Estimation of Carbon Balance Components for an Agricultural Landscape in South Korea

Lindner, Steve (1); Lee, Bora (1); Kettering, Janine (2); Zhao, Peng (3); Seo, Bumsuk (1); Otieno, Dennis O. (1); Walther, Gian-Reto (4); Tenhunen, John (1)

(1) Department of Plant Ecology, University of Bayreuth, 95440 Bayreuth, Germany, steve.lindner@yahoo.de, puplebr@gmail.com, bumsuk.seo@uni-bayreuth.de, Dennis.Otieno@uni-bayreuth.de, john.tenhunen@uni-bayreuth.de
(2) Department of Agro-Ecosystem Research, University of Bayreuth, 95440 Bayreuth, Germany, janine.kettering@uni-bayreuth.de
(3) Department of Micrometeorology, University of Bayreuth, Germany, peng.zhao@uni-bayreuth.de
(4) Federal Office for the Environment, Species and Biotopes Section, Ittigen, Switzerland, gian-reto.walther@bafu.admin.ch

Abstract: The goal of our work is to evaluate as far as possible carbon budget components for an agriculturally dominated landscape in South Korea. In the last decades, rapid changes of land use and land cover due to economic development after the Korean War (Kim and Park, this proceedings) has certainly led to large changes in atmospheric CO_2 exchange in the Haean Catchment in Gangwon Province, South Korea. Our studies represent a first step in trying to understand this change at landscape scale. We hypothesized that crops differ in their CO_2 assimilation rates and also in their patterns of C allocation, thereby influencing the general patterns of CO_2 exchange and production. To test these ideas, we quantified the seasonal patterns of NEE, GPP and Reco in non-irrigated, rain-fed crop fields (radish, potato, cabbage, bean) and in irrigated rice paddies during the growing seasons 2009 and 2010. It was shown that the most important climate factors for gas exchange and biomass development (radiation, temperature, precipitation) were very similar between locations within the catchment. After planting of the crops, the maximum GPP for potato and cabbage is reached in mid-June with up to 70 and 60 µmol m^{-2} s^{-1}, respectively. A similar trend in the increase of GPP for rice, radish and bean with parallel development of plant biomass is evident. Significant differences in the maximum GPP between rice, radish, and bean occur in mid-August with fluxes up to 20, 40 and 55 µmol m^{-2} s^{-1}, respectively. Harvest data on crop yields are reported. Future work is oriented to establishing the links between carbon gain, plant growth and yield; as well as up-scaling the plot results to landscape level.

Keywords: *crop gas exchange, net ecosystem CO_2 exchange, ecosystem respiration, gross primary production, allocation, agricultural yield*

1. Introduction

The interaction between atmosphere and biosphere is a very important process in the earth system specified through the exchange of energy, water, carbon and trace gases. The Asian region is a major contributor to these exchange processes, accounts for a large portion of global biomass (Fu and Wen 1999), and includes cover of ca. 20% of the world's agricultural land (Fan 2005). Agricultural land use in Asia with input-intensive practices (fertilizer, pesticides, machinery) significantly impacts the global carbon budget. The goal of our work is to evaluate as far as possible carbon budget components for an agriculturally dominated landscape in South Korea. In the last decades, rapid changes of land use and land cover due to economic development after the Korean War (Kim and Park, this proceedings) has certainly led to large changes in atmospheric CO_2 exchange in the Haean Catchment in Gangwon Province, South Korea. Our studies represent a first step in trying to understand this change at landscape scale.

The bowl-shaped landscape of the Haean Catchment (referred to as the Punch Bowl; total area of 64 km^2) is occupied by three concentric vegetation zones along an elevation gradient, namely: 1) deciduous forest distributed in the upper zone at an elevation range of ca. 750 to 1100 m with an area of 39 km^2 (61 % of the surface area), 2) dry farm fields, primarily growing summer vegetables, orchards and ginseng (elevation range from ca. 500 to 750 m, covering 17 km^2, constituting 27 % of the surface area), and 3) rice paddies, which are found in the catchment basin (area of 5,07 km^2, which is 8 % of the surface area).

