Abstract

The eddy correlation (EC) technique was employed to measure the sensible heat (*H*) and latent heat (*LE*) flux densities and the net canopy CO_2 flux density (F_c) over a humid C3/C4 co-occurring grassland (*ca.* 20000 m^2) located in the Environmental Research Center (ERC), University of Tsukuba, Japan for most of the 1999 growing season (DOY 140 to 346). This grassland flora was composed of about 50 C3 and C4 perennial species. C3 dominated the early growing period and C4 dominated when canopy closed. The plants were not water restricted throughout the measurement period; volumetric soil water content was generally larger than 0.35. Maximal mean canopy height and maximal leaf area index were 1.0 m and 5.5, respectively.

Closure check of the energy balance shows that the ratio of the sum of EC-measured *LE* and *H* to the available energy (Q_n), was close to unity ($H + LE = 1.01Q_n$ W m^{-2}, n = 2251 h, r^2 = 0.90) on an hourly basis during most of the measurement periods. The latent heat flux densities determined by the EC were consistent with those measured directly with a micro-lysimeter on an hourly basis [*LE* (EC) = 1.00 *LE* (Lysimeter), n = 2193 h, r^2 = 0.85]. The closure, however, varied when measured data were grouped according to the growth stages of grasses. Poor closure was observed during the senescent period, which may be due mainly to spatial heterogeneity (differences in sampling areas) of flowering growth and patch-like aging of the grasses and short fetch. The closure was also affected by wind direction and fetch. The fetch-to-height ratio exceeding 50:1 was at least needed in estimating the canopy-atmosphere fluxes for the ERC grassland.

The daily pattern of the partitioning of available energy was appreciably affected by sensible heat advection so that the Bowen ratio (β) was generally larger in the morning and declined substantially in the afternoon while the evaporative fraction (*EF*) showed the opposite diurnal pattern. Midday (09:00 to 14:00 JST) values of β varied between 0.3 to 1.2 while *EF* ranged between 50% and 90%. The daily maximal evapotranspiration rate was about 0.8 mm h^{-1} (540 W m^{-2}, DOY 213). The maximum value of daily accumulative evapotranspiration was 6.7 mm d^{-1} (16.3 MJ m^{-2} d^{-1}, DOY 231).

Daily and seasonal variations in the partitioning of Q_n into *LE* and *H* were examined through the omega factor (Ω) analysis. In daytime, Ω generally peaked at the mid-morning and decreased thereafter, indicating that the partitioning was determined mainly by Q_n in the morning and thereafter by other factors such as the atmospheric evaporative demand and/or sensible heat advection other than Q_n. During the whole measurement period, Ω ranged from 0.7 to 0.9, which is within the range reported in the literature for grasslands and crops. Ω decreased during the later part of the growing season, which may result from the rougher canopy surface caused by the spatially heterogonous flowering and aging of C3/C4 plants. We also found that the seasonal pattern of partitioning of the available energy seemed not to be well coupled with leaf area index after the canopy closed.

The peak F_c values varied from 7.3 (DOY 304) to 56.7 (DOY 231) μ mol m^{-2} s^{-1} (positive signifies the canopy carbon gain from the air). Nighttime F_c varied between −1.3 and −21.6 μ mol m^{-2} s^{-1}. On clear days, 24-h integration of F_c, i.e. net ecosystem CO_2 exchange (NEE), varied from 0.14 ± 0.20 to 0.75 ± 0.36 mol m^{-2} d^{-1} (mean ± SD) depending on the growth stages. The maximal NEE was observed during the rapid growth period prior to canopy closure. Although the canopy was well developed in the closed canopy period, NEE was not largest due to a sizable carbon loss.

We investigated canopy surface conductance (g_c), computed from inversion of the Penman-Monteith equation; and water use efficiency (WUE), defined as the ratio of F_c to evapotranspiration; they behaved approximately on the daytime trends. The nearly linear decrease in WUE and g_c from mid morning to late afternoon may contribute to increase in vapor pressure deficit (VPD) and sensible heat advection. However, this phenomenon was not observed on individual leaves. On clear days, midday mean g_c varied from 9.6 ± 2.3 to 23.3 ± 6.0 mm s^{-1}, and midday mean WUE ranged from 12.0 ± 1.6 to 18.7 ± 9.1 mg CO_2 g^{-1} H_2O at different growth stages. Decreased photosynthetic capacity of the canopy due to senescence resulted in a decline in g_c.

The responses of daytime F_c to incident photosynthetic photon flux density (PPFD), VPD, air temperature (T_a), and g_c were examined. A rectangular hyperbolic relationship existed between daytime F_c and incident photosynthetic photon flux density (PPFD) with a high coefficient of determination (0.7) indicating that PPFD was the dominant driver of F_c, but features of the relationship depended on plant growth stages and in situ microenvironmental conditions such as VPD and air temperature (T_a). F_c was not light saturated up to PPFD levels of 2000 μ mol m^{-2} s^{-1}. The initial slope estimated with a linear F_c-PPFD regression under low PPFD was about 0.033 mol CO_2 mol^{-1} photon on average. The canopy light compensation point ranged from 140 to 250 μ mol m^{-2} s^{-1} with an average of 210 μ mol m^{-2} s^{-1}. Both the initial slope and the canopy light compensation point decreased as the canopy senesced. Properties of the canopy F_c-PPFD response curve were compared with those for the individual leaves of dominant species.

Nighttime F_c was modeled as an exponential function of air temperature with a temperature coefficient (Q_{10}) of 4.9 on average. Q_{10} was dependent upon growth stage of the canopy.

Key words: eddy correlation; C3/C4 co-occurring grassland; heat budget; CO_2 flux; omega factor; canopy surface conductance; water use efficiency