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Quantitative evaluation of forest floor evaporation and transpiration revealed by soil water content observation in humid temperate pine forests

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Abstract The combined monitoring of soil water content by soil heat conductivity probes and soil matrix potential by tensiometers was done at a Japanese red pine forest site during summer 1997. The total potential distribution during the study period revealed the existence of two separate zero flux planes at depths of 20 and 70 cm. The depth of the shallower zero flux plane was influenced by rainfall events, while the deeper zero flux plane was stable. The deeper zero flux plane was considered to be mainly influenced by the absorption of soil moisture through the root system of the Japanese red pine based on root depth distribution. The daily soil water content recorded by the soil heat conductivity probes was used to evaluate the day-to-day variations of soil water content at the monitored soil depth. The decreasing variations should be the influence of forest floor evaporation, or transpiration through root, or downward soil water infiltration to recharge the groundwater. The total potential distribution monitored by tensiometers can be used to separate those soil water reducing components by the direction of the soil water flow. The combination of the daily soil water content variations, and the soil water flux revealed by the total potential distribution, makes it possible to evaluate the quantitative separation of the forest floor evaporation and the transpiration.

INTRODUCTION

Many studies exist concerning evapotranspiration in forested areas. However, very few discuss the estimation of evapotranspiration using soil water content data (Hodnett *et al.*, 1995, 1996). It is important to understand the soil water regime from the forest floor to the water table, not only for the study of groundwater recharge but also for the study of evapotranspiration.

The decrease in soil water content ought to be influenced by forest floor evaporation, by transpiration through plant roots, or by downward soil water infiltration to recharge the groundwater. This effect can be detected by the continuous monitoring of the soil water content; however it is impossible to separate those

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components only using soil water content. While the total potential distribution observed by tensiometers can trace the daily change of the soil water flux. The object of this study is to evaluate the quantitative separation of forest floor evaporation and transpiration by the combination of the daily soil water content variation data and the soil water flux data revealed by the total potential distribution.

STUDY AREA AND PERIOD

The study site is the Japanese red pine forest at the Environmental Research Centre of the University of Tsukuba (Fig. 1). The soil profile consists of organic forest black soil (0–0.9 m), volcanic ash loam soil (0.9–1.4 m), and clay loam (1.4–1.8 m) (see Fig. 2). The groundwater level varies annually between 1.1 to 2.1 m below the ground surface. Annual precipitation is about 1100 mm and annual evapotranspiration observed by a weighing lysimeter in grassland is about 580 mm. The distribution of the three phases in soil profiles for wet and dry seasons are shown in Fig. 3. The volumetric water content of the soil fluctuates between 40% and 60% depending on the seasonal precipitation.

The study period was from June to October 1997, and included the summer season which is usually characterized by relatively high evapotranspiration rates.

MEASUREMENTS

The volumetric water content was monitored using a heat-probe-type soil moisture sensor. The heat conductance of the soil depends mostly on the heat conductance of

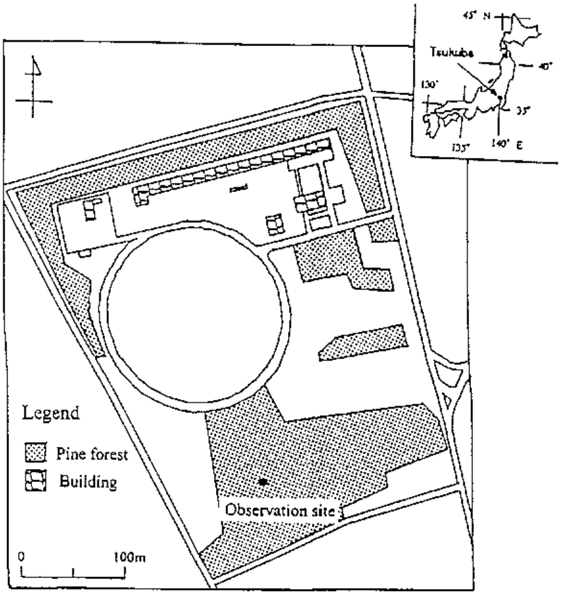

Fig. 1 Location of study site.

