

## Transpiration of a *Cryptomeria japonica* plantation in winter: analysis based on one-year sap flow measurements

Hikaru KOMATSU<sup>\*1</sup>, Tomonori KUME<sup>\*1, \*2</sup>, Natsuko YOSHIFUJI<sup>\*2, \*3</sup>,  
Norifumi HOTTA<sup>\*2</sup> and Masakazu SUZUKI<sup>\*2</sup>

### I. Introduction

Understanding the forest water cycle in Japan is critical because much of the land surface in Japan, approximately 67%, is forested (TADAKI, 1988; FUJIMORI, 2000). Knowledge of the forest water cycle is essential to solve water resource issues in Japan. *Cryptomeria japonica* plantations deserve particular attention because this type of coniferous evergreen forest is one of the most common forest types in Japan (TADAKI, 1988; FUJIMORI, 2000).

Some of these coniferous evergreen forests were developed by converting broad-leaved deciduous forests (e.g., TSUKAMOTO, 1998). From the viewpoint of water resource management, people believe that coniferous forests evaporate more water than broad-leaved deciduous forests (e.g., TSUKAMOTO, 1998). For examining validity of this common belief, researchers should clarify differences in the forest water cycle between *C. japonica* plantations and broad-leaved deciduous forests (KOMATSU *et al.*, 2005, 2007).

Transpiration is generally a large component of the forest water cycle (e.g., Van WIJK *et al.*, 2001; WILSON *et al.*, 2001). Thus, transpiration of *C. japonica* plantations should be examined. However, very few studies have examined transpiration in *C. japonica* plantations (KOMATSU *et al.*, 2005). Other components of *C. japonica* plantation water cycles, such as interception evaporation, have been previously investigated (e.g., SATO *et al.*, 2003; TANAKA *et al.*, 2005).

We have previously measured transpiration in a *C. japonica* plantation at Shinta experimental site, located ca. 60 km southeast of Tokyo (KOMATSU *et al.*, 2006b). In another study (KOMATSU *et al.*, 2006c), we examined the relationship between meteorological factors and canopy conductance. In this study, we compared the amount of winter and summer transpiration in a *C. japonica* plantation based on 1-year sap flow data. Here, the term “winter” refers to the period between December and April. Broad-leaved deciduous forests in the region are leafless, and therefore, do not transpire in the period (OHNO, 1990). Winter transpiration is one of the most apparent differences between the forest water cycle of *C. japonica* plantations and that of broad-leaved deciduous forests. Thus, an examination of the significance of winter transpiration in *C. japonica* plantations is critical to clarify differences in the water cycle between *C. japonica* plantations and broad-leaved deciduous forests.

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<sup>\*1</sup> Kasuya Research Forest, Kyushu University

<sup>\*2</sup> Graduate School of Agricultural and Life Sciences, The University of Tokyo

<sup>\*3</sup> Japan Science and Technology Agency, Japan

## II. Materials and methods

We used meteorological and sap flow data in 1998 from the Shinta experimental site (35°12' N, 140°06' E, elevation 236 m). *C. japonica* trees were planted at this site in 1980. In 1998, the mean tree height was 7.5 m, and stand density was 1300 stems ha<sup>-1</sup>. The projected leaf area index, estimated using a plant canopy analyzer (Li-Cor, LI-2000), was  $3.7 \pm 0.3$ . This value of projected leaf area index can be converted into 8.9 in total surface area index by assuming the converting factor of 2.4 which is intermediate for conifers (LANDSBERG and GOWER, 1997).

Meteorological factors were measured above the forest canopy. Downward solar radiation was measured using a pyranometer (Eko, MS-42), net radiation was measured using a net radiometer (Eko, MF-11), and air temperature and humidity were measured using a thermometer (Vaisala, VHE). According to the meteorological measurements, the annual rainfall and average temperature for 1998 were 2510 mm and 15.0°C, respectively. Seasonal trends in meteorological factors are shown in Figure 1.

