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# Experimental analysis of moisture dynamics of litter layers—the effects of rainfall conditions and leaf shapes

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## Abstract:

The effects of rainfall conditions and the morphological characteristics of leaves on the moisture dynamics of litter layers were investigated. Maximum water storage capacity and interception storage capacity under various rainfall conditions were evaluated for two contrasting litter types: a needle-leaf type, represented by *Cryptomeria japonica* leaves; and a broad-leaf type, represented by *Lithocarpus edulis* leaves. An artificial rainfall simulator was applied to measure each litter type's interception storage capacity under various rainfall intensities. Our results indicated that (1) the maximum water storage capacity of each litter layer was proportional to the litter mass ( $\text{kg/m}^2$ ) regardless of layer thickness; (2) the litter interception storage capacity increased with rainfall intensity in the range of realistic rainfall conditions (under 50 mm/h); (3) the broad-leaf litter of *L. edulis* intercepted more rainwater than the needle-leaf litter of *C. japonica*; and (4) the rainwater moved laterally in the litter layer of *L. edulis* whereas it moved directly down in the litter layer of *C. japonica*. These results show that not only the litter mass but also the rainfall conditions and leaf shapes are important in evaluating the moisture dynamics of litter layers. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS moisture dynamics of a litter layer; maximum water storage capacity; interception storage capacity; rainfall intensity; litter types

## INTRODUCTION

A common feature of the forest floor is the presence of a litter layer, composed of dead leaves, twigs and other fragmented organic materials covering the soil. The litter layer plays an important role in preventing soil erosion by absorbing the impact energy of raindrops (Geddes and Dunkerley, 1999; Miura, 2000) and keeping the infiltration rate high (Rowe, 1955; Janeau *et al.*, 1999). Removal of the litter layer, whether by forest fire or other phenomena, decreases the protection of the soil surface and promotes excessive surface runoff. Therefore, maintaining optimal litter accumulation is an important function of site management (Blow, 1955; Bussiere and Cellier, 1994). For forest fire hazard assessment, predicting the moisture content of the litter layer is also significant (Viney and Hatton, 1990). Furthermore, the litter layer helps limit soil moisture loss from evaporation and reduces the amplitude of soil temperature by insulating the surface (Bristow *et al.*, 1986; Bussiere and Cellier, 1994; Park *et al.*, 1998; Gonzalez-Sosa *et al.*, 1999). These findings show that the litter layer is an important hydrological component in controlling both water and energy transfer between

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the sub-canopy atmosphere and the soil (Pitman, 1989; Viney and Hatton, 1990). In spite of the importance of litter layers in the hydrological cycle, little information on their moisture dynamics is available, mainly because of the difficulties of *in situ* observations (e.g., Putuhena and Cordery, 1996; Schaap *et al.*, 1997; Tobon-Marín *et al.*, 2000). However, some previous studies have been conducted to clarify the moisture dynamics of the litter layer. Rowe (1955) examined the influences of litter-layer depth on evaporation. Dabral *et al.* (1963) and Pradhan (1973) pointed out that litter types and rainfall conditions determine the extent to which a litter layer intercepts rainfall. Schaap and Bouten (1997) investigated long-term moisture dynamics of the litter layer under natural rainfall conditions using a weighing lysimeter. Pitman (1989), Putuhena and Cordery (1996) and Tobon-Marín *et al.* (2000) estimated the interception storage capacities of litter layers by using artificial rainfall in laboratory experiments.

Our review shows that these studies paid scant attention to the effects of rainfall conditions (e.g., the intensity and duration of rainfall) on the moisture dynamics of a litter layer. For example, most of the values of interception storage capacity were estimated at extremely high rainfall intensities (more than 30 mm/h) using artificial rainfall (e.g., Pitman, 1989; Putuhena and Cordery, 1996). These conditions are probably suitable for estimating maximum values of litter interception storage capacity. However, they may not reflect real field conditions, since most rainfall observed under the canopy is much less intense (Dabral *et al.*, 1963; Pradhan, 1973). Therefore, in order to clarify the moisture dynamics of the litter layer, further examination under more realistic rainfall conditions (particularly in light rains) is needed. Furthermore, the previous studies did not consider the effect of leaf shape on the moisture dynamics of a litter layer.

The objectives of this study are to describe the moisture dynamics of two types of litter layer under various rainfall conditions. Several laboratory experiments were conducted using two contrasting litter samples: *Cryptomeria japonica* (as a needle-leaf type) and *Lithocarpus edulis* (as a broad-leaf type). The maximum water storage capacities of these litter layers were examined under fully saturated conditions. Then, these layers' interception storage capacities under various rainfall conditions were investigated using an artificial rainfall simulator. We also investigated the litter flow distributions within each type of litter layer to clarify the mechanisms of litter interception.

## SITE AND MATERIALS

### Study site

This study was carried out within an experimental area in the Research Institute of Kyushu University Forest, located in northeast Fukuoka, Japan (33°38'N, 130°31'E). Two plantation stands were selected for litter sampling plots. The first plot was established within a flat area (225 m<sup>2</sup>) of a 25-year-old *C. japonica* plantation as an evergreen coniferous stand. *Cryptomeria japonica* is a major commercial crop for industrial wood production and is widely planted in Japan. Most of these plantation stands are even-aged monocultures (Ito *et al.*, 2003). The second plot was established within a flat area (196 m<sup>2</sup>) of a 20-year-old *L. edulis* plantation as an evergreen broad-leaf stand. This species has been planted broadly in Kyushu and is used as a coppice and as a windbreak. In both stands, the canopy was fully closed. In July 2002, the average projective canopy cover of the stands of *C. japonica* and *L. edulis* was 98% and 96%, respectively. No understory vegetation was present in either stand. The general characteristics of each stand are shown in Table I.

