Chapter 12
Soil Nitrogen Dynamics in Larch Ecosystem

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12.1 Introduction

About one-third of the stored soil carbon in the world is contained in large organic pools in northern taiga and tundra systems (Oechel and Billings 1992). In these ecosystems, at least 95% of the nutrients were incorporated in the soil (Marion et al. 1982). Therefore, plant growth or net primary production (NPP) is severely constrained by nutrient availability in high-latitude ecosystems, since the cold, wet conditions of arctic soils act to slow the release of nutrients (particularly inorganic N and P) from organic matter and the oxidation of organic C to CO_2 (Hobbie et al. 2002). These processes have led to the critical nutrient limitation on plant growth in these ecosystems (Shaver et al. 1992).

Most studies on productivity and nutrient cycling in arctic and subarctic regions were conducted in North America, especially in interior Alaska (e.g., Van Cleve et al 1983; Chapin et al. 2006). Those studies showed that nutrient pool in leaves and fine roots, which have rapid turnover rates, occupy less than 14% of the total nutrient pool (Jonasson and Michelsen 1996). Net mineralization measured with *in situ* buried bags often showed low or even negative values during the growing season (e.g., Giblin et al. 1991; Jonasson et al. 1999; Schmidt et al. 1999). Despite the large pools of N and P in the soil, net mineralization of N and P was generally low, and in most cases, lower than the plant uptake requirement (Schmidt et al. 2002). Recent estimates also suggested that the annual input of inorganic N (dry and wet deposition, N fixation and mineralization) could not account for the observed plant N uptake (Ruess et al. 1996).

Siberia is represented by a large area of arctic and subarctic ecosystems. The total area of Siberia is 13 million km^2 (Shvidenko and Nilsson 1994) which is about 30% greater than the entire area of Europe (10 million km^2 including European Russia; Stanner and Bourdeau 1995) and 12% greater than boreal North America (11.5 million km^2 of Canada and Alaska). Further, Siberia is much more extensively forested (6 million km^2) than Europe (3 million km^2) or boreal North America (5 million km^2). Therefore, Siberia is important in global C stock. In addition, forest ecosystems of Central Siberia are mostly on the continuous permafrost region, where the depth of soil active layer is generally shallow

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(Chap. 1, this Vol.). This may lead to N and/or P limitation for plant growth in the region; however, there is not enough information on biogeochemistry in these forest ecosystems to confirm this.

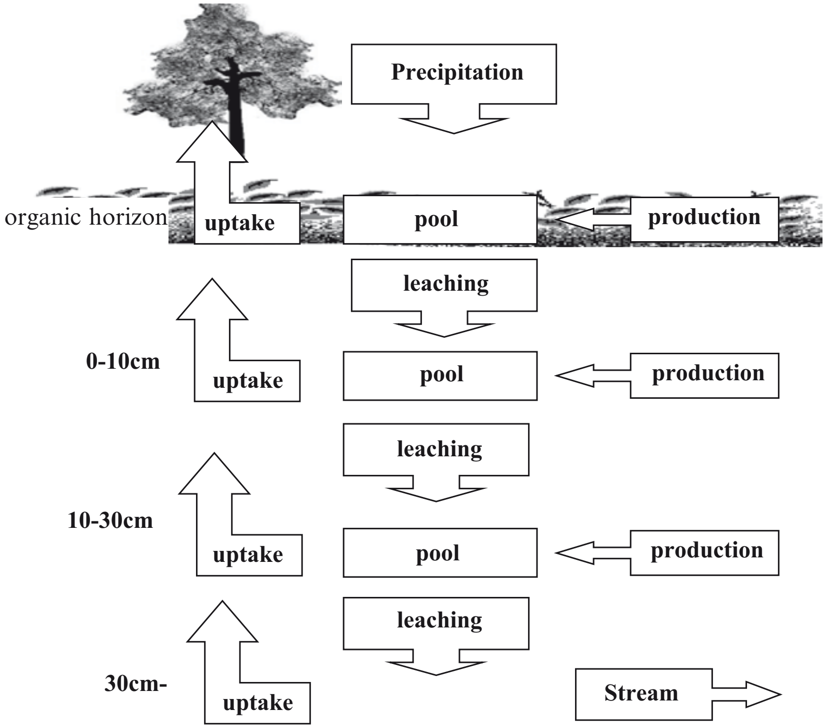
Nonetheless, N deposition has gradually increased over the past few decades, and the change in N status will affect the rate of C sequestration in Siberian forests. The objective of this chapter is to describe results of a study, which was intended as a first step in the investigation of C sequestration in Siberian permafrost forest ecosystem, and was aimed to clarify the N status of the ecosystem. The amount of plant available N from soil was estimated by *in situ* measurements of N dynamics, and annual N requirements for vegetation growth were calculated through the ecological summation method used in estimation of forest productivity (see Chap. 6, this Vol.).

