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# Influences of rainfall and soil water flow upon $CO_2$ concentration in a dryland paddy

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**Abstract** : The $CO_2$ concentration and micrometeorological measurements were carried out in a dryland paddy field throughout a growing season, and the relationship between the concentration and soil water flow was examined.

Generally, $CO_2$ concentrations tend to reach maximum values before sunrise under the influence of both plant respiration and soil respiration, and the concentration decreases during the day caused by photosynthesis. Exception of this trend occurs on windy days and during rain in the night. In such instances, the concentration does not peak before sunrise. Early-morning peaks in $CO_2$ concentration were not detected from the examination of diffusion velocity because the physical effect of falling raindrops did not diffuse the $CO_2$ gas near the plant canopy.

On the other hand, from the comparison between soil water flow with a daily level water balance and $CO_2$ concentration at 4:00 a.m., it was found that the $CO_2$ concentration near the ground surface increased with an upward soil water movement on clear days. However, $CO_2$ concentration did not increase when a downward soil water flow occurred during rain in the night. This suggests that the $CO_2$ concentration decrease before sunrise on rainy nights was mainly caused by the downward movement of soil water, and it restrained the upward emission of soil respiration.

The problem is whether the decrease is a temporary phenomena or an everlasting one. It is necessary to chemically investigate the behavior of carbonated water with atmpspheric $CO_2$ measurement. Also, more detailed experiment with weighing lysimeter are needed, or the same tests applied to drier soil

**Key words** : $CO_2$ concentration, soil respiration, diffusion velocity, soil water movement, daily water balance calculation

## Introduction

Atmospheric $CO_2$ concentration shows a tendency to increase year by year because of the $CO_2$ emission by mass consumption of fossil fuels. About 52% of these emissions remain in the air, and the remainder is fixed near the ground surface (Uchijima and Seino, 1988). However, it is still unknown whether the fixation is conducted by plants or absorbed by the ocean. When we determine the contribution rate by plant fixation, it becomes important to estimate the $CO_2$

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emission by plant respiration and by decomposition of organic matter in a soil (Seino, 1990). The $CO_2$ concentration in the air surrounding a plant canopy during the night changes caused by changes in $CO_2$ emission by both plant and soil respirations (Monteith, 1963). As for the latter, it has previously been thought that the whole organic matter returns to the air as carbon dioxide gas after the organic matter is decomposed.

However, when $CO_2$ concentrations were measured every hour, it was demonstrated that weather, such as lack of cloud cover or rain influenced $CO_2$ concentrations. Therefore, we compared the $CO_2$ concentration at night with vertical soil water movement and precipitation intensity to determine the effect of soil water flow on the $CO_2$ emission from the ground surface.

## Measurement methods

Dryland paddy rice (*Yukihatamochi*) was cultivated at the experimental field of National Institute of Agro-Environmental Sciences located in Tsukuba city in central Japan from May to September, 1991.

Referring to Harazono, *et al.* (1990), micrometeorological parameters necessary for both heat balance method and aerodynamic method, and $CO_2$ concentration by infrared gas analyzer were measured over rice plants. Sampling-nozzles for the $CO_2$ and psychrometers for dry and wet temperatures were established just above the plants and at a height of 70 cm over the plant canopy. The heights of all sampling instruments, including cup anemometers, were changed to adjust to plant growth. Data were recorded every 10 seconds, saved as one minute averages on floppy diskettes, and analyzed using 10 minute averages.

Heat probe soil moisture meters were buried between furrows at depths of -2.5, -5.0, -10.0, and -20.0 cm, and heat conductivity data were collected every 15 minutes. After converting the data to volumetric water content, the amount of water was estimated (Shimada, *et al.*, 1992), and used for water balance analysis. However, it has recently been pointed out that heat probe sensors tend to be influenced by the diurnal changes of soil temperature, because thermocouple cables are used, particularly if sensors are buried too shallow (Hasegawa and Kasubuchi, 1988, Sakuratani, 1991, Yasuhara, 1992). This short coming was avoided by using the daily mean values when calculating water balance.

## Weather and $CO_2$ concentration

Diurnal changes in $CO_2$ concentration in June are shown in Fig.1. Concentration peaks exceeding 400 ppm occurred at night to sunrise on clear nights (upper graph), but the peaks did not occur on rainy nights (lower side). Ranges of $CO_2$ concentration are similar at minimum values during the day at 350 ppm. The same tendencies occurred in August (Fig.2). This phenomenon was found through the whole growing season.

