Carbon balance assessment by eddy covariance method for agroecosystems with potato plants and oats & vetch mixture on sod-podzolic soils of Russia

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Abstract. The carbon balance for the agroecosystems with potato plants and oats & vetch mixture on sod-podzolic soils was evaluated using the eddy covariance approach. Absorption of carbon was recorded only during the growing season; maximum values were detected for all crops in July. The number of days during the vegetation period, when the carbon stocked in the fields with potatoes and oats & vetch mixture was about the same and accounted for 53-55 days. During this period, the increase in gross primary production (GPP) is well correlated with the crop yields. The curve of the gross primary productivity is closely linked to the phases of development of plants; for potatoes, this graph differs significantly for all phases. Form of oats & vetch mixture biomass curve shown linear increases. Carbon losses were observed for all the studied agroecosystems: for fields with an oats & vetch mixture they were 254 g C m⁻² y⁻¹, while for fields with potato plants they were 307 g C m⁻² y⁻¹. Values about 250-300 g C m⁻² per year may be considered as estimated values for the total carbon uptake for agroecosystems with potato plants and oats & vetch mixture on sod-podzolic soils.

1. Introduction

Most of the papers on the carbon balance assessment are devoted to forestry and natural ecosystems, whereas agroecosystems are not given sufficient attention to. However, in Central Russia, carbon losses in arable lands exceed 9 times the losses observed for natural forest ecosystems [1]. Therefore, the task is to monitor carbon losses for typical agroecosystems with different crops in different regions.

The application of the eddy covariance (EC) method for estimating the carbon balance in the agroecosystem is an example of the introduction of modern technologies into agricultural sciences. The EC technique is a statistical method to measure and calculate vertical turbulent fluxes of greenhouse gases within atmospheric boundary layers; today it is a widely used and accurate method [2]. This method can provide continuous, long-term flux information integrated into the ecosystem
scale [3]. Net ecosystem exchange of carbon (NEE) which expresses the potential of each agroecosystem to fix C or to release C by both autotrophic and heterotrophic respiration is particularly important when a comprehensive C balance for agro-ecosystem is performed. The traditional way of addressing net carbon exchange of an ecosystem over multiple years involves quantifying temporal changes in biomass and soil carbon. However, changes in soil organic matter become apparent after decades rather than years and thus soil sampling techniques do not allow to get insight changes in the short term. The eddy covariance technique has been used widely to determine NEE [3] because it is scale appropriate and provides a method to assess net CO₂ exchange at ecosystem level, it produces a direct measure of NEE, it is able to measure ecosystem CO₂ exchange across a spectrum of timescales and the area sampled by this technique (footprint) range from hundred meters to several kilometers.

The balance of organic matter in the soil consists of income and the loss of carbon. An equilibrium is established over the time in natural ecosystems in which the annual carbon input is equal to its output. Agroecosystems feature is that a portion of the carbon is taken out with harvest. Carbon status in agroecosystems depends on climate, land use and the level of agricultural technology.

The objective of this work was to evaluate the carbon balance for the agroecosystems with potato plants and oats & vetch mixture on sod-podzolic soils with eddy covariance approach.

2. Material and methods

The research has been carried out at the 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 and is situated in south taiga zone with Arable Sod-Podzoluvisols (Albeluvisols Umbric) that had around 1% of SOC, pH 5.4 (KCl) and NPK medium-enhanced contents in sandy loam topsoil. Crop rotation included winter wheat (Triticum sativum L.), barley (Hordeum vulgare L.), potato crop (Solanum tuberosum L.) and cereal-legume mixture (Vicia sativa L. and Avena sativa L.). Two fields of the same crop rotation were studied in 2013-2016 with potato plants and oats & vetch mixture.

Planting of crops was carried out in late April-early May, depending on the weather conditions. Oats & vetch mixture was harvested in July - early August. Potato harvesting was in early September.

![Figure 1](image-url)

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

The agroecosystem CO₂ flux seasonal monitoring was done by two eddy covariance stations located on fields A and B at the distance of 108 m (figure 1). The LI-COR instrumental equipment was the same for both stations. Agroecosystems CO₂ fluxes were measured using the EC system mounted 1.4 m above the soil surface for 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. It was assumed that temporal patterns of PAR and precipitation were similar for the both agroecosystems, because the two towers were situated side by side, 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. [4] and Webb–Pearman–Leuning (WPL) correction [5]. Also the dynamic metafile was used to take into account 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. [6]. Quality control tests for fluxes (1 to 9 system) were performed according to Foken [7]. Special algorithm was developed for complex footprints filtering because the fields are located close to each other. The data gap filling by Reichstein M, Falge E, Baldocchi D et al. [8] was used.

