P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol.25 No.4 October - December 2020
Page: [150-162]

Original research article

Effect of Land–Use Changes on Nitrogen Distribution in Soil Profile in Northeast Thailand

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Received 9 July 2019; Received in revised form 22 November 2019
Accepted 18 December 2019; Available online 24 December 2020

ABSTRACT

Nitrogen (N) is an important element for crop production. Conversion from forest to agricultural lands can affect soil total N (TN) status in soil. The objective of this study was to investigate amounts of TN in the soil profile as influenced by changes in land use. Soil samples were collected from five soil depths, i.e. 0–20, 20–40, 40–60, 60–80, and 80–100 cm in four adjacent land uses, including forest, cassava, sugarcane and paddy lands located in six locations of Maha Sarakham Province in northeast Thailand. The air–dried soil samples were analyzed for TN using the micro Kjeldahl method. The results showed that TN stocks in topsoil (0–20 cm) in all land uses from six locations were lower than in subsoil (20–100 cm). Total N stock in the whole soil profile (0–100 cm) was highest in Kantharawichai district, but it was lowest in Muang district. Conversion from forest to agricultural lands without appropriate management led to low amounts of TN in agricultural land uses, and the reductions in TN ranged from 5 to 23% compared to the original forest land. However, the same agricultural land use with different management practices led to different amounts of TN stored in soil profiles.

Keywords: Land–use changes; Nitrogen distribution; Soil profile; Northeast Thailand

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doi: 10.14456/scitechasia.2020.56

1. Introduction

Anthropogenic pressure on land resources has increased the need to evaluate the effects of land-use change on soil quality. Inappropriate land use [1-2] and land-use change [3-4] are the main factors affecting soil erosion and associated nutrient loss. Conversion of forest land to agricultural land is one of the main types of land–use change in northeast Thailand and the largest cause of current global deforestation [5].

In 1973, the total area in northeast Thailand was estimated at 16,771,793 ha, and the region had forest land of 5,067,100 ha, accounting for 30% of the total land area of this region [6]. In the most recent survey in 2017, the forest area was estimated at 2,504,889 ha, which was a 49% reduction of the forest area in 1973.

Deciduous dipterocarp is the most widespread forest type in northeast Thailand. During the last few decades, deforestation became an important issue globally. In the northeast Thailand, a vast area of deforestation arose from conversion of forests to monoculture plantations of major cash crops especially rice paddy, cassava, sugarcane and rubber. As a result, extensive conversion of natural ecosystems to field crops and plantations leads to a reduction in soil fertility and subsequent soil degradation [7]. A better understanding of the impact of land–use changes on soil properties is important for maintaining soil fertility and sustaining crop productivity. The effects of land–use change on soil degradation can be assessed by comparing changes in soil organic matter (SOM) and nutrients [8-9].

Nitrogen (N) is a crucial element for plant nutrition and it is used widely as a fertilizer in agriculture [10]. It also plays a vital role in sustaining soil quality, crop production and environmental quality [11-12] due to its effect on soil chemical and biological properties [13-14]. The type of land use system is an important factor that controls soil N levels as it affects the amount and quality of litter input, the litter decomposition rates and the processes of N storage in soils [15-16]. Changes of land use and management practices influence the amount and rate of N losses [17-20]. For example, in southeastern Ethiopia, Abera and Belachew [21] indicated that conversion from forest to fallow and cultivated lands reduced the amount of soil N. In many ecosystems, forest soils had higher contents of TN than agricultural soils such as poplar plantation, cropland, check–dam cropland, sloped cropland, and topsoil had higher TN than subsoil [22-25]. In the northern Iran, topsoil (0-25 cm) of the forest provided higher amounts of TN than dryland farming topsoil [26]. In sub-tropical regions, conversion of forest to cropland reduced microbial N content but increased the amount of inorganic N (i.e., NH_4^+ and NO_3^-) [27]. The authors suggested that N fertilizer addition to crops enhanced inorganic N in the soil.

Conversion of forests to agricultural lands in most cases reduced soil fertility, and proper agronomic practices could reduce the impact of land use change especially for N status in soils. However, few studies have focused on the amounts of N storage in the tropical soil profile as influenced by land–use changes, and additional information is required. Thus, the aim of this study was to evaluate land–use changes affecting the status of N storage in soil profile.

