B－4　シベリア凍土地帯における温暖化フィードバックの評価に関する研究
（3）シベリアにおける温暖化検出の手法に関する研究
④　国内参照フィールドにおけるフラックス広域評価手法の共同研究

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[要旨] 水田を対象として，二酸化炭素フラックス，水蒸気フラックスなどの観測を行い，広域的評価手法や評価精度の検討を行った．観測対象地は，岡山大学八浜農場であり，広さ9 ha の均一栽培圃場で渦相関法を用いて CO_2，H_2O フラックスを，改良傾度法を用いてメタンフラックスを測定した．

　群落内外の乱流統計量を調べ，フラックス評価法に関する検討を行った．渦相関法に関して，測定時の測器配置と測器自体の空間分解能に依存するスペクトル補正を検討し評価精度を高めた．メタンフラックスに関しては，農環研で開発した NDIR-CH4 分析計により濃度勾配を測定し，CSIRO（オーストラリア）グループの Inverse Lagrangian 法と比較し，精度を検討した．

　水稲群落の乱流構造は，他の類似の植生と同様の特徴を持つことがわかった．水田の CO_2 フラックスや H_2O フラックスなどエネルギ分配は同様の群落状態（構造，高さ）の植生と同様のレベルとその日変化傾向であった．八浜農場は児島湾干拓地にあるため，週単位で灌漑排水を繰り返している．湛水時と排水時とのフラックス観測から，湛水時には土壌からの CO_2 放出が抑制され，夜間の生態系呼吸量が排水時に比べて低下することがわかった．

[キーワード] 二酸化炭素，フラックス，微気象，水田

1. Introduction

　　　Recently, we have initiated a collaborative research to measure and analyze fluxes and concentration profiles of trace gases such as methane and carbon dioxide in a rice paddy. The eddy correlation technique was employed to measure these fluxes along with a suite of other micrometeorological, plant and soil measurements. Here we present some preliminary results on energy partitioning, CO2 exchange, and turbulence statistics measured in a rice paddy in the summer of 1996.

2. Materials and Methods
2.1 Study Site

The study was conducted at a rice paddy located in the agricultural station of the Okayama University (34.5 N, 134 E) in Okayama, Japan. The study site was approximately 300m x 300m wide, surrounded by similar rice paddies. Micrometeorological instruments and masts were deployed on 2 August 1996 and the measurements were made from 6 August through 16 August. The experiment was interrupted from the afternoon of 13 August to the morning of 15 August by a typhoon. During the measurement period the canopy height (hc) was on average 0.72m and the row spacing was about 0.27m. Leaf area index (LAI) was about 3.1. Because of the high salinity, the site was irrigated on a weekly basis (inundated during weekdays and then drained during weekend).

2.2 Micrometeorological Measurements

The eddy correlation instruments were located at the northwestern edge of the site so that the fetch was at least 200m for the winds from east to southwest. To measure the fluctuations in the horizontal and the vertical wind speeds and in the concentrations of carbon dioxide and water vapor, we used a three-dimensional sonic anemometer (Solent, Model-1012R with 0.15m path length) and an infrared CO_2 & H_2O fluctuation meter (Advanet, Model-E009A with 0.2m path length), respectively. These sensors were installed 1.5m above the canopy (i.e., 2.2m above the ground) and the separation between the two was approximately 0.17m. To measure the turbulence within the canopy, we also used the two miniature three-dimensional sonic anemometers (Kaijo-Denki, model-DATW295, 50mm path length). The measurement levels of these miniature sensors were varied throughout the study period to cover the whole canopy height (Figure 1). Also, we measured the surface soil CO_2 flux and the leaf area index using a portable infrared gas analyzer (Licor, LI-6400) and a canopy analyzer (Licor, LI-2000), respectively.

All the signals from the sensors were recorded with a sampling rate of 10 Hz in binary codes and were monitored with a virtual oscilloscope for quality control. Eddy fluxes and other statistics were computed for 30 minute averaging period. The fluxes of CO_2 and water vapor were corrected for the variation in air density due to the transfer of heat and water vapor following the method of Webb et al. (1980). The sign convention used here is that flux toward the surface is negative.

