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RAINFALL PARTITIONING IN A MIXED WHITE OAK FOREST WITH DWARF BAMBOO UNDERGROWTH

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*Throughfall measurements in a 60-year-old white oak (Konara) stand (*Quercus serrata *THUNB.) with under growing dwarf bamboo (*Sasa paniculata*) were carried out during two periods totaling eleven months, from August to November 1993 and from May to November 1994, in order to clarify the role of Sasa on interception loss and rainfall partitioning in this forest. Eight troughs and spiral-type stemflow gauges connected to tipping bucket-gauges were used for Konara throughfall and stemflow measurements. Ten troughs were used for throughfall measurements under the Sasa canopy. Analyses of seventy-five individual storms showed that partitioning of net rainfall in Konara throughfall, Sasa throughfall and stemflow represent 72%, 68% and 10% of the gross rainfall respectively. The stemflow delivered to the trunk base area represented on average 3.5 times more precipitation than any other place below the canopies of the Konara trees. Also, it was determined that maximum rain intensity was highly correlated with stemflow and this variable explained a further 5.5% of the stemflow variation. The interception loss from the forest canopy was estimated at 18% and the total interception loss of forest vegetation (Konara + Sasa) accounted for 31.7%. Sasa interception loss contribution (13.6% of the gross rainfall) was relatively high accounting for 40% of the total interception of the two canopy layers. The canopy saturation of Konara and Sasa were estimated from continuous storms and showed a value of 0.62 mm and 0.37 mm respectively. The trunk storage capacity was estimated at a value of 0.2 mm. The total amount of water stored in both canopies (Konara + Sasa) was assessed to be 1.2 mm. The results indicate that Sasa vegetation plays an important role in the water balance of this kind of forest and possibly in other types of forests where Sasa is widely distributed.*

INTRODUCTION

Studies of forest hydrology in temperate regions have shown that interception loss, the evaporation which results from rainfall intercepted by forest canopy that evaporates before reaching the ground, is an important component of the total forest evaporation (Gash and Morton, 1978). The most important aspect of surface interception is the proportion of rainfall falling on plant communities which is collected, stored and subsequently lost by evaporation. Measurement and modeling of interception loss from forests is an essential requirement in the prediction of the effects of forests on the water yield of afforested catchments.

Interception is usually measured indirectly as the difference between gross (above the canopy) and net (below the canopy) rainfall. The latter is calculated by summing the total throughfall (canopy drip) and stemflow (Voig, 1960; Mitscherlich, 1971; Heuveldop *et al*., 1972; Weihe, 1974; Jackson, 1975; Bultot *et al*., 1976; Tanaka *et al*., 1984; Loustau *et al*., 1992). However, this rainfall interception was often investigated (or restricted to) the forest canopy of artificial plantations with the assumption that the interception of ground vegetation was negligible or not measured because of the problems involved with the investigation of these vegetative layers.

The objective of the present work was to study the rainfall partitioning in a representative mature white oak (Konara) stand (*Quercus serrata* THUNB.) and the role of undergrowth dwarf bamboo (*Sasa paniculata*) on the forest interception loss. This ground vegetative cover is an important consideration, since the Sasa plant is widely distributed throughout Japan and is also an undergrowth component of various forest canopies. In the past, researchers have pointed out that the amount of interception by dense herb layers in openings is comparable to interception by the forest canopy (Gash and Stewart, 1977; Scatena, 1990).

In Japan 25 million hectares are covered by forests, which is approximately 70% of the country and 30% of these woodlands are classified as protected forests, such as Water Conservation Forests which contain upper streams of rivers and water reservoirs (NLAPO 1991). Broad-leaved forests occupy about 38% of the forested area in the Chugoku region in Japan and therefore it is of interest to investigate the hydrological properties of these forests. The ability of canopies to intercept and store water and materials is important for other reasons also. In forest operations, aerially sprayed pesticides and fire retardants are more effective the longer they are intercepted and stored by vegetation. The trapping of salts, dust and air pollutants on the canopy is also an important environmental consideration.

MATERIALS AND METHODS

Study Area and Stand Characteristics

The study area is located in the Hiruzen Experimental Forest of Tottori University, Okayama Prefecture, 80 km Southwest of Tottori City, Japan, (35° 19' N, 133° 35' E). A plot (20 x 20 m) with a dominant over story of 60-year-old Konara trees (*Quercus serrata* THUNB.), and an undergrowth of dwarf bamboo (*Sasa paniculata)* (Kawahara, 1983) was selected at an elevation of 750 m (Figure 1). The mean annual temperature and precipitation are 11.3 °C and 2140 mm (1600 mm from April to November), respectively (Tottori Univ., 1991). The climatic diagram of the Hiruzen area is shown in Figure 2.

According to NLAPO (1991), 20,000 years ago the vegetation of this area was a cool temperate,

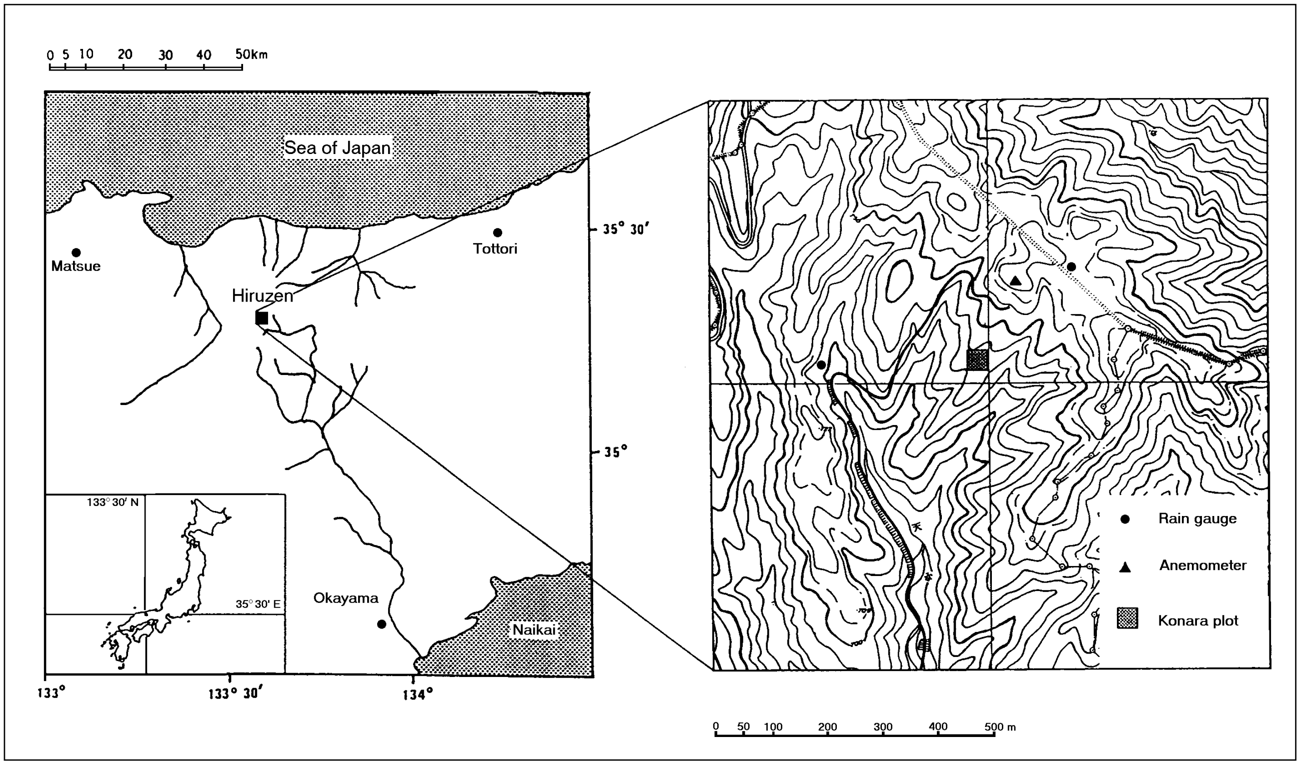

Figure 1. Location of the study site and positioning of instruments (rain gauges and anemometer) at Hiruzen.

