BELOWGROUND FINE ROOTS AND PLANT DETRITUS ALLOCATION IN LARCH FORESTS ON PERMAFROST SOILS OF SIBERIA

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Abstract

We examined specificity of fine root distribution and root detritus stock in permafrost soils under mossy-subshrub larch forests (Larix gmelinii (Rupr.)Rupr.) The sample plots were situated in northern taiga of Central Siberia and in mountain permafrost larch forests in the Lake Baikal Region. It was found that trees, sub-shrubs and grasses have different patterns of fine root distribution inside the 0-20 cm soil layer. Patterns of fine root distribution and plant detritus accumulation can be a result of different root growth strategies of tree and sub-shrub life forms.

Key words: *larch forests, permafrost, fine roots, root detritus, distribution in soil profile*

1. INTRODUCTION

Recently soils of boreal forests arouse a huge interest of scientific community because on the global scale these soils function as a significant sink of carbon. Aboveground plant litter quality and decomposition rates have been proposed as fundamental determinants of long-term soil organic matter accumulation. However, last studies show that 50 to 70% of stored carbon in the soil can derive from roots and root-associated microorganisms (Clemmensen et al. 2013).

Plant roots are important living components of soils. Living roots penetrating soil provide host sites for bacteria and fungi, which can assist in the breakdown and assimilation of nutrients from soil. Moreover underground carbon allocation in the roots links soil ecosystems and vegetation, providing flow of organic carbon to the soil from CO_2 fixed by photosynthesis. Plants allocate large quantities of carbon underground for the construction and maintenance of roots and micorrhizae, such that belowground carbon allocation may represent the largest sink for gross primary production. Root mortality supplies diet for soil saprotrophs and provides accumulation of specific soil organic matter. Despite the magnitude of belowground carbon allocation it remains the least understood C flux in plant communities.

Root biomass depending on tree species, age and growth conditions can reach from 18 to 45% of total tree biomass (Prokushkin & Abaimov 2008; Santantonio et al. 1977, Fogel 1983). More than 50% of annual production can be located in the belowground sphere of forest ecosystems (Harris et al. 1977; Steel et al. 1997). Last studies show as well that humification during decomposition of roots is higher than during decomposition of aboveground plant residues (Katterer et al. 2011). Thus root systems and belowground plant residues can be the main source of organic carbon accumulation in the soil (*Perry* et al. 1989).

Fine roots (roots < 2 mm in diameter) are minor in terms of the total forest biomass but play a prominent role in the functioning of forest ecosystems. Due to their relatively short life span and rapid turnover, fine roots represent a major sink for the trees' annual carbohydrate gain and play a central role in soil C dynamics. It has been estimated that fine root growth may account for about a third of the global annual net primary production (Jackson, Mooney & Schulze 1997), which emphasizes the important role of fine root dynamics in the global C cycle.

Many factors affect root growth and root system size (e.g. Schenk 2005). Temperature, nutrient availability, soil acidity, water availability and some other biotic and abiotic factors have been found to be key factors influencing fine root biomass and fine root turnover.

Fine roots are responsible for the bulk of water and nutrient acquisition and form the most active and short-lived part of the root system. A lively debate is ongoing in the root research community as to what is a fine root. This is largely fuelled by the fact that fine roots are defined on a functional basis (resource uptake), but have to be measured according to a morphological one (root diameter). For simplicity, and to promote comparability of results, fine roots are often assumed to be less than 1 or 2 mm in diameter. Coarse roots, on the other hand, are thought to live for significantly longer periods and fulfill roles related to resource transportation and tree stability. Their biomass will eventually contribute to soil biogeochemical cycles, but this usually happens after many years or decades and their overall contribution to carbon and nutrient cycling is significantly smaller. About 33% of global net primary production is assumed to be used in fine root production and functioning (Jackson et al. 1997). As a result, fine root systems contribute substantially to global terrestrial carbon (C) cycle and are a major reservoir of C (Vogt & Persson 1991).