12.2 Approaches to Examination of Soil Nitrogen Dynamics and Status

Inorganic N dynamics in the soil is summarized in Fig.12.1. Soil inorganic N dynamics is characterized by the interactions among pool, production, and flux. The pool is defined by the amount of inorganic N at the initial time; the production is the amount of net mineralized N added to the pool since the initial time; and flux is the amount of N input and output from/to the soil compartment. Many studies expressed values of soil N pool and flux as per unit of soil weight or ion exchange resin (e.g., Nadelhoffer et al. 1991). With such units, it is often difficult to compare the values among studies. It is also difficult to understand the ecosystem N dynamics using these units. Therefore, measurements of all parameters are given in area-based units in this study.

12.2.1 Study Sites

The study was conducted at Carbon Flux Site (plot CF) – a 105-year-old stand of larch (*Larix gmelinii* (Rupr.) Rupr.) near Tura, Central Siberia (location of the site is described in Figs.1.1 and 1.3, and climate characteristics are described in Chaps. 1 and 10, this Vol.). Soil type is Gelisol with poor drainage. The soil is frozen from mid-October to the beginning of May. In this region, forests are generally dominated by ca. 100-year-old *L. gmelinii* larch with occasional tall shrub (*Duschekia fruticosa*). Ericaceous species and thick moss–lichen cover has developed on the forest floor. At this site, one of four permanent research plots (each 15×15 m^2) was selected for N flux measurements. The mean stem diameter at breast height of *L. gmelinii* was about 3.2 cm, and tree density was 5,480 trees ha^{-1} (for details see Table 6.1).



(Unit; box with arrow; kg N ha^{-1} y^{-1}, box; kg N ha $^{-1}$)

Fig. 12.1 Diagram of N dynamics in forest ecosystem

12.2.2 Soil N Mineralization, Leaching, and Status

Net mineralization rate, namely inorganic N production rate measured by *in situ* buried bag methods (Eno 1960), is one of the good predictors of productivity in temperate forest ecosystems (Nadelhoffer et al. 1984). Fresh samples collected from A_0, 0–10, and 10–30 cm soil horizons were put into polyethylene bags. The bags were buried in the same horizon where the soil was sampled. After one year, the soil samples in buried bags were collected and were extracted. The extracts were brought back to the laboratory, and NH_4^+ and NO_3^-–N concentrations were determined.

While *in situ* incubation rate is good predictor for productivity, there have been few data on *in situ* incubation rate compared to those on laboratory incubation rate. The laboratory incubation rate would be helpful. Unfortunately, there was no facility in Tura, and we measured the laboratory incubation rates in Japan. During the transportation from Tura to Japan, we could not control the sample temperature. Normally it took a week for transportation. Hence, we used the mineralization rate by laboratory incubation as an index. In the laboratory, soil samples were kept at 25°C. The 4-week incubation period included transportation. After the incubation period, the samples were extracted and NH_4^+ and NO_3^--N concentrations were determined. Inorganic N leaching in soil was captured by the ion exchange resin for 2 years (Binkley and Matson 1983).