Table I. General characteristics of studied stands

Species	Age (y)	Plot area (m <sup>2</sup> )	Density (trees/ha)	DBH (cm)	Height (m)	Canopy cover (%)
<i>Cryptomeria japonica</i>	25	225	1467	23.2	15.2	98
<i>Lithocarpus edulis</i>	20	196	3418	10.8	10.2	96

Gross rainfall was measured at a meteorological observation station adjacent to each stand (approximately 100 m from each stand). The mean annual gross rainfall for the 3-year study period (2000–2002) was 1401 mm, and the average annual number of raindays was 137. The rainfall intensity on a daily basis, determined as an annual average, was 3.6 mm/h. The maximum value was 24.2 mm/h, observed on September 16, 2002. The frequency distributions of rainfall intensity and the amount of daily rainfall are shown in Figure 1. It is apparent that the intensities of most rainfalls at this site were less than 10 mm/h, and that almost 90% of the raindays produced less than 25 mm/day.

Throughfall and stemflow were also measured at each stand from April to December 2002. Throughfall was measured using 25–30 storage-type rain gauges and three tipping-bucket rain gauges. To measure stemflow, six trees were selected in each stand. A plastic collar was attached to each stem with silicon rubber at breast height (1.3 m), and the tipping-bucket rain gauge was connected. The relative proportions of throughfall and stemflow in the stand of *C. japonica* were approximately 73.4% and 7.9% of the gross rainfall, and those in the stand of *L. edulis* were approximately 38.4% and 50.1%, respectively.

### Litter

Litter can be divided into two categories of layers: (1) an upper layer of relatively undecomposed material (L layer); and (2) a lower layer of fragmented or decomposed material (F and H layers). The water storage capacities of these two categories of layers are often different due to their physical properties, such as density and porosity. Thus, these two categories should be treated separately to estimate the moisture dynamics of the litter layer. Furthermore, in young plantation stands in temperate regions, such as the *C. japonica* and *L. edulis* stands investigated in this study, more than 90% of the total layer is undecomposed leaf litter (Miura, 2000). Therefore, the upper undecomposed litter layer should play a particularly significant role in the moisture dynamics of the litter layer. Consequently, we focused on the moisture dynamics of the upper, relatively undecomposed litter layer in this study.

Annual litter falls observed in 1996 and 1997 were 0.41 kg/m<sup>2</sup> for the *C. japonica* stand and 0.86 kg/m<sup>2</sup> for the *L. edulis* stand. These litters on the forest floor do not decompose completely within 1 year. Therefore, a certain amount of undecomposed litter is observed throughout a year in each stand.

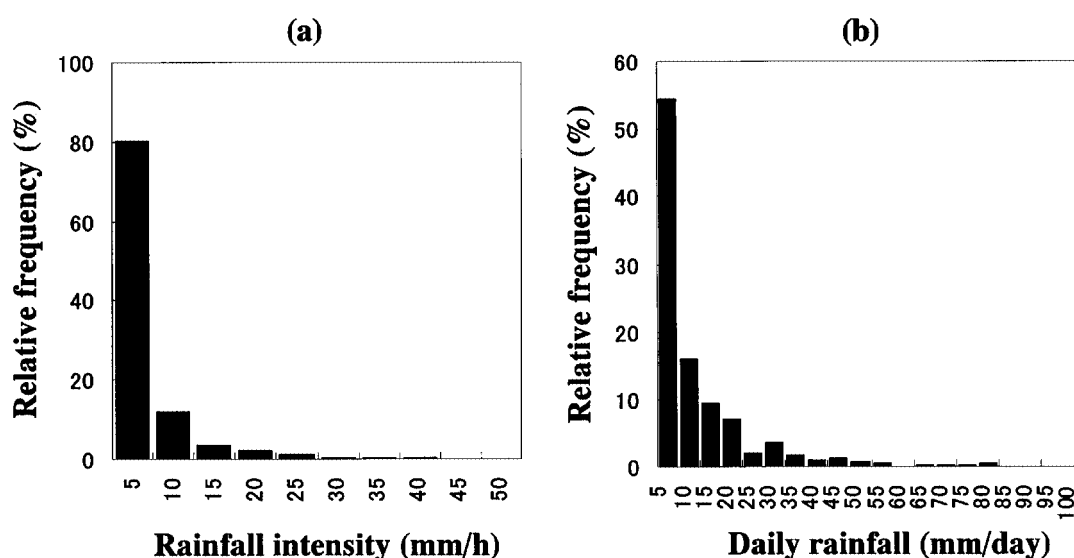


Figure 1. Rainfall characteristics observed at the meteorological observation station during a period from 2000 to 2002 (1096 days). (a) Frequency distribution of maximum intensity of gross rainfall on a daily basis. (b) Frequency distribution of daily gross rainfall. (Number of raindays during the period: 412)

In the litter of *C. japonica*, it was difficult to distinguish needle leaves from twigs, because these litters fall together (Miyaura and Hozumi, 1989) and the twigs are completely covered by needle leaves. Therefore, we treated a shoot (twigs + needles) as our unit of litter for the sake of convenience. The *C. japonica* shoot is composed of curved, awl-shaped needles (average length approximately 1.3–1.9 cm) on twigs (average length approximately 15 cm). A litter of *C. japonica* is usually composed of three to five twigs. The width of the cluster is approximately 5 cm. On the other hand, the litter of *L. edulis* is composed of a broad, oblong-shaped leaf about 6–13 cm long and 2–4 cm wide, with a leathery texture.