Sap flow was measured in three *C. japonica* trees, referred to as trees #1, #2, and #3. Tree height and diameter at breast height were 7 m and 11.5 cm for tree #1, 5 m and 6.8 cm for tree #2, and 12 m and 19.7 cm for tree #3, respectively. Sap flow measurements were based on the thermoelectric heat-pulse method (CLOSS, 1958; MARSHALL, 1958). The instrumentation consisted of a set of three sensors (HP-1, Hayasi Denko Co., Tokyo, Japan) containing a heater

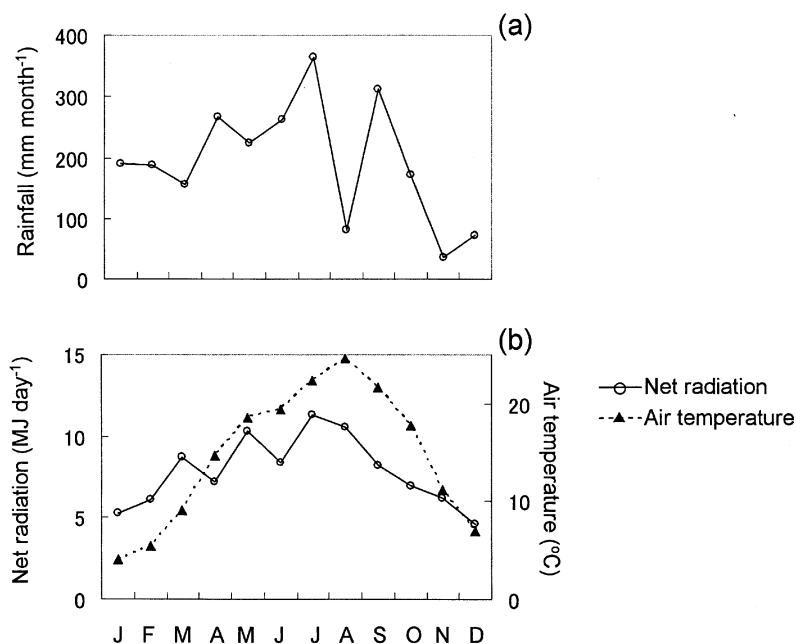


Fig. 1. Seasonal trends in (a) rainfall and (b) daytime net radiation and air temperature. "Daytime" is the part of the day with positive solar radiation.

probe and two thermistor probes (diameter: 2.0 mm; length: 20 mm). The three sensors were installed at the base of the trees in holes drilled to a depth of 15 mm in the outer xylem using a gauge guide. A heat-pulse tracer was released for a duration of 1.5 s every 20 min, and the temperature difference between the thermistor probes was measured every 0.25 s. The time delay for the same temperature increase to occur at both thermistor probes was recorded with a solid-state memory module (CR10X, Campbell Scientific, Logan, UT, USA). To account for the effect of the interruption of sap flow around an implanted sensor, the heat pulse velocity (HPV) was adjusted using Swanson's method (SWANSON and WHITFIELD, 1981; KOMINAMI and SUZUKI, 1993). In addition, we adjusted HPV to satisfy  $HPV = 0$  when the vapor pressure deficit (VPD)  $\approx$