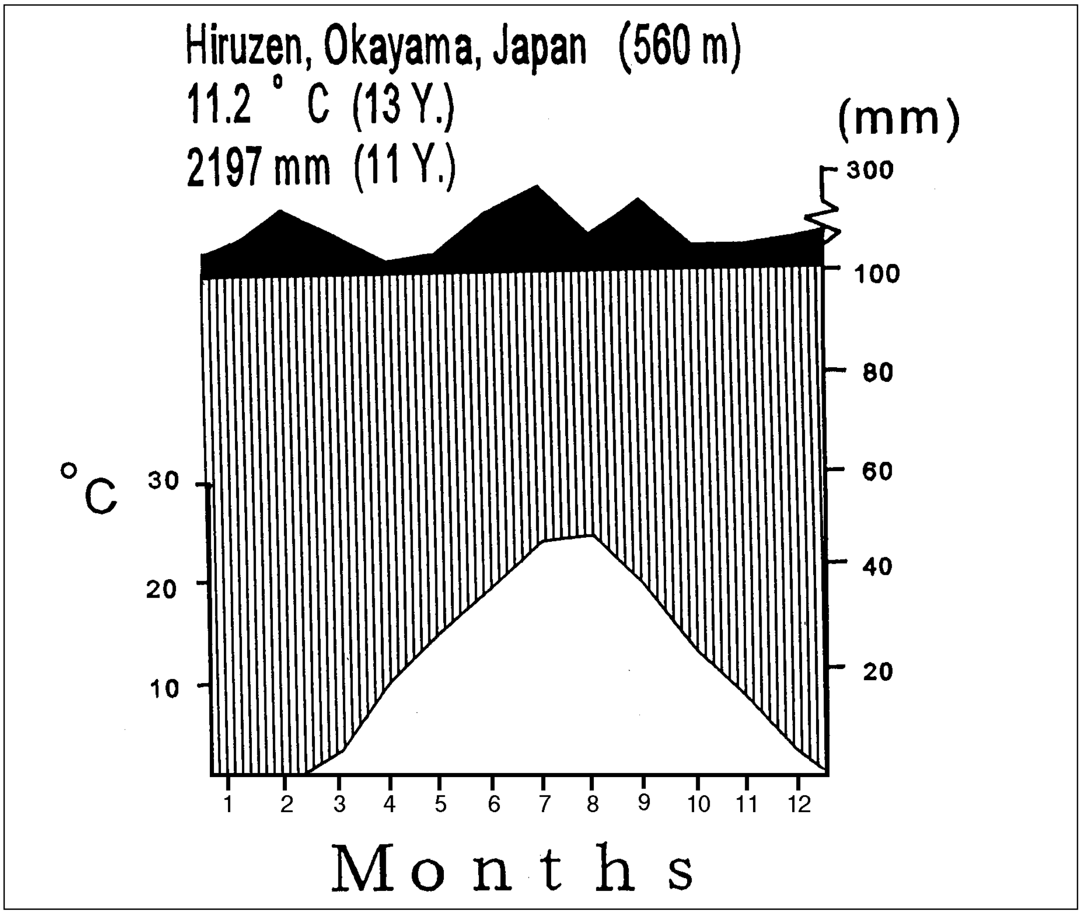

Figure 2. The climatic diagram of Hiruzen area in Okoyama Japan.

deciduous, broad-leaved forest; now the typical vegetation is broad-leaved trees, such as Kunugi *(Quercus acutissima Carruth.)* and Konara. The latter is distributed everywhere in Japan except in Hokkaido (Figure 3). Stand characteristics as mean tree height and mean tree crown area were estimated to be 14.6 m and 21.5 m^2 respectively. Also, the averaged annual leaf dry weights were determined from litter fall measurements using a factor of leaf area per unit of weight of 18 m^2Kg^{-1}. The leaf area index of this stand was estimated at a value of 5.2. The vertical crown projection of trees is shown in Figure 4.

Soil types are Ando soils, generally called volcanic ash soils, and the traditional name, Kurobokudo (black fluffy soils) is also widely used. Kurobokudo have developed from pyroclastic materials or parent materials relatively rich in pyroclastic materials formed by past eruptions of the Daisen volcano. They are characterized by a high organic carbon content (usually exceeding 5%), low bulk density (less than 0.85 g cm^{-3}), high values of exchangeable Al (Otowa, 1986) and soil pH values between 4.5-5.7 (Tottori Univ., 1991).

Measurement of the Rainfall Partitioning Components

After each rainfall event, precipitation in the open area (gross rainfall), Konara throughfall and stemflow were analyzed from August-November 1993 and May-November 1994. During winter, from December to March, no attempt was made to carry out measurements due to heavy snowfall. The research was based on the analysis of individual storms. Thus, only storms preceded by at least twelve hours or eight-hours daylight without prior rain were considered, on the assumption that the canopy was dry (Mitscherlich and Moll, 1970; Jackson, 1975; Gash and Morton, 1978; Rowe, 1983) (Table 1). A total of 75 storms was analyzed and continuous events were selected to obtain the canopy storage capacity. A continuous event is when rainfall data are successive, showing dry gaps which could still occur but of short minutes duration. Errors in the measurement of rainfall, throughfall, and stemflow and their implications for the estimation of interception, are more noticeable in an event-base study (Crockford and Johnson, 1983) than in period-based studies because of the possible canceling of errors in the latter.

Table 1. Time Between Storms Required to Allow a Canopy to Dry Out Completely (After several authors)

Author	Time (hrs.)	Canopy Type
Mitscherlich & Moll 1970	12	Douglas fir-Beech
Jackson (1975)	12	Tropical Forest
Gash & Morton (1978)	8	Pinus
Rowe (1983)	12	Beech
Sambasiva (1987)	8	Cashew Trees
Pook at all. (1991)	4	Pinus-Eucalyptus
Giacomini & Trucchi (1992)	4	Beech
Kelliher at al. (1992)	3.3	Pinus

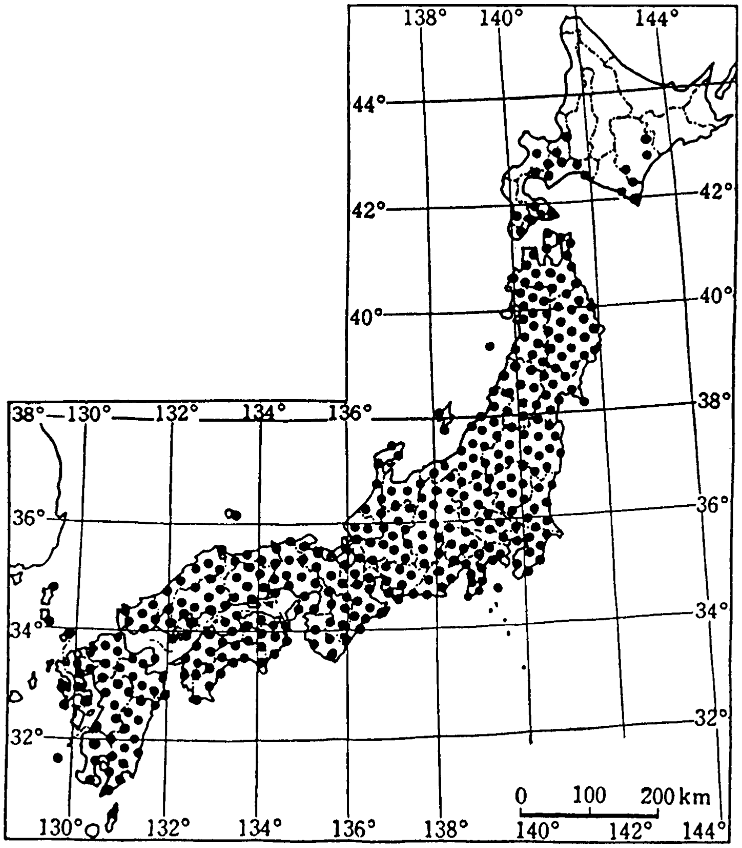

Figure 3. Distribution of Quercus serrata throughout the Japanese archipelago.

