	0.850	0.340	0.204	0.074	0.029	0.575	1.222	1.335	1.083	1.070	38.4	50.7	6.0	4.9
R4	20-30	Forest	4.91	0.337	0.041	0.051	0.030	0.020	0.539	0.681	0.743	0.640	0.552	38.7	52.1	5.4	3.8

R4	50-70	Forest	5.22	0.108	0.021	0.012	0.007	0.009	0.290	0.339	0.375	0.309	0.288	42.5	49.7	5.4	2.5
R4	0-10	Rice	5.18	0.214	0.142	0.027	0.040	0.011	0.190	0.410	0.481	0.455	0.407	42.1	49.5	5.7	2.7
R4	20-30	Rice	5.16	0.114	0.081	0.024	0.005	0.009	0.320	0.439	0.445	0.434	0.335	38.6	51.9	6.3	3.2
R4	50-70	Rice	5.39	0.042	0.021	0.007	0.003	0.007	0.208	0.247	0.361	0.384	0.218	43.0	48.1	6.2	2.8
R5	0-10	Forest	5.16	1.064	1.438	0.452	0.056	0.017	0.144	2.107	2.524	2.313	1.228	44.7	43.8	6.9	4.6
R5	20-30	Forest	5.10	0.178	0.154	0.094	0.014	0.009	0.224	0.494	0.618	0.532	0.393	43.9	47.2	5.7	3.1
R5	50-70	Forest	5.46	0.099	0.063	0.032	0.007	0.011	0.125	0.239	0.314	0.339	0.205	45.0	45.6	7.0	2.4
R5	0-10	Rice	5.03	0.286	0.161	0.045	0.017	0.022	0.863	1.108	0.672	0.626	0.446	48.2	41.6	6.3	3.9
R5	20-30	Rice	5.21	0.094	0.105	0.027	0.006	0.004	0.331	0.472	0.473	0.478	0.242	38.2	45.6	9.8	6.3
R5	50-70	Rice	4.93	0.091	0.717	0.269	0.023	0.041	0.681	1.734	1.718	1.674	0.288	31.6	44.7	12.1	11.6

Table 1.3. Net losses in soil organic carbon, net acid addition, acid addition rate and saturation index (Su) associated with changed land use from forest to cultivation.

Site	OC loss from 0-10cm depth interval[1]	Net acid input for the 0-30 cm depth interval	Acid addition rate	S_u for the 0-10cm depth interval
	(t/ha)	(kmol H^+/ha)	(kmol H^+/ha.yr)	(%)
Upper paddy	3.84	72.74	1.92	52.9
Middle paddy	8.27	79.64	1.59	63.0
Lower paddy	10.11	94.31	0.94	90.3

[1] At a soil bulk density of around 1,300 kg/m^3

Table 1.4. Fitted regression equations describing the relationship between pH (x) and CECb (y) for composite samples collected from paddy sites Northeast Thailand.

Site	Land use	Depth (cm)	Equation	R^2
Upper paddy	Cultivation	0-10	$CEC_b = -0.005x^2+0.431x-1.00$	0.9908
	Forest	0-10	$CEC_b = 0.061x^2-0.011x-0.111$	0.9933
Upper paddy	Cultivation	20-30	$CEC_b = 0.046x^2-0.356x+1.362$	0.9784
	Forest	20-30	$CEC_b = 0.141x^2-0.979x+2.146$	0.9976
Upper paddy	Cultivation	50-70	$CEC_b = -0.059x^2+0.848x-1.791$	0.9898
	Forest	50-70	$CEC_b = 0.019x^2-0.078x+0.389$	0.9891
Middle paddy	Cultivation	0-10	$CEC_b = 0.016x^2+0.013x-0.077$	0.9879
	Forest	0-10	$CEC_b = 0.130x^2-0.864x+2.140$	0.9979
Middle paddy	Cultivation	20-30	$CEC_b = 0.005x^2+0.094x-0.215$	0.9923
	Forest	20-30	$CEC_b = 0.051x^2-0.243x+0.548$	0.9938
Middle paddy	Cultivation	50-70	$CEC_b = 0.001x^2+0.055x+0.017$	0.9944
	Forest	50-70	$CEC_b = 0.016x^2-0.055x+0.206$	0.9899
Lower paddy	Cultivation	0-10	$CEC_b = 0.034x^2-0.160x+0.537$	0.9983
	Forest	0-10	$CEC_b = 0.694x-1.292$	0.9425
Lower paddy	Cultivation	20-30	$CEC_b = 0.011x^2-0.012x+0.197$	0.9964
	Forest	20-30	$CEC_b = 0.021x^2-0.011x+0.035$	0.9995
Lower paddy	Cultivation	50-70	$CEC_b = -0.083x^2+1.124x-1.962$	0.9521
	Forest	50-70	$CEC_b = 0.076x-0.111$	0.9903