Fig.3 shows a time series of the maximum $CO_2$ concentration from 3:00 a.m. to 5:00 a.m.. These values varied greatly from 350 ppm to 500 ppm each day. On the other hand, the ranges of $CO_2$ concentration from 11:00 a.m. to 1:00 p.m. were not larger than those from 3:00 a.m. to 5:00

a.m. (Fig.4). It is thought that the $CO_2$ concentration in the early morning is sensitive to the changes in the weather, but during day $CO_2$ is relatively stable and remains at low concentrations.

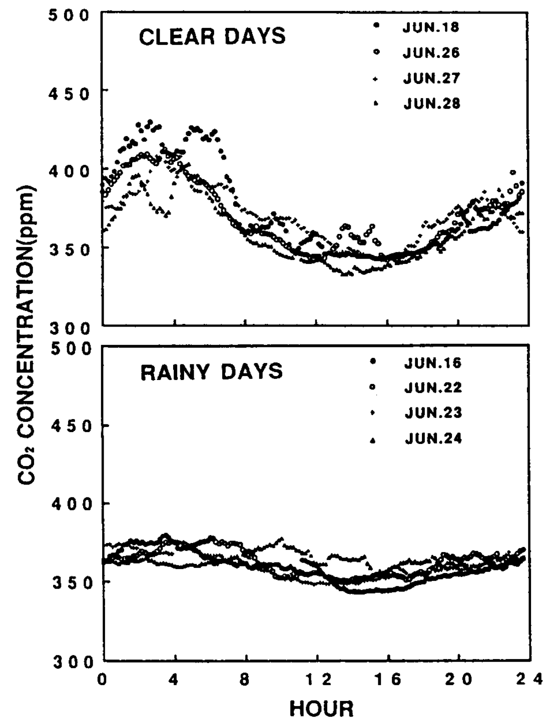

Fig.1 Diurnal fluctuation of $CO_2$ concentration on clear days (Upper) and rainy days (Lower) in June

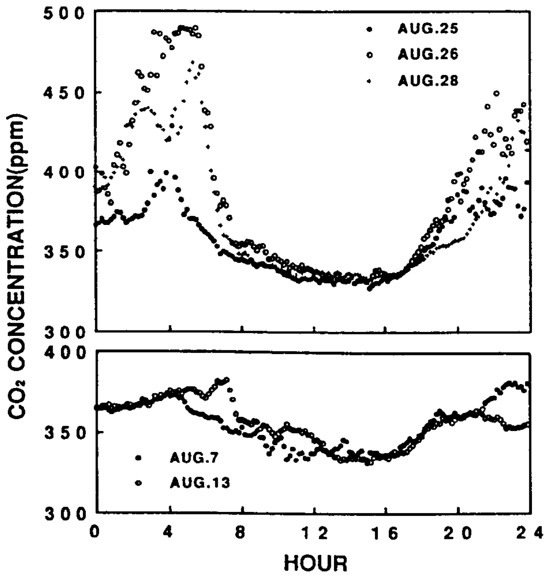

Fig.2 Diurnal fluctuation of $CO_2$ concentration on clear days (Upper) and rainy days (Lower) in August

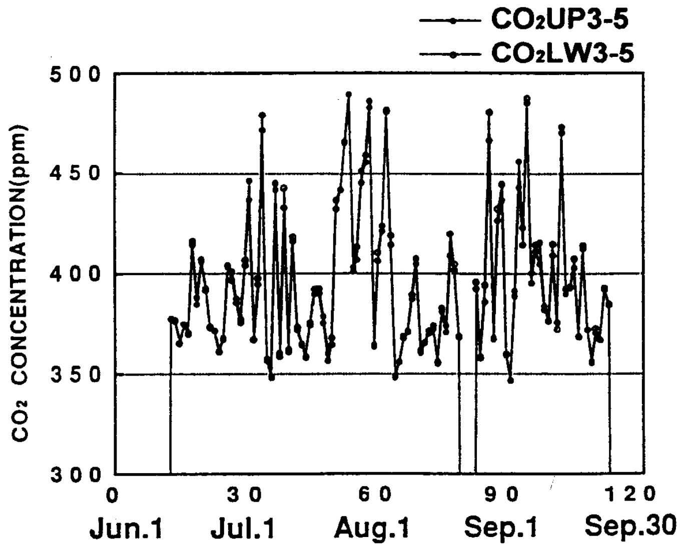

Fig.3 Time series of mean $CO_2$ concentration between 3:00 and 5:00 a.m. through the whole growing season of dryland paddy. White circles are the $CO_2$ concentration at the plant height and black dots are the $CO_2$ concentration measured at the height of 70 cm over the plant canopy.