In each stand, litter samples were collected using a sharp-edged frame at randomly selected points. First the frame was driven into the ground. Then all the material contained in the frame was collected by hand and put into a plastic bag. After the sample was allowed to dry naturally in the laboratory, the decomposed litter and the extremely large litter were removed so that the rest could fit into a sample tray (384 cm<sup>2</sup>). The details of the sample tray are described in the following section. The remaining undecomposed litters were arranged on the sample tray as naturally as possible to reflect real field conditions.

The mass per unit area of litter layer (hereafter referred to as 'litter mass') was estimated in March 2002 by random sampling in each stand. The average value of the litter mass in the *C. japonica* stand was 1.73 kg/m<sup>2</sup> ( $n = 9$ ), and that in the *L. edulis* stand was 2.07 kg/m<sup>2</sup> ( $n = 5$ ). The litter thickness of each stand was observed in January 2003. The spatial distributions of litter thickness in each observation plot are presented in Figure 2. There were 25 sampling points in the *C. japonica* stand (2.5 m intervals), and 36 in the *L. edulis* stand (2.0 m intervals). The average litter thickness was 8.6 cm (SD = 1.9) in the *C. japonica* stand and 5.2 cm (SD = 3.2) in the *L. edulis* stand.

#### Sample tray

The sample tray used in this study had an area of 16 × 24 cm<sup>2</sup> and a height of 16 cm. It consisted of stainless wire netting composed of 2.0 mm diameter strands constituting a 4 × 2 cm<sup>2</sup> mesh, and thus enabled sufficient water drainage. The size of this sample tray is sufficient to examine the moisture dynamics of a litter layer when it is composed of average-sized leaves from the litter. In all of the following experiments,

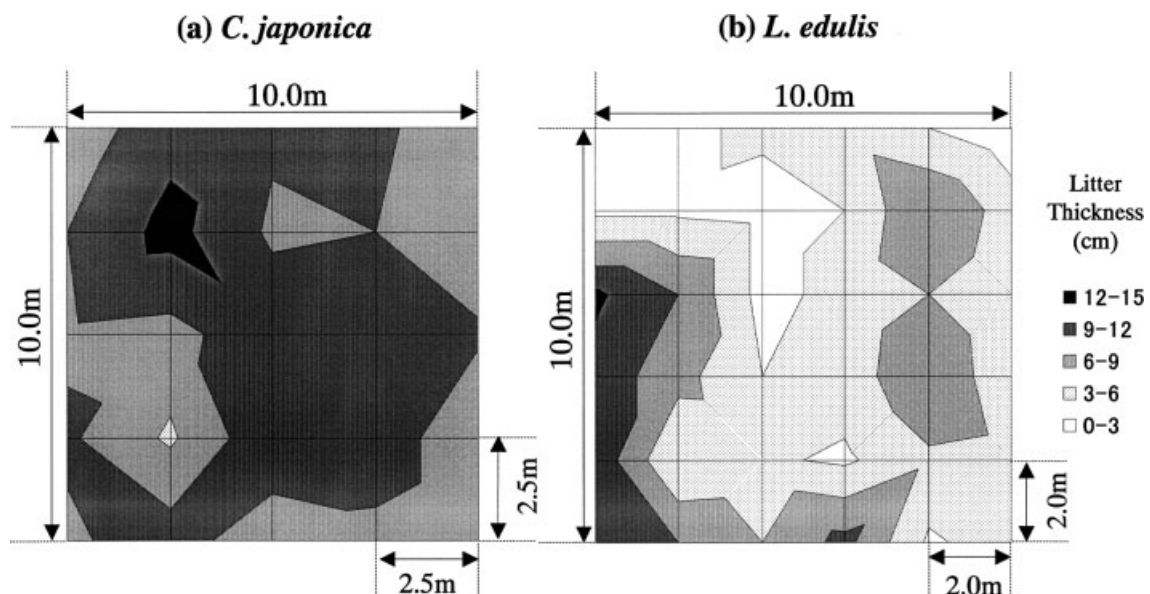


Figure 2. Spatial distribution of the litter layer thickness of each stand. Each mesh area in the *C. japonica* and *L. edulis* stands is 6.25 m<sup>2</sup> and 4 m<sup>2</sup>, respectively

we examined the moisture dynamics of the litter layer using this sample tray. However, the values measured in this tray included the effect of water retained by surface tension between the litter and the strands of the mesh, in what has been called an 'interface effect' (Helvey and Patric, 1965). This effect should be subtracted from the measured value to obtain the actual amount of water held by the litter layer. However, since we used a relatively large-meshed tray to negate this effect, we did not take this effect into account.

## METHODS

### *Maximum water storage capacity*

In order to clarify the moisture dynamics of the litter layer, it is necessary to determine the maximum water holding capacity of the layer. We examined these capacities for litter masses of 0.5, 1.0, 1.5 and 2.0 kg/m<sup>2</sup>. To reflect field conditions, each litter was piled up carefully in the sample trays so as to be as similar as possible. The trays were soaked in water for about 24 h to wet all the litter surfaces completely, and then were lifted from the water and suspended in air. When the drainage ceased completely after 30 min, the litters were weighed by an electronic balance (EK-600H, A&D Co. Ltd, Tokyo, Japan; minimum graduation: 0.1 g). We hereafter refer to this condition as 'full saturation'. The value of maximum water storage capacity *S* of each litter mass was calculated as the difference in sample mass before and after the soaking procedure.

To assess the effect of litter thickness in relation to *S*, two types of experiment (Experiments A and B) were performed. In Experiment A, only the litter mass was controlled. In Experiment B, both the litter mass and the thickness of the litter layer were controlled. The litter layer thicknesses in Experiment B are shown in Table II. Experiment A was conducted 17 times, and the litter samples were replaced every time. We then repeated Experiment B three times without changing the litter samples, to avoid changing their thickness.

