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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том I   Ландшафты в XXI веке: анализ состояния, основные процессы и концепции исследований

В содружестве с Академией почвенного плодорodia Митчерлиха (МИТАК), Паулиненауз, Германия

Москва 2018
Main editors: Viktor G. Sychev and Lothar Mueller

NOVEL METHODS AND RESULTS OF
LANDSCAPE RESEARCH IN EUROPE, CENTRAL
ASIA AND SIBERIA

Monograph in 5 Volumes

Vol. I  Landscapes in the 21th Century: Status Analyses, Basic Processes and Research Concepts

With friendly support of the Mitscherlich Academy for Soil Fertility (MITAK), Paulinenaue, Germany

Moscow 2018

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Монография содержит информацию о самых современных методологиях и результатах в ландшафтных исследованиях. Она может быть использована в качестве руководства для исследователей, преподавателей, студентов и всех, кого интересует тема ландшафтной науки и смежных дисциплин. Монография является особо ценной информационной базой для лиц, принимающих решения на различных уровнях, от местных до международных органов по принятию решений. Приведенная в монографии информация представляет собой современный уровень ландшафтной науки в очень краткой форме.

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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ISBN 978-5-9238-0246-7
ISBN 978-5-9238-0247-4 (Том 1)
DOI 10.25680/7920.2018.82.47.001

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ABSTRACT. To investigate the complex interactions between terrestrial ecosystems and the atmosphere, the Eddy Covariance (EC) method is commonly used nowadays. Its main objective is to estimate the net carbon dioxide (CO\(_2\)) and water (H\(_2\)O) exchange between e.g. forest ecosystem and the atmosphere. The study site is located in coniferous forest stand in Tuczno (Poland) planted on a former cropland area, which is mainly composed with currently 63-year-old Scots pine (Pinus sylvestris L.) trees (afforested area).

The EC measurements of the Net Ecosystem Production (NEP) and latent heat (LE) have been carried out continuously since January 2008. The results of the EC measurements depict that the Tuczno forest can be considered an effective carbon sink. The studied ecosystem sequestered on average about 645 g C-CO\(_2\)·m\(^{-2}\)·y\(^{-1}\) (2008 – 2013). Furthermore, total annual evapotranspiration rates (E) were calculated from LE fluxes for each year, and then the 6-year average value was estimated and equals 422 mm. Water use efficiency run over the measuring period suggests a decline in productivity in investigated forest in the coming years despite increased rainfall.

Резюме. Для исследования сложных взаимодействий между экосистемами суши и атмосферой в настоящее время широко используется метод вихревой Ковариации (ЕС). Его основная цель заключается в оценке чистого обмена диоксида углерода (CO\(_2\)) и воды (H\(_2\)O) между, например, лесной экосистемой и атмосферой. Участок исследования расположен в хвойном лесу в Тучно (Польша), посаженном на бывших пахотных угодьях (облесённая территория), который в основном состоит из 63-летней сосны обыкновенной (Pinus sylvestris L.).

С января 2008 года ЕС непрерывно проводит измерения в области чистого производства в экосистемах (NEP) и скрытого тепла (LE). Результаты измерений ЕС указывают на то, что лес в Тучне можно считать эффективным поглотителем углекислого газа. Исследуемая экосистема скумбрировала в среднем около 645 г C-CO\(_2\)·m\(^{-2}\)·год\(^{-1}\) (2008 – 2013). Кроме того, общие годовые показатели эвапотранспирации (E) рассчитывались на основе потоков LE за каждый год, а затем оценивалось среднее значение за 6 лет, равное 422 мм. Показатель эффективности потребления воды (WUE) в период измерений свидетельствует о снижении продуктивности исследуемых лесов в ближайшие годы, несмотря на увеличение количества осадков.

KEYWORDS: scots pine, eddy covariance, net ecosystem productivity, evapotranspiration, water use efficiency

Ключевые слова: сосна сосновая, вихревая ковариация, продуктивность чистой экосистемы, эвапотранспирация, эффективность использования воды

INTRODUCTION

In recent years several techniques are applied for various GHGs exchange measurements in different ecosystems [1], [2]. Among them, the eddy covariance (EC) method became the most widely used all over the world. The final product of direct EC measurements is the net value of fluxes (e.g. CO\(_2\), H\(_2\)O or CH\(_4\)) which are exchanged between investigated ecosystem and the atmosphere. Net flux means that, it is a balance between the quantity of interest (energy or matter) which was moved up and down by rotating eddies at given time. For example, the carbon balance of each ecosystem is determined by both: carbon uptake (photosynthesis- downward CO\(_2\) movement) and release (respiration - upward CO\(_2\) movement). When carbon dioxide (CO\(_2\)) absorption surpass its loss, then such ecosystem, e.g. forest, is considered a
CO₂ sink and therefore the overall C stock there is increasing. Although, on the other hand, if C losses are bigger than gains it is called a carbon source what results in C stock decrease [3]. Generally, the part of CO₂ exchange flux connected to CO₂ uptake via photosynthesis is called Gross Primary Production (GEP), while the other related to overall CO₂ emission is referred as ecosystem respiration (Reco). The forest ecosystem is one of the biggest C stocks worldwide, and thus any changes in forests’ carbon balance can affect the amount of CO₂ in which stays in the atmosphere [4]. The recognition of vegetation growth dependence on environmental conditions and their common correlations is crucial for environmental researchers. Several issues were already investigated and described in literature i.e.: the relationship between temperature + precipitation and the annual ecosystem production or the correlation between stomatal transpiration (water vapour released to the atmosphere) and CO₂ assimilation (carbon uptake from the atmosphere) [5]. The intensity of processes listed above are determined by several environmental factors such as: light quality/quantity, temperature, water content [6], [7] and also biochemical factors specifically growing season length [8].

