Carbon and nitrogen status of litterfall, litter decomposition and soil in even-aged larch, red pine and rigitaeda pine plantations

Choonsig Kim · Jaeyeob Jeong · Hyun-Seo Cho ·
Yowhan Son

Abstract The carbon (C) and nitrogen (N) status in forest ecosystems can change upon establishment of plantations because different tree species have different nutrient cycling mechanisms. This study was carried out to evaluate C and N status of litterfall, litter decomposition and soil in three adjacent plantations consisting of one deciduous (larch: *Larix leptolepis*) and two evergreen (red pine: *Pinus densiflora*; rigitaeda pine: *P. rigida × P. taeda*) species planted in the same year (1963). Both the pine plantations showed comparatively higher C input from needle litter but significantly lower N concentration and input than the larch plantation ($P < 0.05$). During the decomposition process, the deciduous larch needle litter showed low C concentration and C remaining in soil, but high N concentration and N remaining in soil compared to the two evergreen pine needle litters. However, the soil C and N concentration and their content at a soil depth of 0–10 cm were not affected significantly ($P > 0.05$) by the plantation type. These results demonstrate the existence of considerable variation in C and N status resulting from needle litter input and litter decomposition in these three plantations grown at sites with similar environmental conditions.

Keywords Carbon · Needle litter · Nitrogen · Soil carbon · Tree species effects

C. Kim (✉) · J. Jeong · H.-S. Cho
Department of Forest Resources, Jinju National University,
150 Chilarmdong, Jinju 660-758, Korea
e-mail: ckim@jinju.ac.kr

Y. Son
Division of Environmental Science and Ecological Engineering,
Korea University, Seoul 136-701, Korea

Introduction

Litterfall inputs and litter decomposition represent important components of the carbon (C) and nitrogen (N) cycles in forest ecosystems because the turnover of litter is a major pathway by which C and N enter forest soil (Bray and Gorham 1964; Gower and Son 1992; Berg and Laskowski 2006; Kamei et al. 2009). The inputs of C and N in litterfall depend on several ecological factors and forest management activities such as forest type, climate, site quality, stand increment, stand age, stand density, fertilization, and thinning (Berg and Laskowski 2006; Kim 2008; Kim et al. 2009). Forest type can have a significant influence on litterfall C and N because of the difference in input of leaf litter or non-leaf litter produced by different species (Bray and Gorham 1964; Kamei et al. 2009). Thus, a balance between litterfall and decomposition processes controls development of the soil organic layer, and hence the C and N content in the soil (Finzi et al. 1998; Berg and Laskowski 2006; Hansen et al. 2009). However, it is not easy to compare litterfall and litter decomposition of different forest types due to the potentially confounding effects of site and management factors (Gower and Son 1992; Chen and Li 2003; Kamei et al. 2009).

Soil C and N status can change upon establishment of plantations because different tree species have different nutrient requirements (Son and Gower 1992; Binkley 1995), litterfall inputs and litter decomposition mechanisms (Finzi et al. 1998; Hansen et al. 2009; Kamei et al. 2009). However, conflicting results have been reported on the influence of forest type on soil C and N status (Son and Gower 1992; Kamei et al. 2009) with no discernable effect (Finzi et al. 1998) of different tree species. Although numerous studies to evaluate the effect of forest types on nutrient distribution are reported in the literature (Binkley

1995; Finzi et al. 1998; Hansen et al. 2009), major uncertainties remain about the importance and behavior of C and N status in coniferous plantations in Korea.

Red pine (*Pinus densiflora* S. et Z.), rigitaeda pine (*P. rigida* × *P. taeda*), and larch (*Larix leptolepis* Gordon) have been the three most important coniferous tree species planted throughout Korea during the last 40 years. Red pine occupies more than 23.5% (1.5 million ha) of Korean forest lands. Larch forests were planted on about 600,000 ha between 1957 and 1990 (Korea Forest Service 2006). Rigitaeda pine, a hybrid of pitch (*P. rigida* Mill.) and loblolly (*P. taeda* L.) pines, shows good growth characteristics with enhanced cold resistance compared with pitch or loblolly pine. There is a need for information evaluating the direction and rates of change in C and N status in the soil due to litter input, and litter decomposition by various plantation types because tree species play a primary role in C and N cycling in forest ecosystems (Binkley 1995). The objectives of this study were to quantify the impacts of plantation establishment on C and N status of needle litter, litter decomposition and soil in even-aged larch and pine plantations under similar site conditions. This entailed measuring (1) C and N inputs via litterfall, (2) C and N dynamics in decomposing needle litter, and (3) the distribution of soil C and N.

