E-3.2 Effects of Forest Disturbance on Hydro-Meteorological Processes

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Abstract Field studies were conducted in Peninsular Malaysia to predict effects of forest disturbance on hydro-meteorological processes. Four kinds of investigations were carried out in two study sites: 1) evapotranspiration and energy budget estimation with a long term meteorological monitoring at an observation tower, 2) an observation of CO_2 flux using the same tower, 3) a runoff analysis and a comparison of soil hydraulic properties between a forest catchment and a developed rubber plantation area, 4) a survey of soil morphological and chemical properties in catchments where logging and burning are planned. The following findings were obtained. 1) An application of a big-leaf model to the estimation results of energy exchange above forest showed that the values of surface conductance were mainly controlled by solar radiation and specific humidity deficit in a wet season. 2) A short-term eddy correlation measurement of CO_2 flux gave information on a substantial large uptake of CO_2 by the forest. 3) Changes in soil properties such as decreasing of hydraulic conductivity caused by a disturbance suggested that the runoff generation process might change into frequent occurrences of surface runoff. 4) Soil chemical properties distributed in the two study catchments were classified as Acrisols or Cambisols.

Key Words Meteorological Observation, Energy Exchange, CO_2 Uptake, Runoff Process, Soil Properties

1. Introduction

Understanding the effects of tropical rain forest and its changes on climate and water resources conservation is one of the most important scientific concerns involved in the environmental issues. This requires intense observational studies for estimating energy, water and CO_2 exchange between tropical forest and the atmosphere. Intense field studies on runoff processes and their changes responding to forest disturbance in a small catchment scale are also important to evaluate influences of tropical forest on water resources.

Under a cooperative research project between Malaysia and Japan, a continuous observation on the energy exchange and a short-term monitoring of CO_2 flux exchange were conducted above a tropical rain forest. Under the same cooperative project, intense investigations on soil physical properties were extended from a forested catchment to a developed rubber plantation area to elucidate effects of disturbance on runoff characteristics. Soil morphological and chemical properties were also investigated in the nearby catchments where logging and burning would be carried out.

2. Methods

2.1 Estimation of energy and CO_2 fluxes

The observation for estimating energy and CO_2 fluxes was conducted in the Pasoh Forest Reserve. The core area (650 ha) of the reserve (2450 ha) is covered with a primary lowland mixed dipterocarp forest, which consists of various species of *Shorea* and *Dipterocarpus*. The continuous canopy height is about 35 m, although some emergent trees exceed 45 m. The leaf area index (LAI) is 6.52. A 52 m tower established in the core area was used for our observation. Meteorological factors were monitored by sensors installed at 52.6 m height. They consisted of downward and upward solar radiations, net radiation, air temperature and humidity, wind direction and wind velocity and rainfall. Vertical profiles of air temperature, vapor pressure and wind velocity necessary for an energy flux estimation were measured by two ventilated psychrometers with platinum resistance temperature devices at 43.6 and 52.6 m, and four three-cup anemometers at 43.6, 46.6, 49.1 and 52.6 m. A ground heat flux sensor was installed at 2 cm depth

The Bowen ratio method (BRM) and the profile method considering the effects of atmospheric stability (PFM) were applied for estimating sensible and latent heat fluxes from the forest canopy. The effects of environmental variables on the latent heat flux, that is, the evapotranspiration were analyzed in this report by estimating the surface conductance values. The surface conductance g_C is defined as the reciprocal of the surface resistance r_C introduced to the Penman-Monteith Equation with the aerodynamic resistance r_A . To calculate g_C values, we utilized the values of H and E estimated by BRM. The values of r_A was calculated through the flux estimation processes for PFM, in which the momentum and sensible heat fluxes with the stability correction function were estimated from the observed profiles of wind velocity and air temperature.

The CO_2 flux was measured by a system of eddy correlation method on the top of the tower. A sonic anemometer (DA-600, Kaijo) and a closed-path CO_2 analyzer (LI-6262, LICOR) were used for this eddy correlation measurement.

2.2 Effect of disturbance on runoff characteristics

Investigations on runoff processes and soil properties were conducted at the C1 basin of the Bukit Tarek Experimental Watershed. Both of a rubber plantation area and two catchments (C2 and C3) where the logging and burning are planned are adjacent to the C1 basin.

