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Surface Exchange of Energy and Carbon Dioxide between the Atmosphere and a Farmland in Haenam, Korea

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한국 해남 농경지와 대기간의 에너지와 이산화탄소의 지표 교환

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ABSTRACT

Surface energy and CO_2 fluxes have been measured over a farmland in Haenam, Korea since July 2002. Eddy covariance technique, which is the only direct flux measurement method, was employed to quantitatively understand the interaction between the farmland ecosystem and the atmospheric boundary layer. Maintenance of eddy covariance system was the main concern during the early stage of measurement to minimize gaps and uncertainties in the dataset. Half-hourly averaged CO_2 concentration showed distinct diurnal and seasonal variations, which were closely related to changes in net ecosystem exchange (NEE) of CO_2. Daytime maximum CO_2 uptake was about -1.0 mg $CO_2\,m^{-2}\,s^{-1}$ in August whereas nighttime CO_2 release was up to 0.3 mg $CO_2\,m^{-2}s^{-1}$ during the summer. Both daytime CO_2 uptake and nighttime release decreased gradually with season. During the winter season, NEE was from near zero to 0.05 mg $CO_2\,m^{-2}s^{-1}$. FK site was a moderate sink of atmospheric CO_2 until September with daily NEE of 22 g $CO_2\,m^{-2}d^{-1}$. In October, it became a weak source of CO_2 with an emission rate of 2 g $CO_2\,m^{-2}d^{-1}$. Long-term flux measurements will continue at FK site to further investigate inter-annual variability in NEE. To better understand these exchange mechanism and in-depth analysis, process-level field experiments and intensive short-term intercomparisons are also expected to be followed.

Key words **: CO_2 measurement, eddy covariance system, net ecosystem exchange, farmland**

I. INTRODUCTION

It is a key issue to understand the response of terrestrial ecosystems to environmental change on various time scale (Law *et al.*, 2002). A global network of micrometeorological flux measurement sites (i.e., FLUXNET) has been established to provide better understanding of interactions between terrestrial ecosystems and the atmosphere and to initiate communications and collaborations among different disciplines (Baldocchi *et al.*, 2001). KoFlux is a Korean regional network of tower flux sites (distributed from 10°N to 40°N), launched since January of 2002 under the umbrella of AsiaFlux (i.e., Asian arm of FLUXNET) to provide information on magnitude, spatial and temporal variations of carbon source/sink strength in

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various key ecosystems in and around Korean peninsula (Kim *et al.*, 2002a and b; http://koflux.org).

The farmland site in Haenam (hereafter, FK site), one of the KoFlux sites, is equipped with eddy covariance instrumentation along with radiosonde and wind profiler facilities. Tower-based CO_2 measurement system of FK site has been operated since early July of 2002. The employed eddy covariance technique is a novel tool enabling not only to directly quantify the fluxes over ecosystems but also to provide information on exchange mechanism (e.g., Moncrieff *et al.*, 1997; IPCC, 2001; Baldocchi, 2003). Despite its numerous merits, however, there are still practical difficulties in long-term operation of eddy covariance system in the field with respect to data acquisition, calibration, quality control and data processing particularly during the early stage of site establishment.

The purpose of this paper is twofold. Firstly, the current progress in establishing CO_2 flux measurement system at FK site is reported including the documentation of instrumentation, data acquisition, archiving and processing. Secondly, the result of our first measurement of season-long CO_2 uptake and release over a typical Korean farmland (including various crop fields and rice paddies) is presented.

II. MATERIALS AND METHODS

2.1. Theoretical background

Over a flat, level, homogeneous surface, vertical flux (F) for a scalar can be described as (Kaimal and Finnigan, 1994; Stull, 1988):

$$F = \overline{w'c'} + \text{additional terms} \qquad (1)$$

where w' means the fluctuation of vertical velocity and c' the fluctuation of the density of the scalar. The overbar indicates time averaging. The sign convention is such that positive (negative) flux indicates a transfer from (to) the ground to (from) the atmosphere. When the conditions mentioned above are not satisfied, additional terms must be considered in Equation (1) (e.g., Paw U *et al.*, 2000). For instance, Lee (1998) suggested that additional terms be added in the net ecosystem exchange (NEE) of CO_2, considering the vertical advective effect due to non-zero mean vertical velocity and the storage effect below the measurement height. Paw U *et al.* (2000) showed that the storage term was important for NEE estimation in tall canopies (e.g., forests), but not in short canopies (e.g., agricultural crops). When mechanical turbulent mixing is weak with low friction velocity, the eddy covariance measurement could have large uncertainties that require proper corrections (Law *et al.*, 2001; Massman and Lee, 2002; Paw U *et al.*, 2000).

