Enhancing the agronomic productivity of degraded soils in North-east Thailand through clay-based interventions

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Abstract

Although North-east Thailand occupies one-third of the arable land in Thailand, income per capita for the region is no more than 40% of the national average and poverty affects 37% of the population. A major reason for this high level of poverty is the relatively limited natural resources of the region. The soils of North-east Thailand are dominated by sandy, light-textured soils with low organic matter and low clay. Consequently, they have a low water holding capacity, cation exchange capacity (CEC) and, hence, limited buffering capacity against both man-made and natural stresses. Using a paired site analysis, the degree of chemical degradation between an undisturbed (Dipterocarp forest) and disturbed (agriculture system) was assessed. It was estimated that the amount of soil organic carbon lost in the 0–10 cm depth interval ranged from 3.84 to 10.11 t ha^{-1}. This resulted in a dramatic decline in the CEC of the soil. Using a saturation index (S_u) that quantifies degradation based on CEC, the effects of changed land use resulted in S_u values ranging from 52.9–90.3% clearly indicating the impact of agricultural practices on a fundamental property of these soils. In an effort to remediate the chemical attributes of these degraded soils and enhance productivity, a series of field based experiments have been initiated in the Chiang Yuen area of North-east Thailand. Two structured field trials on remediating soil chemical degradation included the following treatments:

- current farmer practice
- termite mound soil
- composted leaf litter
- locally available lake dredged material
- locally sourced bentonite
- waste bentonite from vegetable oil processing
- soil slotting.

The trial land was planted with forage sorghum and two consecutive crops were harvested over the 2002 growing season. Dry matter production ranged from 0.14 to 0.22 t ha^{-1} in the control treatments of each trial—with the plants having almost completely failed because of drought—to 8.4 and 10.0 t ha^{-1} for the termite mound material and local bentonite plus leaf litter compost respectively. These dramatic increases in productivity are probably due to increases in CEC, plant nutrient supply and water holding capacity of the soil. The application of locally resourced high-activity clay materials at a ratio of 2:1 offers a potential way to increase the productivity of degraded light textured soils within the first growing season. This approach to soil rejuvenation could potentially be used to enhance food security at the household level and allow the development of conservation based farming systems.

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ALTHOUGH North-east Thailand accounts for one-third of the arable land in Thailand, income per capita for the region is no more than 40% of the national average and poverty is at a high level affecting 37% of the population (Matsuo, 2002). A major reason for this high level is the relatively limited natural resources of the region. Inherent fertility of soils is low, water resources scarce and rainfall patterns and distribution erratic (Panichapong, 1988). The soils of North-east Thailand are dominated by sandy, light-textured soils with low organic matter and low clay (Ragland and Boonpuckdee, 1987). Consequently they have a low water holding capacity, CEC and hence limited buffering capacity against both anthropogenic and natural stresses. Although the annual precipitation is 800–1400 mm, most of it falls during the six-months rainy season and is often erratic and poorly distributed resulting in seasonal drought periods.

Before the 1950s the region was dominated by climax *Dipterocarp* forest. These were highly productive ecosystems characterised by tight nutrient cycling through organic matter and efficient water use. Increased demand for arable land associated with population growth led to indiscriminate clearing of these forests and a decline in the fertility status of the soils and consequently, productivity. Continuous production of export crops such as rice, kenaf (rosella), cassava, and sugarcane has resulted in a rapid decline in the inherent fertility status of these soils, with an associated loss of productivity.

Rice is frequently grown in this region on land that has an undulating topography. Initially, farmers establish rice crops on such land at the bottom of depressions and subsequently progress up the slope towards the upland (Limpinuntana, 1988). Rice production in the bottom or lower paddies is considerably more stable than that grown in the upper paddy fields. Accordingly, rice can only be grown in the upper paddy fields for one to three years out of five because of insufficient water for transplanting (Limpinuntana, 1988). These upland soils have been extensively leached and eroded and consequently have a low inherent fertility, low CEC, sandy texture, low water holding capacity, low organic matter content and are acid. Consequently, farmers have moved towards low-input and long-duration crops such as cassava and kenaf.

To maintain the productivity of soils, farmers traditionally apply cattle manure and composts derived from household waste and leaf litter to both upland and lowland fields along with sparing amounts of inorganic fertiliser. The production of composts predominantly relies on the cycling of plant materials from areas in close proximity to the field and household organic waste products which may not be sufficient to provide adequate levels of nutrients for enhanced productivity. In addition, the effects of these organic amendments may not be long lasting because of rapid mineralisation and therefore need regular routine additions. For more intensive high-input systems on these light-textured soils, farmers have resorted to rehabilitating them by adding locally available termite mound material. This clearly demonstrates the ability of traditional farmer knowledge in perceiving and implementing strategies to address the issue of declining fertility associated with their production practices. These materials are commercially excavated from large mounds that are the products of termite activities (*Macrotermes* spp.). Farmers will apply up to 7200 t ha^{-1} to small plots where intensive vegetable production is undertaken.

In recent years the dredging of lowland reservoirs throughout Thailand to increase water storage capacity has been undertaken by local councils. The dredged materials, which have relatively high organic carbon and clay contents, become a waste material that requires disposal. These materials are often used in the construction industry as backfill. Recently, farmer groups have investigated the potential role of these dredged materials in improving the productive capacity of their soils. Their main attraction is that they are relatively cheap (US$1.00–3.00 per 6 t truck load, which is significantly cheaper than any chemical fertilisers with equivalent nutrient levels). This practice has rapidly expanded and is generally confined to areas close to the source. However, this practice can damage the soil if the dredged material contains high levels of iron pyrite (acid sulphate). This produces acid in an oxidising environment. In addition, once the process of dredging ceases there will no longer be a supply of this resource.

As farmers traditionally recognise the value of clay materials in restoring the nutrient and water holding capacity of degraded soils, a possible improvement to current practices is the use of high-activity clays. Bentonites are naturally occurring 2:1 layer silicate clays that have a high permanent negative charge due to isomorphous substitution that occurred during formation. As a result of this, they have a high CEC which is often dominated by essential cations such as

$Ca^{2+}$and Mg^{2+}. When bentonites are added to soils they are able to increase the nutrient holding capacity of the soils and therefore reduce potential losses of nutrients through leaching (Noble et al. 2000).

