B-3 Establishment of an AsiaFlux Network and Its Operation for Carbon Sequestration Estimation in the Eastern Asian Monsoon Ecosystems (Abstract of the Final Report)

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1. Introduction

The global climate change caused by rising of green house gases (GHG) has been recognized as one of the most urgent environmental issues, and also the important factors for policy decision. The situation is the same in the research fields of sequestration estimation and carbon flow in terrestrial ecosystems. However, in an extent of the eastern Asian monsoon, it is indeed the first stage to get accurate quantification and verification of GHG fluxes and its modeling on the carbon cycle processes.

The present project aims to quantify the spatial and temporal distribution of biospheric sources and sinks of carbon on a regional and global scale and to understand the factors that regulate net sequestration of anthropogenic carbon dioxide through biospheric processes. The present project also coordinates the establishment and operation of a global network through the activities of regional networks. Discussions expected in this research will contribute to promotion of the COP6 agreement that each country can begin consultations on the estimation of all greenhouse gasses budgets and the converted amount in terms of carbon dioxide at various land ecosystems.

From the view mentioned above, five research actions following by: 1) understanding of characteristics of fluxes at typical ecosystems in Ease Asia, 2) evaluation of carbon cycle processes using stable isotope ratio, 3) development of database and network system, 4) modeling and development of estimation scheme on carbon budget, 5) quality control of the flux data base, were adjusted to a main projection titled "Establishment of a precise data base and its operation for carbon sequestration estimation in the eastern Asian monsoon ecosystems".

2. Research Objective

Broadleaf deciduous and coniferous forests are the major vegetative constituents of the main island of Japan, Korean Peninsula, northeastern China, and eastern Mongolia. Studying the environmental controls on gross primary production (GPP) and net ecosystem production (NEP) of the ecosystem is, then, one of the main subjects for understanding the carbon cycle of terrestrial ecosystems in the eastern Asia. Differences in the seasonal and diurnal patterns of ecosystem CO_2 exchange involve assimilatory and respiratory processes. To better understand such variations of the ecosystem CO_2 exchange in a forest community, it is required to formulate the ecophysiological processes and responses of the CO_2 fluxes of a forest community to climatic factors.

The principal objectives of this study are to estimate the year-to-year change in NEP of the ecosystem, and to describe the sensitivity of NEP to meteorological variables using an empirical model based on the observed data. And to accumulate ecosystem assimilatory and respiratory data and understandings of processes for the development of process-based CO_2 exchange models.

In addition, objectives relating data acquisition and its quality control are arranged as 1) to unite the fragmental flux observation activities in East Asian ecosystems, 2) to promote establishing an integrated database of observation data, and 3) to standardize flux observation methodology within participating groups that use different instrumentation and different data processing methods. In order to provide the groups participating this study program with database software for sharing data, we reconstruct Ecosystem Database (Eco-DB), which is developed by National Institute for Agro-Environmental Sciences and Japan Science and Technology Corporation, based on Linux operating system.

3. Method

The relationship between CO_2 flux and meteorological conditions and the seasonal and annual change of carbon balance were being investigated. The variables being measured by the measurement tower are: CO_2 flux between the atmosphere and the ecosystem; CO_2 concentration, heat and water vapor fluxes and meteorological variables such as air temperature, wind, humidity and solar radiation. Fluxes of sensible heat, water vapor, and CO_2 have been measured continuously by the eddy covariance method using a three-dimensional ultrasonic anemometer and closed-path or/and open-path infrared gas analyzers. The coordinate rotation for the vertical wind speed normal to the mean wind direction was applied, the time lag required to draw air down was determined every half hour, linear trends were removed from the signals, and the WPL corrections were applied.

The study sites are, 1) Takayama site, which was established in 1993, is about 15 km east of Takayama City, in the central part of Japan, and 2) Fujiyoshida site, which was established in 1999, located on the north slope of Mt. Fuji. The long-term measurement of sensible heat, water vapor and CO_2 fluxes has been conducted at both the sites by the micrometeorological measurement to estimate the year-to-year change in NEP. In order to open the observed data in Takayama site to the public, a database "Ecosystem Database in AIST" was constructed. For the data observed in Fujiyoshida site, the database management system specially designed for the tower flux time-series data was developed. In this study, empirical models were established to describe the sensitivity of NEP to meteorological variables in both sites, using the data available on the databases.

Rice paddy fields are also one of the typical agricultural ecosystems in most of the Asian countries. In order to investigate exchange of carbon dioxide flux, water vapor and energy fluxes between rice paddy ecosystem and the atmosphere a flux observation site at Mase was started in July 1999. Then, in 2002, a sub-theme under EFF study was introduced to the main subjects of this research project. The task is to fill the existing gaps in H and λE fluxes data series measured at Mase site for 2001 using the eddy covariance technique in order to establish a complete series of H and λE fluxes data.

The results obtained in this research at the various sites of typical ecosystems: a cool-temperate broadleaf deciduous forest; a coniferous forest (pine); a Japanese cypress forest; rice paddy fields; a marsh site; an agricultural ecosystem of maize and Italian ryegrass; three types of tropical rain forest are reported below.

Regarding quality control for the long term data, standard method for gap filling of flux data is not yet established. However, three gap-filling methods have been discussed in most recent studies on AMERIFLUX and EUROFLUX by Falge et al.[1, 2]. The methods are: 1) Lookup tables, 2) Mean diurnal variation, and 3) nonlinear regression analysis. The Lookup table method, which is a semi-empirical method, is used for the gap filling of H and λE fluxes in this study. The gap filling using lookup table method is based on the environmental conditions that are closely associated with the missing data.

