Characteristics of soil carbon and nutrient stocks across land use types in a forest region of central Korea

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ABSTRACT

Land use change greatly affects the carbon cycling of the Earth. Soil carbon and nutrient stock distributions were identified in the five land use types: Quercus spp. mixed forest (QM); Larix leptolepis plantation (LP); Castanea crenata plantation (CP); Malus pumila orchard (MF); and abandoned fields (AF). Carbon and nutrient concentrations in the organic horizon and the soil were significantly different according to land use type and soil depth. Carbon concentrations of the organic horizon were higher in QM than in AF, while phosphorus concentrations were higher in MF and AF by 7 times and 4 times compared to that in QM and LP, respectively. The total carbon was distributed in A horizon by 51.8% and in B horizon by 38.0%. The amount of phosphorus decreased in the order of MF > AF > CP > LP ≈ QM, showing clear differences among land use types. This research shows that soil carbon and nutrient contents are significantly different across land use types, and it suggests that the horizontal and vertical distribution properties of carbon and nutrients by land use type need to be considered to accurately predict amounts of fixed carbon and nutrients during the transition of farmland to forest.

Introduction

Land use change is an important factor that affects the Earth’s environment, and thus is a topic of discussion at the UN Climate Change Convention, the Convention of Biological Diversity, and the UN Convention to Combat Desertification. According to the Global Forest Resources Assessment by the Food and Agriculture Organization (FAO) of the UN, world forest area decreased by 3%, from 4128 Mha in 1990 to 3999 Mha in 2015 (Keenan et al. 2015), which is equivalent to the loss of an area larger than South Korea. During the same time period, natural forest decreased by 240 Mha, and plantation land increased from 168 Mha to 278 Mha. The Intergovernmental Panel on Climate Change (IPCC) reported that annual average carbon emissions from deforestation between 2002 and 2011 was 3.3 GtCO2, which accounts for 10% of total carbon emissions by humans; and since the 1970s, emissions from alternative forest use have increased by about 40% (IPCC 2014). Global warming due to increased atmospheric carbon dioxide is causing a reduction in spring snowfall in the Northern Hemisphere; changes in inland precipitation patterns; increased frequency of tree dieback; and changes in the geographical range, seasonal activity, migration patterns, numbers, and interactions of organisms (Dale 1997; Goldewijk 2001; CBD 2014; IPCC 2014).

Korean forests were devastated during the Japanese occupation and the Korean War. In the early 1960s, 40% of the 6.7 Mha classified as forest lands was unstocked, and growing stock was very low at 9.6 m3/ha (Korea Forest Service 2015). Since the 1960s, planned industrial reforestation and forest resource proliferation policies increased growing stock to 142.2 m3/ha in 2014, but forest area was recently reduced by around 5% due to natural factors such as forest fires, disease and pests, and landslides; and human-caused factors such as roads, building sites, factory sites, and farmlands (Korea Forest Service 2015). Diversification of forest land use, and the subdivision of tree species for reforestation, increased the deciduous tree area and stock by 3% and 160%, respectively, and decreased the coniferous tree area while increasing its stock by 11% and 158%, respectively. Korean forests, in 2014, are composed of 40% coniferous trees, 27% deciduous trees, and 29% mixed tree forest, from which the chestnut accounts for 1% (Korea Forest Service 2015).

Alternative forest use greatly affects carbon cycling (Dale 1997; Kwon et al. 2005; Zaehle et al. 2007), and significant differences occur based on forest type, soil depth, soil texture, and soil pH (Ovalles and Collins 1986). Changes in the ratio of coniferous and deciduous trees, as well as the nutrient concentration in the leaves, affect carbon and nutrient concentrations in the soil (Binkley and Valentine 1991; Brandtberg et al. 2000; Prescott 2002), since the lignin and nitrogen content ratio of fallen leaves affects the decomposition rate (Côté et al. 2000; Swift et al. 1979). In the forest regions of Gangwon-do, Korea, organic matter, nitrogen, phosphorus, and potassium in the soil have been reported to be significantly different according to forest type and soil properties as abandoned fields undergo transition to forests (Park and Shin 2008). Furthermore, intensive land use, such as in apple tree orchards, greatly affects nutrient content distribution in the soil and could lead to a nutrient imbalance due to the excess use of livestock by-products and organic fertilizers (Han et al. 2015). In contrast, the following effects can be expected when abandoned fields undergo transition to forest: an increase in the influx of organic carbon to the soil; changes in
temperature and moisture conditions; reduction of erosion; enhancement of the nutrient storing ability of soil water; an increase in soil productivity; and improved water quality (Henderson 1995).

