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Root biomass and underground C and N storage of the primitive Korean pine and broad-leaved forest and its different succession stages in Changbai Mountain, northeast China

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Abstract This paper studied root biomass and underground carbon (C) and nitrogen (N) storage of a more than 200-year-old primitive Korean pine and broad-leaved forest and its two 20- and 80-year-old secondary *Populus davidiana* and *Betula platyphylla* forests in Changbai Mountain, northeast China. The results showed that with forest succession, the root biomass of 20-year-old, 80-year-old, and primitive forests was 2.437, 2.742, and 4.114 kg/m², respectively. The root C storage was 1.113, 1.323, and 2.023 kg/m², soil C storage was 11.911, 11.943, and 12.587 kg/m², and underground C storage was 13.024, 13.266, and 14.610 kg/m², respectively, while the root N storage was 0.035, 0.032, and 0.038 kg/m², soil N storage was 1.208, 1.222, and 0.915 kg/m², and underground N storage was 1.243, 1.254, and 0.955 kg/m², respectively, which indicated that along with forest succession, the forest underground became a potential “carbon sink,” whereas underground N storage did not change obviously.

Keywords Changbai Mountain, primitive Korean pine and

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broad-leaved forest, root biomass, secondary *Populus davidiana* and *Betula platyphylla* forests, underground C and N storage.

1 Introduction

When the primitive forest ecosystem is disturbed and destroyed, the new succession starts over again. Along with secondary forest succession, root biomass and soil C and N storage is renewed because aboveground biomass and vegetation community change gradually. Some studies showed that with succession, forest ecosystem had the potential to create a C sink (Kauffman et al., 1995, 1998) by tree growing and soil C accumulation. In the underground, the root and soil are important C pools (Dewar et al., 1994; Dixon et al., 1994; Schimel, 1995; Koch and Mooney, 1996; Schlesinger, 1997; Gill and Jackson, 2000; Schenk and Jackson, 2002). However, few reports were related to underground N change. Root was not easy to study because it was asymmetrical in the soil and covered with soil (Vogt et al., 1993; Cairns et al., 1997; Huang et al., 1999; Watson et al., 2000). Many studies showed forest aboveground data of secondary forests of different ages (Vogt et al., 1987; Brown and Lugo, 1990; Hughes et al., 1999; Fang et al., 2001). As the changes occurred not only aboveground but also underground, it was important to study forest underground as well.

Among many root studies at Changbai Mountain Reserve of Jilin Province in northeast China (Li et al., 1981; Xu et al., 1987; Shan et al., 1993), studies about the change of root biomass and underground C and N along with forest succession were scarce. This study therefore analyses the root component and underground C and N by comparing the primitive Korean pine and broad-leaved forest with its two secondary *Betula platyphylla* forests on the same latitude. The purpose of this paper was: 1) to compare root distribution in a primitive forest with its two secondary *B. platyphylla* forests;

and 2) to compare underground C and N storage in these forests.

2 Methods

2.1 Study site

The study site was the northern slope of Changbai Mountain Reserve, which was established as an international Biosphere Reserve by UNESCO in 1979. The climate was warm and humid, with an annual average temperature of 0.9–3.9°C. Annual precipitation was 700–800 mm. The area therefore had a typical temperate monsoon climate (Zhang et al., 1980). The soil was a dark brown forest earth (Wang et al., 1980).

2.2 Plot design

From July to August 2001, on the same altitude and the same exposure, we selected typical plots with an area of 40 m×40 m in the 20-year-old *B. platyphylla* secondary forest, 80-year *B. platyphylla* secondary forest, and the primitive forest, whose ages were confirmed by tree growth rings and log registers. The three plots were 1,000 m apart. We used a global positioning system (GPS) to measure the longitude, latitude, and height. In each plot, the main species of trees, shrubs, and grasses were listed. Tree height and diameter at breast height (DBH) were measured for all trees that had DBH of more than 5 cm. Soil type and vegetation were also studied.