Materials and methods

The study was conducted in the Sambong Exhibition Forests located in Hamyanggun, Gyeongsangnamdo, and administered by Seobu National Forest Office, Korea Forest Service. The annual mean precipitation in this area is 1,322 mm and the annual mean temperature is 12.8°C. Experimental plots consisting of one deciduous (larch) and two evergreen coniferous plantations (red pine, rigitaeda pine) were located adjacent to each other on moderately productive sites (Table 1). All three plantations were established in 1963 on northeast facing slopes (5–15°) with small pits and mounds. The study sites were of identical macroclimatic condition, quality, and stand age. The understory species in the larch plantation site included *Viburnum dilatatum* Thunb., *Lindera erythrocarpa* Makino, *Rubus parvifolius* L., *Quercus serrata* Thunb.,

Q. acutissima Carruth., *Q. variabilis* Bl., *Castanea crenata* S. et Z., *Schisandra chinensis* Baill., *Zanthoxylum schinifolium* S. et Z., and *Elaeagnus umbellate* Thunb. The understory species in the red pine plantation site were *Rhododendron mucronulatum* Turcz., *Q. serrata* Thunb., *Q. aliena* Bl., *Lindera glauca* Bl., *L. obtusioloba* Bl., *Smilax china* L. and *Juglans mandshurica* Maxim., and those in the rigitaeda pine plantation site were *Styrax japonica* S. et Z., *Stephanandra incise* Zabel, *Z. schinifolium* S. et Z., *Cornus controversa* Hemsl., *Q. aliena* Bl., *Q. serrata* Thunb., *Symplocos chinensis* var. *leucocarpa* for. *pilosa* Ohwi, *J. mandshurica* Maxim. and *Rhus sylvetris* S. et Z. Data were collected from three 20 m × 10 m plots within each plantation site. The general characteristics of the tree species with regard to their mean stand densities, diameter at breast height (DBH), and basal area of the three coniferous plantations are shown in Table 1. The differences in DBH and stand basal area among the three plantations were due to common forest management practices such as thinning.

To measure litterfall, we installed three circular litter traps made of 1.5 mm nylon net and with 0.25 m^2 surface area at randomly chosen locations in each plot at 60 cm above the forest floor for each plantation. The total number of litter traps used in the whole study was 27. Litter was collected at monthly intervals between July 2006 and June 2008. The collected litter from each trap was transported to a laboratory and then oven-dried at 65°C for 48 h. The dried samples were then separated into needles and other components, and the weight of each portion was recorded. The collected litterfall was ground in a Wiley mill to pass through a 40-mesh stainless steel sieve. The C and N contents in needle litter were determined using an Elemental Analyser (EA1110, ThermoQuest Italia, Milan, Italy). The results of N inputs obtained from this study may have been underestimated as we measured the N concentration in needle litter collected only in the heavy litterfall season, although most of the needle litterfall from these three coniferous plantations takes place in November of each year (Jeong et al. 2009).

The C and N outputs due to decomposing needle litter were estimated using the litterbag technique. Fresh needle litter from each treatment was collected from the forest floor during late November 2006. After collection, the litter

Table 1 General characteristics of the three coniferous plantations at the study sites. Values in parenthesis represent ranges

Plantation	Location	Elevation (m)	Stand density (trees ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})
Larix leptolepis	35°27′26″ N 127°38′30″ E	674	350 (300–400)	31.1 (27.2–36.5)	27.6 (18.1–35.6)
Pinus densiflora	35°27′28″ N 128°38′27″ E	684	216 (200–250)	34.8 (31.3–36.3)	20.7 (19.7–21.3)
Pinus rigida × *Pinus taeda*	35°27′27″ N 128°38′31″ E	678	550 (450–650)	29.4 (28.5–30.3)	35.8 (29.9–41.3)

$N = 3$ plots per species. *DBH* Diameter at breast height (1.2 m)

was air-dried at room temperature for 14 days. A sample of 10 g was then weighed out and placed in a 30 cm × 30 cm nylon net bag with a mesh size of 0.1 mm. Sub-samples from the litter were also taken to determine the oven-dried mass after heating at 65°C for 48 h. Fifteen litterbags for each plot of the plantations were placed randomly on the forest floor in December 2006. The litterbags were held fast by 10 cm long metal pins, and there were five subsequent collections of litterbags (in March 2007, July 2007, December 2007, March 2008, and June 2008) from each plot during the study period. Each litterbag sample was then oven-dried at 65°C for 48 h and the mass loss rates determined. The C and N concentrations of decomposed needle litter samples were determined by Elemental Analyser (EA1110, ThurmoQuest).