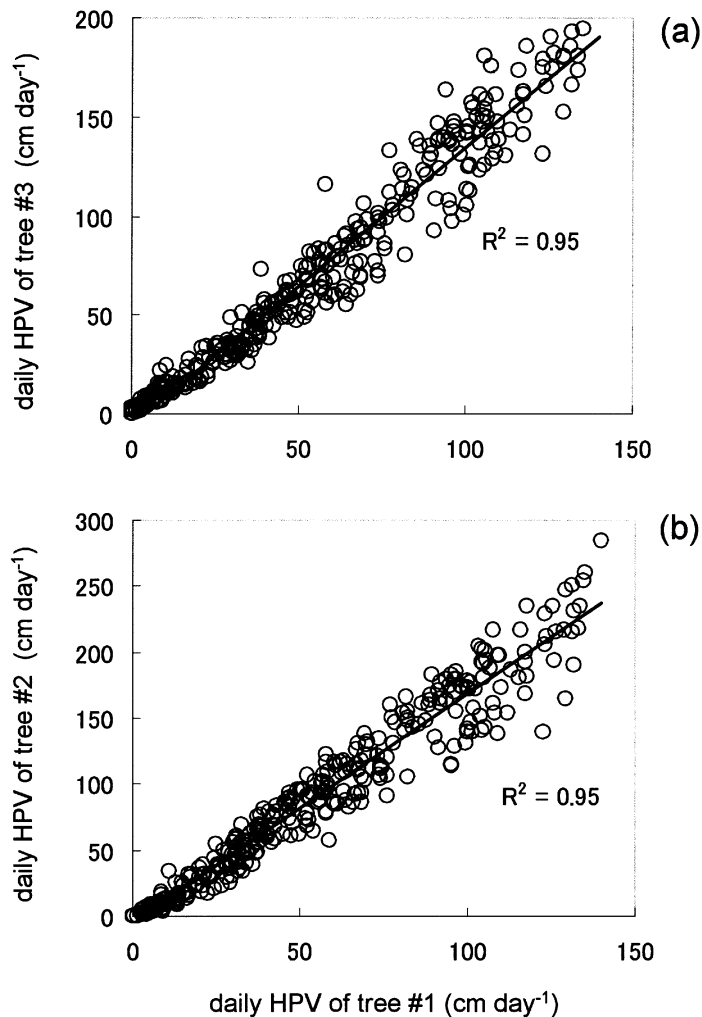


Fig. 2. Relationships in daily HPV (a) between trees #1 and #2 and (b) between trees #1 and #3.

0, in a manner similar to that used by HOGG and HURDLE (1997) and KOMATSU *et al.* (2006c). Although HPV is linearly related to the water uptake rate, HPV remains positive even when no water uptake occurs (HOGG and HURDLE, 1997; KOMATSU *et al.*, 2006b), i.e., the intercept is positive. After the adjustment, HPV is linearly related to the water uptake rate with no intercept (HOGG and HURDLE, 1997).

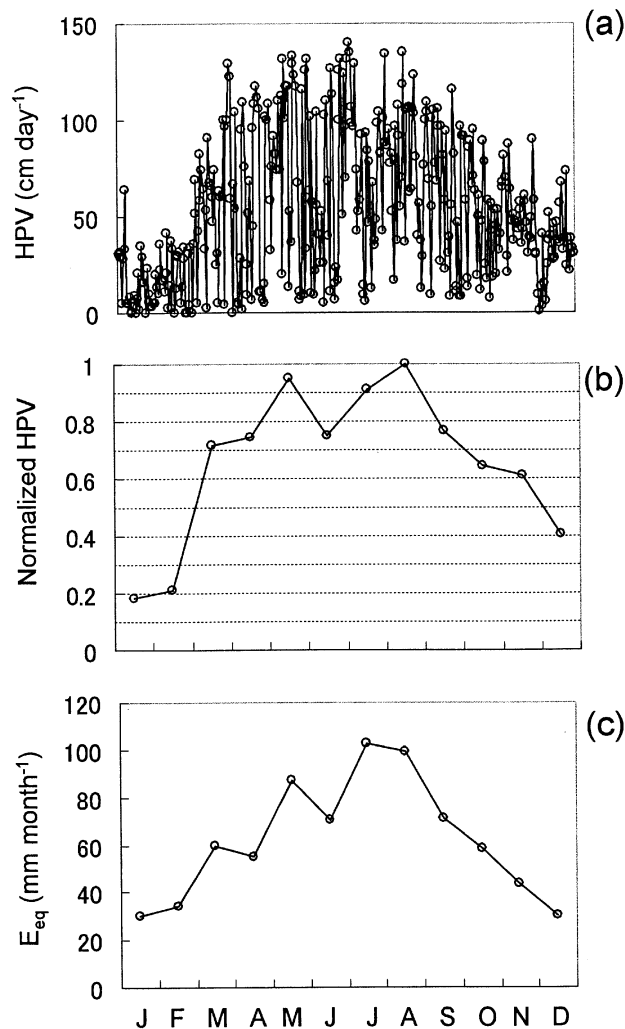


Fig. 3. Seasonal trends in the (a) daily and (b) monthly heat pulse velocity (HPV) of tree #1, and (c) monthly equilibrium evaporation rate  $E_{eq}$ . The monthly HPV was normalized by the HPV in August, when it was at a maximum. The  $E_{eq}$  was calculated using daytime net radiation, not daily net radiation. A soil heat storage of zero was assumed in the calculations. This assumption would not cause much error in the calculation of  $E_{eq}$  because soil heat storage was much lower than net radiation as a result of the relatively dense canopy.

A complete description of the site and all measurements is provided in KOMATSU *et al.* (2006a,b).

### III. Results and discussion

Figures 2a and 2b show relationships in daily HPV between trees #1 and #2 and between trees #1 and #3, respectively. We obtained close correlation in HPV between trees #1 and #2 and between trees #1 and #3. Thus, seasonal trends in the HPV of tree #1 can be used to represent the seasonal trends in canopy transpiration.

