

DYNAMICS OF SOIL NUTRIENTS AND STOICHIOMETRY IN MONGOLIAN SCOTS PINE (*PINUS SYLVESTRIS* VAR. *MONGOLICA*) PLANTATION, IN A SEMIARID AREA OF CHINA

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Abstract. The aim of this study was to investigate about soil nutrients and stoichiometric ratio in Mongolian scots pine plantation forests. Our results showed that along 5 depth increments (0-20, 20-40, 40-60, 60-80, and 80-100 cm), the concentration and storage of total soil organic carbon (TSOC), total nitrogen (TN), and total phosphorous (TP) decrease. A significantly higher TSOC, TN, and TP concentration and storage was recorded at 0-20 cm, indicating that more C, N, and P were found in the upper soil profile. Similarly, the C:N and C: P stoichiometry and soil TSOC concentrations were significantly higher than soil N:P and TN and TP concentrations, indicating that coniferous plantation forests store more C compared to N and P. TSOC, TN, and TP ($p < 0.01$) concentrations and storage were positively correlated at depth of 0-20 and 20-40 cm, showing a relatively constrained C:N:P ratio in this plantation forest. Furthermore, stand density, basal area, and total biomass carbon affected TSOC, TN, and TP concentration. Our findings provide key references to further research studies in Mongolian scots pine plantation regarding TSOC, TN, as well as TP and their variations and storage along other parameters (tree age, soil texture, ground flora, seasons etc.) at the Research Station of Liaoning Institute of Sand-fixation and Afforestation (42°42'0" N, 122°29'0" E, 220.67 m above sea level), Zhanggutai region, Liaoning Province, southeastern Horqin sandy region, China. **Keywords:** *plantation forests, stand characteristics, depth increment, stoichiometric traits, Horqin sandy land*

Introduction

Soil nutrients play an important role in plant growth and development and are essential in vegetation succession, nutrient cycling and ecological management of terrestrial ecosystems (Li et al., 2017a), among which carbon (C) is the basic structural element of plant and contributes one-half of the plants biomass (Yang et al., 2007a,b; Kim et al., 2011;

Sardans et al., 2011). Nitrogen (N) is an essential component of plants and the majority of which are completely dependent on soil N due to lacking of symbiotic bacteria that fix the N (Li et al., 2017a), while phosphorous (P) affects photosynthetic assimilation and dry mass in plants (Ågren et al., 2012) and represents the basic element of DNA, RNA and ATP. The lackage of these nutrient elements can limit the plants growth and development (Kim et al., 2011). The amount and concentration of these nutritional elements and their stoichiometry in plants reveal nutrient uptake, utilization ability and adaptation to the environment during different growth stages (Wright and Westoby, 2003; Yang and Luo, 2011).

In plantation forests, variation in nutrient concentrations with stand developmental stages have attracted attention due to their importance for the development of nutrient management practices (Sardans et al., 2011; Yang et al., 2014). So, the relationship between tree growing stages and soil nutrient concentrations based studies provide a basic information regarding management of plantation forests. Many studies have been conducted on variation and distribution of SOC, N, and P along the stand characteristics, and variation in these elements have been ascribed to the fact that the forest stand can potentially vary these nutrients through the amount and decomposition of litter, canopy composition, roots uptake and basal area (Yuan et al., 2013; Xia et al., 2015; Jiang et al., 2017). As an integrative approach that involves the study of different nutritional elements in ecological relations and involves determining elemental engagements of living organisms (Li et al., 2017a), nutritional stoichiometry is affected by ecological conditions (elevation, precipitation, and temperature), plantation age and sampling time (Han et al., 2005; Sardans et al., 2011). It has been reported that SOC, N, and P are strongly correlated with the stand characteristics, soil texture and topography too (Jiang et al., 2017). Therefore, the determination of C, N, and P dynamics with stand characteristics and development and soil depth can facilitate the quantification of the pattern and distribution of C:N:P stoichiometry in the plantation forest ecosystem. Furthermore, it is not clear whether C, N, and P concentrations and its stoichiometric ratios in plants are controlled over time, stand characteristics and ecological factors in plantation forests.

In arid and semi-arid regions of China, currently much attention has been given on large scale afforestation and reforestation of degraded land, such as that related with “Grain for Green” and “Three Norths Shelter Forest Systems” Projects. Mongolian scots pine (*Pinus sylvestris* var. *mongolica*), only one recommended needle-leaved tree species, had been planted at large-scale in these programs for windbreak and sand stabilization in these regions (Zhang et al., 2019). Despite of the fact that Mongolian pine plantation in these regions has a great role in the combating desertification and controlling land degradation, this plantation forest ecosystem is also acting as carbon, nitrogen, and phosphorous sinks. There is a dire need to study the variation of nutrients in the study area, not only because of the fact that the average soil nutrients concentrations and storage are lower in semi-arid area of China than the global mean, resulting from low nutrients input due to water runoff and soil erosion (Cao and Chen, 2017; Zhang et al., 2017), but also because in semi-arid areas of China the growth of vegetation is restricted due to limited water resources (Chen et al., 2008; Deng et al., 2016). So far fewer information about the role of stand characteristics and depth increment on TSOC, TN, and TP budget in arid and semi-arid areas of China is available, especially in the study area. Thus, this study was conducted with the overall objectives of: 1) to estimate the changes in TSOC, TN, and TP concentration and storage along the depth increment; 2) to determine the TSOC, TN, and TP stoichiometry and their characteristics and nutrients limitations in soil; and, 3) to investigate the effect of stand characteristics on TSOC, TN, and TP concentration and their storage in the Scots Pine

plantation forests. We hope that this study will be a baseline for further studies in monitoring and mapping of TSOC, TN, and TP in Mongolian Scots pine plantation forests.