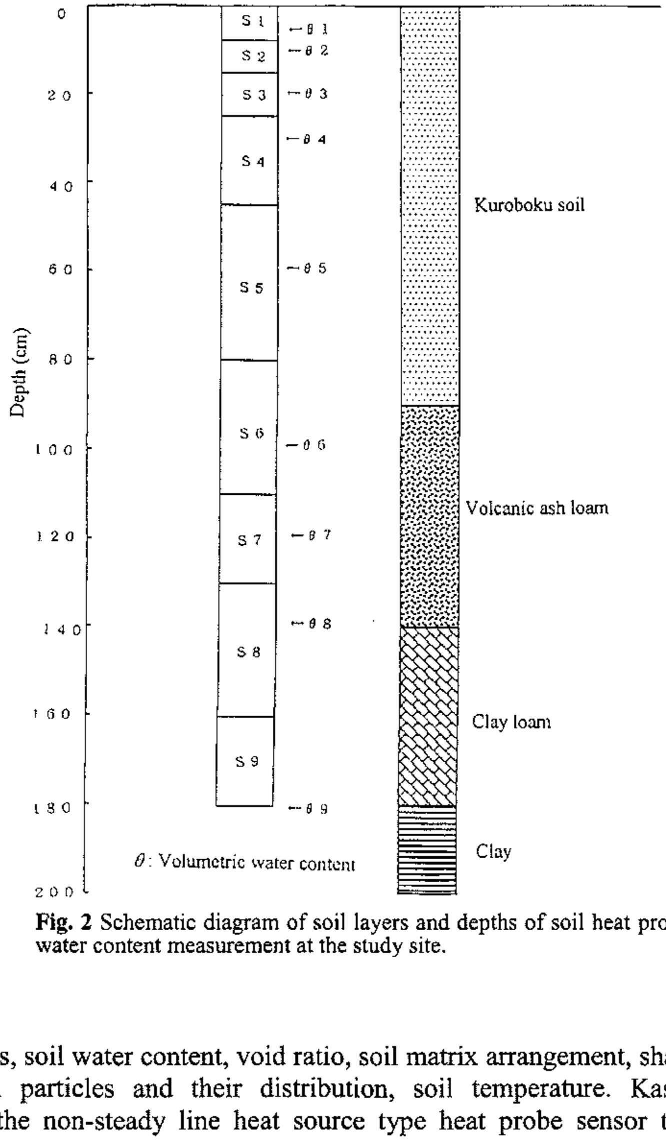

Fig. 2 Schematic diagram of soil layers and depths of soil heat probe sensors for soil water content measurement at the study site.

soil particles, soil water content, void ratio, soil matrix arrangement, shape and the size of the soil particles and their distribution, soil temperature. Kasubuchi (1972) developed the non-steady line heat source type heat probe sensor to measure soil moisture. The probe can monitor soil water content by using the calibration curve between water content and soil heat conductance for the studied soil with an accuracy of ±1 volumetric %. In this study, the sensor was installed at depths of 5, 10, 20, 30, 60, 100, 120, 140 and 180 cm, under the canopy of a red pine forest to monitor daily fluctuations in soil water content. The calibration method between soil water content and heat conductance was that of Shimada *et al.* (1992).

The soil matrix potential was measured by the automatic tensiometer at depths of 5, 10, 20, 30, 40, 50, 60, 70, 100 and 150 cm with an accuracy of ±1 cm H_2O. The pressure sensor for the tensiometer was installed at the same depth as the porous cup to reduce the effect of soil temperature fluctuation. Both soil water content and soil matrix potential were monitored at 30 minute sampling intervals during the observation period.

