B-6.1.1 Modelling and prediction of CO_2 cycling in the Boreal forests

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Total Budget for FY1996-FY1998 16,200,000 Yen (FY1997 5,441,000 Yen)

Abstract: Soil carbon cycling at a Jack pine (*Pinus banksiana*) forest in Saskatchwan, Canada was analyzed by a compartment model and compared with that at the black spruce (*Picea mariana*) forest. The relative decomposition rates of A_0 layer (8.3 % yr^{-1}) and humus in mineral soil (0.8 % yr^{-1}) in the pine stand were higher than those in the spruce stand (6.3, 0.45 % yr^{-1}, respectively), due to higer soil temperature in the pine stand regardless of the drier soil condition. The species composition, vegetation structure and biomass were measured in both northern and southern black spruce stands for predicting the future dynamics of the stands under global warming. The relationship between carbon assimilation rate and photosynthesis available light intensity was obtained at top, middle and bottom of canopies of both tall and small black spruce trees in August of 1997 and 1998 in the northern and southern boreal sites in Saskatchewan, Canada. The asymtotic values of light-saturated carbon assimilation increased from bottom to top of foliage of the tall trees in both sites, but the symtotic values in southern site were higher than in northern site, while those for small trees in both sites showed relatively lower than for tall trees and no clear tendency with the parts of foliage. The facts suggested that the foliage of small trees has lower photosynthesis capacity than tall trees due to edaphic conditions (e.g., higher ground water table). The lower stand sructure and photosynthesis activity in the northern site might be due to relatively longer soil freezing duration than in southern site.

Key Words Boreal forests, Carbon cycling, Global warming, *Picea mariana*, *Pinus banksiana*

1. Introduction

In the global carbon budget, Intergovernmental Panel on Climate Change (IPCC, 1990)[1) has indicated an imbalance of about 1.6 Gt C y^{-1}, i.e. a "missing sink", in global carbon budget, and four years later it was suggested by IPCC (1995)[2) that up to 1.6 Gt C y^{-1} might be sequestered in terrestrial ecosystems, particularly in the Northern Hemisphere. However, no direct terrestrial measurements of carbon are possible at stand and regional scales. The CO_2 uptake by the ocean may be limited to less than 2.0 - 3.0 Gt C y^{-1} (IPCC, 1990)[1). Most of the imbalance has been assigned to forest ecosystems, in particular, temperate and boreal forests in the Northern Hemisphere (Tans et al., 1990) 3). Nakane et al. (1997)[4) analyzed soil carbon cycling and estimated the carbon balance in mature black spruce (*Picea mariana*) stands, which were most common forest type in boreal region of Canada, suggesting that the black forest stands function as the sink of atmospheric CO_2. In this study an attempt was made to measure and analyze the soil carbon cycling synthetically and quantitatively in a jack pine (*Pinus banksiana*) forest stand, second dominant forest type in the boreal region. To predict carbon balance in boreal forests under global warming, the floristic composition, vegetation structure and productivity were measured at both black spruce forest stands in northern and southern sites of boreal zone, and future their dynamics were discussed.

2. Study sites

The study area for soil carbon analysisi of a jack pine forest stand was the Candle Lake, Saskatchewan (53°55' N, 105°05' W) where is within the Southern Study Area (SSA) of the BOREAS project near Prince Albert. This region has a subarctic climate. The annual mean air temperature and annual precipitation in 1991 - 1993 observed in Prince Albert were 1.5 °C (degree centigrade) and 389 mm, respectively. The monthly air temperature showed a maximum (16.7 °C) in July and a minimum (-16.9 °C) in January. The forest stand is about 50 year-old regeneration after forest fire. The plot (25m x 25m) was set up on drier soil condition (ground water table: 200 cm depth beneath the soil surface). The study was conducted from May 1996 to August 1997.

The study sites for prediction of future vegetation dynamics and productivity under global warming were old black spruce forests within SSA near the Candle Lake and in Southend, Saskatchewan (56°40' N, 103°05' W) about 350 km northt from the Candle Lake. Two plots (50mx10m, 25mx10m) were set up in the both sites for measuring floristic composition, vegetation structure and photosynthesis.