Streamflow was continuously recorded at the outlet of C1. On an experimental slope about 130 m upstream of the weir, the soil moisture was measured using mercury manometer tensiometers. Observed water storage was calculated by the results of the soil moisture observations[4] and soil survey[5] on the slope. Soil depth was measured at 23 points in the forest site and at 15 points in the rubber site using a portable dynamic cone penetrometer. The soil profiles were expressed by Nc values obtained from the penetrometer test. The surface soil layer and the weathered soil layer were defined by the Nc value.
Vertical undisturbed soil cores, 100 cm^2 area by 4 cm deep (400 cm^3 in volume) were collected at 10, 20, 40, and 80 cm depth in the both sites. Saturated hydraulic conductivities (Ks) of these cores were measured using a constant head permeameter. The soil water retention curves for these cores were determined by a sand column and a pressure chamber experiments. The relationships between pressure head (ψ) and volumetric water content (θ) were analyzed by the van Genuchten equation[6].

Runoff characteristics were analyzed using HYCYMODEL[2]. Figure 1 illustrates a schematic structure of the HYCYMODEL. The parameters in this model were optimized by trial and error method. Monthly potential transpiration rates were computed from the result of short-time period water balance method considering effects of soil water storage [3].

An investigation on soil morphological and chemical properties were conducted in C2 and C3 catchments of the Bukit Tarek Watershed. Experimental logging is planned within C2, and experimental burning is planned within C3. According to topographic condition within the area, one steep and one gentle slope of C2 area, and one steep slope of C3 area were surveyed. Soil profiles were set up at upper, middle and lower positions along the slope respectively.

Soil profile descriptions were followed to FAO (1990). Particle size distribution, pH (H_2O), pH (KCl), total carbon and nitrogen, cation exchange capacity (CEC), exchangeable Ca, Mg, K, and Na were analyzed based on the procedures by Wan Rasidah et al.[8]. Exchangeable acidity and Al were analyzed after Yuan [9].

3. Results

3.1 Meteorology at Pasoh Tower

Monthly main values of meteorological factors monitored at the Pasoh Tower from March 1995 to November 1998 are shown in Fig. 2. Although seasonal variations are not remarkable under the climate of tropical rain forest, the radiative energy is high at the beginning of every year and tends to decrease toward the end of year. This trend seems to affect the trends of air temperature and vapor pressure deficit. These characteristics may due to a comparatively weak effect of the Southwest monsoon and a major rainy season is produced by the Northeast monsoon in this region as shown in a figure of monthly rainfall amount in Fig. 2. A comparison of the monthly rainfall at the tower with the normal seasonal variation of rainfall at a near meteorological observatory (Pasoh Dua, from 1983 to 1997) in this figure also demonstrates that our observation period lay in substantial dry years except for 1995. This condition must have produced remarkable high values of air temperature and vapor pressure deficit from February to April, 1998.

3.2 Effects of environmental factors on the energy exchange

It has been considered that the surface conductance g_C is mainly controlled by stomata, and empirical expressions were proposed for the response of g_C to environmental variables such as specific humidity deficit, solar radiation, air temperature and soil moisture deficit. Fig. 3 shows relationships between g_C and specific humidity deficit (q_d) in a wet season (November and December 1996). The solar radiation (S_d) is taken as a parameter. The value of g_C is well explained by these two factors. This tendency is empirically modeled as:

$$g_c = 80\, S_d \exp(-0.14 q_d) \quad (1)$$

Fig. 4 shows values of latent heat flux calculated by the Penman-Monteith Equation with the above model of g_C. A fine comparison of them with the latent heat values by the Bowen ratio method suggests that a control of transpiration by the environmental factors were explained by the model in wet seasons. However, this model is considered to have an application limit in drier conditions. The most important subject to be analyzed will be to assess the limit of the model based on its application to data in serious dry conditions.

3.3 CO_2 flux

Diurnal variations of the CO_2 flux above the Pasoh forest (from March 9 to 14, 1998) are shown in Fig. 5. The downward flux is represented as a negative rate and the upward flux is represented as a positive rate. The directions of CO_2 flux were downward in the daytime and upward in the nighttime, in general. However, the flux rates were widely scattered and even the downward rates were shown, in the nighttime. Such downward flux rates might appear under low wind conditions and/or high humidity conditions. The methods of data processing and measurements under these conditions may still include some problems. The mean daily value of the CO_2 flux obtained from the 6-day measurement was about -7.2 $gm^{-2}day^{-1}$, and the total amount in the 6 days was -43.1gm^{-2}. Our short-term observation of CO_2 flux has given information that this forest functioned as a substantial large CO_2 sink. A long-term continuous measurement of CO_2 flux is strongly required to evaluate the actual CO_2 uptake by a tropical forest ecosystem in Southeast Asia.