The focus of the current study is on quantifying changes in surface charge characteristics associated with changed land management under two contrasting cropping systems: rice and cassava. Through the construction of charge fingerprints and the subsequent use of the Saturation Index (S_u) (Noble et al. 2000) an estimation of the degree of charge diminution that the soils had undergone from a 'benchmark' state, in this case remnant *Dipterocarp* forest, can be achieved. A field trial was established at Chiang Yuen, North-east Thailand, to evaluate selected strategies that are currently used by farmers to remediate declining productivity, including the use of high activity clay as a soil amendment.

Materials and methods

Assessment of degradation

Six paired sites covering both upland and lowland cropping systems in North-east Thailand were selected for subsequent analysis (Table 1). The selection of sites was based on the criteria of:

- the existence of *Dipterocarp* forest in close proximity to an agricultural production system
- a well defined boundary separating the two production areas
- the same soil type in both areas
- little topographical difference (i.e. 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 5 m apart and at each point three augur holes (10 cm diameter) were made and soil samples collected at depths of 0–10, 20–30, and 50–70 cm and bulked to form depth-specific, composite samples. Three of the sites were from cassava-based systems (C1–C3) and three from rice-based systems (R1–R3).

Soil analysis

Samples were air dried and sieved to pass a 2 mm mesh. A bulked composite sample was made for each of the paired sites at 0–10, 20–30 and 50–70 cm depth intervals. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M $BaCl_2$–NH_4Cl as recommended by Gillman and Sumpter (1986). Acidic cations were extracted with 1 M KCl and the extractant titrated to pH 8.0 as described by Rayment and Higginson (1992). The effective cation exchange capacity (ECEC) was calculated as the sum of basic and acidic cations ($Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}+Al^{3+}+H^{+}$). Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992) and particle size as described by Coventry and Fett (1979).

Charge fingerprints were determined on the composite samples from each site using the method of Gillman and Sumpter (1986). Records of the amounts of acid or base added to the tubes during the equilibration phase were kept and these converted to $cmol_c$ 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. Curves associated with the charge fingerprints were fitted using the curve fitting function of SigmaPlot 4.0 for Windows.

Soil chemical degradation index

A saturation index (S_u) as proposed by Noble et al. (2000) was used to quantify charge diminution from an agronomic ideal state. The S_u index has the following format:

$$S_u = 100 \times (C_{u5.5} - \Sigma)/C_{u5.5} \qquad (1)$$

where $C_{u5.5}$ refers to the CEC at pH 5.5 of the undisturbed (*Dipterocarp* forest) soil as determined from the charge fingerprint, and Σ is the sum of the base cations actually present in the system under review. A low S_u indicates closeness to the ideal condition for that particular soil.

Field trial

Two independent field trials were established at Chang Yuen Research Station of the Department of Livestock, Region 5, North-east Thailand in the 2001 and 2002 growing seasons. The trial site is in an upland position with a gently undulating topography. The trial consisted of a randomised block design with four replications. Each plot was 5 x 10 m with a 1 m break between treatments. In the trial established in 2001 the following treatments were applied:

Table 1. Selected information associated with location, parent material, land use and soil classification for the samples taken from cassava (C1, C2, C3) and rice-based systems (R1, R2, R3) in North-east Thailand.

Sample site and No.	Province	Thai soil form	Current production system	GPS location	Parent material	Land form	Previous vegetation	Years under production system	Comments
C 1	Sisaket	Korat	Forest	15° 16' 33" N 104° 01' 05" E	Alluvium	High terrace	Dipterocarp	Unknown	Community forest for 14 years
	Sisaket		Cassava		Alluvium	High terrace	Dipterocarp	40	
C 2	Sisaket	Yasothon	Forest	15° 17' 01" N 104° 01' 22" E	Alluvium	High terrace	Dipterocarp	Unknown	Community forest for 14 years
	Sisaket		Cassava		Alluvium	High terrace	Dipterocarp	40	
C 3	Sisaket	Korat	Forest	15° 16' 18" N 104° 01' 44" E	Alluvium	Middle terrace	Dipterocarp	Unknown	Community forest for 14 years
	Sisaket		Cassava		Alluvium	Middle terrace	Dipterocarp	38	
R1	Yasothon	Roi-et	Forest	15° 35' 59" N 104° 10' 38" E	Alluvium	Low terrace	Dipterocarp	Unknown	National Reserved forest
	Yasothon		Low land rice		Alluvium	Low terrace	Dipterocarp	37	
R 2	Roi-et	Roi-et	Forest	15° 47' 36" N 103° 57' 04" E	Alluvium	Low terrace	Dipterocarp	Unknown	Spiritual forest
	Roi-et		Low land rice		Alluvium	Low terrace	Dipterocarp	50	
R 3	Roi-et	Roi-et	Forest	15° 49' 29" N 103° 55' 51" E	Alluvium	Flood plain	Swamp forest	Unknown	Spiritual forest
	Roi-et		Low land rice		Alluvium	Flood plain	Swamp forest	100	

Trial 1

T1.1. Control 1—current farmer practice of tillage and fertiliser additions
T1.2. Termite mound soil applied at 120 t ha^{-1}
T1.3. Leaf compost applied at 10 t ha^{-1}
T1.4. Dredged lake material at 120 t ha^{-1}
T1.5. Waste bentonite at 50 t ha^{-1}
T1.6. Waste bentonite at 50 t ha^{-1} + 5 t ha^{-1} lime

The termite mound soil was excavated from active mounds in the district and brought to the site. Compost was produced locally by farmers using leaf litter collected from remnant *Dipterocarp* forest and household vegetable matter. Over the past five years local governments in the north-east have been dredging water storage facilities to increase capacity. The dredged material is either dumped on farm land or used as landfill in building projects. Dredged material used in the current study was sourced from a local contractor. Waste bentonite is a by-product from the vegetable oil industry where activated bentonite is used to clarify oil. The waste product is acidic and is disposed of in landfills. Waste bentonite from a soybean oil processing plant in the Bangkok area was sourced and two treatments imposed: the waste product on its own, and the waste bentonite with lime applied to neutralise residual acidity (pH approximately 3.5) associated with the activated bentonite. All treatments were broadcast applied and incorporated into the top 20 cm using a rotary hoe. Forage sorghum was established in 2001, however, because of the poor season conditions, the trial had to be abandoned. The trial was re-established to forage sorghum in 2002 and these results are presented.