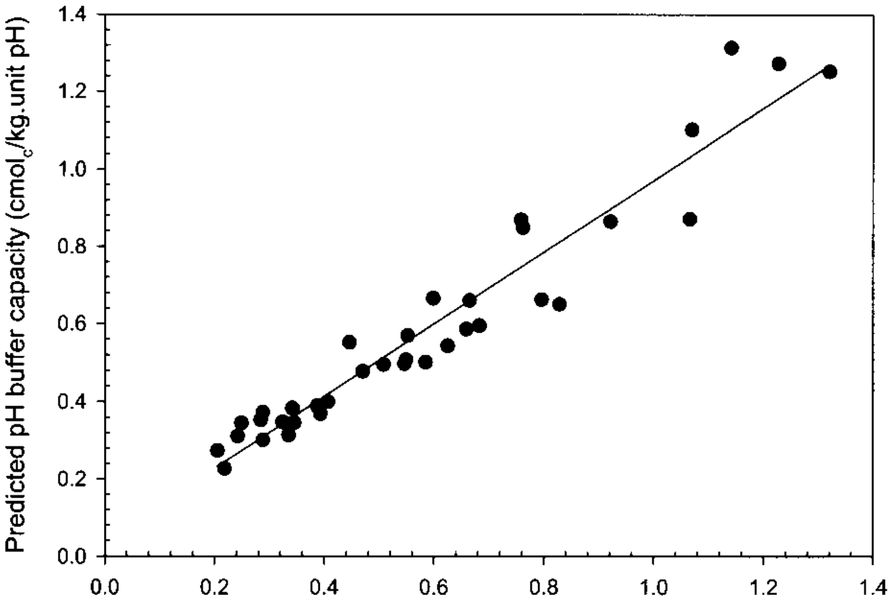

Figure 1.1 Relationship between measured and predicted pHBC using soil organic carbon and clay content from Northeast Thailand. Equation for the curve is $y = 0.042 + 0.928x$; $r^2 = 0.928$.