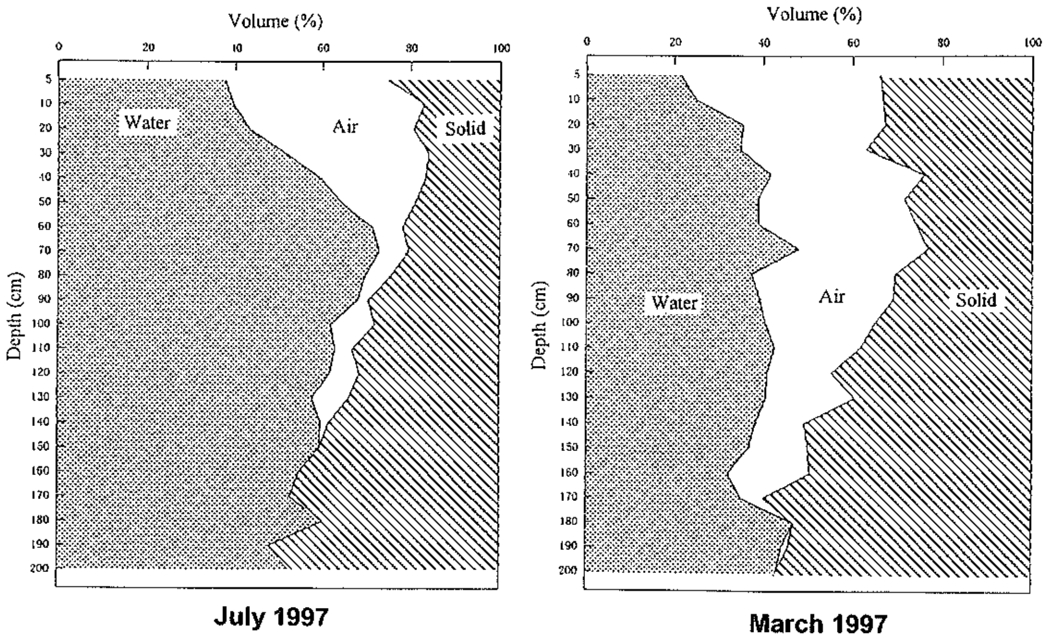

Fig. 3 Three phase distribution of soil profiles for the wet and dry seasons.

RESULTS

Figure 4 shows the variation in soil water content at different depths during the observation period. The shallower depths (0 to 60 cm) show large (over 10% volumetric water content) and clear fluctuation response against the precipitation event, while the deeper portions (below 100 cm) show relatively stable water content response within 10%.

Isopleth diagrams were constructed using the daily average hydraulic head (cm H_2O) from the automatic tensiometer output observed at different depths. To obtain hydraulic head, the elevation head was calculated based on the depth below the ground surface. Figure 5 shows an example of the isopleth diagram for summer at the study site. Two distinct divergent zero flux planes exist (solid lines) for almost all periods. The shallower zero flux plane appeared at depths around 10–20 cm and gradually moved downward during the no precipitation period. It also disappeared after some rainfall events because of the infiltration caused by the related precipitation. On the other hand, the deeper zero flux plane occurred around a depth of 60 cm and remained there during the observation period. The root distribution of the pine forest was as deep as 140 cm but the main root/lateral root development (about 10 mm diameter) was mostly between 0 and 80 cm (Sugita *et al.*, 1986). Thus the deeper zero flux plane may be the effect of extraction by the root system of the pine tree for transpiration. As the study site is flat and no lateral flow can be expected, the existence of these two divergent zero flux planes must be the effect of either the evaporation from the forest floor or the transpiration through the pine tree roots. In the present study, the shallower zero flux plane was considered to be the forest floor evaporation and the deeper zero flux plane was considered to be transpiration through the pine tree.

The daily soil water content observed by the soil heat probe sensors was used to estimate the daily variations of soil water content at the monitored soil column which was determined by the depths between the heat probe sensors (Fig. 2). If soil water content decreased, it was likely due to either the infiltration downward to recharge the