In this study, NEE was estimated from Equation (1) neglecting additional terms. The fluxes were computed after coordinate rotation correction. Here, the conventional rotation was not used because the mean vertical velocities may be non-zero for individual data (i.e., 30-minute average) due to sampling limitations or mesoscale motions (e.g., Finnigan *et al.*, 2003). Instead, planar fit rotation was used based on the assumption that the vertical velocity averaged over the entire measurement period was zero (Wilczak *et al.*, 2001).

2.2. Site Description

FK site is located in a southwestern end of Korean Peninsular (34.55°N, 126.57°E, 13.7 m above m.s.l.). The land cover around the study site was the mixture of rice paddies and various agricultural crops. Within the first 300 m around the tower, the major vegetation was seasonally cultivated crops such as beans, sweet potatoes, Indian millet, and sesame. Beyond this area, rice paddies prevailed in the south and the west. Also, scattered residential areas, roads and isolated forests coexisted. The nearest forest was located about 300 m north of the flux tower. The canopy height of dominant species was approximately 1 m. The soil type at the site was varying from silt loam to loam. Based on the estimation of vertical transform angle (Paw U *et al.*, 2000), the site was relatively flat except the southeast section with a slope of about 4 degrees (Fig. 1). For the past 30 years, mean annual air temperature was 13.3°C with the maximum and minimum of 18.6°C and 8.6°C, respectively. The annual mean precipitation was 1306 mm. In 2002, mean annual air temperature was lower than 30 year normal by 0.7°C and the annual precipitation was above normal by 228 mm.

2.3. Field Measurements and Data Processing

2.3.1. Turbulent flux measurement

Eddy covariance system was installed on a 25 m tower in early July of 2002. The main system was consisted of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc, Logan, UT) and an open-path H_2O/CO_2 gas analyser (LI7500, LICOR, Lincoln, NE). These were installed at 20.8 m above the

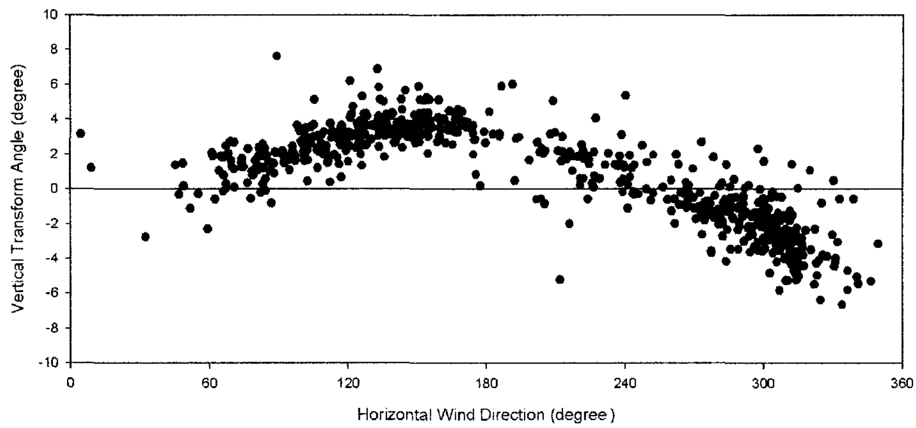

Fig. 1. Vertical transform angle as a function of horizontal wind direction at FK site.

ground. Sampling rate was 10 Hz and the data were stored in a data-logger (CR5000, Campbell Scientific Inc, Logan, UT) with a real-time processing every half hour. All the raw data were recorded on a hard disk of desktop computer at the site and then were archived in the data information system at the Korea Meteorological Administration on a weekly basis.

2.3.2. Auxiliary measurements

Several meteorological variables were also measured to provide input parameters for modeling applications and to assess the influence of environmental changes on energy and carbon cycle. A radiometer (CNR1, Kipp & Zonnen, The Netherlands) was installed at 19.3 m above the ground to measure downward and reflected components of shortwave and longwave radiation. Soil temperatures were measured by two sets of soil thermocouple array (TCAV, Campbell Scientific Inc., Logan, UT) for 0-0.1 m soil layer. Volumetric soil water contents (0-0.1 m layer) were measured by two sets of TDR soil moisture sensor (CS615, Campbell Scientific Inc., Logan, UT). To measure soil heat flux, two set of self-calibrating heat transducers (HFP01SC, Hukseflux, The Netherlands) were installed at 0.1 m depth. Measurements of all these soil parameters began on 14 September 2002. Precipitation was measured using a rain gauge operated by Haenam meteorological station (within 50 m from the flux tower).

2.3.3. Data archiving

In the beginning, continuous data collection was frequently interrupted by various practical problems such as program errors, electric power outage, system failure, instrument calibration, reinstallation and program downloading. Overall, our data retrieval rate was 90% for half-hourly averages and 30% for 10 Hz raw data. By implementing uninterrupted power systems and program debugging, data retrieval rates have been improved further.