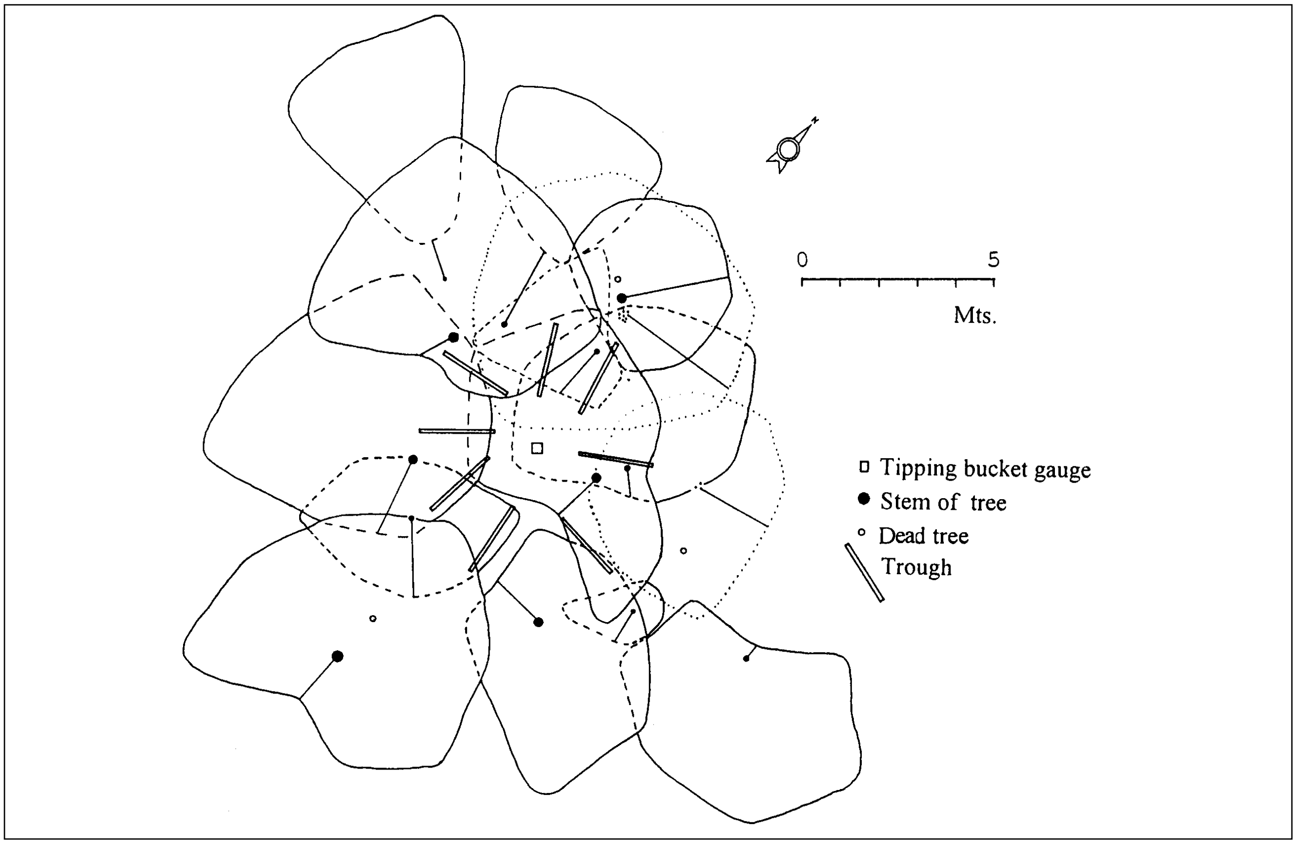

Figure 4. Vertical crown projection map of trees in the Konara plot.

- Gross Rainfall

Three tipping bucket-gauges, one of 0.1 mm and two of 0.5 mm resolutions, were set at 1.5 m above the soil surface in the open area neighboring the experimental plot (Figure 1). Data were stored in KADEC-UP recorders at one and 10-minute intervals respectively. Net rainfall in this study was considered as the quantity of rainfall that reaches the forest floor, the sum of throughfall and stemflow.

- Tree Canopy Throughfall

A plot of 10 x 10 m was selected and troughs were used to collect the throughfall. Because troughs form a continuous transect, they should be more effective in overcoming throughfall variability. Thus, eight V-shaped plastic troughs of 20.5 cm width and 2 m length, which have a cross-section similar to the ideal rain-gauge funnel were set at 1.6 m above the soil surface. Troughs were arranged in a circle and four of them were connected to one 500-cc tipping-bucket gauge by plastic hose of 1.5 cm diameter. This system gave a throughfall resolution of 0.31 mm and data were stored in a Maxell memory card for TEAC DL-101M recorder (eight channels) at 1-minute intervals. Another four troughs were connected individually to standard tipping-bucket gauges giving a system of high precision, which was useful in small rain events to assess throughfall resolutions of 0.039 mm; these data were stored in a KADEC-UP recorder at 1-minute intervals. Inside the troughs a plastic net was used as a strainer to retain litter, which was removed weekly to avoid obstructing water flow into the gauges.

- Stemflow

Stemflow water was measured from the flow on the stems in 16 trees. A wired rubber hose 3 cm in diameter with perforations of 1.5 x 2.5 cm at 4 cm intervals was set on the stems at 1-1.5 m height to make spiral-type stemflow gauges. Every stem was prepared (without bark) by setting the hose on a smooth surface. The stemflow gauges were pressed against the stem along the previous cleaned smooth surface and fastened closely to the trunk. The upper and lower parts of the hose were held by wire and sealed with silicone. Each trough formed two and a half loops around a stem at an angle approximately 30° to the horizontal plane. Twelve trees were connected in groups of four stems to 50-cc tipping bucket-gauges and data were stored at 1-minute intervals in a TEAC DL-101M recorder. In addition, stemflow from another four trees was collected individually and measured in standard tipping-bucket gauges, data were stored in a KADEC-UP recorder at 1-minute intervals. From the crown area a conversion factor was obtained for each tree to change volume of water to mm depth.

The layouts of the instrumental design of the Konara plot are shown in Figure 5.

- Undergrowth Dwarf Bamboo (Sasa) Throughfall

A plot 10 x 10 m was selected adjacent to the Konara throughfall measurement plot. Ten V-shaped plastic troughs of 10.4 cm wide and 2 m length were set on a gentle slope, directly on the soil surface, underneath the dwarf bamboo. Troughs were arranged parallel transect perpendicular to the slope and connected by PVC pipes of 1.5 cm diameter to a central pipe of 5 cm diameter. The flow of this collecting system was measured in a 500-cc tipping-bucket gauge. This system gave Sasa throughfall resolutions of 0.24 mm and data were stored in a KADEC-UP recorder at 1-minute intervals. Inside troughs a plastic net was used as a strainer to retain litter, which was removed weekly to avoid water flow obstruction to the gauge. The instrument layouts and experimental design of the Sasa plot are diagrammed in Figure 6.