2. Materials and Methods

2.1 Study site

Six study sites in six districts including Muang, Kantharawichai, Kosum Phisai, Kut Rang, Borabue and Wapi Pathum in Maha Sarakham Province in northeast Thailand were selected in this study (Fig. 1). At each site, four adjacent land uses including secondary *Deciduous dipterocarp* forest, cassava converted from the forest for about five years, sugarcane converted from the forest for about seven years, and paddy lands converted from the forest for >15 years were employed in this study. The average land altitudes above sea level for forest, cassava, sugarcane, and paddy were 185, 185, 184, 178 m, respectively. *Deciduous dipterocarp* species were dominant in all forest locations in this study. According to farm owner interviews, the agronomic practices for cassava, sugarcane, and rice paddy were different among the locations.

Cassava (Kasetsart50 or KU50) was grown in the early rainy season (May to June). Nitrogen fertilizer as urea (46-0-0) was applied to the crop at the rate of 113 kg ha^{-1} at planting and fertilizer formula 15-15-15 of N-P-K at the rate of 313 kg ha^{-1} was applied three months after planting (MAP). The crop was harvested from March to May of the following year. Green and cattle manures were also added in some years in Wapi Pathum location only. Sugarcane (KK3) was grown in the late rainy season from October to February. Fertilizer formula 15-15-15 of N-P-K was added to the crop at the rate of 313-469 kg ha^{-1} for each split was added to the crop at two splits at planting and at 4 to 6 MAP. Cattle manure was also added in some years in most locations except in Borabue and Wapi Pathum locations. Glutinous rice (RD6) and non-glutinous rice (KDML 105) were transplanted in June. Fertilizer in the form of formula 16-16-8 of N-P-K was applied to crop at the rate of 125-156 kg ha^{-1} at tillering. The crop was harvested from November to December.

Regarding farmer interview, farmers at all locations burned rice stover and sugarcane leaves in the years when the stover and sugarcane leaves were too high. The farmers did not burn cassava leaves. The fertilizer rates applied to the crops for each location were provided in the ranges because the farmers did not know the exact rates in each year.

2.2 Soil sampling and analysis

All locations were divided into four land uses including forest, cassava and paddy. The areas for sampling ranged from 6.0, 3.0, 3.0 and 5.0 ha for the forest, cassava, sugarcane and paddy, respectively. Soil series covered the studied area were Nam Phong, Khorat, Ubon, Roi Et and Satuk. The particle sizes of the soil series are shown in Table 1.

After the locations and land uses were selected, nine sampling points were determined for each land use and there were 216 positions totally. Random soil sampling was done in a dry season in March 2018. The soil samples at each sampling point were collected from five soil depths at 20 cm intervals from the soil surface to 100 cm (0-20, 20-40, 40-60, 60-80 and 80-100 cm) using an auger. Soil samples were air–died and passed through a 2–mm sieve. The soil samples were further analyzed chemically to determine TN content using a micro Kjeldahl method [32].

Corrections were used to the calculation of TN stock by comparing the mass [33-34] from the agricultural land use with soil mass from the original forest land use, both at 100 cm, according to the Eq. (1);

$$\text{Layer thickness (cm)} = (Mf/Mm) \times 100 \text{ cm}, \quad (1)$$

where Mf (g cm^{-3}) is the mean soil bulk density of the forest soil at a given depth and Mm (g cm^{-3}) is the mean bulk density for each studied layer after forest conversion at the same depth. After the equivalent soil layers were corrected, stock of TN (TNm) was calculated by Eq. 2;

$$TNm\ (\text{Mg ha}^{-1}) = \text{TN content (\%)} \times \text{bulk density (g cm}^{-3}) \times \text{layer thickness (cm)}. \quad (2)$$

2.3 Climate of the study site

Rainfall and temperature during soil sampling periods are briefly described. Average monthly rainfall and temperature over the soil sampling periods (July 2017-June 2018) are presented in Fig. 2. This climatic information was obtained from the Northeastern Meteorological Center in Maha Sarakham province. Average monthly rainfall and temperature of the study sites were similar in which the double-bell shaped pattern of temperature dropped during November-February. The rainfall and temperature were high during July-October 2017 and April-May 2018.