To compare soil environmental factors among the three plantations, soil temperature was measured monthly at a depth of 20 cm using a soil temperature probe (Model STP-1) attached to an EGM-4 environmental gas monitoring system (PP systems, Hitchin, UK). Soil samples to measure soil water content were collected monthly at 20 cm depth using an Oakfield soil sampler. The core samples were placed in plastic bags, transported to a laboratory and dried in an oven for 48 h at 105°C to quantify the soil gravimetric water content.

Soil samples were collected in October 2002 from three randomly selected points in each plot. At each point, a soil pit of 50 cm × 50 cm was dug to collect soil samples at three different depths (i.e., 0–10, 10–20, and 20–30 cm) because the top soil at 0–30 cm depth accounted for a large proportion of the soil C content in forest ecosystems (IPCC 2003). Soil samples for bulk density determination were collected at soil depths of 0–10, and 10–20 cm by using 100 cm^3 stainless steel cans. Five bulk soil samples were also collected from each depth and passed through a 2 mm sieve prior to soil C and N analysis. The organic C concentration and total N of the mineral soils were determined by the loss-on-ignition (LOI) method at 375°C for 16 h (Soon and Abboud 1991) and by the Kjeldahl method (Bremmer and Mulvaney 1982), respectively. The data were subjected to analysis of variance at $P < 0.05$ and Tukey's test for mean separation analysis (SAS Institute 1989).

Results and discussion

C and N inputs via litterfall

The mean C concentration of needle litter for the two study years was significantly higher ($P < 0.05$) in the red pine (510 g kg^{-1}) plantation than in the larch (489 g kg^{-1}) or the rigitaeda (489 g kg^{-1}) pine plantations (Table 2). The values in this study are comparable to the C concentrations reported by Moore et al. (2006) of 497 g kg^{-1} for Jack pine (*P. banksiana* Lambert) and 488 g kg^{-1} for Tamarack (*L. laricina* K. Koch) needle litter in Canada. Other studies reported that the variation in C concentration in different tree species is determined by genetic and environmental factors such as site condition, stand characteristics and forest management practices (Bert and Danjon 2006; Zhang et al. 2009). The mean C input by needle litter was significantly higher ($P < 0.05$) in the pine plantations (1,976 kg ha^{-1} year^{-1} for red pine; 1,891 kg ha^{-1} year^{-1} for rigitaeda pine) than in the larch plantations (1,217 kg ha^{-1}year^{-1}). The C input by needle litter in this study is similar to that determined for a 40-year-old red pine stand (1,652 kg ha^{-1} year^{-1}) and a 36-year-old larch plantation (1,181 kg ha^{-1} year^{-1}) in the same region (Kim 2008; Kim et al. 2009). The C amount in needle litter of different tree species could be related to physiological responses, such as a species-specific allocation of resources

Table 2 Carbon (C) and nitrogen (N) concentration and inputs from needle litter at three coniferous plantations. Values in parenthesis represent standard errors

Year	Plantation	Concentration (g kg^{-1})		Input (kg ha^{-1} year^{-1})	
		C	N	C	N
July 2006–June 2007	*L. leptolepis*	489 (1.9) b	11.4 (0.3) a	1,150 (40) b	26.90 (1.19) a
	P. densiflora	507 (3.6) a	6.0 (0.6) b	1,716 (143) a	19.88 (1.66) b
	P. rigida × *P. taeda*	485 (2.6) b	5.6 (0.4) b	1,602 (77) a	18.54 (1.36) b
July 2007–June 2008	*L. leptolepis*	490 (1.0) b	10.8 (0.6) a	1,284 (38) b	28.32 (1.01) a
	P. densiflora	512 (1.2) a	5.2 (0.2) b	2,236 (144) a	22.83 (1.46) b
	P. rigida × *P. taeda*	492 (2.5) b	5.8 (0.5) b	2,179 (139) a	25.36 (0.69) ab
Mean	*L. leptolepis*	489 (0.9) b	11.1 (0.4) a	1,217 (27) b	27.61 (0.97) a
	P. densiflora	510 (2.3) a	5.6 (0.4) b	1,976 (140) a	21.36 (1.52) b
	P. rigida × *P. taeda*	489 (1.7) b	5.7 (0.3) b	1,891 (106) a	21.95 (0.97) b