Characterizing CO_2 exchange between the land surface and the atmosphere in each of these zones is important in order to discern their roles in atmospheric carbon (C) fluxes, estimate net uptake and storage of C as well the conversion of fixed carbon to usable agricultural yields and forest products. Eddy covariance studies comparing CO_2 exchange of oak dominated deciduous forest and a mixed cropland in Korea have shown that controls on annual carbon balance components (NEE, GPP, Reco) differ (Kwon et al. 2010). Especially during the summer season, radiation decreases during the monsoon season and loss of leaves due to storm damage reduce C uptake by the forests. On the other hand, management, which modifies the land surface mosaic, and aspects of crop phenology (i.e., growth, maturation and senescence) determine carbon exchange in croplands. These latter characteristics are also those which are determining for agricultural yields and export of carbon from the landscape.

While eddy covariance studies of carbon exchange of a mixed cropland with a double cropping system in Haenam have illustrated the importance of understanding crop phenology(Kwon et al. 2010), the understanding of carbon fluxes and linking of carbon uptake to plant growth and agricultural yields at landscape scale is much more complex, especially since the production phase of crops is overlapping. In this case, information on the response of individual landscape elements is needed. Our study focuses on providing such information for the major annual crops found growing together in the landscape of Haean Catchment.

We hypothesized that crops differ in their CO_2 assimilation rates and also in their patterns of C allocation, thereby influencing the general patterns of CO_2 exchange and production. Further, that the CO_2 exchange, nutrient dynamics and biomass production of the crops must be understood in terms of species-specific responses to prevailing microclimatic conditions. To test these ideas, we quantified the seasonal patterns of NEE, GPP and Reco in non-irrigated, rain-fed crop fields (radish, potato, cabbage, bean) and in irrigated rice paddies during the growing seasons 2009 and 2010.

2. Materials and Methods

2.1 Site description

The study area for the measurements was the Haean Basin which is located north-east of the city of Chuncheon in Yanggu County between longitude 128° 5' to 128° 11' E and latitude 38° 13' to 38° 20' N with a range in altitude from ca. 500 m to 1100 m. Average precipitation is estimated at 1200 mm with 50 % falling during the summer monsoon (see also Tenhunen – TERRECO Geographical Setting in this proceedings). One field for each crop, including cabbage, radish, potato, rice and bean, was chosen for gas exchange studies. Management was according to local practices. The local farmers carried out tillage of the fields before planting, fertilization, planting, irrigation of the rice paddy and harvests.

2.2 Microclimate

Weather conditions were continuously recorded at meteorological stations set up near the field site (WS-GP1 Delta-T Devices, Cambridge, UK), including precipitation, global radiation, air humidity and temperature (data logged every 30 min). Air (at 50 cm above the ground surface) and soil (at -10 cm) temperatures inside and outside of the CO_2 chambers (as described below) were monitored during measurements and data were logged at the onset and end of every round of NEE measurement on each plot. Similarly, light levels within the chamber were monitored using a quantum sensor (LI-190, Li-Cor, USA) and data were logged every 15 s.

2.3 CO_2 Exchange Measurements

Field measurements of ecosystem CO_2 exchange were conducted at least once in a month between June and October 2009. A set of five soil frames were inserted into the soil, three including crops and two with bare soil. Each frame represents a measurement plot and was studied during a campaign around midday (10h-14h). Daily courses of the ecosystem CO_2 exchange were derived from measurements in 2010 with at least 3 campaigns during the growing season. The one-day campaign was conducted between 9 a.m. and 6 p.m. for each crop.