Fine roots have a much shorter lifespan than coarse roots, as a consequence, their biomass varies both seasonally and due to changing environmental conditions. Because of their rapid production, senescence and decomposition, fine roots contribute significantly to forest soil C flux, making accurate measurement of their biomass and rate of production indispensable for closing the boreal forest C budget (Brunner & Godbold 2007).

Fine root systems of perennial plants are complex networks, with millions of lateral branches associated with mychorrizal hyphae. Because of the complexity of the root system it is important to define fine roots not only by diameter size but also by their function and behavior.

We examined specificity of fine root distribution and root detritus stock in permafrost soils under mossy-subshrub larch forests (*Larix gmelinii* (Rupr.)Rupr.) The sample plots were situated in northern taiga of Central Siberia and in mountain permafrost larch forests in the Lake Baikal Region (Fig.1). The main macroecological factor influencing on forest ecosystems in this region is permafrost in the soil and prevalence of arctic anticyclone in winter time.

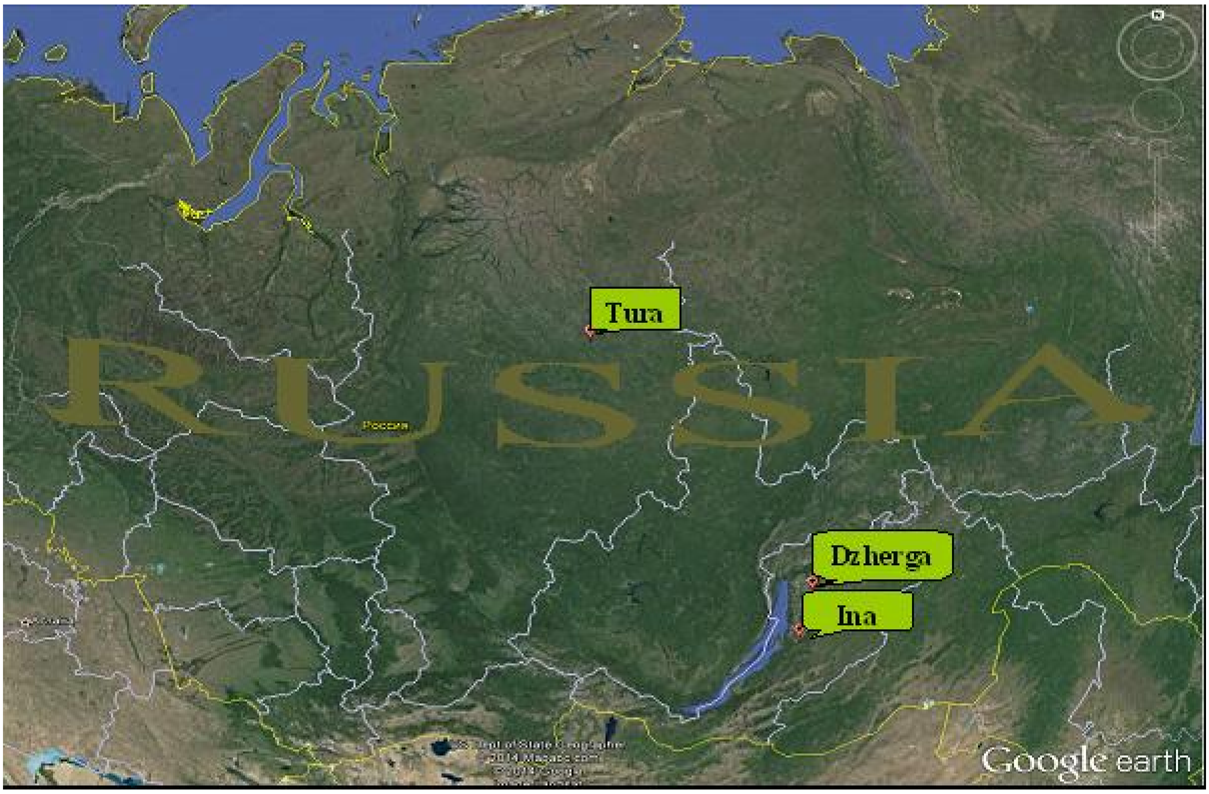

Fig.1 Location of studied sites.