Different letters in each column indicate a significant difference at $P = 0.05$

between woody and photosynthetic components (Berg and Laskowski 2006). The C input from needle litter in this study was determined by the differences in needle litter mass between the larch and the pine plantations rather than the difference in C concentration (Table 2). There was no significant difference in C input from needle litter produced from the red pine and rigitaeda pine plantations ($P > 0.05$) despite a considerable difference in stand basal area and stand density between the two pine plantations (Table 1). The similarity in values of C input by needle litter produced by the two pine plantations could be associated to the canopy closure in these mature plantations, as the annual needle litterfall remains relatively constant after canopy closure (Bray and Gorham 1964; Berg and Laskowski 2006; Hansen et al. 2009).

The mean N concentration of needle litter for the two study years was 11.1, 5.7, and 5.6 g kg^{-1} in the larch, rigitaeda pine, and red pine plantations, respectively (Table 2). The higher N concentration of larch needle litter compared to the two pine needle litters could be due to the inherent characteristic of higher N uptake by the deciduous larch compared to the evergreen pine tree species (Son and Lee 1997; Finzi et al. 1998; Kim 1999). Other studies have attributed the difference in N concentration of needle litter to abiotic factors such as climatic variables, nutrient supply to the site, canopy leaching characteristics; and biotic factors such as the trees' genetic characteristics and re-translocation rates before senescence (Berg and Laskowski 2006; Hansen et al. 2009; Kamei et al. 2009). The N concentration values observed in this study are comparable to the N concentration values of 4.8 and 5.9 g kg^{-1} reported for Scot's pine and White pine, respectively (Berg and Laskowski 2006). However, the values are slightly higher than the values of 3.7 g kg^{-1} for *P. rigida* and 8.2 g kg^{-1} for *L. leptolepis* plantations found in Gyeonggi Province, Korea (Kim et al. 2005). The mean input of N returned to the forest floor via needle litter was 27.61, 21.95, and 21.36 kg ha^{-1} year^{-1} by the larch, rigitaeda pine, and red pine plantations, respectively. The distinct difference in N input was associated with the lower N concentration in pine needle litter compared to larch needle litter. The value of N inputs in this study was higher than the 13.2 kg ha^{-1} year^{-1} reported for *P. rigida* or 23.1 kg ha^{-1} year^{-1} reported for *L. leptolepis* plantations in Gwangneung, Korea (Kim et al. 2005).

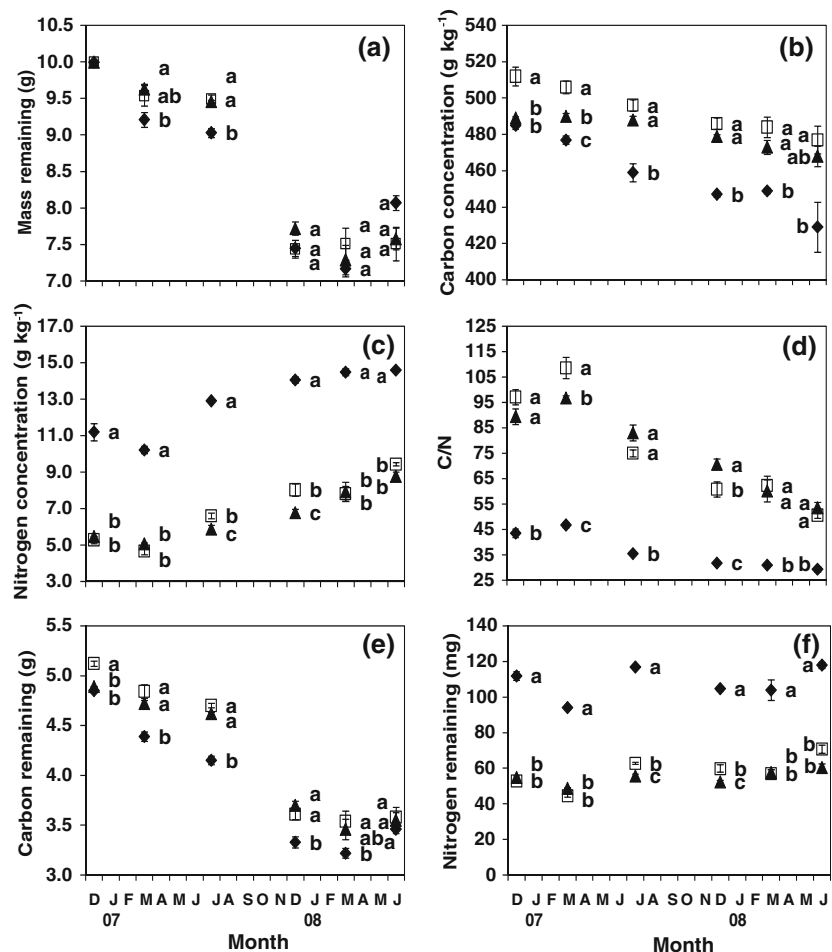C and N dynamics in decomposing needle litter