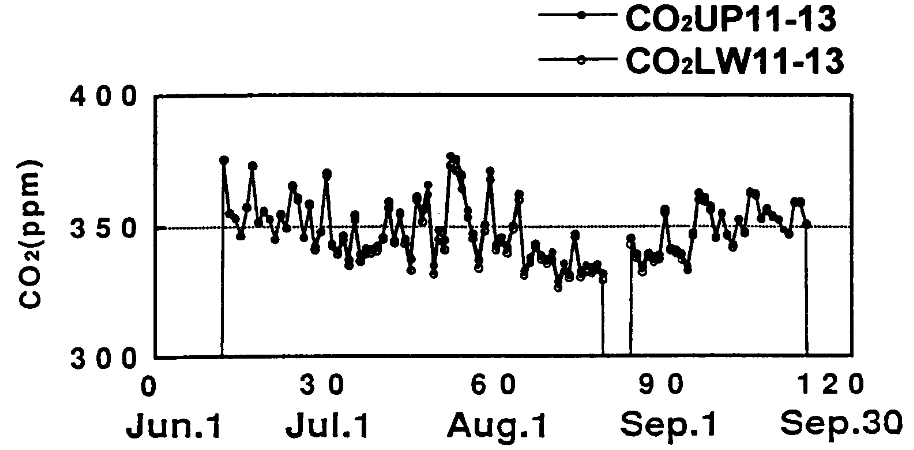

Fig.4 Time series of mean $CO_2$ concentration between 11:00 and 13:00 through the whole growing period of a dryland paddy.

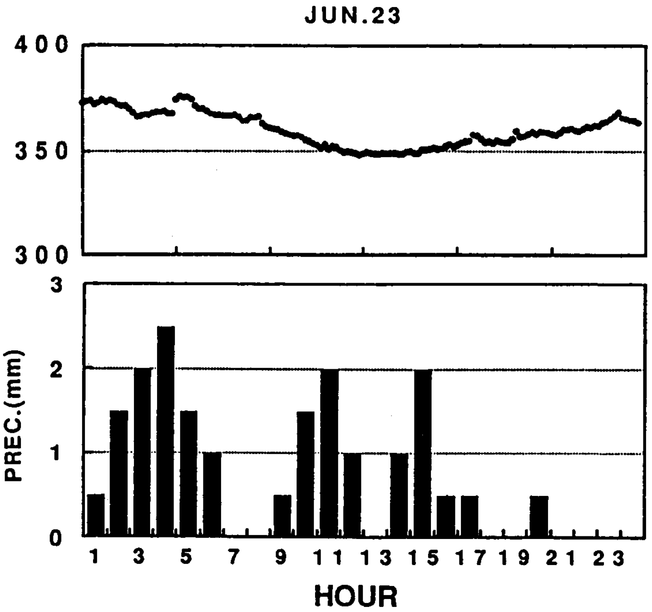

Fig.5 Diurnal variation of $CO_2$ concentration at continuous rain throughout a day.The $CO_2$ concentration is shown in the upper graph and hourly precipitation in the lower graph.

The relationship between weather and $CO_2$ concentration was investigated in more detail. Fig.5 is an example of diurnal fluctuations of $CO_2$ concentration when it rained throughout the day (June 23). Although the precipitation intensity was less than 3 mm/h, the rainfall continued almost a day, and the $CO_2$ concentration remained below 400 ppm. When rainfall stopped before noon (August 31, Fig.6), the maximum concentration of $CO_2$ did not occur in the early morning, but at 22:00 to 23:00 after the rain had stopped. When it rained early in the morning, the $CO_2$ concentration near the plant canopy remained nearly constant all day. It is thought that the rainfall and the relating factor such as soil moisture regulate the $CO_2$ release into the air by soil respiration.