In the primitive Korean pine and broad-leaved forest, the dominant species was the Korean pine, and there were many other broad-leaved tree species. The proportion of the Korean pine was from 30% to 40% of either trunk or stock. The main broad-leaved tree species were *Tilia amurensis* and *Fraxinus mandshurica*, and there were a few of *Acer mono*, *Quercus mongolica*, *B. platyphylla*, and *Ulmus propinqua*. The average trunks were 560 trees/hm² and the crown density was 0.8. The main shrub species were *Corylus mandshurica*, *Deutzia amurensis*, *Eleutherococcus senticosus*, and *Ribes mandshuricum*. The main herb species were *Brachybotrys paridiformis*, *Phryma leptostachya*, *Urtica angustifolia*, and *Impatiens nolitangere*.

In the 80-year-old *B. platyphylla* secondary forest, the main tree species were *B. platyphylla* and *Populus davidiana*. The average tree trunks were 856 trees/hm² and the crown density was 0.7. The shrub species were *C. mandshurica*, *Philadelphus schrenkii*, *Spirea sericea*, *Lonicera chrysantha*, and *Evonymus pauciflorus*. The main herb species were *B. paridiformis*, *Deyeuxia angustifolia*, and *Athyrium spinulosum*. There were many young Korean pine trees, and the average trunk density was 2,010 trees/hm².

In the 20-year-old *B. platyphylla* secondary forest, the main tree species were *B. platyphylla* and *P. davidiana*. The

average trunks were 2,640 trees/hm². The main shrub species were *Rosa dahurica*, *D. amurensis*, *E. senticosus*, and *C. mandshurica*. The main herb species were *B. paridiformis*, *Filipendula palmata*, and *A. spinulosum*. There were a few young Korean pine trees, and the average trunk density was 186 trees/hm². The characteristics of these plots are listed in Table 1.

Table 1 Surroundings of three plots

Plot	Primitive forest	80-year-old secondary forest	20-year-old secondary forest
Average DBH /cm	34.21	22.5	6.9
Average height /m	15	10.5	5
Soil depth /cm	100	80	80
Soil C and N storage /($\text{kg}\cdot\text{m}^{-2}$)	A: 2.389	A: 1.644	A: 1.403
	B: 10.198	B: 10.299	B: 10.508
	Total: 12.587	Total: 11.943	Total: 11.911

2.2.1 Total tree root biomass

From July to August 2001, tree root biomass was investigated in three samples. The reference method (Luo, 2001; Deng et al., in press) used was as follows. In each forest plot, the standard tree was selected. Two samples were taken at 50 cm away from the standard tree stem, and two other samples at the edge of the standard tree crown in the downward direction of the slope. Roots were harvested by digging up the whole root system in 0.5 m×0.5 m quadrates. The soil from each pit was divided into A and B layers. The depth of the pits in the primitive forest was 1 m, and in the two secondary forests, 0.8 m each, as there were hardly any roots at these depths.

To identify root species, the dominant tree roots, shrub roots, and herb roots were dug up in each plot. Root shape, color, and smell were noted, and root samples were saved. Root samples were accordingly sorted in each plot.

All root samples were washed and dried at 80°C to constant mass, and the total mass was recorded. Subsamples were analyzed for total carbon (C) and total nitrogen (N) (modified Kjeldahl procedure) (Miller and Miller, 1948; Technicon Industrial Systems, 1974).

2.2.2 Soil nutrient

Soil samples were collected while digging up the root pits and analyzed for C and N content. Organic C was determined by the Walkley–Black wet oxidation method (Allison, 1965). N was determined by the aluminum block digestion (Gallaher et al., 1976) and semimicro-Kjeldahl unit (Bremner, 1965). The bulk density of the soil (d_v) of the A layer and the B layer were measured by soil cutting rings. Five soil cutting rings were sampled randomly in the A layer and three in the B layer of the three forests.

