P5.7 Fuel Moisture Estimation Model for Deciduous Secondary Forest in Japan

– A Comparison of Parameters under Different Canopies –

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1. INTRODUCTION

Historically, the probability of a forest fire occurring has been estimated using time series weather data. Few studies have estimated the risk of forest fire in individual forest stands using forest data, such as the leaf area index (LAI). Mapped estimates of the risk of forest fire would benefit forest management, and could be used to decide restrictions on the public use of forest areas.

Fuel drying is thought to be one of the factors that contributes to forest fires, and this process is influenced by the forest microclimate. According to Pyne *et al.* (1996), practical early warning systems in use in the U.S.A. and Canada estimate the probability of a forest fire occurring using precipitation, air temperature, and relative humidity data to simulate fuel moisture. The litter layer is thin and thought to dry more quickly than other fuels. As forest fires typically originate in forest litter, before spreading upward to stems and canopies, to estimate the risk of forest fire in individual forest stands requires an understanding of the process of litter drying.

From this perspective, Tamai (2001) promoted a model for estimating the litter moisture ratio using data on solar radiation at the forest floor and precipitation, and simulated the seasonal variation in the litter moisture ratio in a deciduous secondary forest and mixed deciduous-evergreen forest in western Japan. There was a good correlation between litter drying and the number of fires occurring both spatially and seasonally. However, that study used model parameters identified in laboratory experiments. For practical use, the model parameters must reflect the microclimate and litter properties of individual forest stands.

Therefore, this study observed the litter moisture ratio and solar radiation on the forest floor in adjacent plots under different canopy structures to determine the model parameters. Differences in canopy structure affected solar conditions and thereby litter properties.

2. SITE DESCRIPTION AND METHODS

Two plots were established on a west-facing slope in Yamashiro Experimental Forest (34°47' N, 135°50' E) in western Japan. Plot A was covered with a deciduous canopy of oak (*Quercus serrata* Thunb. Ex. Murray). Plot B was covered with an evergreen canopy containing soyogo (*Ilex pedunculosa* Miq.) and Japanese holly (*Ilex crenata* Thunb.). The plots were around 20 m apart. The evergreen litter was thicker and harder than the deciduous litter and was thought to dry more slowly. The LAI was measured using a plant canopy analyzer (LAI-2000, Li-Cor); it was 3-4 in summer and 1-2 in winter in Plot A, and 5-6 and 2-3, respectively, in Plot B (Fig.-1(a)). The solar radiation reaching the litter in each plot was thought to differ due to the differences in the LAI.

The solar radiation on the forest floor was scanned every 10 seconds with a solar meter (MS-100, Eko) set at the center of each plot. Precipitation above the canopy was measured with a rain gauge at a weather station around 100 m from the plots.

The litter layer was sampled and the moisture gravimetric content ratio was calculated using the

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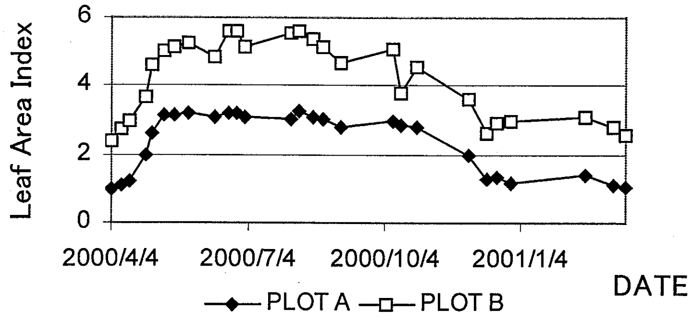
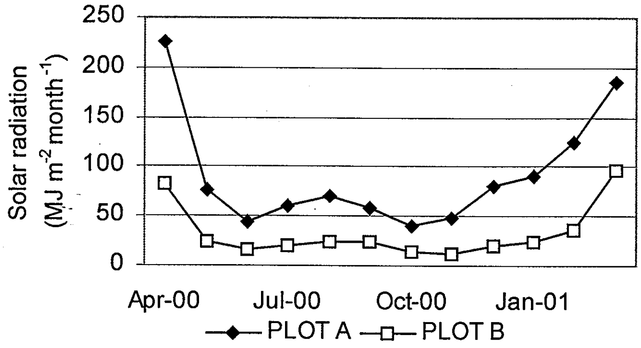
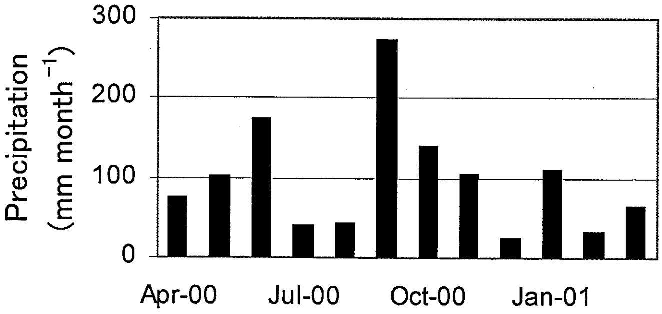


