Preliminary report of environmental regulation of xylem sap-flow at the northern faced forest slope

IIJIMA Yoshihiro[1], ISHIKAWA Mamoru[1], SUZUKI Kazuyoshi[1], DORJGOTOV Battogtokh[2], SHARKHUU Natsagdorj[2], KADOTA Tsutomu[1] and OHATA Tetsuo[1]

[1] Institute of Observational Research for Global Change, JAMSTEC, Yokohama, Japan
[2] Institute of Geography, MAS, Ulaanbaatar, Mongolia

Key words: sap flow, evapotranspiration, phenology, larch forest, northern faced slope

I Introduction

The landscape in northern Mongolia varies grassland to forest with south-north transition. In the upper stream of Tuul River, that is mountain region located north-east of Ulaanbaatar, there is a characteristic ecotone such as north-faced forest slopes and south-faced grassland slopes. Intensive observation is conducting in this area in terms of drainage water cycle and its relationship with cryoshepric environment (Kadota *et al*., 2003). In this research, further observational attempts should be made to estimate evapotranspiration from each land surface in order to understand whole characteristics of water cycle.

Evapotranspiration in forest in complex terrain is, however, difficult to measure under natural conditions due to heterogeneity of forest environments (topography and microclimates). Especially, measuring evapotranspiration using aerodynamical techniques is very difficult to apply in complex terrain. Thus, xylem sap flow measurement which is reliable and inexpensive techniques should be tested.

The objective of the present study is to examine the sap flow measurements using Granier method and to estimate its seasonal variation. In addition, preliminary relationship between xylem sap flow and environmental conditions is discussed.

II Material and methods

1. Study site

The study site is larch (*Larix sibirica* Ledeb) forest of north-faced slope at Terelj (47° 58′ N, 107° 25′ E, 1,646 m a.m.s.l.), located about 50 km north-east of Ulaanbaatar in Mongolia. Characteristic landscape is found in this area; that is, forest distributes mainly on north-faced slope, while grassland dominates south-faced slope. Ground temperature measurements and tomographic surveys had demonstrated the existence of permafrost with the depth of about 2.5 m of active layer in forest site, whereas bare of permafrost under the grassland slope (Ishikawa *et al*., 2003). According to the vegetation measurements in a representative 0.25 ha plot nearby the site, the forest composes mainly larch trees and white birch trees (*betula platyphylla* Sukacz). Tree height of the forest was distinguished two layers, such as canopy and subcanopy layers, separated around 15 m of the height (Fig. 1). Birch trees are mostly within a subcanopy layer. Tree ring counts of sampled cores from canopy trees showed that canopy larch trees are growing over 120-year old.

2. Sap flow measurements

Granier (1985, 1987) developed a method of measuring xylem sap flow that gives an accurate and inexpensive estimate of whole-tree transpiration. Sap flow measurements were made with an apparatus consisting of two cylindrical probes, each 2.5 mm in diameter, that were inserted 2 cm into the sapwood in a tree. The upper probe was installed at a height of 1.5 m and contained a thermal heating at 200 mW. This site, however, could not use constant electricity since location of the site is in remote mountain. Thus, in order to perform longterm observation, intermittent power supply was tested in the present study. These Granier sensors were installed into seven larch trees and two birch trees. Observation was conducted from 6 July to 20 October, 2004. From 6 to 10 July, comparison between sap flows with continuous and intermittent heating was made with three larch trees.

3. Meteorological components measurements

Air temperature, relative humidity, soil moisture, soil temperature and radiation balance were observed automatically at the same site of sap flow measurement within the forest. Precipitation in this site was observed at the opposite south-faced grassland slope. Background global solar radiation and photosynthesis active radiation (PAR) observed at Nalaikh site located 25 km south of the forest site. Measurements were made each 10 minutes, and daily means were calculated and used in the present study.

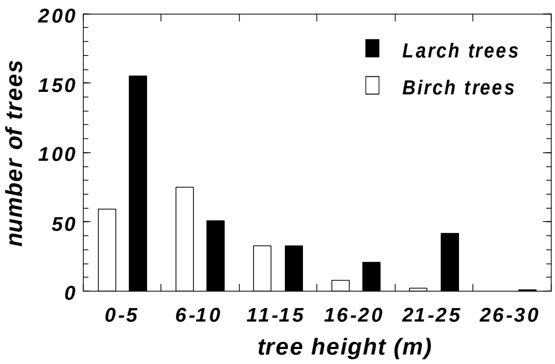

Fig. 1 Distribution of tree height in a 0.25 ha plot in forest site.