A significant difference in needle litter decomposition ($P < 0.05$) was observed during the initial stage (March, July 2007) of the decomposition processes of the three coniferous plantations (Fig. 1). The mass loss rates in decomposing needle litter were more rapid for larch (9.7%)

than for rigitaeda pine (5.4%) or red pine (5.1%) needle litter during the 222-day incubation of initial needle litter. Both red pine and rigitaeda pine showed almost similar mass loss at all five collections (Fig. 1).

Needle litter decomposition can be influenced by abiotic factors, such as soil temperature, soil moisture and nitrogen availability, and by biotic factors such as decay organisms present in the soil, as well as the N and lignin concentration (Berg and Laskowski 2006). In this study, abiotic factors such as soil temperature and water content, which are regarded as the main factors influencing litter decomposition, were significantly different among the three coniferous plantations (Fig. 2). However, the rapid mass loss in larch may be attributed to the difference in substrate quality between larch and pine needle litter (Finzi et al. 1998) and/or to the high leaching loss of soluble labile C components during the early stages of the decomposition process (Li et al. 2009) because soil temperature and water content were significantly lower in the larch than in the red pine plantations (Fig. 2). For example, the initial C/N ratio, which is the most widely used index of litter quality, was significantly lower in larch (44) than in rigitaeda pine (89) or red pine (97) needle litter (Fig. 1). Many studies have reported that litter with high N concentrations and a low C/N ratio is decomposed more rapidly than those with low N concentrations and a high C/N ratio (Finzi et al. 1998; Berg and Laskowski 2006; Kamei et al. 2009). However, mass loss in decomposing larch litter at later stages of decomposition (after 356 days of incubation) was not affected by higher N concentration or lower C/N ratio compared with pine needle litter. This was because the decay rates at later stages of decomposition are determined by accumulation of recalcitrant constituents rather than by water soluble compounds (Berg and Laskowski 2006).

The C concentration and remaining C in decomposing needle litter decreased rapidly in larch litter compared to both the pine needle litters during the study period (Fig. 1). The lower C concentration in the larch needle litter could be attributed to rapid C mineralization throughout the decomposition process (Polyakova and Billor 2007) and/or absorption of dust particles from the air and subsequent precipitation without filtering effects (Binkley 1995) under open canopy during the winter season. In addition, the ash content from decomposing litter after the 461-day incubation (March 2008) of initial needle litter was higher in larch litter (77 g kg^{-1}) than in either of the pine needle litters (46 g kg^{-1} for red pine; 36 g kg^{-1} for regitaeda pine). The C release of each needle litter type was approximately proportional to the mass loss of needle litter, which decreased with increasing incubation times. The C remaining over the study period did not exceed the initial value in undecomposed needle litter.

Fig. 1 Mass remaining (**a**), carbon concentration (**b**), nitrogen concentration (**c**), carbon/nitrogen ratio (**d**), carbon remaining (**e**), and nitrogen remaining (**f**) in decomposing needle litter of three coniferous plantations (*filled diamond*, *Larix leptolepis*; *open square*, *Pinus densiflora*; *filled triangle*, *Pinus rigida* × *Pinus taeda*). *Vertical bars* Standard error. Data represent mean values (*n* = 9); different *letters* indicate a significant difference at *P* = 0.05

The N concentration and remaining N in decomposing needle litter were significantly lower in both pine plantations than in the larch plantation (Fig. 1). The N remaining followed a pattern of N concentration in decomposing needle litter. In contrast to C remaining, the N remaining in decomposing larch needle litter showed higher N gains than in either of the pine needle litters because the N in larch needle litter is readily immobilized by microorganisms due to its high concentration compared with pine needle litter. Nitrogen from the three needle litters is initially leached from the litter, and then immobilized (Fig. 1). Nitrogen immobilization in decomposing needle litter occurred generally during the growing season when microbial activities can be stimulated by increased soil temperature (Baker et al. 2001). The microbial immobilization of N occurred via uptake of N by fungal hyphae from the surrounding litter or mineral soil (Berg and Laskowski 2006).