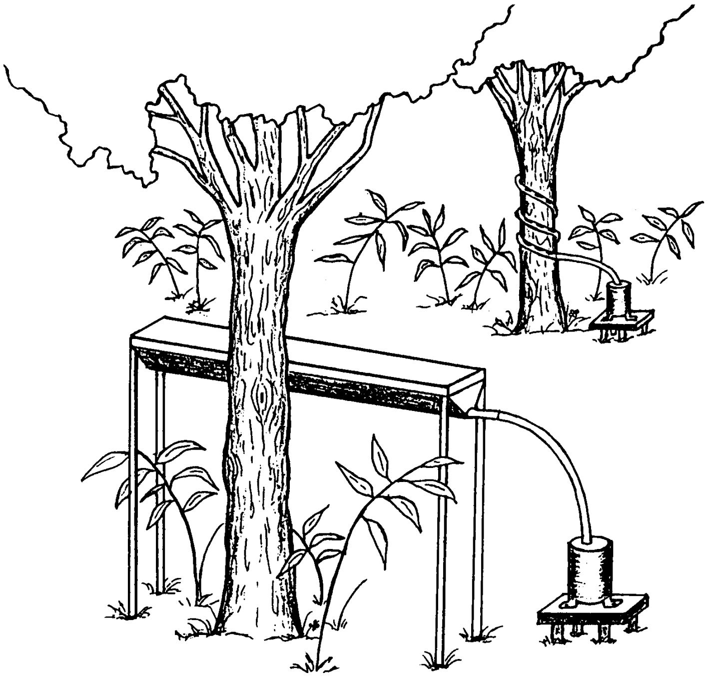

Figure 5. Layout of instruments in a natural forest stand.

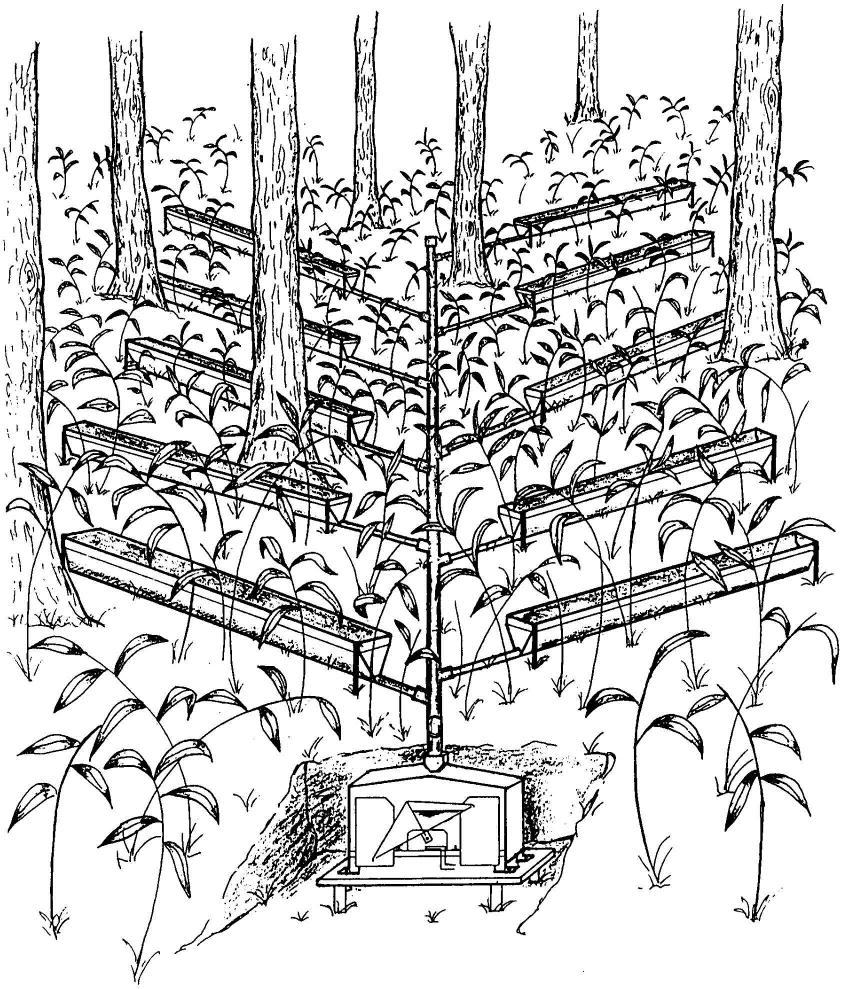

Figure 6. The instrument layout and experiment design in the undergrowth dwarf bamboo plant.

- Windspeed

Windspeed was monitored by means of a 3-cup anemometer placed 1 m above the forest canopy near to the plot (Figure 1). Data were stored in a KADEC-UP recorder at 1-minute intervals.

Estimation of Canopy Storage Capacity

Interception loss is governed by the number of wetting and drying cycles on the vegetation, these in turn, will generally be related to the number and size distribution of the showers. The relevant characteristic of the vegetation is the amount of water stored in the canopy in a single shower sufficient to exceed the capacity of the vegetation to retain water on its surface. This characteristic is known as the interception storage capacity or canopy saturation value. (Leyton *et al.*, 1967). Thus, Konara canopy storage capacity was determined by plotting gross rainfall(R) versus net rainfall (Nr) for individual continuous storms up to 2 mm; extrapolating the relationship between Nr and R to find the amount of rain that falls before throughfall begins, i.e., R at Nr=0. Total interception storage capacity was estimated from the data of continuous rainfalls exceeding 3 mm, which were considered likely to wet both the Konara and Sasa canopies, using the method mentioned above.

RESULTS AND DISCUSSION

Meteorological Factors

The daily rates of meteorological factors (temperature, evaporation, relative humidity and precipitation) for 1994 were monitored in the climatological station at the experimental forest in Hiruzen (Figure 7). During this year there occurred an unusual minimal precipitation throughout the months of June-August and the temperature reached maximum value above 30 C. On the other hand, total rainfall for 1994 represented 55% of the mean normal precipitation for this area.

