LAND-USE DEPENDENT SOIL QUALITY IN THE LAM PHRA PHLOENG WATERSHED, NORTHEAST THAILAND

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Abstract
This study compared soil-quality under different land-use types. The general aim was to identify location-specific indicators that describe long-term effects of land-use on soil quality. The study was conducted in the upper reaches of the Lam Phra Phloeng watershed, north eastern Thailand. Fifty years ago the area was virgin forest. The first agricultural settlements were established in the early 1960s. Since then, the watershed has almost completely been developed into smallholder farmland, with predominantly maize-based cropping. Soils from each identified cropping system and from the forest areas were analyzed for the most common chemical and physical characteristics. Using principal component analysis, important soil-quality indicators were identified and a soil-quality index (SQI) was developed for the area. Four soil-quality regimes were identified which exhibited significantly different SQIs associated with the different land-use types ie., in descending order (i) secondary forest, (ii) reforested land and mungbean-maize rotation, (iii) maize-maize rotation, and (iv) maize-fallow rotation. The two decisive soil-quality indicators that most significantly describe soil-quality differences due to land use were soil organic matter and aggregate strength. The study demonstrated clearly that long-term maize-based cropping has led to a significant degradation of soil quality in the area.

Additional Keywords: land-use succession, soil-quality indicators, soil-quality index (SQI)

Introduction

The term ‘quality’ generally refers to the degree of excellence, grade, distinguishing attribute or degree of conformance to a standard (Merriam-Webster, 1993). In the soil context, quality (i.e., soil quality) has been defined as the ability of a soil to produce sufficient high-quality food while protecting human and animal health and maintaining environmental quality (Lal, 1997). Soil-quality is a key component of sustainable agriculture. It is very difficult to define soil quality because it depends on many factors such as land-use, soil management practices, ecosystems, environmental interactions, social and political priorities, etc. (Doran *et al*. 1996). Soil quality may have different meanings, depending on which term is used, e.g., for agriculture it may be the productive capacity, for environmental management it may be the biodiversity and carbon-sequestration functions of soils that have significance (De Pauw and Zoebisch, 2002; Gregorich, 2002). Changes and dynamics of soil quality are very complex. Land-use and cropping systems significantly change the soil physical and chemical properties, and hence plant growth and crop yields will be affected (Moraes *et al.* 2002). Therefore, maintenance and improvement of soil quality in continuous cropping systems are very important to sustain agricultural productivity for the future. The study aimed to examine soil-quality changes under different land-use types in an agricultural area and in relation to the land-use history.

Materials and Methods

Study Area

The study area is located in the *Lam Phra Phloeng* Watershed, *Pak Chong* District, *Nakhon Ratchasima* Province, approximately 200 km east of Bangkok. On the western side, the watershed borders *Khao Yai National Park* with undisturbed natural forest and forests of various degrees of degradation and restoration. The area is generally characterized by a hilly topography, with undulating slopes and few flat areas. Elevations range from 440-500 m a.m.s.l. for the agricultural land and about 500 -1,000 m a.m.s.l. for the forest areas. The mean monthly maximum temperature ranges between 37º (April) and 27º C (December), and the mean monthly minimum temperature ranges between 24º C (June) and 14ºC (December). The soils in the area are dominantly reddish-yellow Ultisols (*Korat* Series) and Oxisols (*Pak Chong* Series) (LDD, 2002). Overall, the soils are low in nutrients and high in clay dispersion, pointing to inherently low fertility and high erodibility. The soils in the remaining secondary forests, including the relatively recently re-afforested areas in demarcated buffer zones, exhibit significantly higher levels of soil organic matter and lower bulk densities than the arable soils.

Methodology

The study is based on two methodological approaches; (1) land-use history survey and (2) soil sampling and analysis. For the land-use survey, land-use history profiles were identified through group discussions and key-informant interviews. These history profiles were categorized into representative land-use successions. For each land-use succession, representative field plots (on both arable and forest lands) were identified. The soils were assessed in the field using the FAO soil-profile description methodology (FAO, 1977). Topsoil samples from 37 sites were analyzed for 18 physical and chemical characteristics. All soil properties were determined by standard methods. Following an approach modified from Andrews *et al.* (2002) and Breijda *et al.* (2002) principal components analysis (PCA) was used to identify a minimum dataset (MDS) of soil-quality indicators, which were used to develop a compound location-specific soil-quality index. The indicators and the compound soil-quality indexes were then evaluated in the context of the present land-use in the area.