Figures 3a and 3b show seasonal trends in daily and monthly HPV for tree #1, respectively. The HPV was higher in summer than in winter (Figures 3a and 3b), and reached a maximum in August (Figure 3b). The HPV in January and February, March and April, and December was ca. 20, 70, and 40% of that in August, respectively. Thus, the HPV in March and April was higher than that in January, February, and December, and comparable with the HPV from March to December.

The relatively high HPV in March and April indicated that the transpiration component of the forest water cycle of the *C. japonica* plantation was quite different from that of broad-leaved deciduous forests in these months. Transpiration of broad-leaved deciduous forests in the region is a rather small component of the forest water cycle in March and April because the trees in these forests are leafless from early December through late April (OHNO, 1990) and because sap flow and therefore transpiration are not observed for deciduous trees in leafless season (e.g., WILSON *et al.*, 2001; YOSHIFUJI *et al.*, 2006).

The relatively high HPV in March and April was caused by relatively high atmospheric evaporative demand and physiological activity of the trees in these months, as described below.

Figure 3c shows the seasonal trends in equilibrium evaporation rates  $E_{eq}$ .  $E_{eq}$  is the evaporation rate from an extended wet surface (e.g., MONTEITH and UNSWORTH, 1990; KOMATSU, 2005) and represents atmospheric evaporative demand.  $E_{eq}$  was higher in March and April than in January, February, and December (Figure 3c), indicating higher atmospheric evaporative demand in March and April.

Figure 4 shows the relationship between  $E_{eq}$  and the HPV of tree #1. The HPV and  $E_{eq}$  had a specific relationship, except during January and February. The HPV in January and February, the two coldest months of the year (Figure 1b), was lower than expected according to the specific relationship, indicating that tree physiological activity was not reduced much in the period between March and December, whereas it was greatly reduced in January and February. Many studies (e.g., ARAIN *et al.*, 2003; RESTREPO and ARAIN, 2005) have also reported that transpiration or evapotranspiration rates relative to  $E_{eq}$  are fairly conservative when tree physiological activity is not greatly reduced, and are lower than expected when tree physiological activity is greatly reduced.

It is unclear at this stage whether the seasonal trends in transpiration described in this study (Figure 3b) can be generalized for *C. japonica* plantations. Meteorological factors vary among

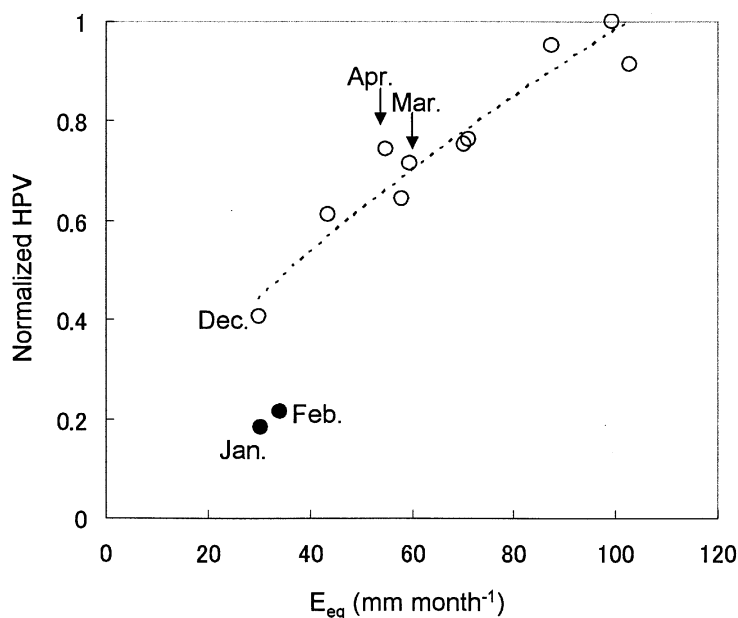


Fig. 4. The relationship between the monthly equilibrium evaporation rate  $E_{eq}$  and monthly heat pulse velocity (HPV) of tree #1. The HPV was normalized by the HPV in August. The regression equation, determined using the least-squares method for data from the period from March to December, was  $y = 0.0467x^{0.662}$  ( $R^2 = 0.93$ ).

sites (National Astronomical Observatory, 2001); annual mean temperature differs by  $\sim 5^\circ\text{C}$  between Kanto and Tohoku regions. Furthermore, meteorological factors vary among years (YOSHIFUJI and KANG, 2002). Therefore, additional studies are required to determine if the seasonal trends in transpiration in *C. japonica* plantations vary annually and with location. Nevertheless, this study is novel because it is the first to describe seasonal trends in the transpiration of a *C. japonica* plantation based on one-year observation data.