Materials and methods

Description of the study area

The study was conducted in 2017 at the Research Station of Liaoning Institute of Sand-fixation and Afforestation (42°42'0" N, 122°29'0" E, 220.67 m above sea level), located in Zhanggutai region, Liaoning Province, southeastern Horqin sandy region, China (Fig. 1). The climate of the area is a typical temperate with continental monsoon, with the mean annual temperature of 7.7°C (for 1954-2010) and mean annual precipitation of 474 mm that mostly (67%) occur during June-August (Song et al., 2016; Zhang et al., 2019). The area faces approximately three times more annual evaporation than the precipitation, with the annual frost-free period of 150-160 days. The geography is categorized by distribution of sand dunes with low-lying land affected by wind erosion. The key soil category is Aeolian sandy soil (89.4%). In 1954, an experimental based trial plantation of Mongolian Scots pine was introduced and planted in this region. Here a large number of Mongolian Scots pine plantation forests with different densities, diameter and age ars intersected by other woody plants like *Populus* L. *Pinus tabuliformis* Carr and *Ulmus pumila* L. Understory vegetation includes *Setaria viridis* (L.), *Cleistogenes squarrosa* (Trin.) Keng, *Eragrostis pilosa* (L.) *Setaria viridis*, *Elymus dahuricus* Turcz, *Geranium wilfordii* Maxim, *Lespedeza bicolor* and *Portulaca oleracea* L (Zhang et al., 2019).

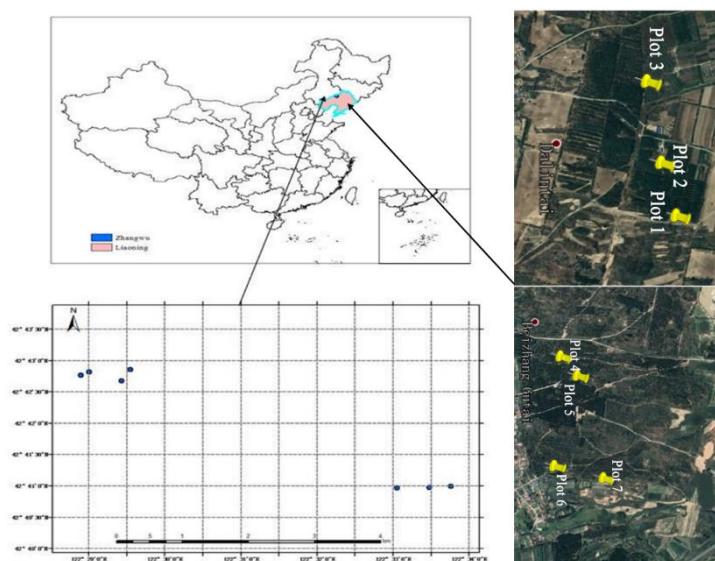


Figure 1. Location of the study area in China

Stand survey and soil sampling and analysis

7 sites were selected with different stand age and density (Table 1). In each site 50 m × 50 m standard plot was setup and then stand variables as diameter at breast height (DBH), height (H), stand density (SD), basal area (BA), and tree cross sectional area (CS) in sample plots were measured (Fig. 2).

Table 1. Stand characteristics and location of Mongolian Scots Pine (*Pinus sylvestris* var *mongolica*) plantation forests

Plot No	Location	Altitude (m)	Total Density (ha ⁻¹)	Mean Diameter (cm)	Mean Height (m)	pH					Bulk Density (g/cm ³)				
						0-20 (cm)	20-40 (cm)	40-60 (cm)	60-80 (cm)	80-100 (cm)	0-20 (cm)	20-40 (cm)	40-60 (cm)	60-80 (cm)	80-100 (cm)
1	42.6832° N, 122.5627° E	204.3	700±35.16	19.5±9.38	9.23±3.04	5.86	6.42	6.44	6.26	6.76	1.54	1.56	1.58	1.57	1.55
2	42.6828° N, 122.5579° E	204.3	572±21.54	19.55±3.04	10.61±1.03	5.48	6.39	6.57	6.46	6.4	1.50	1.59	1.53	1.55	1.56
3	42.6827° N, 122.5508° E	197.3	248±12.52	20.15±2.88	10.19±0.89	6.34	6.45	6.74	6.57	6.32	1.59	1.58	1.59	1.60	1.60
4	42.7127° N, 122.4815° E	247.5	244±11.33	22.97±3.78	11.07±1.05	5.9	8.26	6.67	6.68	6.77	1.55	1.53	1.58	1.60	1.61
5	42.7137° N, 122.4833° E	225.5	312±12.30	23.02±4.31	13.45±11.30	5.73	6.59	6.69	6.85	6.59	1.59	1.58	1.57	1.57	1.56
6	42.7112° N, 122.4904° E	235.4	364±17.60	16.69±3.00	7.95±0.98	6.36	6.55	6.72	6.75	6.7	1.59	1.56	1.56	1.56	1.59
7	42.7143° N, 122.4924° E	230.4	608±62.13	9.81±1.60	4.18±0.56	6.16	6.52	6.53	6.87	6.94	1.63	1.63	1.61	1.58	1.56