An additional study (Trial 2) was established in 2002 to investigate alternative soil amendment technologies that are currently being assessed in the north-east. The following treatments were imposed:

Trial 2

T2.1. Control 2—current farmer practice tillage and fertiliser addition
T2.2. Slotting
T2.3. Slotting + 50 t ha^{-1} bentonite
T2.4. Slotting + 50 t ha^{-1} bentonite + 10 t ha^{-1} compost
T2.5. Local bentonite at 50 t ha^{-1}
T2.6. Local bentonite at 50 t ha^{-1} + compost at 10 t ha^{-1}

Due to the unique particle size distribution of soils in the North-east, repeated tillage operations result in the development of a compact layer at about 15–20 cm and more importantly slumping or structural collapse of the soil that occurs shortly after the start of the wet season. This results in the tilled profile becoming compacted and hard-setting as it begins to dry out. By creating a slot through this compacted layer, roots proliferate better and the crops are able to extract deeper water and nutrients. In addition, the structure of the slots would reduce or even prevent structural collapse. Slots were carefully excavated by hand (Figure 1). The removed soil from the slot was then mixed with the equivalent of 12.5 t ha^{-1} of bentonite before being placed back into the slot. The remaining 37.5 t ha^{-1} was applied as a broadcast application and incorporated into the surface 20 cm. Similarly, for the slot + bentonite + compost, one quarter of the bentonite and compost was added to the slot and the remaining incorporated into the top 20 cm using a rotary hoe. All slots were positioned on the planting row. The bentonite used in Trial 2 was quarried locally in the Lopburi province and is commercially used in the prawn farming industry. The compost used came from the same source as in Trial 1.

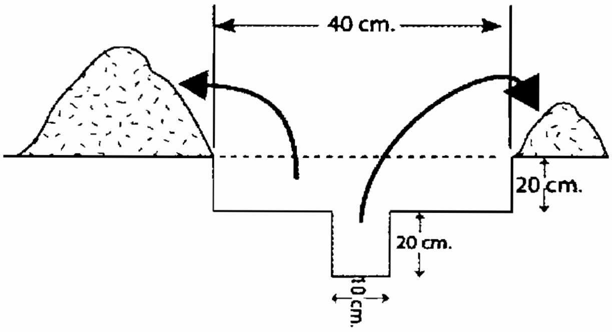

Figure 1. Diagram depicting the structure and dimensions of slots used in field Trial 2 at Chiang Yuen, North-east Thailand.

During the 2002 season forage sorghum was established on 7 June 2002 by sowing seeds in a small furrow and lightly covering them with loose soil. Plants were thinned one month later to a spacing of about 20 cm. An application of a proprietary formulated fertiliser (16–20–0; N:P:K) at a rate of 200 kg/ha was made to all plots one month after establishment and thereafter at monthly intervals. Hand weeding was undertaken throughout the growing season as and when required. Two biomass harvests were conducted during the growing season with the crop being allowed to grow out after the first harvest. The entire plot was harvested and material removed for fresh weight determination and a sub-sample returned to the laboratory for dry matter determination.

Analysis of yield data was undertaken using the ANOVA module of the GENSTAT package for each of the trials (Genstat Committee 1993).

Results and discussion

Assessing degradation

Site history

North-east Thailand has undergone dramatic changes in land use over the past 40 years. This has included a move away from subsistence based agriculture to commercial farming systems. Much of the land affected has been traditionally used for paddy subsistent rice production for more than 100 years. A move towards upland crop production was initiated about 40 years ago with cassava and sugarcane becoming dominant components of these systems in the past 20 years. The production system is characteristically a rotation one with a five-year cropping cycle followed by a two to three-year fallow as a way to improve the fertility of these light textured soils. The three upland sites all currently support cassava production. The adjacent 'benchmark' sites had previously been under cassava production but were abandoned about 14 years ago and have reverted back to regenerated *Dipterocarp* forest. In contrast, the three lowland rice production systems were established on lands that were previously dominated by *Dipterocarp* forest or lowland swamp forest.

Soil chemical and physical properties

The soil series represented at the 6 sites were the Roi-et (fine-loamy, mixed, isohyperthermic Aeric Paleaquults); Korat (fine-loamy, siliceous, isohyperthermic Oxic Paleustults); and Yasothon (fine-loamy, siliceous, isohyperthermic Oxic Paleustults) (Soil Survey Staff, 1990) (Table 1). All of these series were formed from old alluvium and occur on low, middle and high terraces respectively. These soils are dominated by coarse and fine sand with very low clay contents (range: 2.4–15.5%) (Tables 2 and 3). The texture is relatively uniform deep into the soil profile with the percentage of clay ranging from 2.4 to 15.5% (Tables 2 and 3).

Soil pH, organic C, exchangeable basic and acidic cations, effective cation exchange capacity (ECEC), pHBC, CEC_b and CEC_t for each of the depth intervals are presented in Tables 2 and 3. Differences in pH between the benchmark sites and adjacent cultivated sites were not marked and no clear trends in pH changes were seen (Tables 2 and 3). In three cases (C1, C2, R5) there was a small decline in the pH of the surface 0–10 cm between the forest and cultivated sites. For the three cassava sites (C1–C3) this may in part be attributed to the fact that the sites were previously cultivated. Differences in exchangeable acidity reflected trends in soil pH with an increase in exchangeable acidity and a decline in pH. Exchangeable acidity cations (hydrogen and aluminium) dominated the exchange complex at several of the sites as soil pH declined. Exchangeable basic cations were lower at the 0–10 cm level on the disturbed sites, but this trend was reversed with depth suggesting that leaching of basic cations from surface layers to deeper ones had occurred as a result of changed land use (Tables 2 and 3). Of the exchangeable bases, Ca^{2+} dominated the exchange complex. The concentration of K^+ on the exchange complex was very low in the surface 0–10 cm of cultivated sites, suggesting these soils would respond to prophylactic applications of potassium-based fertilisers and that there had been significant removal or loss of potassium with changed land use.

