Accumulative Nutrient Balance on a Toposequence of Sloping Land Used for Upland Crop Production in Northeast Thailand

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ABSTRACT

Soil degradation issues are assuming increasing importance in Northeast Thailand and are challenging the sustainability of current land management systems. In this study, the impacts on soil chemical properties resulting from conversion of natural dipterocarp forest to agricultural production are compared. Soil samples were collected at 10 cm increments to a depth of 1 m from a dipterocarp forest and an adjacent agricultural (cultivated) production system along a transect. Since conversion to agricultural production, the cultivated site has undergone a significant decline in soil pH as a result of reduction in soil organic C leading to the loss of exchangeable basic cations, especially Ca, Mg, and K, and Al domination of the exchange complex. Consequently, the ability of the cultivated soil to retain basic cations has been compromised. A significant proportion of the extracted cations from the surface soil of the cultivated site was non-exchangeable and therefore subject to leaching at the onset of the wet season.

In this study, the assessment of soil degradation from a soil chemical perspective has demonstrated the fragility of these soils after continuous agricultural production. This is evidenced by the degree of degradation measured by an index that takes into account changes in the surface charge characteristics and the basic cation retention capacity of the 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 at this site. Soils that have a low buffering capacity (i.e. low clay and organic matter content) are prone to acidification and cation depletion, which has a dramatic effect on the productivity of these soils.

INTRODUCTION

Light-textured sandy soils are relatively widespread in the tropics and constitute an important economic resource for agricultural production despite their low inherent fertility (Panichapong, 1988). Such soils occupy a significant area of the Northeast Thailand plateau (Ragland and Boonpuckdee, 1987), and up until 40 years ago were dominated by climax dipterocarp forests. Subsequently, they were then extensively cleared for timber and agricultural production. Continuous agricultural production of crops such as rice, kenaf (rosella) cassava, and sugarcane has resulted in a rapid decline in soil fertility, with an associated loss of productivity. For the 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 socioeconomic conditions, it is one of the most fragile. A study was conducted to understand soil degradation and some nutrient losses of these soils for appropriate land-use planning and potential soil improvement technologies.

MATERIALS AND METHODS

The soil was classified as belonging to the Yosothon series (LDD, 1993) or a fine loamy siliceous, Oxic Paleustults (Soil Survey Staff, 1994). The cultivated farmer's field—50 km due east of Khon Kaen (16° 56' N; 102° 50' E)—was cleared of climax dipterocarp forest in 1962 for the production of kenaf (or rosella) until 1969. Thereafter, cassava was planted in rotation with peanut until 1990. Since 1991, a sugarcane-cassava rotation has been practiced.

Soil Sampling and Analysis

A paired site approach was used to quantify differences between the dipterocarp forest (undeveloped) and agricultural (developed) sites. The selection of the sites was based on the following criteria: (i) the existence of an undisturbed dipterocarp forest in close proximity to an agricultural production field of known history with respect to the period under production; (ii) a well-defined boundary separating the two land-use systems; (iii) the same soil type in both areas; and (iv) few topographical differences (i.e. slope) between the two areas. Soil samples were collected during the dry season in March 2000 by hand auguring at five points at each of the sites on a toposequence along a transect at right angles to the boundary separating the two systems. Sampling points were 5 m apart and samples were collected at 10 cm increments to a depth of 1 m.

Samples were air-dried and sieved to pass a 2 mm mesh before the pH was measured in a 0.01 M $CaCl_2$ solution using a 1:5 soil:solution ratio. 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 was 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+Mg+K+Na+Al+H). Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992). Statistical analysis was performed for each of the site x depth combinations, thereby testing for any effect due to the contrast between the developed and undeveloped sites. The analysis of variance routine of the GENSTAT 5 (Anon, 1989) statistical package was used and least significant differences were calculated where appropriate.

RESULTS AND DISCUSSION

The mean soil pH, organic C, exchangeable basic and acidic cations, and ECEC to a 100 cm depth for forested and cultivated soils are presented in Tables 1-3. Significant differences in pH between the forest and adjacent cultivated sites were observed to a depth of 100 cm. Soil pH decreased by around 0.2 to 0.3 in the 0 to 100 cm depth (Tables 1-3). The decline in pH was accompanied by a significant increase in exchangeable acidity at the cultivated sites. Exchangeable K levels were significantly lower for the cultivated site at all depth intervals when compared to the forested site. In contrast, exchangeable Ca decreased significantly at the cultivated site in the surface 20 cm but increased thereafter, suggesting that there was leaching of Ca from the surface horizons.