During each monthly measurement campaign, net ecosystem exchange (NEE) and ecosystem respiration (Reco) were sequentially observed with a systematic rotation over all plots using manually operated, closed gas exchange chambers, modified from the description given by Droesler (2005), Wohlfahrt and others (2005), and

Li and others (2008a,b) as used in central European bogs and alpine grasslands. The 38 x 38 x 54 cm^3 chambers of our system were constructed of transparent plexiglass (3 mm XT type 20070; light transmission 95%). Dark chambers, for measuring ecosystem respiration, were constructed of opaque PVC and covered with an opaque insulation layer and with reflective aluminum foil. Using extension bases, chamber height was adjusted to the canopy height. Chambers were placed on the plastic frames that were inserted 7 cm into the ground. They were sealed to the chamber with a flexible rubber gasket and the chamber firmly secured using elastic cords fastened onto the ground from two sides. Increased air pressure in the chamber was avoided by a 12 mm opening at the top of the chamber, which was closed after the chamber had been placed onto the frame and before any records were taken. Circulation of air within the chamber was provided by three fans yielding a wind speed of 1.5 m s^{-1}. Change in chamber CO_2 concentration over time was assessed with a portable, battery operated IRGA (Li-Cor 820).

Measurements were carried out in most cases within 3–5 min of placing the chamber on the frames. Once steady state was attained, data were logged every 15 s for 2 min and CO_2 fluxes were calculated from a linear regression describing the time dependent change in CO_2 concentration within the chamber. Influence of the CO_2 concentration change on plant physiological response was ignored. By mounting frozen ice packs inside and at the back of the chamber in the airflow, temperature during measurements could be maintained within 1°C relative to ambient.

Cooperative studies with measurements of the CO_2 flux, sensible and latent heat fluxes were conducted in 2010 with the eddy covariance technique from May 12th to November 8th in a dry farm land planted with potatoes and an irrigated rice paddy (see Zhao – Eddy Covariance in Haean in this proceedings). The instruments were moved between the two sites every 2 weeks and biomass was sampled every two weeks. In parallel, chamber measurements were carried out for comparison.

2.4 Biomass Allocation and C/N Ratio in Plant Materials

After the end of each gas exchange campaign, the biomass in each plot was harvested, and separated into leaves, stems, roots, and reproductive parts. The area determination of the leaves was conducted with a leaf area meter (LI-3000c, Li-Cor, USA). Plot biomass was then oven dried at 80°C until a constant weight was reached (minimum 48h). Soil samples were taken from each plot to determine the moisture content as calculated from the sample weight before and after drying for 2 days (80°C). Fine powdered soil from each plot was analyzed for the carbon and nitrogen content using the Nitrogen Analyzer 1500 (Carlo Erba Instruments, Milan, Italy)

In the catchment, 32 fields were chosen for biomass sampling of a square meter ground area (3 replicates per field) during the local harvesting period at the end of the growing season 2009. The fields were distributed throughout the catchment, and the harvest of the crops included rice, radish, bean, potato and cabbage. The plant material was divided into plant parts and the fresh weight was determined. Sub-samples were used to obtain dry to fresh weight ratios, and used to measure carbon and nitrogen content.

3. Results

The total area of arable land was 17,2 km^2 in 2009 and covered around 27 % of the total land surface in the Haean Catchment (in total ca. 64 km^2). The rice paddies covered around 30% of the cultivated land, whereas the four most important annual dry-land crops (radish, bean, potato, cabbage) account for approx. 52% of the cropped area (Yanggu County Office 2010). The area of land use and the percentage of cover per crop for the Haean Catchment in 2009 is shown in Table 1.

Table 1. Land use 2009 in Haean, area and percentage of cultivated land for each crop (Yanggu County Office 2010)

2009	[ha]	[%]
Total	1720,1	100
Rice	507,0	29,5
Radish	415,8	24,2
Bean	219,9	12,8
Potato	175,0	10,2
Ginseng	129,0	7,5
Others	112,6	6,5
Orchard	82,0	4,8
Cabbage	78,8	4,6

The solar radiation recorded at two weather station (WS 6 located in rice paddies in the basin & WS 8 in the dry field zone on an east-facing slope), showed only minor differences from July to December 2009 (Figure 1). Similar results are found for the course of minimum and maximum temperature at both locations (Figure 2) as well as precipitation and vapour pressure deficit (data not shown). A temperature decrease with elevation (TLR, temperature lapse rate) of around 0,5 °C per 100 m has been described by Choi et al. (see Lapse Rate in this proceedings).

