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# Total Nitrogen Stock in Soil Profile Affected by Land Use and Soil Type in Three Counties of Mollisols

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Soil total nitrogen is the major indicator of soil fertility and quality in agricultural ecosystems. However, few comparative studies investigated the spatial patterns of soil total nitrogen density (STND) in deep soils of different land uses and soil types. Therefore, our study aimed to identify the influence of environmental factors on spatial variability in STND by comparing the STND spatial patterns of different land uses and soil types in a typical Mollisols in northeast China. Results showed that land use types did not significantly affect STND, but the soil types did. The STND was more heterogeneous above 60 cm than that in subsoil, and no significant changes in STND were found in the same land use or soil type. The STND had a significant correlation with SOC, soil BD and pH regardless of land use or soil type. The STND in the soil profile (100 cm) and top 20 cm was fitted using a mathematical model. The results provided insights into nitrogen cycle and stock in similar areas in northeast China.

**Keywords: soil nitrogen stock, spatial pattern, profile distribution, soil nitrogen density, black soil**



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## INTRODUCTION

Soil total nitrogen (STN) is the major determinant and indicator of soil fertility and quality in an agricultural ecosystem and is closely related to soil productivity (Al-Kaisi et al., 2005). STN reduction leads to decrease in soil fertility, soil nutrient supply, penetrability and soil productivity (Gray and Morant, 2003). A good understanding of STN distribution and associated soil factors is of great importance to sustainable land-use management and provides a basis for agricultural measurements (McGrath and Zhang, 2003).

STN is heterogeneously distributed in soils, and its variation, affected by research scale or degree of support, spacing and range (Wang et al., 2009), is caused by multiple factors, including parent material and land use (Jenny, 1941; Ross et al., 1999; Jin-Shi et al., 2009; Wang et al., 2009). Soil types strongly affect STN distribution (Jia et al., 2017; Yao et al., 2019). Meanwhile, land use change stimulates dynamic effects adjusting the spatial distribution of STN. Climate change and human activities, especially current policy interference, have increased the frequency of land use changes (Ostwald and Chen, 2006). Previous studies mostly focused on the upper soil (<0.2 m) and rarely considered the vertical distribution of deep soils. However, like soil organic carbon, the storage of STN at 100 cm is equivalent to 2–3 times of the terrestrial pool storage (Smith, 2004). Small changes can cause global greenhouse effect changes, and the impact of land use type and soil type on STN cannot be ignored.

Mollisols plays a vital role in national food security and the most important soil resource for crop production in China (Liu et al., 2012). However, few comparative studies investigated the spatial

**TABLE 1** | Different depths of soil total nitrogen density (STND) distribution under different land use and soil types.

| Sample | 0–20 cm | 20–40 cm | 40–60 cm | 60–80 cm | 80–100 cm |
|---|---|---|---|---|---|
| Dry land (*n* = 50) | 46.1 ± 13.2Aa | 36.3 ± 13.7Ba | 25.2 ± 10.5Ca | 19.9 ± 7.5Da | 17.2 ± 6.9Da |
| Rice paddy (*n* = 16) | 42.6 ± 16.8Aa | 32.6 ± 12.5Ba | 21.5 ± 9.9Ca | 17.3 ± 6.8Ca | 15.1 ± 7.3Ca |
| *p* value | 0.395 | 0.350 | 0.222 | 0.220 | 0.311 |
| Haplic Phaeozem (*n* = 24) | 47.4 ± 10.9Aa | 38.1 ± 12.3Ba | 27.5 ± 9.5Ca | 22.5 ± 5.4CDa | 19.5 ± 6.4Da |
| Haplic Chernozem (*n* = 21) | 37.9 ± 4.8Ab | 23.8 ± 7.3Bb | 16.9 ± 7.5Cb | 11.5 ± 6.1Db | 10.8 ± 6.0Db |
| Luvic Phaeozem (*n* = 21) | 46.7 ± 16.2Aa | 37.1 ± 15.6Ba | 23.7 ± 11.5Ca | 19.3 ± 8.1Ca | 16.2 ± 7.0Ca |
| *p* value | 0.014 | <0.001 | 0.002 | <0.001 | <0.001 |
| All samples (*n* = 66) | 44.2 ± 12.2A | 33.2 ± 13.7B | 22.9 ± 10.4C | 18.0 ± 8.0D | 15.7 ± 7.3D |

*Within the same horizon, different capital letters show significant differences among soil depths; different lowercase letters show significant differences among land use and soil types ($p < 0.05$).*

distribution of STN density (STND) in different land use and soil types in deep soils in identical landscape ecosystems, and thus strategies for forecasting ecosystem responses to environmental changes when land use changes are currently limited. Thus, the aims of this study were to identify and compare the spatial patterns of STND in a typical Mollisols among different land uses and among soil types in deep soils and further analyze the influence of relevant environmental factors on its spatial variation.