3 Results

3.1 Root biomass and component in different succession stages

Total root biomass increased gradually and the component changed with succession (Fig. 1a). Root biomass was 2.437 kg/m² in the 20-year-old sample, 2.742 kg/m² in the 80-year-old sample, and 4.114 kg/m² in the primitive sample. The sequence of dominant tree root biomass was similar to the total biomass with succession, and it also increased. The biomass in the samples was 1.394, 2.207, and 3.627 kg/m², respectively. However, the sequences of shrub and herb root biomass were reversed from dominant tree root biomass. Shrub and herb root biomass in the 20-year-old sample were the highest, 0.586 and 0.531 kg/m², respectively; in the 80-year-old sample, they were 0.387 and 0.148 kg/m², respectively; and in the primitive forest, they were 0.376 and 0.111 kg/m², respectively.

3.2 Total root C and N storage in different forests

Total root C storage increased gradually (Fig. 1b) from the 20-year-old sample to the 80-year-old sample to the primi-

tive sample, 1.113, 1.323, and 2.023 kg/m², respectively. The trend of C storage in dominant tree roots was similar to the total C storage, 0.627, 1.082, and 1.807 kg/m², respectively. However, C storage in shrub roots gradually reduced from the 20-year-old sample to the 80-year-old sample to the primitive sample (Fig. 1b), 0.269, 0.178, and 0.169 kg/m², respectively. C storage in herb roots was similar to that of the shrubs 0.217, 0.063, and 0.047 kg/m², respectively. C storage in shrub and herb roots was much more in the 20-year-old sample than in the other two samples.

Total N storage was different from the C storage in the three samples (Fig. 1c). In the primitive sample, total N storage was the highest, 0.038 kg/m², and total N storage in the 20-year-old sample was higher than in the 80-year-old sample, 0.035 and 0.032 kg/m², respectively. N storage of dominant tree roots increased gradually from the 20-year-old sample to the 80-year-old sample to the primitive sample, 0.017, 0.025, and 0.029 kg/m², respectively. N storages of shrub and grass roots were different in the three samples. N storage of shrub roots was highest in the 20-year-old sample, 0.008 kg/m², in the primitive sample, it was 0.006 kg/m², and in the 80-year-old sample, it was lowest at 0.005 kg/m². N storages of herb roots in the primitive and 80-year-old samples were similar, 0.002 kg/m², and was higher in the 20-year-old sample, 0.010 kg/m².