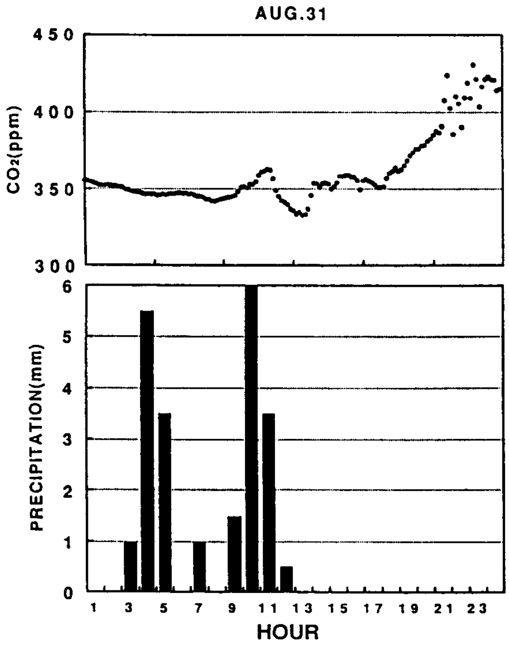

Fig.6 Diurnal variation of $CO_2$ concentration during morning rain.

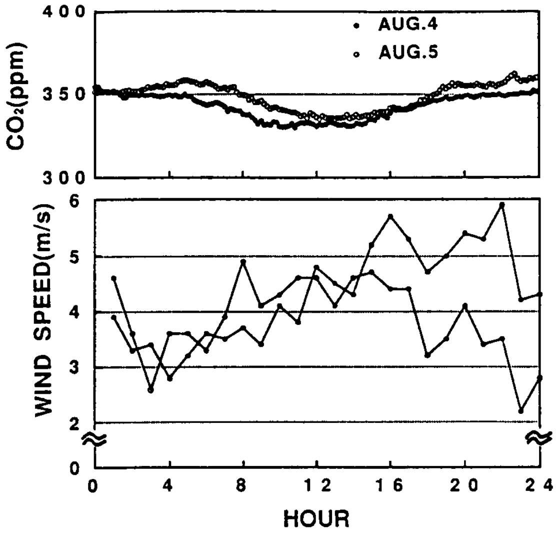

Fig.7 Diurnal variations of $CO_2$ concentration on windy days.

Fig.7 is a time series of the CO2 concentration in which wind velocity was strong at 3 m/sec. throughout a day (August 4 and 5). Although both days had clear skies, the maximum CO2 concentrations were about 360 ppm like on rainy days, and conspicuous peaks in CO2 concentration did not occur, because the CO2 gas near the ground surface was diffused by the strong winds of over 3 m/sec.

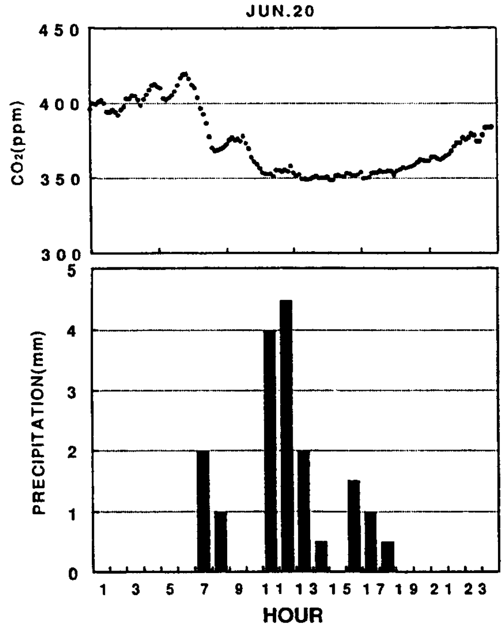

Fig.8 Diurnal variation of $CO_2$ concentration during day time rains.

On rainy days the early morning concentration peak occurred like on clear days except when the rain fell in the early morning (Fig.8). This occurred on June 20, when it began raining at 7:00 a.m..

At this time the plants began absorbing $CO_2$ gas for photosynthesis after releasing it through respiration by night. However, the abrupt decrease from 420 ppm to 370 ppm in one hour suggests that another factor besides plant activity influenced $CO_2$ concentration. Therefore, when the mean $CO_2$ concentration between 3:00 a.m. and 5:00 a.m. is related to the daily mean soil moisture, the time of rainfall must be taken into account.