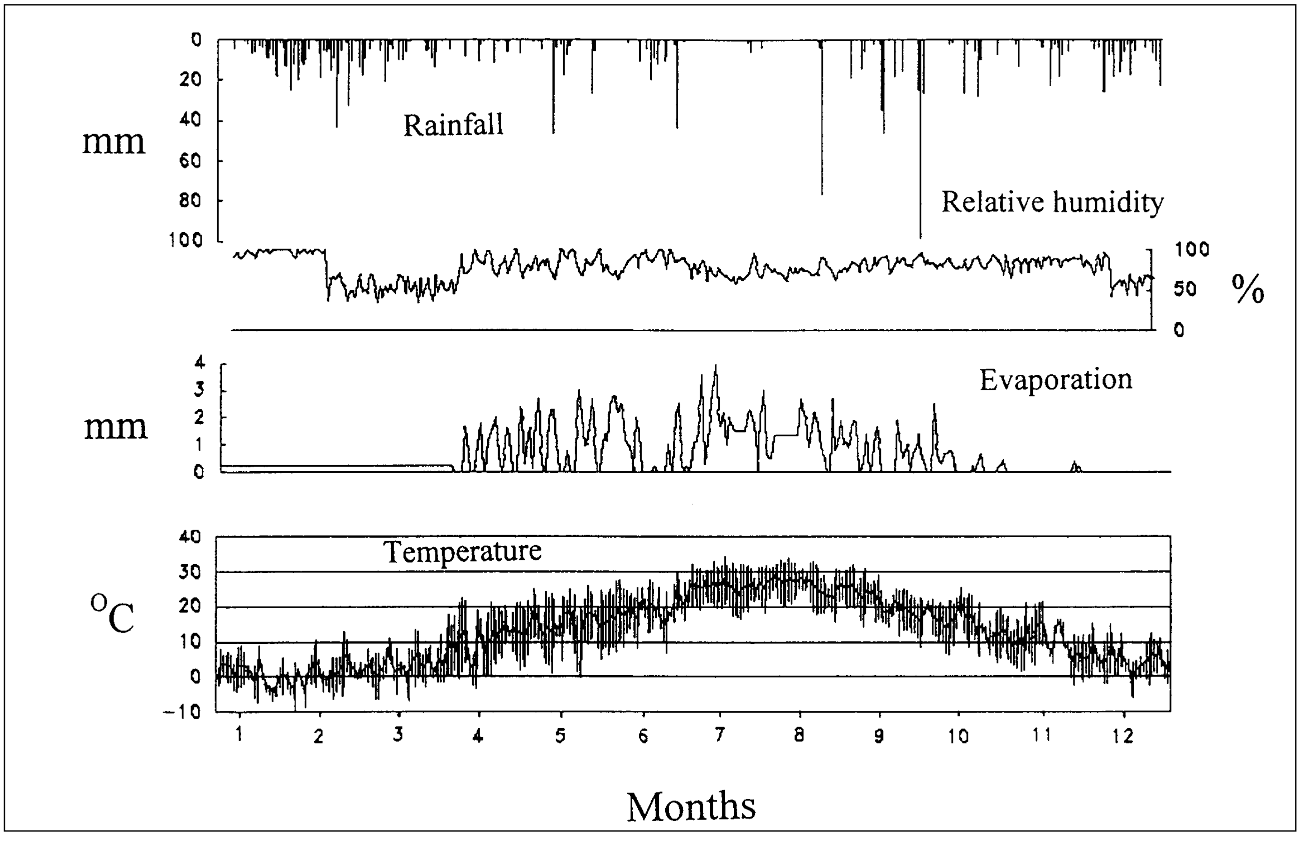

Figure 7. The seasonal variation in the daily rates of meteorological factors in Hiruzen forest for 1994.

Rainfall Partitioning

- Net Rainfall of the Konara Canopy

Net rainfall (*NK*), Konara throughfall (*Kt*) and stemflow catches (*SF*) are correlated with gross rainfall (*R*) (Figure 8). In the net rainfall and throughfall case, the correlation is particularly high (with a correlation coefficient of 0.995), while a lower correlation coefficient (0.90) is observed for stemflow.

On a storm basis Konara throughfall averaged 72.3% with a range of 45.1-87% of the total precipitation and standard deviation of 8.8%. The spatial variability of throughfall of five automatic recording gauges averaged 11.8% and ranged from 5-25% coefficient of variation.

Stemflow averaged 5.23% with a range of 0-17% of the total precipitation and a standard deviation of 4.3% on a per-storm basis. The variability of stemflow of seven automatic recording gauges averaged 42% and ranged from 20-70% coefficient of variation. Stemflow is more variable than throughfall, but these errors in the stemflow estimates will have only a small effect on the net rainfall because of the relatively small proportion of precipitation involved, especially in light storm events.

Several statistical relationships were conducted with the stepwise procedure including variables of storm characteristics (duration and intensity) and windspeed, in order to assess the contribution of such variables to the variation of stemflow. A multiple regression analyses for stemflow (*SF*) including the variables gross rainfall (*R*) and maximum rain intensity (*MaxRi*) showed highly significant correlation and explained a further 5.5 per cent of the variation of stemflow. The equation is as follows:

$$SF = (0.1154)R - (0.397)MaxRi + 0.0307$$

with $r^2 = 0.95^{***}$, $n = 75$.

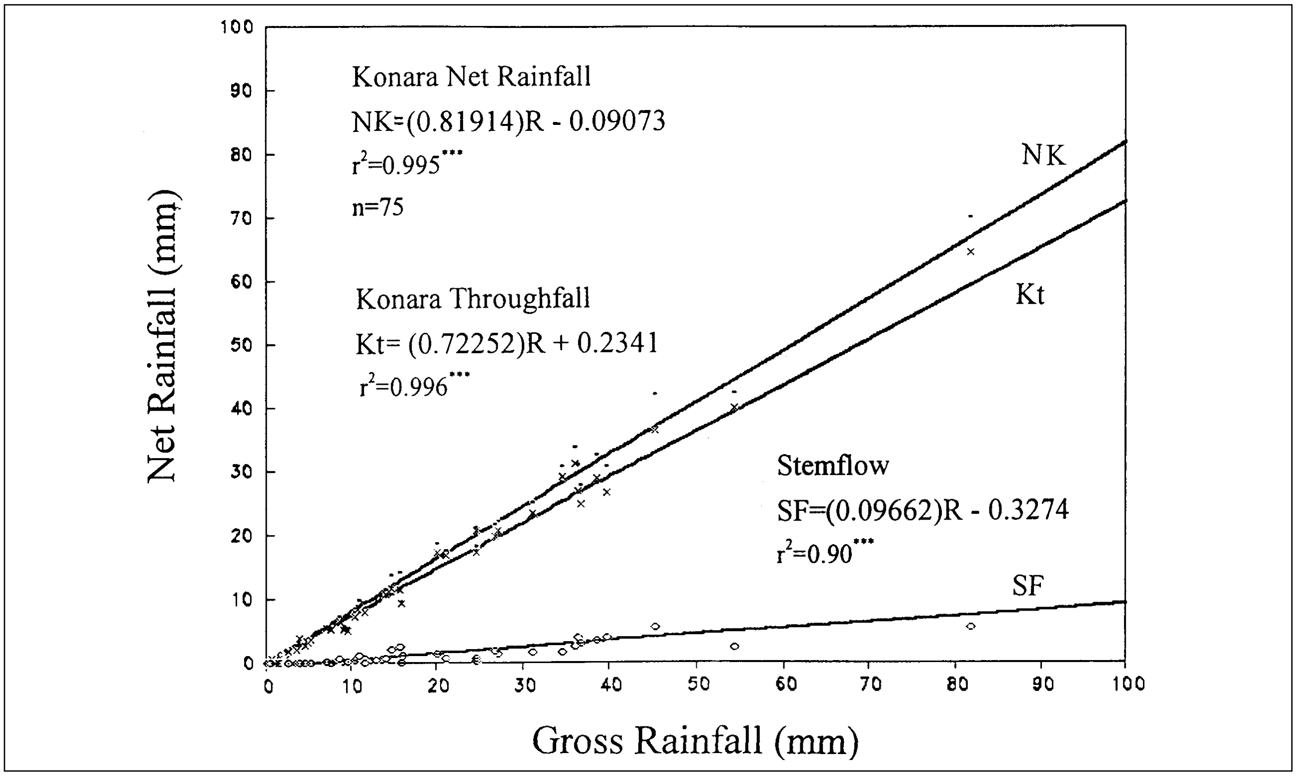

Figure 8. Relationship between the partitioning of net rainfall and gross rainfall.