2. OBJECTS AND METHODS

Sample plots in northern taiga are situated in 5-7 km from town Tura, Evenkya (64°N, 100°E.) on the contrast conditions of southern and northern slopes. Relief of studied territory is erosion-denudation low mountain about 130-600 m a.s.l. Studied territory is situated in the permafrost zone. Soil cover is presented by Cryosols. Climate is continental, humid. Mean annual temperature is -8.9°C, sum of the active temperatures above 10°C is equal to 1000 °C. Mean annual precipitation equal to 369 mm and evenly distributed between year seasons. Duration of vegetative period is about 70-80 days (Climatic atlas 1960).

Sample plots in mountain permafrost larch forests are situated in Ikatskiy ridge (site Ina) and on the territory of State reservation “Dzherginskiy”(site Dzherga) on the north of the Republic Buriatya. Ikatskiy ridge is a part of the large orographical area – Sayan-Baikal plateau, and a part of Pribaikalie mountain system (Geomorphological regionalization… 1980). Relief of this territory is erosion-denudation middle mountain, height about 1200–1450 m a.s.l. Mean annual temperature is – 6,7^{o} C. Mean annual precipitation is equal to 600 mm (Reference book … 1968). Soils in the mountain-taiga belt are presented by Podburs.

Territory of the State reserve “Dzherginskiy” is situated in the high part of Barguzin river basin in the place where Ikatskiy, Barguzinskiy and Yuzhnomuyskiy ridges meet. Climate of this region is strong continental. Mean annual temperature is -5,3° C. Mean annual precipitation vary from 300-400 mm in valleys to 1000 mm on the ridge tops. Sum of the active temperatures (>0°C) varies from 2000°C in valleys to 1200°C on tops of ridges. Frost free period is equal to 68-117 days depending on the height above sea level (Reference book… 1966-1970). Soils of the region are long-term seasonal frozen and permafrost (Vaseeva et al. 1967).

Sample plots in Tura site are presented by cowberry-moss larch forest on the southern slope (TuraSS) and by ledum-moss larch forest on the northern slope (TuraNS). Onground cover in mountain-taiga larch forest in the site Ina is presented by cowberry and in the site Dzherga forest type is cowberry-herbaceous-moss (Fig. 2).