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## Summary

*Cryptomeria japonica* plantations, a type of coniferous evergreen forest, are one of the most common forest types in Japan. It is critical to clarify the differences between the forest water cycle of *C. japonica* plantations and that of broad-leaved deciduous forests because as many *C. japonica* plantations in Japan have been converted from broad-leaved deciduous forests. This study examined the significance of the transpiration of a *C. japonica* plantation in winter using one-year heat pulse velocity (HPV) data. HPV would be linearly related to the canopy transpiration rate and was higher in summer than in winter, with a maximum in August. In January and February, March and April, and December, HPV was approximately 20, 70, and 40% of that in August, respectively. The relatively high HPV in March and April indicated that the forest water cycle of the *C. japonica* plantation during these months was quite different from that of broad-leaved deciduous forests in the same region in terms of transpiration.

**Key words:** *Cryptomeria japonica* plantation, Evergreen, Sap flow, Transpiration, Winter

## References

- ARAIN, M.A., BLACK, T.A., BARR, A.G., GRIFFIS, T.J., MORGENSTERN, K., and NESIC Z. (2003) Year-round observations of the energy and water vapour fluxes above a boreal black spruce forest. *Hydrol. Process.* 17: 3581-3600.
- CLOSS, R.H. (1958) The heat pulse method for measuring rate of sap flow in a plant stem. *N. Z. J. Sci.* 1: 281-288.
- FUJIMORI, T., 2000. *Living with Forest*. 236 pp, Maruzen, Tokyo. (in Japanese).
- HOGG, E.H. and HURDLE, P.A. (1997) Sap flow in trembling aspen: implications for stomatal responses to vapor pressure deficit. *Tree Physiol.* 17: 501-509.
- KOMATSU, H. (2005) Forest categorization according to dry-canopy evaporation rates in a growing season: Comparison of the Priestley-Taylor coefficient values from various observation sites. *Hydrol. Process.* 19: 3873-3896.
- KOMATSU, H., HASHIMOTO, S., KUME, T., YOSHIFUJI, N., HOTTA, N., and SUZUKI, M. (2006a) Seasonal trends in the net radiation/solar radiation ratio above a *Cryptomeria japonica* plantation forest. *Bull. Tokyo Univ. For.* submitted.
- KOMATSU, H., KANG, Y., KUME, T., YOSHIFUJI, N., and HOTTA, N. (2006b) Transpiration from a *Cryptomeria japonica* plantation, part 1: Aerodynamic control of transpiration. *Hydrol. Process.* 20: 1309-1320.
- KOMATSU, H., KANG, Y., KUME, T., YOSHIFUJI, N., and HOTTA, N. (2006c) Transpiration from a *Cryptomeria japonica* plantation, part 2: Response of canopy conductance to meteorological factors. *Hydrol. Process.* 20: 1321-1334.
- KOMATSU, H., SAWANO, S., KUME, T., and HASHIMOTO, S. (2005) Relationship between forest properties and evapotranspiration rates. *J. Jpn. For. Soc.* 87: 170-185 (in Japanese with English summary).
- KOMATSU, H., TANAKA, N., and KUME, T. (2007) Do coniferous forests evaporate more water than broad-leaved forest in Japan? *J. Hydrol.* 336: 361-375.
- KOMINAMI, Y. and SUZUKI, M. (1993) Comparison of transpiration rate measured by heat pulse method and water uptake rate in single trees of *Chamaecyparis obtusa* and *Pinus densiflora*. *IAHS Publ.* 212: 27-34.
- LANDSBERG, J.J. and GOWER, S.T. (1997) *Applications of Physiological Ecology to Forest Management*. 354 pp, Academic Press, San Diego.
- MARSHALL, D.C. (1958) Measurement of sap flow in conifers by heat transport. *Plant Physiol.* 33: 385-396.