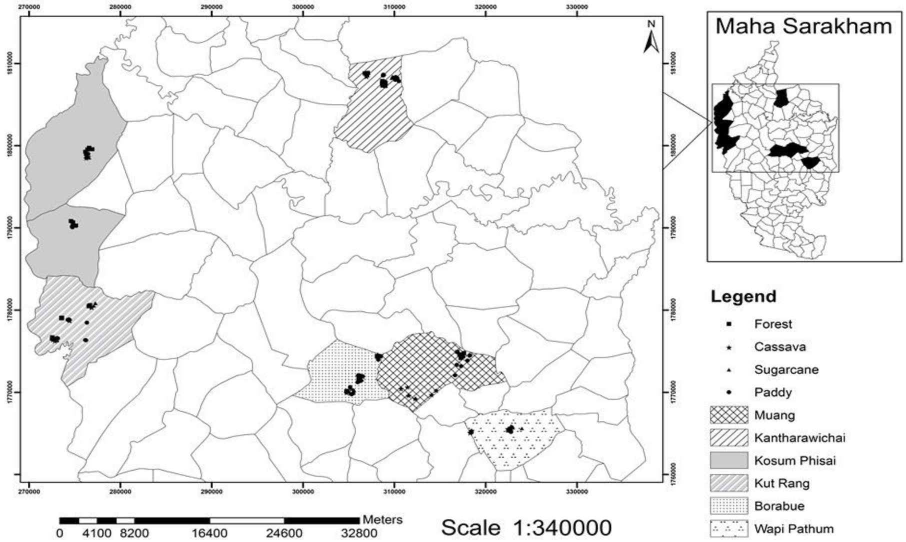

Fig. 1. A map presenting study sites in Maha Sarakham province in the Northeast Thailand.

Table 1. Soil particles and textures of the studied soils.

Soil series	Soil classification[4]	Soil depth (cm)	Particle (%)			Texture
			Sand	Silt	Clay	
Nam Phong[1]	Grossarenic Haplustalfs	0–20	90.9	6.5	2.6	Sand
		20–40	90.9	6.5	2.6	Sand
		40–60	91.2	2.1	6.7	Sand
		60–80	91.2	2.1	6.7	Sand
		80–100	91.2	2.1	6.7	Sand
Khorat[2]	Typic (Oxyaquic) Kandiustults	0–20	79.3	13.5	7.2	Loamy sand
		20–40	77.5	11.4	11.1	Sandy Loam
		40–60	74.9	16.7	8.4	Sandy Loam
		60–80	67.1	20.1	12.8	Sandy Loam
		80–100	57.7	19.9	22.4	Sandy clay loam
Ubon[2]	Grossarenic Halpustalfs	0–20	72.6	19.4	8.0	Sandy Loam
		20–40	69.2	18.0	12.8	Sandy Loam
		40–60	61.5	22.5	16.0	Sandy Loam
		60–80	65.0	21.4	13.6	Sandy Loam
		80–100	59.2	21.0	19.5	Sandy Loam
Roi Et[2]	Aeric Kandiaquults	0–20	73.9	16.9	9.2	Sandy Loam
		20–40	74.9	12.3	12.8	Sandy Loam
		40–60	75.5	11.3	13.2	Sandy Loam
		60–80	70.8	13.6	15.6	Sandy Loam
		80–100	66.3	12.3	12.4	Sandy Loam
Satuk[3]	Typic Paleustults	0–20	80.1	0.7	19.2	Sandy Loam
		20–40	N/A	N/A	N/A	N/A
		40–60	N/A	N/A	N/A	N/A
		60–80	N/A	N/A	N/A	N/A
		80–100	N/A	N/A	N/A	N/A

N/A: not available. [1]Toung et al. [28]; [2]Saenya et al. [29]; [3]Kaweewong et al. [30]; [4]Soil Survey Staff [31].