The difference at the ground surface between wet and dry conditions was also investigated (Fig.9). The $CO_2$ concentration did not increase during the night of July 5 although it did not rain. This occurred because it had been raining not only on July 5 but also the previous four out of five days from June 30. Therefore the soil water content was very high. The weather rapidly improved on July 6 as soon as it stopped raining, and soil water began to evaporate by a great amount of short wave radiation (RS), and $CO_2$ concentration started to increase at night.

Furthermore, the vertical diffusion of $CO_2$ gas on rainy days was examined, because the falling raindrops might physically diffuse the $CO_2$ gas near the plant canopy. The relationship between diffusion velocity and the $CO_2$ concentration was investigated from June 21 to 25 (Fig.10).

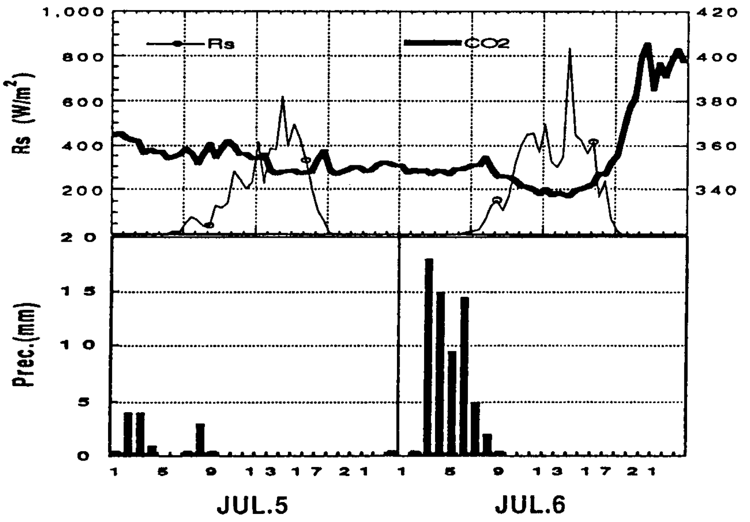

Fig.9 Relationship between wet/dry ground surface condition and $CO_2$ concentration. On July 6, the ground surface was heated by a great amount of short wave radiation ($R_S$) during the day, the $CO_2$ concentration increased at night.

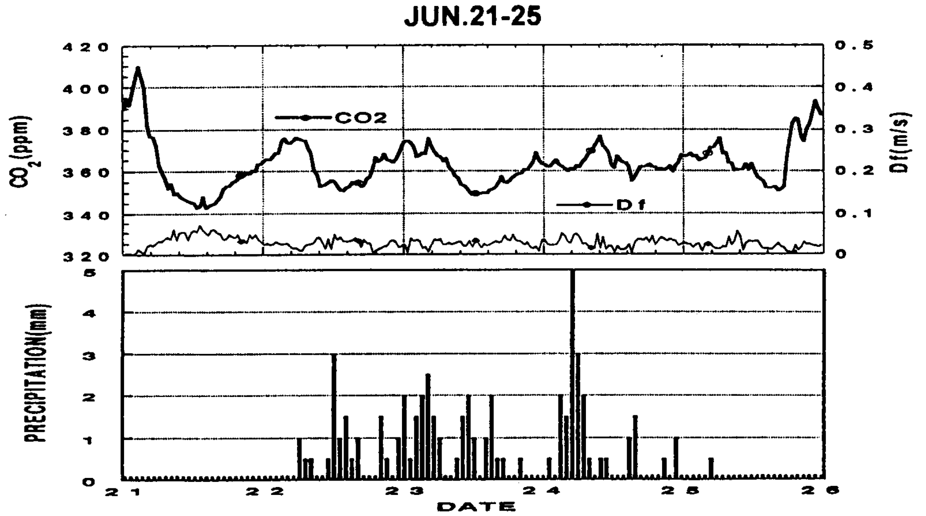

Fig.10 Fluctuation of diffusion velocity (Df) on rainy days. Although the $CO_2$ concentration is stable, this phenomenon is not brought about by the diffusion of the boundary layer by raindrops.

The diffusion velocity in this figure was calculated from the following processes with measured wind velocity data. The 10 minutes average wind velocity at five heights recorded every one minute were used. The heights of cup anemometers were 40 cm, 70, 110, 200, and 310 cm above the ground in the end of June.