2.3.4. Data processing

For coordinate rotation, we applied a planar fit coordinate system to each 45 degree sector of wind direction, considering the differences in terrain characteristic at the site (e.g., Wilczak *et al.*, 2001; Finnigan *et al.*, 2003; AmeriFlux, 2003). In estimating appropriate regression planes to observed wind velocities and directions, bad data were removed from the regression through quality control. The effective canopy height and the roughness length were assumed to be 1 m and 0.1 m, respectively for all wind directions (e.g., Arya, 2001).

Open-path H_2O/CO_2 gas analyser was calibrated every two months. For checking the span, a standard CO_2 gas of 445.1 ppm was used for CO_2. For H_2O, a dew point generator was used to set the temperature 3 to 5°C below the ambient temperature. Anthoni *et al.* (1999) estimated that the overall uncertainty of the daytime CO_2 flux was about ±12% including uncertainties in the calibration of the gas analyzer and sonic anemometer. Density correction was made to raw CO_2 flux, which reduced the magnitude typically by about 20% during daytime (Webb *et al.*, 1980; Paw U *et al.*, 2000; Massman and Lee, 2002). Quality check of the data was based on Foken and Wichura (1996). We used the following criteria to remove bad data: (1) turbulence and flux data with low wind speed (<1 m s^{-1}); (2) positive momentum fluxes; (3) data with >50% difference between theoretical and measured values of integral turbulent characteristic for vertical velocity; and (4) bad wind directions with insufficient fetch or flow distortion. For gap filling strategy, methods of Falge *et al.* (2001) were applied. In this paper, gap filling was accomplished for nighttime data only when the missing data were less than 10% by using interpolation and/or ensemble of data window. Otherwise, data set from that day was excluded from our analysis. Detailed information on data processing and the program can be found in Hong and Kim (2002).

III. RESULTS AND DISCUSSION

3.1. Environmental variables and energy partitioning

Net ecosystem CO_2 exchange on various time scale is determined mainly by the relative contribution of photosynthesis and respiration of plant and soil, which are in turn controlled by environmental variables such as radiation, air temperature, vapour pressure deficit, and precipitation (or soil water content) (e.g., Anthoni *et al.*, 1999; Falge *et al.*, 2002; Law *et al.*, 2002; Dolman *et al.*, 2002). Figs. 2 and 3 show the seasonal variation of environmental variables in FK site in 2002. Precipitation occurred frequently even after the summer monsoon, and soil water content remained about 0.3 through the season. Daily mean air temperature ranged from 25 to

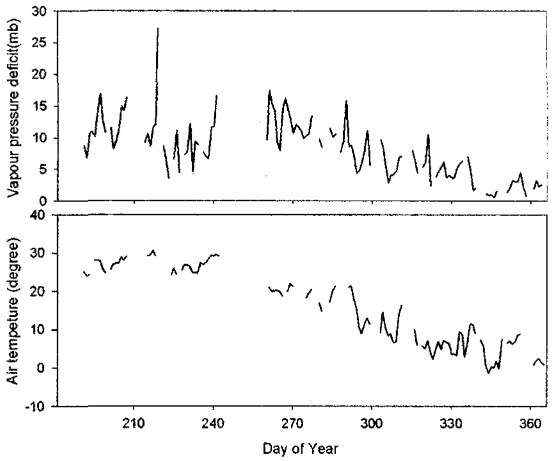

Fig. 3. Seasonal variation of air temperature and daytime mean vapour pressure deficit at FK site in 2002.

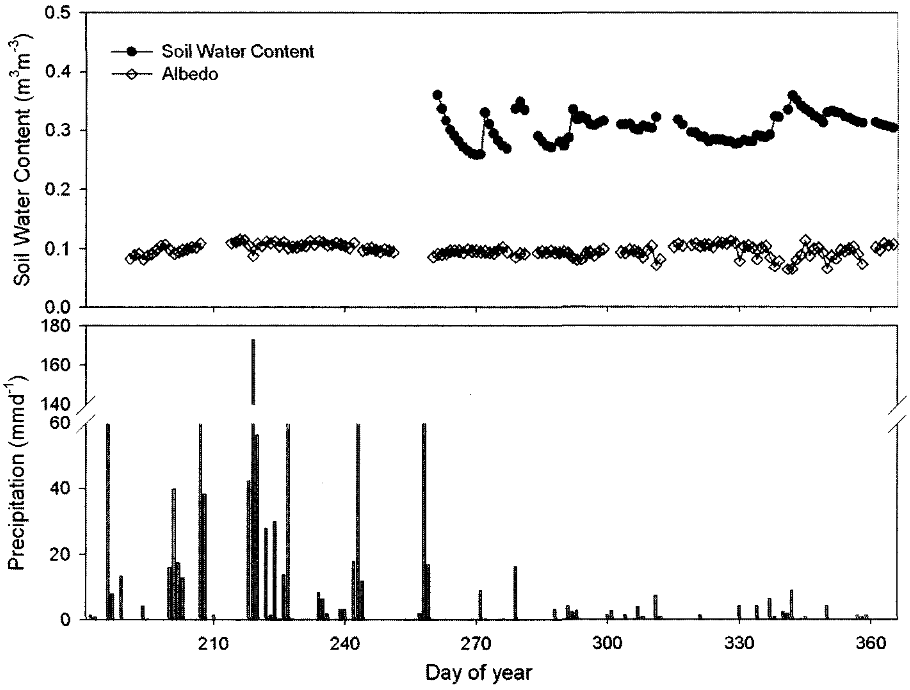

Fig. 2. Seasonal variation of soil water content, daytime mean albedo and precipitation at FK site in 2002.