3. Methods

3.1 Soil carbon cycling

Soil temperature was observed continuously using thermistors and a data logger (KADEC-U, KONA system Co. Ltd., Tokyo) at two points in the plot. Litter and surface soil core (5cm across, 5cm deep) samples for the estimation of their moisture content were collected at the time of soil respiration measurement.

Eight plastic funnel-type litter traps of 1mm mesh and with a 0.25 m^2 'mouth' were placed at random 1 m above the ground within the study area. Woody litterfall (leaf, seed (cone), branch & bark, and others) was collected from May 1996 to August 1997.

Evolution of CO_2 from the ground surface was measured using the method proposed by Kirita (1971)[5]. Two sets of the apparatus (cylindrical box), with and without A_0 layer were set on the forest floor, to measure total and mineral soil respiration rates. Eight pairs of the apparatus were fixed in the plots in May 1996.

Loss rate of moss and woody litters, and dead roots was measured by litter bag method.

Amount of A_0 layer was measured in five quadrants (50cm x 50cm) at the time of soil respiration measurement. Two profile pits for mineral soil sampling were dug. Soil samples were collected at each layer at 5 cm depth intervals along the profile by a cylindrical steel sampler (5cm across, 5cm deep). The carbon content of moss and woody litters, F+H layer, mineral soil and roots were determined by carbon analyzer (Model MT-500, YANAGIMOTO).

3.2 Vegetation and photosynthesis in black spruce stands

The species of all trees, and height and diameter of trees more than 1.3 m in height in all subquadrats (5m x 5m) in both plots were identified or measured.

The net photosynthesis rate and stomatal conductance were measured at top, mid and bottom foliage layers of tall and small trees by IRGA (Li-Cor 6400) and photosynthesis - light curves were obtained. The study was conducted in Augusts in 1997 and 1998.

4. Results and Discussion

4.1 Soil carbon cycling in a jack pine forest stand

Based on the data of flows and stocks of soil carbon obtained at a jack pine (*Pinus banksiana*) forest in Saskatchwan, Canada through the years (1996 - 1997), the soil carbon cycling was analyzed by a compartment model as shown in Fig. 1, and compared with that at the black spruce (*Picea mariana*) forest reported by Nakane et al. (1997)[4] (Fig. 2).

Fig. 2 indicates that the relative decomposition rates of Ao layer (8.3 % yr^{-1}) and humus in mineral soil (0.8 % yr^{-1}) in the pine stand were higher than that in the spruce stand (6.3, 0.45 % yr^{-1}, respectively), due to higer soil temperature in the pine stand regardless of the drier soil condition. The most of soil carbon was accumulated at the upper soil layer (0 - 5cm depth) more than in the black spruce stands, where the stock of soil carbon concentrated more surface of soil profile than in temperate and tropical forests. The facts suggested that the soil carbon cycling may be accelarated by global warming more than any other forests in the world, because soil carbon stocks in most upper soil layer and most highest increase of temperature is predicted under global warming (IPCC 1995)[2].

4.2 Comparative study of vegetation and photosynthesis in northern and southern black spruce forest stands.

The floristic composition, vegetation structure, air and soil temperature, and light condition were measured in each plot. The canopy was composed of black spruce of 10~14m in height at Candle Lake and 5~10m in height at Southend, and the openness of the canopy was 25% and 38%, respectively. Fig. 3 shows the relationship between the ratio of tree diameter to height (H/D) and tree diameter (D) in the northern (Southend) and southern (Candle Lake) black spruce stands, suggesting lower tree height in northern site than in southern site, even if the same tree diameter. The aboveground biomass was estimated to be 102t ha^{-1}, 88t ha^{-1} for Candle Lake and 43t ha^{-1}, 51t ha^{-1} for Southend. Soil temperature is below 0 for 5 months of the year in Candle Lake and for 6 months in Southend (Fig. 4). It may cause a negative effect on the growth of black spruce forest stands in Southend.

The relationship between carbon assimilation rate and photosynthesis available light intensity was obtained at top, middle and bottom of foliage of both tall and small black spruce trees in August of 1997 and 1998 in the northern and southern boreal sites, as shown in Fig.5. The asymptotic values of light-saturated carbon assimilation increased from bottom to top of foliage of the tall trees in both sites, while those for small trees showed relatively lower than for tall trees and no clear tendency with the parts of foliage. The facts suggest that the foliage of small trees has lower photosynthesis capacity than tall trees due to edaphic conditions (e.g., higher ground water table). On the other hand, the lower stand sructure and photosynthesis activity in the northern site might be caused by relatively longer soil freezing duration than in the southern site.