It was assumed that the 10 minutes wind velocity data (Um) met a logarithmic function of the following equation (Thom, 1975, McCaughey and Saxton, 1988).

$$Um(Z) = (U^*/\kappa)\ \ln\{(Z - d)/Z_0\} \tag{1}$$

where: $U^*$ = friction velocity, $\kappa$ = von Karman constant,
Z = height of cup anemometer, d = zero-plane
displacement, and $Z_0$ = roughness length.

Substituting Um and (Z - d) in each height to the next equation (2), the values of a (gradient), b (y-intercept) and least squares correlation coefficient were calculated from:

$$\ln(Z - d) = aUm + b \tag{2}$$

Here, changing the value of d every 0.1 cm, the zero-plane displacement (d) was determined when the correlation coefficient reached the maximum.

Using a and b in which the maximum correlation coefficient was determined, $U^*$ and $Z_0$ were calculated from the following equations.

$$U^* = \kappa/a \tag{3}$$

$$Z_0 = \exp(b) \tag{4}$$

Finally, from these parameters, the diffusion velocity in each analysis unit was solved as follows.

$$Df = U^{*2}/Um = \kappa^2 Um/\{\ln(Z - d) - \ln(Z_0)\} \tag{5}$$

It had been raining from June 22 to the morning of June 25 (lower graph of Fig.10). The $CO_2$ concentration during this period ranged from 345 ppm to 375 ppm; only a slight change.

The Df value in question was a little larger compared with the one during the night on clear days such as at 3:00 a.m. on June 21 and at midnight of June 25, but the Df value did not exceed 5 cm/s. Therefore, I conclude that there was no obvious difference between the Df values.

Also, the difference in $CO_2$ concentration during this period between the two heights was almost zero. This means that there was no $CO_2$ gas supply from the lower air layer, and suggests that the raindrops did not greatly change the atmospheric stability. Therefore it is necessary to investigate the behavior of water after the rain reaches the ground.

## Soil water movement and the early morning $CO_2$ concentration

Fig.11 shows the seasonal variation of daily mean soil moisture to a depth of -15 cm as measured by a heat probe sensor. The decrease of soil water with the ending of rainy season (*Baiu*) on July 20, and the increase in rainfall during the typhoon season are illustrated in Fig.11. However, there is no obvious relationship between the mean $CO_2$ concentration at 3:00 a.m. to that at 5:00 a.m.. Daily level water balance was analyzed and compared with the vertical soil water movement.

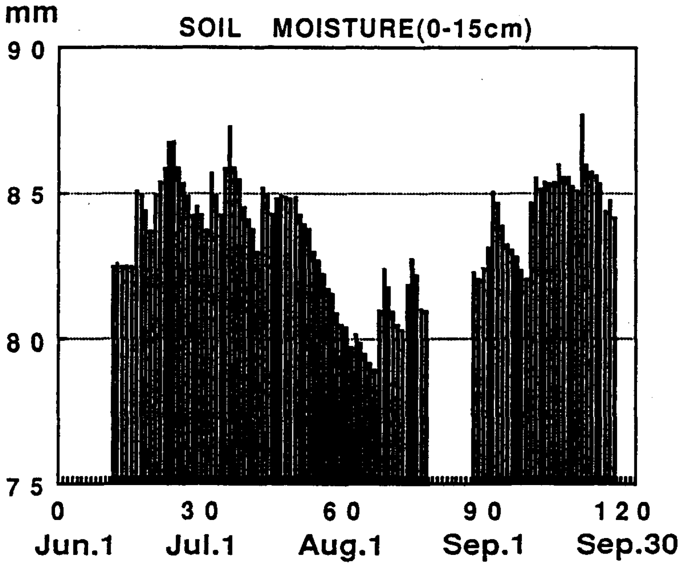

Fig.11 Seasonal change of soil moisture between the ground surface and at -15 cm below ground.