### *Interception storage capacity*

The interception storage capacities under the various rainfall conditions were measured using an artificial rainfall simulator as shown in Figure 3a. This artificial rainfall simulator controlled the amount of rainfall and the rainfall intensity by programming the operating time and the flow rate of the digital pump (Masterflex EW-7524-10, Cole-Palmer Instrument Co., Illinois, USA). Uniform artificial raindrops were produced by a raindrop maker (a network of small holes in a silicon tube). In this experiment, we used litter masses of 0.5, 1.0 and 2.0 kg/m<sup>2</sup> and applied three rainfall intensities corresponding to light, moderate and high intensity rainfalls (5, 10 and 50 mm/h) for durations of 300 min to obtain the maximum values of litter interception storage capacity under each rainfall intensity. A drainage collector, composed of a water storage tank and an electronic balance, was used to collect the drained water from the base of the litter layer. The amount of drainage water was recorded by a computer once per minute. The litter interception storage capacity was calculated as the difference between the amount of rainfall supplied from the simulator and the amount of drainage from the base area of the litter layer.

Tobon-Marin *et al.* (2000) suggested that litter flow is an important factor in the moisture dynamics of the litter layer, because a wide range of variability in litter flow could be expected due to the variability of

Table II. Thickness of the litter layer in Experiment B

Litter mass (kg/m <sup>2</sup> )	<i>Cryptomeria japonica</i>		<i>Lithocarpus edulis</i>	
	Thin (mm)	Thick (mm)	Thin (mm)	Thick (mm)
0.5	20	30	10	15
1.0	40	60	20	30
1.5	60	90	30	45
2.0	80	120	40	60

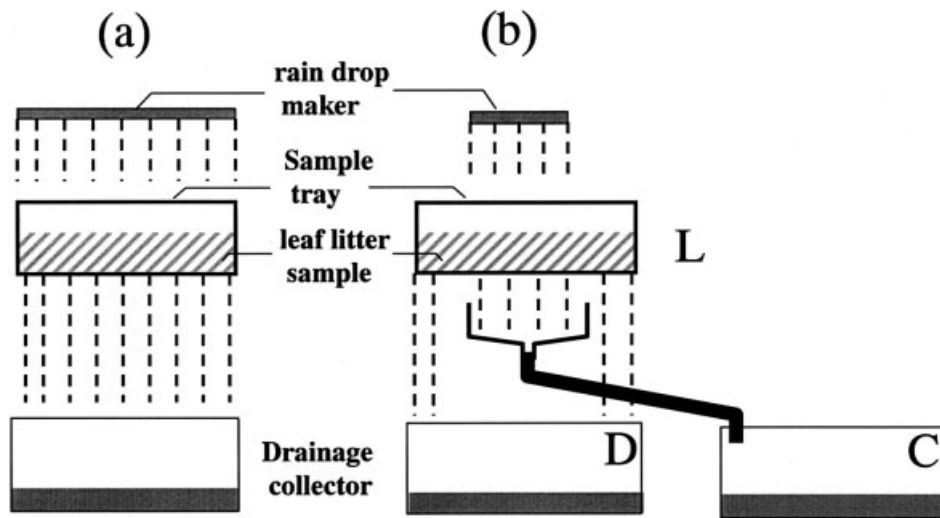


Figure 3. Experimental set-up for the measurement of litter interception storage capacity. (a) Standard set-up. (b) Extra set-up to investigate the litter flow mechanisms. C: Drainage from the centre. D: Drainage outside the centre

litter thicknesses and rainfall conditions. Therefore, we also conducted the experiment to investigate the litter flow using another artificial rainfall simulator (Figure 3b). In this experiment, we supplied the rainfall into only a central part of the litter surface, approximately one-third of the surface area. However, water drained not only from the central part but also from the outside. Thus, we collected the drainage water from these two sources separately: drainage collectors C and D from the centre of the litter base area and from the area outside the centre, respectively (Figure 3b). The rainfall intensities applied in this experiment were 10 and 50 mm/h, using litter masses of 0.5, 1.0 and 2.0 kg/m<sup>2</sup>.

## RESULTS AND DISCUSSION

### *Maximum water storage capacity*

The litter layer of *C. japonica* was thicker than that of *L. edulis* (Figure 4). However, the maximum water storage capacity ( $S$ ) of the two litter layers was almost equal when they had the same litter mass (Figure 5). In each species, the litter mass and  $S$  showed a linear relationship. Similar linear relationships between  $S$  and litter mass were found by Pitman (1989) and Putuhena and Cordery (1996).

In this study, litter mass ranging from 0.5 to 2.0 kg/m<sup>2</sup> retained approximately 0.8 to 3.0 mm of water, and the values of  $S$  per unit litter mass (1 kg/m<sup>2</sup>) of *C. japonica* and *L. edulis* were 1.59 mm and 1.56 mm, respectively.

Values of  $S$  per unit litter mass were reported in various previous studies. According to Pitman (1989), the  $S$  of bracken litter was 1.67 mm. Putuhena and Cordery (1996) reported the  $S$  of eucalyptus and pine leaf litters was 1.13 mm and 0.97 mm, respectively. Crockford and Richardson (2000) determined the  $S$  of the same upper loose litter layers of eucalyptus and pine to be 1.23 mm and 1.35 mm, respectively. In an Amazonian forest floor, the average  $S$  of litter layers was 1.51 mm (Tobon-Marín *et al.*, 2000). The values of  $S$  obtained in Experiment A of the present study were within the range of these previous studies. It seems that  $S$  is relatively constant regardless of litter types and shapes.