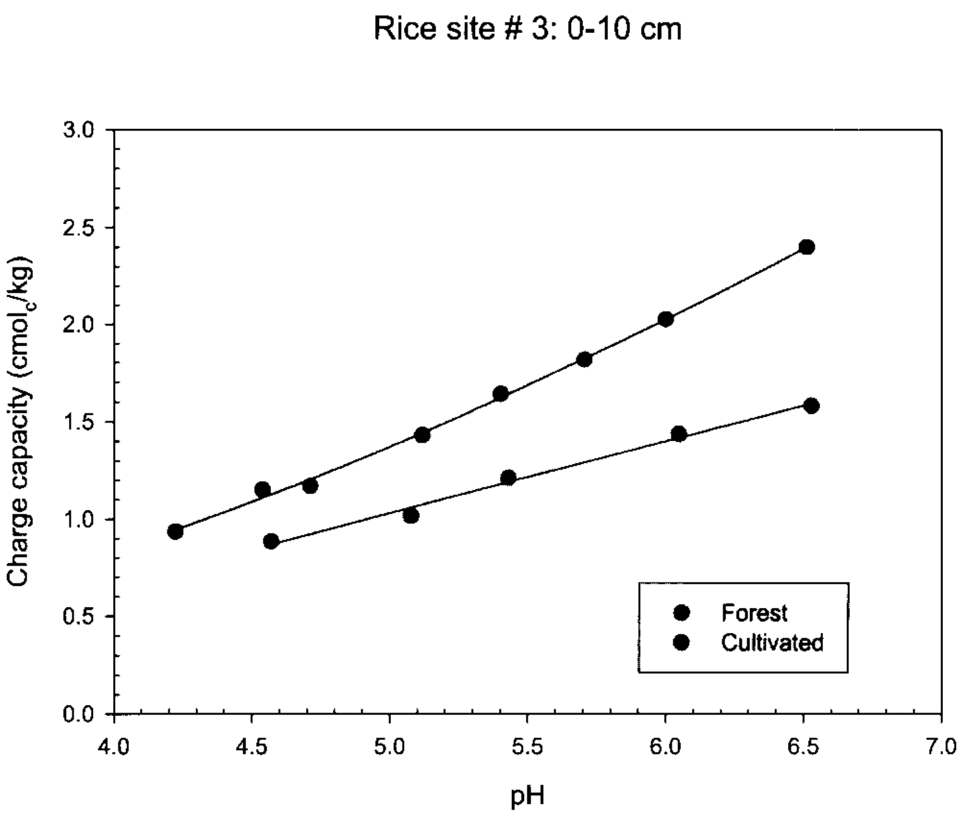

Figure 1.2 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at upper paddy in Northeast Thailand. Depth interval 0-10 cm.

Rice site # 3: 20-30 cm

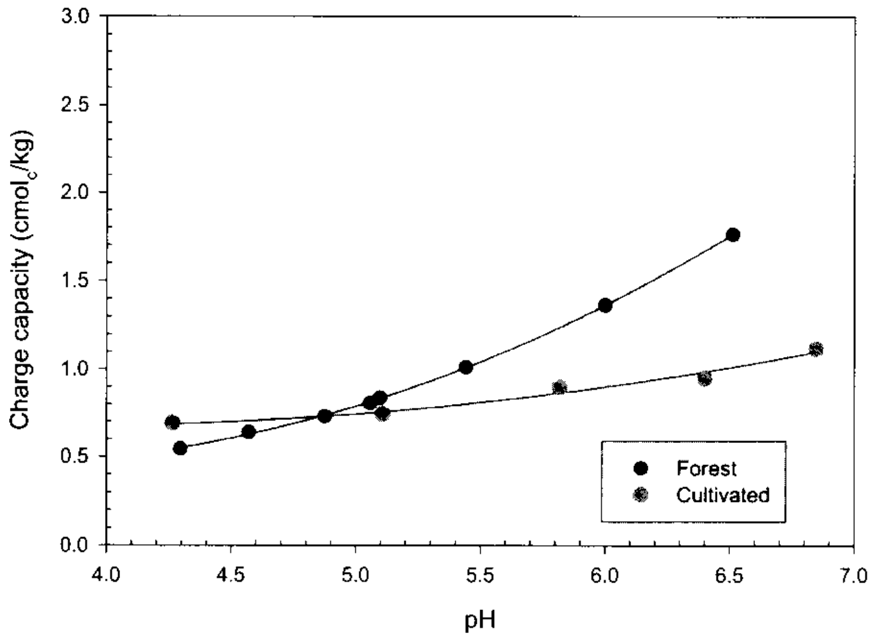

Figure 1.3 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at upper paddy in Northeast Thailand. Depth interval 20-30 cm.