Results and Discussion

Land use successions

The land-use history profiles revealed that permanent agriculture had been practiced in the area since the 1970s, when large parts of the original natural forest were converted to agricultural land. Six typical land-use successions for the arable land and three types of forests were identified (Table 1).

Table 1. Typical land-use successions after forest clearance in the 1970s

#	Land-use successions	Characteristics
A	Maize-Maize	2 crops per year
B	Maize-Fallow	1 crop per year
C	Maize-Maize ►Mungbean-Maize	Both crops within a year; no fallow
D	Maize-Maize ►Orchard	Permanent plantations
E	Maize-Maize ►Orchard ►Maize-Maize	2 crops of maize per year
F	Maize-Maize ►Orchard ►Vegetables	Irrigated crops; very small areas
R	Reforested area	Reforestation of encroached forestland land; since 1997
S	Secondary forest of natural re-growth	Natural re-growth of encroached forestland; since 1980
NF	Natural dry evergreen forest	Undisturbed natural forest; *Khao Yai* National Park area

All of the successions indicate the clear orientation of the farmers towards cash crops Table 1). Maize is the dominant crop, as maize-maize (i.e., two maize crops per year), maize-mungbean, and maize-fallow rotation. Orchards are increasingly phased out, due to a declining productivity of the trees. The field survey showed that the reasons and driving forces behind the changes in land-use and management are basically rooted in changing market opportunities and declining productivity (i.e., yields) of crops.

For four agricultural land uses and the three types of forestland, a general assessment of common soil-characteristics was made using the general rating scales for soil quality proposed by Landon (1991) (Table 2).
Using these broad scales no distinct or drastic differences could be detected that would allow a differentiation of soil quality among the land use types in the area. The soil physical characteristics are fairly uniform, without an obvious pattern related to the land uses. Likewise, no clear land-use related differences are shown for the chemical soil-fertility status (i.e., nutrients, CEC, pH) and erodibility, two parameters which are usually assumed to be strongly associated with crop cultivation, and hence should diverge. These rating systems often provide an initial impression of the relative status of soils in an area. The soils in the study area are of the same origin and types. Their differentiation over time is therefore most likely due to the different types of land uses that have been practiced in the area, causing degradation and enrichment in their various characteristics.

Table 2. General ratings of soil properties for selected land use types

Parameter	**A** Maize-Maize	**B** Maize-Fallow	C Mungbean-Maize	**D** Orchards	**R** Reforested Land	**S** Secondary Forest	**NF** Natural Forest
Physical characteristics							
BD (g m^{-3})	Medium	Medium	Medium	High	Medium	Medium	Medium
Friability (%)	Medium	Low	Medium	Medium	Low	Low	Low
Texture	Clay loam	Clay	Clay loam	Clay loam	Sandy loam	Clay loam	Sandy clay loam

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Table 2 continued

Parameter	**A** Maize-Maize	**B** Maize-Fallow	C Mungbean-Maize	**D** Orchards	**R** Reforested Land	**S** Secondary Forest	**NF** Natural Forest
Clay Dispersion (%)	Erodible	Erodible	Erodible	Erodible	Erodible	Erodible	Erodible
Chemical characteristics							
pH	Medium	Medium	Medium	Medium	Medium	Low	Medium
EC (dS m^{-1})	Salt free	Salt free	Salt free	Salt free	Salt free	Salt free	Salt free
CEC (cmol kg^{-1})	Low	Low	Low	Low	Low	Low	Low
Soil Organic Matter (%)	Low	Low	Low	Medium	Medium	Medium	Medium
Total N (%)	Very low	Low	Very low	Low	Low	Low	Low
Exchangeable P (ppm)	High	Very low	Low	Low	Very low	Very low	Low
Exchangeable K (ppm)	Medium	Very low	Low	Medium	Medium	High	Medium
Profile characteristics							
Packing density	Low	High	Low	Medium	Low	Low	-
Root density	High	High	Very high	Very high	Very high	Very high	-
Aggregate shape	Sub-ang.	Sub-ang.	Sub-ang.	Sub-ang.	Sub-ang.	Sub-ang.	-
Aggregate grade	Medium	Clear	Clear	Clear	Medium	Medium	-
Aggregate size	Medium	Coarse	Medium	Medium	Medium	Medium	-
Dominant pores	Fine-many	Medium-some	Fine-many	Medium-many	Fine-many	Fine-many	-
Aggregate strength	Little firm	Firm	Loose	Firm	Loose	Loose	-