This research aims to identify soil carbon and nutrient stock distribution horizontally and vertically, according to land use type in a forest region. Research targets were forest, farmland, and abandoned land commonly found in the central regions of Korea. This research will enhance our understanding of soil carbon and nutrient stock distribution across various land use types.

Materials and methods

Study areas

This research was conducted around Mt Jubong located in Gyewon-ri, Miwon-myeon, Cheongwon-gun, Chungcheongbuk-do (36°35’N, 127°45’E). The area’s annual average temperature is 13.3 °C and annual average precipitation is 1240.7 mm (Korea Meteorological Administration 2013). The area of Miwon-myeon is 12,964 ha, of which forest accounts for 74.2%, farmland for 16.9%, and orchards for 0.1% (Statistics Korea 2013). Forest in this area is composed of deciduous trees, coniferous trees, mixed trees, and areas without trees, each accounting for 41.6%, 39.7%, 11.4%, and 7.3%, respectively. The fruit production area of Miwon-myeon is 63 ha, in which apple, peach, grapes, and pear each account for 61.9%, 22.2%, 4.8%, and 1.6%, respectively (Statistics Korea 2010). Considering the current land use status, this study has categorized land use types into the following classes: Quercus spp. mixed forest (QM); Larix leptolepis plantation (LP); Castanea crenata plantation (CP); Malus pumila orchard (MF); and abandoned field (AF). The investigated areas in this study are located within 2 km of lineal distance from each other; differences in altitude are within 100 m, reflecting a gentle slope (excluding QM); and all have a similar Northern exposure (Table 1).

Organic horizon and soil sampling

Based on a forest type map and local vegetation survey, representative areas of each land use type were selected. Organic matter and soil samples were collected from the organic horizon and soil using a line transect method.

Samples of 20 cm × 20 cm were collected from the organic horizon following a contour line 20 m long, and five replications were taken. To minimize variation by collection location, the same size samples were collected 2 m to the left and right perpendicular to the contour line, and the average value was used. For sample collection, organic matter outside of the 20 cm × 20 cm square frame was first removed, and then the leaf horizon + degradation horizon (OiE horizon or LF horizon) and the humus horizon (Oa horizon or H horizon) were collected separately. The organic horizon was separated using the method from the National Forest Inventory (Korea Forest Service 2013). The collected samples were placed in zipper bags to be transported to laboratories, and were kept in a 2 °C refrigerator until their dry weights were measured. Dry weight was measured after the samples were dried in a 65 °C dry oven for 48 hours.

Soil samples were collected at the same location as the organic horizon samples, at soil depths of 0–25 cm and 25–50 cm. To measure bulk density of the soil, undisturbed soil was collected using a 100 mL soil can. Samples for soil texture and chemical analysis were collected 2 m to the left and right perpendicular to the contour line at the same location of the organic sample collection, and samples from each soil horizon were mixed into 500 g in total weight. Soil samples were placed in zipper bags to be transported to laboratories and were kept in a 2 °C refrigerator until subsequent analysis.

Organic horizon and mineral soil analysis

Organic horizon samples dried in a 65 °C dryer for 48 hours were mixed, and then their carbon and nutrient contents were analyzed as described below. To analyze the physical properties of the soil, the collected soil samples were dried in an 80 °C dryer for 48 hours. Soil texture was measured using a hydrometer at 30 °C. Bulk density was calculated by dividing the dry weight of the soil sample by the fresh weight.