Thus, we may assume in the first approximation within the agricultural zones, all crops develop under essentially the same conditions. However, this analysis is not so far adequate to eliminate all possibilities of slope and exposure effects Additionally, inter-annual variations in radiation, temperature and precipitation have significant effects on plant development and carbon exchange. Climate conditions during 2009 and 2010 were in fact very different and remain to be analyzed.

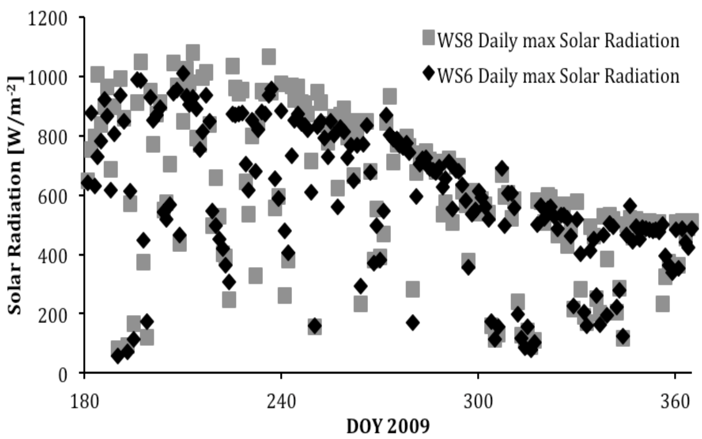

Figure 1. Daily max solar radiation of two weather stations installed at the Haean catchment during the growing season 2009

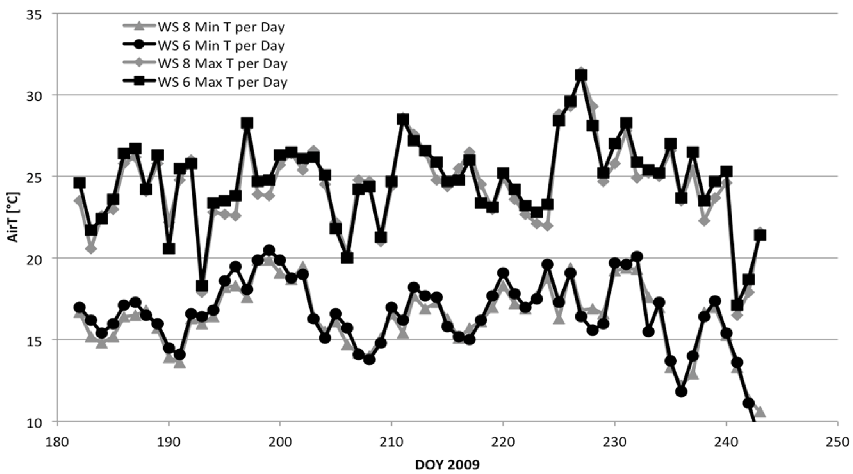

Figure 2. Daily minimum and maximum air temperature of weather station six and eight installed at the Haean catchment during the growing season 2009

The planting and harvest dates for rice and the most important annual dry-land crops are summarized in Figure 3. After application of the basal fertilization (detailed information's are given in Kettering – N Budget in this proceedings), the farmers plant seed potatoes at the end of April. With increases in radiation and temperature before the monsoon period in June and July (cf. Shope et al. 2010), the cropping conditions for bean, cabbage, radish and rice are favorable, with planting beginning in mid-May. The maturity of cabbage and radish is reached after ca. 2.5 month and the harvest of cabbage, radish, potato starts in August. The longest growing periods are