- MONTEITH, J.L. and UNSWORTH, M. (1990) Principles of Environmental Physics. 291 pp, Arnold, London.
- National Astronomical Observatory (2001) Chronological Scientific Tables 2002. 984 pp, Maruzen, Tokyo. (in Japanese).
- OHNO, K. (1990) Leaf flushing processes of *Quercus serrata* Thunb. Bull. Chiba Cent. Nat. Hist. Muse. 1: 31-27 (in Japanese).
- RESTREPO, N.C. and ARAIN, M.A. (2005) Energy and water exchanges from a temperate pine plantation forest. Hydrol. Process. 19: 27-49.
- SATO, Y., KUME, A., OHTSUKI, K., and OGAWA, S. (2003) Effects of the difference in canopy structure on the distribution of throughfall — a comparison of throughfall characteristics between the coniferous forest and the broad-leaved forest. J. Jpn. Soc. Hydrol. Water Resour. 16: 605-617 (in Japanese with English summary).
- SWANSON, R.H. and WHITFIELD, D.W.A. (1981) A numerical analysis of heat pulse velocity theory and practice. J. Exp. Bot. 32: 221-239.
- TADAKI, Y. (1988) History of Culture between Forest and Human Beings. 211 pp, Nippon Hoso Kyokai, Tokyo. (in Japanese).
- TANAKA, N., KURAJI, K., SHIRAKI, K., SUZUKI, M., SUZUKI, M., OHTA, T., and SUZUKI, M. (2005) Throughfall, stemflow and rainfall interception at mature *Cryptomeria japonica* and *Chamaecyparis obtusa* stands in Fukuroyamasawa watershed. Bull. Tokyo Univ. For. 113: 197-240 (in Japanese with English summary).
- TSUKAMOTO, Y. (1998) Conservation of Forest, Water, and Soil. 138 pp, Asakura, Tokyo. (in Japanese).
- Van WIJK, M.T., DEKKER, S.C., BOUTEN, W., KOHSIEK, W., and MOHREN, G.M.J. (2001) Simulation of carbon and water budgets of a Douglas-fir forest. For. Ecol. Manage. 145: 229-241.
- WILSON, K.B., HANSON, P.J., MULHOLLAND, P.J., BALDOCCHI, D.D., and WULLSCHLEGER, S.D. (2001) A comparison of methods for determining forest evapotranspiration and its components: sap-flow, soil water budget, eddy covariance and catchment water balance. Agric. For. Meteorol. 106: 153-168.
- YOSHIFUJI, N. and KANG, Y. (2002) Meteorology at the Shinta experimental site. In Reports on the Paired-Watershed Experiment at Fukuroyamasawa, University Forests, The University of Tokyo, SUZUKI, M. and OHTA, T. (eds.), 260 pp, The University of Tokyo, 19-26 (in Japanese).
- YOSHIFUJI, N., KUMAGAI, T., TANAKA, K., TANAKA, N., KOMATSU, H., SUZUKI, M., and TANTASIRIN, C. (2006) Inter-annual variation in growing season length of a tropical seasonal forest in northern Thailand. For. Ecol. Manage. 229: 333-339.

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## スギ人工林の冬季の蒸散：通年樹液流計測に基づく解析

小松光<sup>\*1</sup>・久米朋宣<sup>\*1, \*2</sup>・吉藤奈津子<sup>\*2, \*3</sup>・堀田紀文<sup>\*2</sup>・鈴木雅一<sup>\*2</sup>

<sup>\*1</sup> 九州大学福岡演習林

<sup>\*2</sup> 東京大学農学生命科学研究科

<sup>\*3</sup> 日本科学技術事業団

### 要 旨

常緑林であるスギ人工林は日本でもっとも一般的な森林タイプのひとつである。日本のスギ人工林の多くは落葉広葉樹林を伐採して作られたものであり、このような土地利用変化の影響を考えるうえで、スギ人工林と落葉広葉樹林の水循環の違いを明らかにすることは重要である。本研究では、スギ人工林における冬の蒸散量の大きさについて、通年計測されたヒートパルスデータを用いて検討した。林分蒸散量と対応するヒートパルス速度は、夏に大きく冬に小さかった。ヒートパルス速度の月間値は8月に最大となった。1・2月、3・4月、12月におけるヒートパルス速度の月間値は、それぞれ8月の20%、70%、40%だった。このように3・4月においてヒートパルス速度は比較的大きく、蒸散から見た場合、この時期のスギ人工林の水循環は同地域の落葉広葉樹林の水循環と大きく異なることが示された。

**キーワード：** スギ人工林・常緑・樹液流・蒸散・冬季