(a) Leaf Area Index



(b) Solar radiation on the forest floor



(c) Precipitation above the canopy

Fig.-1 Seasonal variations of Leaf Area Index (a), Solar radiation on the forest floor (b) and Precipitation (c).

oven drying method 26 times between April 2000 and January 2001 at irregular intervals.

3. MODEL

3.1 Structure

The model for estimating fuel moisture used in this study consists of a tank corresponding to the litter layer (Fig. 2). The depth of water in the tank equals the moisture in the litter layer. Precipitation is stored in the tank and water in excess of the maximum moisture content outflows into deeper soil. The water in the tank decreases with evaporation (E:mm), calculated using Eq. (1).

$$E = (a\theta - b)\,S \quad \text{when } \theta < c \qquad (1)$$
$$\;\;= (ac - b)\,S \quad \text{when } c \le \theta$$

where S is the solar radiation on the forest floor (kJ m^{-2}), θ is the gravimetric litter moisture ratio (g

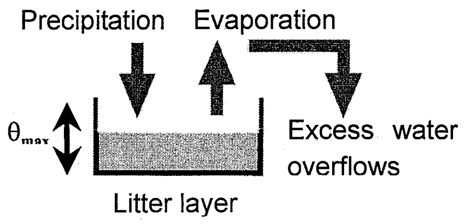


Fig.-2 The estimation model for litter moisture ratio

g^{-1}), and *a*, *b*, and *c* are parameters in the model. The identified parameters are *a*, *b*, *c*, and the maximum gravimetric moisture ratio (θ_{max}: g g^{-1}). The parameter values determined in the laboratory experiment in Tamai (2001) were a = 1.02E-04, b = 1.3E-05, c = 1.8, and θ_{max} = 2.0.

2) Parameter identification

The seasonal variation in the litter moisture ratio was simulated during March 2000 and January 2001 using various parameter values. Although initially θ = 0.00, θ ultimately equaled θ_{max} in a precipitation event (12 mm) on May 24, before the first measurement of the litter moisture ratio on April 14. The parameter values were determined to minimize the error (E_{sum}) calculated using Eq. (2).

$$E_{sum} = \Sigma . |\theta_{cal} - \theta_{obs}| \qquad (2)$$

where θ_{cal} and θ_{obs} are the calculated and observed gravimetric litter moisture ratio (g g^{-1}), respectively.

Park *et al.* (2000) reported that in the Yamashiro Experimental Forest the canopy intercepted 13.6% of precipitation between April and October and 10.5% between November and May. Therefore, the precipitation reaching the forest floor was assumed to be 86.4% and 89.5%, in April – October and November – March, respectively. Strictly speaking, the amounts of precipitation reaching the forest floor should be estimated to reflect differences in the canopy structure based on parameter identification. However, in this study it was assumed to be equal in Plots A and B. This simplifying assumption should not affect the calculation, since most precipitation in excess of θ_{max} overflows. Moreover, the value of θ_{max} is usually several millimeters.

4. RESUTS AND DISCUSSION

4.1 Observed litter moisture ratio and solar radiation on the forest floor

Fig.3 compares θ_{obs} in Plots A and B. The lowest value of θ_{obs} for 26 observations was 0.031 and 0.039 g g^{-1} on 16 August 2000 in Plots A and B, respectively. Although the highest θ_{obs} was larger in Plot A than Plot B, θ_{obs} generally tended to be lower in Plot A.

The monthly rates for *S* are shown in Fig. 1(b). The rates were remarkably higher in May and April than in other months. The annual rates from April 2000 to May 2001 were 1,103 and 393 MJ m^{-2} year^{-1} in Plots A and B, respectively.