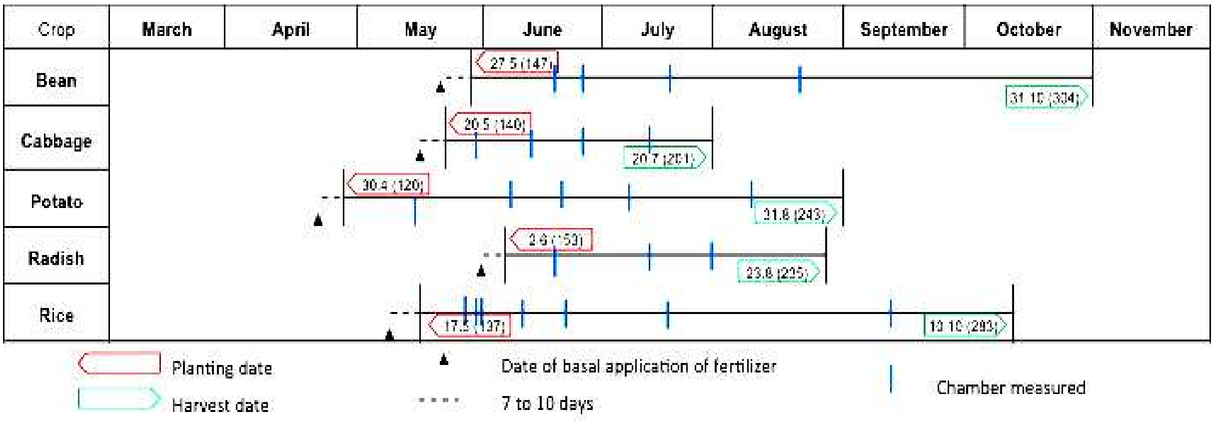

Figure 3. Planting and harvest days of bean, cabbage, potato, radish and rice in 2009

for beans and rice with 5.5 months of vegetative development, and harvests in mid-October.

Figure 4 presents the seasonal variations in net ecosystem exchange and ecosystem respiration in 2009 with the highest Reco for potato in June (~ 25 µmol m^{-2} s^{-1}), cabbage in early June (~ 50 µmol m^{-2} s^{-1}), bean in August (~ 58 µmol m^{-2} s^{-1}) and radish in September (~ 50 µmol m^{-2} s^{-1}). The ecosystem respiration in the rice paddies was minor due to waterlogged conditions of the soil during the measurements (up to 5 µmol m^{-2} s^{-1}). The NEE for bean, rice, cabbage and potato was negative (net CO_2 uptake) during the growth period with highest values for cabbage and potato in June of around - 40 and - 100 µmol m^{-2} s^{-1}, respectively.

The seasonal course of the maximum gross primary production (GPP) derived from the CO_2 chamber measurements is shown for rice, cabbage, potato, bean and radish in Figure 5. The GPP is calculated from the net ecosystem exchange (NEE) and the ecosystem respiration (Reco) during each measurement campaign. After planting of the crops, the maximum GPP for potato and cabbage is reached in mid-June with up to 70 and 60 µmol m^{-2} s^{-1}, respectively. A similar trend in the increase of GPP for rice, radish and bean with parallel development of plant biomass is evident. Significant differences in the maximum GPP between rice, radish, and bean occur in mid-August with fluxes up to 20, 40 and 55 µmol m^{-2} s^{-1}, respectively. A decrease of the maximum GPP after reaching maturity is found for potato and radish early in the growing season (mid-June), and for rice, radish and bean in August.

Two types of typical farmlands were chosen to apply eddy-covariance technique (results shown in Figure 6), including a dry farm land planted with potatoes and an irrigated rice paddy. Preliminary results showed in general larger values of NEE measured by eddy-covariance technique than by chamber measurements, which may depend on site differences. The patterns in seasonal changes in NEE agree with the chamber-based observations.

