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Central Russia agroecosystem monitoring with CO_2 fluxes analysis by eddy covariance method

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Abstract

The eddy covariance (EC) technique as a powerful statistics-based method of measurement and calculation the vertical turbulent fluxes of greenhouses gases within atmospheric boundary layers provides the continuous, long-term flux information integrated at the ecosystem scale. An attractive way to compare the agricultural practices influences on GHG fluxes is to divide a crop area into subplots managed in different ways. The research has been carried out in the Precision Farming Experimental Field of the Russian Timiryazev State Agricultural University (RTSAU, Moscow) in 2013 under the support of RF Government grant # 11.G34.31.0079, EU grant # 603542 LUC4C (7FP) and RF Ministry of education and science grant # 14-120-14-4266-ScSh. Arable Umbric Albeluvisols have around 1% of SOC, 5.4 pH (KCl) and NPK medium-enhanced contents in sandy loam topsoil. The CO_2 flux seasonal monitoring has been done by two eddy covariance stations located at the distance of 108 m. The LI-COR instrumental equipment was the same for the both stations. The stations differ only by current crop version: barley or vetch and oats. At both sites, diurnal patterns of NEE among different months were very similar in shape but varied slightly in amplitude. NEE values were about zero during spring time. CO_2 fluxes have been intensified after crop emerging from values of 3 to 7 μmol/s·m² for emission, and from 5 to 20 μmol/s·m² for sink. Stabilization of the fluxes has come at achieving plants height of 10-12 cm. Average NEE was negative only in June and July. Maximum uptake was observed in June with average values about 8 μmol CO_2 m⁻² s⁻¹. Although different kind of crops were planted on the fields A and B, GPP dynamics was quite similar for both sites: after reaching the peak values at the mid of June, GPP decreased from 4 to 0.5 g C CO_2 m⁻² d⁻¹ at the end of July. The difference in crops harvesting time that was equal two weeks did not significantly influence the daily GPP patterns. Cumulative assimilation of CO_2 at the end of the growing season was about 150 g C m⁻² for both sites. So the difference in NEE was the consequence of essentially higher respiration rates in case of vetch and oats (about 350 g C m⁻²) comparing to barley (250 g C m⁻²) that needs additional research. The results have shown high daily and seasonal dynamic of CO_2 emission too as a result of different and contrasted conditions: crop type, crop development stage, soil moisture and air temperature. Obtained unique for Russian agriculture data are useful for land-use practices environmental assessment, for soil organic carbon dynamics analysis and agroecological evaluation.

Keywords: agroecology, soil functions, greenhouse gases, eddy fluxes, ecological monitoring, agroecosystems

Article Info

Introduction

The eddy covariance (EC) technique is a statistical method to measure and calculate vertical turbulent fluxes of greenhouses gases within atmospheric boundary layers. The 3D wind, gas concentration and other

variables are decomposed into mean and fluctuating components in frame of it. The covariance between the fluctuating component of the vertical wind and the fluctuating component of gas concentration is proportional to the measured flux. The EC methods can improve our understanding of the impact of reclamation on ecosystem scale C budgets, since it can provide continuous, long-term flux information integrated at the ecosystem scale (Aubinet et al., 2012; Baldocchi, 2003; Burba, 2013).

The agricultural management practices are expected to impact the carbon fluxes and budget. An attractive way to compare the agricultural practices influences is to divide a crop area into subplots managed in different ways. In this study, we set up paired EC flux towers to measure net ecosystem exchange (NEE) in two adjacent agroecosystems, a field with barley and a field with vetch and oats in Moscow region, Russia. The objectives of this study was to determine the diurnal and seasonal variation of ecosystem CO_2 exchange during the growing season and the year for two agroecosystems in Moscow region situated on the adjusted fields.

Material and Methods

The research has been carried out in 2013 on Precision Farming Experimental Field of the Russian Timiryazev State Agricultural University (RTSAU: 55°55'14''N, 37°33'56''E) situated in Moscow, Russia. The experimental site has a temperate and continental climate with distinctive seasons. The annual mean temperature is 3.8° C, with minimum and maximum mean temperatures of −6° C in January and 18.5° C in July, respectively. The growing season with an average daily temperature of 5° C continues during 175 days: from April, 18 to October, 11. The average annual precipitation is 550–650 mm: two-thirds of precipitation is in the form of rain and one third is in the form of snow. Nearly 40% of the precipitation falling during the cold period between November and March, and the other 60% falls during April-October. Soil type is Umbric Albeluvisols (arable sod-podzolic soils under Russian soil classification), and the topsoil texture is mainly sandy loam. Arable sod-podzolic soils have around 1% of SOC, 5.4 pH(KCl) and NPK medium-enhanced contents. The natural vegetation in this area consists of mixed forests of the temperate climate.

