Land–use changes affecting nitrogen accumulation in top–sub soils

Benjapon Kunlanit[1,2*]

ABSTRACT: The objective of this study was to investigate accumulation of total nitrogen (TN) in top–subsoil as influenced by land use changes. Soil samples were collected from five soil depths, i.e. 0–15, 15–30, 30–60, 60–80, and 80–100 cm under three land uses, including paddy, cassava, and forest lands located in Don Wan sub–district, Muang district, Maha Sarakham province. The air–dried soil samples were subjected to determine TN using the Kjeldahl method. The results showed that TN stocks had a trend to be higher in topsoil (0–30 cm) than in subsoil (30–100 cm) in all land uses. Paddy topsoil had a higher amount of TN than in forest and cassava topsoils. For TN accumulation in soil profiles from 0 –100 cm depth, forest (10.5 Mg ha^{-1}) and paddy (9.3 Mg ha^{-1}) soils had higher stocks of TN than cassava soil (7.5 Mg ha^{-1}). The results of this study revealed that conversion from forest land to cassava land without appropriate management led to low soil fertility as seen by low amounts of TN in this soil.

Keywords: Total nitrogen, land use change, soil depth, Northeast Thailand

Introduction

Nitrogen (N) plays vital roles for growth and yield of plants (Marchner, 1996). Its cycle varies with native vegetation, climate, soil type, management practice, land use history and time since conversion (Kassa et al., 2017; Prather et al., 1995). The increasing human population and the growing need for extension of agricultural land have led to deforestation for decades (Kassa et al., 2017). Land use change causes disturbance to the soil ecosystem through harvesting and land preparation, which may have an effect on microbial communities and subsequently N availability (Burton et al., 2007; O'Connell et al., 2004). It could also have impacts on environmental conditions such as temperature and moisture, which also influence soil N transformations, particularly losses of N from the soil through leaching or gentrification (Blumfield and Xu, 2003), resulting in soil N accumulation (Assefa et al., 2017). Murty et al. (2002) reported that N decreased (-15%) after conversation of forest to agricultural land use. In Ethiopia, natural forest had higher TN stock in 0–20 cm soil depth than agricultural land (i.e., eucalyptus plantation, grazing land and cropland (Assefa et al., 2017; Kassa et al., 2017; Emiru and Gebrekidan, 2013). In New Zealand, Ross et al. (1999) also found that forest soil (2.90 g kg^{-1}) had higher TN than pine plantation soil (2.70 g kg^{-1}). In Northeast Thailand, Thantrakanpong (2002) found that forest soil resulted in larger amount of TN in soil at 0-15 cm

[1] Department of Agricultural Technology, Faculty of Technology, Mahasarakham University, Maha Sarakham 44150, Thailand
[2] Soil Organic Matter Management Research Group, KhonKaen University 40002, Thailand
* Corresponding author: benjapon.k@msu.ac.th

than agricultural soil. These findings were similar to a study in China by Wang et al. (2016), who found that forest soil provided higher N than upland crop soil. Most studies showed that fallen leaf litter decomposition contributed to N accumulation in forest topsoil. This is in contrast to a study in China by Xu and Xu (2015), who demonstrated that N content in 0–10 cm soil depth increased after conversion from forest (*Pinus yunnanensis* Franch) (1.48 g kg^{-1}) to wheat–maize rotation (1.85 g kg^{-1}). They suggested that higher N in the wheat–maize rotation could result from N fertilizer input and returning harvested crop residues to soil. However, these studies have focussed on N accumulation in topsoil (0–20 cm) only. Also, crop cultivation (open system) with different agricultural practices and forest (close system) might have different patterns of Naccumulation in topsoil (0–20 cm) and deeper soil layer (>20-100 cm soil depth).