## MATERIAL AND METHODS

Three counties Lindian, Hailun and Baoqing (longitude 124°32′–131°42′, latitude 45°55′–47°59′) were selected as the representative fields of key soil textures [Haplic Phaeozem, Haplic Chenozem and Luvic Phaeozem (FAO/UNESCO)] in Heilongjiang Province, China. The land use types of the three typical counties included dry cropland and rice (*Oryza sativa* L.) paddy. Soil samples at this stage were collected under a "carbon project" supported by the Chinese Academy of Sciences. After the collection of soil samples along the soil profile, the physical and chemical properties were determined. Based on the values obtained from the weighted average depth of each soil profile, the STN concentration of each fixed deep layer (20 cm) was calculated. Each profile was divided into five layers (0–20, 20–40, 40–60, 60–80, and 80–100 cm). Detailed description of the scientific research area, soil analysis, STN density calculations and data processing can be seen in the article of Li et al. (2019).

All analyses were carried out using SPSS 18.0 statistical analysis package (SPSS Inc., Chicago, IL, United States). The correlations between STNDs and influencing factors (SOC, pH, soil BD and soil texture) were analyzed using one-way variance and bivariate correlations. The effects of land use types, soil types, soil depths and mutual influences were determined using three-way variation, and the significance of the difference was evaluated with Duncan's test ($p < 0.05$). A stepwise method involving the double elimination method was used in selecting the predictive analysis independent variables in the regression analysis. The regression analysis was used in exploring the correlation between the STNDs of the 0–20 and 0–100 cm layers.

## RESULTS AND DISCUSSIONS

### Soil Total Nitrogen Density Distribution at Different Depths Under Different Land Uses and Soil Types

Three-way ANOVA showed that land use types did not significantly affect STND, but soil types and depths affected STND. Their interactions did not significantly affect STND (**Supplementary Table S1**). Differences in STND among the 0–20, 20–40, and 40–60 cm deep layers were significant ($p < 0.05$), whereas the difference between the 60–80, and 80–100 cm deep layers was not significant ($p > 0.05$, **Table 1**). The effect of land use types on STND was not significant ($p > 0.05$), but soil types significantly affected STND ($p < 0.05$, **Table 1**). The results showed that the STND above 60 cm depth was more heterogeneous than that below 60 cm, and the STND below 60 cm depth had no significant difference in the same land use or soil type. The influence of soil type on soil nitrogen stock has been confirmed (Wang et al., 2009). The influence is related to soil basic properties, such as texture. Specific surface area increases with the content of fine particles, and STND increases with the adsorption capacity of soil (Wang et al., 2009). Previous studies reported that the average SOC density of paddy fields was usually higher than that of dry land (Yu et al., 2004), and thus the carbon sequestration potential of paddy soils was higher than that of dry lands and is usually interpreted as low organic carbon mineralization under wet conditions (Liu et al., 2006). However, we did not observe significant difference in STND between the rice paddy and dry land in the present study (**Table 1**). This result indicated that difference in STND between land use types is likely affected by soil layers, soil types, and other factors (Liu et al., 2006).

### Relationships Between Soil Total Nitrogen Density and Soil Variables

A large-scale study (Jin-Shi et al., 2009) found a positive correlation between STND and soil variables. However, the correlation coefficients were inconsistent in variables and land use types because agriculture-related factors (e.g., tillage, fertilization and irrigation) were more critical than natural factors in influencing the STND of agricultural ecosystems (Wang et al., 2009). In this study, Pearson analysis between STND and soil properties showed that the STNDs on all land use and soil types was significantly