The results showed that rain intensity affected principally stemflow but not throughfall. High rainfall intensity may produce branch flow that exceeds the capacity of the flow paths (Herwitz, 1987), and drips occur. This causes stemflow yield to be lower than for an event of similar total volume but with lower intensity (Cantú and Okumura, 1996). Likewise, Weihe (1985) reported that the relation stemflow-throughfall was influenced for rainfall intensity. On the other hand, although several studies have showed that throughfall increased with wind speed because of the drip effect (Mitscherlich, 1971; Heuveldop*et al.*, 1972; Jackson, 1975; Weihe, 1985), in this study throughfall did not show any relationship with wind speed.

In general, depending upon rainfall intensity, stemflow did not occur for rainfall events below about 5 mm. Similar findings were reported by Brown and Barker (1970) in a mixed oak stand and by Crabtree and Trudgill (1985) for a beech stand. Moreover, Neal *et al.* (1991) found that about 8 mm of rainfall was required before stemflow occurs in beeches. Also, analysis of stemflow volumes showed that the stemflow delivered to the trunk base area represented in average, 3.5 times more precipitation than any other places below the canopies of the Konara trees.

- Konara and Sasa Net Rainfall

The linear regressions for Konara (*NK*) and Sasa net rainfall (*NS*) on gross rainfall (*R*) yielded a highly significant correlation (0.99) and are compared in Figure 9.

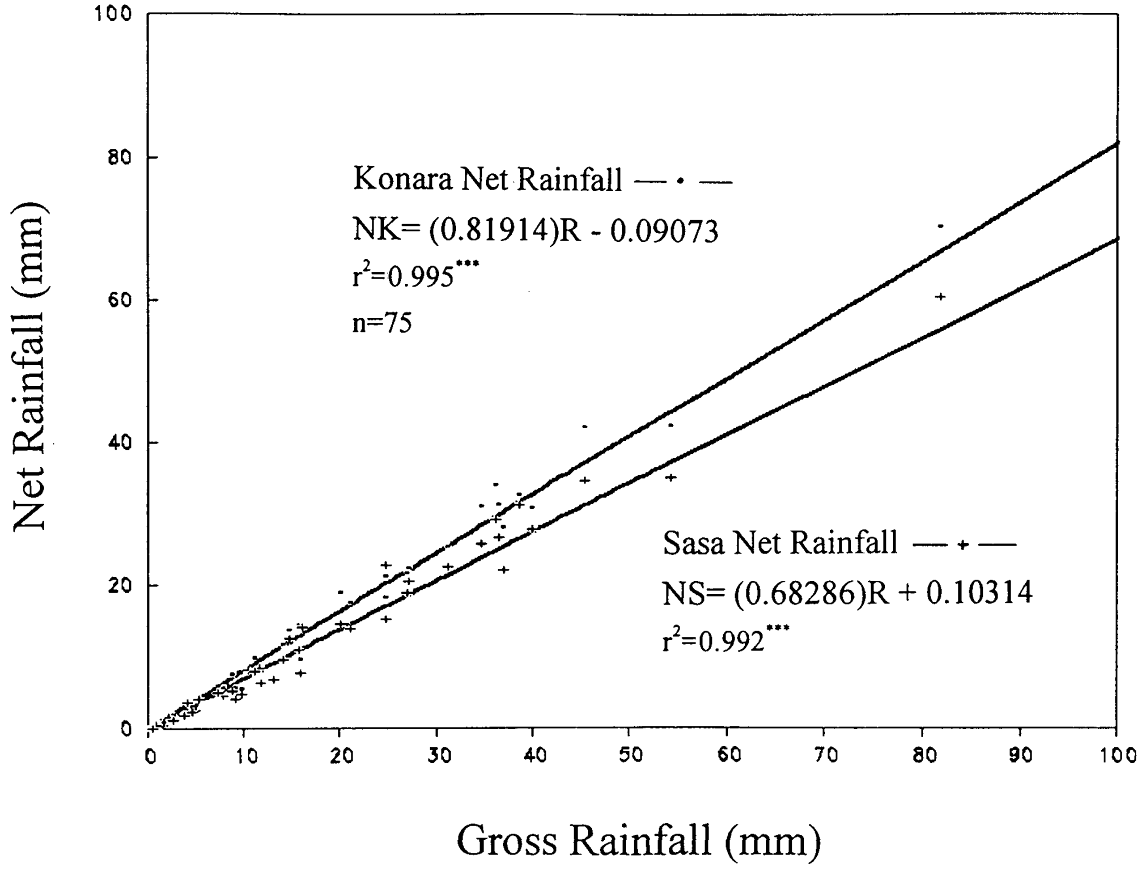

Figure 9. The relationship between the net rainfall and gross rainfall for Konara and Sasa canopies.

Interception Loss

-Storage Capacity

Interception storage capacity was determined by the method of Leyton *et al.* (1967) and estimations gave a Konara canopy saturation value (S_k) of 0.62 mm. Likewise, Rutter *et al.* (1975) and Dolman (1987) reported a canopy saturation value of 0.8 mm for oak stands. Total interception storage capacity was estimated from the data of continuous rainfalls exceeding 3 mm, which were considered likely to wet both the Konara and Sasa canopies, using the method above mentioned. Thus, the canopy saturation value of the two vegetation layers (S_{ks}) was approximately 0.99 mm. Similar findings were reported by Pearce and Rowe (1981) in a multi-storied mixed forest in New Zealand. Canopy saturation value for Sasa (S_s) was obtained from the difference between total canopy saturation (S_{ks}) and Konara canopy saturation value (S_k). An estimated value of 0.37 mm was determined for S_s. The relative low saturation value for Sasa was apparently due to the canopy characteristics and because raindrops slide down easily through the smooth leaves. Also, the presence of a wax layer in stems was likely to reduce the water retention. Nevertheless, the interception loss for individual storms was relatively high. Trunk saturation capacity, the depth of water required to saturate the trunk, was estimated to be about 0.2 mm from linear regressions between stemflow and gross rainfall, using the method outlined in Gash and Morton (1978).

- Interception Loss of Konara Canopy

The interception loss (*Ic*) for each storm was estimated by the difference between gross rainfall and the sum of throughfall and stemflow. The linear regression of interception loss on gross rainfall for individual storms is shown in Figure 10.

The interception loss results of this study agree well with those reported by Dolman (1987) in an oak stand in The Netherlands and show similar trends with Tanaka *et al.* (1984). Konara interception