From the results of all measurements, we estimated available inorganic N for the vegetation using the following equation (Nadelhoffer et al. 1984; Tokuchi et al. 2007):

$$\text{Available N} = \text{Production N} + (\text{input N-output N}) - \Delta\text{N pool} \qquad (12.1)$$

where production N is in situ net mineralization, input N input is N leachate from upper horizon or precipitation N if the horizon is surface horizon, output N is N leachate from the soil surface, and ΔN pool is inorganic N pool at current sampling year minus inorganic N pool at previous sampling year. In this study,we examined the N acquisition of larch forest under a likely N limitation in this study site. Larch and *Duschekia* leaves and soil were sampled in the growing season of 2003. Samples of leaf and soil were grounded. The ground samples were analyzed for stable isotope ratios using an isotope ratio mass spectrometer (Kielland et al. 1998; Kielland 2001).

12.3 Soil Nitrogen Dynamics

12.3.1 Soil Inorganic N Pool

Soil inorganic N pools ranged from 1.0 to 8.1 kg N ha^{-1} in A_0 horizon, 5.9–22.6 kg N ha^{-1} in 0–10 cm horizon, and 11.4–34.0 kg N ha^{-1} in 10–30 cm horizon, respectively (Fig.12.2). NH_4^+ dominated inorganic N pool irrespective of horizons and years (data not presented). In interior Alaska, it has also been reported that extractable concentrations of NH_4^+ are typically one order of magnitude greater than that of NO_3^-.

The soil inorganic N pool sizes estimated for our old larch forest in Central Siberia (Fig. 12. 2) were in the range similar to those reported for boreal forests in northern Canada (Lamontagne 1998), but were larger than those of previous studies in tundra and/or in some boreal forests in Alaska (Table.12.1). Nitrogen pool in mineral soil was 6,580 kg N ha^{-1} in an old multi-aged (>220-year-old) *L. gmelinii* forest (plot C1) in Central Siberia (Matsuura et al., unpublished data), while it was 3,070 (ranged 1,920–4,060) kg N ha^{-1} in mineral soil of a black spruce forest in Alaska (Van Cleve et al. 1983). This suggests a large difference in N pool size between Siberia and Alaska. Also the N pool in aboveground biomass of the old multi-aged larch stand was 51 kg N ha^{-1} in Central Siberia (Matsuura et al., unpublished data), while it was 62.5 kg ha^{-1} in the black spruce forest in Alaska (Van Cleve et al. 1983). The proportion of the N pool in soil to above ground biomass in Siberian old larch forest was larger than that in Alaska, 129 vs. 49, respectively. This suggests that the quality of organic matter may be different

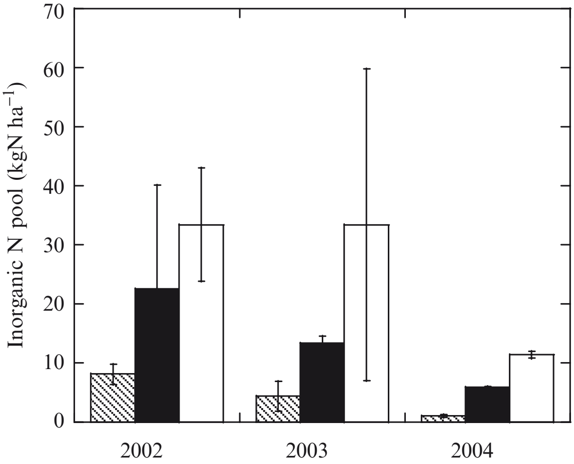


Fig. 12.2 Soil inorganic N pool from 2002 to 2004 in *L. gmelinii* forest in Central Siberia. *Gray bar* is for A_0 horizon, *black bar* is for 0–10 cm horizon and *white bar* is for 10–30 cm horizon. Unit is kg N ha^{-1}. Data are mean ± SE ($n = 4$)

between Central Siberia and Alaska. We need further research on the quality of organic matter in Siberia.

Although inorganic N pool was relatively large, it was not stable. Namely, there was high heterogeneity in soil inorganic N pool size among the plots in each observation year (Fig.12.2). Also, the total soil inorganic N pool size across the three horizons was significantly different among the observed years ($p < 0.05$).