Note: Values are mean ± standard deviation



Figure 2. Sampling/experimental design, site habitat and data collection

In each sample plot, the soil samples at five depth levels (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) (*Fig. 2*) were collected using a steel core (dimensions = 5 cm) and were packed and brought to a laboratory for further analysis (Nelson and Sommers, 1982; Bremner, 1996). All the soil samples were sieved through a 2 mm wire mesh after removing the litter plant roots and stones, and ovened for 24 hours at 105°C and the dry weight of each sample was measured. Soil pH value was measured using FE20 pH meter (Mettler Toledo, Shanghai, China) at soil-to-water (deionized) 2:2.5. $K_2Cr_2O_7/H_2SO_4$ method, a Semimicro-Kjeldahl method and sodium hydroxide (NaOH) fusion and Mo-Sb colorimetric method were applied to determine SOC, N, and P respectively (Ouyang et al., 2017).

Stand and soil parameter calculation

Soil bulk density

Soil bulk density (SD) ($g\ cm^{-3}$) of each sample at the respective depth was calculated as:

$$pb = M_s/V_t \quad (Eq.1)$$

where; pb is the bulk density of the soil ($g\ cm^{-3}$), M_s (g) is an oven-dry mass and V_t is the core volume (cm^3).

Stand density, basal area and biomass carbon

Stand basal area was calculated from the calculated stand density and cross sectional area of each tree at respective diameter following *Equation 2* (Ahmad et al., 2018)

$$BA = SD \times CS \quad (Eq.2)$$

where, BA is the basal area ($\text{m}^2 \text{ha}^{-1}$), SD is the stand density (ha^{-1}), and CS is the cross sectional area of each tree.

For calculating the above and below ground biomass the experimental model was used for different organs (stem, branch, foliage, and root) of Mongolian Scots pine (Xing et al., 2017). To determine the carbon stock for tree layers, the total carbon concentration was used to the biomass estimates in the different stand diameter classes, then summed up and scaled on the basis of total area (ha^{-1}). For calculation of carbon concentration, following Equation 3 was used (Hoover, 2008; Lorenz and Lal, 2010).

$$Cc = B \times \rho_c \quad (\text{Eq.3})$$

where Cc is carbon concentration (Mg ha^{-1}) and B is biomass (Mg ha^{-1}), ρ_c is conversion factor as 0.5.

TSOC, TN, and TP

Following equations were used to calculate the mass storage per area (Mg ha^{-1}) of TSOC (C_s), TN (N_s), and TP (P_s) for each individual soil profile (Ouyang et al., 2017).

$$C_s = \sum_i^n [D_i \times \text{TSOC}_i \times \text{BD}_i \times (1 - G_i)/100] / 100 \quad (\text{Eq.4})$$

$$N_s = \sum_i^n [D_i \times \text{TN}_i \times \text{BD}_i \times (1 - G_i)/100] / 100 \quad (\text{Eq.5})$$

$$P_s = \sum_i^n [D_i \times \text{TP}_i \times \text{BD}_i \times (1 - G_i)/100] / 100 \quad (\text{Eq.6})$$

where n is the number of soil layers; i is the ith soil layer; TSOC_i , TN_i , and TP_i are the TSOC, TN, and TP concentrations (g kg^{-1}) in the ith soil layer, respectively. Similarly, BD_i , G_i and D_i are the soil bulk density (g cm^{-3}), the proportion (%) of coarse (> 2 mm) fragments, and the thickness (cm) in the ith layer, respectively. In our study, TSOC, TN, and TP were calculated for depth of 100 cm, divided in to five soil layers (0-20, 20-40, 40-60, 60-80, and 80-100 cm).

Statistical analysis

Soil pH, soil bulk density (g cm^{-3}), TSOC (t ha^{-1}), TN (t ha^{-1}), TP (t ha^{-1}), C:N, C:P, and N:P were tested with soil profile layers by using ANOVA. Similarly, stand density (ha^{-1}), basal area (ha^{-1}), and total biomass carbon (t ha^{-1}) were fitted with TN (t ha^{-1}), TSOC (t ha^{-1}), TP (t ha^{-1}), C:N, C:P, and N:P as regression analysis (polynomial cubic). All the statistical analysis was performed using statistical software packages Statistix 8.1 and SigmaPlot 12.5.