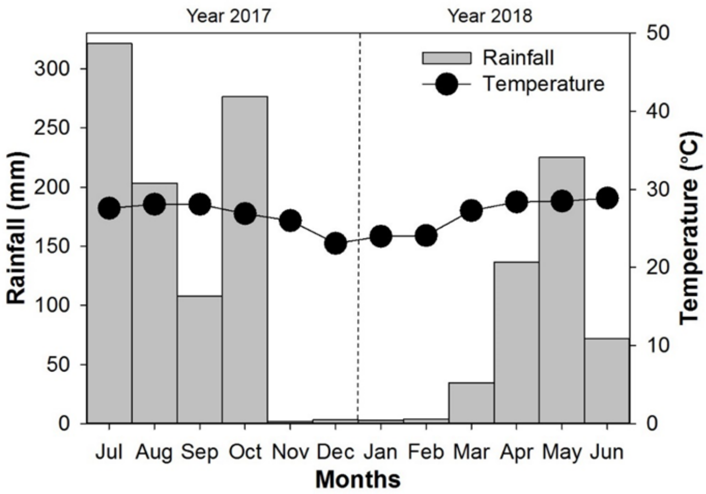

Fig. 2. Average monthly rainfall and temperature (°C) during July 2017–June 2018.

2.4 Statistical analysis

The statistical design for analysis of variance was general ANOVA with three factors, i.e. location (six levels) x land use (four levels) x soil depth (five levels) and three replications. Data were analyzed statistically employing Statistix 8.0 software (Analytical Software, Tallahassee, FL, USA). The data were checked for normality and homogeneity of variances to meet the assumptions for ANOVA. Individual analysis of variance was firstly performed for each location. Combined analysis of variance was performed for all locations across location, land use and soil layer. Means comparisons were done by least significant difference (LSD) at $P<0.05$.

3. Results

3.1 ANOVA for nitrogen stocks in soil profiles at six locations and four land uses

Three analyses of variance were performed for TN content (Table 2). Analyses 1, 2 and 3 were conducted for one (0-100 cm), two (0-20, 20-100 cm) and five (0-20, 20-40, 40-60, 60-80, 80-100 cm) soil layers, respectively. All analyses revealed that the differences among locations and among land uses for TN contents were significant. The difference between topsoil (0-20 cm) and subsoil (20-100 cm) as well as the differences among the five soil layers was significant for TN content. All primary level interactions (location x land use, location x soil depth, land use x soil depth) and the secondary level interaction (location x land use x soil depth) for TN contents were significant.

Across six locations, land uses for sugarcane and cassava had a significantly lower amount of TN than forest and paddy (Table 3). The stock of TN in cassava soil considerably decreased by 23% followed by sugarcane (11%) and paddy soils (5%), respectively, compared with the TN stock in the original forest soil.

3.2 Distribution of nitrogen in soil profiles as influenced by land–use changes

For TN stock in the whole soil profile (0-100 cm), forest soil tended to have higher TN stock than agricultural soils in most locations except at Kantharawichai and Wapi Pathum (Fig. 3). Among agricultural land uses, sugarcane, and paddy tended to have higher TN stocks than cassava for Muang and Kantharawichai locations (Fig. 3a–3b). Stock of TN was higher in paddy than in upland soils (i.e., sugarcane, cassava) for the Kosum Phisai location (Fig. 3c), whereas the upland

Table 2. Mean squares for total nitrogen in different soil depths from four land use types and six locations.

Source of variation	Degree of freedom	Mean square	F–ratio
One soil depth			
Location	5	47.15*	71.64
Land use type	3	8.54*	14.10
Location × Land use type	15	2.98*	4.92
Error	36	0.61	
Two soil depths			
Location	5	23.57*	70.80
Land use type	3	4.26*	11.74
Soil depth/1	1	149.65*	411.95
Land use type × Soil depth/1	3	0.18	0.51
Location × Soil depth/1	5	1.49*	4.09
Location × Land use type	15	6.55*	18.02
Location × Land use type × Soil depth/1	15	1.69*	4.66
Error	84	0.36	
Five soil depths			
Location	5	9.43*	51.40
Land use type	3	1.70*	14.30
Soil depth/2	4	20.67*	174.34
Land use type × Soil depth/2	12	0.46*	3.85
Location × Soil depth/2	20	0.59*	5.01
Location × Land use type	15	1.41*	11.91
Location × Land use type × Soil depth/2	60	0.52*	4.38
Error	228	0.12	

1/two soil depths, including topsoil (0–20 cm), subsoil (20–100 cm).
2/five soil depths, including 0–20, 20–40, 40–60, 60–80, 80–100 cm.
*: represents significantly different by LSD (P<0.05).