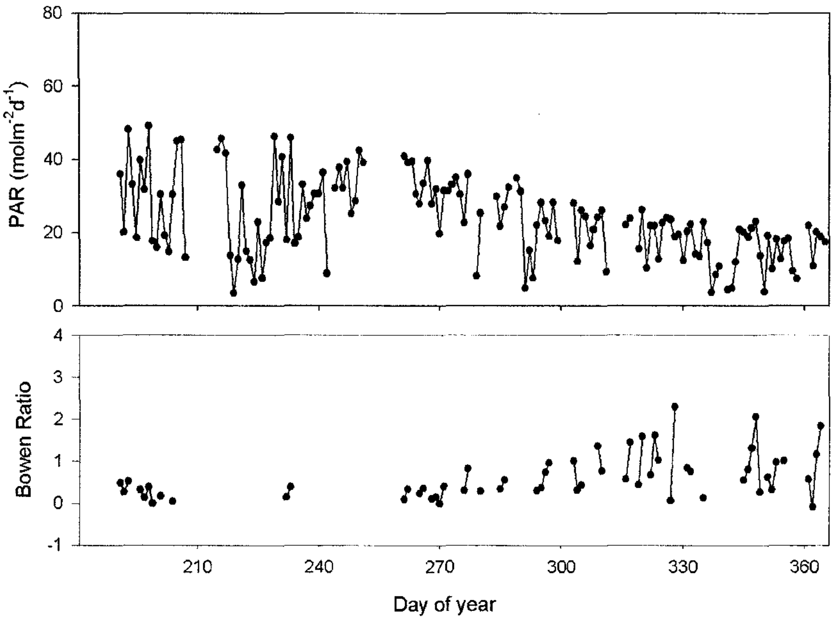

Fig. 4. Seasonal variation of the photosynthetically active radiation (PAR) and the Bowen ratio at FK site in 2002.

30°C in summer and from 0 to 10°C in winter. These ranges were similar to those of 30 year normal. Vapour pressure deficit was on average 10 mb during the summer. Fig. 4 presents the variation of photosynthetically active radiation (PAR) and the surface energy partitioning (in terms of the Bowen ratio, β=H/LE, where H and LE are sensible and latent heat flux, respectively). The maximum PAR was about 50 mol m^{-2}d^{-1} during the growing season, but about 25 mol m^{-2}d^{-1} during the winter season. As the season progressed, the Bowen ratio was about 0.3 in growing season. In winter season, averaged β increased from 0.3 in summer to 2 in winter.

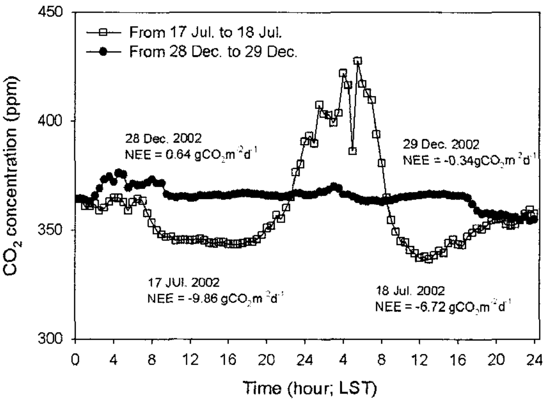

Fig. 5. Diel variation of CO$_2$ concentration in summer and winter at FK site in 2002.

3.2. Diel variation of CO$_2$ flux

Half-hourly averages of both CO$_2$ concentration and fluxes demonstrated clear diel and seasonal variations (Figs. 5 and 6). During the growing season, CO$_2$ concentration was about 340 ppm during daytime and 430 ppm at night. During the winter season, no apparent diurnal pattern of CO$_2$ concentration was observed. It remained around 360 ppm for all day. As expected, daily difference of CO$_2$ concentration between day and night decreased with vegetation's senescence. Such differences in concentration is not only positively correlated with our direct measurement of NEE but also reflected in the overlying atmospheric boundary layer whose depth waxes and wanes throughout the day. In conjunction with wind profiler measurements at FK site, continuous observation of concentration/flux and their footprint analysis would provide useful information on scaling efforts from local to regional scales and bridging the gaps in land-atmosphere interaction studies.