In Northeast Thailand, agricultural land uses (i.e., paddy rice and upland field crops) are major crops. Dynamics of Nunder these paddy rice and upland crop systems are inherently different. That is, paddy soils are under periodically anaerobic and temporarily aerobic conditions, while field crop soils (e.g., cassava and sugarcane) are totally under aerobic condition (Vityakon et al., 2000). Conversion from forest to agricultural lands might differently contribute to N accumulation in their top–subsoil. Therefore, this study was designed to examine land use changes affecting the stocks of TN in soil profiles (0-100 cm).

Materials and methods

Study site and soil sampling

A study site for soil sampling around Don Wan sub–district, Muang district in Maha Sarakham province was shown in **Figure 1**. There were three land uses employed in this study, including secondary deciduous dipterocarp forest, cassava converted from forest for 5 years, and paddy lands converted from forest for >10 years. There were 34, 27 and 37 sampling points from the forest (21 ha), cassava (5 ha) and paddy (13 ha) land uses, respectively. In each sampling point, five soil depth intervals were collected, i.e., 0-15, 15-30, 30-60, 60-80, and 80-100 cm. Soil samples were air–died and passed through a 2–mm sieve for further laboratory analyses.

Soil analysis

Soil samples were subjected to determined soil particle sizes using the pipette method (modified from Dewis and Freitas, 1970). Total N content was determined by the Kjeldahl method (Raymentand Higginson, 1992).The soil was digested with concentrated H_2SO_4 and catalyst mixture (K_2SO_4:$CuSO_4$:Se, 100:10:1 w/w) to raise the boiling temperature and promote the transformation of organic–N into ammonium–N (NH_4^+–N). Then, NH_4^+–N from the digestion was obtained by distillation using excess 40%NaOH. The distillation is collected in saturated H_3BO_3; and then titrated with 0.005 $N H_2SO_4$.

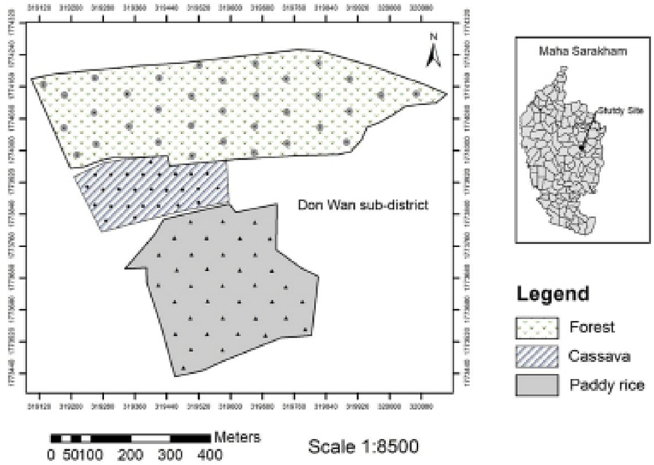

Figure 1 A map showing location of soil sampling sites in Maha Sarakham of Northeast Thailand

Climate and temperature during the experiment periods

Precipitation and temperature during soil sampling periods are briefly described. Average monthly precipitation and temperature over the soil sampling periods (July 2015–June 2016) were revealed in Figure 2. This climatic information was received from the Northeastern Meteorological Center in Maha Sarakham province. Monthly average rainfall and temperature of the study site was similar in which the double–bell shaped pattern dropped during November–March. The precipitation was highest during August–September. Soil samples were randomly collected in the dry season after crops were harvested in March 2016.

Statistical analysis

Statistical analyses were performed using Statistic 8.0 software (Analytical Software, Tallahassee, FL, USA) was employed for this purpose. The data were checked for normality and homogeneity of variances to meet the assumptions for ANOVA. Means comparisons among the different land uses and soil depths were carried out by least significant difference (LSD).