Temperature is one of the essential environmental conditions influencing soil N dynamics. There was a significant correlation between summer air temperature (June–August) and inorganic N pool in each horizon, and inorganic N pool exponentially increased with summer air temperate in our old *L. gmelinii* forest (Fig. 12.3). In taiga soils, it was reported that N mineralization and nitrification do not respond significantly to temperature until it exceeds 15–20°C (Klingensmith and Van Cleve 1993). In our larch forest, the correlation coefficient was the highest between soil inorganic N pool and the highest mean monthly air temperature (July) ($r = 0.862$ in A_0 horizon, $r = 0.707$ in 0–10 cm soil depth and $r = 0.548$ in 10–30 cm soil depth; Fig.12.3). Thus, one of the reasons of interannual variability of soil inorganic N pool is likely due to the fluctuation of air temperature in this larch forest.

In the relationship between soil inorganic N pool and summer soil temperature (data not presented), the correlation was stronger in the surface than in the deeper soil horizon, but the slope of the linear relationship was greater in the deeper horizon. This indicates that mineralization in the deeper soil responds more sharply to temperature than the surface soil: soil microbes in the deeper soil horizon may be more sensitive to temperature than that in the surface soil horizon.

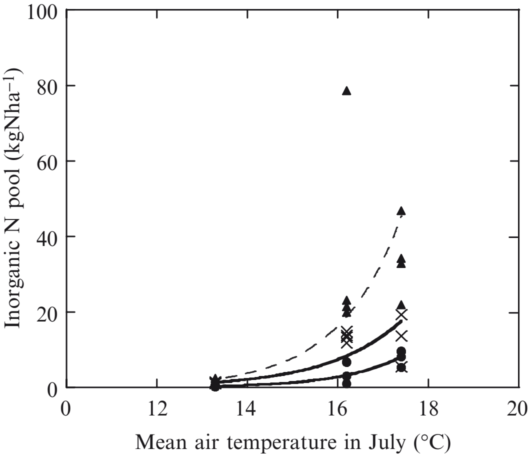


Fig. 12.3 Relationship between mean air temperature (June to August) and soil inorganic N pool in *L. gmelinii* forest. Regression curves are shown for each horizon among years ($p < 0.05$). *Black circle* with *bold* line is for A_o horizon, cross with dashed line is for 0–10 cm horizon and *black triangle* with fine line is for 10–30 cm horizon

12.3.2 Soil N Mineralization

In the *in situ* buried bag method, net mineralization rate was variable among the soil horizons and years (Fig.12.4). Half of *in situ* net mineralization rates were negative. It means the immobilization of inorganic N was larger than the production of inorganic N. One of the reasons for strong immobilization seems due to the incubation period. The incubation period is longer than the previous studies. Thus, we checked the amount of one month *in situ* incubation in 2004. Even if incubation period was considered one month, the net in situ incubation rates also showed high variability and negative values; –0.22±0.76 kg N ha^{-1} mo^{-1} in 0–10 cm soil. In the previous studies, the net mineralization measured with *in situ* buried bags often showed low or even negative values during the growing season in arctic and subarctic regions (Giblin et al. 1991; Jonasson et al. 1999; Schmidt et al. 1999). Thus, it is considered that the highly variable N mineralization rate and strong immobilization are the characteristics of soil N dynamics in cold regions including our study site in Central Siberia.

Net N mineralization rate by laboratory incubation varied among the years (Fig. 12.5). Net N mineralization by laboratory incubation was negative in 2002 in all soil horizons. It means that the immobilization of N exceeded the inorganic N production in 2002. On the other hand, N was mineralized in 2004 in all soil horizons. In 2003, N was immobilized in the surface and 10–30 cm depth, while N was mineralized in 0–10 cm depth. The periods of transport among years were similar. Based on both measurements of N mineralization rates, it could be summarized that N mineralization rate is variable among soil horizons and years, and immobilization process is dominant at this study site.