The maximum photosynthesis rate of the black spruce under light-saturation in southern site was higher than jack pine and white spruce (*Picea glauca*), but lower than broad-leaved trees (*Populus tremuloides, Corylus americana*) (Meddleton et al. 1997)[6], which are common species in the southern area. It indicates that the black spruce could develope dominantly at the mature stage in these boreal zone in Canada.

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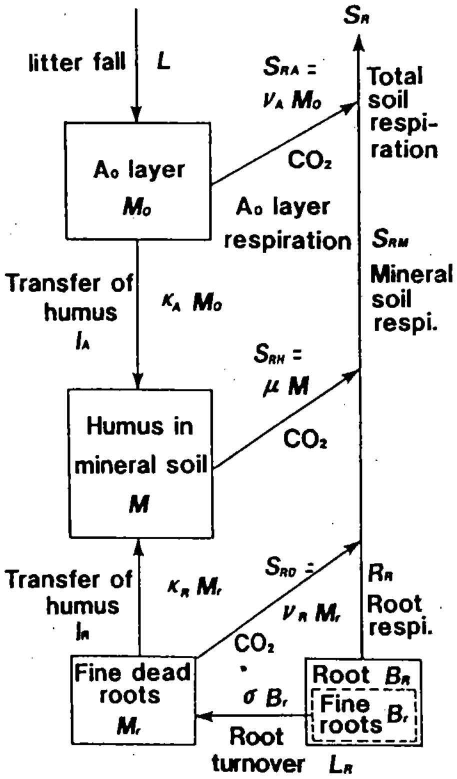

Fig. 1 A Compartment model of soil carbon cycling in forest ecosystem (Nakane 1980)[7]

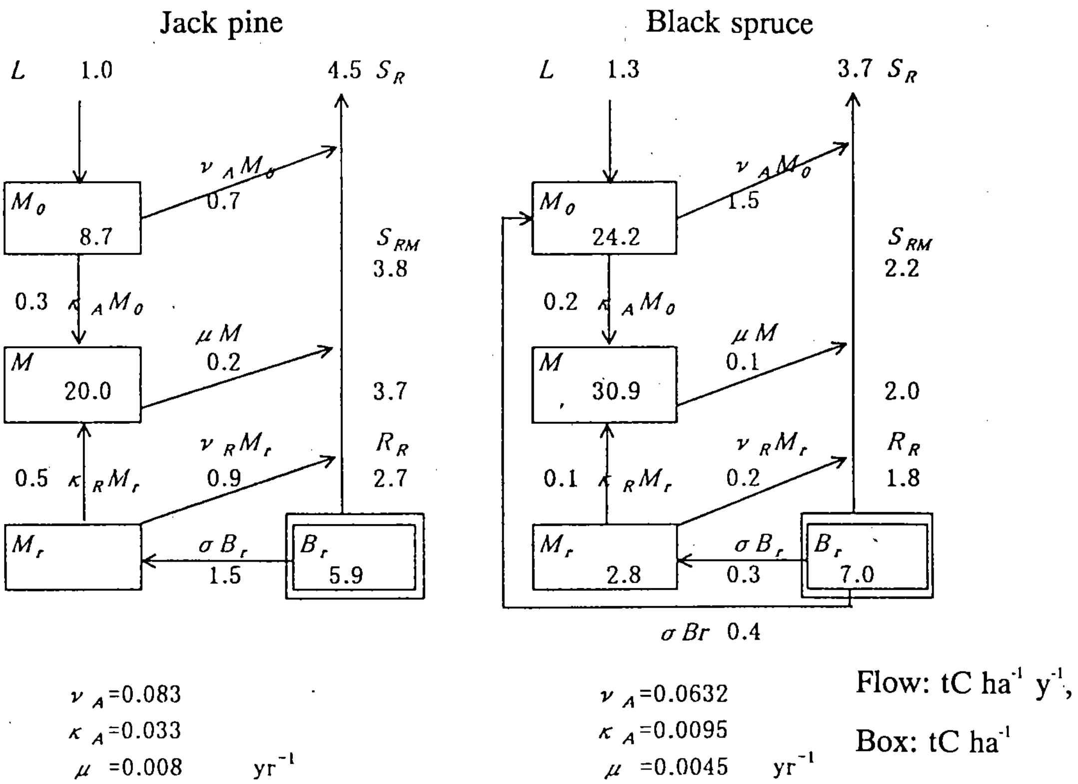

Fig. 2 Comparison of soil carbon cycling between jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) forests in the boreal zone in Saskatchwan, Canada.