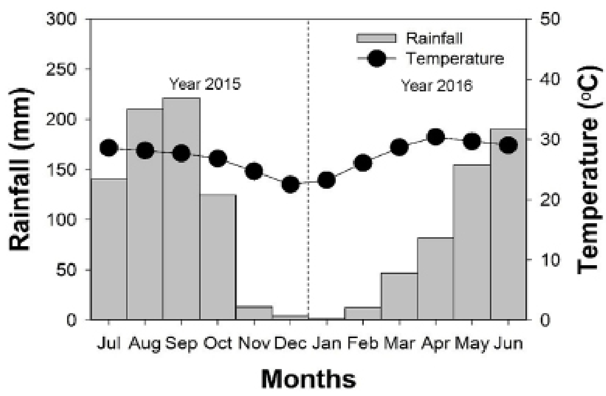

Figure 2 Climate condition and average temperature (°C) during July 2015–June 2016

Results and Discussion

Soil texture throughout soil profile under different land uses

Paddy and cassava soil textures at 0-80 cm were loamy sand, meanwhile at 80-100 cm were sand and sandy loam, respectively **(Table 1)**. Forest soil texture at 0-60 cm was a loamy sand, but the soil textures at 60-80 and 80-100 cm were sandy loam and sandy clay loam, respectively. In this study, soil texture has a trend to be finer with depth increasing with the exception of the texture at 80–100 cm under paddy land. This is similar to the results of Riise et al. (2000).

Table 1 Some soil physical properties under different land uses. Data sources: Kunlanit (2018; 2017)

Land use types	Soil depths (cm)	Particles (%)			Soil textures
		Sand	Silt	Clay	
Forest	0–15	82.6	8.0	9.4	Loamy sand
	15–30	84.0	9.0	7.0	Loamy sand
	30–60	84.0	7.9	8.1	Loamy sand
	60–80	76.5	11.8	11.7	Sandy loam
	80–100	65.0	10.9	24.1	Sandy clay loam
Cassava	0–15	84.8	9.4	5.7	Loamy sand
	15–30	82.7	9.6	7.7	Loamy sand
	30–60	84.2	9.9	5.9	Loamy sand
	60–80	81.9	10.2	7.9	Loamy sand
	80–100	74.0	9.9	16.1	Sandy loam
Paddy rice	0–15	79.1	14.1	6.8	Loamy sand
	15–30	79.9	13.1	7.0	Loamy sand
	30–60	80.8	12.9	6.3	Loamy sand
	60–80	87.4	7.2	5.4	Loamy sand
	80–100	93.6	2.0	4.5	Sand

Distribution of total nitrogen in soil profile

Total nitrogen stocks in all land uses were significantly higher in 0-15 cm than in 15-100 cm soil depth ($P<0.05$) **(Figure 3)**. At both of 0-15 and 15-30 cm depths, paddy and forest soils had higher TN stock than cassava soil ($P <0.05$), exception of at 15-30 cm. The TN stocks were not significantly different between forest and cassava soils ($P>0.05$). However at 60–80 cm, the TN stocks were higher in forest and cassava soils than paddy soil ($P<0.05$).At 30–60 and 80–100 cm depths, there were no statistically significant differences among the TN stocks at each soil depth under three land uses.

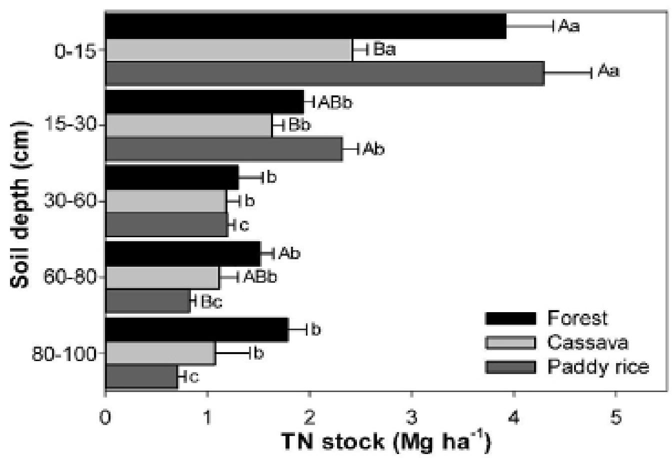

Figure 3 Land use changes affecting TNstock in soil profile. Similar uppercase letters on the top of horizontal bar graphs represent the mean of TN stocks among the different land uses in each soil depth, while lowercase letters represent the mean of TN stocks among fives oil depths in each land use, which indicate no significant differences (P >0.05) as calculated by the least significant difference (LSD). Error bars represent standard error of the mean