3.4 Soil physical properties

Figure 6 shows schematic diagrams showing the results of soil physical properties. The thickness of surface soil layer and total soil depth in the forest (site F) ranged from 52 to 160 cm (mean: 93 cm) and from 118 to 640 cm (mean: 277 cm), respectively. The thickness of surface soil layer and total soil depth in the rubber plantation (site R) ranged from 0 to 121 cm (mean: 41 cm) and from 80 to 217 cm (mean: 132 cm), respectively. The thickness of surface soil layer and total soil depth at the terrace bench are smaller (mean: 20 and 127 cm) than those at the raiser bank (mean: 84 and 141 cm). The saturated hydraulic conductivity (Ks) in the site F and the site R ranged from 6.40×10^{-6} to 7.51×10^{-4} m s^{-1} and from 1.79×10^{-6} to 5.68×10^{-4} m s^{-1}, respectively. The Ks values decreased with increasing soil depth at both sites. The average Ks values in the site F were larger (e.g., 10cm: 1466 mm h^{-1}, 80 cm: 169 mm h^{-1}) than observed prevailing rainfall intensity in the basin[3]. Though the average Ks values at riser bank in the site R were similar to those in the site F, the average Ks values at terrace benches were smaller (e.g., 10 cm: 30-154 mm h^{-1}, 40 cm: 18-40 mm h^{-1}). The soil water retention curves were generated by the van Genuchten model. The macro- and meso-porosites of soil also decrease with increasing soil depth. The prosities of soils were in the following order of magnitude: forest > terrace raiser > bench terrace. The differences between the site F and site R affect the runoff characteristics.

3.5 Runoff characteristics

The simulated discharge using the model agreed well with the observed discharge for two years (Figure 7). The relative error (F_1) and the water balance error (F_2) were calculated by following equations:

$$F_1 = \frac{1}{N}\sum \frac{|Q_{ob}(t) - Q_{ca}(t)|}{Q_{ob}(t)} \quad (2)$$

$$F_2 = \frac{|\sum Q_{ob}(t) - \sum Q_{ca}(t)|}{\sum Q_{ob}(t)} \quad (3)$$

where $Q_{ob}(t)$ is the observed discharge, $Q_{ca}(t)$ is the calculated discharge, N is the number of the observed data. F_1 and F_2 were 0.293 and 0.079, respectively. Figure 3 shows observed water storage (Sob) and calculated water storage in Tank II and III (Su+Sb) for two years. The responses of Sob to rainfall are more sensitive than those of Su+Sb. In addition, the amount of Sob is lower than that of Su+Sb. There are two probable reasons for the difference between Sob and Su+Sb. One reason can be deduced from difference of the calculated area; Sob and Su+Sb were calculated for the experimental slope and the entire basin, respectively. A second reason might be difference of calculated soil depths; while soil moisture measured for Sob from 10 to 160 cm soil depth using tensiometers, an average soil depth in the watershed was 270 cm using cone penetrometer tests[5]. On the other hand, seasonal pattern of variation about Su+Sb through two years is similar to that of Sob.

The results using the HYCYMODEL showed a good applicability for Bukit Tarek Experimental Watershed. Parameters of the model express useful information about runoff characteristics. The parameters in the surface soil tank might be changed after forest disturbances such as clear cutting. It is suggested that changes of runoff characteristics caused by the disturbance can be evaluated using this model.

3.6 Soil morphological properties

Soil morphological properties were similar among the profiles. Thin dark colored Ah horizons and light colored underlying horizons were observed commonly. Weak subangular blocky structures were common throughout the profiles, granular structures were observed at top layer. Cutanic features were obvious. Differences among slope (gentle or steep) and positions were not clear from morphological properties.

Steep slope series of C2 and middle and lower site were rich in clay. Upper part of gentle slope at C2 and soils of C3 steep slope were rich in silt. From particle distribution pattern the soils were divided into silty and clayee groups. Silty soils did not show clay movement. Clayee soils suggested clay movement or accumulation. Baharuddin et al.[1] suggested exposure of surface by logging provided the wash out of soil fine fraction, especially silt fraction. Clay and silt content at surface horizons may change after experiment.

