B-2. 2 Analysis and Modeling of Carbon Sequestration of Forest Stands

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Abstract We measured ecological parameters of larch forests in continuous permafrost region in central Siberia, for constructing a model of carbon sequestration at a stand level. The maximum photosynthetic rate of *Larix gmelinii* was 1.5 fold higher than that of Japanese larch. Tree respiration derived from aboveground and belowground part was 112 and 104 $gC/m^2/yr$, respectively. Soil respiration was 331 $gC/m^2/yr$, of which approximately 30 % were root respiration. Biomass allocation rate between above- and belowground was nearly 1:1. This suggests that below ground part is large sink. The unique relationship of self-thinning processes occurred in continuous permafrost region. Soil nutrient status is one of key factors that determine stand development patterns. Soil organic carbon storage and tight nitrogen cycling in the larch ecosystems are discussed.

Key Words permafrost, Siberia, larch forest, above- and below-ground biomass, carbon storage

1. Introduction

The boreal forests is a large carbon pool in terrestrial ecosystems, which stores 3-fold soil organic carbon than tropical forests and 6-fold than temperate forests (Kasischke 2000). The distribution of permafrost affects about 70 % of boreal forests in the Northern Hemisphere, where precise estimation for carbon budget is needed (Potter & Klooster 1997, Schulze et al. 1999).

2. Research Objectives

For construction of carbon sequestration model in a larch forest stand in permafrost region of Siberia, we measured ecological parameters as follows; photosynthetic characteristics, tree respiration, and soil respiration, biomass allocation rate, the relationship between stand density and aboveground biomass, and soil organic carbon storage and nitrogen mineralization.

3. Research Method

We settled research plots in Tura Experiment Forest, managed by Sukachev Institute of Forest, Russian Academy of Sciences. This forest is typical larch taiga developed after forest fires in continuous permafrost region in central Siberia.

Maximum photosynthetic rates of larch and shrub species on north-facing and south-facing slope were measured. Chlorophyll a and b were extracted and analyzed. Respiration rates of above and below ground part were measured by whole-tree system. Soil respiration was also measured together with soil temperature. Tree biomass was measured in several sites, including fine root and ground vegetation. Stand densities in 60 plots were analyzed for biomass estimation. Soil organic carbon was estimated within 1-meter depth of soil. Nitrogen mineralization rate and N cycling in a larch forest were estimated with litterfall N and retranslocated N.

4. Results

(1) Photosynthesis

Light photosynthetic curves were measured *in situ* on representative tree species grown under the contrasting north- and south-facing slopes in central Siberia. Except for *Larix gmeinii* and *Picea ovobata*, maximum photosynthetic rate of trees grown under the north-facing slope was slightly higher than that of the south-facing slope, especially for *Salix* and *Vaccinium uliginosum*. *L. gmelinii* and *P. ovobata* grown on both sides showed similar value of net photosynthesis even though they showed lower value of net photosynthesis of the north-facing slope in late summer. Except for *Juniperus sibirica* on the south-facing slope, shrubs had relatively high photosynthetic rate at light saturation. On an average, chlorophyll content of south-facing slope was slightly larger than that of plants grown on north-facing slope.

Chlorophyll content of *L. gmelinii* regenerated after forest fire was largest among species tested. However, the range of chlorophyll content was similar to those on south-facing slope. Chlorophyll b stands for acclimation capacity to low light environment because Chl. b is tightly connected with light harvesting chlorophyll complex. Therefore, chlorophyll a/b ratio of the north-facing slope was smaller than that of the south-facing slope, which means leaf level acclimation to low light regime was found. Shrubs showed relatively high photosynthetic rate under light saturation. Based on former and present results, we would estimate photosynthetic production by way of photosynthetic responses to light environments of the slopes.

(2) Respiration

We estimated annual respiration rates of soil and above- and belowground parts of larch trees. The annual soil respiration was 331 $gC/m^2/yr$, based on the annual change of soil temperature. This value is within the range of boreal forests (Raich & Schlesinger 1992).

We measured intact daytime whole-plant respiration rates of aboveground parts of 14 larch trees, using various sizes of dark chambers. The sample trees were representatives of the size class distribution in the plot. Irrespective of tree size, the whole-plant respiration rates dependency on temperature was constant, namely Q10 was 2. The relationship between respiration rates r (μmolCO_2/tree/sec) of above- and below-ground parts of whole-plant level related to their fresh weight *w* (kg) by the power function: $r= 0.3866\ w^{0.9116}$ (r^2=0.98).