To estimate the effect of the thickness of the litter layer, in Experiment B we determined  $S$  using two types of controlled litter thickness ('thin' and 'thick') with the same litter mass (see Table II). These 'thin' and 'thick' conditions correspond to the minimum and maximum thicknesses of natural litter arrangement indicated

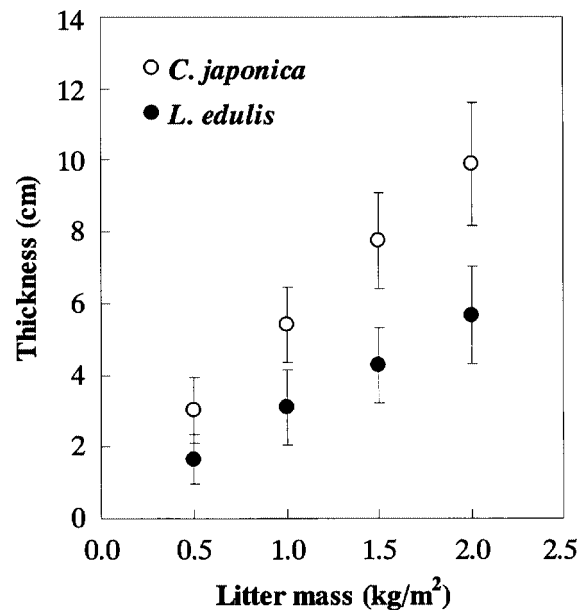


Figure 4. Relationship between the thickness of the litter layer and litter mass in Experiment A. Error bars indicate SD ( $n = 17$ )

in Figure 4. Although we repeated this experiment three times using the same litter samples, no differences were observed in the  $S$  of these two different litter thicknesses in either *C. japonica* or *L. edulis* (Figure 6). These results indicate that the  $S$  of the litter layer depends on the litter mass regardless of its thickness. In this experiment, the same samples were pressed to change their thicknesses; therefore, the amount of total surface area of leaves in the litter layer was unchanged. This implies that the  $S$  of the litter layer may not be determined by the 'capillary water' held in the gaps created between litters, but by the 'adhesion water' held by each litter surface. Thus, the variations of  $S$  among the litter samples of the same litter mass (Figure 5) may be caused by the difference in the amount of adhesion water in the litter layer, since all of the litter samples were exchanged each time.

#### Interception storage capacity

The interception storage capacity of the litter layer under rainfall conditions is different from  $S$  because the supplied rainwater cannot always be spread equally within the litter layer during the rain. Therefore, interception storage capacity must be considered to change with rainfall conditions.

According to Putuhena and Cordery (1996), there are two different litter interception storage capacities, defined as follows.

1.  $C_{\max}$  is the maximum interception storage capacity of the litter layer, taken as the amount of water detained in the litter layer when the litter interception stopped increasing during the rainfall. It includes gravitational water.
2.  $C_{\min}$  is the minimum interception storage capacity of the litter layer, taken as the amount of water detained in the litter layer when free drainage ceased after rain. It does not include gravitational water.

For moisture dynamics in a forest area,  $C_{\min}$  is more important than  $C_{\max}$  because gravitational water is readily drained within about 30 min after the cessation of rainfall (Putuhena and Cordery, 1996).

In our experiment, the time series of litter interception using the 2.0 kg/m<sup>2</sup> litter mass sample at three different rainfall intensities is shown in Figure 7. The retained rainwater in the litter layer increased rapidly

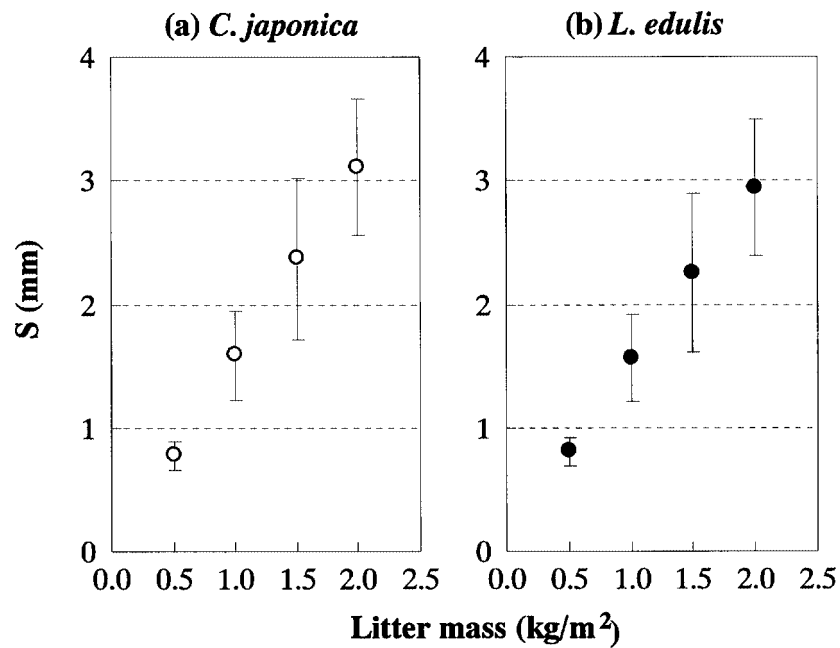


Figure 5. Maximum water storage capacity ( $S$ ) of the litter of *C. japonica* (a) and that of *L. edulis* (b) without thickness control. Error bars indicate SD ( $n = 17$ )