Over the course of 37 years since conversion from forest to continuous agricultural production, soil organic carbon has declined significantly ($p<0.05$) in the upper soil layers (0–20 cm) (Tables 1-3). The loss in soil organic carbon from the cultivated site amounted to the equivalent of 19.9 mt C ha^{-1} over the 37-year period. Clearly such dramatic declines in soil organic C would have a significant impact on properties associated with cation retention and fertility.

A direct consequence of a decline in soil pH is an increase in exchangeable Al on the exchange complex with an associated decline in exchangeable bases (Ca, Mg, and K). This decrease in exchangeable cations and increase in exchangeable Al has a direct impact on the agronomic performance of the cultivated site. Since Ca is relatively immobile in the phloem of plants and therefore not subject to redistribution within the plant (Mengel and Kirkby, 1982), adequate supplies of this nutrient at the actively growing root tip are required for root elongation. With a decrease in exchange Ca on the exchange complex and the associated increase in Al, it is likely that crops grown on these soils would have restricted root growth due to Al phytotoxicity and Ca deficiency.

Furthermore, the results indicate that a large percentage of the already low amounts of basic cations extracted in the laboratory determination are not associated with the exchange complex in the semiarid environment, and are therefore vulnerable to leaching at the beginning of the wet season. In the humid subtropical region, extractable cations are dominantly exchangeable, and are therefore afforded some measure of protection from leaching.

Table 1. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites on the top slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	6.33	6.51	6.57	6.69	6.74	6.70	6.49	6.35	6.23	6.20
	Cultivated	6.02	6.23	6.33	6.34	6.37	6.21	6.16	6.23	5.86	5.76
Ca cmol$_c$/kg	Forest	1.457	0.729	0.323	0.279	0.252	0.329	0.265	0.168	0.152	0.155
	Cultivated	0.137	0.127	0.131	0.182	0.284	0.381	0.325	0.271	0.363	0.306
Mg cmol$_c$/kg	Forest	0.789	0.477	0.303	0.248	0.258	0.459	0.693	0.700	0.743	0.768
	Cultivated	0.073	0.059	0.055	0.083	0.174	0.383	0.527	0.698	0.771	0.906
K cmol$_c$/kg	Forest	0.057	0.049	0.048	0.057	0.085	0.072	0.060	0.062	0.070	0.088
	Cultivated	0.088	0.066	0.052	0.077	0.043	0.040	0.041	0.041	0.043	0.049
OC%	Forest	0.90	0.53	0.22	-	-	-	-	-	-	-
	Cultivated	0.24	0.25	0.23	-	-	-	-	-	-	-
Al + H cmol$_c$/kg	Forest	0.112	0.127	0.167	0.340	0.462	0.679	0.921	1.186	1.318	1.411
	Cultivated	0.375	0.446	0.492	0.429	0.321	0.565	0.770	1.009	1.488	1.815
ECEC cmol$_c$/kg^{-1}	Forest	2.506	1.442	0.870	0.967	1.043	1.539	1.950	2.125	2.295	2.409
	Cultivated	0.657	0.699	0.746	0.768	0.870	1.415	1.705	2.065	2.712	3.127