Table 3. Means for total nitrogen stocks (Mg ha^{-1}) in different soil depths from four land uses and six locations.

Land use types	Soil depth		
	1/1	**2/2**	**5/3**
Forest	7.04A	3.52A	1.41A
Cassava	5.43C (–23%)/4	2.72C (–23%)	1.09C (–23%)
Sugarcane	6.28B (–11%)	3.14B (–11%)	1.26B (–11%)
Paddy	6.66AB (–5%)	3.33AB (–5%)	1.33AB (–5%)
CV (%) (Location x Replication x Land use x Soil depth)	12.77	18.16	27.08
F–test	*	*	*

Means in a same column followed by the different uppercase letters are significantly different by LSD (P<0.05, *).
1/: One soil depth, 0–100 cm.
2/: Two soil depths, including topsoil (0–20 cm), subsoil (20–100 cm).
3/: Five soil depths, including 0–20, 20–40, 40–60, 60–80, 80–100 cm.
4/: Percentage of total nitrogen reduced under converted agricultural land uses as compared to the original forest.

soil had higher TN stocks than paddy soil for the Borabue location (Fig. 3e).

Among soil depths, TN stock in 0-20 cm (topsoil) in general was higher than in the deeper four soil depths (i.e., 20-40, 40-60, 60-80, 80-100 cm) (Fig. 4) except in paddy soil in the Muang location (Fig. 4a), and cassava soil in the Wapi Pathum location (Fig. 4f).

3.3 Land-use changes affecting nitrogen stocks in top-subsoil

TN stocks in subsoil (20-100 cm) from six locations were higher than in topsoil (0-20 cm) (Fig. 5). The forest topsoil tended to have higher TN stock than agricultural topsoil (i.e., cassava, sugarcane, and paddy) for Muang, Kut Rang and Wapi Pathum locations (Fig. 5a, 5d, 5f). However, it was lower than sugarcane and paddy soils for Kantharawichai and Kosum Phisai locations, respectively (Fig. 5b, 5c).

Stock of TN in forest subsoil was higher than cassava and paddy soils for Muang and Borabue locations, respectively. However, it was not significantly different from those in sugarcane and paddy soils for the Muang location as well as cassava and sugarcane soils for the Borabue location, respectively (Fig. 5a, 5e). In the other four locations, the TN stocks in all land uses were not significantly different (Fig. 5b, 5c, 5d, 5f).