Over the intervening period since conversion from forest to continuous agriculture, soil organic carbon (OC) declined markedly in the upper soil layers (0–10 cm) (Tables 2 and 3). The loss in soil OC resulting from cultivation ranged from 3.84 t ha^{-1} at site R1 through to 10.11 t ha^{-1} at site R3, a site previously dominated by swamp forest (Table 4). Clearly such dramatic declines in OC would significantly affect properties associated with cation retention, pH buffering and the water-holding capacity of these soils.

Surface charge fingerprints

The dominant soil series of North-east Thailand are sandy with little OC, and have a clay mineralogy dominated by highly ordered kaolinite and oxides (Panichapong, 1988). These soils have only modest surface charge, with both permanent and variable charge components. For brevity, graphical representations of surface-charge fingerprints for each of the composite depths for the forest and cultivated sites are presented for two of the six sites (Figures 2 and 3). The general trend exhibited for each site is that the greatest degree of charge diminution occurred in the surface 0–10 cm depth interval. A distinctive characteristic of the curves derived for the 0–10 cm depth interval at the C1 site is that the negative charge generated varied from approximately 1.1 to 2.1 $cmol_c\ kg^{-1}$ and 0.5 to 1.2 $cmol_c\ kg^{-1}$ over the pH

Table 2. Selected chemical and physical properties of composite samples collected from selected depth intervals from paired sites in North-east Thailand that are currently under a cassava cropping system (C).

Site No.	Depth (cm)	Vegetation	$pH_{0.002}$	OC (%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	Exch. acidity	ECEC	$CEC_{B5.5}$	CEC_T	pHBC ($cmol_c$/kg.pH)	C Sand	F Sand	Silt	Clay
					($cmol_c$/kg)									(%)			
C1	0–10	Forest	5.18	0.667	0.742	0.404	0.092	0.003	0.115	1.356	1.571	1.402	0.922	47.2	43.0	5.0	4.9
C1	20–30	Forest	4.95	0.399	0.184	0.231	0.041	0.004	0.628	1.087	1.132	1.043	0.665	45.9	42.4	4.3	7.4
C1	50–70	Forest	5.18	0.114	0.039	0.173	0.015	0.002	0.495	0.725	0.602	0.640	0.249	44.9	44.9	4.7	5.5
C1	0–10	Cassava	5.00	0.327	0.250	0.109	0.034	0.001	0.354	0.749	0.827	0.608	0.625	46.5	45.7	3.0	4.7
C1	20–30	Cassava	4.86	0.364	0.169	0.067	0.027	0.001	0.978	1.242	1.162	1.084	0.599	40.7	46.8	4.5	8.0
C1	50–70	Cassava	5.04	0.103	0.152	0.049	0.013	0.003	0.617	0.834	0.742	0.750	0.284	40.8	47.8	4.8	6.6
C2	0–10	Forest	5.05	1.081	0.798	0.454	0.068	0.003	0.219	1.541	2.091	1.767	1.142	39.5	46.4	6.4	7.7
C2	20–30	Forest	4.96	0.570	0.215	0.256	0.051	0.003	0.616	1.141	1.292	1.137	0.762	35.3	49.1	5.2	10.3
C2	50–70	Forest	4.91	0.210	0.093	0.119	0.015	0.004	0.684	0.915	0.969	0.858	0.508	37.8	45.4	5.2	11.6
C2	0–10	Cassava	5.02	0.427	0.338	0.113	0.036	0.003	0.435	0.924	0.912	0.768	0.829	44.6	48.3	3.2	3.9
C2	20–30	Cassava	5.01	0.397	0.619	0.196	0.023	0.004	0.452	1.293	1.373	1.216	0.796	36.9	46.1	5.3	11.7
C2	50–70	Cassava	5.02	0.204	0.498	0.179	0.014	0.003	0.574	1.268	1.201	1.124	0.546	30.2	49.1	5.2	15.5
C3	0–10	Forest	5.08	0.651	0.591	0.366	0.045	0.004	0.316	1.322	1.643	1.418	1.066	42.5	47.0	5.4	5.1
C3	20–30	Forest	4.98	0.285	0.085	0.146	0.024	0.003	1.043	1.302	1.187	1.059	0.659	40.4	47.4	5.3	6.8
C3	50–70	Forest	4.94	0.162	0.095	0.132	0.012	0.003	1.081	1.323	1.309	1.229	0.470	37.5	47.3	5.7	9.6
C3	0–10	Cassava	5.25	0.284	0.303	0.108	0.031	0.003	0.291	0.736	0.731	0.692	0.585	47.4	43.2	3.1	6.3
C3	20–30	Cassava	4.96	0.228	0.205	0.065	0.016	0.004	0.861	1.151	1.054	0.956	0.549	50.6	38.3	4.4	6.7
C3	50–70	Cassava	5.09	0.087	0.193	0.041	0.009	0.006	0.741	0.992	0.774	0.758	0.345	46.2	43.6	4.3	5.8

Table 3. Selected chemical and physical properties of composite samples collected from selected depth intervals from paired sites in North-east Thailand that are currently under a rice cropping system (R).

Site No.	Depth (cm)	Vegetation	$pH_{0.002}$	OC (%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	Exch. acidity	ECEC	$CEC_{B5.5}$	CEC_T	pHBC ($cmol_c$/kg.pH)	C Sand	F Sand	Silt	Clay
					($cmol_c$/kg)									(%)			
R1	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
R1	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
R1	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
R1	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
R1	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
R1	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
R2	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
R2	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
R2	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
R2	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
R2	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
R2	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
R3	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
R3	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
R3	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
R3	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
R3	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
R3	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

range for the forested and cultivated sites respectively (Figure 2). Conversely, for the same depth interval, the negative charge generated for the R4 site ranged from 0.8 to 1.8 $\mathrm{cmol_c\ kg^{-1}}$ and 0.2 to 0.8 $\mathrm{cmol_c\ kg^{-1}}$ over the imposed pH range (Figure 3). The greatest difference in the shapes of the charge curves was observed in the surface horizons, this being ascribed to the higher OC content (Table 2 and 3) under the forest sites. This clearly quantifies the potentially deleterious effects of clearing, and subsequent use for agriculture, of forest lands that have soils with a relatively low permanent charge component. In short, the role of OC in maintaining negative charge on these soils is critical for retaining and supplying cations. 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 other engineering solutions. With increasing depth, the effect of a change in land use on the surface charge between the two sites decreased (Figure 2 and 3) thus confirming that the negative effects are confined to surface horizons.