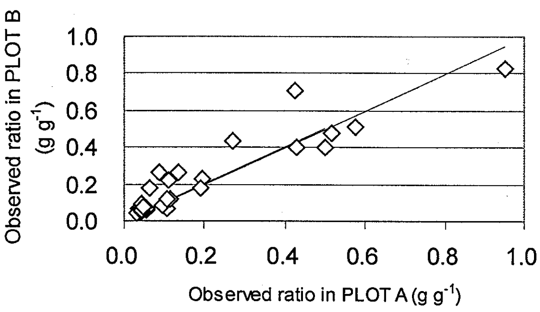


Fig.-3 The comparison of the observed ratio of litter moisture ratio in plots A and B.

4.2 Individual parameters identified for each plot

The identified results and function shape for Eq. (1) are shown in Fig. 4 and Table 1. Obviously they differed. They also differed from the values determined in the laboratory experiment (Tamai, 2001). The calculated evaporation rates for the same *S* and θ were larger using the parameters identified for Plot B, Plot A, and the laboratory experiment (Tamai, 2001), in that order. The x-intercept of Eq. (1) in Fig. 4 was 0.04 and 0.06 g g^{-1} in Plots A and B, respectively. This means that the potential lowest θ is lower in Plot A than in Plot B. The identified

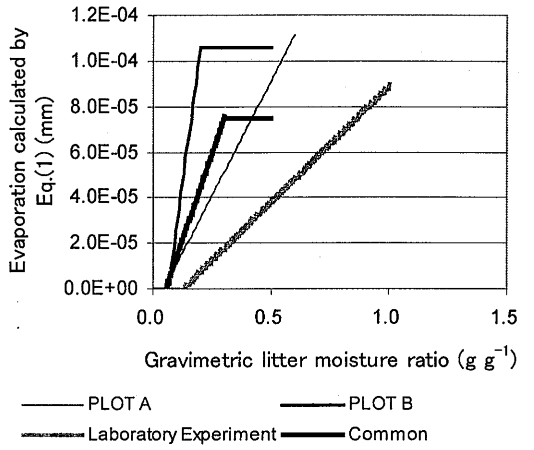


Fig.-4 The comparison of the identified function shape of Eq. (1).

Table-1 The identified parameter values.

	PLOT A	PLOT B	Common	Laboratory Experiment
a	2.0E−04	8.0E−04	3.0E−04	1.02E−04
b	9.0E−06	5.4E−05	1.5E−05	1.3E−05
c	0.6−	0.2	0.3	1.8
θ_{max}	0.6	0.5	0.5	2.0

θ_{max} was almost the same in Plots A and B, at 0.6 and 0.5 g g^{-1}, respectively.

Figs. 5(a) and (b) compare θ_{cal} and θ_{obs} in Plots A and B, respectively. Despite the wide scatter, they agreed well over the range of θ_{obs} lower than 0.42 g g^{-1}, while θ_{cal} was underestimated when $\theta_{obs} > 0.42$ g g^{-1} in Plot A. The underestimate of θ_{cal} in the wet range was more pronounced in Plot B, because θ_{max} was lower than the maximum θ_{obs}. Therefore, the model needs to be improved.

Kobayashi *et al.* (1991) reported that oak litter in western Japan was not inflammable when the moisture content ratio exceeded 0.20 g g^{-1}. This means that $\theta = 0.20$ g g^{-1} or less to imply a risk of forest fire. Therefore, the distribution of θ_{cal} and θ_{obs} around the criterion value (0.20 g g^{-1}) is shown in Table 2. On 26 observation days in the two plots, θ_{cal} and θ_{obs} were usually on the same side of the criterion value. This means that the model used in this study can estimate the probability of a forest fire occuring, though it needs the improvement.

4.3 Parameters common to both plots

In the last section, the parameters were identified for each plot individually. However, in practice it is preferable to use the same parameters for a large area. Therefore, parameters common to both plots are identified in this section. The error estimate using Eq. (2) was calculated for 52 observations in Plots A and B. The parameters and function shape were between the individual values for Plots A and B (Fig. 4 and Table 1).

Fig. 5(c) and Table 3 compare θ_{cal} and θ_{obs}, when θ_{cal} was calculated using the common parameters. The results are the same as when θ_{cal} was calculated with the individual parameters, as shown in Figs. 5(a) and (b) and Table 2. Therefore, there are only small differences in the drying properties of deciduous and evergreen litter.