Seasonal pattern of biomass development of the crops was up-scaled from the CO_2 measurement plots to a square meter ground area and tabulated (Table 2). Yield values of radish root was 9.5 kg/ m^{-2}, cabbage leaves 22.9 kg/ m^{-2}, potato tuber 5.7 kg/ m^{-2}, husked bean seeds 0.3 kg/ m^{-2} and husked rice seeds 1.8 kg/m^{-2}.

The results of the crop yield in 2009 measured at harvest is given in Table 3. These are the statistical means for crop yield in the catchment. Radish root reached in 2009 a statistical weight of 9.9 kg/ m^{-2}, cabbage leaves 8.4 kg/ m^{-2}, potato tuber 4.4 kg/ m^{-2}, husked bean seeds 2.1 kg/ m^{-2} and husked rice seeds 1.2 kg/ m^{-2}.

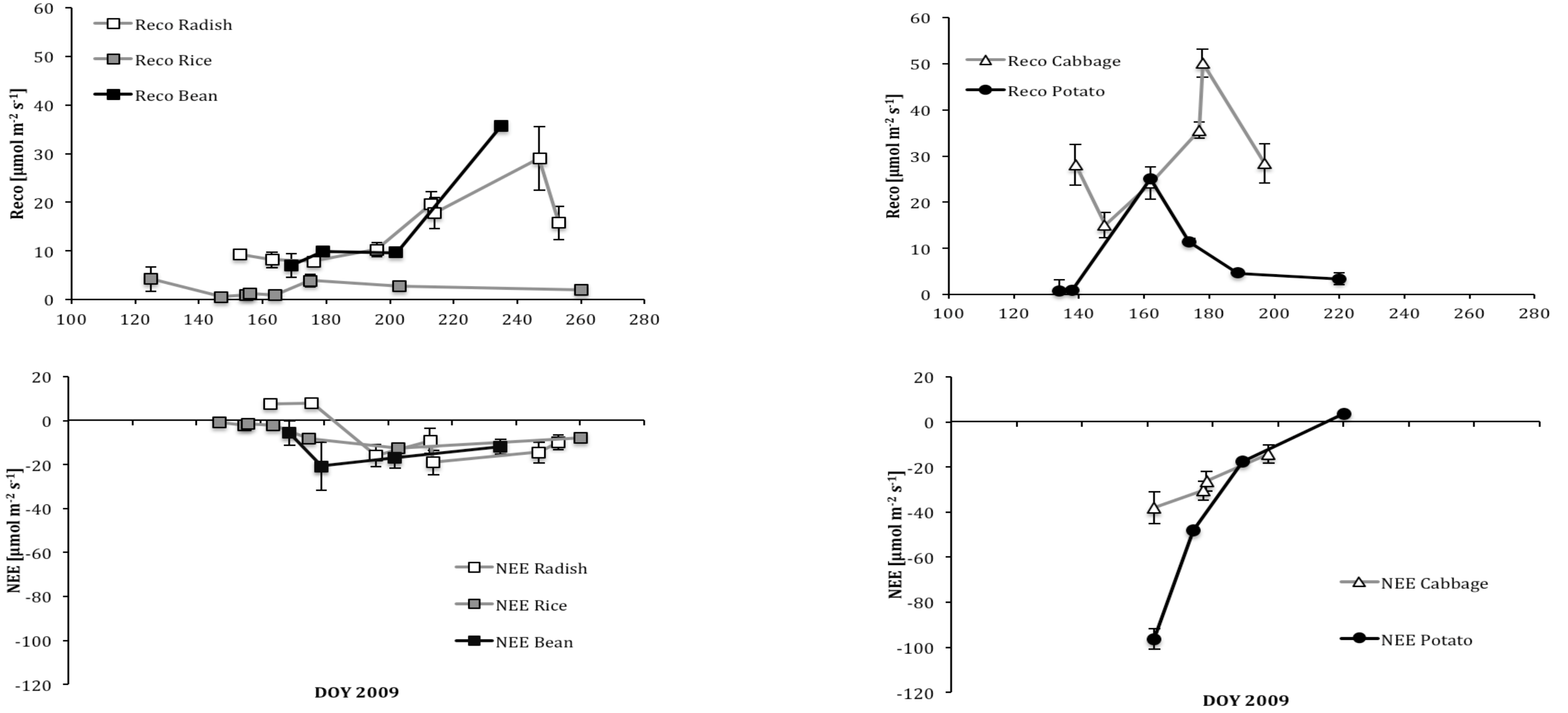

Figure 4. Seasonal variations in maximum ecosystem respiration and net ecosystem exchange in 2009 for rice, potato, cabbage, radish and bean determined from midday flux measurements

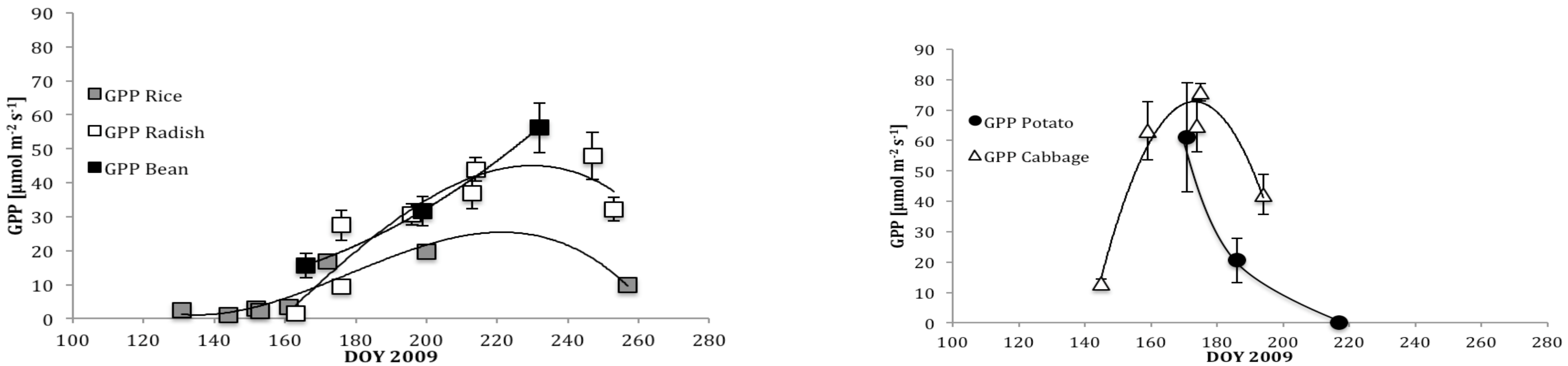

Figure 5. Seasonal variations in maximum gross primary production in 2009 for rice, potato, cabbage, radish and bean determined from midday flux measurements