The CO_2 flux seasonal monitoring has been done by two eddy covariance stations located at the distance of 108 m from each other (Figure 1).
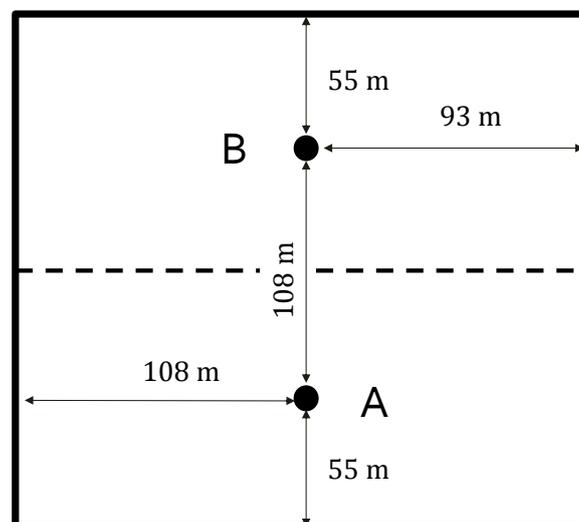

Figure 1. The layout of two EC stations (A and B) located on two adjacent fields, named according to stations.

The terrain at the two sites is flat with a sufficient fetch to meet the basic assumption for proper application of the EC technique. The stations differ only by current crop type. Two fields located next to each other and named according to stations (A and B). The field A was used for barley planting (*Hordeum vulgare L., breed Mihailovsky*). The field B was used for planting together common vetch (*Vicia sativa L.*) and oats (*Avena sativa L.*). Sowing was in early May 2013 and harvest was in August, 14 for barley; vetch and oat were harvested July, 31. During our study, the canopy height was 0.00–0.40 m high for the both sites. The height of crop residues was 7 cm.

Eddy covariance and microclimate measurements were conducted at both research sites during the spring, growing season and continued until the end of the year (March–December). Agroecosystems CO_2 fluxes were

measured using the EC system mounted 1.4 m above the soil surface for the both stations. The EC system included a three-axis sonic anemometer (CSAT-3, Campbell Scientific Inc., USA) and enclosed path infrared gas analyzer (IRGA, LI-7200, Li-COR Inc., USA). The flux data were recorded at 20 Hz by a data logger (CR1000, Campbell Scientific Inc., USA) at 30 min intervals. Meteorological parameters were measured simultaneously with the same array of sensors: including net radiation (NR01, Hukseflux Thermal Sensors B.V., the Netherlands), air temperature and relative humidity (HC2S3, Campbell Scientific, Inc., USA) and heat flux at the depths of 8 cm (HFP01, Hukseflux Thermal Sensors B.V., the Netherlands). Soil temperature and water content were measured at 3 depths (5, 20 and 50 cm) with multi-parameter sensor (CS650, Campbell Scientific Inc., USA). Photosynthetic active radiation (PAR) (LI-190SB, Li-Cor Inc., USA) and precipitation (TE525 MM tipping bucket gauge, Texas Electronics, Texas, USA) were measured only on the field A. We have assumed that temporal patterns of PAR and precipitation were similar for the both agroecosystems, because the two towers were situated site by site, at the negligible distance regarding to PAR and precipitation differences. All meteorological data were measured every 10 s and then averaged half-hourly.

Raw data were processed using the eddy covariance processing software EddyPro, version 4.1 (LI-COR Inc., USA) to determine NEE with an averaged half-hourly period with the following settings. Data processing followed standard methods and included coordinate rotation with tilt corrections, linear detrending, despiking, time lag corrections, correction of low-pass filtering effects with Moncrieff et al. (1997) and Webb–Pearman–Leuning (WPL) correction (Webb et al., 1980). Also the dynamic metafile was used to take into account in the model the canopy growth and snow melting. The surface roughness was neglected. The flux footprint estimation was made using the model of Kljun et all. (2004). Quality control tests for fluxes (1 to 9 system) were performed according to Foken (2003).