3.7 Soil chemical properties

Result of soil chemical analysis was tabulated in appendix. pH(H_2O) and pH(KCl) were acidic at surface horizons and increased the values with depth. Carbon and nitrogen content declined sharply with depth at every profile. C-N ratio was low throughout the profile and did not change so much as carbon and nitrogen content. Value of CEC was usually highest at top horizon, declined with depth and showed peak at subsoil. Every exchangeable cations content level was low in general. Tendency of ex-Ca in the profile was not clear. Ex-K and ex-Mg contents showed highest at the surface horizon and sharply declined with depth. Ex-Na content was extremely low throughout every profile.

Base saturation % ((ex-Ca + ex-Mg + ex-K + ex-Na)/CEC) were low, several percent for every sample. Exchangeable acidity sharply declined with depth and their values of C3 soils were two or three times higher than those of C2. Exchangeable Al content also showed great difference between C2 and C3.

Values of CEC of the clay[7] were usually less than 24cmol/kg for C2 soils, whereas those were higher than 24cmol/kg for C3 soils. The C2 soils can be classified as Acrisols group of FAO classification, and the C3 soils can be classified as Cambisols.

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Partial charge of the report arrangement

The persons taking partial charge of the four kinds of investigations included in this report are listed as: 1) Makoto Tani (FFPRI) for an evapotranspiration and energy budget estimation, 2) Yoshikazu Ohtani, Tsutomu Watanabe and Michiaki Okano (FFPRI)for an observation of CO_2 flux, 3) Shoji Noguchi and Yoshio Tsuboyama (FFPRI) for a runoff analysis and a measurement of soil hydraulic properties, and 4) Kazuhito Morisada (FFPRI) for a survey of soil morphological and chemical properties. The report was arranged based on cooperation with Abdul Rahim Nik, Zulkifli Yusop, Baharuddin Kasran and Wan Rasidah Wan Abdul Kadir (FRIM).

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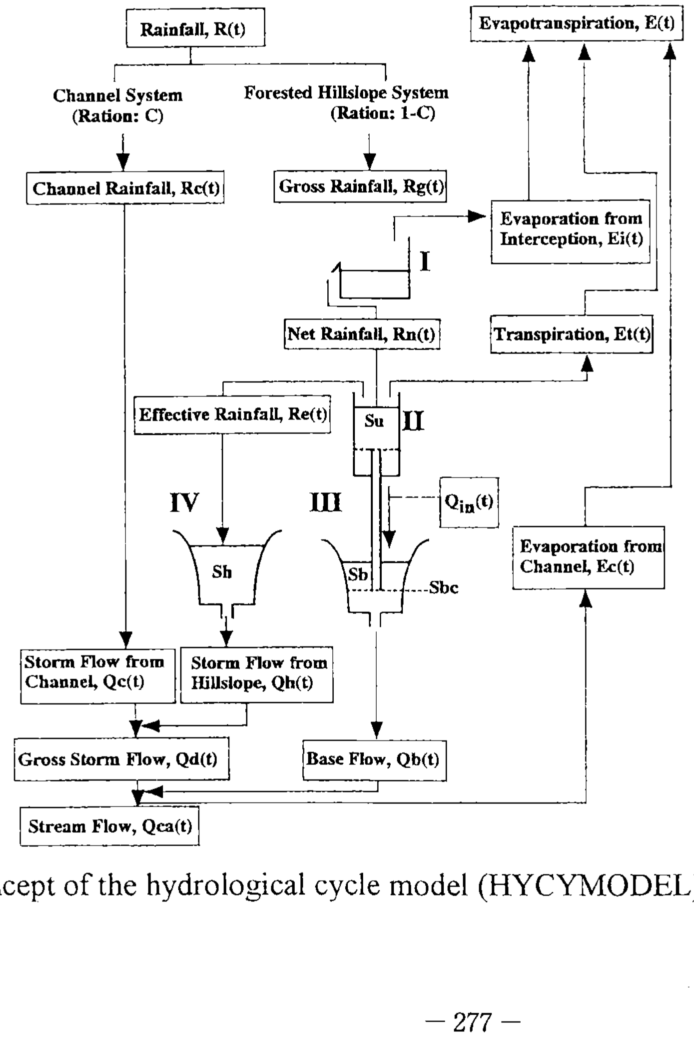
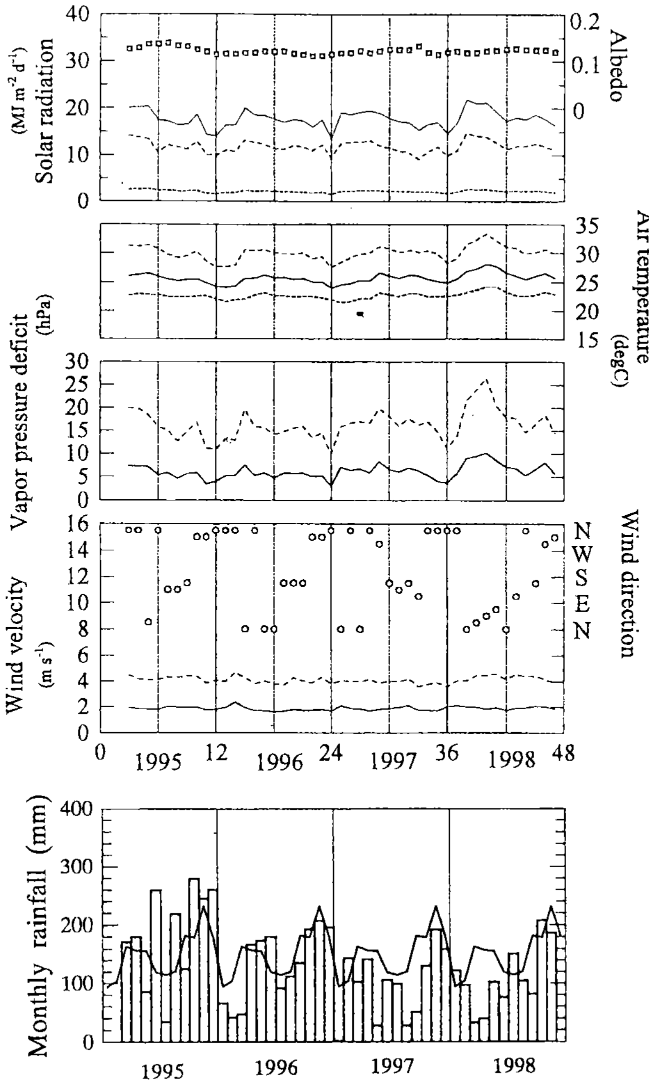