Total nitrogen accumulation in top-subsoil

Topsoil (0–30 cm) showed a trend to have higher TN stocks than in subsoil(30–100 cm) in all land uses, but the TN stock was significantly higher in the topsoil than in the subsoil of paddy rice only (P <0.05) (Figure 4a, 4b). When considering absolute amount of TN throughout the soil profile (0–100 cm), forest (10.5 Mg ha^{-1}) and paddy (9.3 Mg ha^{-1}) soils had higher TN stocks than cassava soil (7.5 Mg ha^{-1}) (P <0.05) (Figure 4a).However at the subsoil, forest and cassava land uses had higher TN stocks than in the paddy land use. For relative amount of TN, the paddy topsoil tended to have higher TN stock than in forest and cassava top soils (P >0.05), but the TN stock in the subsoil was opposite (Figure 4b).

In the current study, higher amount of TN accumulation in topsoil was found in paddy land (lowland). That is likely because during rice cultivation, N fertilizer is applied to maintain high rice productivity. High addition of N is a vital reason for N accumulation in the surface layer (Li et al., 2017; Wang et al., 2017; Li et al., 2010), and hardpan layer under paddy soil could impede a movement of N from topsoil to subsoil. In addition, remaining rice stover topsoil might contribute to TN accumulation. Neue et al. (1997) also reported that flooding is the most feature way of rice cultivation, organic matter decomposition proceeds at lower rates under anaerobic conditions, and this could lead to the accumulation of soil organic N instead of N loss to atmosphere. Similar to the recent study, studies have shown that TN in topsoil scan increasingly accumulate during the short–term rice plantation (Tong et al., 2009; Yang et al., 2005; Lal, 2002). Meanwhile in the upland crop (cassava), TN stock was lower in cassava than in paddy soils. It is because of less remained residues after harvesting cassava. Also, N can be lost to atmosphere and subsoil in this aerobic condition with intensive agricultural disturbance. This was seen by large amount of TN in the cassava subsoil **(Figure 4a).**

For forest soil in the current study, TN stock throughout the soil profile (0–100 cm) was high (10.5 Mg ha^{-1}).It is possible that decomposition of fallen leaf litters can provide N to soil. This is similar to many studies who found that N content were higher in forest topsoil than in agricultural topsoil (Assefa et al., 2017; Kassa et al., 2017; Emiru and Gebrekidan, 2013; Murty et al., 2002; Thantrakanpong, 2002; Ross et al., 1999). However in this study, no N fertilizer input in forest soil may have contributed to low amount of TN accumulation in the forest topsoil as compared to the lowland paddy topsoil. In addition, N loss from topsoil layer (containing less hardpan) to subsoil might also be a reason of high TN accumulation in the subsoil (30-100 cm) under forest land **(Figure 4a).**