The dry oxidation method was used to measure organic carbon and nitrogen contents in the organic horizon and the soil. Available phosphorus (P2O5) was measured using the Lancaster method, and exchangeable cations (K+, Ca2+, Mg2+) were extracted using 1 N of NH4OAc and measured with an Atomic Absorption Spectrometer (AA280FS, USA). Soil acidity was measured with a pH meter after 10 g of soil was diluted with distilled water at a ratio of 1:5.

Statistical analysis

Carbon and element contents per unit area in the organic horizon were calculated by multiplying the dry weight of the organic matter and by the element concentration. Carbon and nutrient contents in the soil were calculated by multiplying bulk density, element concentration, and soil depth in each horizon. Furthermore, the nutrient distribution ratio (%) per horizon, according to land use type, was calculated.

Using Duncan’s multiple comparison tests, carbon and nutrient concentrations and contents by horizon among land use types were statistically analyzed (SAS9.3) with a two-way analysis of variance at a significance level of 5%.

Table 1. Site characteristics and dominant vegetation of the study sites.

| Site | Stand age | Elevation (m a.s.l.) | Aspect | Slope (°) | Tree density (tree ha⁻¹) | Basal area (m² ha⁻¹) | Dominant species |
|------|-----------|---------------------|--------|----------|------------------------|---------------------|-----------------|
| QM   | 32        | 330                 | North-east | 38.8  | 833                    | 1.78                | Quercus mongolica, Quercus variabilis, Quercus acutissima, Quercus serrata, Linderia obtusiloba, Betula costata, Acer pseudosieboldianum, Prunus sargentii |
| LP   | 28        | 289                 | North-west | 10    | 833                    | 4.86                | Larix leptolepis, Quercus acutissima, Cornus controversa, Styrax japonica |
| CP   | 30        | 253                 | North-west | 5     | 800                    | 9.26                | Castanea crenata, Pinus densiflora, Quercus acutissima, Quercus serrata |
| MF   | 8         | 267                 | North     | 12.8   | 1300                  | 0.30                | Malus pumila |
| AF   | na        | 245                 | North     | 4      | na                    | na                  | Miscanthus sinensis |

Notes: Species in bold are dominant trees. DBH and tree density were measured for all trees > 6 cm in diameter. na = not available.


Table 2. Element concentrations of the organic horizon at the study sites. Parentheses represent standard errors (n = 5). Different letters within the column show significant differences among sites at α = 0.05.

| Site | N (%) | P (%) | K (%) | Ca (%) | Mg (%) |
|------|-------|-------|-------|--------|--------|
| QM   | 47.0 (0.8) | 14.5 (1.3) | 0.5 (0.0) | 2.8 (0.5) | 9.0 (1.1) |
| LP   | 41.9 (2.3) | 14.4 (0.6) | 0.6 (0.1) | 3.5 (0.6) | 1.5 (0.2) |
| CP   | 42.0 (2.5) | 16.4 (1.4) | 1.0 (0.1) | 4.0 (0.8) | 2.8 (1.1) |
| MF   | 39.5 (1.5) | 16.8 (0.3) | 3.5 (0.6) | 2.3 (0.3) | 5.3 (1.0) |
| AF   | 40.5 (1.5) | 16.0 (1.6) | 2.1 (0.3) | 5.6 (0.6) | 6.9 (1.7) |

Results

Carbon and nutrient concentration of the organic horizon

Carbon concentrations in the organic horizon were the highest in QM with 47%, and the lowest in MF and AF, both with c. 40%; while carbon values in CP and LP were intermediate, with no significant difference between them (P = 0.07; Table 2). Nitrogen concentrations were higher in MF than LP by 17%, although there was no statistical significance (P = 0.48). Phosphorus concentrations in MF and AF, as compared to QM and LP, were higher by 7 times and 4 times, respectively (P < 0.01). Potassium concentrations were significantly higher in AF and CP, and lowest in MF (P < 0.01). Both calcium (P < 0.01) and magnesium concentrations (P < 0.01) were lowest in LP and were higher in MF and AF.