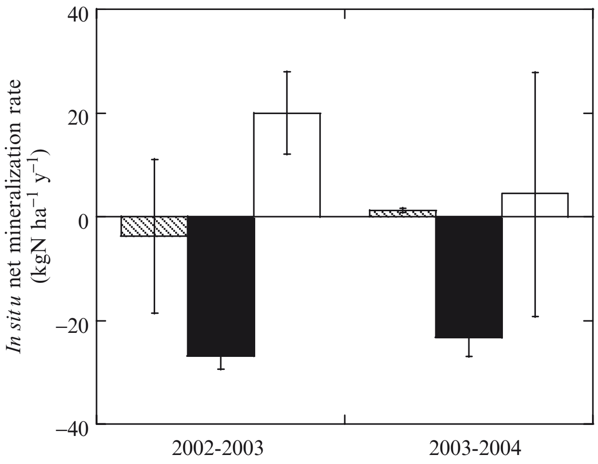


Fig. 12.4 *In situ* net N mineralization rate in larch forest ecosystem. *Gray bar* is for A_o horizon, *black bar* is for 0–10 cm horizon and *white bar* is for 10–30 cm horizon. Unit is kg N ha^{-1} y^{-1}. Data are mean ± SE ($n=4$)

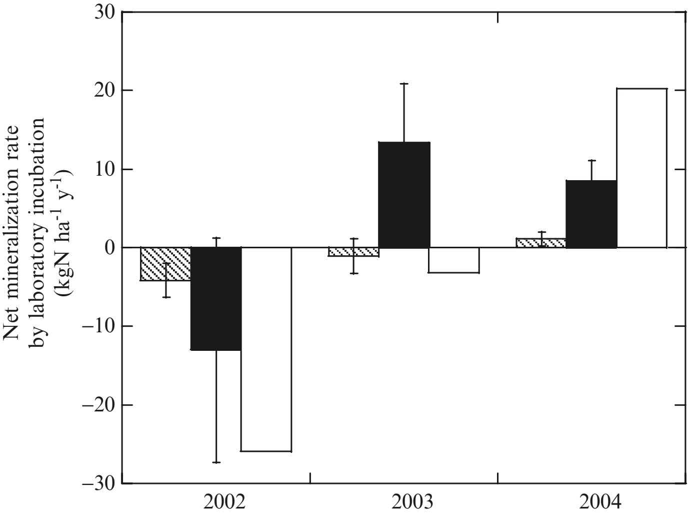


Fig. 12.5 Net N mineralization rate in laboratory incubation in *L. gmelinii* forest. *Gray bar* is for A_o horizon, *black bar* is for 0–10 cm horizon and white bar is for 10–30 cm horizon. Unit is kg N ha^{-1} y^{-1}. Data are mean ± SE ($n=4$)

12.3.3 Controlling Factors on Soil N Dynamics

The trend of soil N mineralization tends to be different when estimated in the laboratory and through *in situ* incubation (Figs. 12.4 and 12.5). One of the possible reasons of the difference is the incubation period; 4 weeks for laboratory versus one year for *in situ* incubation. It is considered that the incubation period influenced soil N transformation. We could discuss the short-term characteristics from the result of the laboratory incubation and the long-term characteristics from *in situ* incubation.

Based on the result of the laboratory incubation, N was immobilized in all soil horizons in 2002 (Fig. 12.5). In that year, soil inorganic N pool was the highest among all observation years (Fig. 12.2). In the short-term mineralization, the substrate for N mineralization tends to be exhausted. It is confirmed that in 2004 when soil inorganic N pool was the smallest, the N mineralization rate was the highest among the observation years.

As for the long-term mineralization characteristics, *in situ* soil N mineralization rate significantly correlated with soil inorganic pool size (p <0.05, Fig.12.6). Additionally, half of the *in situ* soil N mineralization rates were negative. This means that *in situ* soil N mineralization reflects the immobilization of the soil inorganic N pool. High immobilization of inorganic N suggests that a large proportion of the total C is available for microbes (Nadelhoffer et al. 1991). In terms of C availability, Schmidt et al. (2002) questioned the effectiveness of the buried bag method. The buried bag method prevents not only the uptake of nutrients by plant roots, but also the supply of labile carbon to soil microbes in the form of root exudates. However, they showed that the limitation of C was higher in bags than outside from a comparison of dissolved organic carbon (DOC) concentration between the inside and outside of the bags, and that C/N changed with microbial biomass change. They conclude that when N availability increases, the high immobilization of N in microbes would, probably, always take place regardless of the amount of available C (Schmidt et al. 2002). Therefore, it is hypothesized that there is a large available C pool for microbes in our *L. gmelinii* stand, and microbes would be the stronger competitor against plants for N uptake.