2. Result and Discussion

(1) Characteristics of Fluxes at Six Typical Ecosystems

a. Cool-temperate broadleaf deciduous forest :Takayama site

The study site, which was established in 1993, is about 15 km east of Takayama City, in the central part of Japan (36°08' N, 137°25' E, elevation 1420 m). Annual mean air temperature is 7.3℃, with an annual precipitation of about 2400 mm. The site is usually snow-covered from December to April, with snow depth up to 1-2 m. The site consists of a broadleaf deciduous secondary forest of about 50-year-old, with canopy height of about 15-20 m. Dominant species are oak and birch. The forest floor is covered with dense dwarf bamboo.

The uncertainty of annual NEE (Net Ecosystem CO_2 Exchange) was described based on the eddy covariance method using the data from 1999 to 2001. The uncertainty of annual NEE (52-67 gC $m^{-2}year^{-1}$) was caused mostly by the nighttime flux measurements. The nighttime correction of NEE depending on the atmospheric stability has a large impact on the annual NEE for this site.

Temperature dependence is one of the most complicated and important subjects for understanding and modeling ecosystem response to environmental controls. Further studies are necessary to monitor NEP for a long period to clarify the relationship between Net ecosystem production(NEP = -NEE), NEP and environmental variables in different biomes under various climatic regimes. The relation between daily GPP and APAR is shown in Fig. 1. Seasonal and inter-annual variations in NEE were estimated from 1994 to 2001 by the eddy covariance method and the aerodynamic method. The annual NEP was 224±82 gC m^{-2} $year^{-1}$ (mean ± SD), with a large year-to-year variation of up to 158 gC m-2 year-1. The annual NEP was the highest in 1998 during the last eight years of observation. It was suggested that an unusually warm spring in 1998 caused an early leaf emergence and a large CO_2 uptake in the first half of the growing period.

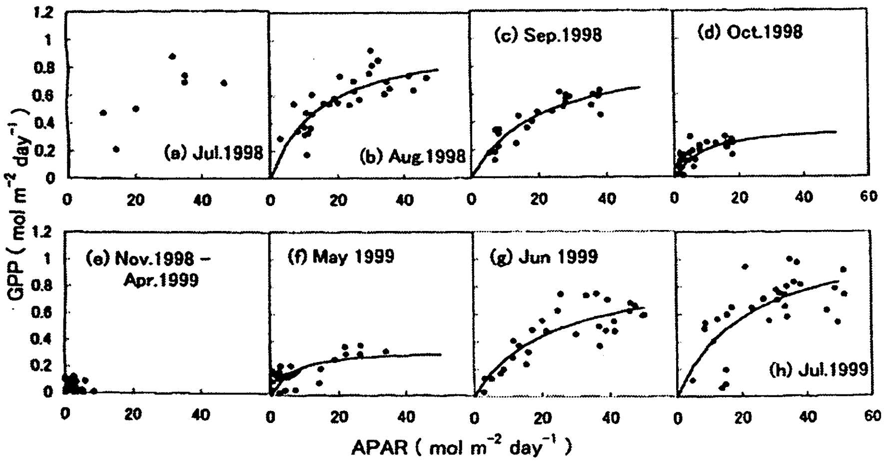

Fig.1 Daily GPP as a function of APAR.

b. Coniferous forest (pine); Fujiyoshida site

Fujiyoshida tower flux site is located on a gentle slope of Mt. Fuji covered with cool-temperate coniferous forest. The dominant tree species are Japanese red pine and Japanese holly. The eddy correlation fluxes of energy and CO_2, and the related meteorological elements were observed from the year 2000 to 2002 (continuing), and the data were stored in the 30-minutes based time series database designed for the tower flux measurement. For filling about 10% of the data gap in the observed net ecosystem exchange (NEE), the nighttime ecosystem respiration and the daytime gross primary production were parameterized by the semi-empirical method adopted the exponential and hyperbolic functions, respectively, and then the continuous data of the NEE were obtained.

The calculated annual NEP (= -NEE) by the tower flux measurement showed 371 gC $m^{-2}y^{-1}$, 295 gC $m^{-2}y^{-1}$, 475 gC $m^{-2}y^{-1}$ (tentative values) for the year 2000 through 2002, respectively. The NEP had a large inter annual variation, for example the NEP in 2002 was about 28% larger than that of 2000. Fig. 2 shows the changes in the monthly NEP among the three years. The table and the figure suggested that the variation in the annual NEP seemed to closely relate to the seasonal variations among the years rather than the annual mean of the meteorological elements.

Summarized by the monthly-based data, the NEP showed negative (release of CO_2) in January and February in 2000 and 2001. By contraries, the NEP was positive in both months in

2002, i.e. the forest worked as a CO_2 sink throughout the year. The year 2002 was characterized by the warm winter and early came spring. The monthly NEP showed absorption in the remaining period but the variations among the years were very large. The maximum monthly NEP appeared in May (in April in 2001) and then it decreased from late spring to autumn. The NEP increased again in late autumn to early winter. The NEP, induced by the balance of the ecosystem assimilation and respiration, might be basically controlled by the seasonal radiation and the temperature changes.