The main aim of this paper is to present the results of EC measurements from the Tuczno forest site located in Poland, regarding carbon and water fluxes as well as so called water use efficiency, during the period 2008-2013.

MATERIAL AND METHODS

Site description

The study site is located in the Tuczno Forest District (North-West of Poland, 53° 11’ N, 16° 5’ E). The dominating tree species there is a Scots pine (Pinus sylvestris L. - 54-year-old year in 2008) with an admixture of birch (Betula pendula L.), which cover 99% and 1% respectively. Such tree species composition is typical for a vast part of Polish lowland forests, where about-60-year-old Scots pine afforestation is prevailing. The average tree diameter at the breast height (DBH) was 21cm and the average tree height was about 20m at the beginning of this study. The growing season was estimated to be 232 days and ranged from 216 to 251 days (over the 6 years of the study), which is consistent with the report by [9], which shows that average growing season length in this region is 220 days using similar methodology [6].

Eddy Covariance and micrometeorological measurements

The EC system was installed at a 4-meter tall mast, which was mounted on a top of 34-meter scaffold tower. The measuring system consists of two main instruments: an open path infra-red analyser IRGA Li-7500 (Li-Core, Lincoln, NE, USA) and a three-dimensional asymmetric sonic anemometer CSAT3 (Campbell Scientific, Logan, UT, USA). Both instruments operated at a 20Hz sampling rate. EC system was used for the measurements of half-hourly averaged turbulent fluxes of CO₂ (Fc) and water vapour (E). Moreover, the Photosynthetic Photon Flux Density (PPFD) was measured by Quantum sensor (SKP 215- Skye, UK). The basic meteorological parameters such as: wind speed and direction, precipitation (without snow), barometric pressure, air temperature and relative humidity were measured by an automatic weather transmitter WXT510 (Vaisala, Helsinki, Finland). The weather station has been operating since August 2009. All sensors were connected to a data-logger CR5000 (Campbell Scientific, Logan, UT, USA).

RESULTS

METEOROLOGICAL BACKGROUND

The basic meteorological elements such as annual mean air temperatures (Ta) and precipitation (P) totals measured at the top of the EC tower were used to describe thermal and wetness conditions during measuring period. In case to give a broader climatic context, this data were referred to the 30-year data set (1983–2013) of daily values recorded at the Piła meteorological station.

The mean annual value of Ta ranged from 8.49 °C in 2012 to 9.51 °C in 2008 with the 6-year mean value being 8.65 ± 0.67 °C (±standard deviation). Furthermore, except for 2009, the values of P were also higher than the 30-year mean value, while in 2012 it exceeded the 6-year mean (624 ± 89 mm) substantially. Thus 2008–2013 was represented by not only warmer but also mostly wetter years than the 30-year averages.

NET ECOSYSTEM PRODUCTION (NEP) AND EVAPOTRANSPIRATION (E) FLUXES

The net exchange of CO₂ between the atmosphere and the ecosystem (NEP - positive values mean gain by the ecosystem) was determined as the sum of Fe and the CO₂ storage flux (Sc), which is the rate of
change of CO₂ storage in the air layer below the EC sensors per unit ground area. Final values of monthly NEP (Fig. 2a) and GEP totals were obtained after a gap filling of missing half-hour flux data as well those rejected during quality checks, e.g.: after discarding nighttime fluxes when friction velocity (u*) was less than 0.2 m s⁻¹ (calculated friction velocity threshold using the moving window procedure described by Barr [10]). Monthly water fluxes were calculated on the basis of latent heat (LE) measurements and given as evapotranspiration totals (E) (Fig. 2b).