Fig. 6 presents typical diel patterns of CO$_2$ flux through the season. Changes in diel patterns were closely related to the plant growth stages. As shown earlier, diel pattern of CO$_2$ exchange followed that of PAR (not shown)

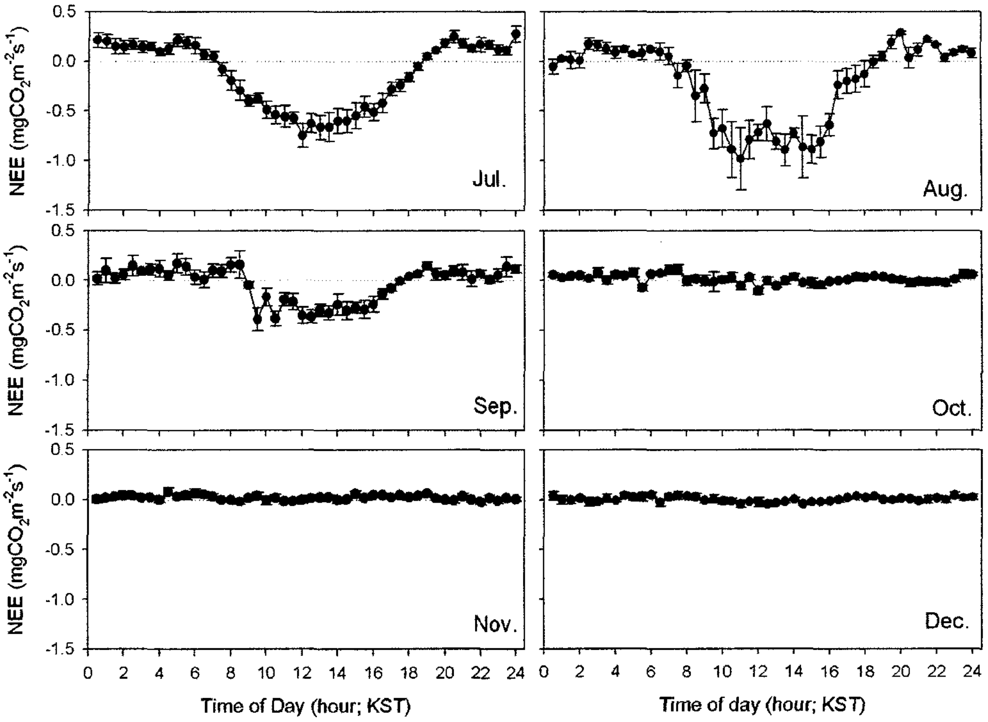

Fig. 6. Seasonal changes in diel variation of net ecosystem exchange (NEE) from July to December 2002 at FK site.

during the stages of vigorous plant growth. With the absence of photosynthetic activity, no apparent diel pattern was observed in winter. During the non-growing season, observed CO_2 flux represents release of CO_2 from soil respiration and its magnitude depended mainly on soil temperature.

3.3. Seasonal variation of NEE

Timing and duration of plant growth stages and light/moisture conditions mainly affect the changes in NEE throughout the season. Seasonal changes in diel variation of NEE for each month are also shown in Fig. 6. Daytime minimum NEE (net CO_2 uptake) was about -1.0 mg CO_2 $m^{-2}s^{-1}$ in August; whereas nighttime release of CO_2 was about 0.3 mg CO_2 $m^{-2}s^{-1}$ in July and August. In other studies in rice paddies, the minimum daytime NEE was reported almost -3 mg CO_2 $m^{-2}s^{-1}$ during the peak in growing season (e.g., Campbell *et al.*, 2001). For accurate comparison with FK site, however, we need to consider further information on leaf area index, air temperature, PAR and footprint, for instance. Nighttime NEE represents net CO_2 release from respiration of plants and soil. Its magnitude ranged from near zero to 0.3 mg CO_2 $m^{-2}s^{-1}$, depending on the changes in soil temperature and moisture conditions.

Fig. 7 shows the variation of nighttime NEE with nocturnal air temperature. (In this analysis, soil temperature can also be used instead of air temperature depending on the purpose of the study). Nighttime NEE exponentially increased with air temperature,

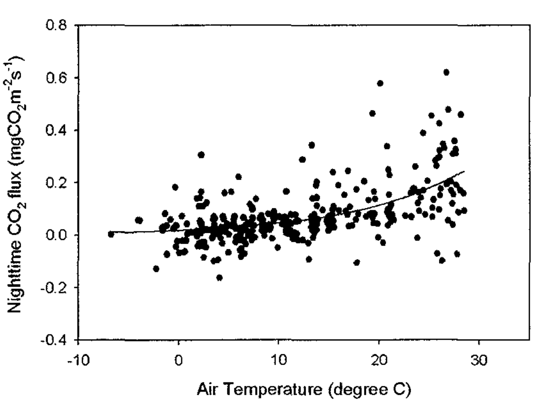

Fig. 7. Variation of nighttime CO_2 flux with nocturnal air temperature.