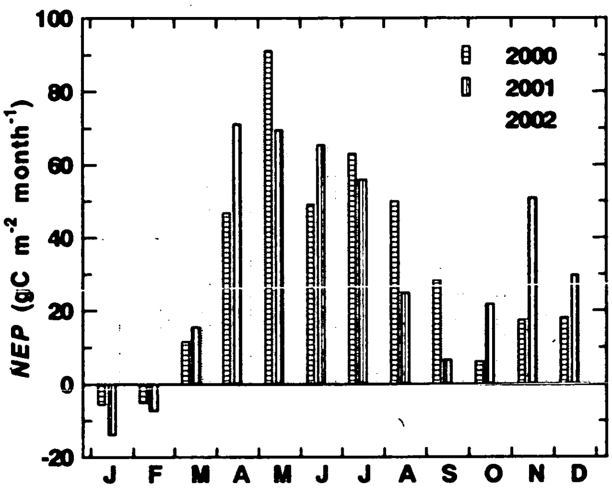

Fig. 2 Variations in monthly NEP from 2000 to 2002 observed at Fujiyoshida site

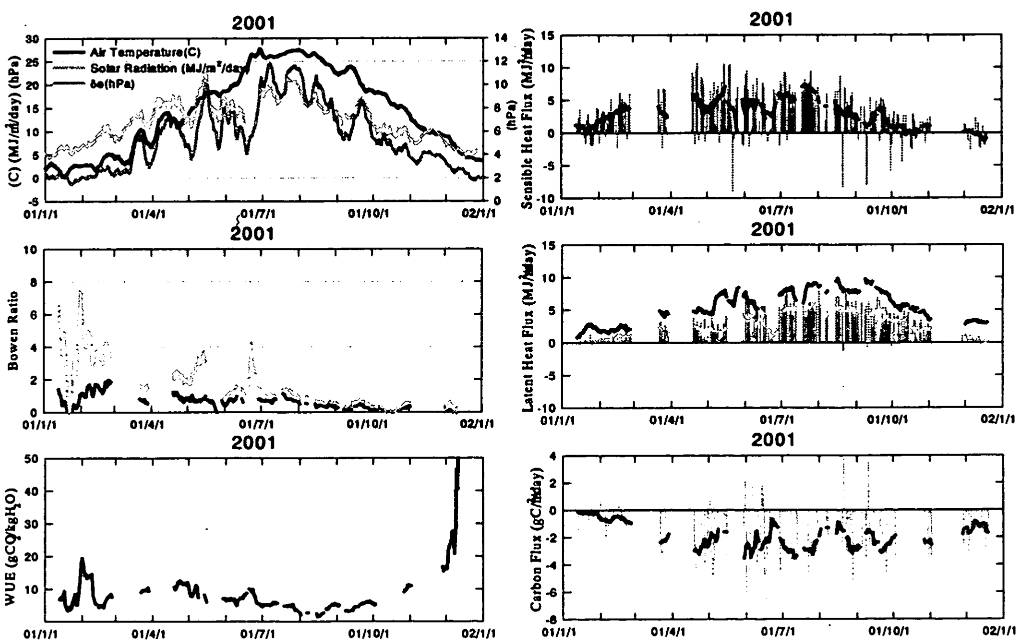

Fig.3. Seasonal changes of air temperature, solar radiation, δ e, sensible heat flux, latent heat flux, carbon flux, Bowen ratio and water use efficiency.

c. Japanese cypress forest; Kiryu site

Energy, heat and H_2O/CO_2 flux measurements have been carried out in Kiryu experimental watershed, Shiga prefecture in Japan. Fluxes above the Japanese cypress canopy were measured with eddy covariance method, using an ultrasonic anemometer/thermometer and closed-pass gas analyzers. CO_2 flux measurement with the relaxed eddy accumulation (REA) method was also tested in this forest. REA method is useful for flux estimation of trace gases for which analyzer does not have fast response to apply the eddy correlation technique. This REA method was compared with open path eddy correlation method for CO_2 flux and satisfactory results were obtained. Fig.3 shows the seasonal changes of air temperature, solar radiation, δ e, sensible heat flux, latent heat flux, carbon flux, Bowen ratio and water use efficiency.

d. Rice paddy fields: Tsukuba and Okayama sites

Rice paddy fields are one of typical agricultural ecosystems in Monsoon Asia. Among them single rice cropping paddies that dominates in northeastern Asia are characterized by two contrasting periods, a flooded growing period and dry fallowed period which lasts two thirds of a year. In order to investigate exchange of carbon dioxide (CO_2), water vapor and energy between single rice cropping paddies and the atmosphere, we made continuous flux measurement at two paddy sites in Japan, Mase and Hachihama, from 1999. Mase site (36°03'N, 140°01'E, 15 m above sea level) is located in the central part of Japan (Kanto Region), about 50 km northeast of Tokyo, while Hachihama site (34°32'N, 133°56'E, 2 m) is located within reclaimed paddy area in the southern part of Okayama Prefecture. Rice (Oryza sativa) was cultivated as a common practice at each area, details of which are shown in Table 1. Fluxes of CO_2, sensible and latent heat were measured by the eddy covariance method with open-path infrared gas analyzers. CO_2 storage below the flux measurement height was neglected in the calculation of NEE. Photosynthetic flux was separated from daytime CO_2 flux by subtracting respiratory flux which was estimated by use of an empirically determined function between nighttime CO_2 flux and air temperature. At Mase site, methane flux was also measured by the aerodynamic method.

NEE showed a distinct seasonal variation with rice growth and the maximum downward flux of about 10 g C m^{-2} d^{-1} in mid-growing season. NEE turned positive after harvest and showed a seasonal change with soil temperature during the non-cultivation period. Annual NEE at Mase site was estimated at –201 gC $m^{-2}yr^{-1}$ in 2001 and –91 gC $m^{-2}yr^{-1}$ in 2002 (Table 1). The difference in NEE between the two years is attributed to 1) an increase of ecosystem respiration in 2002 owing to the delay of harvest and 2) an increase of gross primary production caused by ratoon regrowth after the 2001 harvest. Annual NEE at Hachihama site was –240 gC $m^{-2}yr^{-1}$ on the average from 1999 to 2002. In the paddy sites, negative monthly NEE was observed in three (Mase) or four month (Hachihama) only, and in the rest of the year monthly NEE was positive.