Subsequently, quality filtering was applied to the half-hour flux data according to the following rejection criteria: (1) incomplete half-hour measurements; (2) NEE with flags values 8 and 9 of quality control tests for fluxes; (3) data with the cumulative flux footprint originated outside the borders of field A or field B respectively (Figure 1); (4) excessive spikes of NEE exceeding $3*\sigma$ for the half-hour of monthly averaged data. Negative nighttime CO_2 fluxes were also removed from the datasets. After post-processing and quality filtering, 48.0% of the CO_2 flux data for the tower A and 67.0% for the tower B were suitable for analysis.

The gap-filling of the eddy covariance and meteorological data was performed through methods proposed by Eddy covariance gap-filling & flux-partitioning tool of Department Biogeochemical Integration at the Max Planck Institute for Biogeochemistry ([http://www.bgc-jena.mpg.de/ ~MDIwork/eddyproc/ind ex.php], website). Methods are similar to Falge et al. (2001), but consider that both the co-variation of fluxes with meteorological variables and the temporal auto-correlation of the fluxes (Reichstein et al. 2005).

Based on the assumption that daytime respiration was of similar magnitude and responsiveness as nighttime ecosystem respiration ($R_{eco, night}$) the daily ecosystem respiration (R_{eco}) was determined as an average of $R_{eco, night}$ summarized for a 24-hours period. Gross primary production (GPP) was calculated as the balance between daytime NEE and R_{eco}: GPP = R_{eco} – NEE. The calculations were made for daily data.

A paired samples t-test was used to test the significant differences in diurnal variations of NEE, and the mean daily values of NEE, GPP, and R_{eco} between the tower A and the tower B. In all tests, a significance level of 0.05 was used. Quality filtering, flux gap filling and statistical analysis were performed using R Statistical Software (Foundation for Statistical Computing, Vienna, Austria [http://www.r-project.org/] website), a free software environment for statistical computing and graphics.

Results and Discussion

Meteorological and environmental conditions were similar for two eddy covariance stations (A and B) located on two adjacent fields, as expected. Correlation coefficients between microclimate measurements data were 0.83-0.99. Daily PAR reached its maximum two times: at the end of May and at the end of the June (Figure 2a).
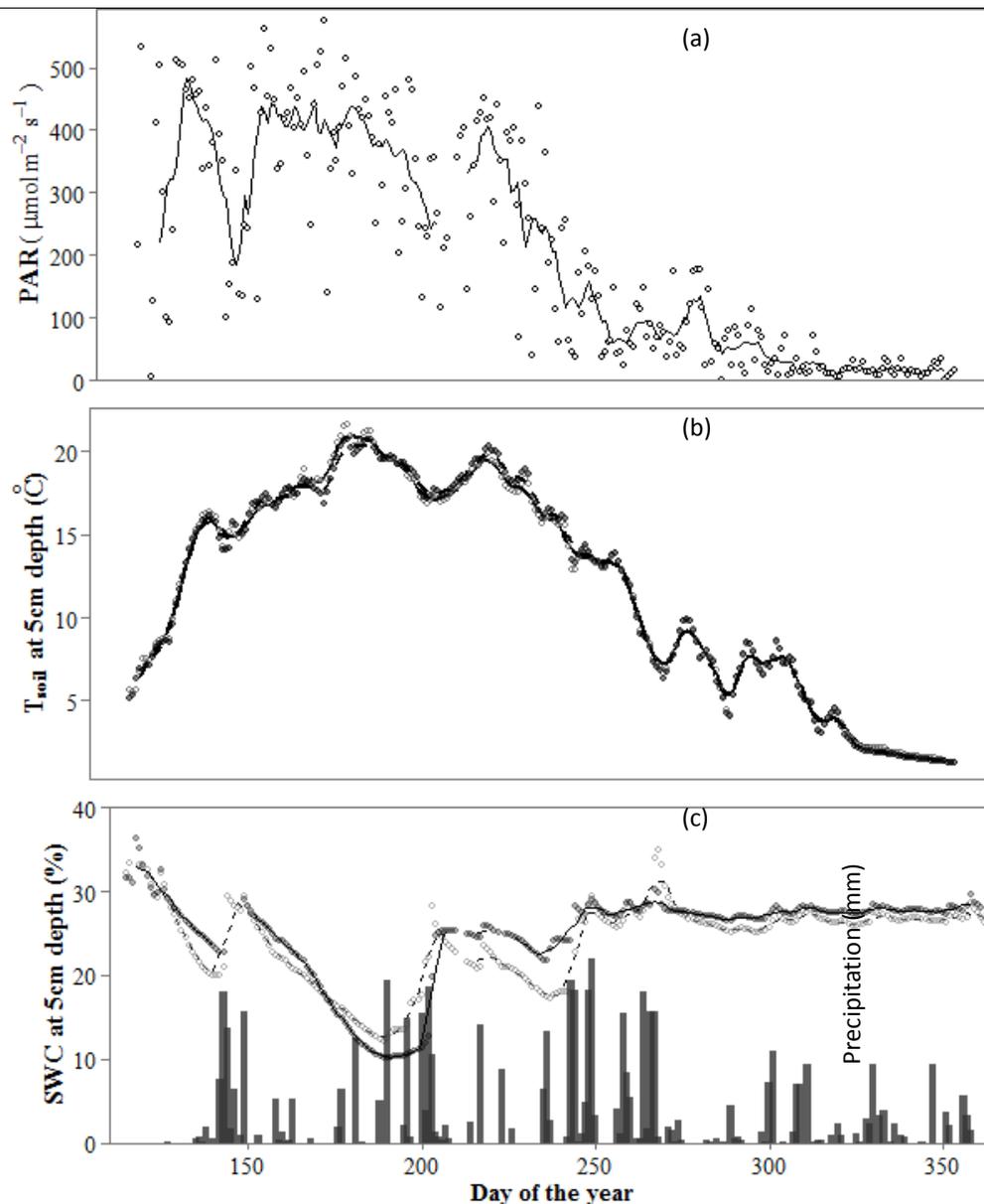
Figure 2. Seasonal variations of (a) daily photosynthetic available radiation (PAR), (b) daily soil temperature (T soil) at 5 cm depth, (c) daily precipitation and daily mean soil water content (SWC) at 5 cm depth, during the growing season and the end of the year (from May to December) at the eddy covariate station A (empty dots) and station B (black dots). Solid line represent 7-day running mean values of PAR.