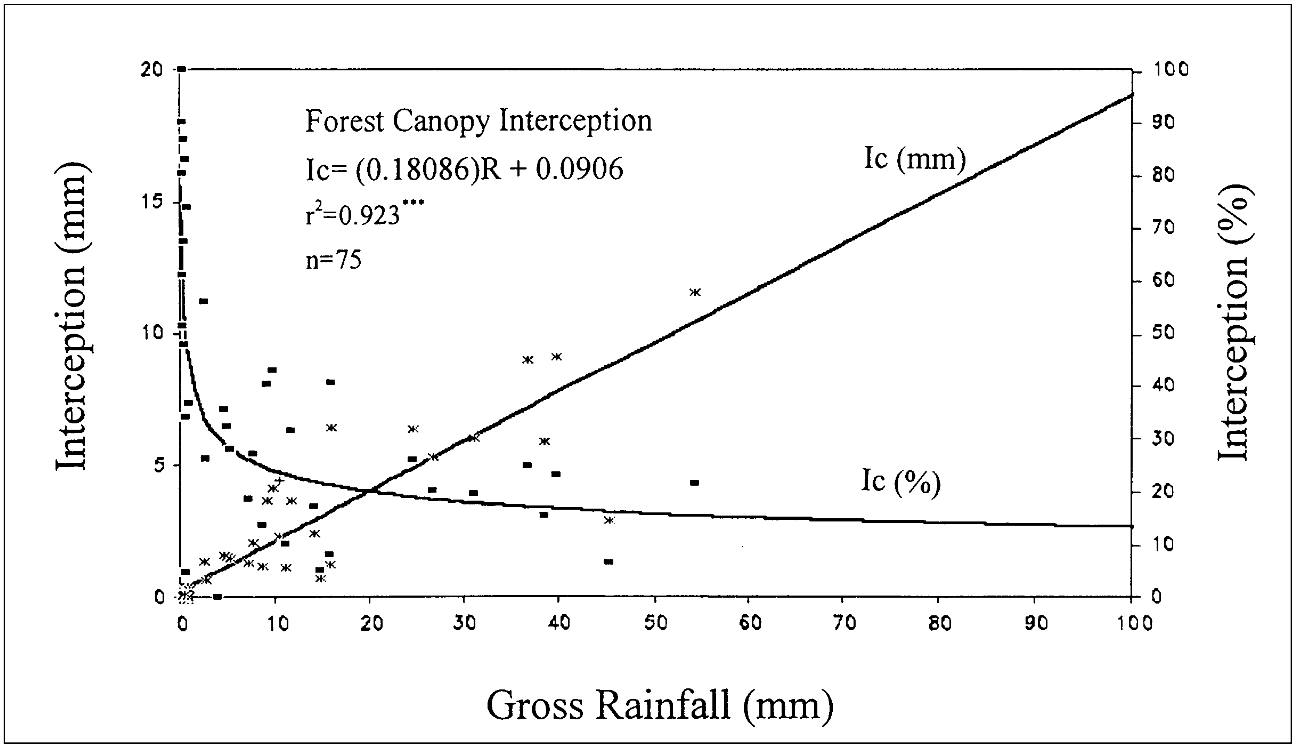

Figure 10. Relationship of the forest canopy interception loss and the gross rainfall.

loss values ranged from 0.08-36.3 mm on a storm basis or 4.8-100% of gross rainfall.

-Total Interception Loss of Forest (Two Vegetative Layers)

Total interception loss of the two vegetative layers (I_{ks}) was determined by the difference between gross rainfall and the sum of Sasa throughfall and stemflow. The effect of the additional intercepting surface of Sasa (Sasa interception) was estimated for each storm by the difference between Konara canopy and Sasa throughfall value. The linear regressions of interception loss on gross rainfall for Konara (I_k), Sasa (I_s) and both layered canopies (I_{ks}) are shown in Figure 11. All correlations were highly significant and Sasa interception loss contribution (13.6% of the gross rainfall) was relatively high accounting for 40% of the total interception of the two layers. Likewise, Gash and Stewart (1977) reported that undergrowth of bracken account for less than 15% of the total annual interception loss in a pine forest. On the other hand, Velthorst and Van Breemen (1989) reported that in an oak-birch stand the ground vegetation intercepted between 2-4% of the total of water dripping from tree canopies. On a storm basis total interception (Konara+Sasa) loss values ranged from 0.02-56.2 mm or 4-100% of gross rainfall.

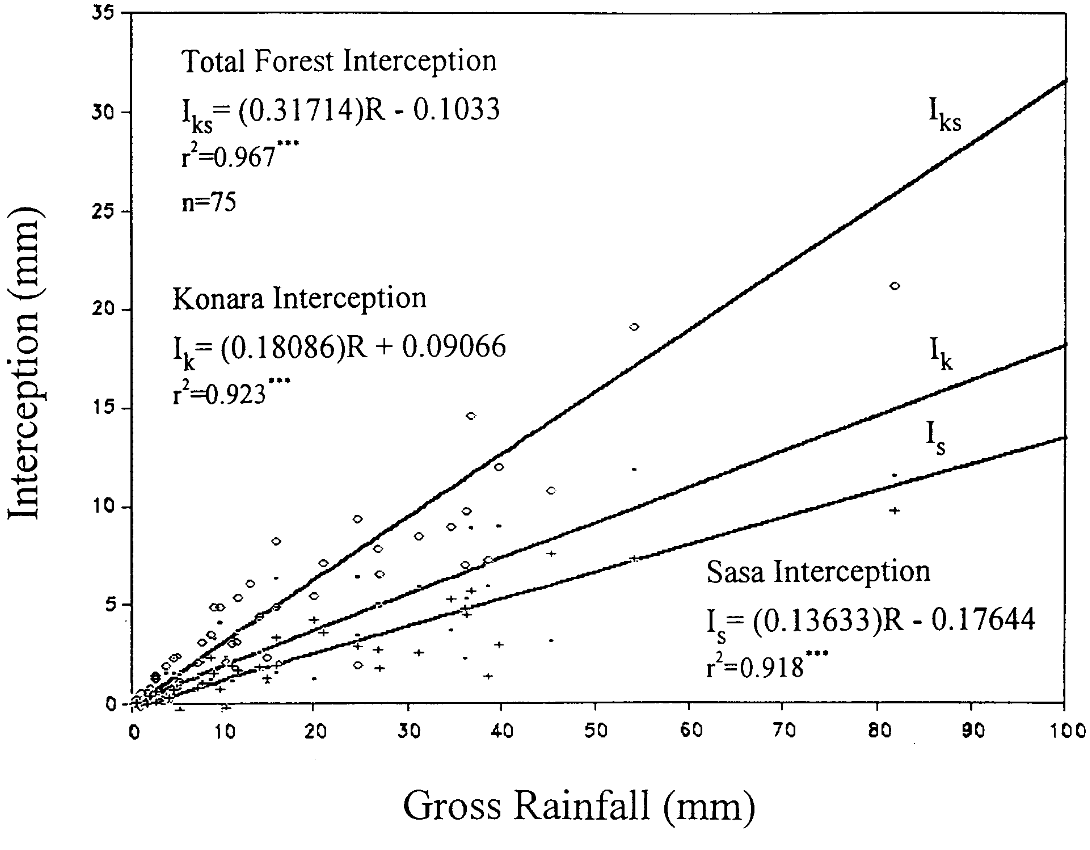

Figure 11. Relationship of the interception loss and gross rainfall for Sasa, Konara and both layers.

The total interception loss of the forest vegetative cover (Konara+Sasa) for the eleven months study period was 375 mm, about 31.2% of the gross rainfall. Konara canopy interception accounted for 223.7 mm (18.6%), while Sasa canopy contribution accounted for 151.3 mm (12.6%). Evaporation from Sasa will also be small because of their sheltered position for wind and radiation. It is important to mention that the Sasa stemflow component was not deduced in this study due to the fact that most of the stems were leaning down slope and in this position could divert all or part of the flow to drip, which then became throughfall. Furthermore, the presence of a wax layer in stems likely reduces the water retention causing the interruption of the flow paths and occurrence of drips. The interception loss for the 1994 period (fifty-four events) is shown in Figure 12. The percentage of interception loss is relatively variable throughout the study period and is dependent on the amount of rainfall.