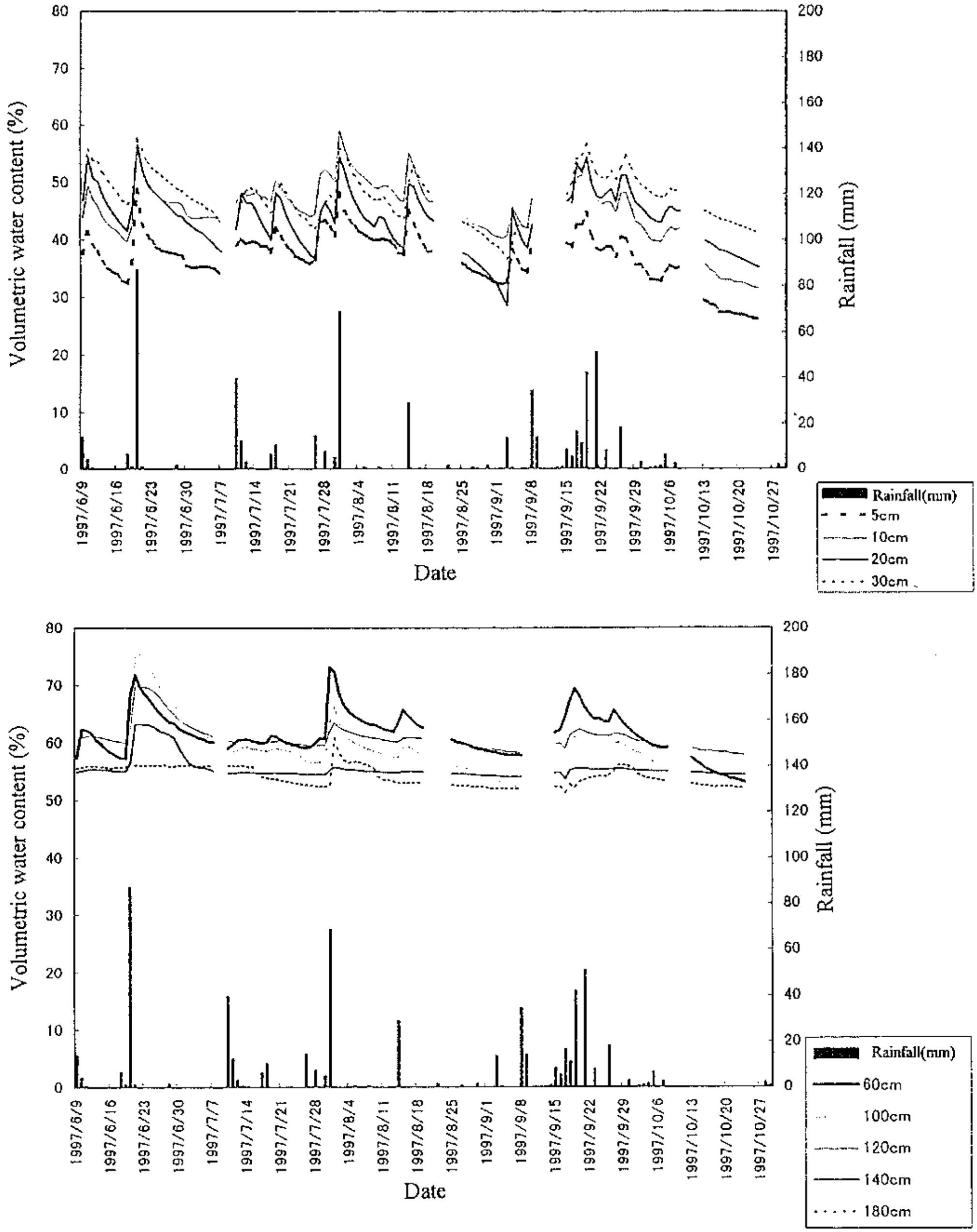

Fig. 4 Variation of soil water content at different depths during the observation period.