3. Preliminary Results....

3.1 Energy partition

In Fig. 2A, the detail variation of energy partitioning (averaged for the study period) is shown in terms of the Bowen ratio, b (=H/lE, where H and lE are the sensible heat and latent heat fluxes, respectively). During the day b ranged from 0.01 to 0.23. It reached the peak around 10:00 hrs (when H was the maximum) and then gradually decreased, indicating that more energy was partitioned into latent heat flux as the day progressed. There was small but consistent evaporation from the soil at night, resulting in small negative values of b.

3.2 CO_2 exchange

With the onset of photosynthetic activity after sunrise, CO_2 uptake by the rice canopy

increased rapidly and its magnitude ranged from 1 to 1.3 mg m-2 s-1 during midday (Fig. 2B). At night it released CO_2 at a rate of 0.18 - 0.4 mg m-2 s-1(about 20-30% of the midday magnitude). The soil surface CO_2 flux showed a large spatial variation with a daytime average of about 0.43 (+- 0.3) mg m-2 s-1 when the soil was not flooded. After irrigation, however, the surface soil CO_2 flux became almost zero. The persistent standing water probably impaired the respiratory CO_2 release from the soil surface. In fact, we found at some locations significantly positive flux values (< 0.01 mg m-2 s-1), indicating that CO_2 was taken up by the water surface. Interestingly, the partial pressure of CO_2 in the paddy water at our site was increasing during the day (Ohtaki, personal communication, Watanabe et al., 1997).

3.3 Turbulent statistics

To understand properly the transport within the rice canopy we need knowledge of the turbulence statistics. Some of these were obtained from the measurements of u* and sw in the air layer above the canopy and measurements of sw and su within the canopy made with 3-dimensional sonic anemometers. Because the most important scale within the canopy is of order hc, leaf area profile and statistics of the wind moments as functions of z/hc in Fig. 3 and Fig.4. The mean stream wise wind component U is normalized with value at the reference height (1.5 m above the canopy), U (z=3.1 hc) in Fig. 3B. The mean wind profile is strongly sheared near z=hc, attenuating within the canopy depending on the LAI profile. The upper layer within the canopy exerted most of the drag on the wind above the rice crop. The profiles of turbulence statistics, su and sw (normalized for u*), are shown in Fig.4. The ratios su/u* approached typical surface-layer values (e.g., Raupach, 1988; Kaimal & Finnigan, 1994) of 2.5 and 1.25, respectively. Both ratios seem to fall with decreasing z above the canopy with values at z=hc of approximately 2.1 and 1.1, respectively. The turbulence was strongly height-dependent and su/u* and sw/u* decreased more rapidly as z decreases within the canopy.

4. Concluding remarks

We have measured and analyzed fluxes of carbon dioxide and water vapor in a rice paddy. Energy partitioning and the CO_2 exchange in a rice canopy showed generally similar characteristics to those of plant canopies with similar structure (e.g., Verma et al., 1995 for a review). Turbulent statistics (normalized by hc) of rice canopy seem to fall within the range of those reported from previous studies. Detailed analyses on these micrometeorological data including concentration profiles of CO_2, H_2O and CH_4 are currently in process.

References

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Verma, S.B>,   J. Kim, R.J. Clement, N.J. Shurpali, and D.P. Billesbach, 1995 : Trace gas and energy fluxes: Micrometeorological perspectives, In : R. Lal,   J. Kimble, E. Levine and B.A. Stewart (Editors), Soil and Global Change,   Advances in Soil Science,   Lewis Publishers,   361-376.