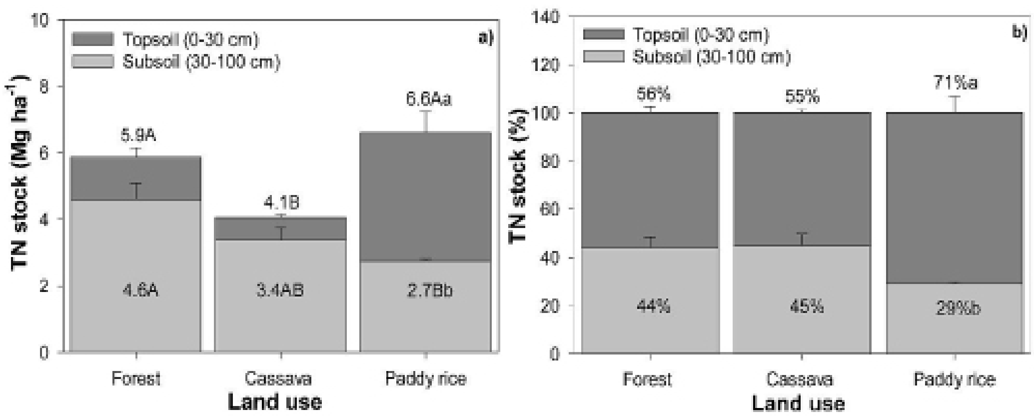

Figure 4 Land use changes affecting TN stocks in top–subsoil: a) absolute amount of TN stock (Mg ha^{-1}) and b) relative amount of TN stock (%). Similar uppercase letters on the top of vertical bar graphs represent the mean of TN stocks among the different land uses in topsoil and subsoil, while lowercase letters represent the mean of TN stocks in topsoil and subsoil in each land use, which indicate no significant differences (P>0.05) as calculated by the least significant difference (LSD). Error bars represent standard error of the mean.

Conclusions

Total N stocks had a trend to be higher in top soils (0–30 cm) than in sub soils (30–100 cm) in all land uses. Paddy topsoil provided a higher amount of TN in than forest and cassava top soils. For accumulation of TN in soil profiles of 0–100 cm, forest (10.5 Mg ha^{-1}) and paddy (9.3 Mg ha^{-1}) soils had higher contents of TN than cassava soil (7.5 Mg ha^{-1}). This study pointed out that conversion of forest land to cassava land without appropriate management led to low soil fertility as indicated by low N content in this soil. Meanwhile, remaining rice stover on topsoil after harvesting rice could enhance N accumulation in the paddy soil. Further in–depth studies are recommended on the mechanisms of aggregate formation as influenced by land use changes to highlight the role of N in aggregate formation, leading to soil organic matter sequestration.

Acknowledgements

This research was financially supported by Mahasarakham University 2016 and 2018 as well as the Soil Organic Matter Management Research Group, Khon Kaen University. Special thanks to P.T.Higgins for his assistance in editing the paper.

References

Assefa, D., B. Rewald, H. Sandén, C. Rosinger, A. Abiyu, B. Yitaferu, and D. L. Godbold. 2017. Deforestation and land use strongly effect soil organic carbon and nitrogen stock in Northwest Ethiopia. Catena. 153: 89–99.

Blumfield, T. J. and Z. H. Xu. 2003. Impact of harvest residues on soil mineral nitrogen dynamics following clearfall harvesting of a hoop pine plantation in subtropical Australia. For EcolManag. 179: 55–67.

Burton, J., C. R. Chen, Z. H. Xu, and H. Ghadiri. 2007. Gross nitrogen transformations in adjacent native and plantation forests of subtropical Australia. Soil BiolBiochem. 39: 426–433.

Dewis, J., and F.Freitas. 1970. Physical and chemical methods of soil and water analysis. Food and Agriculture Organization of the United Nations.

Emiru, N. and H. Gebrekidan. 2013. Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat watershed, WesternEthiopia. ARPN J AgricBiol Sci. 8: 206–212.

Kassaa, H., S. Dondeyne, J. Poesen, A. Frankl, and J. Nyssen. 2017. Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia. AgricEcosyst Environ. 247: 273–282.

Kunlanit, B. 2018. Distribution of some macronutrients in soil profiles as influenced by land use changes. KhonKaenAgr J. 46 (supplement 1): 1161–1168.

Kunlanit, B. 2017. Dynamics of soil organic matter and humic acid contents asinfluenced by land use changes.KhonKaenAgr J. 45 (supplement 1): 1334–1341.