Rice site # 3: 50-70 cm

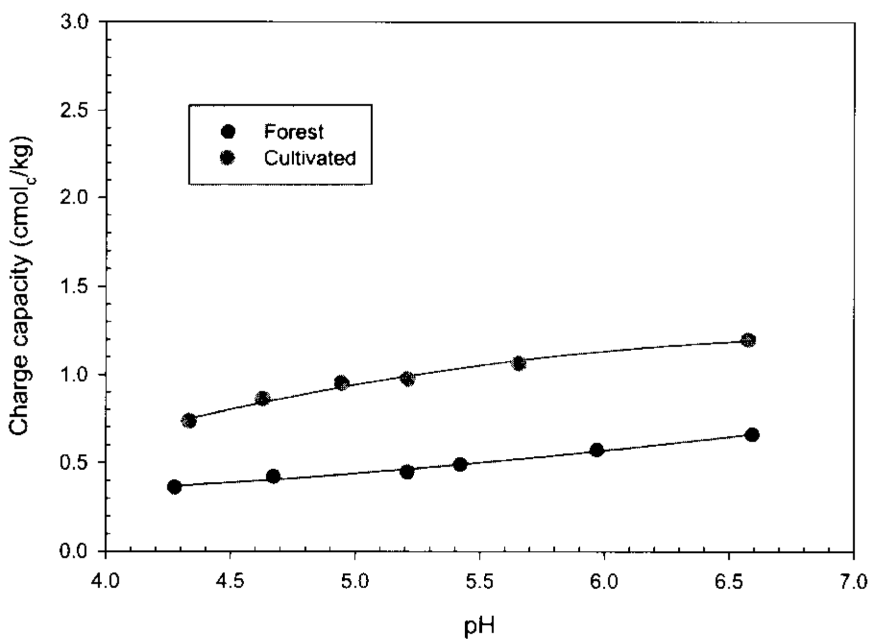

Figure 1.4 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at upper paddy in Northeast Thailand. Depth interval 50-70 cm.

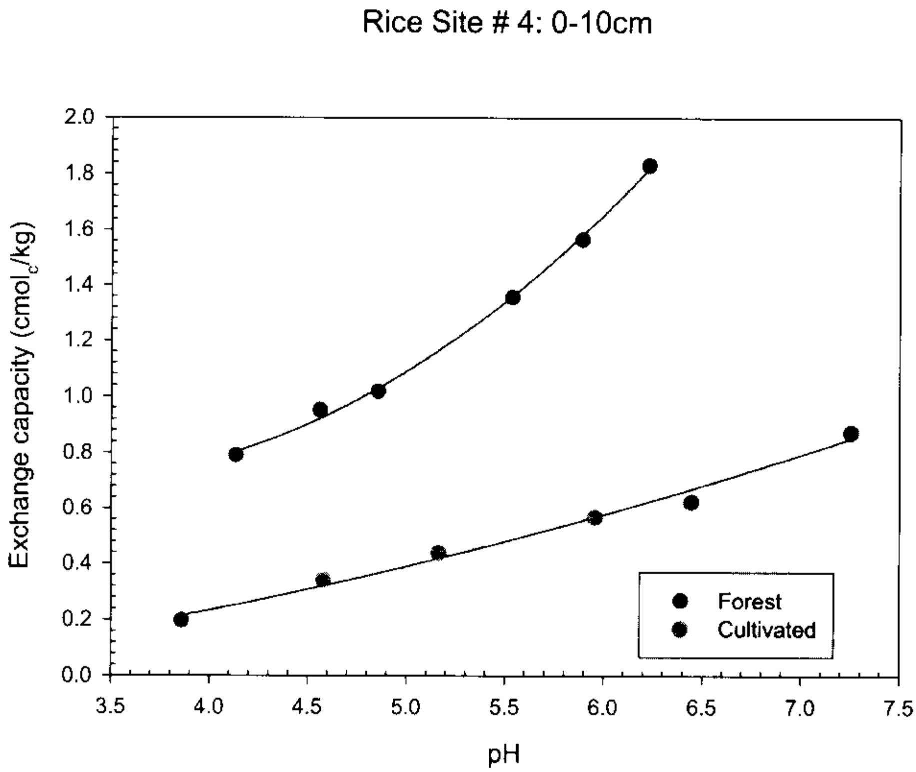

Figure 1.5 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at middle paddy in Northeast Thailand. Depth interval 0-10 cm.