There is a sharp decline after the first maximum for a week in mid-June that is typical for this area. PAR was stable until the end of August, and then the average monthly PAR started to decrease gradually. Minimal average monthly PAR was registered during December (18 $\mu mol\ m^{-2}\ s^{-1}$) and maximal one was detected in June (414 $\mu mol\ m^{-2}\ s^{-1}$). Difference in mean soil temperature at the 5 cm depth was negligible for the both fields (Figure 2b). Average monthly soil temperature at the 5 cm depth was higher than 15°C from May to August. Monthly precipitation (mm) suited well the local seasonal variation (Figure 2c). The total precipitation during the growing season was about 200 mm; it is approximately one third of the total precipitation per year. The seasonal patterns of soil water content (SWC) were similar for two eddy covariance stations (Figure 2c). Higher SWC dynamics were detected during vegetation season associated with the PAR and precipitations changes. SWC for the tower A was significantly less than the values for the tower B in mid-May and at the end of July. On the contrary, the tower B values are much smaller than the tower A ones; and they dropped to the minimal value of 10% in early July.

Diurnal patterns of NEE clearly showed significant inter-seasonal differences (Figure 3). At both sites, diurnal patterns of NEE among in different months were very similar in shape but varied slightly in

amplitude. NEE values were about zero during March, when the soil was covered by snow. Snow melt in mid-April did not change much NEE diurnal dynamic. CO_2 fluxes have been intensified after crop emerging from values of 3 to 7 μmol CO_2 m^{-2} s^{-1} for night time emission, and from 5 to 20 μmol CO_2 m^{-2} s^{-1} for day time sink. Stabilization of the fluxes has come at the moment plants reached height of 10-12 cm. The resulted CO_2 sink during the day is approximately 2-5 times higher than emissions at night. For example, in mid-June, the sink value was about 0.45 mol m^{-2} during the day-time, and the emission value was about 0.1 mol m^{-2} at night. Average NEE was negative only in June and July. Maximum uptake was observed in June with average values about 8 μmol CO_2 m^{-2} s^{-1}. After sunrise, the NEE moved from a positive value (release) to a negative value (uptake), and CO_2 uptake increased from 7:00 h gradually, till peak values were achieved between 11:00 and 14:00 h. Then, CO_2 uptake declined through the afternoon, and turned to a release of CO_2 after 19:00 h. Duration of positive and negative values changed clearly among different months, because of their differences in photoperiod (the time between sunrise and sunset). Low uptake in August can be clearly explained by harvesting. There was no significant uptake and diurnal dynamics of CO_2 in autumn and winter. Mean values of CO_2 release during this period were about 1 μmol CO_2 m^{-2} s^{-1}. Significant differences in diurnal variations of NEE between the two eddy covariance stations were not found in any month.
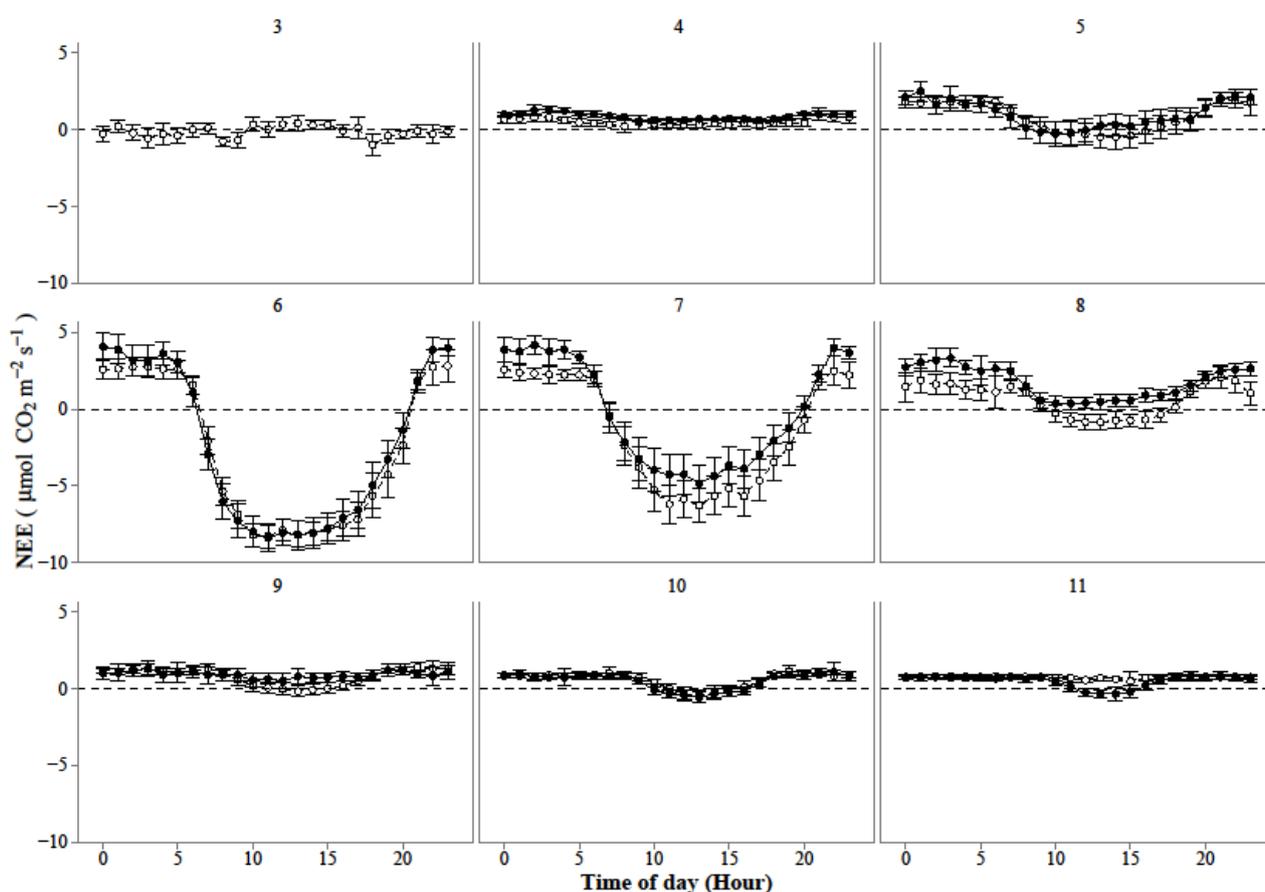

Figure 3. Diurnal patterns of monthly averaged net ecosystem CO_2 exchange (NEE) at the eddy covariate station A (empty dots) and station B (black dots) during the growing season and the end of the year of 2013. Black bars denote the 95% confidence intervals of the hour averages.