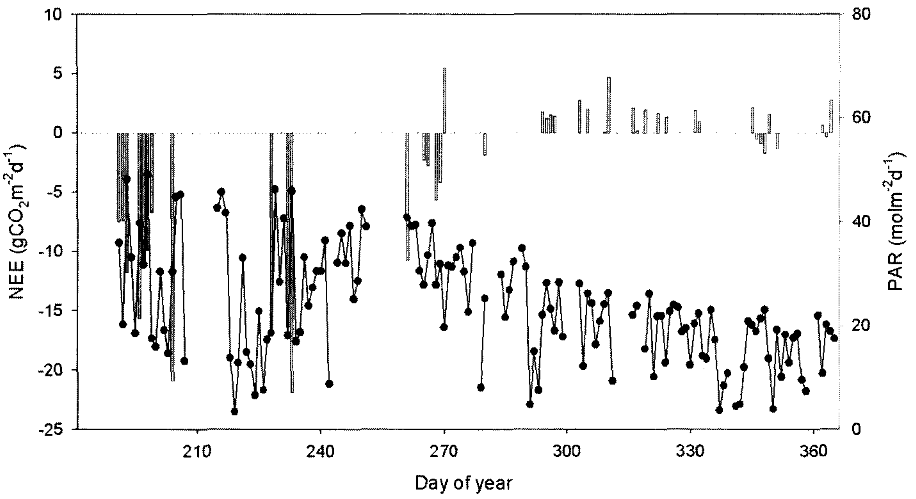

Fig. 8. Seasonal variation of daily accumulated NEE and photosynthetically active radiation (PAR) at FK site in 2002.

resulting in Q_{10} value of 2.48 (e.g., Fang and Moncrieff, 2001). In formation on this nighttime respiration could also be obtained from the light response curve of NEE. This analysis is currently in progress and will be used in our gap filling process to produce more complete database. From October to December, the averaged NEE (CO_2 release) was less than 0.05 mg CO_2 $m^{-2}s^{-1}$. Despite its small magnitude, overall contribution of CO_2 release during the non-growing season could become sizable when it is integrated for six months or so.

Fig. 8 presents the seasonal variation of daily accumulated NEE and PAR. It is noted that there are many missing days in this computation. To produce more complete data set, gap filling of these missing days is currently underway. Therefore, only the days with no major gaps were used in this analysis. During July-August period, the maximum uptake was about -22 g CO_2 $m^{-2}d^{-1}$ whereas the net release of CO_2 during October-December period averaged to be 2 g CO_2 $m^{-2}d^{-1}$. Similar results can be inferred from the data shown in Fig. 6. Most of the fields around the measurement site was harvested by the end of September. FK site was apparently a moderate sink of atmospheric CO_2 until September and then became a weak source of CO_2 after October.

IV. SUMMARY

Tower-based CO_2 and energy fluxes have been measured since July 2002 in a mixed farmland in Haenam. This is one of the KoFlux network sites located in southwestern end of Korean Peninsula, representing typical agricultural ecosystem in East Asia. In spite of numerous practical difficulties in operating eddy covariance system in the field, continuous flux measurements have been accumulated for one entire year now and the first half of these data were analyzed and presented here.

In summary, diel and seasonal exchange of CO_2 over the farmland were quantified for the whole growing season of 2002. Based on the days with no missing data, direct measurements of net ecosystem CO_2 exchange were evaluated to assess the role of this ecosystem as sink/source of atmospheric CO_2. Significant correlations between daytime/nighttime NEE with photosynthetically active radiation/temperature were confirmed from our preliminary data analyses. These relationships and their changes with different environmental conditions can be parameterized to establish better gap filling strategy and to produce complete database for further analyses. The final dataset will be open to KoFlux website (www.koflux.org) and also be submitted to FLUXNET (daac.ornl.gov/FLUXNET/) and CEOP/GEWEX (www.ceop.net/www.gewex.org) for global scientific community. Finally, to deal with temporal and spatial variability of flux footprint and ecophysiological and biophysical properties of the site vegetation and topography, new approach is currently investigated to improve flux evaluation by combining analyses of flux footprint climatology and those of GIS information and satellite images.