Results

Variation in soil pH and bulk density along the depth increment

Depth increment and interaction affected the soil pH but there was no significant effect on bulk density value along depth (Fig. 3A,B). Soil pH was found statistically lower in 0-20 cm layer, while no significant difference among the other layers was recorded (Fig. 3A). The bulk density showed no significant change with increasing depth (Fig. 3B).

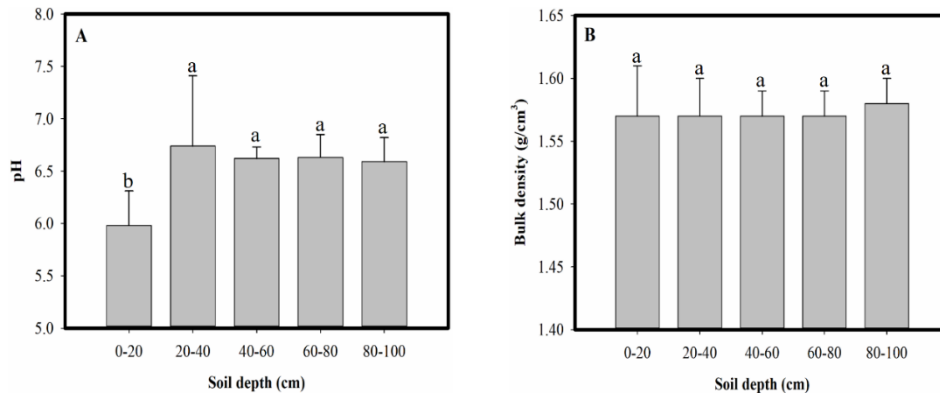


Figure 3. Mean values of soil pH (a) and bulk density (b) along the depth increment. Values are mean \pm standard deviation, different alphabets on each error bar denote the significant differences ($p < 0.01$, $n=7$) at a given soil depth

Variation in soil TSOC, TN, and TP along the depth increment

The results showed that the soil TSOC, TN, and TP followed a decreasing trend with the depth increment (Fig. 4). Among the different layers the maximum values for TSOC, TN, and TP storage was found in 0-20 cm layer. The results presented in Fig. 4 revealed that a significantly higher TSOC, TN, and TP storage occurred at the first layer increment (0-20 cm). Nevertheless, there was slight or no significant variation in their values among the other layers.

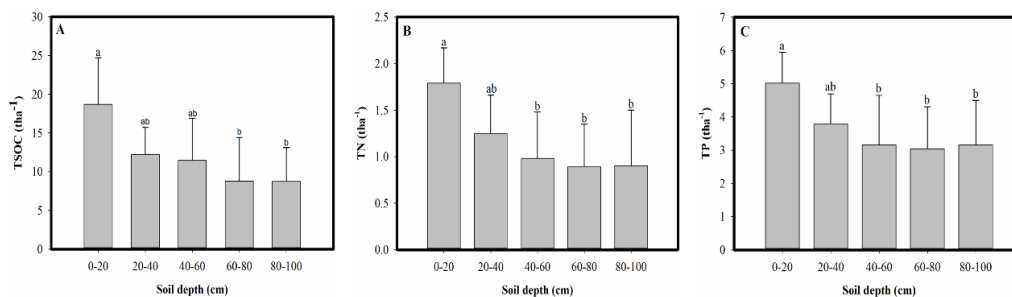


Figure 4. Mean values of total soil organic carbon ($t\ ha^{-1}$) (a), total nitrogen ($t\ ha^{-1}$) (b) and total phosphorous ($t\ ha^{-1}$) (c) along the depth increment. TSOC, TN, and TP indicate the total soil organic carbon, total nitrogen, and total phosphorous. Values are mean \pm standard deviation, different alphabets on each error bar denote the significant differences ($p < 0.01$, $n=7$) at a given soil depth

Variation in soil C:N, C:P, and N:P ratios along the depth increment

Fig. 5 showed the values of C:N, C:P, and N:P along the depth. Results of the figure highlighted that among all the depths, C:N and C:P showing no significant variation, however, the highest C:N was found in 40-60 cm layer and lowest in 20-40 cm (Fig. 5A). Similarly, the maximum C:P was recorded in 0-20 cm layer while it was minimum in 80-100 cm layer (Fig. 5B). In contrast to C:N and C:P, a significant variation in the N:P was observed across the depth. A significant larger ration was recorded in the 0-20 cm and lower in 80-100 cm layer. However, no significant variation was recorded 20-40, 40-60 and 60-80 cm layer for N:P (Fig. 5C).