Other components in ecosystem carbon budget were also measured at Mase site. The budget of dissolved carbon which consists of precipitation, irrigation, drainage and percolation were almost balanced in the total of the irrigation period. The seasonal methane emission was 5.4 to 6.2 gC $m^{-2}yr^{-1}$, which was negligible in the annual carbon budget of the ecosystem. The methane emission, however, is equivalent to 42 to 50 gC $m^{-2}yr^{-1}$ of CO_2 in the Global Warming Potential (GWP; 100 years horizon) and cannot be neglected against the annual NEE when we discuss the greenhouse gas budget of the ecosystem. The main components in the annual carbon budget of the paddy ecosystem are NEE, namely CO_2 exchange with the atmosphere, and biomass removal at harvest. By considering these components, the annual carbon budget at Mase site was estimated at losses of 100 g Cm^{-2} yr^{-1} in 2001 and 160 gC m^{-2} yr^{-1} in 2002. The result is different from previous chamber-based studies that estimated carbon budget of single rice cropping paddies to be almost balanced.

Table 1 Field management and CO_2 budget at two rice paddy sites

Site name	Mase (Ibaraki Prefecture)	Hachihama (Okayama prefecture)
Rice cultivar	Koshihikari	Akebono
Transplanting or seeding	Transplanted in early May	Seeded in mid-May
Density	18-19 hills m^{-2}	2.5 g m^{-2}
Irrigation	From mid-April to mid-August with temporary drainage in July and August	Mid-June to October with intermittent drainage after mid-July
Standing water depth (cm)	3	15
Harvest	Early September. Rice straw was left in the filed.	Late October. Rice straw was removed from the field.
Dry matter yield	4,800-6,000 kg ha^{-1}	5,000 kg ha^{-1}
Pallowing	Several times in autumn	March
NEE (g C m^{-2})		
cultivation period	-463 (2001), -398 (2002)	-481*
non-cultivation period	262 (2001), 308 (2002)	241*
annual	-201 (2001), -91 (2002)	-240*

* Average from 1999 to 2002.

e. Northern wetlands: Kushiro sites

Northern wetlands, which lie between 40°N and 70°N, cover about a half of the total area of natural wetlands in the world. The northern wetlands have important roles in global carbon balance, and also in the global budget of atmospheric methane as the largest biogenic source. In order to investigate greenhouse gas budgets and energy exchange in natural wetlands in mid-latitudes of northeastern Asia, we made continuous flux measurements of CO_2, methane, sensible heat and latent heat at two sites in Kushiro Marsh, northern Japan: a reed-dominated flooded site (KSO site, 43°06'N, 144°20'E, 8 m) and a Sphagnum-dominated site with sparse sedges (KSM site, 43°06'N, 144°22'E, 6 m) in 2001 and 2002.

The difference in the growing period between the two sites also affected the seasonal variation of NEE. At reed-dominated KSO site, NEE showed positive fluxes from snowmelt to June, whereas at KSM site, negative NEE was observed in May and continued for five months by the end of September. The annual NEE at KSM site in 2002 was estimated at about –200 gC $m^{-2}yr^{-1}$, and almost equal to the paddy sites. Methane emission at KSM site was observed throughout the year including snow-covered period. The annual methane emission was estimated at about 13 gC $m^{-2}yr^{-1}$, 6.3% of the annual NEE on carbon basis. When we consider

GWP, the annual methane emission is equivalent to a half of annual CO_2 absorption by the ecosystem although the ecosystem still works as a sink of greenhouse gases in total.

f. Agricultural ecosystem of maize and Italian ryegrass

Fluxes of CO_2 and H_2O were observed above a rotational forage field in order to evaluate the CO_2 balance of an agricultural ecosystem in temperate humid region. Moreover we compare dry matter production obtained from flux and gravimetric measurements to validate the CO_2 flux measurements. The research site is a rotational forage field (31'44'5"N, 131'00'50"E) in National Agricultural Research Center for Kyushu Okinawa Region. The forage field extends about 400m East to West and 300m North to South. A mast of 5m height for the flux measurement was built at the south-east corner of the field. The fetch for main wind direction (northwest) was over 1km. The CO_2 flux was slightly positive at fallow. The downward flux in daytime exceeded the upward flux in nighttime from 14 days after seeding, and the forage field began to absorb CO_2 by photosynthesis increased when vegetation grew up. The seasonal variation of CO_2 flux during the growth period of maize from May to August was 10 to 400mmol CO_2 $m^{-2}day^{-1}$ of maximum value.