Table 4. Net losses in soil organic carbon (OC) and saturation index (S_u) estimating the degree of degradation associated with changed land use from forest to cassava based (C) and rice based (R) cultivation for the surface 0–10 cm depth interval. Values in the table represent the differences between forested and agricultural production systems taken from three sites in each agriculture system.

Site no.	OC loss from 0–10 cm depth interval (t $\mathrm{ha^{-1}}$)	S_u for the 0–10 cm depth interval (%)
C1	4.42	74.8
C2	8.50	76.6
C3	4.77	72.9
R1	3.84	52.9
R2	8.27	63.0
R3	10.11	90.3

To compare surface charge diminution with depth due to changed land use, the $\mathrm{CEC_b}$ at pH 5.5 was calculated from the surface charge regression curves for each of the sites and are presented in Tables 2 and 3. The greatest differences between $\mathrm{CEC_b}$ at pH 5.5 were generally observed in the surface 0–10 cm (Table 2 and 3). These differences always diminished with depth other than at sites C1 and R3 where the $\mathrm{CEC_b}$ increased under the cultivated system. This can partly be attributed to the increase in clay content at depth under the cultivated system indicating a degree of heterogeneity of soils at these sites. The decline in OC with cultivation invariably alters the ratio of organic-to-inorganic surfaces, resulting in marked changes in the surface charge characteristics of the soil. Therefore, OC has a direct influence on the CEC of the soil as has been clearly demonstrated by Willett (1995) for light textured sandy soils of Northeast Thailand. Consequently, conservation of organic matter should therefore become the focus of land management strategies.

The charge fingerprint allows $\mathrm{CEC_t}$ to be estimated at the inherent soil's pH. If the basic and acidic cations removed by the $\mathrm{BaCl_2}$_$\mathrm{NH_4Cl}$ and KCl extractants respectively are all exchangeable cations then their sum (the ECEC) should be equal to $\mathrm{CEC_t}$ at soil pH, within the limits of the experimental error. A graph of ECEC against $\mathrm{CEC_t}$ at the soil's pH for the forested and cultivated soils shows excellent agreement between these independently determined properties for all depth intervals suggesting that most of the cations extracted were effectively on the exchange complex (Figure 4). Points showing the greatest deviation from the 1:1 line were from surface horizons suggesting some of the cations extracted were not associated with the exchange complex.

A potential measure of the degree of chemical degradation that a soil has undergone because of changed management is achieved by the quantification of acidification through the percent acid saturation of the CEC. A limitation of this method lies in the assumption that the CEC is a fixed quantity, and that degradation is associated with increasing occupation of it by $\mathrm{Al^{3+}}$, to the exclusion of important nutrients (basic) cations (Noble et al. 2000). However, the charge fingerprint demonstrates that CEC itself, particularly the agronomic important $\mathrm{CEC_b}$, decreases with pH. Hence, the saturation index (S_u) was proposed by Noble et al. (2000) to take into account the effect of changed land use on the intrinsic surface charge characteristics of a soil. The S_u values were calculated for the 0–10 cm depth interval using equation 1 and are presented in Table 4. The S_u index ranged from 53–90% when compared to the forest benchmark (Table 4). This degree of degradation is considerable and clearly shows the vulnerable nature of these soils to damage associated with changed land use.

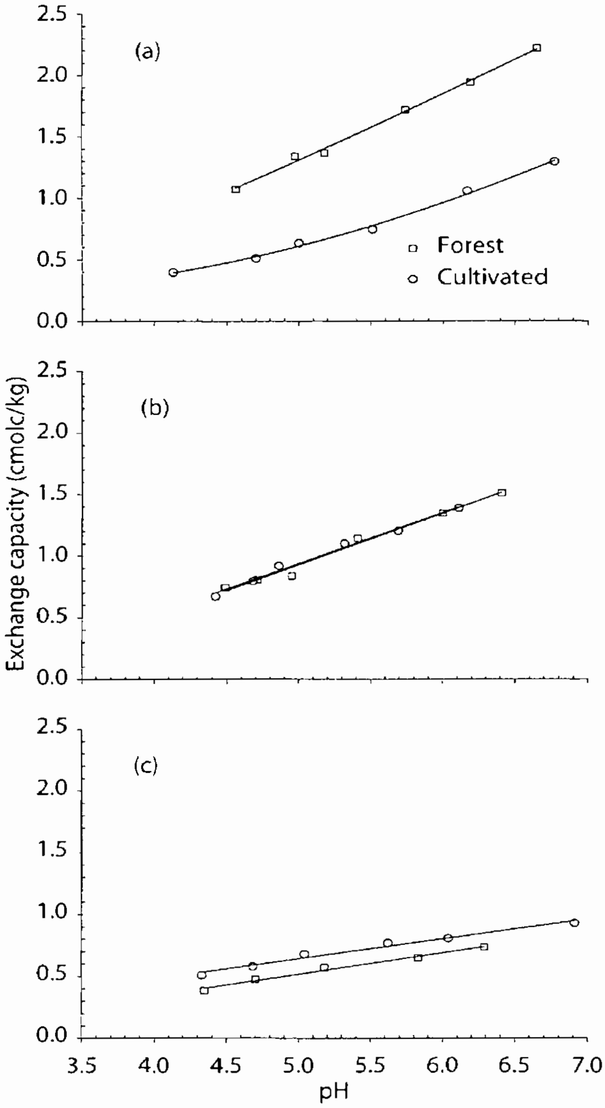

Figure 2. Surface charge fingerprints (CEC_b) at one site of a cassava based cultivation system (C) and adjacent forest sites for the (a) 0–10 cm; (b) 20–30 cm; and (c) 50–70 cm depths respectively.