Physical and chemical properties of the soil

Table 3. Physical and chemical characteristics of the mineral soil at the study sites. Parentheses represent standard errors (n = 5). Different letters within the column show significant differences among sites at α = 0.05.

| Soil depth (cm) | Site | N (g kg⁻¹) | P (mg kg⁻¹) | K (cmol kg⁻¹) | Ca (cmol kg⁻¹) | Mg (cmol kg⁻¹) |
|----------------|------|------------|-------------|---------------|---------------|---------------|
| 0–25           | QM   | 2.12 (0.15) | 2.5 (0.5)   | 0.21 (0.01)   | 0.46 (0.15)   | 0.41 (0.07)   |
|                | LP   | 2.81 (0.29) | 7.0 (0.6)   | 0.18 (0.03)   | 0.42 (0.13)   | 0.22 (0.05)   |
|                | CP   | 2.75 (0.16) | 13.2 (5.3)  | 0.31 (0.05)   | 0.40 (0.14)   | 0.45 (0.13)   |
|                | MF   | 1.05 (0.08) | 115.0 (31.3) | 0.48 (0.04)   | 2.03 (0.28)   | 0.93 (0.14)   |
|                | AF   | 1.60 (0.04) | 112.2 (9.3)  | 0.36 (0.02)   | 3.25 (0.25)   | 0.68 (0.05)   |
| 25–50          | QM   | 1.28 (0.10) | 1.0 (0.0)   | 0.21 (0.01)   | 0.49 (0.10)   | 0.66 (0.22)   |
|                | LP   | 1.21 (0.07) | 2.4 (0.5)   | 0.14 (0.02)   | 0.25 (0.04)   | 0.13 (0.01)   |
|                | CP   | 2.00 (0.33) | 3.2 (0.4)   | 0.20 (0.02)   | 0.51 (0.05)   | 0.38 (0.13)   |
|                | MF   | 0.96 (0.11) | 96.6 (36.9)  | 0.42 (0.07)   | 2.14 (0.31)   | 0.86 (0.12)   |
|                | AF   | 1.15 (0.02) | 35.2 (10.4)  | 0.23 (0.03)   | 2.50 (0.21)   | 0.68 (0.10)   |

Although there was no significant difference by horizon in soil pH, it was high in AF and significantly low in LP in the 0–25 cm horizon (P < 0.01; Table 3). Nitrogen concentrations in the 0–25 cm horizon was the highest in LP and significantly low in MF; while in the 25–50 cm horizon, CP had a significantly high value (P < 0.01). Phosphorus concentrations in MF and AF were extremely high in the 0–25 cm horizon, but there was no statistical significance between them. Potassium concentrations in the 0–25 cm horizon were significantly high in MF and low in LP. Calcium concentrations in the 0–25 cm horizon were significantly high in MF and low in LP.

Carbon and nutrient content distribution by horizon

Total organic matter content in the organic horizon (Oie+Oa) was the highest in MF, followed by LP and QM, although there was no statistical significance; and it was significantly lower in CP and AF. Organic content of the Oie horizon was around 50% lower in MF, while there was no statistical significance in the other sites (P < 0.01). In contrast, the organic content of the Oa horizon was significantly higher in MF and there was no significant difference in the other sites (P < 0.01; Figure 1).

Total carbon content in the organic horizon and the soil was highest in CP and lowest in MF (Figure 2). Carbon content in the organic horizon was significantly higher in QM, LP, and MF, as compared to CP and AF. In A horizon, CP had the highest value, while MF had the lowest. In B horizon, CP had the highest value and there was no significant difference in the other sites. Total carbon content in the distribution ratios averaged 51.8% in A horizon and 38.0% in B horizon, which reflects a significant difference in distribution ratios by horizon according to land use type. In the organic horizon, the distribution ratio of carbon at the MF with highest ratio was 19.1% higher than the CP with the lowest ratio. Meanwhile, LP showed the highest ratio in A horizon, and MF and AF showed the highest in B horizon.
The distribution pattern of nitrogen content by horizon was similar to that of organic carbon. However, the average nitrogen content ratio in A horizon was 3.8% higher than that of the carbon content.