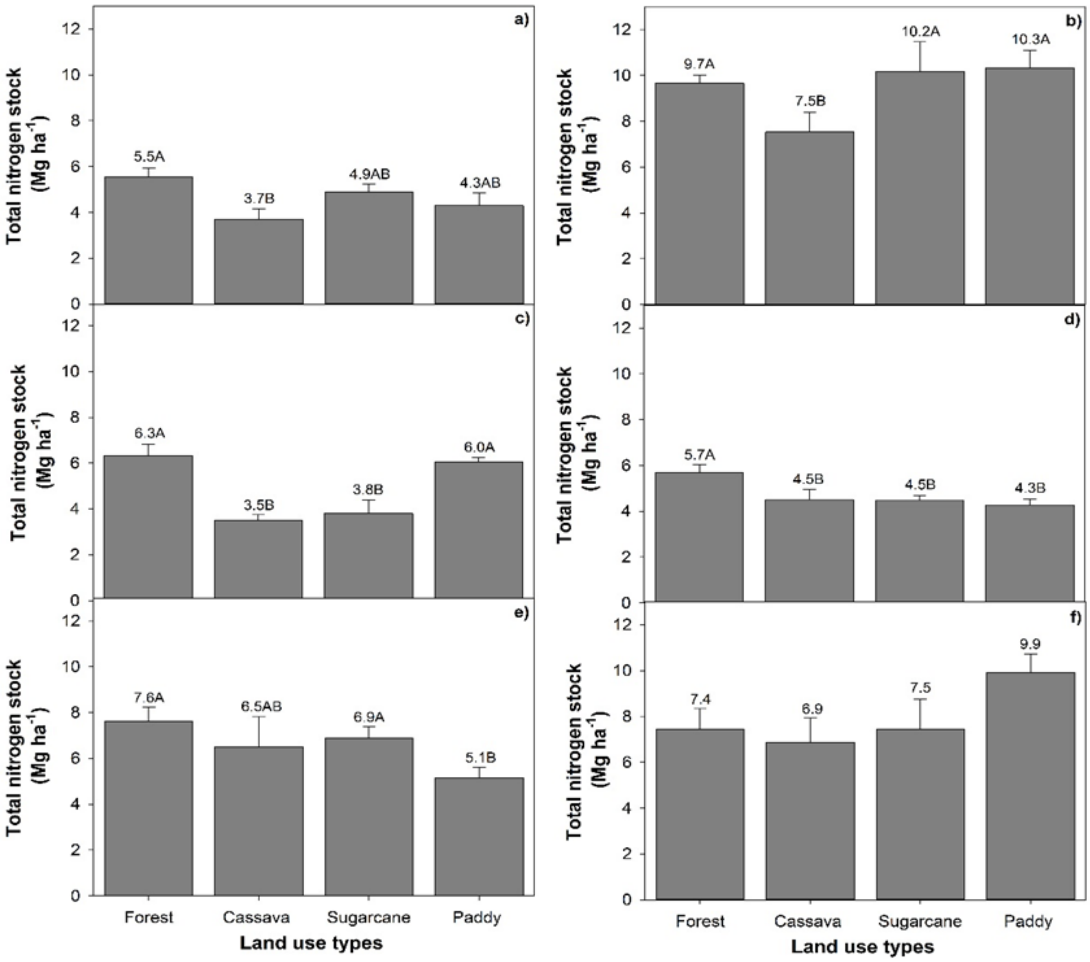

Fig. 3. Land–use changes affecting total nitrogen stocks in whole soil profile (0–100 cm) in 6 districts: a) Muang, b) Kantharawichai, c) Kosum Phisai, d) Kut Rang, e) Borabue and f) Wapi Pathum. Similar uppercase letters on top of bar graphs indicate no significant differences (P>0.05) as calculated by the least significant difference (LSD). Error bars represent standard error of the mean.