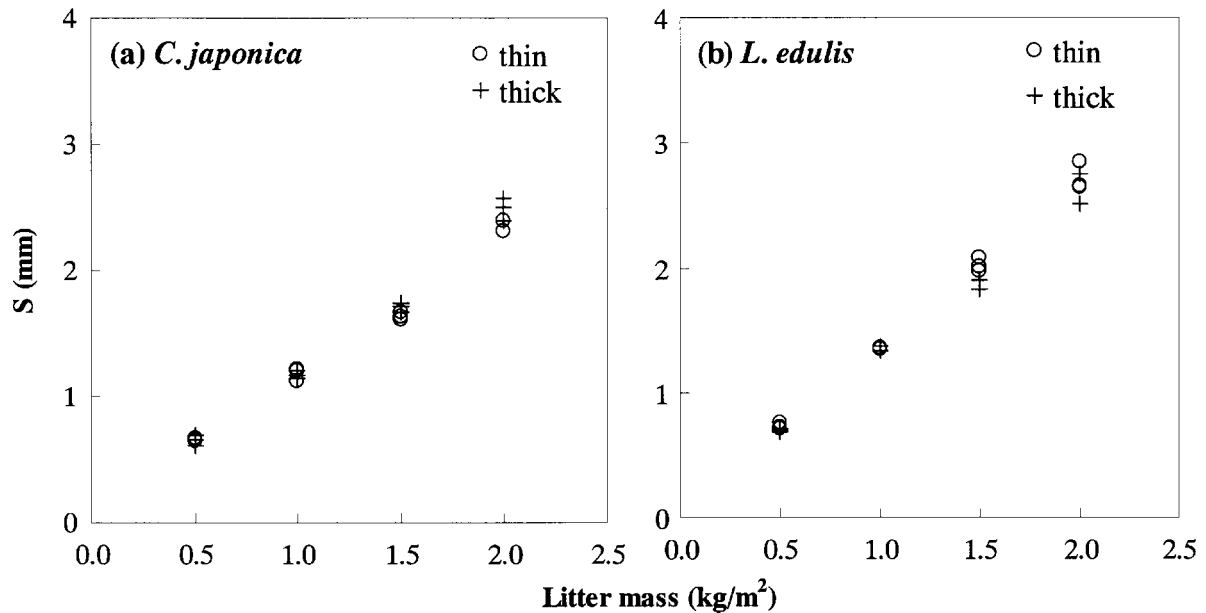


Figure 6. Maximum water storage capacity ( $S$ ) of the litter layer of *C. japonica* (a) and that of *L. edulis* (b) with thickness control. The definitions of 'thick' and 'thin' are given in Table II

when the rainfall started, and it became almost constant after 300 min. Thus, we stopped the rainfall at this point and used this value as  $C_{\max}$ . When the drainage ceased completely 30 min after the rainfall stopped,



we used the value at this point as  $C_{\min}$ . Both  $C_{\max}$  and  $C_{\min}$  evidently increased with rainfall intensity. The relationships between  $C_{\min}$  and the litter mass at three different rainfall intensities are shown in Figure 8.  $C_{\min}$  increased with rainfall intensity regardless of the litter mass. As in the case of  $S$ , both  $C_{\min}$  of *C. japonica* and *L. edulis* increased with the litter mass at every rainfall intensity. Putuhena and Cordery (1996), on the other hand, reported that neither  $C_{\max}$  nor  $C_{\min}$  depended on the rainfall intensity. This is probably because their results were obtained under extremely high rainfall intensities (34–75 mm/h), at which the litter layers may be almost fully saturated. However, litter interception becomes more important hydrologically at lower rainfall intensities (Dabral *et al.*, 1963; Pradhan, 1973; Pitman, 1989; Tobon-Marin *et al.*, 2000). Therefore, we can say that  $C_{\max}$  and  $C_{\min}$  increase with rainfall intensity in realistic rainfall conditions (less than 50 mm/h).

Table III summarizes the values of  $S$  and  $C_{\min}$  obtained in this study. Although the  $S$  values of *C. japonica* and *L. edulis* were almost identical when the litter mass was the same, the litter of *L. edulis* apparently intercepted more rainwater than that of *C. japonica* under the rainfall conditions.

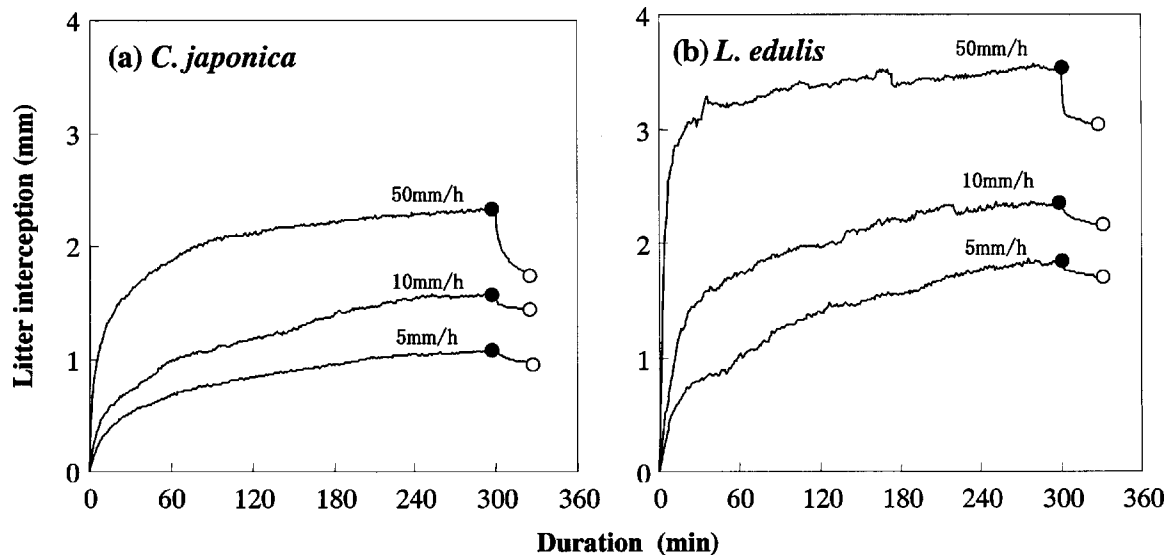


Figure 7. Time series of litter interception of *C. japonica* (a) and *L. edulis* (b) at three different rainfall intensities (litter mass: 2.0 kg/m<sup>2</sup>). Closed symbols indicate  $C_{\max}$  and open symbols indicate  $C_{\min}$