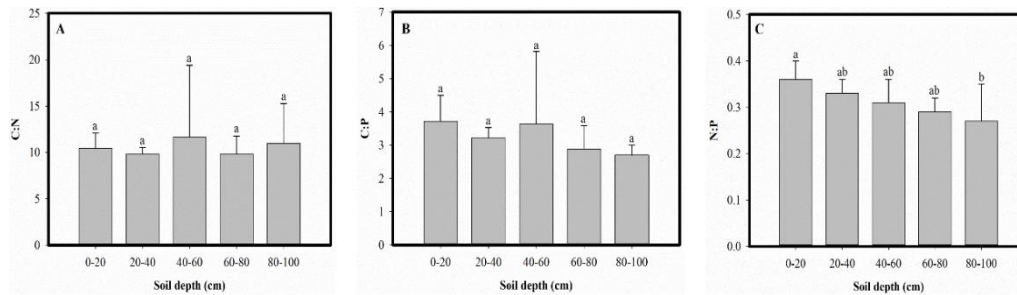


Figure 5. Stoichiometric ratios of soil C, N, and P along the depth increment in Mongolian Scots pine plantation. Values are mean \pm standard deviation, different alphabets on each error bar denote the significant differences ($p < 0.01$, $n=7$) at a given soil depth

Regression analysis (polynomial cubic) between TSOC, TN, and TP with the stand characteristics

The values of TSOC, TN, and TP were positively correlated with stand different characteristics with R^2 value more than 0.5 (Fig. 6a,b,c). The relationship of stand density with TSOC, TN and TP was a polynomial cubic. The results of the regression analysis (Fig. 6b) showed that the amount of TN increased with increasing stand density, and reached to a maximum value of 9.48 ($t\ ha^{-1}$) at high stand density of 572 (ha^{-1}). However, a decreasing trend in TN was recorded with increasing density and reached to a minimum value of 4.02 ($t\ ha^{-1}$) at 700 (ha^{-1}) (Fig. 6b). Similarly, TP, TSOC followed nearly the same pattern and presented a high value i.e. 26.93 ($t\ ha^{-1}$) (Fig. 6c) and 93.64 ($t\ ha^{-1}$) (Fig. 6a) of TP and TSOC at high density 572 (ha^{-1}), respectively.

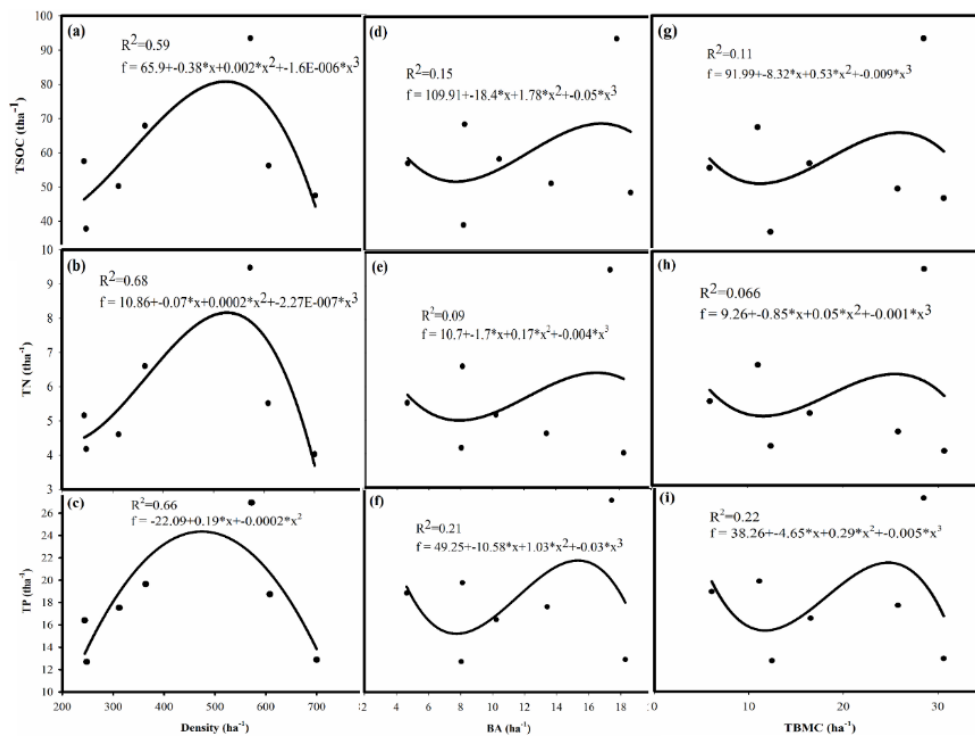


Figure 6. Regression analysis (Polynomial Cubic) of total soil organic carbon (TSOC), total nitrogen (TN), and total phosphorous (TP) with stand density (a, b, c), stand basal area (d, e, f) and total biomass carbon (g, h, i), ($p < 0.05$, $n=7$)

Consistently, TSOC, TN and TP though positively correlated with basal area and biomass carbon, but a week (Fig. 6d,e,f,g,h,i) compared to stand density. The amount of TSOC, TN, and TP were found maximum at basal area of 17.43 (ha⁻¹) and minimum at basal area of 18.28 (ha⁻¹) (Fig. 6d,e,f), respectively. Similarly, the amount of TSOC, TN, and TP was recorded higher at biomass carbon of 28.52 (t ha⁻¹) and lower at biomass carbon of 30.63 (t ha⁻¹) (Fig. 6g,h,i), respectively.