Note: No profile description for Natural Forest (NF). Samples were taken with soil auger.
BD – bulk density; EC – electrical conductivity; CEC – cation exchange capacity

Comparison of soil parameters between land uses

To investigate the differences in soil characteristics between the land uses, one-way analysis of variance (ANOVA) with LSD of $P<0.05$) was used (Table 3).

Table 3: Effects of land use systems on soil properties. One-way analysis of variance with LSD of P<0.05

Parameter	**A** Maize-Maize	**B** Maize-Fallow	C Mungbean-Maize	**D** Orchards	**R** Reforested Land	**S** Secondary Forest	**NF** Natural Forest
Physical characteristics							
BD (g cm^{-3})	1.47^{ab} ± 0.05	1.47^{ab} ± 0.10	1.44^{ab} ± 0.03	1.52^{a} ± 0.04	1.46^{ab} ± 0.07	1.29^{b} ± 0.06	1.33^{b} ± 0.03
Friability (%)	0.52^{ab} ± 0.04	0.43^{ab} ± 0.02	0.51^{ab} ± 0.03	0.66^{a} ± 0.1	0.40^{b} ± 0.05	0.48^{ab} ± 0.02	0.39^{b} ± 0.03
Sand (%)	31.11^{c} ± 2.22	23.60^{c} ± 6.00	42.25^{abc} ± 4.09	34.55^{bc} ± 3.71	50.27^{ab} ± 10.35	37.60^{abc} ± 11.37	57.60^{a} ± 6.11
Silt (%)	37.86^{a} ± 2.76	25.00^{b} ± 1.00	25.95^{b} ± 2.56	31.98^{ab} ± 2.63	32.67^{ab} ± 8.67	31.33^{ab} ± 5.69	22.00^{b} ± 2.31
Clay (%)	32.46^{b} ± 3.60	51.40^{a} ± 5.00	31.80^{b} ± 4.25	33.47^{b} ± 3.14	17.07^{c} ± 1.76	31.07^{bc} ± 6.36	20.40^{bc} ± 4.62
Dispersion ratio (%)	25.82^{a} ± 2.01	27.39^{a} ± 0.86	21.41^{a} ± 2.33	25.51^{a} ± 2.09	22.12^{a} ± 6.59	22.79^{a} ± 5.75	24.29^{a} ± 1.01
Chemical characteristics							
pH	6.42^{a} ± 0.26	6.30^{ab} ± 0.32	5.56^{b} ± 0.21	6.42^{a} ± 0.15	5.76^{ab} ± 0.21	5.40^{b} ± 0.31	5.88^{ab} ± 0.55
EC (dS m^{-1})	0.03^{a} ± 0.002	0.04^{a} ± 0.002	0.03^{a} ± 0.002	0.04^{a} ± 0.01	0.02^{a} ± .002	0.02^{a} ± .0009	0.03^{a} ± 0.005
CEC (cmol kg^{-1})	14.17^{a} ± 2.30	15.60^{a} ± 3.00	8.45^{b} ± 1.96	13.59^{a} ± 1.78	6.47^{b} ± 1.04	10.20^{ab} ± 2.71	11.63^{a} ± 4.13