The amount of phosphorus was in the order of MF > AF > CP > LP = QM, which reflects clear differences; and phosphorus content by horizon also showed a distinct trend across land use type. In the organic horizon, phosphorus content was highest in MF and there was no significant difference in the other sites. In A horizon, MF and AF had equally high phosphorus content and all other sites had low content. In B horizon, MF showed the highest content, while other sites showed low content. In contrast to the distribution ratio by horizon for carbon and nitrogen, the phosphorus ratio of the organic horizon was 3.8% in AF and 52.9% in QM, showing a wide range. In A horizon, AF had the highest ratio with 76.5%, and QM had the lowest with 31.5%. In B horizon, MF

Figure 1. Organic matter in the organic horizon at the study sites. Vertical bars represent standard errors (n = 5). Different letters show significant differences among sites at α = 0.05.

Figure 2. Element contents and their proportion in the soil profile at the study sites. “A” and “B” represent 0–25 cm and 25–50 cm in soil depth, respectively. Vertical bars represent standard errors (n = 5). Different letters show significant differences among sites at α = 0.05.
showed more than a twice higher phosphorus distribution ratio, as compared to all other sites.

Potassium content showed a similar trend to that of phosphorus, in the order of MF > AF > CP ≈ LP ≈ QM. There was no significant difference in potassium content in the organic horizon by land use type; it was highest in MF and lowest in QM and LP, in both A and B horizon. However, the potassium distribution ratio by horizon was extremely different from the pattern of phosphorus; the distribution ratio average was 8.7% in O horizon, 48.6% in A horizon, and 42.6% in B horizon. The potassium distribution ratio of the organic horizon in LP was about 4 times higher, as compared to the lowest ratio in MF.

Calcium content was in the order of AF > MF > QM ≈ CP ≈ LP. In the organic horizon, calcium content was highest in QM and lowest in LP and CP. AF and MF showed the highest content in A and B horizon, while the other sites showed low content. The calcium distribution ratio of the organic horizon was 1~20 times higher in QM, as compared to the other sites with no significant difference between them. The distribution ratio of B horizon was 46.6% on average.

Magnesium content and the distribution ratio by horizon were similar to that of potassium, excluding the low values in LP. Magnesium content in the organic horizon was highest in MF, and similar in all other sites. Furthermore, in A and B horizon, MF had the highest content and LP had an extremely low content. The distribution ratio by horizon was highest in LP in the organic horizon and in QM in B horizon, and there was no significant difference between land use types in A horizon.

**Discussion**

Horizontal and vertical distributions of soil carbon and nutrients showed extremely different trends according to land use type. For example, carbon and nitrogen contents were higher in forest lands, while phosphorus, potassium, calcium, and magnesium contents were higher in non-forest sites. Organic carbon and nitrogen contents showed a
decreasing trend with soil depth; in contrast, phosphorus, potassium, calcium, and magnesium showed a reduced rate of decrease with soil depth. Phosphorus content was extremely high in the surface horizon.

No data have been recorded in the literature or from aerial photographs of the studied sites that reflected past land use. Organic content in the organic horizon at the QM was lower than that of LP and MF. This could be due to the fact that QM is located on a steep slope, which led to the loss of organic matter from the upper slope to the valley bottom, respectively. This research has only quantified soil carbon and nutrient distribution according to forest type and tree species Korea 2010). Changes in land use type significantly affect carbon and nutrient cycling according to forest type and tree density. If the MF site in Miwon-myeon was converted into QM and LP in terms of alternative forest use and abandoned field-to-forest transition, the amount of fixed carbon by this conversion was predicted to be 45 Mg/ha and 74 Mg/ha, respectively. This research has only quantified soil carbon and nutrient distribution according to five types of land use.

To precisely identify carbon and nutrient contents during the transition from farmland to forest lands, productivity in both above- and below-ground components should be included.

**Disclosure statement**

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