Regression analysis (polynomial cubic) between C:N, C:P, and N:P ratios with the stand characteristics

The results showing the values of regression analysis between C:N, C:P, and N:P ratios with different stand characteristics are given in the Fig. 7. The results highlighted that C:N and C:P (Fig. 7a,b) showed a maximum value of 11.79 and 3.69 with maximum value of 700 (ha⁻¹) stand density and with minimum value of 9.04 and 2.86 at stand densities of 248 (ha⁻¹) and 312 (ha⁻¹), respectively, but N:P (Fig. 7c) showed a different pattern from C:N and C:P with the maximum and minimum value of 0.35 and 0.26 with respective stand density of 572 (ha⁻¹) and 312 (ha⁻¹). Similarly, maximum and minimum value of C:N and C:P and N:P (Fig. 7d,e,f) were found at their respective maximum and minimum stand basal areas of 18.28 (ha⁻¹) and 8.04 (ha⁻¹). Fig. 7g,h,i highlighted the regression analysis between C:N, C:P and N:P with total biomass carbon and figured out the maximum and minimum value of 11.79, 9.04 and 3.69, 2.86 and 0.35, 0.26 with their respective total biomass carbon of 30.63 (t ha⁻¹), 12.44 (ha⁻¹) and 30.63 (t ha⁻¹), 25.78 (t ha⁻¹) and 28.52 (t ha⁻¹), 25.78, respectively.

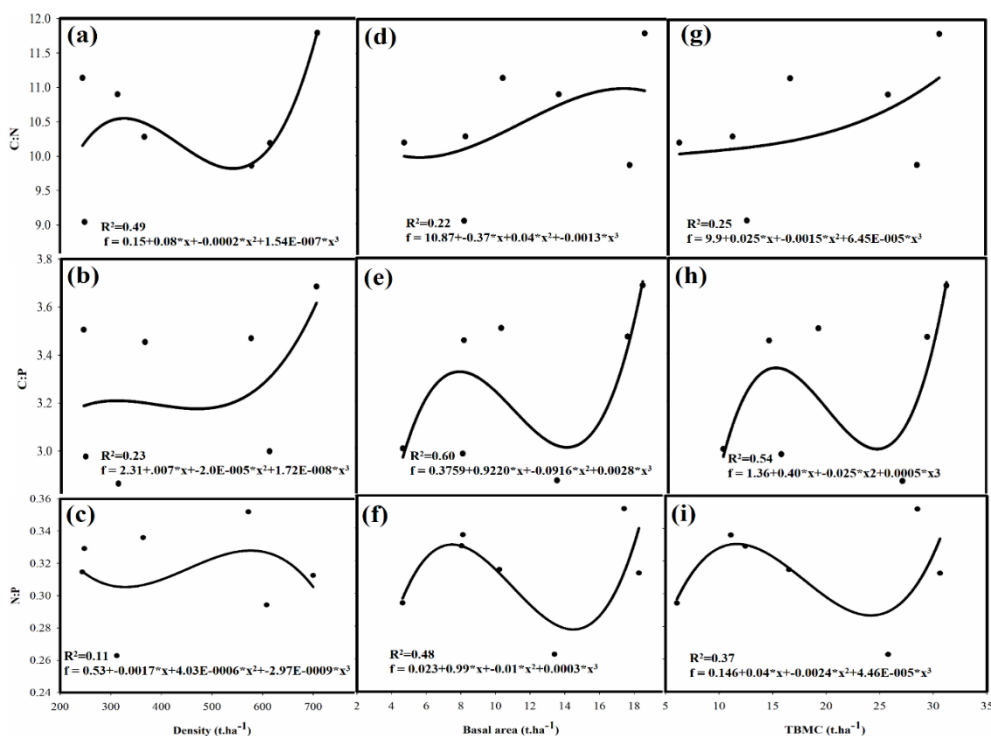


Figure 7. Regression analysis (Polynomial Cubic) of C:N, C:P, and N:P with stand density (a, b, c), stand basal area (d, e, f) and total biomass carbon (g, h, i), ($p < 0.01$, $n=7$)

Discussion

Effect of soil depth on soil TSOC, TN, and TP storage and concentration

Variation in soil TSOC, TN, and TP storage and concentration are the key indicators of changes in soil fertility and long-term ecosystem sustainability and management and variation in soil organic carbon concentration have consequences for the influence of land cover change on atmospheric carbon dioxide concentration and global warming (Ross et al., 1999). Our Results show that depth and soil nutrients are significantly correlated and the nutrients concentration decreases significantly with depth increment under scots pine plantation (*Pinus sylvestris* var *mongolica*) (Fig. 4). These results match the statement of some previous observations in arid and semi-arid regions of China (Hu et al., 2008; Chen et al., 2010). There are many reasons affecting the variation of TSOC, TN, and TP concentration along the soil depth. For instance, the balance between inputs and outputs can affect the concentration of these nutrients status, and variation in the amount and quality of plant litter contribution with land cover change may be important factors to change the ecosystem practices and eventually ecosystem properties (McKinley et al., 2008). Soil disturbances during plantation establishment in the area may also result in the faster mineralization of soil nutrients and increase the potential for nutrients loss (Guo and Gifford, 2002). The plant community, species composition, topography and soil texture can also alter the soil nutrients status (Guo and Gifford, 2002; Paul et al., 2002; Archer et al., 2004) and the coarse soil in this region might have limited soil carbon accumulation after the establishment of Scots pine plantation (Richter et al., 1999). TSOC concentration decreased with depth because of the unavailability of easily decomposed organic matter in the deep soil (Liang et al., 2010) and the soil carbon mineralization is mostly controlled by easily available decomposable soil organic carbon. Similarly, the soil nutrient concentration and availability in the top soil are mostly observed after planation of arid and semi-arid sites (Billings, 2006; McKinley et al., 2008). Furthermore, Zeng et al. (2009) reported that after conversion of arid and semi-arid regions of China to Mongolian Scots pine plantation, the concentration and mineralization of soil nutrients increased in the upper soil because of increased annual root biomass and litter input and its decomposition in the upper soil as compared to the grassland and Savana.