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Table 3 continued

Parameter	A Maize-Maize	B Maize-Fallow	C Mungbean-Maize	D Orchards	R Reforested Land	S Secondary Forest	NF Natural Forest
Organic matter (%)	1.61^{b} ± 0.23	1.33^{b} ± 0.14	1.80^{b} ± 0.26	3.09^{a} ± 0.28	3.19^{a} ± 0.65	3.97^{a} ± 0.43	3.55^{a} ± 1.13
Total nitrogen (%)	0.08^{b} ± 0.01	0.12^{ab} ± 0.01	0.09^{b} ± 0.01	0.15^{a} ± 0.01	0.16^{a} ± 0.03	0.19^{a} ± 0.02	0.18^{a} ± 0.06
Available P (ppm)	27.71^{a} ± 12.27	2.00^{c} ± 0.00	13.75^{ab} ± 2.22	6.64^{b} ± 1.91	4.33^{b} ± 0.88	4.00^{b} ± 1.15	6.33^{ab} ± 3.53
Available K (ppm)	104.86^{a} ± 18.70	34.50^{b} ± 6.50	51.88^{a} ± 7.89	125.73^{a} ± 54.39	106.33^{a} ± 28.85	175.00^{a} ± 14.29	105.00^{a} ± 60.56
Profile characteristics							
Packing density	1.43^{b} ± 0.20	2.50^{ab} ± 0.50	1.37^{b} ± 0.18	2.27^{a} ± 0.27	1.33^{b} ± 0.33	1.33^{b} ± 0.33	-
Root density	4.43^{b} ± 0.20	4.00^{b} ± 0.00	4.87^{a} ± 0.12	4.82^{a} ± 0.12	5.00^{a} ± 0.00	5.00^{a} ± 0.00	-
Shape of the aggregate	1.14^{ab} ± 0.14	1.50^{ab} ± 0.50	1.13^{ab} ± 0.13	1.55^{a} ± 0.16	1.00^{ab} ± 0.00	1.00^{ab} ± 0.00	-
Grading of the aggregate	3.14^{b} ± 0.14	3.50^{ab} ± 0.50	3.63^{ab} ± 0.32	3.91^{a} ± 0.28	3.00^{ab} ± 0.00	3.00^{ab} ± 0.00	-
Size of the aggregate	1.86^{c} ± 0.14	3.00^{a} ± 1.00	2.25^{ab} ± 0.16	2.36^{ab} ± 0.15	2.67^{ab} ± 0.33	2.00^{bc} ± 0.00	-
Dominant pore sizes	1.59^{a} ± 0.18	2.20^{a} ± 0.00	1.55^{a} ± 0.25	2.00^{a} ± 0.24	1.30^{a} ± 0.0	1.63^{a} ± 0.33	-
Mechanical strength	3.86^{a} ± 0.46	1.50^{b} ± 0.50	4.25^{a} ± 0.31	2.45^{b} ± 0.37	4.67^{a} ± 0.33	4.33^{a} ± 0.67	-

Note: No data for Natural Forest (NF). BD – bulk density; EC – electrical conductivity; CEC – cation exchange capacity

The data reveal certain evidence of the influences of land use on the characteristics of the soil (Table 3). Clay dispersion is generally high –independent of land use–, indicating a high potential erosion susceptibility of the soils in the area. Bulk density is clearly lowest in the natural and secondary forests, probably due to the absence of soil disturbance, such as tillage and traffic. The cation exchange capacity (CEC) is surprisingly low in the reforested areas and in the mungbean-maize rotation; it is highest in the maize-maize and maize-fallow rotations. No obvious reason for this is evident. As expected, soil organic matter (SOM) contents are lowest in the annual cropping land-use types, most probably due to the widely practiced burning of the crop residues. Nutrient levels are generally very low, pointing to highly leached and inherently low-fertility soils, a condition frequently found in humid tropical regions. However, P-levels are significantly higher in the maize-maize and mungbean-maize rotations, probably due to the regular application of fertilizers. There are differences in soil-structure characteristics, but they cannot be explained readily by land use, e.g., in the maize-fallow system, aggregate strength is significantly lower than in all other land uses.

Soil-quality index

Applying principal component analysis (PCA) to the dataset, those soil characteristics were identified which represent significant soil quality indicators for the land use systems in the study area. The PCA identified 13 important soil properties in eight principal components (Table 4). These soil properties represent the minimum dataset (MDS). The MDS was used to develop a soil-quality index (SQI) for the studied land use systems.

Cumulative variance shows that 86% of the overall variance of the entire dataset can be explained by the MDS indicators (Table 4). Most of the higher weighted variables in the MDS are related to the physical soil characteristics, i.e., texture and structure. Whereas texture may be assumed as ‘given’, structure is a result of land use and management, indicating a dominant influence of human activities on soil quality.