Seasonal variation of dry matter accumulation rate predicted from daily CO_2 flux and that predicted from biomass measurements had changed similarly. However, the dry matter of absorbed CO_2 gas estimated by aerodynamic method agreed well with that estimated by gravimetric method. The annual absorption of CO_2 gas by the canopies of maize and Italian ryegrass was about 19.41 ton CO_2 $ha^{-1}year^{-1}$. The annual amount of dry matter by the gravimetric method was 20.30 ton CO_2 $ha^{-1}year^{-1}$.

g. Tropical rain forests

(Sakaerat) Although evergreen tropical seasonal forest has no clear change of leaf area index LAI, photosynthetic activity decreases in dry season. Net ecosystem exchange NEE is large is the transitional period from wet to dry season, because photosynthesis is strong, and ecological respiration becomes small by soil dryness. In the last stage of dry season, canopy becomes source of CO_2. However, canopy continues being sink in dry season of 2003, because there were many rainy days in the last stage of dry season. Annual NEE became 10 ton C $ha^{-1}yr^{-1}$ which was too large to the mature forest. There is possibility that CO_2 stored in the forest floor outflows in the stable and light-wind night. Using the empirical relation about dependency of NEE with wind velocity, NEE in light windy nights was changed that in strong windy nights. After this correction, NEE decreased up to 6 ton C $ha^{-1}yr^{-1}$.

(Maeklong) The deciduous tropical seasonal forest has clear phenology. Leaves (especially leaves of bamboo) start to emergent about two weeks after wet season starts, and leaves start to fall rapidly from the beginning of January, that is, two months after dry season starts. Almost all leaves fall in the middle of February. Thus, leaf phenology is determined by soil wetness. LAI, and soil wetness, which are important parameters of photosynthesis, change seasonally. Thus, carbon cycle system also changes seasonally. NEE is large from wet season to the first stage of the dry season, and canopy becomes source of CO_2 in the end of the dry season. In total, CO_2 absorption became 3.7 ton C $ha^{-1}yr^{-1}$ in 2002.

(Bukit Soeharto) Yearly NEE was 7.0 ton C $ha^{-1}yr^{-1}$ in 2001 when typical tropical rain forest climate was predominant. While NEE in 2002 when there were no rain terms between June to October by ENSO event was 5.3 ton C $ha^{-1}yr^{-1}$. Daily NEE was large in July and August in the beginning of dry season, maybe because of many leaves, ample sunshine. NEE was small in the last stage of dry season, because of decreasing photosynthetic activity by dryness and leaf fall. CO_2 balance of this ecosystem is roughly estimated, assuming the ratios of 'below the surface' with 'above the surface' for biomass increase ΔB, plant respiration *Ra*, and litterfall *L* are the same with ratio of 'below the surface' with 'above the surface' for biomass *B*. That ratio is assumed to be 0.2, which is the in spite of the type of forest throughout the world. According the ecological statistics obtained by the above simple method, litterfall *L* is similar to non-plant respiration *Rh*, which shows all litterfall is decomposed and changed to *Rh* in the time scale of one year. As a result, NEP coincidences with ΔB.

(2) Studies on carbon cycle processes in various ecosystems using stable isotope measurements

a. Study on carbon cycle processes in a temperate deciduous forest using CO_2 concentration and its isotope measurements

To examine the carbon cycle processes in a temperate deciduous forest and factors governing their variation, measurements of concentration and isotopic ratios of CO_2 in the atmosphere and soil air in the forest were made. Inter-annual difference in appearance of the start of decrease in the atmospheric concentration in the seasonal cycle was related to those of air temperature in spring and snow melting time. From analyses of diurnal variation in vertical profile of the concentration, it was suggested that respective contributions of photosynthesis and respiration by trees and bamboo grasses and soil respiration (decomposition) on the carbon cycle in the forest are seasonally changed. In the warm season, negative correlations of diurnal variation of atmospheric CO_2 concentration with those of its stable isotopic ratios (δ 13C and δ 18O) were clearly seen, reflecting enhanced biological activities. Similar negative correlation of seasonal variations between the CO_2 concentration and δ 13C was observed, while the correlation between the CO_2 concentration and δ 18O was not clearly detected.

b. Study on spatial and temporal variations in stable isotope ratio of atmospheric CO_2 and soil respiration flux in Larix forest ecosystem

Temporal variation in the carbon stable isotope ratio of CO_2 respired from ecosystem (δ 13Cr) had been investigated since July 2000 at an artificial deciduous needle-leaf forest dominated by Japanese Larch (Larix kaempferi) in northern island of Japan. δ 13Cr was evaluated from the nighttime data using Keeling plot approach. δ 13Cr observed during the green season of the forest had significant temporal variability with range of larger than 2‰, and its arithmetical mean was –28.0‰ PDB (Fig. 4). This mean value was lower than those observed in evergreen needle-leaf forests in the North America. The correlations between δ 13Cr and environmental variables showed that δ 13Cr had link with vapor pressure deficit of several days earlier. 13C measurements of plant/soil organic matter collected from 25 locations in the site revealed that δ 13C of those organic matters had significant spatial variation in the ecosystem.

However, we could find a feature common to most of the locations that δ 13C of organic matter was less depleted as decomposition progressed.