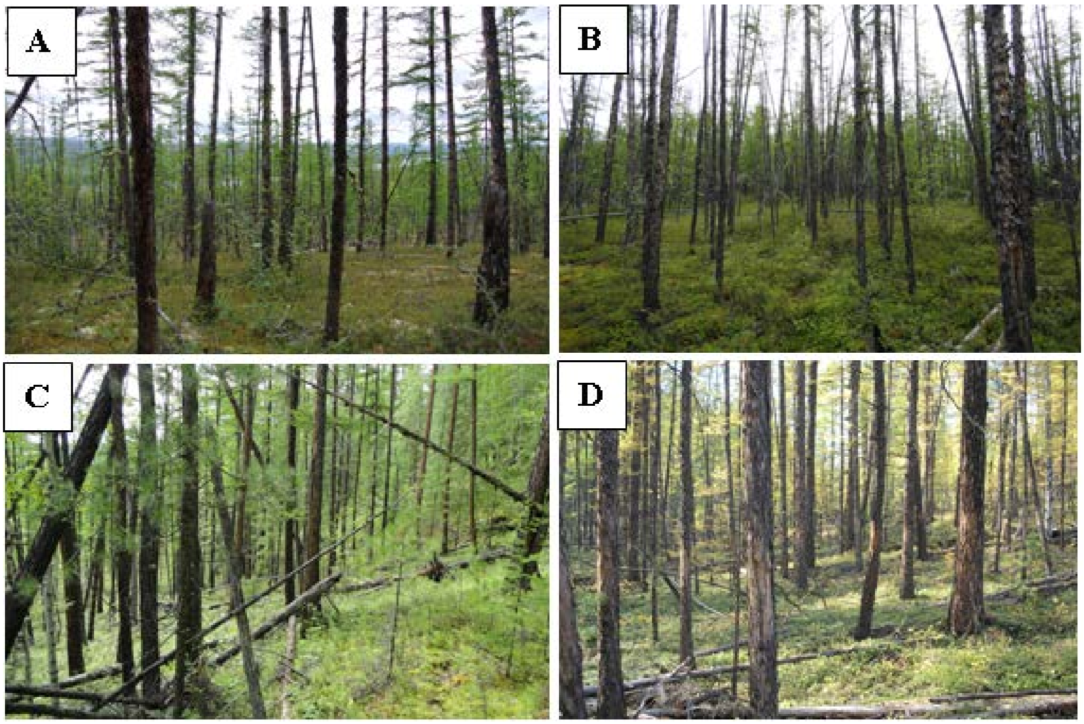

Fig. 2 Sample plots: A – northern slope in northern taiga (TuraNS); B – southern slope in northern taiga (TuraSS); C - mountain permafrost larch forests (site Dzherga); D - mountain permafrost larch forests (site Ina).

To assess pools of live and dead fine roots, and belowground plant detritus we have used a monolith method (Weaver & Voigt 1950; Orlov 1967). Soil monoliths 5cm in diameter were taken separately in each 5 cm depth for the whole active soil profile. For each depth soil monoliths were taken in 6 replicates. Roots and plant detritus from soil monoliths were washed on sieves with minimal size of mesh 0.5mm. Plant material was separated on following fractions: alive roots (trees, subshrubs and herbaceous) < 2 mm in diameter (fine roots); alive roots (trees, subshrubs and herbaceous) with diameter >2 mm and >1cm ; dead roots (trees, subshrubs and herbaceous) < 2 mm, >2 mm and > 1 cm ; plant detritus – decomposed and fragmented plant residues.

On the site in northern taiga active soil profile in the August was 15-20 cm on the northern slope and about 50 cm on the southern slope. On the site Ina depth of the active soil profile was 25-30 cm and on the site Dzherga the active soil profile did not exceed 20 cm..

3. RESULTS AND DISCUSSION

Total stock of plant material (live roots + root detritus) under the larch forests reaches 3427-7066 g m^{-2} in the soil layer 0-20 cm. About 67-79% of this stock is plant detritus. Fine roots contribute from 10-12% to 18-20% of total stock of plant material in the soil under the mountain larch forests and in the northern taiga larch forests, respectively. About 67-96 % of fine roots and 84-98 % of plant detritus stock is situated in 0-20 cm soil layer. The most amount of fine roots was observed in the top 0-5 cm layer in all sample plots (Fig. 3).