III Results and discussion

1. Estimation of sap flow velocity

Seasonal variation in xylem sap flow velocity was estimated using intermittent heating. In order to estimate actual sap flow velocity, comparison was made between intermittent and continuous heating techniques at the beginning of the observation (from 6 to 10 July). Three larch trees were used for the comparison with 1 minute interval data acquisition.

Actual sap flow velocity of Granier method (u; mm/s) is calculated using temperature difference between heated and unheated (reference) probes (ΔT; °C). According to Iida *et al.* (2003), daily maximum of ΔT ($\Delta T_{\max}$) that is observed during a night can be assumed to be a stop of u (0 mm/s). Equations are as follows:

$$u = 1.19 \times 10^4 K^{1.23} \qquad (1)$$

$$K = \frac{\Delta T_{\max} - \Delta T}{\Delta T} \qquad (2)$$

The relationship between intermittent heating (u_i) and continuous heating (u_c) was tested in days of summer (9 and 10 July). As shown in Fig. 2, these two velocities have significant nonlinear relationships, though u_i underestimates 30% of u_c. This can be applied a three dimensional regression curve, that is;

$$u_c = 754.78 u_i^3 - 58.137 u_i^2 + 2.5782 u_i \qquad (3)$$

Seasonal variation in sap flow velocity was estimated using this relationship. However, it should be noted that this is only summer day relationship. Further clarification of seasonal difference in intermittent and continuous heating is needed.

2. Seasonal variation in xylem sap flow

Seasonal variation in sap flow velocity was calculated in seven larch trees. Based on the tree height, we identified canopy trees (three) and subcanopy ones (four), and made average velocities of these layers. In addition, mass flow flux of water through the xylem of trees (sap flux; kg day^{-1}) was estimated using DBH and sap wood area (A_{sw}) relationship, according to results measuring of sap wood length of sixty core samples (Fig. 3). That is;

$$A_{sw} = 0.0155\, DBH^{1.8113} \qquad (4)$$

Uniform sap wood length and circle shape was assumed to calculate A_{sw}. These coefficients are comparable to those made in larch forest in eastern Siberia (Ohta *et al.*, 2001). Thus, sap flux (F) was estimated as follows;

$$F = A_{sw} \times u_c \qquad (5)$$

Fig. 4a shows seasonal variations in sap flow velocity (u) of canopy and subcanopy trees. Maximum of u appeared in July with nearly 15 cm h^{-1} (canopy) and 5 cm h^{-1} (subcanopy). The sap flow velocity in canopy trees is about three times larger than in subcanopy throughout the observational period. Gradual decrease of u was found after mid-August until mid-September. In mid-September, abrupt decrease was observed. During October, weak sap flow sometimes appeared. It is doubtful, however, that this velocity indicates actual sap flow since

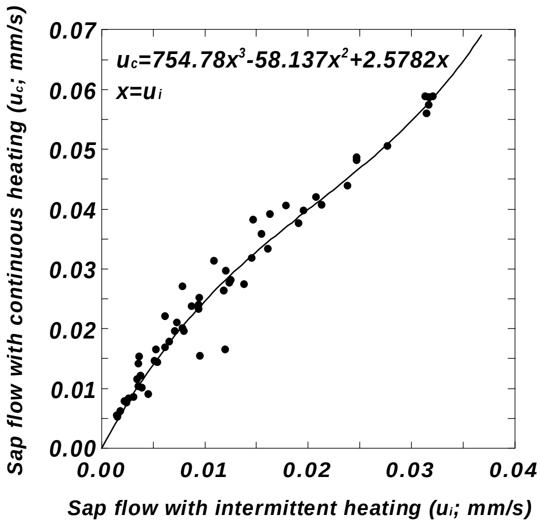

Fig. 2 The relationship between sap flows with intermittent and continuous heating. The curve is a regression with 0.982 of a correlation coefficient.

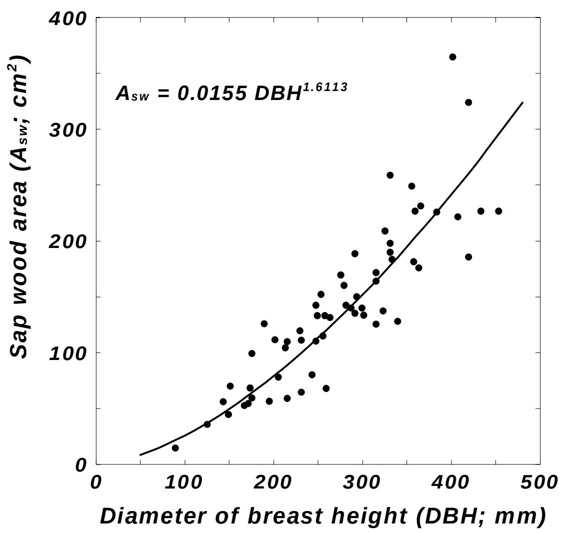

Fig. 3 The relationship between diameter of breast height (DBH; mm) and sap wood area (cm^2). The curve is a regression with 0.914 of a correlation coefficient.