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Fig. 1.   Eddy correlation system installed (A) above and (B) within the rice canopy during Okayama study in Japan (August 1996).
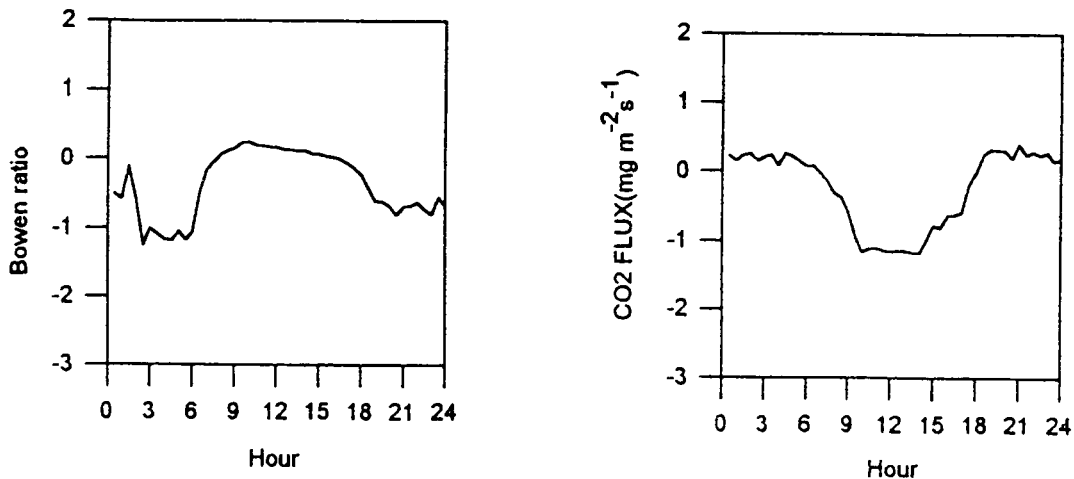
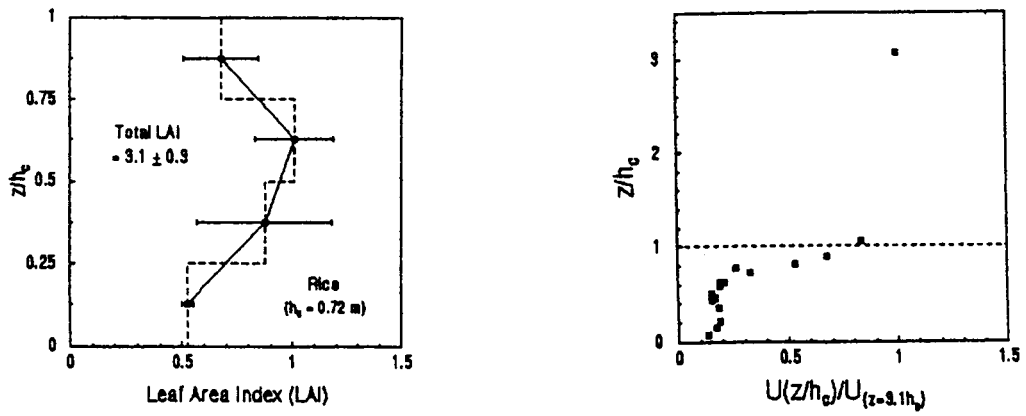Fig. 2.   Averaged daily variations of (A) b and (B) CO2 flux.
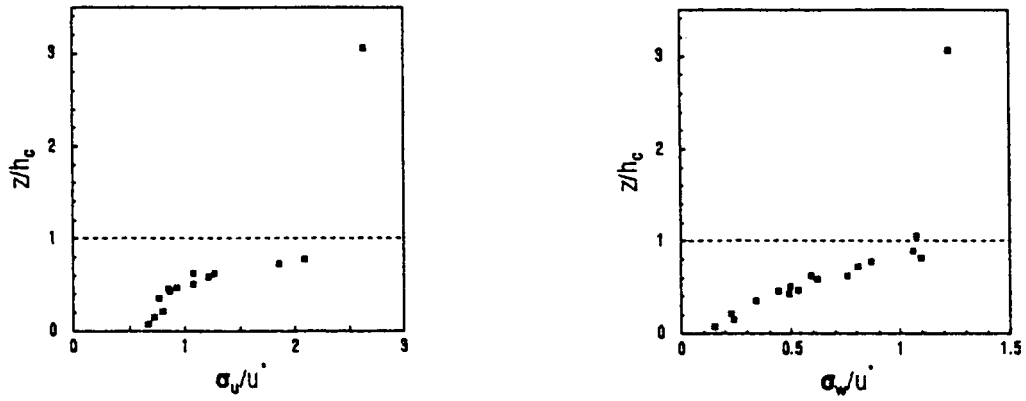
Fig. 3. Profiles of (A) LAI and (B) U for rice canopy.

Fig. 4. Profiles with height of (A) su and (B) sw.