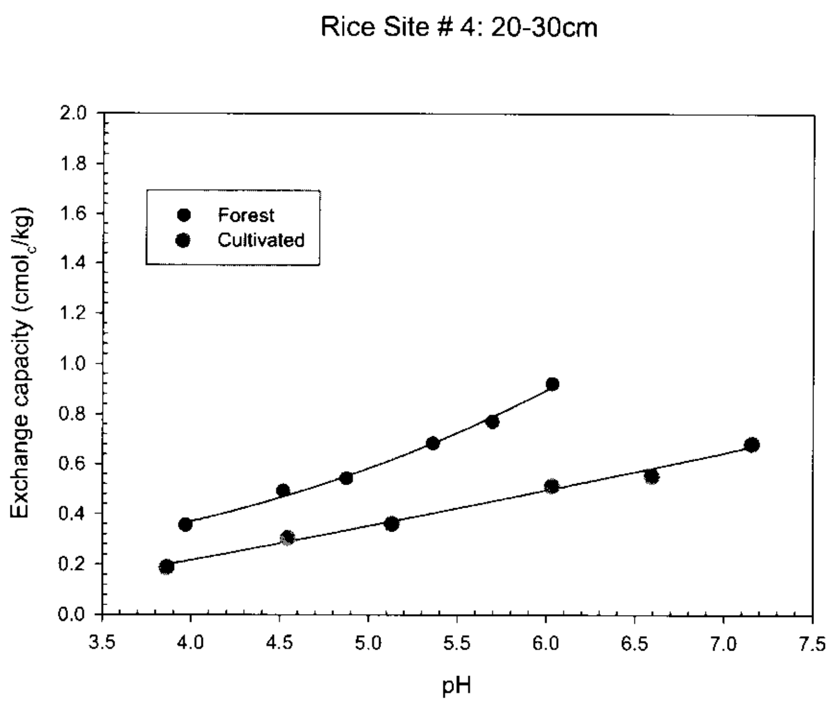

Figure 1.6 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at middle paddy in Northeast Thailand. Depth interval 20-30 cm.

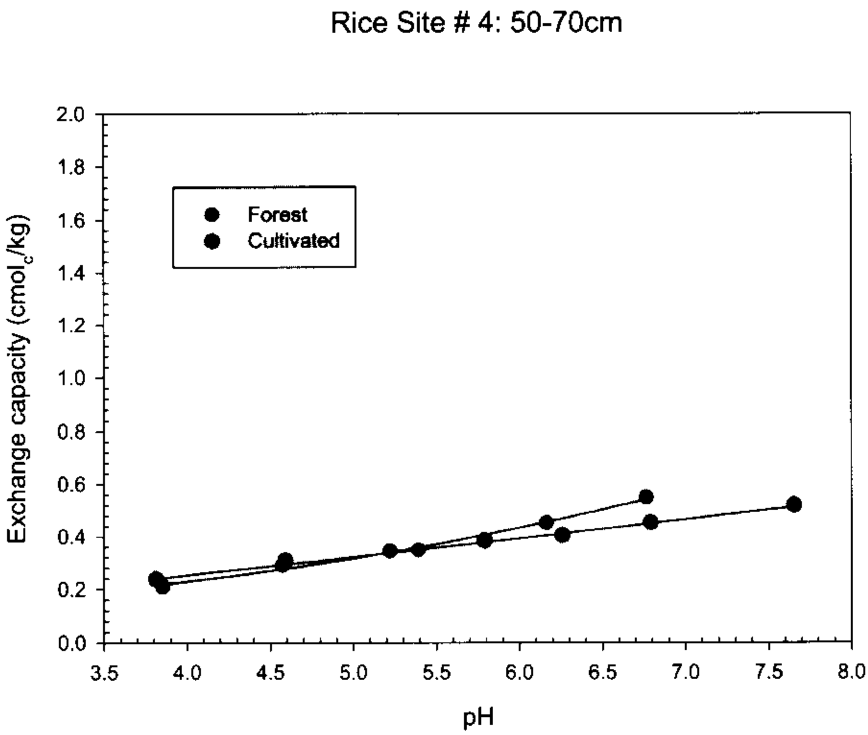

Figure 1.7 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at middle paddy in Northeast Thailand. Depth interval 50-70 cm.