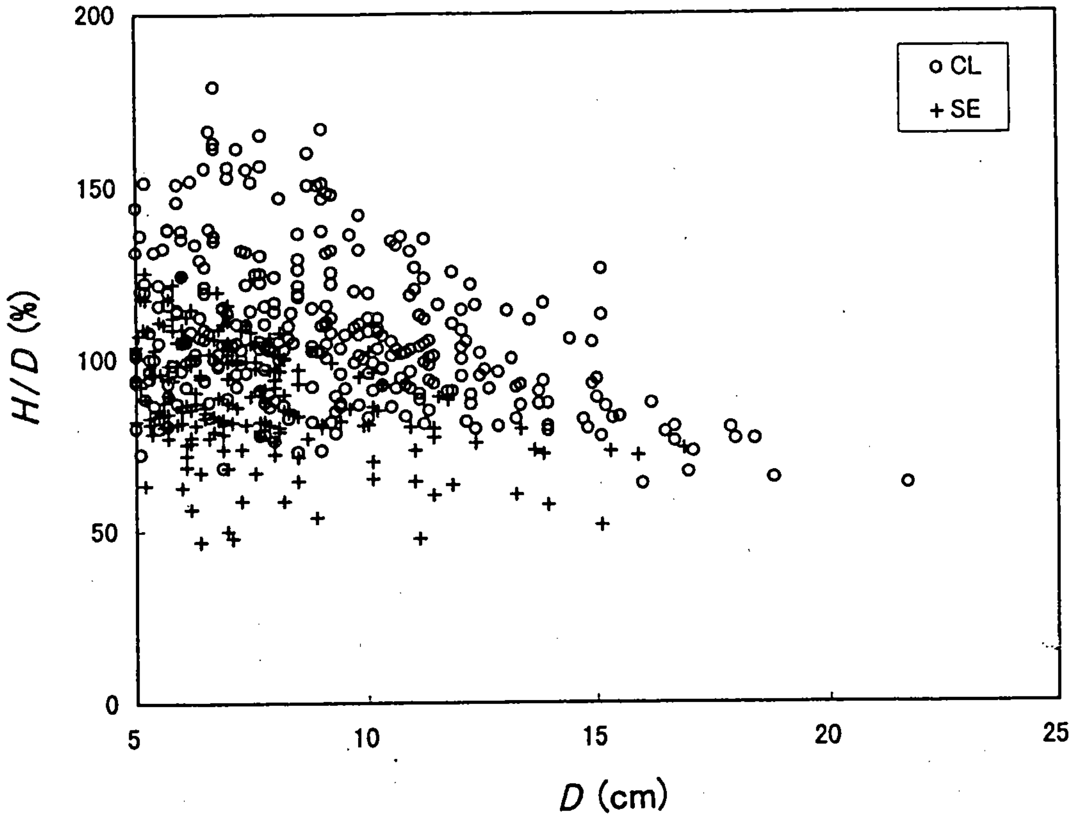

Fig. 3 Relationship between the ratio of tree diameter to height (H/D) and tree diameter (D) in the northern (Southend) and southern (Candle Lake) black spruce stand.
CL: Candle Lake, SE: Southend