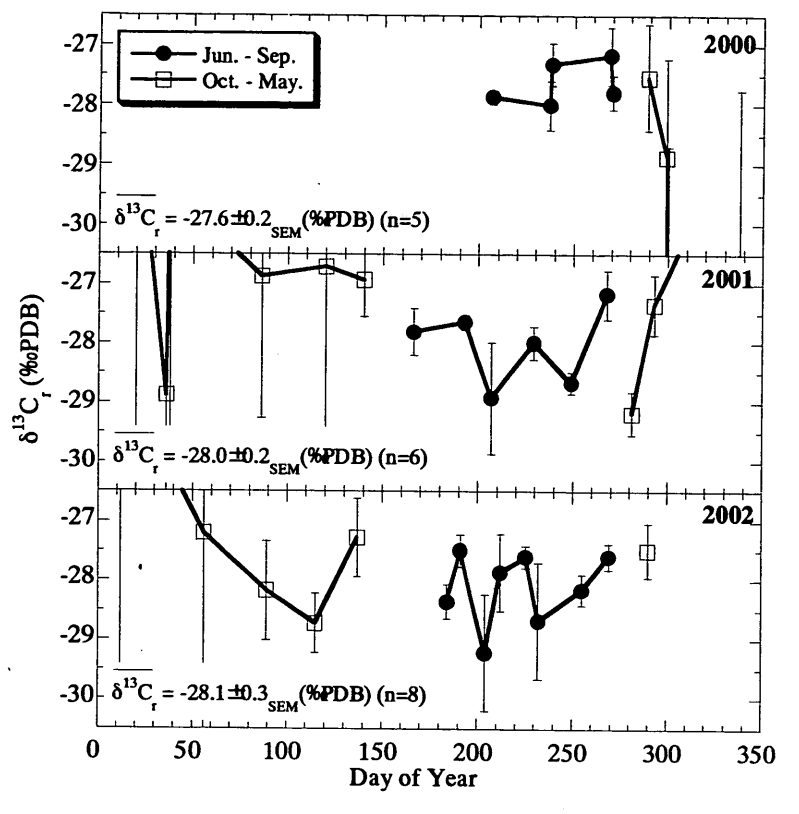

Fig. 4 Temporal variation of carbon stable isotope ratio of CO2 respired from the ecosystem. Solid symbols show the data obtained during growing season (Jun.-Sep.), and open symbols show the data obtained in the other seasons.

c. Carbon balance on a paddy field ecosystem considering dissolved carbon fluxes and their stable carbon isotope ratios

Annual carbon balance on a rice paddy was investigated based on water balance measurement and the analysis of dissolved carbon species as well as gaseous flux measurement in Tsukuba, Japan (Fig.5). The largest carbon input was CO_2 fixation by photosynthesis of rice, 64-65% of the fixed carbon was harvested in autumn. Inflow and outflow of dissolved carbon accounted for 5-9% of the total input and output. Carbon concentration of dissolved carbonate species (CO_2(aq) and HCO3-) was higher than that of dissolved organic matter in most case, consistently increasing through the growing season. This was probably due to the increase of biotic CO_2 production corresponding to rising temperature and the growth of rice. Carbon isotope ratios of the dissolved carbonate also indicated that the source of the carbonate was mainly biogenic, and the mixing of atmospheric CO_2 was less than 10% even in surface water. Annual carbon balance of the paddy was +54 gC m^{-2} in 2000-2001, and –106 gC m^{-2} in 2001-2002. Dissolved carbonate as the major flux of dissolved carbon in paddy ecosystems and the estimate of its source using carbon isotope ratio were rarely discussed in previous studies, so this report gives some important suggestions about the carbon cycle in a paddy.

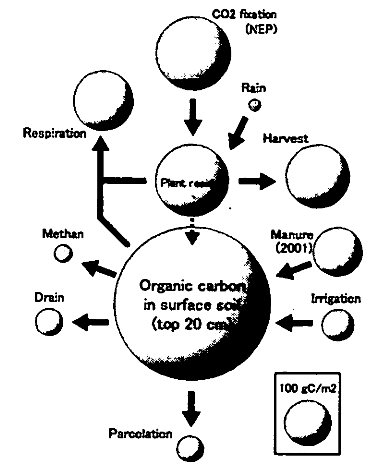

Fig. 5 Annual carbon balance on a paddy field

d. Study on carbon cycling process in forest ecosystem by stable isotope measurements

Carbon cycling process was investigated in a cool temperate deciduous forest by stable isotope measurements. The experiments were carried out in central Japan, between April 2000 and March 2003.

1) Soil respiration rate increased from spring with the increasing of soil temperature, and reached the maximum level of 926 mgCO_2 $m^{-2}h^{-1}$ in August, then decreased toward winter with the decreasing of soil temperature. The spatial variation of soil respiration ranged from 24% to 37% through a year.

2) Light-photosynthetic response was measured in Sasa senannensis, a dominant understory species in a cool-temperate deciduous broadleaf forest. Light-photosynthetic curves, light-stomatal conductance curves and CO_2-photosynthetic curves were similar between current year leaves and one-year old leaves. Light-saturated rate of photosynthesis was found to be high as compared to the general forest understory species, and it was about 10 μmol $m^{-2}s^{-1}$. Daily photosynthesis was estimated to be about 200 and 400 mmol m^{-2} day^{-1} in August and October, respectively.

3) δ13C value of Sasa senannensis ranged from −28‰ to −30‰. Using the obtained data, it was estimated that approximately 10% of the carbon in understory species (Sasa senannensis) originated from respired CO_2 during summer and 2 % of that during autumn.

e. Study on carbon discharge through hydrological processes from a warm temperate forested watershed

This study clarified the dynamics of dissolved organic and inorganic carbon (DOC and DIC) in several elemental hydrological processes of the Kiryu Experimental Watershed using stable isotopes of water and carbon. The mean residence time of soil water calculated using stable isotopes of water (δD and δ 18O) was estimated 2-16 weeks. During the vertical infiltration with this duration of contact with soil, the vertical variation was generated in the rate of decrease in the DOC concentration, which we postulated to result from two different mechanisms in the infiltration process. In the upper mineral soil layer, the relationships between DOC and Al and Fe indicated that organically complexed Al and Fe contributed to decreasing the DOC concentration. In the lower mineral soil layer, the easily adsorbed DOC fraction had been removed, and that decomposition contributed to decreasing the DOC concentration. Based on these findings, we compared the DOC removal rate with other formed C (soil C, dissolved inorganic carbon (DIC), and CO_2 gas) in soil. In the upper mineral soil layer, only 0.8% of soil C was retained from DOC annually. In the lower mineral soil layer, only 6.7% of the total production of inorganic C (DIC and CO_2 gas) was derived from DOC. We concluded that the DOC removal rate was much smaller than the soil C storage or DIC and CO_2 gas production rates, but 11% of the net ecosystem production (NEP) was stored in soil via the dissolved form, suggesting that the DOC dynamics are not negligible when considering soil C storage in forest ecosystems.