C and N distribution in soil

Soil bulk density was significantly different among the three plantations (*P* < 0.05). The bulk density in the surface depth (0–10 cm) was lower in the red pine than in other two plantations (Table 3). Coarse fragment content (>2 mm) of each depth except for the surface depth was not significantly different (*P* > 0.05) among the three plantations.

The soil organic C concentration among the three plantations was not significantly different at a depth of 0–10 cm, but that at other depths showed a significant difference. The organic C concentration in the subsurface depth (10–30 cm) was significantly higher in the red pine than in the other two plantations (Table 3). It is not easy to compare the property of soil C in the three coniferous plantation sites because of the non-availability of data on soil conditions prior to plantation establishment, and the high variation in nutrient concentration, bulk density and coarse fragment of mineral soil layers (Binkley 1995).

The C and N distribution of the surface soil layer might reflect differences in the quality and quantity of litterfall inputs, litter decomposition dynamics, and the production and turnover of fine roots, which are the principal pathways for the return of C and N to the soil (Finzi et al. 1998; Wang et al. 2009). Despite having different mechanisms affecting the C and N cycle from litterfall inputs and

decomposition processes, the absence of any significant difference in the soil C and N status of the larch and pine plantations might be due to other factors such as fine roots, which are also a main source affecting soil C and N
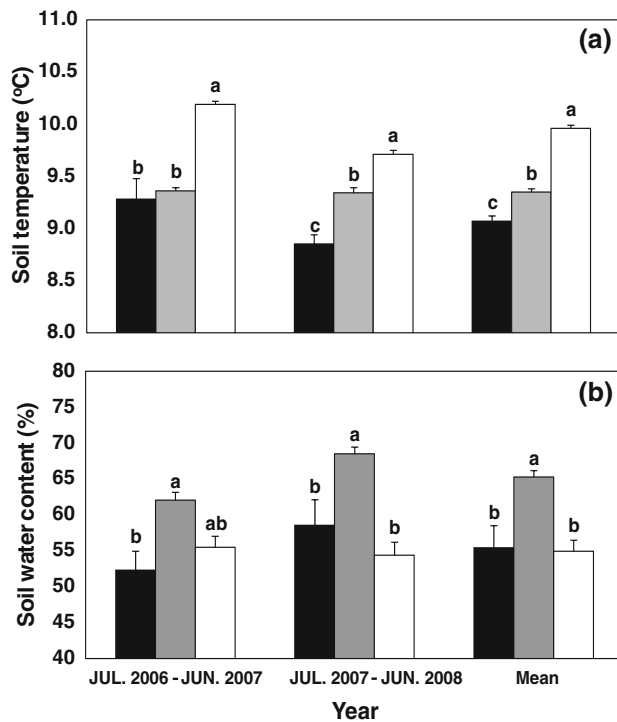

Fig. 2 Means of monthly measured temperature (a) and water content (b) in soil at a depth of 20-cm of three coniferous plantations (*filled square*, *L. leptolepis*; *shaded square*, *P. densiflora*; *open square*, *P. rigida × P. taeda*). *Vertical bars* Standard error. Mean ($n = 9$); *different letters* indicate a significant difference at $P = 0.05$

contents. For example, Hwang et al. (2007) found that the production of fine roots was significantly greater in 44-year-old Japanese larch (1,762 kg ha^{-1} year^{-1}) than in 40-year-old pitch pine (1,108 kg ha^{-1} year^{-1}) plantations. This may explain why larch with low C input from needle litter showed a similar soil organic C content as both the pine plantations at surface depth. In addition, the slow decomposition rates of pine needle litter may result in more C accumulation in the forest floor and less C incorporation into mineral soils compared with larch needle litter. In contrast to the surface depth, the organic C concentration at subsurface depths (10–30 cm) was significantly higher in the red pine than in the larch or rigitaeda plantations. High understory vegetation cover (above 90% cover rates) by *R. mucronulatum* in the red pine plantation compared with the other two plantations could increase sources of organic matter such as fine roots and litterfall under dense understory vegetation. Chen and Li (2003) reported that shrubs can store more C at the deep soil horizon because shrubs may allocate more biomass to roots, especially fine roots.