Fig. 1 Concept of the hydrological cycle model (HYCYMODEL)



□ . Albedo
— Downward solar radiation
··· Upward solar radiation
--- Net radiation
— Daily mean air temperature
--- Daily maximum air temperature
··· Daily minimum air temperature
— Daily mean vapor pressure deficit
--- Daily maximum vapor pressure deficit
○ Daily mean wind direction
— Daily mean wind velocity
--- Daily maximum wind velocity
Bar Monthly rainfall at Pasoh Tower
— Normal monthly rainfall at Pasoh Dua

Fig. 2 Seasonal variations in monthly values of meteorological factors at Pasoh Tower

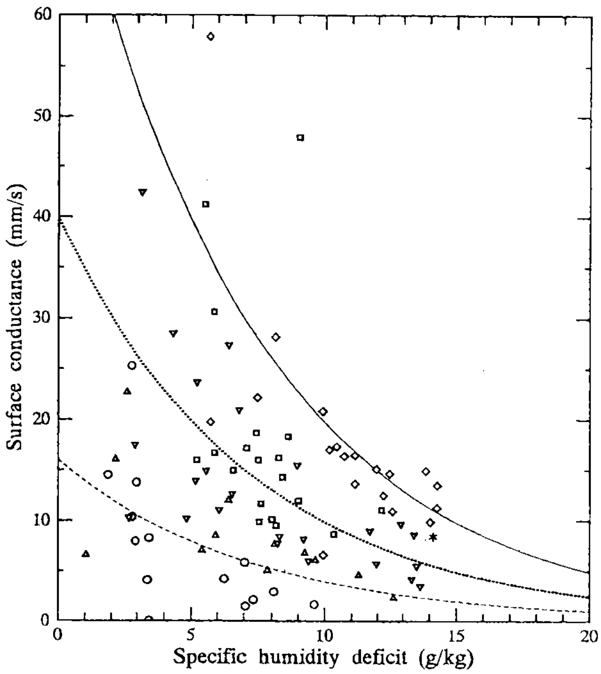


Fig. 3 Relationships of surface conductance to specific humidity deficit and solar radiation.
Observation: $S \leqq 0.2$ kw m^{-2}, △、$0.2<S\leqq 0.4$, ▽$0.4<S\leqq 0.6$., , □$0.6<S\leqq 0.8$, ◇.$0.8<S$
Calcilation: —S = 1, ··· S = 0.5, - - - S=0.2