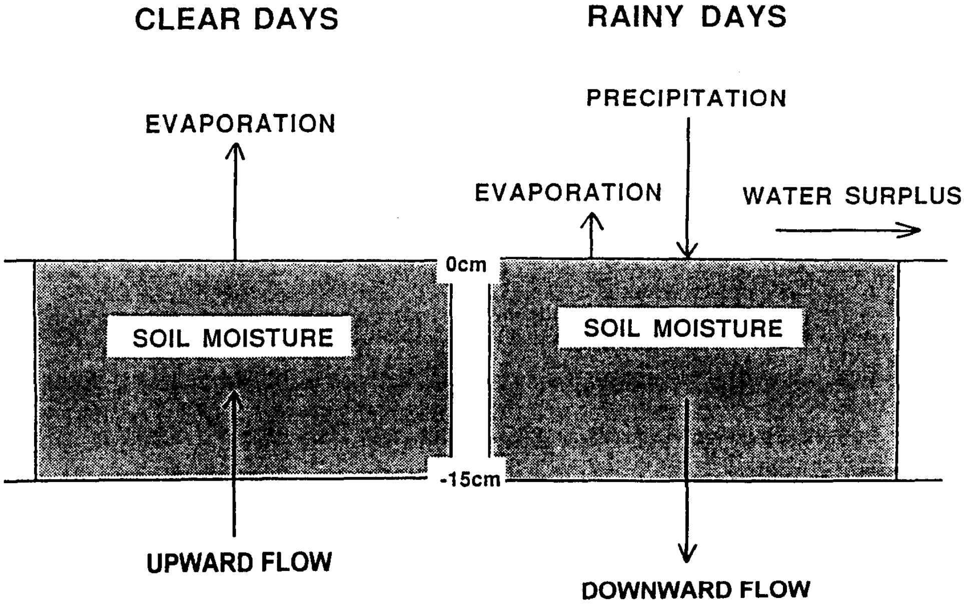

Fig.12 Flowchart of water distribution on clear and rainy days.

A flowchart of water distribution near the ground surface on clear and on rainy days is shown in Fig.12. Here, within the top 15 cm of the soil layer, the amount of water is supplied from below on clear days and is described as an upward flow. But on rainy days water filters through the soil and is described as a downward flow (infiltration).

Soil moisture on a given day can be expressed as the precipitation on that day added to the soil moisture of the previous day, less evaporation, runoff (water surplus) and infiltration (Watanabe, 1987).

$$SMi = SMi_{-1} + Pi - Ei - SPi - IFi \tag{6}$$

where: SM = soil moisture, P = precipitation, E = evaporation,
SP = water surplus (runoff), and IF = infiltration.

Both P and SP equal zero on clear days, then:

$$IF = - \Delta SM - Ei \tag{7}$$

On rainy days, the value of E equals zero, and using the $\Delta$SM at a soil depth of -7.5 to -15 cm to minimize the error, I calculated the infiltration value.

Through these daily water balance calculations mentioned above, a time series of soil water flow was obtained (Fig.13). Minus values mean water filtrated down to a depth of -15 cm, the plus values mean the water moved to the upper layer from below.

This soil water flow was compared to the $CO_2$ concentration at 4:00 a.m. (Fig.14). However, the days when wind velocity exceeded 3 m/s, and the days when it rained only during the day (a total of 24 days) were removed from the comparison, leaving a total of 76 sample days.

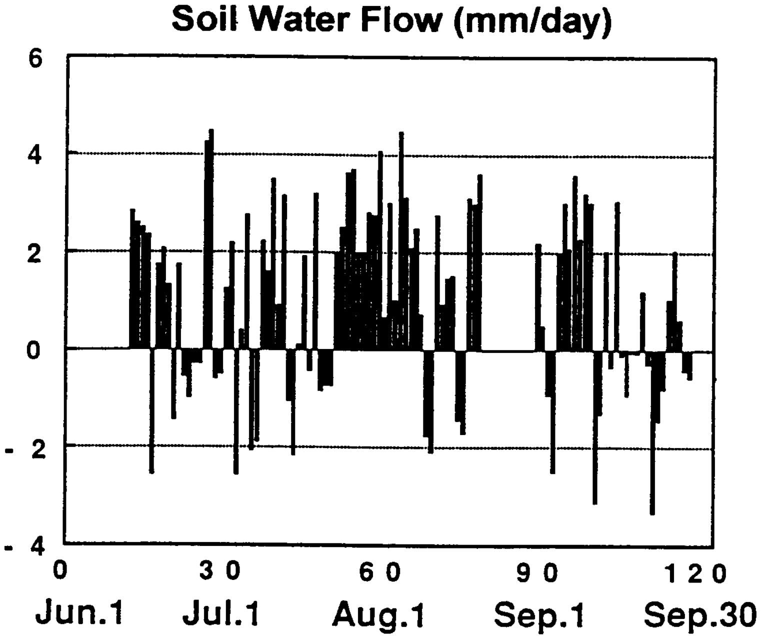

Fig.13 Seasonal change of soil water flow (mm/day) according to daily water balance calculation.