The soil N concentration and content were not significantly different ($P > 0.05$) among the three coniferous plantations, with the exception of 10–20 cm depth in the rigitaeda plantation. The soil N content was generally higher in the larch than in both the pine plantations except at 20–30 cm depth (Table 3). The high soil N content in the larch plantation could be attributed to a combination of high N input by needle litterfall and N remaining in decomposing needle litter (Fig. 1, Table 2). In addition, N input by fine roots was higher in 44-year-old Japanese larch (23.1 kg ha^{-1} year^{-1}) than in 40-year-old pitch pine (10.9 kg ha^{-1} year^{-1}) plantations (Hwang et al. 2007).

Table 3 Bulk density, coarse fragment (>2 mm), soil carbon and nitrogen content at each depth of three coniferous plantations. Values in parenthesis represent standard errors

Soil depth (cm)	Plantation	Bulk density (Mg m^{-3})	Coarse fragment (g kg^{-1})	Concentration (g kg^{-1})		Content (Mg ha^{-1})	
				C	N	C	N
0–10	*L. leptolepis*	0.67 (0.01) a	205 (5) ab	73.9 (5.6) a	4.6 (0.8) a	39.3 (3.15) a	2.58 (0.60) a
	P. densiflora	0.56 (0.02) b	179 (6) b	85.1 (3.6) a	4.5 (0.3) a	38.6 (1.51) a	2.03 (0.03) a
	P. rigida × P. taeda	0.69 (0.03) a	221 (13) a	72.6 (1.9) a	3.8 (0.3) a	39.1 (1.73) a	1.99 (0.14) a
10–20	*L. leptolepis*	0.71 (0.02) a	216 (8) a	53.1 (3.0) b	3.4 (0.2) a	29.8 (2.38) a	1.99 (0.12) a
	P. densiflora	0.68 (0.05) a	238 (14) a	66.6 (2.5) a	3.4 (0.1) a	34.3 (1.73) a	1.77 (0.13) a
	P. rigida × P. taeda	0.73 (0.01) a	230 (7) a	55.7 (2.7) b	2.2 (0.1) b	31.4 (1.49) a	1.23 (0.08) b
20–30	*L. leptolepis*	–	196 (9) a	38.5 (2.2) b	1.9 (0.2) a	22.1 (1.86) b	1.11 (0.13) a
	P. densiflora	–	222 (14) a	56.8 (2.6) a	2.7 (0.2) a	29.9 (1.90) a	1.42 (0.13) a
	P. rigida × P. taeda	–	230 (9) a	41.9 (1.6) b	2.2 (0.7) a	23.6 (1.00) b	1.24 (0.48) a

Different letters in each column indicate a significant difference at $P = 0.05$

–, Not determined

Conclusions

Carbon and N status arising from needle litter input and decomposing needle litter differed considerably between a deciduous larch and two evergreen pine plantations established on sites with similar conditions. However, the C and N content at 0–10 cm soil depth were relatively little influenced by needle litter and decomposition dynamics over about 45 years of plantation establishment. Further studies will be needed to evaluate C and N contributions by the forest floor and fine roots to ascertain the impact of different tree species.

References

Baker TT III, Lockaby BG, Conner WH, Meiner CE, Stanturf JA, Burke MK (2001) Leaf litter decomposition and nutrient dynamics in four southern forested floodplain communities. Soil Sci Soc Am J 65:1334–1347

Berg B, Laskowski R (2006) Litter decomposition: a guide to carbon and nutrient turnover. Adv Ecol Res 38:20–71

Bert D, Danjon D (2006) Carbon concentration variations in the roots stem and crown of mature *Pinus pinaster* (Ait.). For Ecol Manage 222:279–295. doi:10.1016/j.foreco.2005.10.030

Binkley D (1995) The influence of tree species on forest soils: processes and patterns. In: Mead DJ, Cornforth IS (eds) Proceeding of the trees and soil workshop. Lincoln University Press, Canterbury, pp 1–33

Bray JR, Gorham E (1964) Litter production in forests of the world. Adv Ecol Res 2:101–157

Bremmer JM, Mulvaney CS (1982) Nitrogen-total. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2. Chemical and microbiological properties, 2nd edn. ASA and SSSA, Madison, pp 595–624