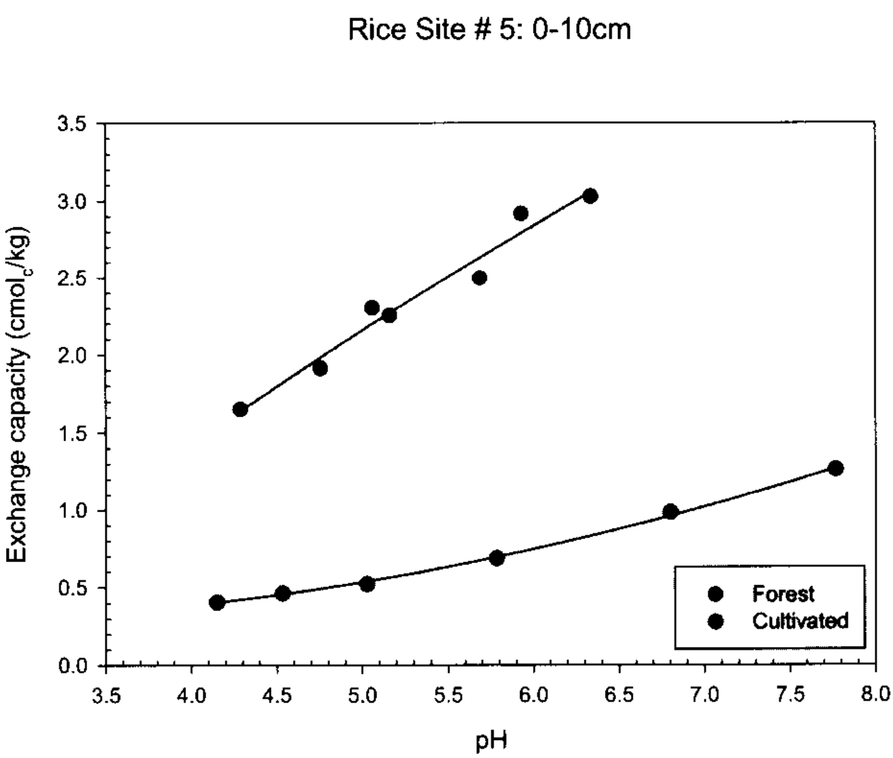

Figure 1.8 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at lower paddy in Northeast Thailand. Depth interval 0-10 cm.

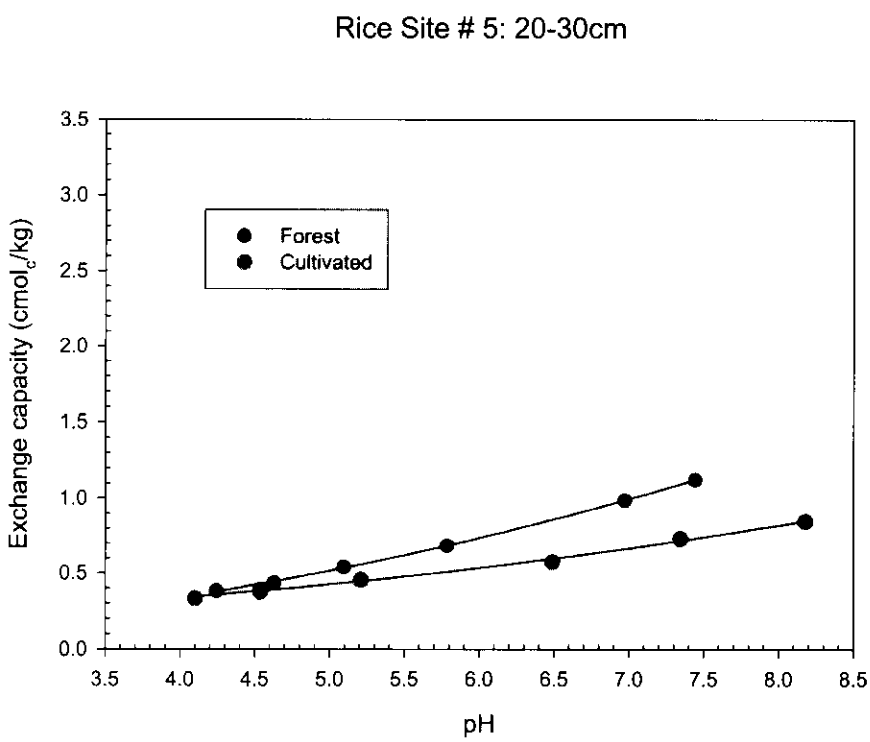

Figure 1.9 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at lower paddy in Northeast Thailand. Depth interval 20-30 cm.