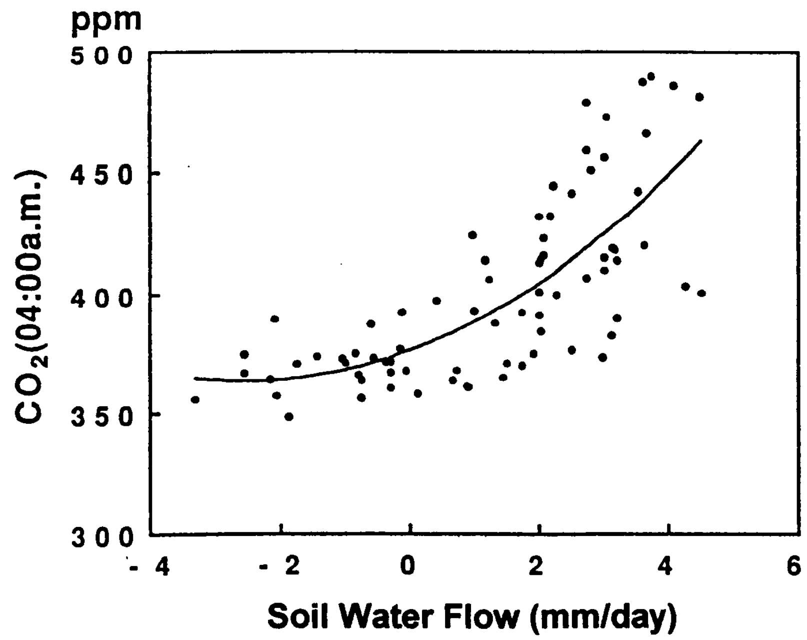

Fig.14 Relationship between soil water flow and the $CO_2$ concentration at 4:00 a.m

When a downward soil water movement occurred, the early morning $CO_2$ concentration became lower, and when an upward soil water flow occurred, the $CO_2$ concentration increased. On the other hand, the $CO_2$ gas restrained by rainfall was not amplified, and not released with the improvement of weather. For example, a $CO_2$ emission rate of over 500 ppm has never occurred throughtout the measurement.

Therefore, I concluded that the $CO_2$ was dissolved and was taken away by ground water with rainfall infiltration. This suggests that we can not overlook the $CO_2$ dissolved in infiltrating water when we consider the $CO_2$ balance between soil and atmosphere; especially in humid area such as in the tropical rain forests.

## Conclusion and future prospect

Diurnal fluctuation of $CO_2$ concentration near the ground surface changed not only through the physical effect by wind velocity, by plant activities such as $CO_2$ emission by respiration and $CO_2$ assimilation by photosynthesis, but also by dissolution of $CO_2$ gas in soil water when a downward soil water flow occurred on rainy days.

This phenomenon was confirmed in that $CO_2$ concentrations peaked in the early morning of clear days, but the peaks did not occur on rainy nights. Also, since a vertical $CO_2$ diffusion by raindrops did not occur, it is concluded that the $CO_2$ concentration decrease in the early morning of rainy days was caused by an absorption by downward soil water flow.

If these events also occur in other plant communities, such as tropical rain forests, then it has important implications in the $CO_2$ balance. Even if the amount of soil respiration in tropical rain forests is more than other regions, the emitted amount from the ground surface may be less. Therefore it may be a clue to solve the missing $CO_2$ problem at a global scale.

I hope to use weighing lysimeter to monitor an infiltration rate more accurately and to measure the $CO_2$ concentration in the soil. Since this study was carried out in a year with high rainfall, and since the soil had good water retention qualities, it is necessary to conduct this experiment when soil moisture is kept artificially low.

The activities of soil microorganisms are proportional to the degree of fertilization. Therefore I plan to study $CO_2$ concentration in two areas with different fertilization rates, and to compare the $CO_2$ emissions by decomposition on rainy and clear days.

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