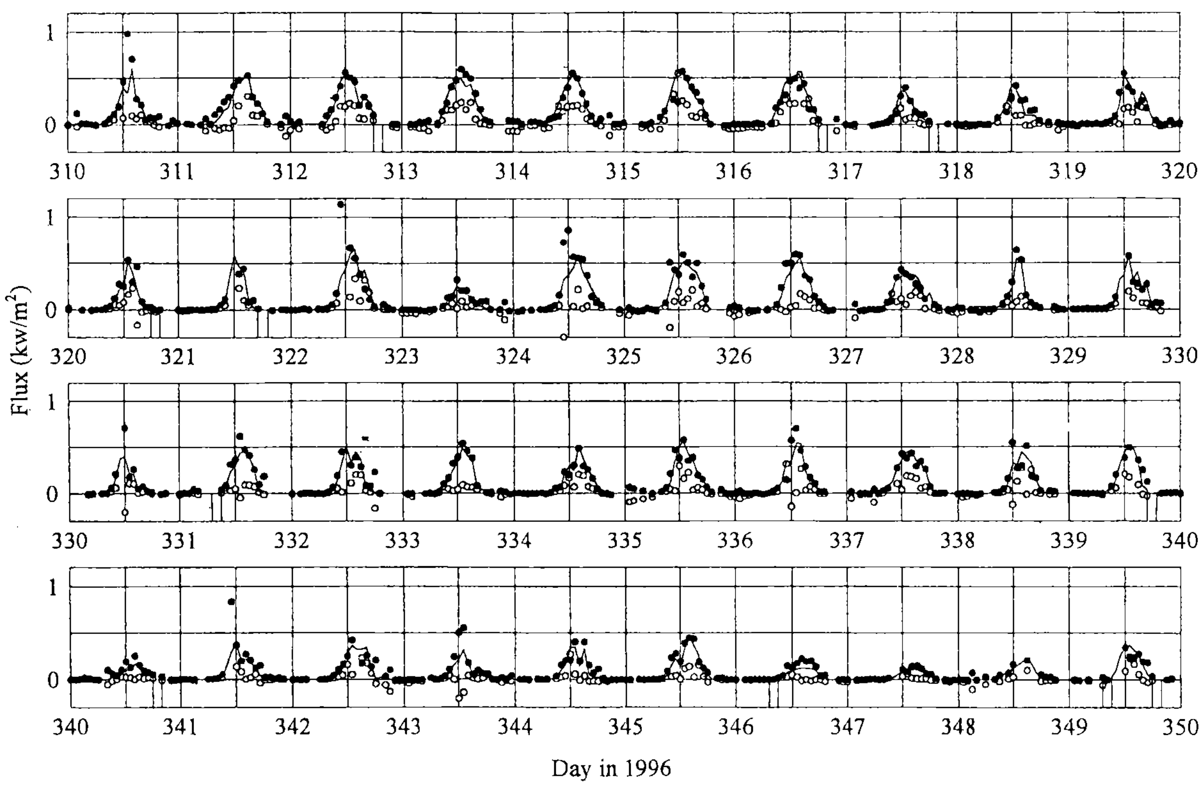


Fig. 4 Acomparison of latent heat fluxes between estimated by the Bowen ratio method (●)and calculated by a surface conductance model (—).
○: Sensible heat flux estimated by the Bowen ratio method