Table 4: Minimum dataset (MDS) indicators

PC†	Variance (%)	Cumulative variance (%)	Weight*	Indicators (soil properties)
1	24	24	0.282	Sand content Aggregate strength
2	14	38	0.163	Clay dispersion Silt content
3	12	50	0.135	Soil organic matter, SOM Exchangeable K
4	9	59	0.108	Aggregate grade
5	9	68	0.106	Friability Bulk density, BD
6	7	75	0.076	Root density Exchangeable P
7	6	81	0.067	Aggregate size
8	5	86	0.059	Electrical conductivity, EC

***** Weight = Variance of PC/total cumulative variance
† Principal component

For the four agricultural land uses and two types of forestlands (due to missing data, natural forest was not included in the analysis) four different SQIs were identified (Figure 1).

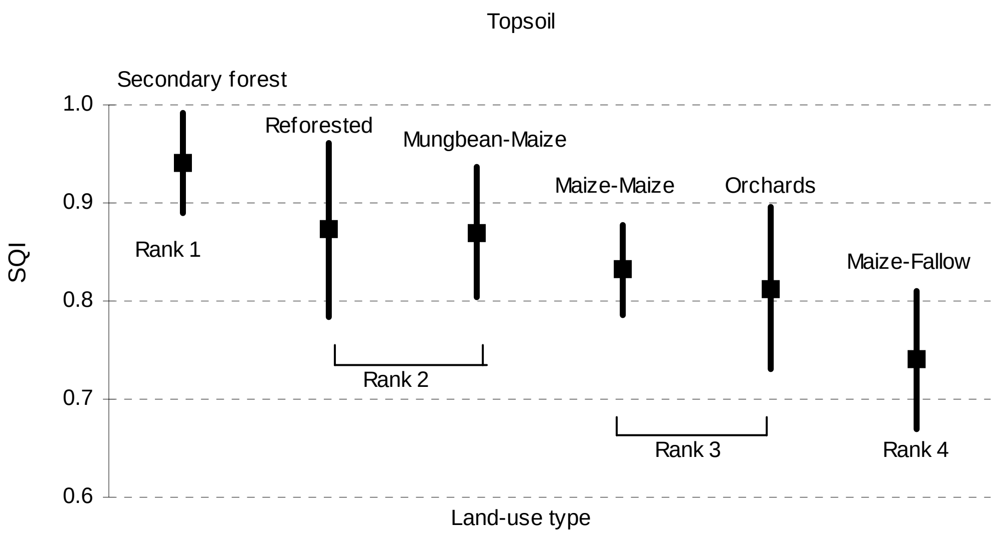

Figure 1: SQI ranks for different land use

Results show that the naturally re-grown secondary forest has the highest SQI (Figure 1). The orchards –expected to show overall good soil conditions because of their permanent cover with low soil disturbance– only ranked third – together with maize-maize. A similar situation can be observed with maize-fallow (4^{th} rank, i.e., the lowest). The fallow period and lower tillage intensity would suggest a better overall soil condition, than the continuous maize-maize and maize-mungbean rotations. However, the SQI analysis rejected this assumption.

Conclusions

From this study, we can conclude: (1) Over a period of about 30 years (i.e., since the early 1970s), maize-based land use has had a negative effect on soil quality. This effect, however, is less pronounced with the maize-mungbean rotation where mungbean probably contributed to the enhancement of soil structure. (2) Change from continuous maize to orchard around 1980 did not contribute significantly to an improvement in soil quality, probably because of the soil disturbance by intercropping the plantations with maize for up to 5-7 years after establishment. (3) The maize-fallow use had the lowest SQI rank among all studied land uses. It is remarkable that seasonal fallowing after maize, which has been practiced continuously over the last 30 years, has not led to an improvement of soil quality. The reasons for this have not been studied in detail. It is generally assumed that fallow periods help soils to recover from the 'cultivation stresses'. It is likely that the single-season fallow periods of this system are not long enough to develop the expected 'land-resting effects' and, hence, the SQI drops. To improve soil quality, soil management practices need to be adopted at the farm level that increase the efficiency of organic matter cycling, maintain favorable soil structure and reduce soil-degradation risks. With improved soil management, the decreasing trends of soil quality in the study area can probably be reversed in the long run.

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