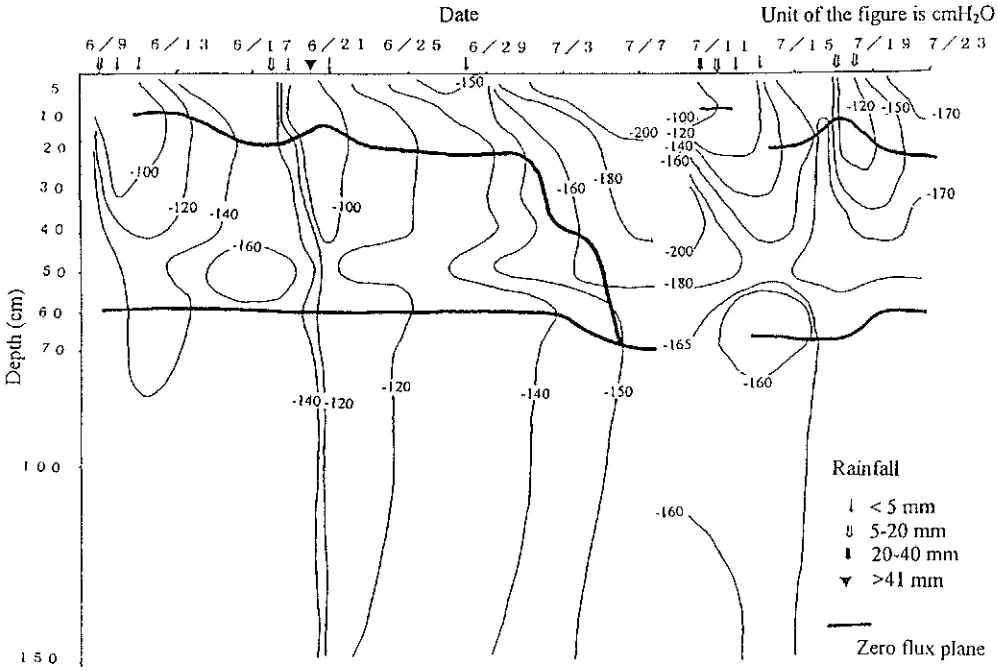

Fig. 5 Example of isopleth diagram of daily average hydraulic head for the summer season at the study site.

groundwater or upward evapotranspiration. The separation of this soil water movement could be done by using the isopleth diagram of the hydraulic head including the zero flux plane. In this study, the day-to-day soil water content decrease caused by the upward soil water movement above the shallower zero flux plane (zone A) was determined to be the result of forest floor evaporation, while the soil water content decrease between the two zero flux planes (zone B) was thought to be the result of transpiration through the pine tree roots. The soil water content decrease below the deeper zero flux plane must be evaluated as groundwater recharge.

Figures 6 and 7 show the fluctuation of the cumulative day-to-day soil water content decreases during the observation period for zones A and B respectively. In these figures, the positive values of the cumulative daily water content show the soil water increase caused by infiltration, and the negative values show the soil water decrease either by evaporation or by transpiration. The maximum evaporation calculated for zone A was 10.3 mm day^{-1} on 21 June 1997, following 87.1 mm of precipitation on 20 June. Maximum transpiration for zone B was 14.6 mm day^{-1} on 20 September 1997, which was after 42 mm of precipitation on 19 September. The total evaporation during the observation period for zone A was 142.2 mm, which is equivalent to a daily average evaporation of 1.29 mm. The total transpiration for zone B was 316.3 mm, which is equivalent to a daily average transpiration of 2.87 mm. The total evapotranspiration for the observation period can be calculated as 458.5 mm which is equivalent to 4.16 mm day^{-1}. Since the total amount of precipitation during the observation period was 562.6 mm, the groundwater recharge was calculated as 104.1 mm for the 5-month period, which is less than 1 mm day^{-1}. The actual evapotranspiration observation data from the weighing lysimeter in grassland at the