During the growing season, the daily NEE, R_{eco} and GPP showed distinct seasonal patterns at both fields (Figure 4), which indicates their responses to the combined effects of weather and vegetation growth. At the beginning of the growing season (early May), the daily GPP and R_{eco} of the two agroecosystems were low; and the daily NEE values at both sites were about 1 g C CO_2 m^{-2} d^{-1}, (release CO_2 to the atmosphere) (Figure 4). From the middle of May NEE started to grow up to the value of 2 g C CO_2 m^{-2} d^{-1}. The increase driver was R_{eco}; and GPP still about zero. Dynamics of all three variables was similar till the end of the May for both sites. With biomass development and temperature increase, GPP and R_{eco} at these two sites began to increase

gradually and reached their peak values at the mid of June. Simultaneously NEE decrease continued till the mid of June when it reached its negative peak and it retained approximately the same values until the end of June. NEE started to grow up in the beginning of July, reached its maximal summer values at the beginning of August and then slowly decreased till the end of the year. There are no differences between the two eddy covariance stations in daily NEE till the mid of June. Then there is the weekly "lag" of daily NEE values of tower B comparing with the ones of tower A. The differences in moving average values are significant. In the field B, the peak period of CO_2 uptake was from June,12 to June, 19 with a maximum value of NEE approaching -3.71 g C CO_2 m^{-2} d^{-1}, while that of the field A it was from June,19 to June, 27 with the maximum NEE -4.00 g C CO_2 m^{-2} d^{-1}. The peak coincided with high PAR and still high but decreasing SWC (Figure 2). The 7-day running average of daily NEE showed the transition from the CO_2 adsorption to the CO_2 release to atmosphere at July, 19 for the tower B and July, 26 for the tower A respectively. From the end of July to the beginning of September, the field A is characterized by low values of daily NEE compared to field B; the difference was about 1.0 g C CO_2 m^{-2} d^{-1}.
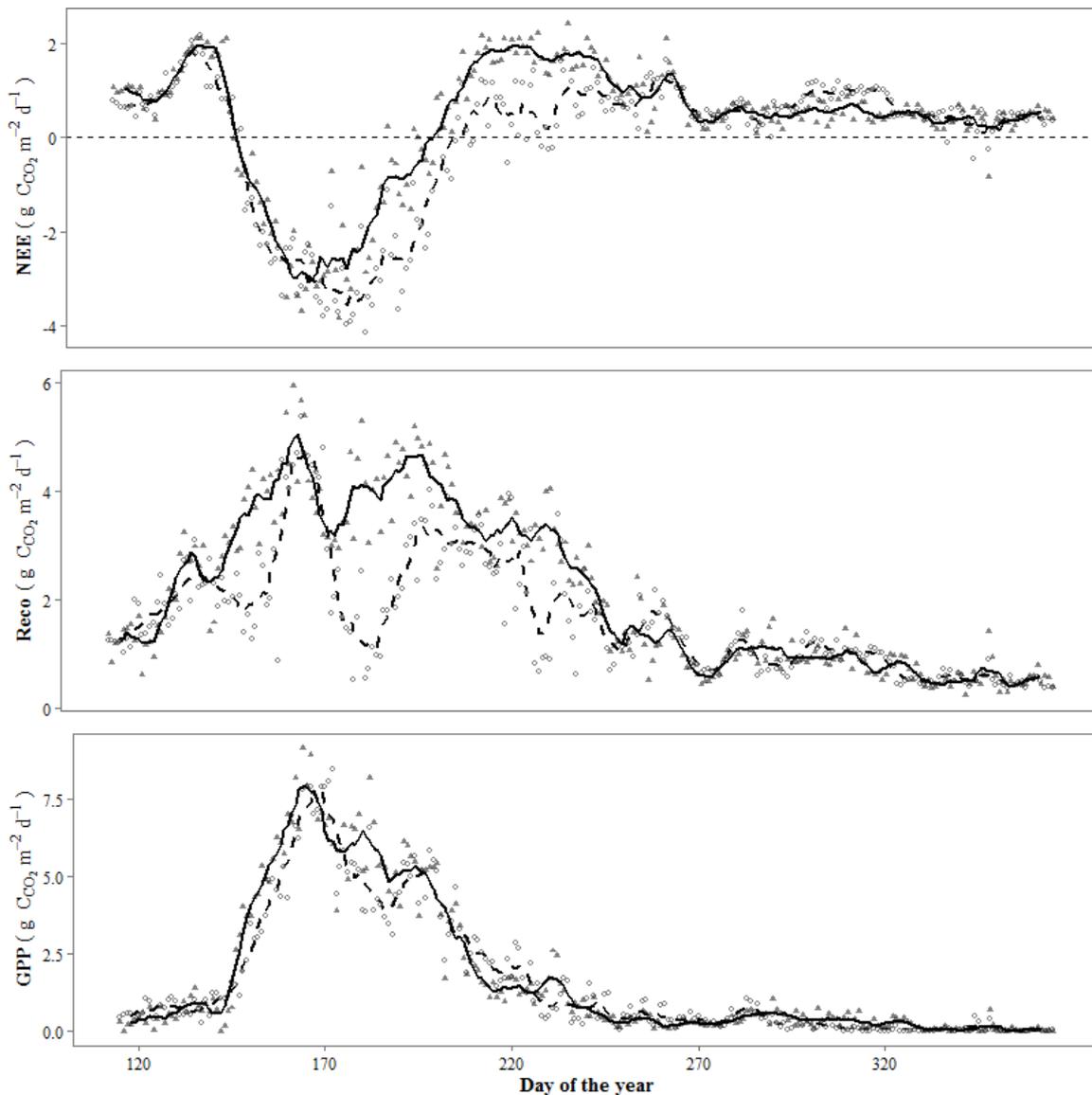