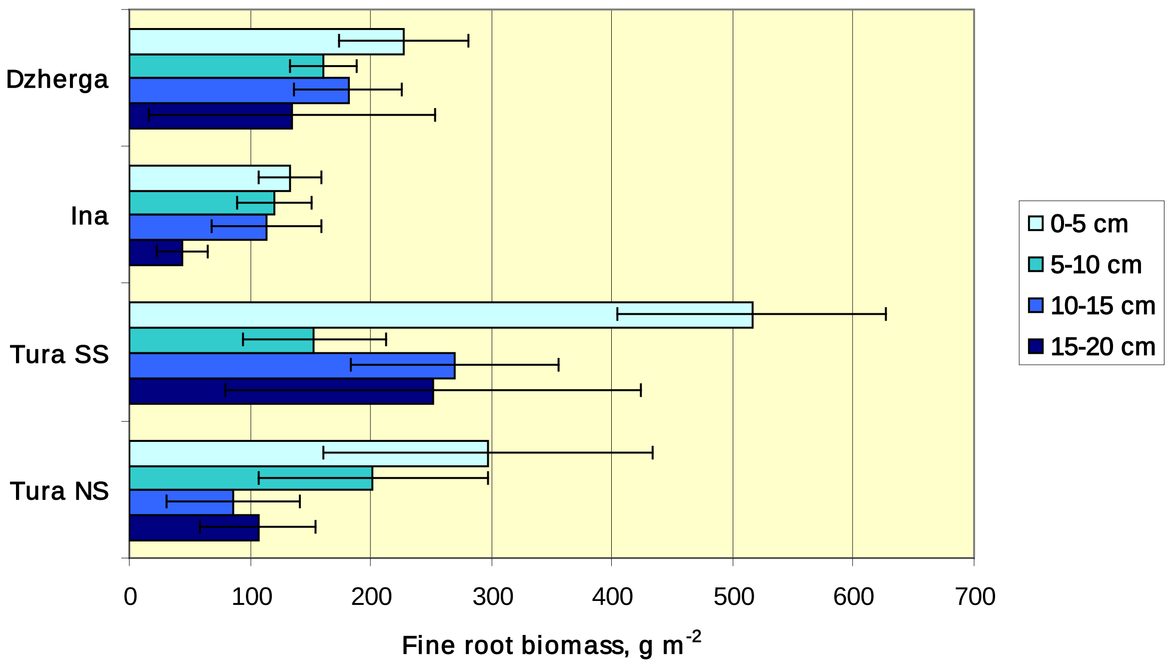

Fig. 3. Distribution of fine root biomass in the upper 0-20 cm soil layer

Distribution of belowground plant detritus inside 0-20 cm layer showed two peaks: on the depth 0-5 cm and 10-15 cm (Fig.4). If stock of plant detritus on the depth 0-5 cm can be partly a result of plant material input from forest litter, on the depth 10-15 cm the main source of plant material for detritus pool most probably is a residues of root systems.

Dead roots contribute about 13-14% of belowground plant detritus. Distribution of root necromass within 0-20cm depth is similar to the distribution of plant detritus mass.

Inside of 0-20 cm soil layer with depth some increasing of tree roots contribution was observed. In contrast, contribution of fine roots of plants of onground cover (subshrubs and herbaceous) decreased (Fig. 5). Distribution of herbaceous fine roots for studied plots is different.