Table III. Maximum water storage capacity ( $S$ ) and minimum interception storage capacity ( $C_{\min}$ ) with litter mass

Litter mass (kg/m <sup>2</sup> )	$S$ (mm)	Rainfall intensity:		
		5 mm/h	10 mm/h	50 mm/h
Minimum interception storage capacity ( $C_{\min}$ , mm)				
<i>Cryptomeria japonica</i>				
0.5	0.77	0.27(35)	0.44(57)	0.70(90)
1.0	1.59	0.44(28)	0.95(60)	1.03(65)
2.0	3.11	0.95(31)	1.44(46)	1.72(55)
<i>Lithocarpus edulis</i>				
0.5	0.81	0.67(83)	0.90(111)	1.32(164)
1.0	1.56	1.33(85)	1.47(97)	1.74(112)
2.0	2.94	1.68(57)	2.16(73)	3.05(104)

Note: Relative water content to maximum water storage capacity (%) is given in parentheses.

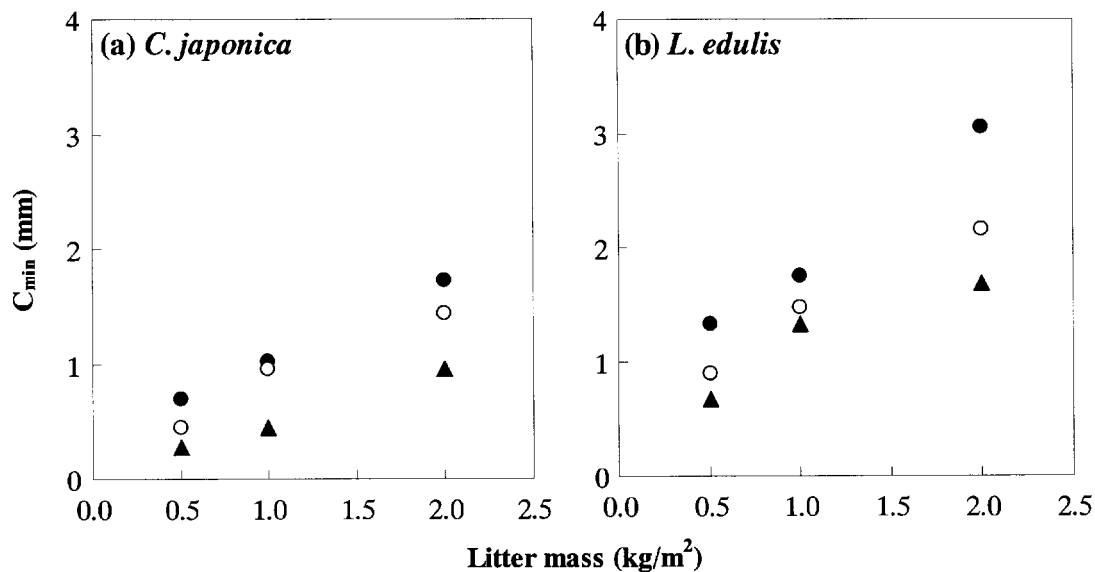


Figure 8. Relationships between  $C_{\min}$  and litter mass at three different rainfall intensities of *C. japonica* (a) and of *L. edulis* (b). Closed triangles indicate 5 mm/h, open circles indicate 10 mm/h and closed circles indicate 50 mm/h

As mentioned above,  $C_{\min}$  may not be influenced by rainfall intensities over 30 mm/h, because at such high intensities  $C_{\min}$  corresponds to the 'maximum' value of  $C_{\min}$ . Therefore, we assumed a  $C_{\min}$  of 50 mm/h to be the maximum value of  $C_{\min}$  (hereafter referred to as ' $C_{\min 50}$ ') in this experiment. We then compared  $C_{\min 50}$  with  $S$ . The  $C_{\min 50}$  of *C. japonica*, ranging from 0.5 to 2.0 kg/m<sup>2</sup>, intercepted the rainwater at approximately 0.7 to 1.7 mm, and the relative storage capacity  $C_{\min 50}/S$  ranged from 55% to 90%. Therefore, the litter layers of *C. japonica* were always unsaturated under the rainfall conditions. On the other hand, the  $C_{\min 50}$  of *L. edulis*, ranging from 0.5 to 2.0 kg/m<sup>2</sup>, intercepted the rainwater at approximately 1.3 to 3.1 mm, and the relative storage capacity  $C_{\min 50}/S$  ranged from 104% to 164%. The reason why these relative values of *L. edulis* exceeded 100% may be that the upper part of the litter layer could catch rainwater in its surface pits. These upper surface pits exist only in broad-leaf type litters, and they seem to act as extra water storage vessels when they are situated at a standstill state. However, if we were to place the sample tray on an incline or shake it, this 'loose' water would drain easily (Crockford and Richardson, 2000). Therefore, the 'loose' water (approximately 0.1–0.5 mm) might have already drained by the time  $S$  was determined. Thus, it is possible that the values of  $C_{\min 50}/S$  of *L. edulis* exceed 100%.