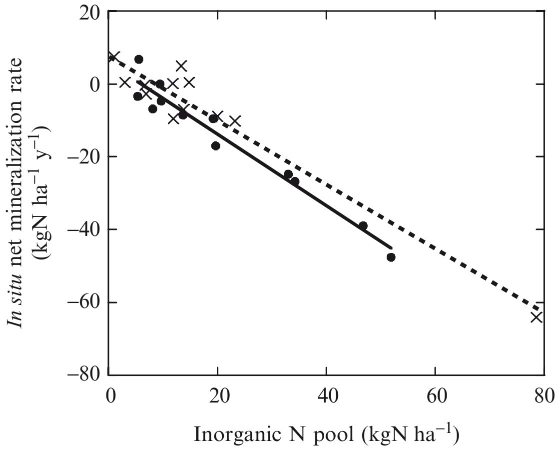


Fig. 12.6 Relationship between inorganic N pool and in situ net N mineralization. *Dashed line* is regression for the data of 2002–2003, and bold line is for 2003–2004 (p <0.001)

12.3.4 Inorganic N leaching in Soil

The values of annually captured inorganic N for 2 years were 1.90 and 1.97 kg N ha^{-1} y^{-1} at the A_0 horizon, 1.70 and 1.95 kg N ha^{-1} y^{-1} at the 10 cm soil depth, and 0.70 and 1.02 kg N ha^{-1} y^{-1} at the 30 cm soil depth. The captured inorganic N amount decreased with soil depth, presumably because of the microbial and vegetative uptake. It resulted in low inorganic N concentration in the stream (lower than the detection limit, <1 μmol L^{-1}). Inorganic N loss from the soil was estimated as less than 0.1 kg N ha^{-1} y^{-1}. Few roots were present below 30 cm soil depth due to the permafrost in the old larch stand (see Chap. 16, this Vol.), indicating little uptake of N by vegetation at this horizon. One of the possible reasons of the discrepancy in inorganic N concentrations between 30 cm soil depth and the stream is denitrification occurring in the deeper soil horizons.

12.4 Soil Nitrogen Status in Larch Forest in Central Siberia

12.4.1 Available N

In 2002–2003, the estimated available N was −1.4, 14.6, −31.8, and 0.6 kg N ha^{-1} y^{-1} at A_0 horizon, 0–10 cm horizon, 10–30 cm horizon, and under 30 cm horizon, respectively. Negative values were regarded as zero for available N. The total amount of available inorganic N was 15.2 kg N ha^{-1} y^{-1} in 2002–2003. In 2003–2004, the estimated N was 15.3 kg N ha^{-1} y^{-1}.

In comparison, Ruess et al. (1996) estimated N uptake as the sum of net N mineralized plus input via precipitation and fixation. When we used the method of their calculation, available inorganic N was estimated as 7.3 kg N ha^{-1} y^{-1} in 2002–2003 and 2.1 kg N ha^{-1} y^{-1} in 2003–2004. These estimates of annual available N in this study (from 2.1 to 7.3 kg N ha^{-1} y^{-1}) is in a range similar to the annual N demand suggested for black spruce forest (9.2 kg N ha^{-1} y^{-1}) in upland sites in Alaska (Ruess et al. 1996).

12.4.2 The Possibility of N Limitation of Larch Forest in Central Siberia

In Central Siberia, Kajimoto et al. (1999) reported that NPP was 1.81 Mg ha^{-1} y^{-1} in an old multi-aged *L. gmelinii* stand (> 220 years old; plot C1); NPP was estimated as the sum of annual woody biomass increment (stem, branch, and coarse root) and needle biomass (see also Chap. 6, this Vol.). N concentration in each component of the larch trees was 0.12% in stem, 0.35% in branch, 1.58% in green needle, 0.24% in coarse root, and 0.76% in fine root (Matsuura et al., unpublished data), and N retranslocation ratio before needle senescence was about 70% (i.e., N concentration in needle litter fall was about 0.48%)(see Table 8.1, this Vol.). N retranslocation was subtracted from annual N increment to needles to obtain an estimate of N for foliage. Based on these values, the amount of N required for annual production of woody parts and needle (i.e., multiplying NPP by N concentration) would be about 8.1 kg N ha^{-1} y^{-1} in this old multi-aged larch forest. However, the estimate of N demand seems underestimated, since it excludes the proportion for fine root production.