(3) Development of Database and Network System

The improved Eco-DB was set up at several participating sites and now being operated. The database system like the improved Eco-DB is the first in FLUXNET community and shows one of the directions of how to share observation data. We also collaborated with other database systems related to the study program like the FFPI (Forestry and Forest Production Research Institute) network and showed whereabouts information of the observation data on the AsiaFlux homepage. In order to standardize flux observation methodology, we showed a guide of calibration frequency required for open-path infrared gas analyzers (IRGAs) by examining long-term stability of the IRGAs. Current observation sites and their locations are tabulated in Table 2.

Table 2 Observation site and location

Code	Name of the Site	Location	URL	Stand	Related Sub Theme
①	Northern wetlands (Akanuma)	43° 07'N 144° 20'E 8mMSL	http://ecomdb.niaes5.affrc.go.jp/	Reed	1
②	Northern wetlands (Kushiro)	43° 07'N 144° 22'E 6mMSL	http://ecomdb.niaes5.affrc.go.jp/	Bogmoss and others	1
③	Coniferous deciduous forest (Tomakomai)	42° 44'N 141° 31'E 115~140mMSL		Japanese larch	2
④	Paddy field (Tsukuba)	36° 03'N 140° 01'E 15mMSL	http://ecomdb.niaes5.affrc.go.jp/	Paddy	1·2 ·5
⑤	Paddy field (Okayama)	34° 32'N 133° 56'E 2mMSL	http://ecodb.civil.okayama-u.ac.jp	Paddy	1
⑥	Coniferous forest (Fujiyoshida)	35° 27'N 138° 46'E 1030mMSL		Pine and others	1·4
⑦	Cool-temperate broadleaf deciduous forest (Takayama)	36° 08'N 137° 25'E 1420mMSL	http://pxeco.aist.go.jp	Mizunara and others	1·2·4
⑧	Japanese cypress (Kiryu)	34° 96'N 135° 99'E 250mMSL		Japanese cypress and others	1·2
⑨	Agricultural ecosystem in temperate humid region (Kyushu)	31° 44'N 131° 01'E 185mMSL		Maize and Italian ryegrass	1
⑩	Tropical rain forest (Maeklong, Thailand)	14° 35'N 98° 51'E 150mMSL	http://pxeco.aist.go.jp http://staff.aist.go.jp/old-gamo/	Mixed deciduous forest Dipterocarp	1
⑪	Tropical rain forest (Sakaerat, Thailand)	14° 29'N 101° 55'E 535mMSL	http://pxeco.aist.go.jp http://staff.aist.go.jp/old-gamo/	Hopea ferrea Pierre	1
⑫	Tropical rain forest (Bukit Soeharto, Indonasia)	0° 50'S 117° 03'E 20mMSL	http://pxeco.aist.go.jp http://staff.aist.go.jp/old-gamo/	Macaranga related genera Dipterocarp	1

We also showed guides of quality control and gap filling methods of flux data and a tentative plan of a common dataset to be shared by AsiaFlux. These results will be spread through AsiaFlux Steering Committee that promotes data exchange among AsiaFlux, and also be utilized in the successive study program to integrate observation data. We closely collaborated with AsiaFlux Steering Committee and assisted the AsiaFlux workshops held in 2000 and 2002. In the workshops, the policies on integrating and sharing observation data within AsiaFlux and on linkage to other regional networks were decided. These policies were utilized in the present study program and also gave impact on the successive study program.

(4) Modelling and Estimation on Carbon Budget

Equations (1), (2), and (3) show the relation among NEP, GPP, and the ecosystem respiration (*Rec*).

$$NEP = GPP - R_{ec} \qquad (1)$$

$$R_{ec} = A \cdot Q^{(T-10)/10} \qquad (2)$$

$$GPP = \frac{b \cdot APAR}{1 + a \cdot APAR} \qquad (3)$$

a. Takayama site

The seasonal and inter-annual variation of NEP was estimated from 1994 to 2001 by the aerodynamic method and the eddy covariance method. The annual NEP was 224 ± 82 gC $m^{-2}year^{-1}$ (mean ± SD), with a large year-to-year variation of up to 158 gC $m^{-2}year^{-1}$. The annual NEP was the highest in 1998 (329 gC m^{-2} $year^{-1}$), mainly caused by high CO_2 uptake observed during the first half of the growing period. The air temperature was significantly higher in April 1998 than in a usual year. High spring air temperature resulted in an unusually earlier leaf emergence (up to 24 days early in this forest) compared to other years. It was supposed by the model that a high air temperature increased the ecosystem respiration; however, the result in the present study suggests that the increase in CO_2 uptake due to a long growing period in 1998 was more remarkable than the enhancement of the respiration.

