Agriculture, Ecosystems and Environment 199 (2015) 132–145

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Carbon dioxide exchange and its regulation in the main agro-ecosystems of Haean catchment in South Korea

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ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 3 September 2014
Accepted 6 September 2014
Available online 29 September 2014

Keywords:
Agricultural landscapes
Ecosystem CO_2 exchange
Closed-chamber technique
Crop productivity
Biomass development

ABSTRACT

The Asian agricultural landscape, which accounts for approximately 12.6% of the world's agricultural land, is highly heterogeneous due to the multicultural cropping system. Information regarding CO_2 exchange and carbon (C) balance of these agro-ecosystems is scarce, even though they are likely to immensely contribute to the global C budget. Net Ecosystem CO_2 Exchange (NEE) and Ecosystem respiration (R_{eco}) were measured between 2009 and 2010 on 5 dominant crops (potato, rice, radish, cabbage and bean) in the Haean catchment of South Korea, using a closed chamber system to quantify CO_2 fluxes in this agricultural landscape characteristic of the Asian cropping system. Parallel measurements were conducted on leaf area index (LAI), plant biomass and climatic variables, mainly photosynthetic active radiation (PAR), air temperature, soil temperature and soil moisture. Biomass and LAI development differed among the crops likely as a result of differences in light use efficiencies (α) and carbon allocation patterns. The peak total biomass for radish, cabbage, potato, rice and bean were 0.53 ± 0.07, 0.55 ± 0.12, 1.85 ± 0.51, 2.54 ± 0.35 and 1.01 ± 0.26 kg m^{-2}, respectively, while the respective maximum LAI were 2.8, 3.7, 6.4, 6.3 and 6.7 m^2 m^{-2}. Variations in seasonal patterns, magnitudes and the timing of maximum NEE and gross primary production (GPP) among the crops were likely the result of differences in LAI and α. The lowest peak R_{eco} rate was 3.8 ± 0.5 μmol m^{-2} s^{-1}, measured on rice paddies while the highest was 34.4 ± 4.3 μmol m^{-2} s^{-1} measured on the cabbage fields. The maximum NEE rates were -29.4 ± 0.4 and -38.7 ± 6.6 μmol m^{-2} s^{-1}, measured in potato and cabbage fields, respectively. Peak GPP rates in potato and cabbage fields were 39.5 ± 0.6 and 63.0 ± 7.2 μmol m^{-2} s^{-1}, respectively. PAR explained more than 90% of the diurnal variations in GPP, while LAI and α determined the seasonal trends of maximum GPP. The timing of maximum CO_2 assimilation (GPP_{Max}) differed among the crops, thus, even though maximum CO_2 uptake in the respective crops only lasted a couple of weeks, the effect of the staggered peak GPP resulted in extended period of high CO_2 uptake. These differences among crops were significant, hence, modeling approaches need to consider the heterogeneity in ecosystem CO_2 exchange associated with these multicultural agriculture landscapes.

1. Introduction

There is a general consensus regarding the contribution of natural ecosystems such as forests, wetlands, grasslands, savannas and the tundra to the global carbon (C) budget. However, agro-ecosystems, particularly croplands which currently constitute 12.6% of the total land area (FAO, 2014) have been less regarded (Gilmanov, 2010; Smith et al., 2010). Due to their small spatial coverage, croplands were for a long time considered moderate contributors to the global atmospheric C pool (Smith and Falloon, 2005), but this is changing owing to the ongoing massive conversion of natural ecosystems such as forests and grasslands into croplands, increasing their spatial coverage globally (Desjardins et al., 2007; Corbin et al., 2010). Crop production is seasonal in nature hence as a result of their expansion, they are likely to play an increasingly important role as drivers of annual and inter-annual fluctuations in the global atmospheric CO_2 concentrations (Moureaux et al., 2008).

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http://dx.doi.org/10.1016/j.agee.2014.09.005
0167-8809/

Our current knowledge on CO_2 fluxes and annual C budgets of croplands originate from measurements conducted on the extensive monocultural agricultural landscapes such as maize and soybean rotations in North America (Hollinger et al., 2005; Pattey et al., 2002; Suyker et al., 2004, 2005; Hernandez-Ramirez et al., 2011); corn, soybean, wheat (Falge et al., 2002a; Corbin et al., 2010); maize, winter wheat and barley (Sus et al., 2010; Jans et al., 2010) in central and northern Europe. Similar data are available for sugar beet (Moureaux et al., 2006; Aubinet et al., 2009), winter wheat (Hoyaux et al., 2008; Moureaux et al., 2008; Dufranne et al., 2011; Schmidt et al., 2012), potato (Aubinet et al., 2009) and triticale (Béziat et al., 2009) from other parts of Europe. Results from long-term measurements of net ecosystem CO_2 exchange (NEE) in 17 flux sites in Europe for 45 cropping periods were summarized by Moors et al. (2010). Soegaard et al. (2003) reported CO_2 fluxes over a mixed agricultural landscape in western Denmark planted with winter wheat, winter barley, spring barley, maize and grass. In Asia, Lei and Yang (2010), Qun and Huizhi (2013) reported annual CO_2 fluxes and C storage for winter wheat and summer maize rotation fields representative of the main cropping system in the North China plains. Data on rice field CO_2 fluxes are available from North America (Campbell et al., 2001), Korea (Moon et al., 2003), Japan (Saito et al., 2005), and China (Ren et al., 2011).