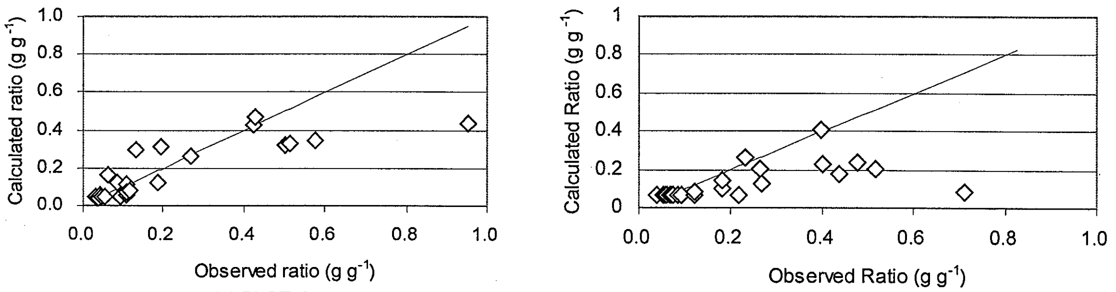
By contrast, Tamai (2001) simulated the seasonal variation in the litter moisture ratio for a deciduous forest (Yamashiro Experimental Forest) and a deciduous-evergreen mixed forest and reported that the rates of drying were very different. The maximum monthly rate of solar radiation on the forest floor in the deciduous-evergreen forest in Tamai (2001) was around 17 MJ m^{-2} $month^{-1}$ in July (Tamai *et al.*, 1998) and the annual rate was only 140 MJ m^{-2} $year^{-1}$. This is 36% of the value measured in Plot B in this study. The large difference in solar radiation is thought to cause the difference in the simulated litter moisture content.

Table-2 The distribution of the observed and calculated litter moisture ratio around the criterion ratio (0.20 g g^{-1}) using the individual parameters for plots A and B.

	Number		Share	
Individual	PLOT A	PLOT B	PLOT A	PLOT B
$\theta_{obs} < 0.20$ and $\theta_{cal} < 0.20$	17	15	0.65	0.58
$\theta_{obs} >= 0.20$ and $\theta_{cal} < 0.20$	0	4	0.00	0.15
$\theta_{obs} < 0.20$ and $\theta_{cal} >= 0.20$	2	0	0.08	0.00
$\theta_{obs} >= 0.20$ and $\theta_{cal} >= 0.20$	7	7	0.27	0.27

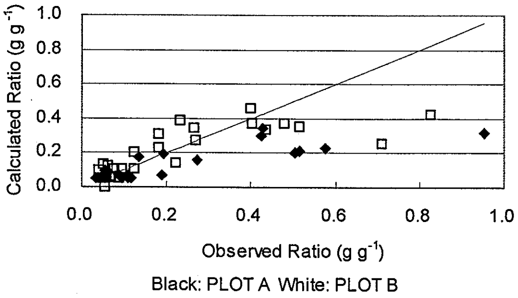
Table-3 The distribution of the observed and calculated litter moisture ratio around the criterion ratio (0.20 g g^{-1}) using the common parameters.

	Number		Share	
Common	PLOT A	PLOT B	PLOT A	PLOT B
$\theta_{obs} < 0.20$ and $\theta_{cal} < 0.20$	19	12	0.73	0.46
$\theta_{obs} >= 0.20$ and $\theta_{cal} < 0.20$	1	1	0.04	0.04
$\theta_{obs} < 0.20$ and $\theta_{cal} >= 0.20$	0	3	0.00	0.12
$\theta_{obs} >= 0.20$ and $\theta_{cal} >= 0.20$	6	10	0.23	0.38



(a) PLOT A

(b) PLOT B



(c) Common

Fig.-5 The comparison of the calculated and observed litter moisture ratio.

Summarizing the above discussion, a large difference in the common and individual parameter values led to only a small difference in the calculated litter moisture ratio (Fig. 5 and Table 2 and 3). Conversely, differences in solar conditions caused a marked difference in litter drying, even with the same parameter values (Tamai, 2001). This suggests that litter moisture depends on the microclimate, such as solar radiation, rather than on the intrinsic drying properties of the litter.

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