Table 2. Seasonal variation in fresh weight biomass for radish, cabbage, potato, bean and rice, up scaled from CO_2 measurement plots; thick formatted characters are crop yield at the end of the season 2009.

Radish DOY	Fresh weight [kg/m^2] Green+Stem	Fresh weight [kg/m^2] Root	
163	0,01	0,0019	
176	0,06	0,0034	
196	1,35	1,0397	
213	2,19	8,8605	
247	2,31	8,5035	
253	1,43	**9,5378**	
Cabbage DOY	Fresh weight [kg/m^2] Green+Yellow+Stem	Fresh weight [kg/m^2] Root	
148	0,08	0,0041	
162	1,22	0,0222	
177	6,51	0,1236	
197	**22,90**	0,2184	
Potato DOY	Fresh weight [kg/m^2] Green+Stem	Fresh weight [kg/m^2] Root	Fresh weight [kg/m^2] Seed
138		0,0085	
159	0,79	0,1334	0,3500
174	0,94	0,0657	1,4362
189	1,03	0,1159	3,0013
220			**5,6840**
Bean DOY	Fresh weight [kg/m^2] Green+Stem	Fresh weight [kg/m^2] Root	Fresh weight [kg/m^2] Husked seed
169	0,08	0,0224	
179	0,17	0,0293	
202	0,96	0,1082	
235	1,87	0,1743	**0,3419**
Rice DOY	Fresh weight [kg/m^2] Green+Stem	Fresh weight [kg/m^2] Root	Fresh weight [kg/m^2] Husked seed
147	0,33	0,22	
155	0,23	0,12	
164	0,38	0,25	
175	1,24	0,92	
203	4,06	3,03	
260	3,39	2,56	**1,81**