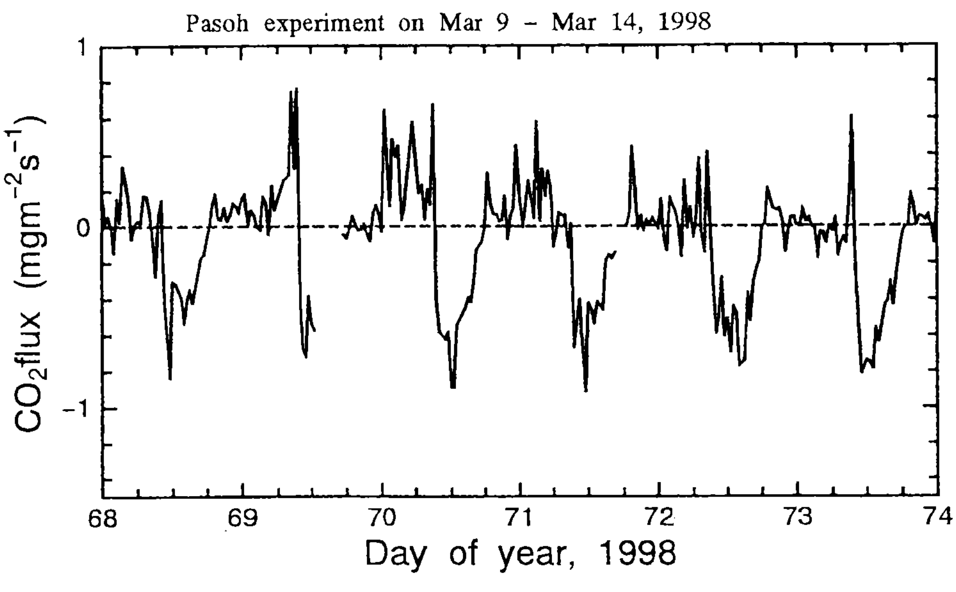


Fig. 5 Diunal variations of the CO2 flux above the Pasoh Forest (from March 9 to 14 , 1998).