적 요

육상생태계와 하층 대기와의 상호작용 및 환경변화에 대한 생태계의 반응을 정량적으로 이해하기 위하여 2002년 7월부터 논과 밭이 혼합되어 있는 해남(FK) 관측지에서 이산화탄소 관측이 이루어지고 있다. 관측 초기에는 안정된 자료 확보를 위하여 에디 공분산 시스템의 유지 관리를 중점적으로 추진하였다. 30분 평균된 이산화탄소 평균 농도와 순 생태 교환량(Net Ecosystem Exchange)은 뚜렷한 일변화와 함께 계절적인 차이를 나타내었다. 낮 시간의 이산화탄소 플럭스는 8월에 최대 1.0 mg CO_2 $m^{-2}s^{-1}$의 흡수율이 관측되었고, 야간에는 최대 0.3 mg CO_2 $m^{-2}s^{-1}$ 정도의 이산화탄소가 대기중으로 방출되었다. 이산화탄소 흡수량과 방출량 모두 점차적으로 감소하여 겨울철에는 거의 0에 가까운 값이거나 0.05 mg CO_2 $m^{-2}s^{-1}$ 보다 작은 방출율을 나타내었다. 해남 플럭스 관측지역은 7월부터 9월까지 이산화탄소의 상대적으로 강한 흡원으로 작용하여 일 최대 22 g CO_2 m^{-2} 정도의 이산화탄소를 흡수하였다. 이후 10월부터 12월까지는 약한 발원으로 작용하였는데, 일 평균 2 g CO_2 m^{-2} 정도의 이산화탄소를 방출하였다. 해남 관측지에서의 환경 변화에 대한 생태계의 반응 및 격년 변동 등에 대한 정량적 연구를 위하여 장기 관측은 지속적으로 이루어질 것이며, 심도 있는 분석과 교환 메커니즘의 이해를 위해 토양 및 식물과 관련된 집중 관측과 단기 실험들이 뒤따라야 하겠다.

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REFERENCES

AmeriFlux Workshop, 2003: Summary and Synthesis of Recommendations of the AmeriFlux Workshop on Standardization of Flux Analysis and Diagnostics, Corvallis, Oregon, August 2002, 16p.

Anthoni, P. M., B. E. Law and M. H. Unsworth, 1999: Carbon and water vapor exchange of an open-canopied ponderosa pine ecosystem. *Agric. For. Meteorol.*, **95**, 151-168.

Arya, S. P., 2001: *Introduction to Micrometeorology, second ed.*. Academic Press, 420pp.

Baldocchi, D., E. Falge, L. Gu, R. Olson, D. Hollinger, S. Running, P. Anthoni, CH. Bernhofer, K. Davis, R. Evans, J. Fuentes, A. Goldstein, G. Katul, B. Law, X. Lee, Y, Malhi, T. Meyers, W. Munger, W. Oechel, K. T. Paw U, K. Pilegaard, H. P. Schmid, R. Valentini, S. Verma, T. Vesala, K. Wilson and S. Wofsy, 2001: FLUXNET: A New Tool to Study the Temporal and Spatial Variability of Ecosystem-Scale Carbon Dioxide, Water Vapor, and Energy Flux Densities. *Bull. Am. Meteorol. Soc.*, **82**, 2415-2434.

Baldocchi, D., 2003: Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. *Global Change Biology*, **9**, 479-492.

Campbell, C. S., J. L. Heilman, K. J. McInnes, L. T. Wilson, J. C. Medley, G. Wu and D. R. Cobos, 2001: Diel and seasonal variation in CO_2 flux of irrigated rice. *Agric. and For. Meteorol.*, **108**, 15-27.

Dolman, A. J., E. J. Moors and J. A. Elbers, 2002: The carbon uptake of a mid latitude pine forest growing on sandy soil. *Agric. For. Meteorol.*, **111**, 157-170.

Falge, E., D. Baldocchi, R. Olson, P. Anthoni, M. Aubinet, C. Bernhofer, G. Burba, R. Ceulemans, R. Clement, H. Dolman, A. Granier, P. Gross, T. Grünwald, D. Hollinger, N.-O. Jensen, G. Katul, P. Keronen, A. Kowalski, C. T. Lai, B. E. Law, T. Meyers, J. Moncrieff, E. Moors, J. W. Munger, K. Pilegaard, Ü. Rannik, C. Rebmann, A. Suyker, J. Tenhunen, K. Tu, S. Verma, T. Vesala, K. Wilson and S. Wofsy, 2001: Gap filling strategies for defensible annual sums of net ecosystem exchange. *Agric. For. Meteorol.*, **107**, 43-69.

Falge, E., J. Tenhunen, D. Baldocchi, M. Aubinet, P. Bakwin, P. Berbigier, C. Bernhofer, J.-M. Bonnefond, G. Burba, R. Clement, K. J. Davis, J. A. Elbers, M. Falk, A. H. Goldstein, A. Grelle, A. Granier, J. Grünwald, J. Gu-Ômundsson, D. Hollinger, I. A. Janssens, P. Keronen, A. S. Kowalski, G. Katul, B. E. Law, Y. Malhi, T. Meyers, R. K. Monson, E. Moors, J. W. Munger, W. Oechel, K. T. Paw U, K. Pilegaard, Ü. Rannik, C. Rebmann, A. Suyker, H. Thorgeirsson, G. Tirone, A. Turnipseed, K. Wilson and S. Wolfsy, 2002: Phase and amplitude of ecosystem carbon release and uptake potentials as derived from FLUXNET measurements. *Agric. For. Meteorol.*, **113**, 75-95.