Figure 4. Seasonal variation in daily (a) NEE, (b) R_{eco} and (c) GPP in growing season and the end of 2013 at the EC station A (empty dots) and station B (gray triangles). Solid lines represent 7-day running mean values.

Although different kind of crops were planted on the fields A and B, GPP dynamics was quite similar for the both sites: after reaching the peak values at the mid of June, GPP decreased from about 7.5 to 2 g C CO_2 m^{-2} d^{-1} at the end of July. GPP pattern showed two local minimum on the gradually declined curve during this

period. The first minimum was related to the cold snap in mid-June and the second one could be explained by the low SWC values due to low precipitation during the period before second decade of July (Figure 2). The difference in crops harvesting time that was equal two weeks did not significantly influence the daily GPP patterns. This can be explained that at the end of July (the time of field B harvesting) the barley on the field A was at the stage of ripening grain. Values of daily GPP different from zero during August and the beginning of September could be explained by the photosynthetic activity of stubbles and some weeds remained after harvesting in the fields A and B. So, the crop type contribution to the agroecosystem CO_2 exchange in the fields A and B was negligible in 2013.
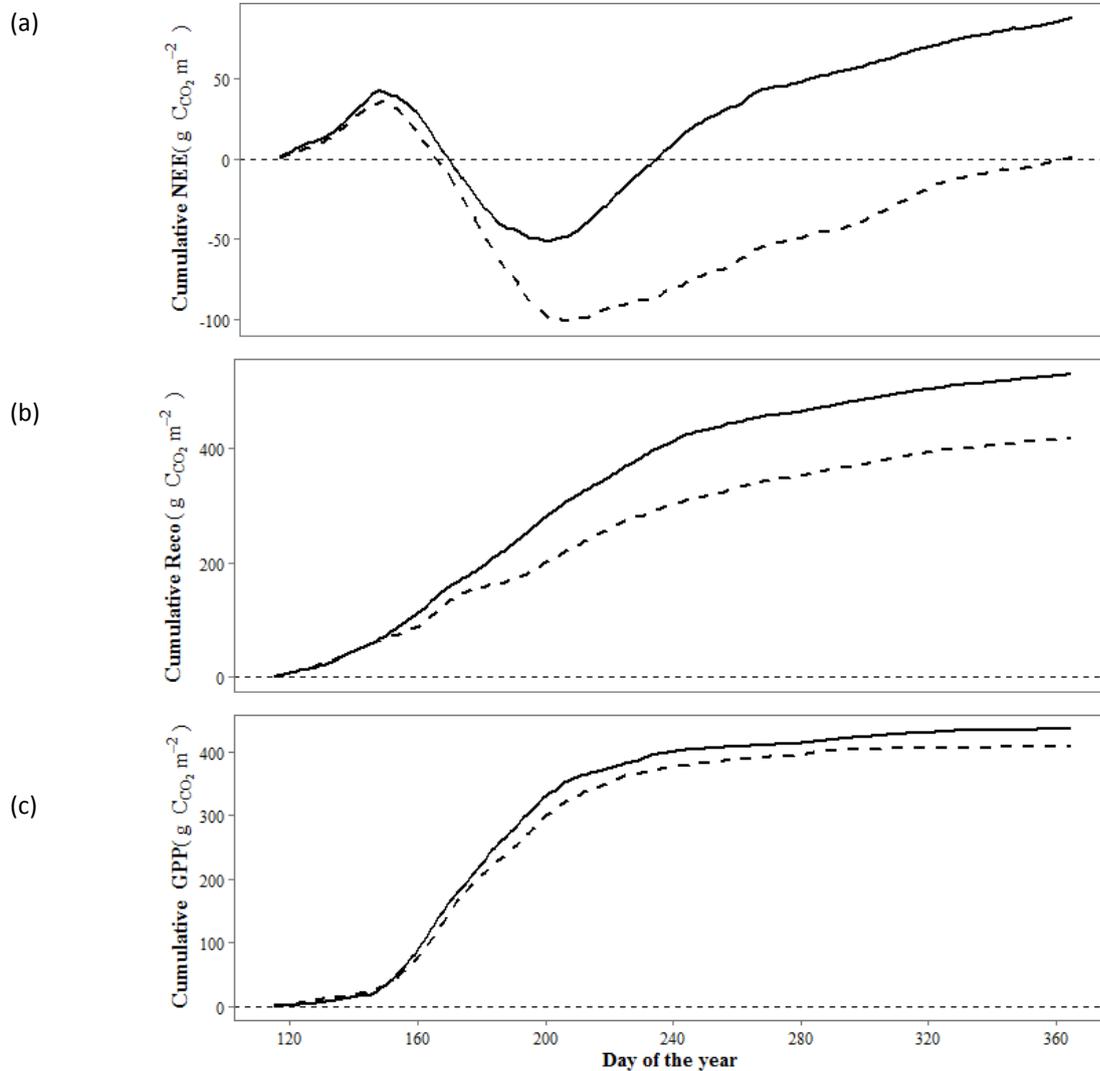