Granier method is low accuracy of weak sap flow and is influenced by water content difference within sap wood (Iida *et al*., 2003). According to the core sampling in late October, it is noted that sap wood was still wet after leaf fall. Thus, physiological response of water uptake after leaf fall should be investigated to clarify this weak sap flow velocity.

Sap flux (*F*) demonstrates remarkable difference in canopy and subcanopy trees due to large difference in sap wood area. The difference of *F* reaches nearly fifteen times during July and August. Comparison with larch trees in Siberia (Arneth *et al*., 1996), although sap wood area, namely DBH, of canopy trees (18 $m^2 \times 10^{-3}$ in average) in this site is nearly three times larger than emergent trees in Siberia (6.7 $m^2 \times 10^{-3}$), sap flux is almost the same intensity in mature season in July (40 to 60 kg day^{-1}).

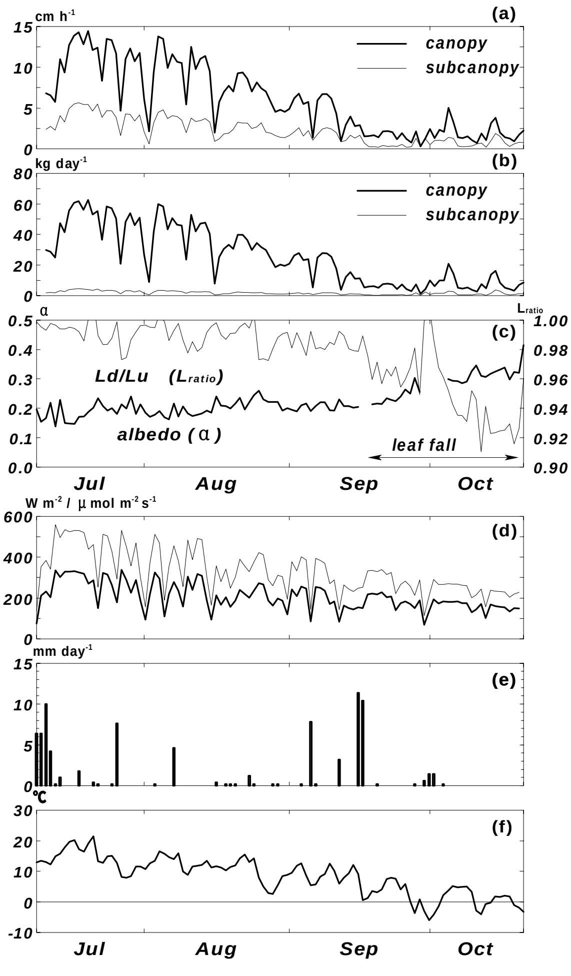

Fig. 4 Seasonal variation in (a) sap flow velocity (*u*) and (b) sap flux (*F*) of larch trees, (c) albedo and longwave ratio in forest site, (d) background global solar radiation and PAR at Nalaikh site, (e) precipitation at grassland slope, and (f) air temperature in forest site from 9 July to 20 October, 2004. Canopy and subcanopy trees are defined as tree heights with more and less than 15 m, respectively.

3. Relationship with environmental factors

Seasonal variation in surface albedo (α) and a ratio of downward to upward longwave radiation (L_{raito}) within the forest demonstrate some phenological change of the larch trees. As shown in Fig. 4c, α with lower than 0.2 and L_{raito} with more than 0.98 during July and August exhibit understory surface and foliated canopy conditions. On the other hand, decreasing L_{raito} and increasing α after mid September denote falling leaves and their accumulation on the surface. Around mid-October 0.3 of α and 0.92 of L_{raito} likely indicate ending of leaf fall.