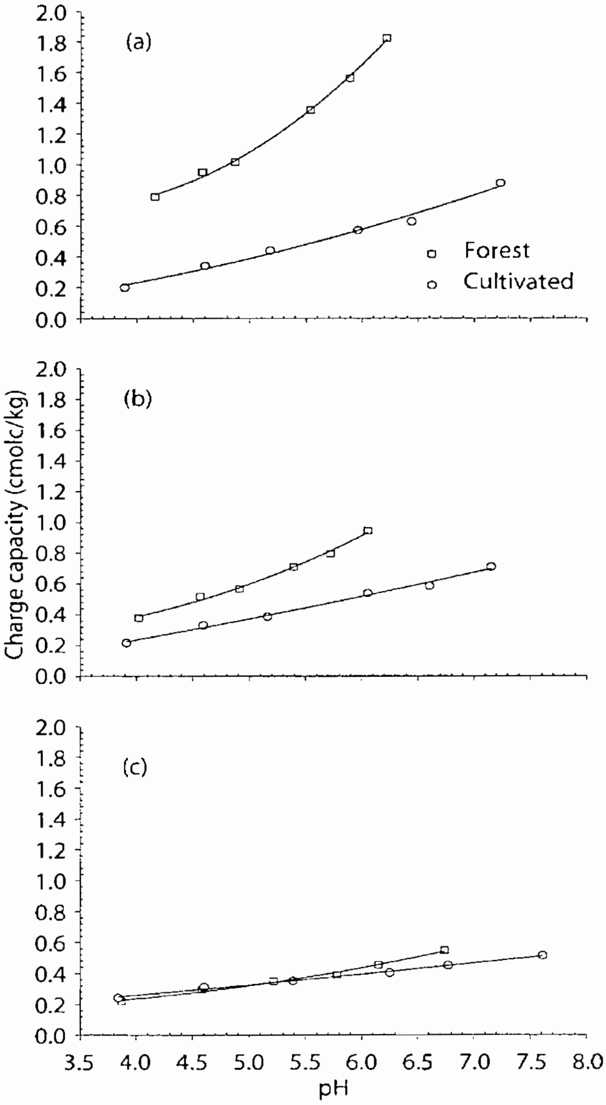

Figure 3. Surface charge fingerprints (CEC_b) at one site of a rice based cultivation system (R) and adjacent forested site for the (a) 0–10 cm; (b) 20–30 cm; and (c) 50–70 cm depths respectively.

Field trials—Chiang Yuen

The soil used in the study was classified as a Satuk (fine-loamy, siliceous, isohyperthermic Oxic Paleustults) (Soil Survey Staff, 1990) with a low CEC (mean of 1.80 $cmol_c$ kg^{-1} over a 40 cm depth) and acid in reaction (pH_{Ca} 4.0). Before the trials were established, *Stylosanthes* had been cultivated for forage production.

While soil moisture conditions were ideal for establishing the crop, growing conditions rapidly deteriorated after the crop emerged in the middle to latter part of June (Figure 5). Further dry periods were experienced for much of the month of July. This significantly affected the performance of the crop under different treatments, with crops on the bentonite treatments appearing to withstand the stress conditions more effectively.

Trial 1

The dry matter (DM) yields of the two harvests during the 2002 growing season for Trial 1 are presented in Table 5. A high degree of variability was observed between replicates of the same treatment this being attributed to the variable growing conditions and the unthrifty re-growth that was evident on some plots after the first harvest. Accordingly, the control and dredge treatments were unable to sustain a crop of forage sorghum beyond the first harvest while only a single replicate in the compost treatment was able to support sorghum re-growth (Table 5). Yields from the two harvests remained relatively stable with termite mound material (T1.2) suggesting a persistence of the response and better growing conditions. The addition of lime to the waste bentonite had a positive effect on DM yield over the two harvest periods when compared with the waste bentonite on its own (Table 5). An ANOVA was undertaken on the cumulative yield from the two harvests. Due to the skewed distribution of the data and therefore non-conformity to normality, a $\log_{10}$ of the data was undertaken resulting in a reduction of the coefficient of variation from 44.3 to 10.1% (Table 6). All applied treatments differed significantly ($p < 0.05$) from the control (Table 6) with the termite mound material resulting in significantly higher yields than all treatments. The second best performing treatment was the waste bentonite with lime applied to neutralise the excess acidity (Table 6).

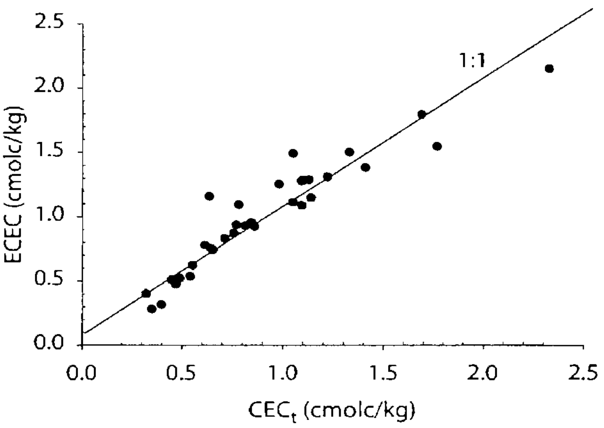

Figure 4. Relationship between the effective cation exchange capacity (ECEC) and the total cation exchange capacity (CEC$_t$) over all depth intervals.

These results clearly demonstrate the positive role of traditional termite mound soil as a way to remediate degraded soils. The application rate of 120 t ha^{-1} is extremely conservative when compared to rates of over 7200 t ha^{-1} that are commonly used by vegetable farmers in the region to increase productivity of soils.