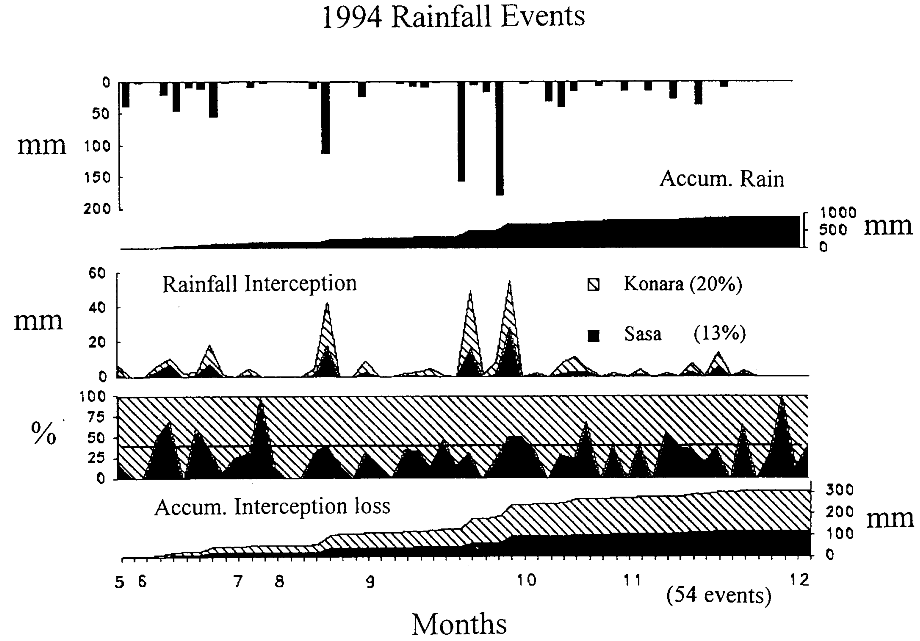

Figure 12. Rainfall and interception loss on a storm basis for Konara and Sasa canopies from May-Nov. 1994. The 40% line in the graph represents the averaged Sasa interception loss contribution.

Rainfall partitioning in this study was defined in three fractions. The part of rain which reaches the forest floor as throughfall and stemflow (Net rainfall). The proportion of rain intercepted by the forest canopy (Konara interception) and the fraction of rain intercepted by the undergrowth dwarf bamboo (Sasa interception).

The monthly variation of the components of rainfall partitioning from May to November 1994 is shown in Figure 13. A peak of precipitation appeared in September and accounted about 43% of the total rainfall, while in July the precipitation was almost insignificant (12.5 mm) and atypical compared with the mean monthly precipitation (270 mm). However, the monthly percent of net rainfall shows a constant trend through the period, both for Konara and Sasa interception.

CONCLUSION

The percentage of the rainfall partitioning resulting in Konara throughfall, Sasa throughfall and stemflow were 72%, 68% and 10% respectively. Storm events never gave negative interceptions. The coefficients of variation for throughfall and stemflow in this study ranged between 5-25% and 20-70% respectively. These ranges are considered acceptable and agree well with those reported for other studies (Helvey and Patric, 1965; Duijsings *et al.*, 1986).

Multiple regression analyses showed that the addition of maximum rainfall intensity to the simple linear equation (*SF* vs *R*) explained a further 5.5 per cent of the variation of stemflow. Rain intensity

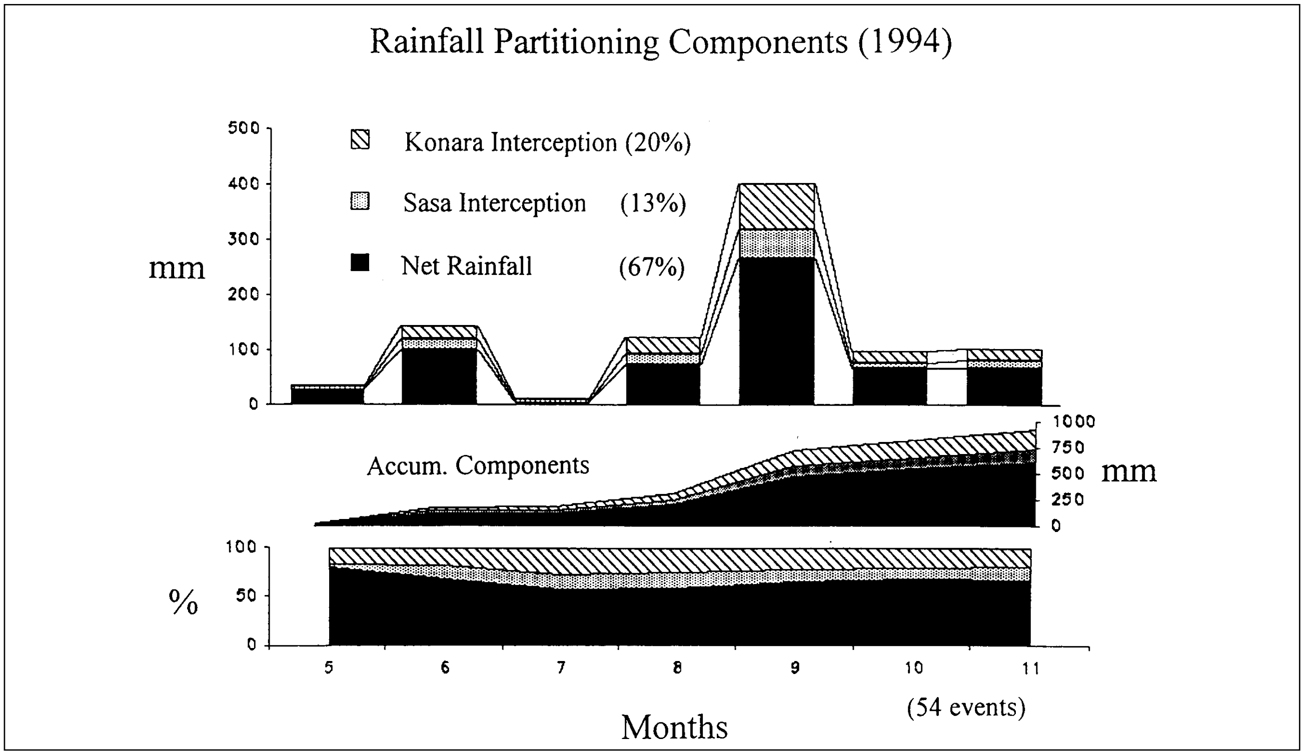

Figure 13. Monthly variation of the components of rainfall partitioning for May-Nov. 1994.

affected principally stemflow but not throughfall. Stemflow began after 5 mm of rainfall and the results showed that the stemflow delivered to the trunk base area represented on average 3.5 times more precipitation than any other places below the canopies of the Konara trees. Stemflow may be important ecologically because it is absorbed by the soil of the primary rooting zone at the base of the tree. Interception losses for Konara and Sasa canopies were estimated to be 18% and 13.6% respectively. Estimated values of the canopy storage capacity of Konara and Sasa were 0.62 mm and 0.37 mm respectively. Also, the trunk storage capacity was estimated at a value of 0.2 mm. The total amount of water stored in Konara (canopy and trunk) and Sasa canopies were assessed to be 1.2 mm. Results showed that significant seasonal variation did not exist for any component of the rainfall partitioning from May to November.

To the authors' knowledge there are no preceding interception studies for undergrowth dwarf bamboo. It seems to be that many researchers suppose or work under the assumption that understory interception is irrelevant. The present study showed that the interception process in Konara forest canopy has features in common with other forests, but that the importance of undergrowth dwarf bamboo in the process may be significant. Since Sasa is a common plant component of forest canopy undergrowth that is widely distributed in Japan and many other Asian countries.

A realistic description of the interception process in Konara-Sasa communities requires the definition of two subsystems, each with its own storage capacities, retention characteristics, drainage and evaporation functions. The resulting information will be of use for further process modeling.

On the other hand, from climatological considerations, it is likely that semi-arid vegetal communities intercept greater amounts of water. Thus, in semi-arid ecosystems where water is one of the major constraints and the forest (or shrub) canopies are more open, the undergrowth vegetation may play an important role in the interception process of this communities.

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