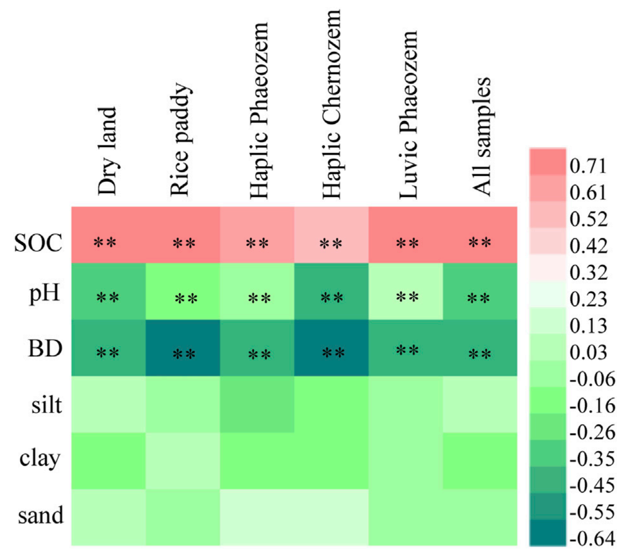


**FIGURE 1 |** Relationship of soil total nitrogen density (STND) and soil properties in 0–100 cm depth was analysed using Pearson correlations; ** represent significance at the 0.01 probability level.

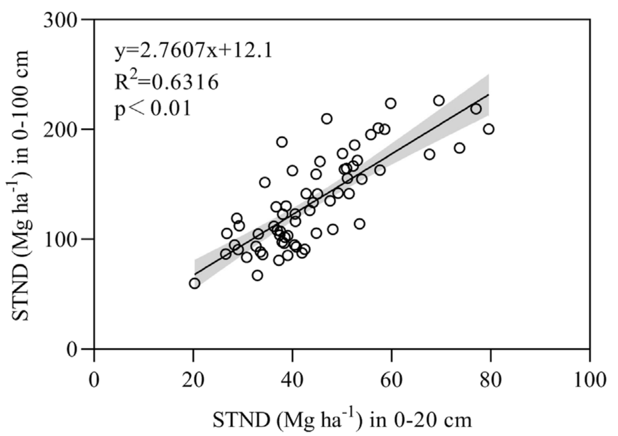


**FIGURE 2 |** Relationship of total nitrogen density (STND) between 0–20 and 0–100 cm depths.

correlated with SOC, soil BD and pH (**Figure 1**). Soil pH affects microbial community structure and diversity, and controls decomposition and nitrification processes (Zhou et al., 2019). In addition, as an indicator of compactness, BD can affect soil water and nutrient flow and reduce biodiversity. Therefore, there is a correlation between soil pH, BD, and STND (Zhang et al., 2020). In addition, using multiple step-wise method regression, the relationship between STND and soil properties in different land use and soil types was quantitatively analyzed. SOC was only selected as an important predictor variable in the linear model, which explained 32.1–66.7% of variation in STND (**Supplementary Table S2**). According to the correlation and multivariate linear regression results, these relationships were independent of land uses.

## Relationships of Soil Total Nitrogen Density Between Topsoil and Subsoil

Deep STND estimates are time consuming on a large scale. The accurate estimation of the STNDs of deep soils on the basis of the STND of the topsoil saves a considerable amount of time. In our previous study, we found that SOC densities of the top 20 cm layer and 100 cm-deep layer had a good linear relationship (Li et al., 2019). The present study showed a linear relationship between STND in the top (20 cm) and deep (100 cm) soils (**Figure 2**). Thus, we suggested that the STND in the top (20 cm) soil can be used in estimating the STND of the 0–100 cm layer in similar areas. A previous study indicated that because of the difference of chemical composition of carbon and nitrogen in topsoil and subsoils, TN stocks in topsoil were higher than those in subsoil in different land use. Forest, paddy and cassava topsoil had different profile distribution (Liu et al., 2018; Kunlanit et al., 2019). Thus, estimation accuracy can be increased by using the following conditions: the application of a lower soil classification module (such as subclasses or soil genus) and the STND in the soil profile are stable for a long time (Li et al., 2019).

In conclusion, land use types did not significantly affect STN density (STND) in contrast to soil types. The STND below the 60 cm depth showed no significant difference in the same land use type or soil type. SOC, soil BD and soil pH were significantly correlated with STND. Establishing a good mathematical model between the 0–20 and 0–100 cm profile is a practical approach for estimating STN in deep soils using topsoil STND data in the future.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## AUTHOR CONTRIBUTIONS

ML and L-JL conceived the conceptual design and methodology of the article. ML and XH carried out the formal analysis, which was validated by all co-authors. ML wrote the manuscript with contributions from all co-authors.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.945305/full#supplementary-material

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