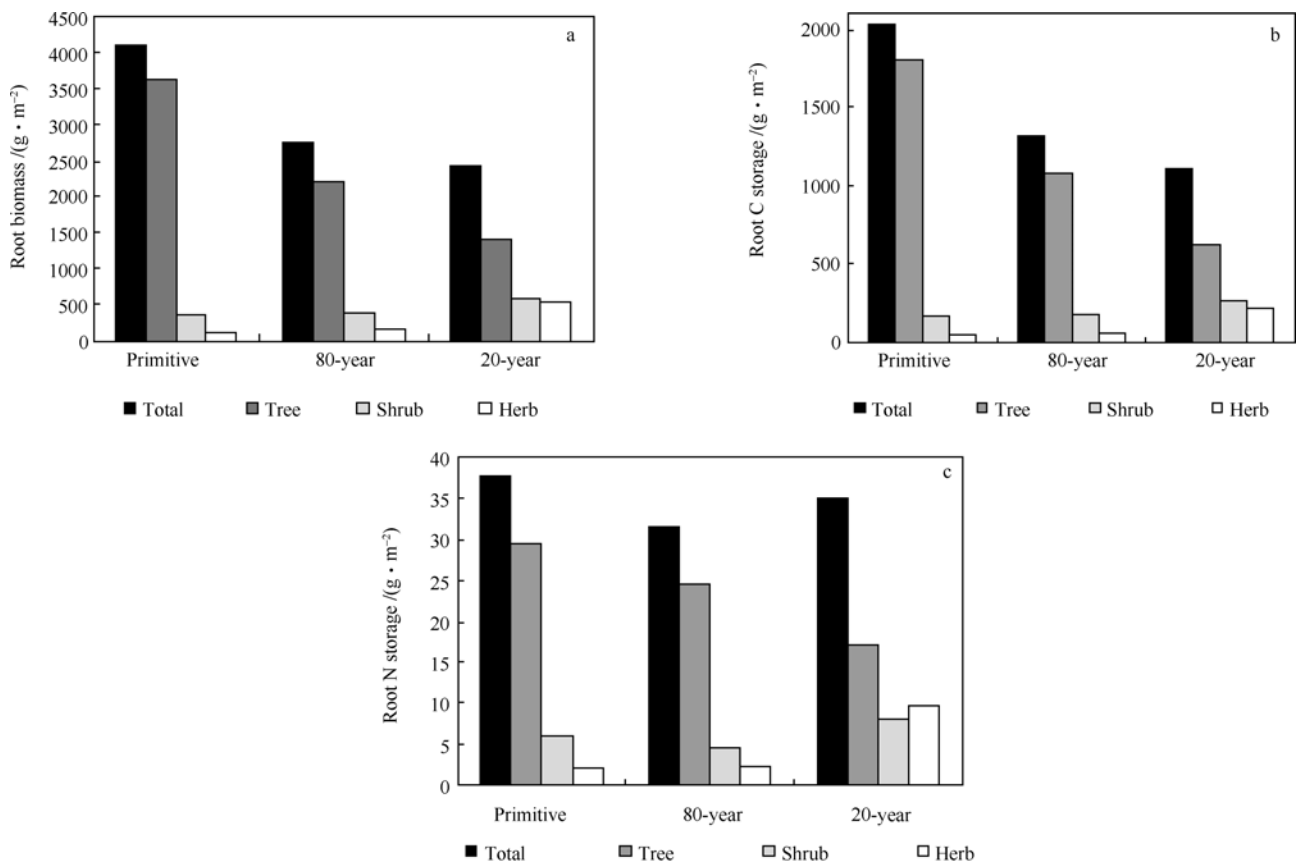


Fig. 1 Root biomass, C and N storages of different samples

3.3 Total C and N storage in the soil and the underground at succession stage

With succession, soil C increased gradually (Fig. 2). Soil C storage was highest in the primitive sample, 12.587 kg/m², and in soil A and B layers it was 2.389 and 10.198 kg/m², respectively. In the 80-year-old sample soil C storage was moderate, 11.943 kg/m², and in soil A and B layers it was 1.645 and 10.298 kg/m², respectively. In the 20-year-old sample soil C storage was lowest, 11.911 kg/m², and in soil A and B layers it was 1.403 and 10.508 kg/m², respectively.

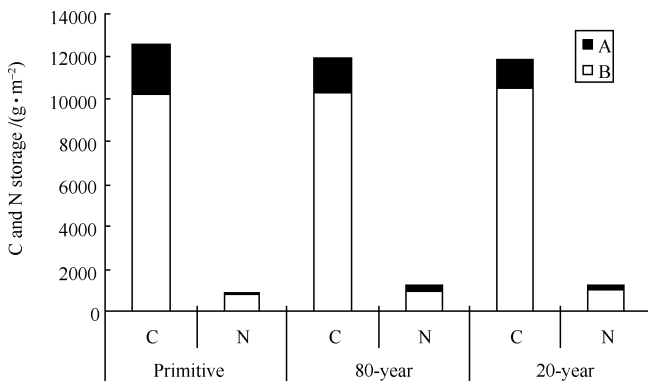


Fig. 2 C and N storage in A lay and B layers of soil of three samples

With succession, soil N storage changed at random. Soil N storage was highest in the 80-year-old sample at 1.222 kg/m², and in soil A and B layers, it was 0.205 and 1.017 kg/m², respectively. In the 20-year-old sample soil N storage was moderate at 1.208 kg/m², and in soil A and B layers it was 0.181 and 1.026 kg/m², respectively. In the primitive sample soil N storage was lowest at 0.915 kg/m², and in soil A and B layers it was 0.104 and 0.811 kg/m², respectively.