Figure 2ab shows the variation in the annual cycles of NEP and E (monthly totals). Differences in NEP between years were relatively big, especially in spring months (March – May). Low values were related to the late onset of vegetation growth due to low temperatures. This was particularly noticeable in 2013 where contrary to other years monthly NEP totals were negative (higher CO₂ emission than absorption rates) until April. On the other hand, early spring promotes increased annual CO₂ assimilation as recorded for 2008. This is cause evergreen trees can react to increasing temperature very quickly, but in case of unfavourable conditions at the beginning of growing season, like in 2013, NEP value switches from winter negative to positive values later. Not only temperature but also precipitation drives CO₂ sequestration. Regardless of the fact that rain events supply the ecosystem with water, which in reasonable doses stimulate plants growth, when they are long and happen frequently it also decreases the amount of incoming solar radiation (cloudiness). We thus hypothesise that unusually high precipitation in the growing season 2012 most likely hampered photosynthesis on one hand and probably enhanced respiration on the other, which resulted in lowering the NEP values in the warm part of the year (Fig. 2a). In general, the highest annual NEP total was recorded in 2009 (765 g C-CO₂·m⁻²) and the lowest in 2012 (494 g C-CO₂·m⁻²) and 2013 (520 g C-CO₂·m⁻² – see Table 1). What is

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Tab. 1. Annual means of the air temperature and, precipitation, NEP and evapotranspiration totals in Tuczno forest during 2008-2013 measuring period.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Air temperature (Ta) (°C)</th>
<th>Precipitation (P) (mm)</th>
<th>NEP (g C-CO₂·m⁻²·y⁻¹)</th>
<th>Evapotranspiration (E) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>9.51</td>
<td>572</td>
<td>747</td>
<td>379</td>
</tr>
<tr>
<td>2009</td>
<td>8.69</td>
<td>512</td>
<td>765</td>
<td>431</td>
</tr>
<tr>
<td>2010</td>
<td>7.40</td>
<td>760</td>
<td>645</td>
<td>337</td>
</tr>
<tr>
<td>2011</td>
<td>9.24</td>
<td>561</td>
<td>699</td>
<td>395</td>
</tr>
<tr>
<td>2012</td>
<td>8.49</td>
<td>725</td>
<td>494</td>
<td>494</td>
</tr>
<tr>
<td>2013</td>
<td>8.57</td>
<td>613</td>
<td>520</td>
<td>496</td>
</tr>
<tr>
<td>Avg</td>
<td>8.65</td>
<td>624</td>
<td>645</td>
<td>422</td>
</tr>
<tr>
<td>SD</td>
<td>0.67</td>
<td>89</td>
<td>105</td>
<td>58.5</td>
</tr>
</tbody>
</table>

30-year 8.06 553
interesting. Tuczno forest appeared to be a relatively high productive ecosystem in comparison with other European pine forests [6].

As noticeable from the comparison of panel a) and b) in Figure 2, there was no clear link between the NEP and E fluxes patterns. For example: in relatively productive year (2010) the evapotranspiration in summer months was low, while in the least productive (2012) it was one of the highest.

Moreover, the peak in monthly NEP values did not occur at the same time as the peak in E. It can be attributed to the “economical water management” of the Scots pine as well as the impact of wetness (soil moisture) on the ecosystem respiration - under similar thermal conditions higher water content in the soil increases respiration, lowering NEP value at the same time. To further investigate the relationship between carbon and water fluxes in this particular forest ecosystem, it was decided to use water use efficiency (WUE) as a better description of photosynthesis and evapotranspiration processes coupling.

**WATER USE EFFICIENCY (WUE) TREND OVER MEASURING PERIOD**

Water use efficiency (WUE) trend can be used as a measure of the ecosystem productivity in relation to the amount of water used under changing weather and biochemical conditions, which determine processes of photosynthesis, respiration and evapotranspiration [11]. Therefore, it serves as an important indicator of ecosystem functioning. Respective WUE values were calculated as the ratio of daily daytime (PPFD > 200 μmol m⁻² s⁻¹) GEP to E totals: WUE = GEP/E [5]. The WUE time series in the following years was presented on Figure 2c. The general pattern is that, in the cold months (October - March) the WUE values were much more scattered than in the warm part of the year. During such period interpretation of the results is thus very difficult. It comes from the fact that from late autumn to the early spring both NEP and E fluxes are very small and therefore even slight changes in their values can lead to unreasonable WUE values. For this reason, it is suggested to assess the condition of the ecosystem on the basis of WUE values in the growing period only. During the entire measuring period 2008-2013, WUE
values were about 5 g kg$^{-1}$ most of the time (5 g of C sequestered by each kg of water vapour released to the atmosphere), with some seasonal trend: higher values at the beginning and the end of growing season, and the lowest values in July and August (Fig 2c, red line). This pattern was valid until 2012, when WUE decreased slightly to about 4 g kg$^{-1}$. It is difficult to clearly identify the cause of such a change, except for the hypothesis of precipitation influence given above. Taking all into consideration, it seems that investigated ecosystem could not increase its productivity (slightly downward NEP trend in subsequent years) even with more rainfall and higher temperatures (warm and wet period 2012 - 2013). This may be a sign, that the most intensive growth period for this forest ecosystem is coming to an end.

CONCLUSIONS
1. The Tuczno Scots pine forest was a very productive European evergreen forest, sequestering on average 645 g C m$^{-2}$ y$^{-1}$. The annual net CO$_2$ exchange over 6-year period was sensitive to spring time wetness and thermal conditions.
2. NEP and E fluxes were not clearly linked in Tuczno forest, suggesting that in this ecosystem water management is either less coupled with carbon sequestration than e.g. in cropland ecosystems or it is a sign of annual growth slow down with aging.

REFERENCES