The concentration and seasonal distribution of soil total carbon is governed by the size and quantity of soil microbial biomass (Wei et al., 2009). Soil TSOC and the depth increment significantly correlated (Fig. 4a), suggests that soil depth was an important factor influencing the soil TSOC in our study area. Difference in the amount of soil organic matter added to the soil under forest vegetation can affect the soil organic carbon (Chen et al., 2010). The significant higher TSOC concentration in the top soil of Mongolian pine plantation reflected the greater amount and availability of organic matter accumulated in the top soil and the same was reported for pine plantation (Zeng et al., 2009). Similarly, some other studies also concluded that with the development of plantation on arid and semi-arid regions, the more TSOC and nutrients are being released from accumulation and decomposition of microbial biomass and litter input into the top soil, which could result in higher TSOC and related nutrients concentration in the upper soil surface (Cleveland and Liptzin, 2007; Li et al., 2017b). Although, initially plantation consistently resulted in the loss of some SOC from top soil in this region by altering the soil properties, but later on with the development of plantation, the C concentration gradually increased (Chen et al., 2010).

Our results for total soil nitrogen concentration was consistent with the previously reported for Keerqin sandy land (Chen et al., 2006; Holst et al., 2007; Zeng et al., 2009). Soil depth, litter fall, land cover change and sampling season has a valid interaction with the TN storage and can significantly alter the available nitrogen concentration (*Fig. 4b*), consistent with many other studies of soil nitrogen changes following land cover changes (Owen et al., 2003; Parfitt et al., 2003; Zeng et al., 2009).

Our results (*Fig. 4c*) demonstrated that afforestation in semiarid region of China significantly reduced TP stocks, which is consistent with the previously reported global scale study stating that the TP concentration below 20 cm significantly decreased (Deng et al., 2017). As it has also been explained in many studies that the microbial biomass, mineralization of organic P and phosphate activities and susceptibility of organic matter to microbial attack and enzymes hydrolysis take place in top surface and decreases gradually as the depth increases (Magid et al., 1996). The same phenomenon was also demonstrated for Mongolian pine plantation (Zhao et al., 2007). In our study, the pH level is low in the top soil (*Fig. 3a*), which may also improve organic P mineralization by increasing the susceptibility of organic P to enzyme hydrolysis in the top soil, and the same was also reported for Mongolian scots pine in Keerqin sandy land of China (Zhao et al., 2007). The decrease in the concentration of TSOC, TN, and TP with increase in the soil depth under Mongolian scots pine can be attributed to the development of juvenile plantation that require more nutrients in top soil than leaching down as the same was reports in other studies too (Laclau et al., 2003; Zhao et al., 2007).

Effect of depth increment on soil nutrients stoichiometry

The soil mean P and N concentrations and its stoichiometry in our study is lower than the global level (Zhang et al., 2005), may be because of weathering and soil erosion in the in Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*) plantation forests in semiarid areas of China. It can also be attributed to the lower P concentration in China soil than global value (Han et al., 2005). Similarly, the C: N and C: P stoichiometry and soil C concentration was significantly higher than soil N and P concentration and stoichiometry, indicating that coniferous forests store more C, consistent with other studies for coniferous forests (Güsewell and Koerselman, 2002; Zeng et al., 2009). In addition, our study findings reveal higher C: N ratio than C: P and N: P, which might be the result of higher human influence in the plantation, and the same was reported (Zhang et al., 2017). The soil nutrient concentrations and stoichiometric ratios in our study were significantly correlated with depth increment, consistent with a previous study (Zeng et al., 2016), due to a large amount of the nutrients in litter and deadwood were released into the soil as litter is a main source of soil nutritional elements.