In mature season from July to mid-August, the maximum sap flow was in conjunction with favorable climatic conditions; that is, high incoming solar radiation, namely PAR (Fig. 4d) with more than 400 μmol m^{-2} s^{-1}, frequent precipitation (Fig. 4e) with 43.2 mm from 9 July to 10 August, large soil water content (not shown), and high air temperature (Fig. 4f) mostly over 15 °C. Gradual reduction of sap flow after mid-August is mainly corresponding with reduction in solar radiation, and in addition, it is likely due to occurrence of dry period with a little precipitation with 2.8 mm from 11 to 31 August. In 26 August, air temperature reduced to 5 °C, senescence (with leaf coloring) may proceed after that event. Further air temperature decrease reaching to 0 °C in 16 September relates with abrupt reduction of sap flow and leaf falling. Generally, sap flow mainly correlates with solar radiation (PAR) in both canopy and subcanopy trees (Fig. 5). However, some climatic events affected the seasonal transition. That is, summer dry period associated with soil moisture variation within active layer and atmospheric dryness, and low temperature events after autumn. Thorough comparison with these environmental

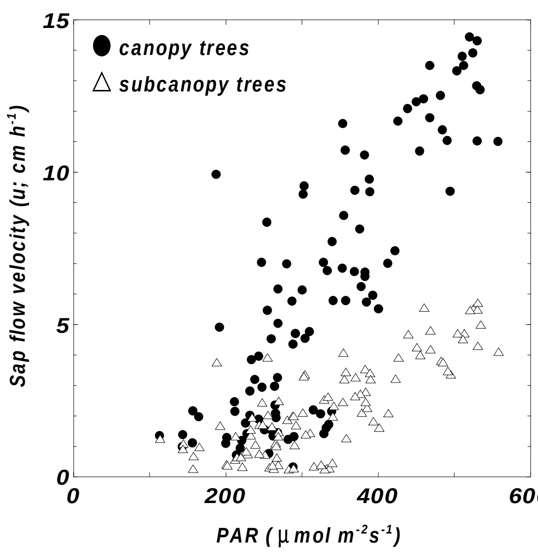

Fig. 5 Relationship between photosynthesis active radiation (PAR) and sap flow velocity of canopy and subcanopy trees. PAR was observed at Nalaikh site.

regulations is necessary, and additional measurements, especially above canopy incoming radiation and water vapor deficit should be made in future study.

IV Conclusions

Preliminary measurement of xylem sap flow in a larch forest of north-faced slope in Terelj, Mongolia, was conducted in the present study. Based on seasonal estimation of sap flow, the relationship with environmental conditions was found. Summarized insights were as follows;

1) Using intermittent heating system based on Granier method, longterm observation of sap flow velocity could be conducted at the remote and non-electricity site. Further clarification of this measurement is needed to observe reliable sap flow.
2) Seasonal estimation of sap flow velocity (*u*) exhibited that canopy larch trees had three times larger than that in subcanopy trees. Furthermore, sap flux (*F*) in canopy trees showed fifteen times larger during mature season in July and August.
3) Generally, sap flow correlates with incoming solar radiation (PAR). However seasonal transition in sap flow, corresponding with senescence of trees, is likely affected due to some climatic signals, such as dryness and low temperature events.

References

Arneth, A., Kelliher, F. M., Bauer, G., Hollinger, D. Y., Byers, J. N., Hunt, J. E., McSeveny, T. M., Ziegler, W., Vygodskaya, N. N., Milukova, I., Sogachov, A., Varlagin, A. and Schulze, E.-D. (1996): Environmental regulation of xylem sap flow and total conductance of Larix gmelinii trees in eastern Siberia. *Tree Physiology*, **16**, 247-255.

Granier, A. (1985): Une nouvelle methode pour la mesure du flux de seve brute dans le tronc des arbres. *Ann. Sci. For.*, **42**, 193-200.

Granier, A. (1987): Evaluation of transpiration in a Douglasfir stand by means of sap flow measurements. *Tree Physiol.*, **3**, 309-320.

Iida, S., Kobayashi, Y. and Tanaka, T. (2003): Continuous and long-term measurement of sap flux using Granier method. *J. Japan Soc. Hydrol. Water Resour.*, **16**, 13-22. (in Japanese with English abstract)

Ishikawa, M., Kadota, T., Zhang, Y., Ohata, T., Sharkhuu, N., Battogtokh, D. and Buyambaa, D. (2003): Frozen ground monitoring by combined use of DC resistivity and neutron probe methods. *The second International Workshop proceedings on Terrestrial Change in Mongolia*, 26-29.

Kadota, T., Amarsanaa, Y., Purevdagva, K., Batkhuu, D., Bayasgalan, J., Oyunbaatar, D., Davaa, G. and Ohata, T. (2003): Study on water cycle in the Khentei Mts., Mongolia – Status of observation in 2003 –. *The second International Workshop proceedings on Terrestrial Change in Mongolia*, 42-44.

Ohta, T., Hiyama, T., Tanaka, H., Kuwada, T., Maximov, T. C., Ohata, T. and Fukushima, Y. (2001): Seasonal variation in the energy and water exchanges above and below a larch forest in eastern Siberia. *Hydrol. Process.*, **15**, 1459-1476.