Table 3. Crop yield and crop fresh weight biomass at harvest; rice and bean seeds are measured with husk. Yield is indicated in bold type

	[kg/m^2] Green+Stem+Yellow	[kg/m^2] Root	[kg/m^2] Seed
Radish	1,38	**9,90**	
Cabbage	**8,39**	0,40	
Potato	0,72	0,08	**4,44**
Bean	3,67	0,33	**2,13**
Rice	2,70	1,09	**1,20**

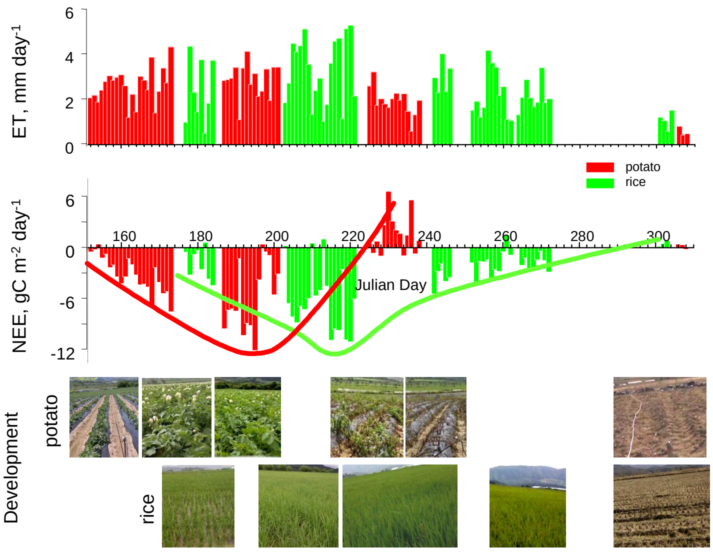

Figure 4. Evapotranspiration and net ecosystem exchange of CO_2 in rice and potato field during the growing season 2010 (see Zhao – Eddy Covariance

4. Discussion and Projections

Our study in 2009 examined the CO_2 exchange and biomass development of the most important annual dry-land crops (potato, radish, cabbage, bean) and rice in the Haean Catchment. It was shown that the most important climate factors for gas exchange and biomass development (radiation, temperature, precipitation) were very similar between locations within the catchment. A temperature lapse rate of around 0,5 °C per 100 m was significant and reported by Choi (this proceedings). Dependent on the phenology of the particular crop, variations in the growth period duration occurs and is controlled by the local farmers. Detailed descriptions of the seasonal timing in the vegetation activity on a landscape level are given in Lee et al. (see Lee – Local NDVI in this proceedings). The specific phenology of a particular crop is important since it influences the CO_2 exchange at different stages of the vegetation period and determines finally the agricultural yield. The parallel application of CO_2 chamber measurements and the eddy covariance technique to determine the gas exchange at different scales will be used to get the best approach for prevailing fluxes in the field. This is part of the further upscale process from plot level to landscape level. The challenge is to fill the gap between the measurements from the CO_2 chamber plots with crops under ideal conditions and the statistical average in the catchment including a spatial distribution. Already available data sets of crop yields from Asian, European and American sites combined with the use of the PIXGRO model will characterize the net uptake and storage of carbon at a specific period in the area and estimate the gas exchange on landscape level.

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