Figure 4. Cumulative flux for (a) NEE, (b) R_{eco} and (c) GPP at the EC station A (dashed line) and station B (solid line).

The daily R_{eco} patterns of the two agroecosystems were quite different during the period from the end of May to the beginning of September. Field B, where the vetch and oats were grown, showed the daily R_{eco} pattern similar to that one observed for GPP with the same periods of lowering. The third time R_{eco} declined at harvesting time, and then it slightly increased in August. The daily R_{eco} for the field A, where barley was planted, showed during the growing season three significant drops of R_{eco} values in comparison with one of the field A. It seems that these depressions are associated with the decreases of SWC. All this indicates that the micro biota of the field A with barley was less resistant to deterioration of environment parameters compared to the one of the field B with vetch and oats.

During September, October and November values of GPP, R_{eco} and NEE at the fields A and B were falling, apparently with the decrease of solar radiation and temperature. Each of these two agroecosystems showed the net CO_2 release.

During the growing season, the number of net sink days in the field A and field B were 67 and 53 days, resulting in respective cumulative NEE values of -15 and +75 gCm^{-2} (Figure 4). The cumulative NEE in the

agroecosystem on the field B was consistently higher than that in the field A throughout from the mid June to the end of the year. As results the uptake of CO_2 on the field A and the release of CO_2 on the field B were observed. Cumulative assimilation of CO_2 at the end of the growing season was 375 g C m^{-2} and 401 g C m^{-2} for A and B sites, respectively. So the difference in NEE was the consequence of higher respiration rates at the site B (about 413 g C m^{-2}) comparing to the site A (300 g C m^{-2}). For the entire growing season, the ratio of R_{eco} /GPP for the field A was 0.8, while it was 1.03 for the field B, confirming other results that the agroecosystem with barley (field A) were acting as net C sinks and agroecosystem with vetch and oats released CO_2 in the atmosphere. Summarizing data for the entire 2013 year: the agroecosystem with barley has the CO_2 NEE about zero, and the agroecosystem with vetch and oats released CO_2 at the atmosphere that needs additional research.

Conclusion

The study with two adjusted eddy covariance stations situated in Moscow (Russia) placed at the distance of 108 m on two adjusted field with different crops showed that the cumulative NEE in the agroecosystem with vetch and oats was consistently higher than that in the field with barley. Although there were different kind of crops, GPP dynamics was quite similar for the both sites. So the difference in NEE was the consequence of higher respiration rates in case of vetch and oats (about 413 g C m^{-2}) comparing to the barley site (300 g C m^{-2}). Diurnal patterns of NEE among different months were very similar in shape but varied slightly in amplitude. Average NEE was negative only in June and July. Summarizing data for the entire 2013 year: the agroecosystem with barley has the CO_2 NEE about zero, and the agroecosystem with vetch and oats released CO_2 at the atmosphere. The results have shown high daily and seasonal dynamic of CO_2 emission as the result of different and contrasted conditions: crop type, crop development stage, soil moisture and air temperature. Obtained unique for Russian agriculture data are very useful for land-use practices, environmental assessment, soil organic carbon dynamics analysis and agroecological evaluation, and for food C-footprint calculation.

Acknowledgements

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