This study demonstrated the same trend of C:N>C:P>N:P, which is also reported in other studies (Tian et al., 2010; Ouyang et al., 2017). Different studies (Li, 2012; Ren et al., 2016) showed a different CNP ratios along the soil profile increment because of difference in land use practices and management system, but followed the same trend as presented in this study. Li et al. (2012) studied that difference in C: N: P ratios might be the result of different vegetation cover and land use management practices. Zhao et al. (2015) demonstrated that forest types and plant communities can effect soil nutrients stoichiometry. Similarly, Fan et al. (2015) concluded that together, soil depth and successional stage significantly influence soil CNP stoichiometry. Globally, a well-balanced CNP stoichiometry for top 0-10 cm profile is 186:13:1 (Cleveland and Liptzin, 2007; Wang, 2014), while a general CNP stoichiometry for rich organic nutrients soil for

0-10 cm depth is 134:9:1 and for the entire soil depth i.e., 0-250 cm is 60:5:1 in China (Tian et al., 2010). In our study, the average C:N:P ratio was 10.53:3.24:0.32 for 0-100 cm soil depth, while for 0-20 cm and 20-40 cm the C:N:P ratios were 10.44:3.2:0.36 and 9.80:3.22:0.33, respectively. Our estimates for C:N:P ratios are lower than the estimated average value of C:N:P as reported above. Our C:N:P value for 0-20 cm was much lower than reported for China soil (Tian et al., 2010). These differences might be due to the soil samples containing more humidified litter in Tian et al. (2010), resulting in relatively higher C:N:P ratios compared to our estimates. In this study the average value for C:N ratio was nearly >10, and a low (<25) C:N ratio suggests that the soil organic matter accumulation is slower than its decomposition (Yang et al., 2007b).

Relationship between soil nutrients and stand characteristics

Stand characteristics and soil property has an encouraging interaction and soil nutrients can vary along stand characteristic variations (Jiang et al., 2017; Xu et al., 2018). We investigated that the stand density has a significant effect on the biomass carbon production that can bring variation in TSOC, TN, and TP concentration and storage. Our results show that TSOC, TN, and TP followed an increased pattern with increase in stand characteristics (stand density, basal area and total biomass carbon) up to some extent and then dropped (*Fig. 6*). This difference in nutrients distribution and fluxes among plantations along different stand characteristics have implications for management of successive *Pinus sylvestris* var *mongolica* plantations forests in the study area in order to maximize nutrients concentration and cycling. It has been investigated that stand density has an impacts on soil nutrients and can alter the amount of soil TSOC, TN, and TP concentration (Ma et al., 2007) and the stand characteristics like, Density, basal area and total aboveground biomass have a key role in soil nutrients concentration in plantation forests because of the litter fall and fast decomposition rate (Little and Shainsky, 1995; Sheng and Yang, 1997). Our study findings are consistent with previous study (Ma et al., 2007), stating that the soil nutrients decreased with the competition among Chinese fir plantation increased. It could also be explained that with highest basal area, density and biomass, higher accumulation of litter with lower decomposition rate due unavailability of sun light and proper aeration (Jiang et al., 2017). However, the mean TSOC and TP concentration in our results were higher compared to Jiang et al. (2017). It could be attributed that there is more SOC and P input (litter and deadwood decomposition) from plants and rapid turnover of litter (Tong et al., 2012; Yang et al., 2014). In contrast, Yang et al. (2014) attributed higher soil TSOC and TN but lower TP concentration in broadleaved deciduous forest and our study shows high TSOC and TP as compared to TN. These differences might be due to the differences in forest nature and topography because Yang et al. (2014) studied a broadleaved plantation while we studied a Pine plantation forests. Polynomial regression analysis showed that the variations in soil TSOC, TN, and TP in the plantation investigated were positively and significantly correlated with the stand characteristics, including stand density, basal area and total biomass carbon. This shows a potential influence of stand characteristics on the variation of soil nutrients in the forests (Xia et al., 2015). Yuan et al. (2013) studied that the basal area and canopy structure can alter the soil nutrients concentration because it may affect the temperature and soil moisture contents of forest floor soil, which are important factors affecting the litter and deadwood decomposition process. Similarly, our results demonstrated a high value of C:N but slightly low C:P and N:P with high stand density, basal area and total biomass carbon (*Fig. 7*). It could be attributed that in soil, mostly TP contents is available

in inorganic forms, that show little or no variation along the stand characteristics and may lead to the high ratios of C:N (Jiang et al., 2017). Soil nutrients stoichiometric ratios didn't show any good correlation along different stand characteristics (Fig. 7) might be because that stoichiometry is a combine result of multiple activities, like elemental uptake, excretion and storage, thus it cannot fully specify the ability of plants to achieve limiting resources. Furthermore, it has been investigated that stoichiometric and elemental compositions of vegetation vary significantly along stand characteristics (Yang et al., 2011; Liang et al., 2018). However, there might be other factors like, over grazing, land use change practices etc., that might also alter the soil nutrients and its stoichiometry.

Conclusion

Our findings support the hypothesis that depth increment and stand characteristics have a significant effect on TSOC, TN, and TP storage, stoichiometry, and concentration. Stand characteristics like stand density, basal area, and total biomass carbon could significantly affect the TSOC, TN, and TP concentration and storage. Furthermore, soil C:N and C:P ratios increase more as compared to N:P with depth, showing the organic N and P limitation for plant growth in the region. This study is the first attempt to indicate the TSOC, TN, TP and its stoichiometry at the vertical profile scale and along the stand characteristics. Similarly, this study will provide useful information for sustainable management of Mongolian Scots Pine plantation forest. For future, it is strongly recommended to conduct more research studies on climate change, soil nutrients dynamics and growth response relationship.

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