In the 105-year-old *L. gmelinii* stand of the present study (plot CF), N requirement (or annual plant uptake) can also be evaluated by applying the same values of N concentration in each component and N retranslocation rate. Aboveground net primarily production (ANPP) of this old stand is 0.48 Mg ha^{-1} (Table 6.3, this Vol.). Among belowground production, biomass increment of roots (both coarse and fine roots) due to secondary thickening was not estimated in the stand, and here it is assumed to be equivalent to that of >220-year-old stand (0.48 Mg ha^{-1}; Kajimoto et al. 1999). The amount of N that is required for annual production of aboveground components is 2.5 kg N ha^{-1} y^{-1}. Furthermore, fine root production was estimated at 0.76 Mg ha^{-1} by using in-growth core method in the stand (Tokuchi et al., unpublished data). When the fine root production is included, the N demand for the total belowground (both coarse and fine roots) reaches about 8.5 kg N ha^{-1} y^{-1}. Consequently, the estimated N requirement at the whole stand level is 11.0 kg N ha^{-1} y^{-1}. The value is slightly less than the annual N availability (averaged about 15.3 kg N ha^{-1} y^{-1}) estimated in this study. As compared to other ecosystems, however, the plant N uptake is in a order similar to those reported at high latitudes, such as tundra (Giblin et al. 1991; Jonasson et al. 1999), and larch (*L. gmelinii*) and Scots pine (*Pinus sylvestris*) mixed forests in Central Siberia (Shugalei and Vedrova 2004)(Table 12.1).

In this study, the N uptake of other plants on the forest floor was not estimated. However, aboveground biomass of forest floor was about 2.2 Mg ha^{-1} (Matsuura et al., unpublished data), which reached about 40% of aboveground biomass of larch trees (5.7 Mg ha^{-1}) in the old stand (see Table 6.2, this Vol.). This indicates that the annual N uptake by some woody shrubs, lichens, and mosses is not negligibly small. Therefore, it is possible that available inorganic N is likely a limiting factor for plant growth in the study area.

12.4.3 N Source of Larch Forest in Central Siberia Based on Isotopic signature

It is suggested that the isotopic change in plant organs is functionally caused by soil N turnover (Garten and Van Miegoet 1994). The isotopic signature of N in tissues of northern species provides evidence of niche differentiation regarding acquisition of different N forms (Schulze et al. 1994; Valentine et al. 2006).

Table 12.1 Comparison of N dynamics among arctic Tundra and boreal forest ecosystems

		Arctic tundra		Boreal forest			
		Alaska[a,b]	Scandinavia[e]	Alaska[f]	Canada[h]	Central Siberia[j]	Central Siberia[l]
				(Mixed forest)	(Pine, spruce)	(Larch, pine)	(Larch)
	[Soil horizon]						
N pool size	Organic horizon	0.8–2.6[c]	1.0	–	–	–	4.8–8.1
(kg N ha^{-1})	0–10 cm	–	–	–	–	21.1–39.8[k]	13.4–22.6
	10–30 cm	–	–	–	–	–	34.0–35.8
N production(kg N ha^{-1} y^{-1})	Organic horizon	5.0[c]	0.5–1.1	4.0	3.9–6.3[i]	3.4–5.9	0.0
	0–10 cm	–	–	6.0[g]	–	–	0.0
	10–30 cm	–	–	–	–	–	0.0
Plant uptake N(kg N ha^{-1} y^{-1})		1.0–23.0[d]	10.0	–	–	22.4–45.8[k]	11.1

[c] A_0 + mineral soil. [d] belowground + new uptake. [g] 0–20 cm horizon. [i] include forest floor. [k] include mineral soil (averaged for 2 years). Data source: [a] Giblin et al. (1991), [b] Shaver and Chapin (1991); [e] Jonasson et al. (1999); [f] Van Cleve et al. (1993); [h] Lamontagne (1998); [j] Shugalei and Vedrova (2004); [l] Tokuchi et al. (2003)