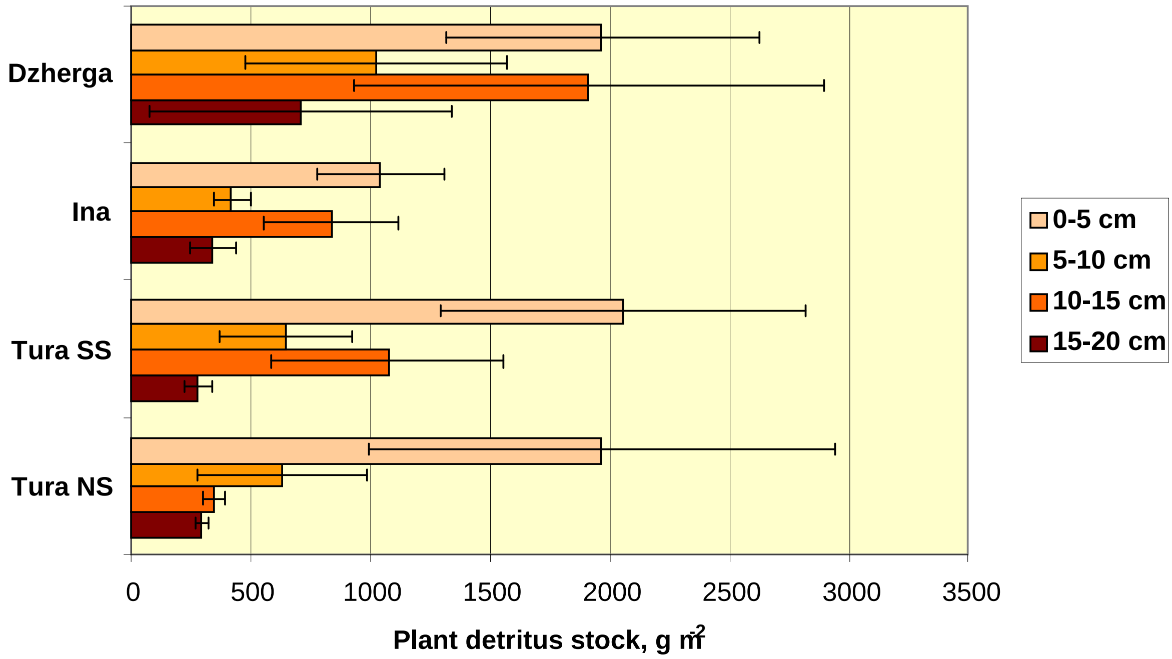

Fig. 4. Distribution of plant detritus in the upper 0-20cm soil layer.

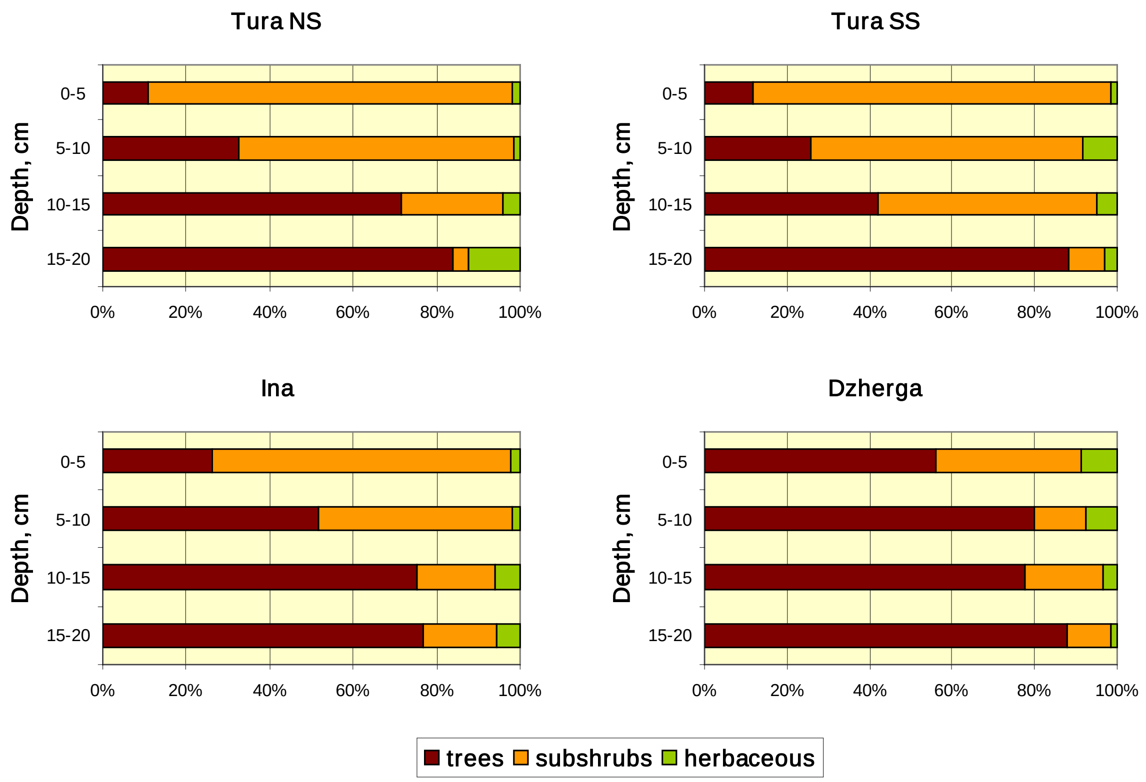

Fig. 5. Contribution of trees, subshrubs and herbaceous vegetation to the total biomass of fine roots in the upper soil layer 0-20 cm.