In Asia, most of the agricultural landscape is characterized by multicultural cropping systems comprising of relatively small (1–2 ha) land holdings (Pookpakdi, 1992). Although smaller than the world average holding range of 3.7 ha, combined, these farms contribute around 20% of the world's agricultural land and play a critical role in the global C budget. Fragmentation of the landscape through multicultural cropping is also likely to induce strong fluctuations in C fluxes through varied timing and growing lengths of different crop types and might be contributing to the oscillations observed in the atmospheric CO_2 concentration during the year. In a multicultural landscape, quantifying CO_2 fluxes and C budgeting for the respective ecosystem patches (small farms) are major challenges. Also, linking CO_2 fluxes at landscape scales to the agricultural yields is difficult, especially when the production phases of the crops are overlapping.

Quantification of CO_2 exchange between ecosystems and the atmosphere have been achieved with the two widely accepted measurement techniques, namely the chamber (CT) and the eddy covariance (EC) techniques (Aubinet et al., 2000; Pavelka et al., 2007; Wohlfahrt et al., 2005). While the EC technique applies best in open habitats (from hundreds of m^{-2} to km^{-2}) where fluxes are related to clearly defined vegetation types (footprint), the use of portable chambers allows direct evaluation of NEE, ecosystem respiration (R_{eco}) and gross primary productivity (GPP) at small spatial scales (plot level), making it possible to key out functional differences within a heterogeneous landscape like mixed farming systems in the Asian agricultural landscape. In this study, we focused on CO_2 exchange on fields of major crops grown in the heterogeneous agricultural landscape of the Haean-myun catchment to: (1) determine the seasonal patterns and magnitudes of CO_2 exchange and productivity of five main crop types, (2) identify the factors that regulate CO_2 fluxes and biomass production and the intensity of regulation among different crops in the fragmented agricultural landscape in the Haean catchment. We hypothesized

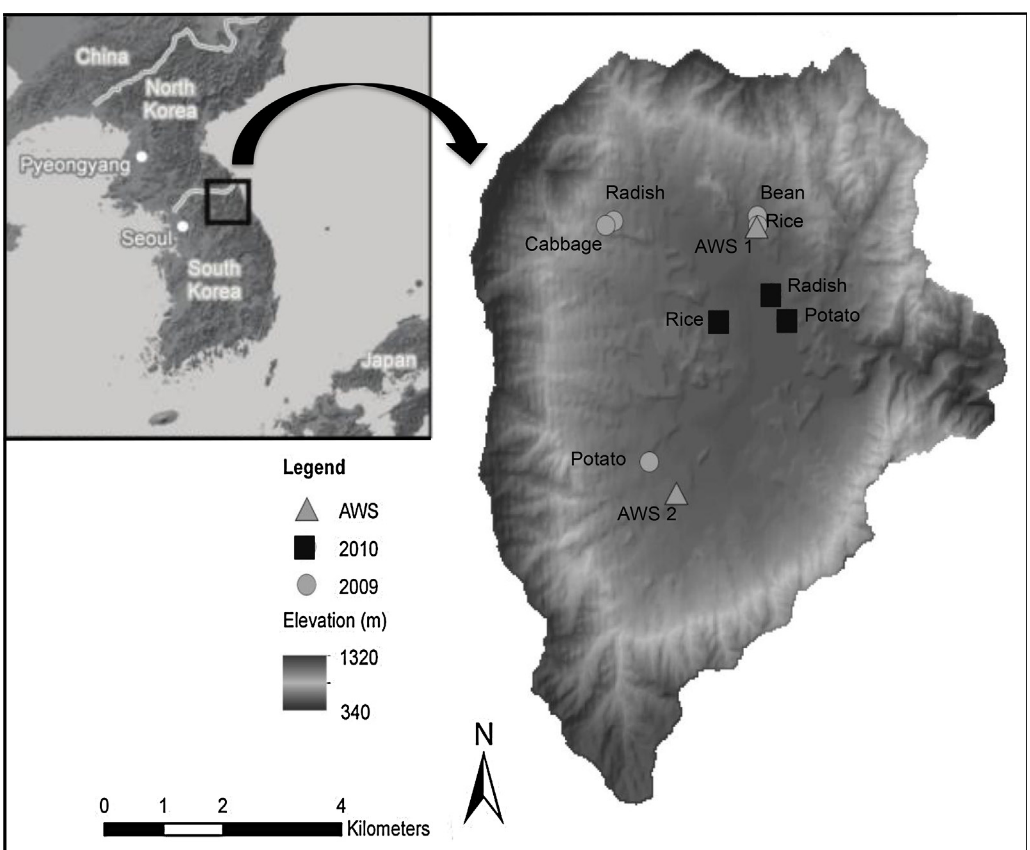

Fig. 1. Location of the Haean-myeon catchment on the Korean peninsula with the experimental sites where our measurements were conducted during 2009 (circles) and 2010 (squares). Locations of the automatic weather stations are indicated with triangles.