On the basis of C and N storages in soil and root, total underground C and N storage can be calculated. With succession, total underground C storage increased in the three samples. In the primitive sample underground C storage was highest at 14.610 kg/m², and in A and B layers it was 3.978 and 10.634 kg/m², respectively (Fig. 3). In the 80-year-old sample it was moderate at 13.266 kg/m², and in A and B layers it was 2.709 and 10.558 kg/m², respectively. In the 20-year-old sample it was lowest at 13.024 kg/m², and in A and B layer it was 2.422 and 10.602 kg/m², respectively.

With succession, total underground N storage changed at random. Total N storage was highest in the 80-year-old sample at 1.254 kg/m², and in A and B layers it was 0.231 and 1.023 kg/m², respectively. In the 20-year-old sample total N storage was moderate at 1.243 kg/m², and in soil A and B layers it was 0.214 and 1.030 kg/m², respectively. In the primitive sample total N storage was lowest at 0.955 kg/m², and in soil A and B layers it was 0.134 and 0.818 kg/m², respectively.

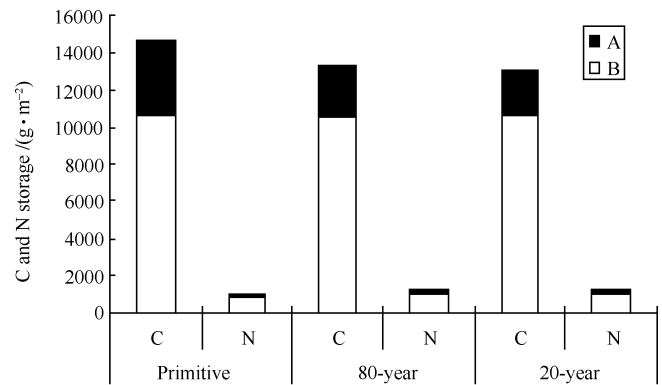


Fig. 3 C and N storage in A and B layers in the underground of three samples

4 Discussion

As might be expected, in Changbai Mountain the total root biomass increased with secondary forest succession, which could be explained by the dominant tree. The dominant tree root biomass was an important component. The relation between DBH and tree root system biomass was consistent over a wide range of diameter sizes (Santantonio et al., 1997), and tree root biomass gradually increased with the aboveground stem with succession. Shrub and herb root biomass in the 20-year-old sample were higher than in the other two. Because the closing of the overstory canopy generally coincided with a dramatic decrease in aboveground understory biomass associated with reduced penetration of light (MacLean and Wein, 1977; Grier et al., 1981; Alaback, 1982), underground biomass probably decreased with the aboveground biomass.

Like total root biomass, C storage of the roots increased with growing forest age. C storage in the roots of the 20-year-old and 80-year-old forests was 55% and 65%, respectively, of those in the primitive forest of Changbai Mountain. This showed that the root C pool was gradually accumulating during secondary forest growth. With succession, soil C storage also increased, which was due to the soil A layer. Figures 2 and 3 showed that soil C storage increased in the A layer and did not vary in the B layer with succession. Because of the litter and dead root accumulation and decomposition, the humus A layer thickened, which resulted in increased C storage during secondary forest growth. Hughes et al. (1999) stated that the aboveground pool of C increased with secondary forest growth in Los Tuxtlas, and demonstrated that secondary forests represent potential accumulators of atmospheric C, but only if they were allowed to establish, persist, and attain maturity.

However, in Changbai Mountain N storage of the root, soil, and underground was unordered with succession. Root N storage was related to the vegetation component. Root N storage was higher in the young forest than in the others,

because in the young forest, herb and shrub roots constituted 46% of total root biomass, and N storage in grass and shrub roots was higher than in tree roots. N storage was not obviously ordered in the soil and underground.

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