Fang, C. and J. B. Moncrieff, 2001: The dependence of soil CO_2 efflux on temperature. *Soil Biology & Biochemistry,*

33, 155-165.

Finnigan, J., R. Clement, Y. Malhi, R. Leuning and H. A. Cleugh, 2003: A re-evaluation of long-term flux measurement techniques Part I: Averaging and coordinate rotation. *Boundary-Layer Meteorol.*, **107**, 1-48.

Foken, Th. and B. Wichura, 1996: Tools for quality assessment of surface-based flux measurements. *Agric. For. Meteorol.*, **78**, 83-105.

Hong, J. K. and J. Kim, 2002: On processing raw data from micrometeorological field experiments. *Korean J. Agric. For. Meteorol.*, **4**(2), 119-126.

IPCC, 2001: *IPCC Third Assessment Report - Climate Change 2001*, Intergovernmental panel on Climate Change.

Kaimal, J. C. and J. J. Finnigan, 1994: *Atmospheric Boundary Layer Flows: Their Structure and Measurement.* Oxford University Press, New York, 289pp.

Kim, J., W. Kin, B. Lee, C. Cho, B. Choi, D. Lee, E. Park, J. Lee, J. Lim, J. Oh, J. Yun and C. Rho, 2002a: KOFLUX:A New Network of Reference Sites for AsiaFlux/FLUXNET and CAMP/CEOP. *Proceedings of the Second International Workshop on Advanced Flux Network and Flux Evaluation*, Jeju Island, Korea, 9-11 January, 6-7.

Kim, J., W. Kim, C. Cho, B. Choi, H. Chung, B. Lee, K. Kim, K. Kim, M. Kim, B. Lee, D. Lee, G. Lee, J. Lee, J. Lim, J. Oh, E. Park, J. Shim, J. Yun and C. Rho, 2002b: *KOFLUX*: A New Tool to Study the Biosphere-Atmosphere Interactions in Asia. *Ecology of Korea*, edited by D. Lee and Co-editor, 215-229.

Law, B. E., F. M. Kelliher, D. D. Baldocchi, P. M. Anthoni, J. Irvine, D. Moore and S. Van Tuyl, 2001: Spatial and temporal variation in respiration in a young ponderosa pine forest during a summer drought. *Agric. For. Meteorol.*, **110**, 27-43.

Law, B. E., E. Falge, L. Gu, D. D. Baldocchi, P. Bakwin, P. Berbigier, K. Davis, A. J. Dolman, M. Falk, J. D. Fuentes, A. Goldstein, A. Granier, A. Grelle, D. Hollinger, I. A. Janssen, P. Jarvis, N. O. Jensen, G. Katul, Y. Mahli, G. Matteucci, T. Meyers, R. Nonson, W. Munger, W. Oechel, R. Olson, K. Pilegaard, K. T. Paw U, H. Thorgeirsson, R. Valentini, S. Verma, T. Vesala, K. Wilson and S. Wofsy, 2002: Environmental controls over carbon dioxide and water vapor exchange of vegetation. *Agric. For. Meteorol.*, **113**, 97-120.

Lee, X., 1998: On micrometeorological observations of surface-air exchange over tall vegetation. *Agric. For. Meteorol.*, **91**, 39-49.

Massman, W. J. and X. Lee, 2002: Eddy covariance flux corrections and uncertainties in long-term studies of carbon and energy exchanges. *Agric. For. Meteorol.*, **113**, 121-144.

Moncrieff, J. B., J. M. Massheder, H. de Bruin, J. Elbers, T. Friborg, B. Heusinkveld, P. Kabat, S. Scott, H. Soegaard and A. Verhoef, 1997: A system to measure surface fluxes of momentum, sensible heat, water vapour and carbon dioxide. *J. Hydrology*, **188-189**, 589-61.

Paw U, K. T., D. D. Baldocchi, T. P. Meyers and K. B. Wilson, 2000: Correction of eddy-covariance measurements incorporating both advective effects and density fluxes. *Boundary-Layer Meteorol.*, **97**, 487-511.

Stull, R., 1988: *An Introduction to Boundary Layer Meteorology.* Kluwer Academic Press, The Netherlands, 666pp.

Webb, E. K., G. I. Pearman and R. Leuning, 1980: Correction of flux measurements for density effects due to heat and water vapour transfer. *Quart. J. R. Met. Soc.*, **106**, 85-100.

Wilczak, J. M., S. P. Oncley and S. A. Stage, 2001: Sonic anemometer tilt correction algorithms. *Boundary-Layer Meteorol.*, **99**, 127-150.