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

The difference between micrometeorological conditions on two fields was negligible during the same year. The correlation coefficients between the respective biometric data differed from 0.7 to 0.9. Thus, climatic features and crop type were main drivers of \( \text{CO}_2 \) flux dynamics on.

3. Results and discussion

Climatic conditions were different in 2013 and 2014: the spring started earlier in 2014; the summer of 2014 was warmer and drier. So, the year 2013 was less favorable for oats & vetch mixture than 2014 due to climatic conditions. As a result, the yield of oats & vetch mixture was two times higher in 2014 compared with 2013 (Table 1).

| Table 1. Carbon output (g C m\(^{-2}\) per year) with the yield within the agroecosystems during the year. |
|---------------------------------------------------------------|
| ![Table](image) |

Climatic conditions were quite close in 2015 and 2016; it is possible to consider those years as favorable for potato plants. The harvest of potatoes was approximately the same. The yields for potato plants and oats & vetch mixture in 2014 were close to average yields for the crop rotation.
The cumulative NEE in the agroecosystem with oats & vetch mixture in 2014 was consistently higher than that in 2013 throughout from the mid-February to the beginning of the growing season; after that the curve for 2014 was lower on the graph compared to the curve for 2013 (figure 2).

![Cumulative NEE, Reco, and GPP graphs](image)

**Figure 2.** Cumulative net ecosystem exchange of carbon (NEE), ecosystem’s respiration (Reco) and gross primary production (GPP) estimated by EC method for agroecosystems with oats & vetch mixture in 2014 (the dotted line) and 2013 (solid line).

The considerable uptake of CO$_2$ in 2014 comparing to 2013 was observed during the growing season. The agroecosystems with oats & vetch mixture released CO$_2$ into the atmosphere, but in 2014 the emission was much less. For potato plants the graph of cumulative NEE, Reco and GPP did not show differences in 2015 and 2016.

Absorption of carbon was recorded only during the growing season; maximum values were detected for all crops in July. The number of days during the vegetation period, when the carbon stocked in the fields with potatoes and oats & vetch mixture was about the same and accounted for 53-55 days. During this period, the increase in GPP is well correlated with the crop yields. The curve of gross primary productivity was closely linked to the phases of development of plants; for potatoes, this figure differed significantly for all phases. Form of oats & vetch mixture biomass increase curve was linear. However, in 2014, with more favorable conditions, the slope of the curve was steeper.

The ecosystem respiration for potato and oats & vetch mixture fields fluctuated from 420 to 580 g C m$^{-2}$ per year and was closely related to weather conditions. Carbon balance assessment is shown in Table 2. The carbon entered to ecosystem by seeding was only 9.5-17% from the carbon taken out with the yield.

The resulting difference in cumulative values of NEE of the CO$_2$ fluxes between the two agroecosystems during the two years was quite similar (Table 2). Carbon uptake (NEE negative values) was not registered for studied crops. All cases showed CO$_2$ emission. So, the soil and vegetation respiration during the year exceeded the carbon uptake by the photosynthesis process. The difference of 82 g C m$^{-2}$ per year in NEE for fields with oats & vetch mixture was related with the two
times difference in grass yields. NEE for potato plants was positive all the year; taking into consideration only the growing season, NEE for potato plants was about 0 g C m$^{-2}$.

Table 2. Carbon input and output (g C m$^{-2}$ per year) within the agroecosystems during the year.

|                      | Field B 2013 | Field A 2014 | Field B 2015 | Field A 2016 |
|----------------------|-------------|-------------|-------------|-------------|
| Input in soil with seeds | -22*        | -22         | -24         | -24         |
| Output with the yield  | 121         | 223         | 210         | 211         |
| NEE of the CO$_2$ fluxes | 145         | 63          | 118         | 123         |
| Total:                | **244**     | **264**     | **304**     | **310**     |

* Negative values correspond to carbon uptake as it is accepted in micrometeorology

Closing balance for the year showed that carbon losses were observed for all the studied agroecosystems: for fields with an oats & vetch mixture they were 254 g C m$^{-2}$ y$^{-1}$, while for fields with potato plants – 307 g C m$^{-2}$ y$^{-1}$. Values about 250-300 g C m$^{-2}$ per year may be considered as estimated values for the total carbon uptake for agroecosystems with potato plants and oats & vetch mixture on sod-podzolic soils.

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