Lal, R. 2002. Soil carbon sequestration in China through agricultural intensification, and restoration of degraded and desertified ecosystems. Land Degrad Dev. 13:469–478.

Li, D., L. Wen, W. Zhang, L. Yang, K. Xiao, H. Chen, and K. Wang. 2017. Afforestation effects on soil organic carbon and nitrogen pools modulated by lithology. Forest EcolManag. 400: 85–92.

Li, Z., M. Liu, X. Wu, F. Han, and T. Zhang. 2010. Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil derived from barren land in subtropical. Soil Tillage Res. 106: 268–274.

Marschner H. 1995. Mineral nutrition of higher plants 2nd edition. Academic Press, San Diego, CA.

Murty, D., M.U.F. Kirschbaum, R.E. Mcmurtrie, and H. Mcgilvray. 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? a review of the literature. Global Change Biol. 8: 105–123.

Neue, H., J. Gaunt, Z. Wang, P. Becker–Heidmann, C. Quijano. 1997. Carbon in tropical wetlands. Geoderma. 79: 163–185.

O'Connell, A.M., T.S. Grove, D.S. Mendham, and S.J. Rance. 2004. Impact of harvest residue management on soil nitrogen dynamics in Eucalyptus globulus plantations in south western Australia. Soil BiolBiochem. 36: 39–48.

Prather, M., R. Derwent, and D. Ehhait. 1995. Other trace gases and atmospheric chemistry. In: Climate change 1994: radioactive forcing of climate change and the IPCC IS92 emission scenarios (Houghton J.T. et al. ed.). Cambridge: Cambridge University Press. 73–126.

Rayment, G. E. and F. R. Higginson. 1992. Australian Soil and Land Survey Handbook, Australian Laboratory Handbook of Soil and Water Chemical Methods. Australia: Inkata Press.

Riise, G., P. Van Hees, U. Lundstrom, and L. T. Strand. 2002. Mobility of different size fractions of organic carbon, Al, Fe, Mn and Si in podzols. Geoderma. 94: 237–247.

Ross, D. J., K. R. Tate N. A. Scott, and C. W. Feltham. 1999. Land–use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. Soil BiolBiochem. 31: 803–813.

Thantrakanpong, S. 2002. Changes of different pools of soil organic matter under different land use systems in undulating terrain of Northeast Thailand. Master of Science Thesis in Soil Science, Graduate School, KhonKaen University. 171 p. (in Thai with English abstract).

Tong, C., H. Xiao, G. Tang, H. Wang, T. Huang, H. Xia, S.J. Keith, Y. Li, S. Liu, and J. Wu. 2009. Long–term fertilizer effects on organic carbon and total nitrogen and coupling relationships of C and N in paddy soils in subtropical China. Soil Till Res. 106: 8–14.

Vityakon, P., S. Meepech, G. Cadisch, and B. Toomsan. 2000. Soil organic matter and nitrogen transformation mediated by plant residues of different qualities in sandy acid upland and paddy soils. Neth J Agr Sci. 48: 75–90.

Wang, J., S. Zhuang, and Z. Zhu. 2017. Soil organic nitrogen composition and mineralization of paddy soils in a cultivation chronosequence in China. J Soils Sediments. 17: 1588–1598.

Wang, T., F. Kang, X. Cheng, H. Han, and W. Ji. 2016. Soil organic carbon and total nitrogen stocks under different land uses in a hilly ecological restoration area of North China. Soil Till Res. 163: 176–184.

Xu, Y., and Z. Xu. 2015. Effects of land use change on soil gross nitrogen transformation rates in subtropical acid soils of Southwest China. Environ SciPollut Res. 22: 10850–1086.

Yang, C., L. Yang, and Z. Ouyang. 2005. Organic carbon and its fractions in paddy soil as affected by different nutrient and water regimes. Geoderma. 124: 133–142.