#### Characteristics of litter flow

The broad-leaf litter of *L. edulis* retained more rainwater than the needle-leaf litter of *C. japonica*. We assume that this result was caused by the different water flow channels within the litter layer, depending on the litter types. To verify this assumption, we conducted a litter flow experiment using another rainfall simulator (as shown in Figure 3b). The results of the litter flow experiment at a rainfall intensity of 50 mm/h are shown in Figure 9. In fact, we found significant differences between these two types of litter. The litter layers of *C. japonica* drained most of the rainwater from the central part of the litter bottom. No lateral drainage was observed at 0.5 kg/m<sup>2</sup>, and slight lateral drainage was observed at 1.0 and 2.0 kg/m<sup>2</sup>. However, the proportion of lateral drainage was always smaller than that of central drainage. This tendency was unchanged under the 10 mm/h conditions. On the other hand, the lateral drainage of the litter layer of *L. edulis* was significantly larger than that of *C. japonica* at the same litter mass. In the case of *L. edulis*, we observed lateral drainage

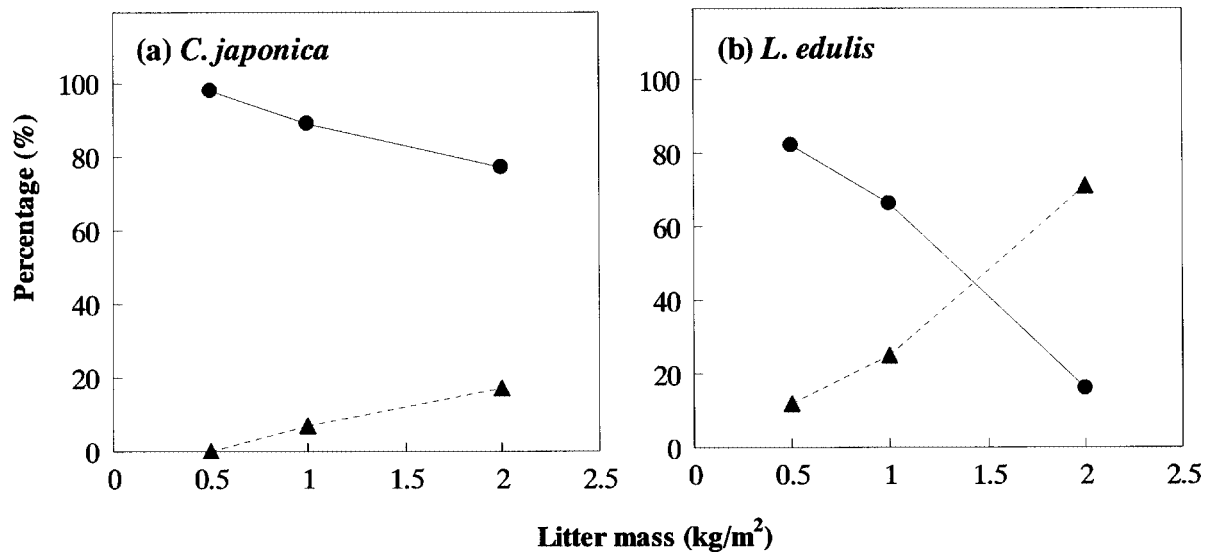


Figure 9. The rainwater distribution in the litter layer of *C. japonica* (a) and *L. edulis* (b) (rainfall intensity: 50 mm/h). Closed circles indicate central drainage (C) and closed triangles indicate lateral drainage (D)

even at 0.5 kg/m<sup>2</sup>. The proportion of lateral drainage increased with litter mass, and this tendency did not change under the 10 mm/h conditions.

These results suggest that the litter flow channels developed in the litter layer have a great influence on the interception storage capacity under rainfall conditions. Within the layer of a needle-leaf litter such as that of *C. japonica*, rainwater does not disperse sufficiently because of the extremely porous accumulation structures. On the other hand, in a broad-leaf litter such as that of *L. edulis*, the rainwater spreads easily because the flat leaves move the rainwater laterally. Thus, the broad-leaf litter can intercept more rainwater than the needle-leaf litter, because the former is more likely to have wet surfaces than the latter. These results show that the difference in the shapes of litter components affects the distribution of the litter flow channels (the wetting area) in the litter layer. Thus, when we consider the mechanisms of litter interception precisely, the effect of the morphological characteristics of the leaf litter should be considered.

## CONCLUSION

The moisture dynamics of litter layers were investigated using two different litter types: a needle-leaf type composed of *C. japonica* leaves and a broad-leaf type composed of *L. edulis* leaves. The two types were equal in water storage capacity ( $S$ ) under fully saturated conditions, and the values of  $S$  showed a linear relationship with the litter mass regardless of the layer's thickness. However, in the range of realistic rainfall conditions (under 50 mm/h), the interception storage capacities differed significantly according to litter type and rainfall intensity. The interception storage capacities increased with rainfall intensities within the range of our experimental conditions (5, 10, 50 mm/h), and the litter layers of *L. edulis* always intercepted more rainwater than those of *C. japonica*. According to the results of the litter flow experiment, the needle-leaf type litter layer (such as that of *C. japonica*) could not spread rainwater sufficiently within the litter layers due to the extremely porous accumulation structures of that type of litter. On the other hand, larger amounts of rainwater spread within the flat-type litter layer (such as that of *L. edulis*), because the broad leaves enabled the rainwater to move laterally.

Consequently, the maximum water storage capacity of a litter layer should be determined by the litter mass, which corresponds to the amount of adhesion water in the litter layer. However, the interception storage capacities under the realistic rainfall conditions will change with the rainfall intensities and litter types, because the distribution of the litter flow channels in a litter layer differs according to the morphological characteristics of its leaves. Furthermore, the channels in the litter layer also changed with litter mass and rainfall intensity. Therefore, in order to estimate the moisture dynamics of the litter layer, it is necessary to take not only the litter mass but also the effects of rainfall intensity and the morphological characteristics of the litter into consideration.

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