On the basis of annual change of air temperature and actual measurements, we estimated the annual respiration rates of aboveground parts to be 112 gC/m^2/yr in the control site. Belowground part of 15 sample trees was excavated from soil. We measured the root respiration using the same chambers as mentioned above. Estimated annual root respiration was 104 gC/m^2/yr. Thus, about one thirds of the annual soil respiration rate was derived from root respiration.

(3) Biomass allocation

Total biomass was rather small, ranging from 36 to 41 ton/ha. A sparse forest developed on swampy site had the smallest biomass (16 ton/ha). Biomass allocation ratio (trunk to root ratio: T/R ratio) was stable, ranging from 0.9 to 1.3. Other larch forest in eastern Siberia showed the same T/R ratio, which was extremely low compared to other climate zones (T/R=4～5). Such high accumulation in root system may reflect that larch allocates more carbon to acquire nutrients under nutrient poor soil condition.

(4) Stand density and biomass relationships

According to 60 plots census data in Tura, when the tree density declines less than 5000 individual per ha, maximum aboveground biomass converges at the level of 50 ton/ha. The self-thinning law under constant biomass is not usual pattern. Such biomass convergence occurs around 30 years in the course of regeneration process after forest fire. After 30 years, the aboveground biomass asymptotes at the level of 50 ton/ha.

The phenomena of biomass asymptote in larch forests may be associated with severe soil nutrient condition. Nutrient depletion may be promoted by permafrost table re-rising. Permafrost table descends below 1.0 to 1.5m after forest fire. As the forest floor recovers, it insulates sun heat. Then, the permafrost table again ascends to the undisturbed level after about 30 years. We may conclude that severe climate condition and the specific phenomena of permafrost dynamics controls nutrient availability in larch ecosystems. Therefore, the depth active layers explains maximum (or attainable) aboveground biomass in a given site condition of permafrost.

(5) Soil carbon storage and nitrogen cycling

Mean soil organic carbon storage in soil was 9.73 kgC/m^3 (n=10). Despite of high latitudes near Arctic Circle, inorganic carbon (carbonate C) accumulation occurred at the surface to subsoil on south-facing slope and burnt forest sites. Soil C/N ratio was rather stable among sites, ranging from 18.3 to 22.9.

Soil C/N ratio of central Siberia converges about 20, on the other had, soil C/N ratio of eastern Siberia is less than 15 in most cases. Though both of the regions are the same larch forest ecosystems on continuous permafrost, soil parent materials are different.

Nitrogen cycling in a larch ecosystem are tight and under low N availability, comparing to other northern forest studies (Nadelhoffer et al. 1992). Maximum N mineralization was 4.3 kgN/ha/yr in Tura, which is in the N mineralization regime of tundra ecosystems. According to our estimation for nitrogen economy, 70 % of annual demand of nitrogen were retranslocated N before needle senescence.

5. Discussion

Our results suggest that the peculiar self-thinning law governs larch ecosystems on continuous permafrost region, with T/R ratio (nearly 1.0) and with stable biomass convergence. Soil respiration was in the ordinary range as northern forest ecosystems, whereas nitrogen mineralization rate was so low that serious nitrogen depletion may occur in mature stands. According to our results, two thirds of total soil respiration was derived from organic matter decomposition, i.e. microbial respiration. Microbial activity and competition for soil nitrogen acquisition between plant roots may be a key factor that controls tree growth under severe nutrient condition.

The long-term effect of permafrost table dynamics on the forest stand structure in the course of forest regeneration processes has not been focused and formulated, because most of northern forest ecosystems examined in North America and Europe are on permafrost-free region. Our findings and results in larch ecosystems on continuous permafrost region are very important, since 20 % of northern forests exist on continuous permafrost and totally 70 % of them are associated with permafrost.

References

Kasischke ES, Stocks BJ (eds.) (2000) Fire, climate change and carbon cycling in the boreal forest., 461pp, Springer-Verlag, New York.

Nadelhoffer KJ, et al. (1992) Microbial processes and plant nutrient availability in arctic soils. In "Arctic ecosystems in a changing climate", 281-300pp., Academic Press, Inc., San Diego.

Potter CS, Klooster A (1997) Global model estimates of carbon and nitrogen storage in litter and soils pools: response o changes in vegetation quality and biomass allocation. Tellus 49B: 1-17.

Raich JW, Schlesinger WH (1992). The global carbon dioxide flux in soil respiration and its relationships to vegetation and climate. Tellus 44B: 81-99.

Schulze E-D et al. (1999) Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink –a synthesis. Global Change Biology 5:703-722.