b. Fujiyoshida site

We have analyzed the seasonal patterns and spatial variations of ecophysiological parameters such as assimilatory and respiratory processes, and of the crown structure of the Japanese red pine (Pinus densiflora) forest. The seasonal and spatial variations of leaf gas exchange of current- and 1-year-leaves were analyzed in relation to light conditions within a tree crown. Then we clarified the effects of N contents in the leaves to the photosynthetic potential closely related to light environment in the crown. Photosynthetic responses to CO_2 and irradiance were used to determine the key parameters (maximum carboxylation rate, electron transport capacity, dark respiration rate) of the biochemical photosynthesis model. Stem wood respiration was also measured at the different height along the tree trunk. The analyses of the temperature dependence of stem respiration can be approximated by the respective exponential formula. The variations of these key parameters were also analyzed associated with climatic factors in the tree crown. Architectural development of tree crown provides the foliage display and the effective allocation of photosynthesis. Thus we investigated the three-dimensional display of shoots and their age structures, which leads to the modeling of crown development. Additionally the detail analyses of needle and branch mass distribution within a tree crown were used to simulate the diurnal change of photosynthesis rate on tree crown basis. The estimate of annual net photosynthesis obtained by biochemical photosynthesis model was comparable to the annual growth rate of the tree weight.

(5) Gap Filling Approach of Sensible and Latent Heat Fluxes Measured by the Eddy-Covariance Technique at the Mase Rice Paddy Field in Japan

Sensible heat flux and latent heat flux were measured at the height of 2.97 m above the Mase rice paddy fields using eddy covariance method, which is a modern technique used worldwide in FLUXNET studies. Measurements of sensible and latent heat flux data through the eddy covariance technique are of importance for the calculation of carbon budget of the ecosystem. The gap filling of both data series for the year 2001 has been undertaken and the preliminary outcome is reported. After quality control, the total gaps in the sensible heat flux and latent heat flux data were 18.6% and 51.8% receptively. Lookup tables were worked out to calculate the existing gaps in both fluxes. The linear regression model was applied for the validation of calculated data for both fluxes during the follow-I period of rice cultivation against the original data, and the calculated data found to be in good agreement. The study also suggested that it is necessary to consider the most suitable environmental factors in the preparation of the lookup tables in order to calculate most appropriate data for the gap filling of sensible heat flux and latent heat flux data series of the rice paddy field ecosystem.

Basic characteristics of the gaps in H flux and λE Flux data in 2001 are shown in Table 3. After the quality control process of the eddy-covariance measured data, a high percentage of gaps are found for H flux data for follow-I period (30%), irrigated I period (23.4%), and follow-II period (24.7%). In case of λE flux the gaps are higher as 50% for most periods in particular fallow-I period (58.45%), ratoon period (59.6%), and follow II- period (64.1%). The calculated data for the gaps in the H and λE fluxes using lookup tables method show a good agreement with the quality-controlled H and λE fluxes data. Therefore, the calculated flux data are of particular importance to establish the Asia Flux Network Data Base.

Table 3 Basic characteristics of the gaps in *H*-flux and *λE*-Flux data in 2001

Duration			Total number of data	Recorded number of data	Gap percentage (%)	Total number of data	Recorded number of data	Gap percentage (%)
DOY	Period	Name	Original *H*-flux data			Original *λE*-Flux data		
1	01/01/2001	Fallow-I	5376	4487	**16.5**	5376	4487	**16.5**
113	23/04/2001	Ponding	552	550	0.4	552	550	0.4
124	04/05/2001	Irrigate-I	2424	2238	7.7	2424	2152	11.2
175	24/06/2001	Drainage-I	576	576	0.0	576	576	0.0
187	06/07/2001	Irrigate-II	576	523	9.2	576	523	9.2
199	18/07/2001	Drainage-II	337	336	0.3	337	336	0.3
206	25/07/2001	Irrigate-III	529	524	0.9	529	524	0.9
217	05/08/2001	Drainage-III	432	432	0.0	432	432	0.0
226	14/08/2001	Irrigate-IV	192	150	**21.9**	192	150	**21.9**
230	18/08/2001	Drainage-IV	600	600	0.0	600	600	0.0
243	30/08/2001	Ratoon	4392	4292	2.3	4392	4292	2.3
334	30/11/2001	Fallow	1536	1536	0.0	1536	1536	0.0
Through the year			17520	16242	**7.3**	17520	16156	**7.8**
DOY	Date	Period	Quality-controlled *H*-flux data			Quality-controlled *λE* -flux data		
1	01/01/2001	Fallow-I	5376	3762	**30.0**	5376	2238	**58.4**
113	23/04/2001	Ponding	552	526	4.7	552	352	36.2
124	04/05/2001	Irrigate-I	2424	1967	18.9	2424	1240	**48.8**
175	24/06/2001	Drainage-I	576	556	3.5	576	352	38.9
187	06/07/2001	Irrigate-II	576	496	13.9	576	407	29.3
199	18/07/2001	Drainage-II	337	328	2.7	337	240	28.8
206	25/07/2001	Irrigate-III	529	501	5.3	529	422	20.2
217	05/08/2001	Drainage-III	432	419	3.0	432	365	15.5
226	14/08/2001	Irrigate-IV	192	147	**23.4**	192	128	33.3
230	18/08/2001	Drainage-IV	600	565	5.8	600	374	37.7
243	30/08/2001	Ratoon	4392	3844	12.5	4392	1773	**59.6**
334	30/11/2001	Fallow	1536	1156	**24.7**	1536	552	**64.1**

(DOY= day of the year)

Reference

1) Falge, E., Baldocchi, D., Olson, R. et al., 2001a: Gap filling strategies for defensible annual sums of net ecosystem exchange. Agric. For. Meteorol. 107, 43-69.

2) Falge, E., Baldocchi, D., Olson, R. et al., 2001b: Gap filling strategies for long term energy flux data sets. Agric. For. Meteorol., 107, 71-77.