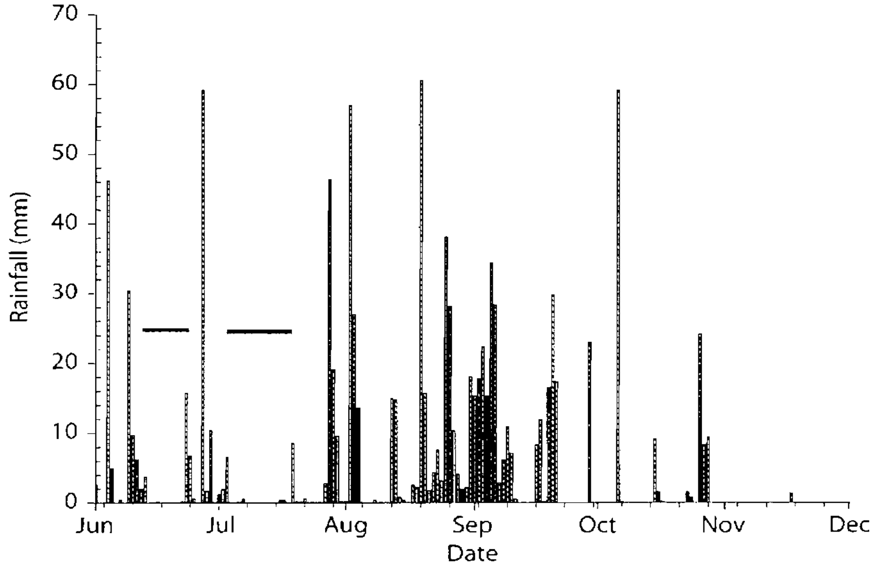

Figure 5. Rainfall distribution over the 2002 growing at Chiang Yuen, North-east Thailand. Bars indicate potential water stress periods during the early part of the growing season.

The benefits associated with these high rates of application warrant the initial financial investment as vegetable growers are often able to recover these costs within the first year (personal communications), and as increased productivity persists for between five and 10 years depending on the cropping intensity and quality of the material. This is certainly an economically viable proposition.

Table 5. Dry matter (DM) yields of forage sorghum for each harvest date (days after planting) over the 2002 growing season for Trial 1. Values in parentheses are the SE of the mean.

Treatment code	Description	100 DAP[a]	166 DAP
		DM (kg ha^{-1})	
1.1	Control	117.7 (27.8)	nh
1.2	Termite soil	3517.8 (468.8)	3195.1 (181.1)
1.3	Leaf compost	865.8 (469.0)	[b]513.3 (513.3)
1.4	Dredged lake material	643.8 (88.5)	nh
1.5	Waste bent	392.5 (93.3)	651.5 (376.8)
1.6	Waste bent[a] lime	1180.9 (221.7)	911.3 (551.3)

[a] DAP = days after planting

[b] A single replication was harvested due to failure of growth after the first harvest in the other two replicates.

nh = no harvest; bent = bentonite

Table 6. Cumulative adjusted mean dry matter and log transformed yield data for forage sorghum over the 2002 growing season for Trial 1.

Treatment Code	Description	Cumulative yield (kg ha^{-1})	Log transformed
1.1	Control	138.1	2.040
1.2	Termite soil	8379.1	3.823
1.3	Leaf compost	837.9	2.823
1.4	Dredged lake material	789.2	2.797
1.5	Waste bent	927.2	2.867
1.6	Waste bent + lime	2219.2	3.246
LSD$_{(0.05)}$			0.445
CV (%)			10.1

bent = bentonite

Trial 2

The results from the two consecutive harvests for Trial 2 are presented in Table 7. Once again the control (T2.1) with the few plants remaining and slotting treatments (T2.2) were unable to sustain yields beyond the first harvest (Table 7). There was a high degree of variability between replicates within the same treatments. It is of note that in both the slotting treatments that received bentonite (T2.3 and T2.4) yields between the first and second harvests increased substantially, possibly because the crop was able to take advantage of the effects of the imposed treatments as it developed. Contrasting this, the yields of the broadcast bentonite treatments with or without compost remained relatively stable over the two harvest periods. The cumulative yield for each of the treatments was subjected to ANOVA and required a $\log_{10}$ transformation (Table 8). Those treatments receiving a broadcast application of bentonite (T2.5 and T2.6) gave significantly ($p<0.05$) higher increases in dry matter than all other treatments with yields of 9.9 and 10.0 t ha^{-1} respectively. Similarly, the slotting treatments that incorporated bentonite (T2.3 and T2.4) had significantly higher yields than slotting on its own (T2.2) and the control (T2.1) (Table 8). It would appear that the addition of bentonite enhanced the efficacy of the slots although one could argue that the response may in part be due to the presence of a localised region with high activity clays.

Table 7. Dry matter (DM) yields of forage sorghum for each harvest date over the 2002 growing season for Trial 2. Values in parentheses are the SE of the means.

Treatment Code	Description	100 DAP[a]	166 DAP
		DM (kg ha^{-1})	
2.1	Control	220.2 (37.7)	nh
2.2	Slotting	169.8 (32.9)	nh
2.3	Slotting + bent	389.2 (93.9)	2836.36 (320.1)
2.4	Slotting + bent + comp	1242.1 (307.1)	4085.7 (558.6)
2.5	Local bent	5443.9 (1395.3)	4380.0 (443.9)
2.6	Local bent + comp	5959.8 (1497.7)	4283.2 (733.8)

[a] DAP = days after planting

nh = no harvest; bent = bentonite; comp = compost

Table 8. Dry matter yields of forage sorghum for each harvest date over the 2002 growing season for Trial 2. Values in parentheses are the SE of the means.

Treatment code	Description	Cumulative yield (kg ha^{-1})	Log transformed
2.1	Control	222.5	2.323
2.2	Slotting	170.7	2.208
2.3	Slotting + bent	3367.5	3.503
2.4	Slotting + bent + comp	5461.5	3.713
2.5	Local bent	9915.4	3.972
2.6	Local bent + comp	10053.3	3.978
$LSD_{(0.05)}$			0.219
CV(%)			4.4

bent = bentonite; comp = compost

In evaluating results from both experiments the increases in yield associated with termite mound material and bentonite plus compost is of the order of 57 and 46 times higher than the current best practice (control treatments). These are exceptionally high increases and one should treat them with caution as the growing season was atypical. Notwithstanding this, the response to soil improvement technologies has been substantial and clearly demonstrates the responsiveness of these systems to such intervention. What is important for farmers is that tangible yield increases are observed within the first season after the imposition of treatments as this will strongly influence adoption. The fact that farmers will use termite mound material to improve their soils clearly shows their willingness to make a significant financial investment to facilitate improved productivity on the basis of an assured return. Applying locally available bentonite clay materials at lower rates of application than are currently used for termite mound materials may achieve the same outcomes with little if any negative environmental impact (i.e. the destruction of termite populations).