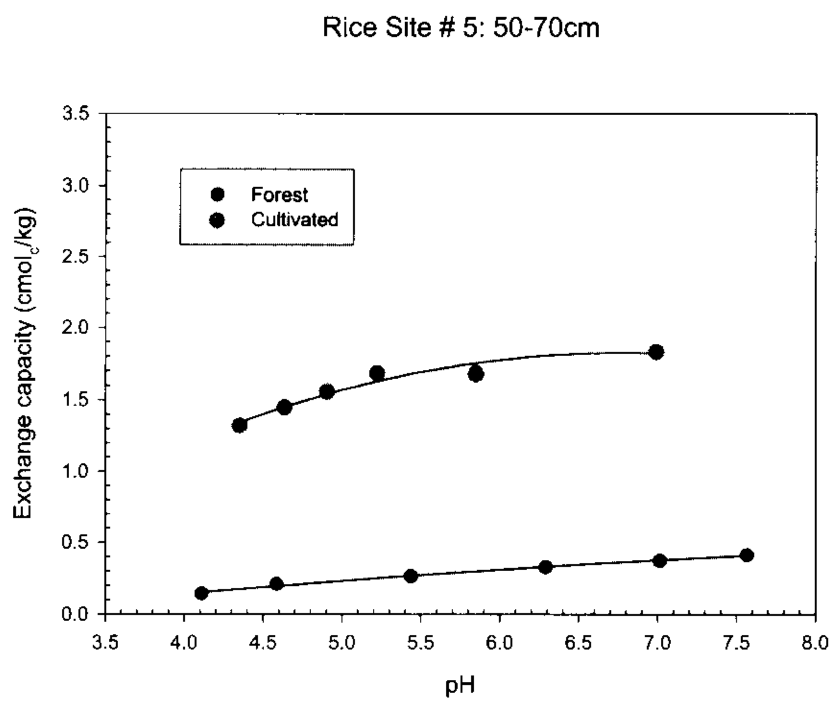

Figure 1.10 Surface charge fingerprints (CECb) of cultivated and adjacent forest sites at lower paddy in Northeast Thailand. Depth interval 50-70 cm.