Chen X, Li BL (2003) Change in soil carbon and nutrient storage after human disturbance of a primary Korean pine forest in northeast China. For Ecol Manage 186:197–206

Finzi AC, van Breemen N, Canham CD (1998) Canopy tree-soil interactions within temperate forests: species effects on soil carbon and nitrogen. Ecol Appl 8:440–446

Gower ST, Son Y (1992) Differences in soil and leaf litterfall nitrogen dynamics for five forest plantations. Soil Sci Soc Am J 56:1959–1966

Hansen H, Vesterdal L, Schmidt IK, Gundersen P, Sevel L, Bastrup-Birk A, Pedersen LB, Bille-Hansen J (2009) Litterfall and nutrient in five tree species in a common garden experiment. For Ecol Manage 257:2133–2144. doi:10.1016/j.foreco.2009.02.021

Hwang J, Son Y, Kim C, Yi MJ, Kim ZS, Lee WK, Hong SK (2007) Fine root dynamics in thinned and limed pitch pine and Japanese larch plantations. J Plant Nutr 30:1821–1839

IPCC (2003) Good practice guidance for land use, land-use change and forestry. IPCC National Greenhouse Inventories Programme, pp 3.23–3.68

Jeong J, Kim C, An HC, Cho HS, Choo GC (2009) A comparison of litterfall dynamics in three coniferous plantations of identical age under similar site condition. J Ecol Field Biol 32:97–102

Kamei J, Pandey HN, Barik SK (2009) Tree species distribution and its impact on soil properties, and nitrogen and phosphorus mineralization in a humid subtropical forest ecosystem of northeastern India. Can J For Res 39:36–47. doi:10.1139/X08-151

Kim C (1999) Aboveground nutrient distribution in pitch pine (*Pinus rigida*) and Japanese larch (*Larix leptolepis*) plantations. J Korean For Soc 88:266–272

Kim C (2008) Soil carbon storage, litterfall, and CO_2 efflux in fertilized and unfertilized larch (*Larix leptolepis*) plantations. Ecol Res 23:757–763. doi:10.1007/s11284-007-0436-2

Kim C, Koo KS, Byun JK (2005) Litterfall and nutrient dynamics in pine (*Pinus rigida*) and larch (*Larix leptolepis*) plantations. J Korean For Soc 94:302–306

Kim C, Son Y, Lee WK, Jeong J, Noh N (2009) Influences of forest tending works on carbon distribution and cycling in a *Pinus densiflora* S. et Z. stand in Korea. For Ecol Manage 257:1420–1426. doi:10.1016/j.foreco.2008.12.015

Korea Forest Service (2006) Statistical year book of forestry (in Korean). Korea Forest Service, Daejeon City, Korea

Li Q, Moorhead DL, DeForest JL, Henderson R, Chen J, Jensen R (2009) Mixed litter decomposition in a managed Missouri Ozark forest ecosystem. For Ecol Manage 257:688–694. doi:10.1016/j.foreco.2008.09.043

Moore TR, Trofymow JA, Prescott CE, Fyles J, CIDET Working Group, Titus BD (2006) Patterns of carbon, nitrogen and phosphorus dynamics in decomposing foliar litter in Canadian forests. Ecosystems 9:46–62

Polyakova O, Billor N (2007) Impact of deciduous tree species on litterfall quality, decomposition rates and nutrient circulation in pine stands. For Ecol Manage 253:11–18. doi:10.1016/j.foreco.2007.06.049

SAS Institute Inc (1989) SAS/STAT user's guide. Version 6. 4th edn, vol 2. Cary, NC

Son Y, Gower ST (1992) Nitrogen and phosphorus distribution for five plantation species in southwestern Wisconsin. For Ecol Manage 53:175–193

Son Y, Lee IK (1997) Soil nitrogen mineralization in adjacent stands of larch, pine and oak in central Korea. Ann Sci For 54:1–8

Soon YK, Abboud S (1991) A comparison of some methods for soil organic carbon determination. Commun Soil Sci Plant Anal 22:943–954

Wang Q, Wang S, Zhang J (2009) Assessing the effects of vegetation types on carbon storage fifteen years after reforestation on a Chinese fir site. For Ecol Manage 258:1437–1441. doi:10.1016/j.foreco.2009.06.050

Zhang Q, Wang C, Wang X, Quan X (2009) Carbon concentration variability of 10 Chinese temperate tree species. For Ecol Manage 258:722–727. doi:10.1016/j.foreco.2009.05.009