Biomass of tree fine roots in the layer 0-20 cm is in average 216 – 495 g m^{-2} , additionally 194 - 755 g m^{-2} is fine roots of onground cover. About 70-80% of subshrub fine roots is situated in the upper soil layer 0-10 cm, and 70-80% of larch fine roots are situated deeper in the layer 10-20 cm. Herbaceous fine roots contribute not more than 2.5-3.0% from total fine root biomass and 80-90% of this biomass is situated lower than 5 cm depth.

We suppose that such patterns of fine root distribution can be explained by different strategies of these plant life forms. Sub-shrubs are vegetative mobile life forms that need a shallow root system for vegetative dissemination. Additionally, sub-shrubs are oligotroph species that can survive under xerophytic conditions with low nutrient availability. It allows them to occupy forest litter layer that can be seasonally overdried. Larch is a mesotrophic long living life form that requires higher water and nutrient supply for transpiration and growth needs. In addition, larch roots are very good adapted to growth and functioning under the hypothermal conditions (Prokushkin & Abaimov 2008, Prokushkin & Kaverzina 1988). Grasses growing in these forests are mostly mesotrophic species as well.

It is possible that such stratification of fine roots biomass in the upper soil layer causes different sustainability of these life forms to forest fire events. Subshrubs and grasses are able to the vegetative reproduction and colonization after fire and so they need to have shallow root system. Damage of the larch root system can lead to the death of the whole tree. Thus penetration of larch roots to the deeper soil layers can be one of the elements of strategy of this species, which is necessary for its survival after fires. Studies of some authors (Grier et al. 1981, Ruess et al. 1996, Steel et al. 1997) indicated that fine roots are almost completely replaced each year, i.e., annual mortality of fine roots often exceeds standing fine root biomass even in cold climate forests (Kajimoto et al., 1999) It means that accumulation of the stock of plant detritus due to the vital activity of fine roots and their turnover can provide specificity of organic matter accumulation in the profile of soil in permafrost larch forests.

In addition, so far as about 78% of fine root biomass in the lower soil layer is a tree roots, death of tree stands due to some natural or antropogenic disturbances can lead to the sufficient decrease of fine root biomass in this layer and, as consequence, to the significant decrease of plant detritus mass in the lower part of soil profile (Mukhortova et al., in press).

The similar patterns of tree fine root distribution in the soil of permafrost larch forests where observed in other regions (Zaytsev 2000, 2008). He reported that a big part of tree fine roots biomass in the larch forests of Ural region (near city Ufa) is situated lower than 10 cm of soil depth. As it was shown by other researcher root growth of coniferous trees is generally affected by micro-scale soil condition of three factors: temperatre, water and nutrients (e.g. Friend et al. 1990, Oren & Sheriff 1995) and generaly, carbon allocation patterns vary according to local site conditions (Schulze 1982, Cannell 1985). Despite that we have found similar patterns of fine roots distribution in the soils of larch forests of different regions of Siberia (in northern taiga of Central Siberia and in mountain larch forests of Southern Siberia).

4. CONCLUSION

Understanding the factors controlling fine root production and mortality, which are together called - turnover, is very important for understanding element fluxes in ecosystems.

We have found similar patterns of fine roots and plant detritus distribution in soil of permafrost larch forests in northern taiga of Central Siberia and in mountain larch forests in Southern Siberia. Main reason of differences of fine root distribution of tree roots, roots of subshrubs and roots of herbaceous vegetation can be different life strategy of these plant life forms and their reaction on exogenous impact (such as fire, seasonal drought and soil permafrost). Belowground plant detritus accumulated due to this fine root activity provides specificity of organic matter accumulation in the profile of permafrost soils under the larch forests.

5. ACKNOWLEDGMENT

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