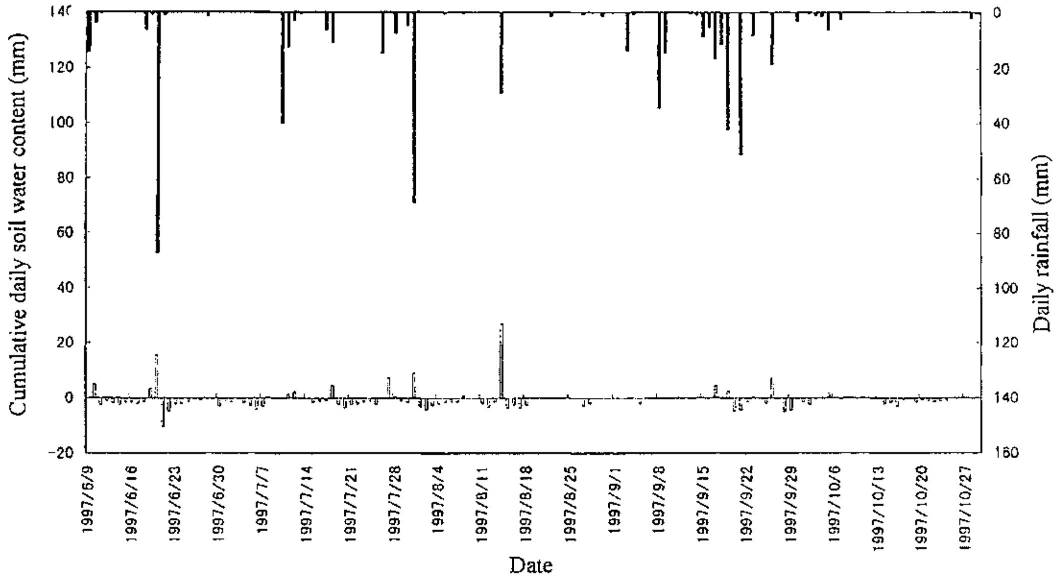

Fig. 6 Cumulative day-to-day soil water content differences for zone A during the observation period.

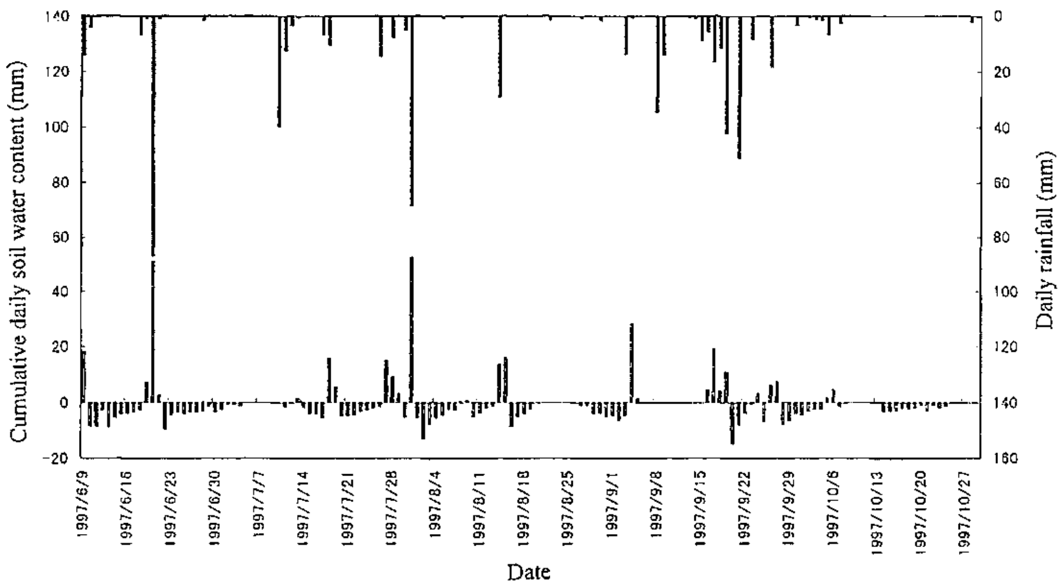

Fig. 7 Cumulative day-to-day soil water content differences for zone B during the observation period.

Environmental Research Centre of the University of Tsukuba was about 2.2 mm day^{-1}. If we consider the difference in the vegetation, the result of the present study can be considered as a relatively representative figure for pine forest evapotranspiration in a warm humid area such as Japan.

CONCLUDING REMARKS

The results of the study demonstrated that the combined monitoring of soil water content by soil heat conductivity probes and soil matrix potential by tensiometers makes it possible to evaluate the quantitative separation of forest floor evaporation and transpiration.

The total potential distribution during the study period revealed the existence of two separate zero flux planes at depths of 20 and 70 cm. The depth of the shallower zero flux plane was influenced by rainfall events, while the deeper zero flux plane was stable and considered to be mainly influenced by the absorption of soil moisture through the root system of the Japanese red pine. The daily soil water content record was used to evaluate the day-to-day variations of soil water content at the monitored soil depth, while the total matrix potential distribution monitored by tensiometers was used to separate those soil water reducing components by the direction of the soil water flow.

The estimated average evaporation during the observation period was 1.29 mm day^{-1} and the transpiration was 2.87 mm day^{-1} for the study site, which was quite a reasonable value for warm humid forest evapotranspiration.

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