Table 2. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites on the middle slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	5.92	5.99	6.01	5.98	5.93	5.69	5.68	5.33	5.20	5.06
	Cultivated	5.71	5.80	5.83	5.71	5.73	5.57	5.13	5.11	5.05	4.97
Ca cmol$_c$/kg	Forest	1.891	0.752	0.420	0.302	0.216	0.255	0.180	0.173	0.237	0.517
	Cultivated	0.121	0.123	0.102	0.115	0.237	0.328	0.384	0.379	0.338	0.267
Mg cmol$_c$/kg	Forest	0.536	0.250	0.153	0.128	0.139	0.176	0.175	0.170	0.178	0.233
	Cultivated	0.571	0.492	0.513	0.611	0.342	0.372	0.293	0.374	0.347	0.456
K cmol$_c$/kg	Forest	0.096	0.077	0.058	0.064	0.061	0.078	0.090	0.077	0.081	0.091
	Cultivated	0.036	0.047	0.031	0.030	0.042	0.044	0.046	0.050	0.058	0.057
OC%	Forest	0.85	0.42	0.24	-	-	-	-	-	-	-
	Cultivated	0.21	0.20	0.16	-	-	-	-	-	-	-
Al + H cmol$_c$/kg	Forest	0.091	0.128	0.262	0.617	1.051	1.417	1.720	1.834	1.832	1.999
	Cultivated	0.397	0.397	0.511	0.570	0.940	1.092	1.197	1.624	1.788	2.015
ECEC cmol$_c$/kg	Forest	2.675	1.477	1.279	1.619	1.698	2.148	2.308	2.487	2.522	3.087
	Cultivated	0.663	0.669	0.721	0.806	1.417	1.851	2.229	2.656	2.830	2.882

Table 3. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites at the bottom of the slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	5.78	6.00	6.17	6.20	5.83	5.47	5.43	4.91	4.75	4.60
	Cultivated	5.51	5.81	5.91	5.75	5.39	4.98	4.72	4.59	4.56	4.53
Ca cmol_c/kg	Forest	1.300	1.240	1.407	1.000	1.428	1.377	0.937	1.051	0.761	0.671
	Cultivated	0.156	0.143	0.109	0.120	0.288	0.450	0.236	0.146	0.133	0.167
Mg cmol_c/kg	Forest	0.533	0.302	0.271	0.341	0.523	0.773	0.731	0.591	0.548	0.634
	Cultivated	0.542	0.426	0.407	0.158	0.102	0.090	0.094	0.136	0.299	0.382
K cmol_c/kg	Forest	0.073	0.054	0.041	0.036	0.044	0.068	0.122	0.137	0.118	0.124
	Cultivated	0.052	0.046	0.046	0.036	0.041	0.039	0.045	0.045	0.149	0.052
OC%	Forest	0.49	0.24	0.13	-	-	-	-	-	-	-
	Cultivated	0.15	0.14	0.12	-	-	-	-	-	-	-
Al + H cmol_c/kg	Forest	0.072	0.091	0.114	0.206	0.436	0.747	0.994	1.280	1.466	1.517
	Cultivated	0.297	0.342	0.443	0.632	0.737	0.820	1.133	1.175	1.291	1.356
ECEC cmol_c/kg	Forest	1.993	1.705	1.849	1.600	2.448	2.984	2.800	3.078	2.911	2.964
	Cultivated	1.073	1.065	1.027	0.973	1.191	1.419	1.530	1.522	1.893	1.981

GENERAL DISCUSSION

The results from this study highlight the impacts of land clearing on a sloping terrain and continuous cultivation of light-textured soils in the semiarid tropics; this has particular relevance to important soil properties such as organic matter content, soil pH, and cation retention capability. A reduction in soil organic matter in the surface horizons of the cultivated Ultisol (by 30 to 50 percent of that found in the forested counterpart) reduced the cation exchange capacity severely, the major portion of which became Al dominant. The high percentage of Al on the cation exchange complex denotes a high *reserve* acidity, which in turn maintains a high *active* acidity in soil solution, expressed as low pH.

As an alternative to the more conventional approaches to soil fertility improvement, involving additions of organic material or attempts to increase soil organic matter content, inorganic amendments may have a useful role. Thus, the addition of clays to sandy-textured soils would result in an increase in permanent negative charge, which in turn could be supplied with well-balanced quantities of slowly released Ca, Mg, and K from basic and ultrabasic rock sources such as crushed basalt (Gillman, 1980).

CONCLUSION

This study has contrasted the almost irreversible degradation of a soil in the semiarid tropics under continuous crop production with a milder degradative management practice in the humid subtropics, which is easily reversible.

The long-term consequences of soil degradation are permanent and bring into question the sustainability of current agronomic production systems practiced in some regions. Soils that have a low buffering capacity (i.e. low clay and organic matter content) are prone to acidification and cation depletion, which has a dramatic effect on the productivity of these soils.

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