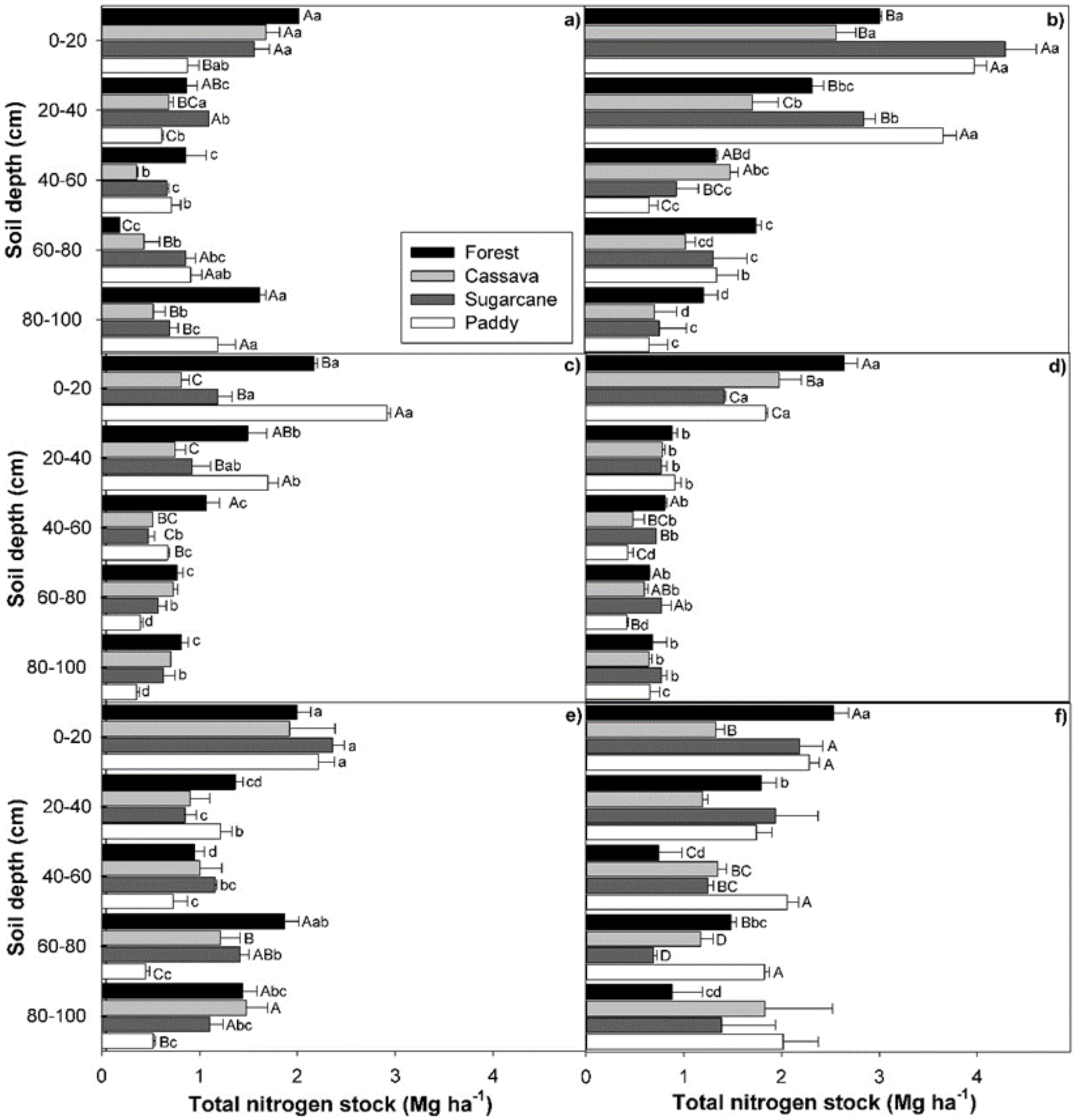

Fig. 4. Land–use changes affecting the distribution of total nitrogen stocks in soil profiles in 6 districts: a) Muang, b) Kantharawichai, c) Kosum Phisai, d) Kut Rang, e) Borabue and f) Wapi Pathum. Uppercase letters accompanying bar graphs denote comparisons of total nitrogen stocks among different land uses at each soil depth. Lowercase letters denote comparison of total nitrogen stocks among different soil depths within a land use type. Similar letters indicate no significant differences (P>0.05), as analyzed by the LSD method. Error bars represent standard error of the mean.

4. Discussion

4.1 Land use types affecting total nitrogen stocks

Our results showed that the effect of location, land use type, and soil depth as well as their interactions on amount of TN were significant, indicating that location, land use, and soil depth are important factors influencing the TN distribution in the soils. The results were in agreement with previous studies [24, 35–38]. In the whole soil depth of 100 cm, conversion of forest to agricultural land reduced TN stocks by 6 to 23%.

Similar results were also reported in previous studies. For instance, a study in Calcaric Cambisol soil in Loess Plateau, China reported that TN stock of cropland soil at 0–500 cm soil depth was decreased by 37% compared to wood, shrub and natural grass lands [24]. In southeastern Ethiopia, the amount of soil TN in cultivated and fallow lands was reduced by 60 to 70%, compared to the original forest [21]. In northwest Ethiopia, TN stocks in eucalyptus plantation and croplands (e.g., *Zea mays*, *Sorghum bicolor*, *Triticum aestivum*) were declined by 44 to 65% compared to woodland soil [40].

Decomposition of leaf litter is responsible for the higher TN stock in forest land. Input of litter fall and fine roots are major sources of N in forest soil [39]. In contrast to forest soil, inappropriate land management practices (no returning of residues to the fields and removing of crop residues after harvest) are a reason for low amount of TN in agricultural lands. Our findings essentially agreed well with those in previous studies, which found that TN in croplands was lower than in forest soils [20, 27, 35, 39].

Decomposition of rice stover remaining after harvest could enhance TN stock in lowland (rice paddy) soil. In addition, movement of organic materials from upland area (184–185 m above sea level; MASL) to lowland (178 MASL m above sea level) through water runoff is another reason for higher amount of TN in the paddy land. Removal of leaves and stems of cassava and sugarcane from the fields after harvest results in lower amounts of TN in the upland soils compared to the lowland soil. The results in this study also supported previous findings that paddy soil had higher TN content than upland soils (i.e., sugarcane, cassava) [41].