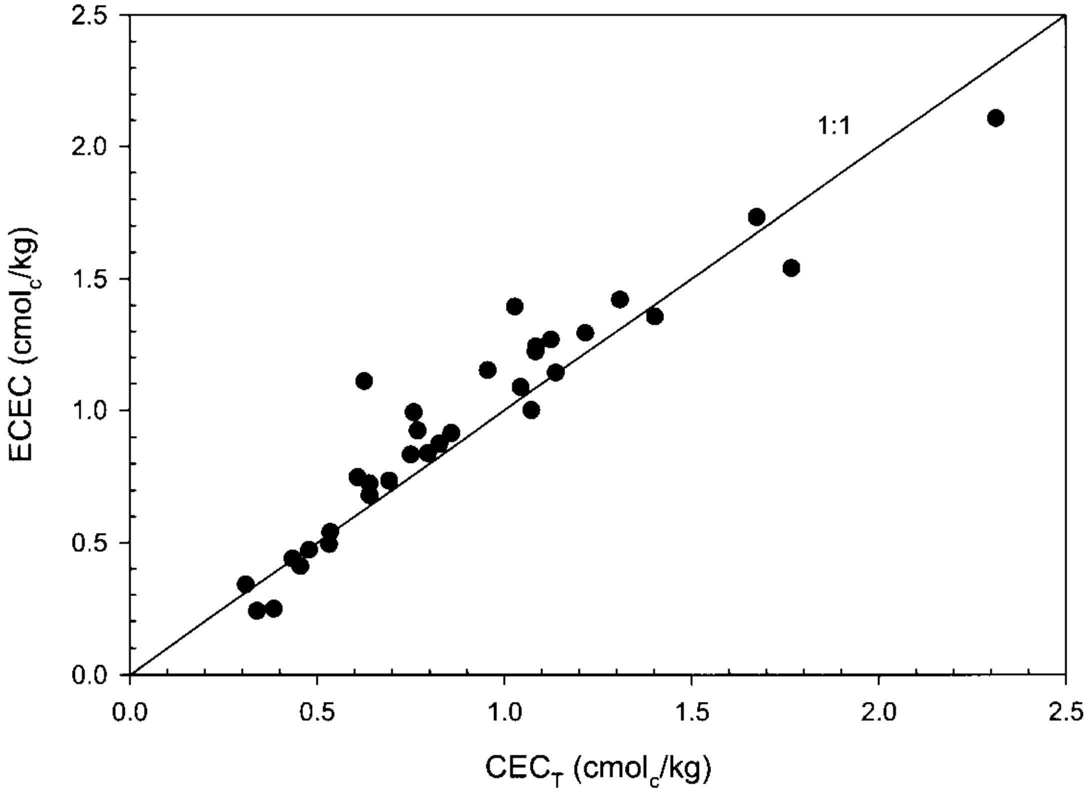

Figure 1.11 Relationship between the effective cation exchange capacity (ECEC) and the total cation exchange capacity in paddy soils.

Conclusions

The approach adopted in this study to assess paddy soil degradation in the Northeast from a soil chemical point of view has contrasted the almost irreversible degradation of a sandy kaolinitic soil in a tropical climate under continuous cropping system. The degree of degradation expressed as an index, S_u, takes into account changes in the surface charge characteristics and amounts of basic cations remaining in the soil. We think that this index should assist in quantification of the degree of degradation due to changed land use.

The long-term consequences of soil degradation in the Northeast of Thailand site are significant for all representative types and bring into question the sustainability of current agricultural practices in some regions. Soils that have a low buffering capacity (i.e. little clay and organic matter) are prone to acidification and cation depletion, which can have a dramatic effect on their productivity and food security. Rehabilitation measures such as integrated farming system and agroforestry system should be considered to reduce losses or improving soil productivity of this region.

Acknowledgements

We are grateful to the Australian Centre for International Research (ACIAR) for their financial support, and to Ms S. Berthelsen at CSIRO, Townsville, Australia for analyzing the samples.

References

Bartlett, R.J., Ross, D.S. & Magdoff, F.R. 1987. Simple kinetic fractionation of reactive aluminum in soil "solution". *Soil Science Society of America Journal,* 51, 1479-1482.

Coventry & Fett (1979) Soil particle size fractionation. Soil Analysis manual. ASSS.

Genstat Committee. 1993. Genstat 5 Reference Manual. Oxford University Press, Oxford.

Gillman, G.P. & Abel, D.J. 1986. A Summary of the Surface Charge Characteristics of the Major Soils of the Tully-Innisfail Area, North Queensland. CSIRO Australia Division of Soils Divisional Report No 85. CSIRO, Melbourne.

Gillman, G.P. & Sumpter, E.A. 1986. Modification of the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soils Research* 24, 61-66.

Helyar, K. R. 1991. The management of acid soils. In Plant-Soil interactions at Low pH. Eds. R,. J. Wright, V. C. Baligar and R. P. Murrmann. Pp 365-382. Kluwer Academic Publ., Dordrecht, The Netherlands.

Menzies, N.W. & Gillman, G.P. 1997. Chemical characterization of soils of a tropical humid forest zone: A methodology. *Soil Science Society of America Journal* 61, 1355-1363.

Noble, A.D., Gillman, G.P. and Ruaysoongnern, S. 2000. A cation exchange index for assessing degradation of acid soil by further acidification under permanent agriculture in the tropics: EJSS; Volume 51 no 2 (June), 2000, 233-243.

Panichapong, S. 1988. Soil and water resources in Northeast Thailand. In: *Soil, Water and Crop Management Systems for Rainfed Agriculture in Northeast Thailand* (eds. C. Pairintra, K. Wallapapan, J.F. Parr & C.E. Whitman.) , pp. 2-13. USDA, Washington D.C.

Ragland, J. & Boonpuckdee, L. 1987. Fertilizer responses in Northeast Thailand: 1. Literature review and rationale. *Thai Journal of Soils and Fertilizers* 9, 65-79.

Rayment G.E. & Higginson, F.R. 1992. *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Inkata Press, Melbourne.

Soil Survey Staff, 1990. Characterisation of Soil Series Established in the Northeastern Region and their Interpretation for Uses. Technical Report No 314. Department of Land Development, Bangkok.