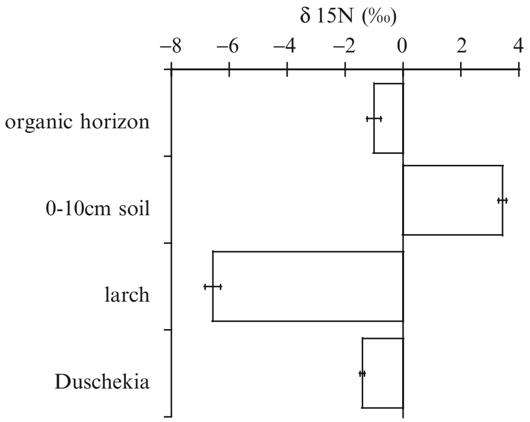


Fig. 12.7 Mean $\delta^{15}N$ values of soil (organic and 0–10 cm horizons) and leaves (*L. gmelinii* and *Duschekia fruticosa*) sampled in the larch forest ecosystem. Data are mean ± SE (*n* = 8) (Tokuchi et al., unpublished data)

In the larch forest of present study, $\delta^{15}N$ values were −1.01 ± 0.23‰ in the A_0 horizon, and 3.43 ± 0.38‰ in the 0–10 cm soil horizon (Fig.12.7). The leaf $\delta^{15}N$ values of larch and *Duschekia* were −6.56 ± 0.26 and −1.41 ± 0.04‰.

Even coexisting larch and *Duschekia* showed large difference in the leaf $\delta^{15}N$ values. *Duschekia* leaves showed $\delta^{15}N$ values close to that of atmospheric N_2 (=0‰), suggesting that *Duschekia* is likely to be fixing and using atmospheric N_2 (i.e., N_2 fixing species).

In Alaska, a large variation in foliar $\delta^{15}N$ values was observed among plant species (Nadelhoffer et al. 1996, Kielland et al. 1998; Kielland 2001). The most depleted $\delta^{15}N$ value was observed in *Picea mariana* (−9.7‰) and *Picea glauca* (−8.0 ‰) (Kielland et al. 1998; Kielland 2001), indicating that the *Picea* spp. were highly depleted in $\delta^{15}N$. The larch in Central Siberia showed a value of $\delta^{15}N$ similar to that of *Picea* in Alaska.

In both areas, there was a large discrepancy of $\delta^{15}N$ value between the leaf of *Picea* or larch and soil. It suggests that a long history of soil N processing should have enriched soils in ^{15}N via chronic losses of ^{14}N, while plant tissues are highly depleted in ^{15}N indicating a less direct pathway from soil into plant (Valentine et al. 2006).

12.5 Conclusions

Based on the present results it is possible that available inorganic N is likely to be a limiting factor for plant growth in this region. In Alaska, the annual net mineralization could account for half of the N taken up by plants (Schimel and Chapin 1996). Ruess et al. (1996) also indicated that inorganic N budget method was difficult to be applied in Alaska. A possible reason for the discrepancy between N supply and demand is that boreal trees may absorb a part of their N demand as the organic form (Kielland 2001). In boreal surface soils, free amino acid concentrations are about 4–8 μg N g^{-1} in dry weight (Kielland 2001; Jones and Kielland 2002), similar to the values in arctic tundra soils (Kielland 1994). Concentrations of dissolved organic N (DON) in mineral soil are typically two to three times greater than the concentration of NH_4^+ (Walker 1989; McFarland et al. 2002). Hobara and Hirobe (2007) also showed a significant amount of DON in Alaska. A probable gross rate must be DON ammonium > nitrate.

However, the available amount of organic N form for plants could not have been clarified until now. Also it is not clear whether the direct organic N uptake contributes to the large depletion of ^{15}N. If the organic N uptake is the major uptake process, there might be little discrepancy of the ^{15}N values between soil and vegetation. One possible explanation is the highly dynamic amino acid pool and plant uptake of the amino acids. For example, free amino acid turnover time in soils is about 1–12 h (Jones and Kielland 2002). However, there was not enough data on plant N use in Siberia. Therefore more research on organic N dynamics is needed using ^{15}N in this permafrost region.

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