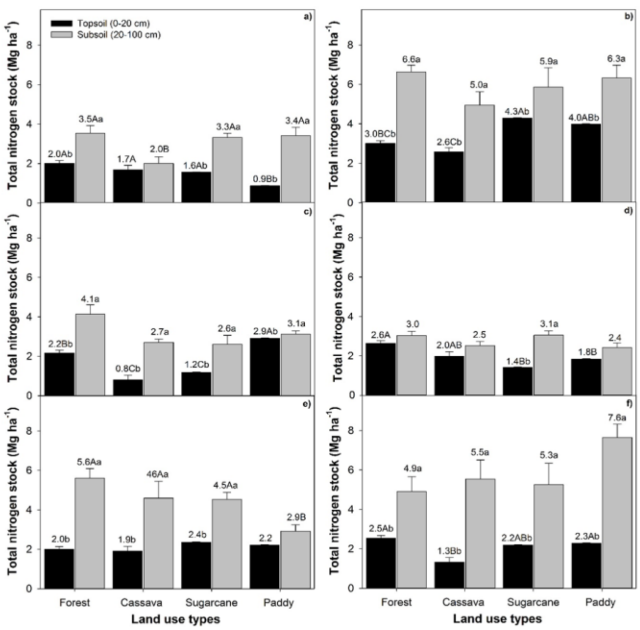

Fig. 5. Land–use changes affecting total nitrogen stocks in topsoil (0–20 cm) and subsoil (20–100 cm) in 6 districts: a) Muang, b) Kantharawichai, c) Kosum Phisai, d) Kut Rang, e) Borabue and f) Wapi Pathum. Uppercase letters accompanying bar graphs denote comparisons of total nitrogen stocks among different land uses at each soil depth (topsoil; 0–20 cm and subsoil; 20–100 cm). Lowercase letters denote comparison of total nitrogen stocks between topsoil (0–20 cm) and subsoil (20–100 cm) within a land use type. Similar letters indicate no significant differences ($P>0.05$), as analyzed by the LSD method. Error bars represent standard error of the mean.

4.2 Sequestration of nitrogen in the soil profile

In the current study, TN stocks among locations and land use types decreased with increasing soil depth. Higher TN values ranging from 0.8 to 4.3 Mg ha^{-1} were found in the topsoil (0–20 cm) and TN values ranging from 0.2 to 3.7 Mg ha^{-1} were found in subsoil horizon (20–40, 40–60, 60–80 and 80–100 cm). Higher TN values in topsoil were due to high input of surface litter, resulting in a higher amount of TN in A than in B horizons [38, 40, 42–43].

Although subsoil had lower values of TN stocks than topsoil, it is a major location for TN storage. The Proportion of TN stocks up to 52 to 81% was accumulated in subsoils, whereas only 19 to 48% was stored in topsoils (0–20 cm). In previous studies, larger amounts of TN were stored in subsoil (below 20 cm soil depth) than in topsoil (0–20 cm) [21, 24, 26]. High storage of TN in subsoil was due to the movement of N from topsoil to the subsoil, especially in the form of inorganic N. According to Xue et al. [44], inorganic N was highly leached from topsoil (0–10 cm) to subsoil (10–30 cm) as indicated by a higher content of NO_3^- accumulated in the subsoil.

In the current study, we speculated that N could be highly leached from topsoil to accumulate in the subsoil especially in the rainy season because the studied soils contained low contents of clay, but high contents of sand. Clay has high capacity for adsorption [45–46], and, thus, surface soil layers with low clay content had low amount of accumulated N and hence low N storage.

The correlations between SOM (i.e., SOC and SON) stock and clay content were positive [26, 47], and subsoil (>17 cm soil depth) with higher clay content had higher TN accumulation than topsoil (0–17 cm) with lower clay content [23].

5. Conclusions

Land–use changes affected accumulation of TN in the soil profile. Forest had the highest TN stock followed by paddy, sugarcane and cassava lands. Conversion from natural forest to agricultural lands with inappropriate management reduced TN stock by 5 to 23% compared to the original forest land. In the same agricultural land use with different management practices by farmers, TN accumulations in soil profile were different.

Acknowledgements

This research was financially supported by Mahasarakham University 2018 and the Soil Organic Matter Management Research Group, Khon Kaen University.

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