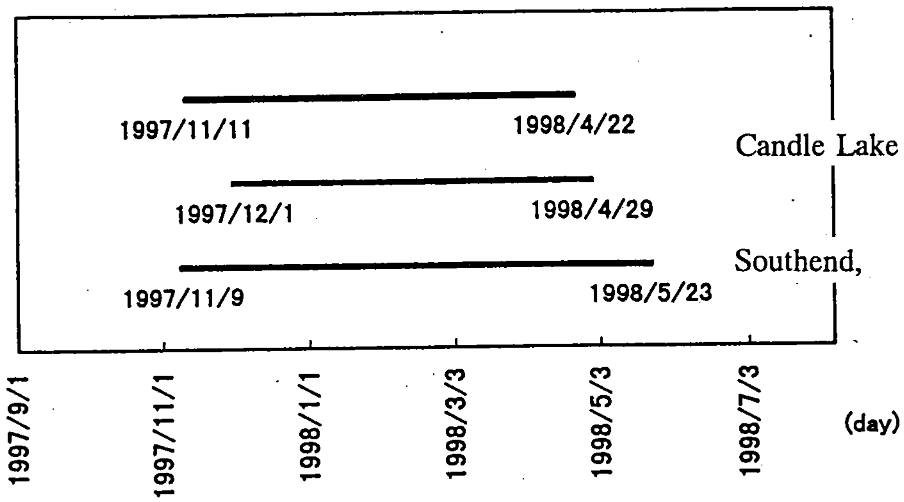

Fig. 4 Freezing duration in northern (Southend) and southern (Candle Lake) black spruce stands, observed in 1997-1998.

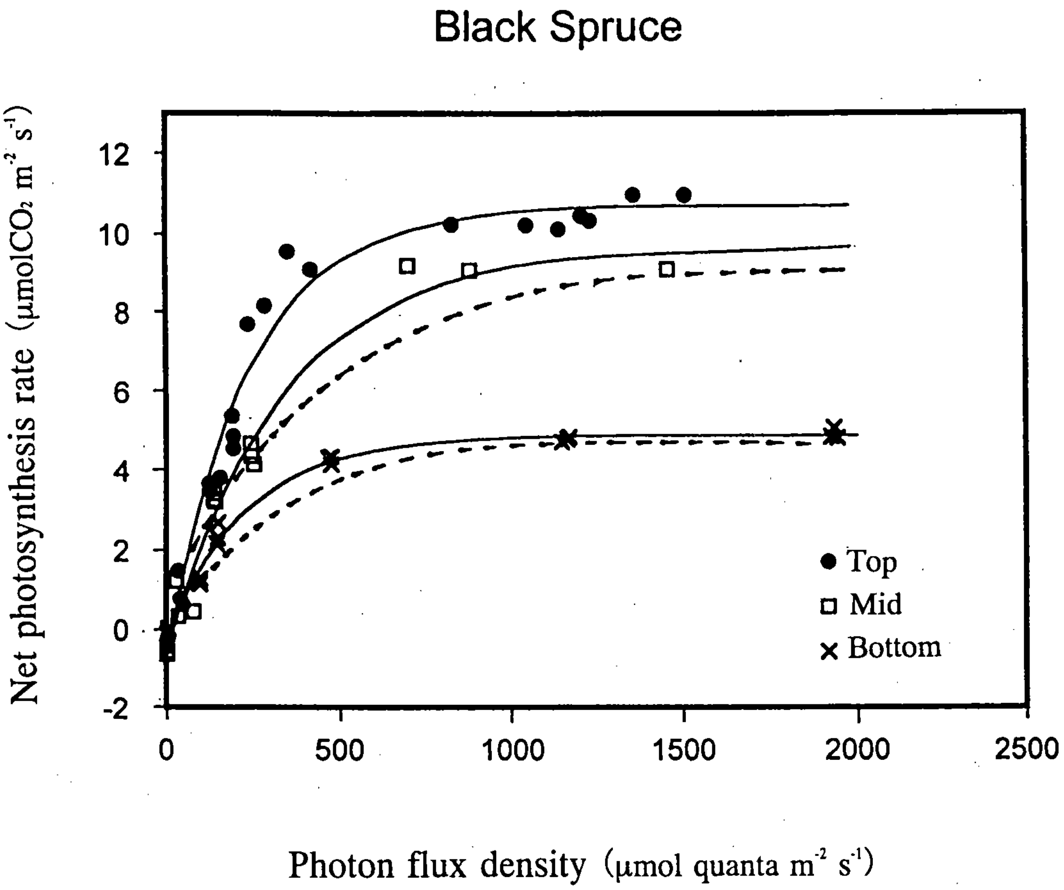

Fig. 5 Relation between net photosynthesis rate and photon flux density at top, mid and bottom layers of black spruce foliage in the northern and southern black spruce stands.
Soild lines: Candle Lake, broken lines: Southend (data were not given)