Conclusions

Light-textured, sandy soils are common throughout the tropics and constitute an important economic resource for agriculture despite their inherent infertility (Panichapong, 1988). During the period 1982 to 1998, 500,000 ha of climax *Dipterocarp* forest was cleared for agricultural activities in North-east Thailand, this largely being driven by a population increase of 4.8 million in the region (Office of Agricultural Economics, 2001). Changed land use has dramatically decreased the nutrient status of these soils. This has largely been caused by declining soil OC in surface horizons where the greatest degree of mixing occurs. Moreover, this study clearly demonstrated the fragility of these soils when cleared of their native *Dipterocarp* climax communities for agricultural production and supports the preliminary findings discussed for this region by Noble et al. (2000). These negative impacts on the soil resource base are not confined to particular parts of the landscape but have occurred in both upland and lowland areas.

The key driver associated with chemical degradation on these soils is charge diminution through a loss of OC due to continuous tillage. The restoration of soil organic matter status would significantly reduce the decline in CEC and cation loss due to changed land use. However, this is not easily achievable in tropical and sub-tropical environments where regular cultivation is used to prepare seedbeds and control weeds. The introduction of long-term grass leys in rotation with crops would increase the soil organic carbon content and directly benefit the charge characteristics of the soil, and carbon sequestration (Noble et al. 1998; 2003). However, for resource poor farmers in developing countries whose primary objective is house-hold food security, the implementation of long-term grass leys into their farming systems is often viewed as an unattractive option. In addition, in situ generation of organic matter on these degraded soils may not be possible without large inputs of inorganic fertilisers and water.

The extent of soil fertility decline is well recognised by farmers in the region as they have developed a strategy to reverse chemical degradation based on the use of termite mound materials and, more recently, the application of lake-dredged materials. Both these strategies have been assessed in the current study along with the use of high-activity bentonite clays either naturally mined or as a waste by-product. The application of permanently-charged high-activity bentonite clays to soil will have a positive effect on the surface charge characteristics of soils as demonstrated by Noble et al. (2001). In the current study relatively modest rates of application of these materials have been shown to result in significant enhancements in productivity on these degraded soils during a season that could be described as atypical and not conducive to maximum crop production. The use of these materials may offer an alternative to current traditional practices that could be viewed as ecologically unsustainable in the case of termite mound materials. In addition, lake-dredged materials will only be available while these activities continue in the North-east. There is also the risk of exposing acid sulphate materials that could significantly damage the soil if incorporated. Further assessment of selected strategies for remediating degraded soils by farmers in a participatory action research program is currently being undertaken in the region.

Acknowledgments

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References

Coventry, R.J., Fett, D.E.R. 1979. A pipette and sieve method of particle-size analysis and some observations on its efficacy. Townsville, Australia, CSIRO Division of Soils Divisional Report No. 38.

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

Gillman, G.P. and Sumpter, E.A. 1986. Modification of the compulsive exchange method for measuring exchange characteristics of soils. Australian Journal of Soil Research 24, 61–66.

Limpinuntana, V. 1988. Soil, water and crop management practices for rainfed agricultural systems in Northeast Thailand. In: Pairintra, C, Wallapapan, K, Parr, J.F. and Whitman, C.E., ed., Soil, water and crop management systems for rainfed agriculture in Northeast Thailand. Washington D.C, USDA, pp. 85–94.

Matsuo, K. 2002. Development of upland cropping systems for crop-animal integrated farming systems in Northeast Thailand. September 2002. Japan International Research Center for Agricultural Sciences (JIRCAS), Thailand, Department of Agriculture (DOA) and Khon Kaen University (KKU).

Noble, A.D., Thompson, C.H., Jones, R.J. and Jones, R.M. 1998. The long-term impact of two pasture production systems on soil acidification in southern Queensland. Australian Journal of Experimental Agriculture 38, 335–343.

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. European Journal of Soil Science 51, 233–243.

Noble A.D., Gillman, G. P., Nath S. and Srivastava R.J. 2001. Changes in the surface charge characteristics of degraded soils in the tropics through the addition of beneficiated bentonite. Australian Journal of Soil Research 39, 991–1001.

Noble A.D., Moody, P. and Berthelsen, S. 2003. Influence of changed management of sugarcane on some soil chemical properties in the humid wet tropics of north Queensland. Australian Journal of Soil Research 41, 1–12.

Office of Agricultural Economics. 2001, Agricultural Statistics of Thailand crop year 2000/2001. Ministry of Agriculture & Cooperatives, Bangkok, Agricultural Statistics No. 9/2001, 142–143.

Panichapong, S. 1988. Soil and water resources in Northeast Thailand. In: Pairintra, C., Wallapapan, K., Parr, J.F. and Whitman, C.E., ed., Soil, water and crop management systems for rainfed agriculture in Northeast Thailand pp. 2–13. Washington D.C, USDA.

Ragland, J. and 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., and Higginson, F.R. 1992. Australian laboratory handbook of soil and water chemical methods. Melbourne, Inkata Press.

Soil Survey Staff. 1990. Keys to Soil Taxonomy. 4th edn. SMSS Technical Monograph No. 19. Blacksburg, VA, Virginia Polytechnic Institute and State University.

Willett, I.R. 1995. Role of organic matter in controlling chemical properties and fertility of sandy soils used for lowland rice in Northeast Thailand. In: Lefroy, R.D.B., Blair, G.J. and Craswell, E.T., ed., Soil organic matter management for sustainable agriculture. Canberra, ACIAR Proceedings No. 56, pp. 109–114.