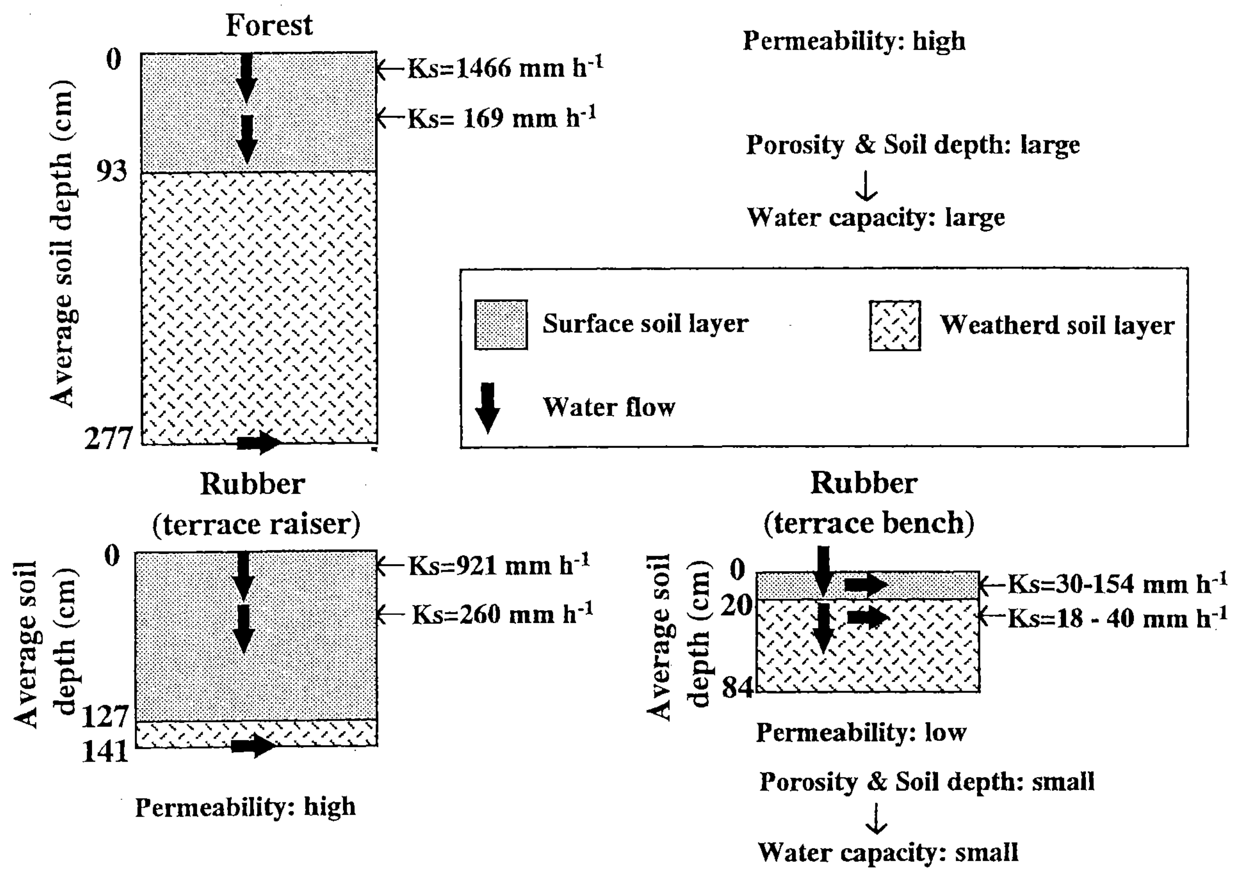


Fig. 6 Schematic diagrams showing the results of soil physical properties.

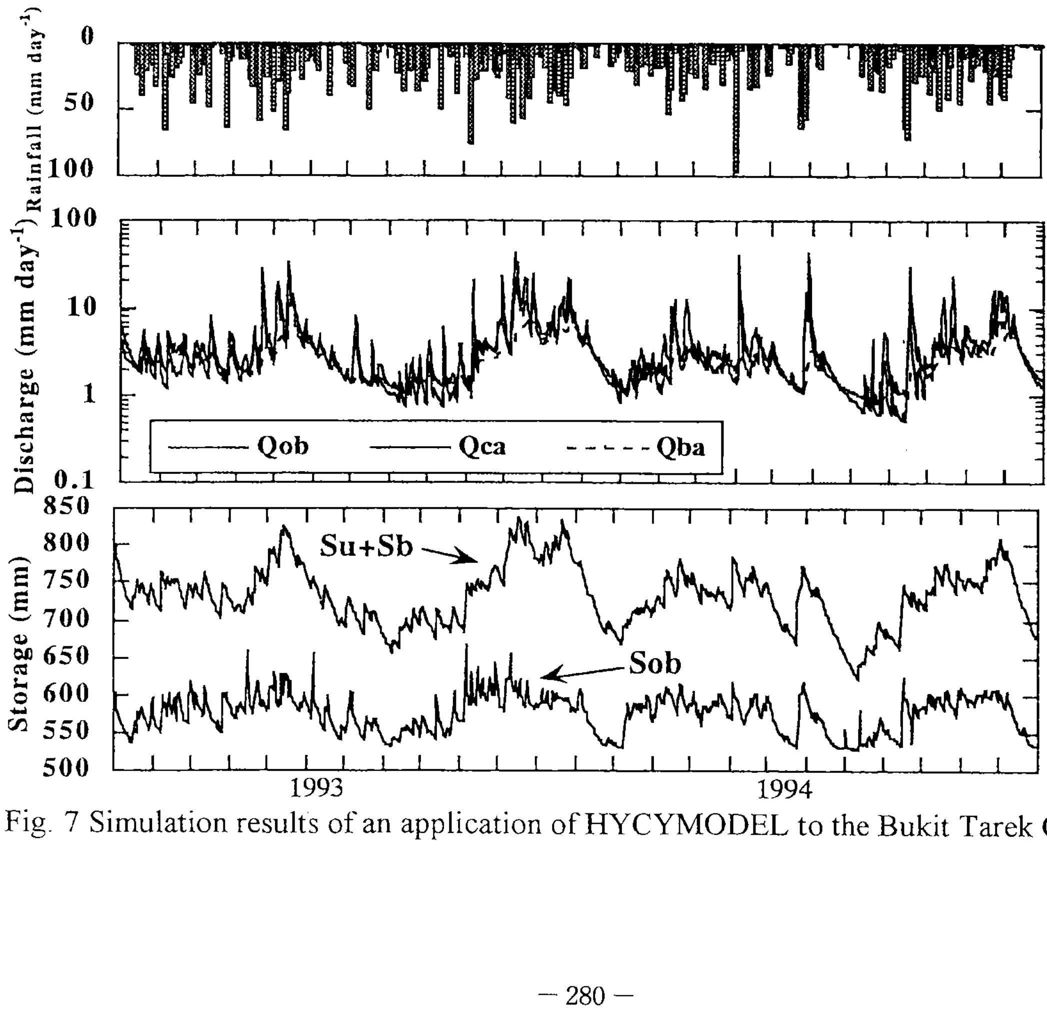


Fig. 7 Simulation results of an application of HYCYMODEL to the Bukit Tarek C1 basin.