CO_2 flux measurement in four different ecosystems

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Abstract: The ability of four different ecosystems (Norway spruce forest, mountain grassland, wetland and cropland) to bind the atmospheric carbon was estimated using eddy covariance technique. Net ecosystem production resulted from the potential of ecosystems to bind carbon and from their specific growth conditions. The growing season of the spruce forest is the longest in comparison to the other ecosystems, which results in its high productivity potential. Its activity starts early in the spring, when the soil is still covered with snow and the buds do not germinate yet. The growing season of mountain grassland is restricted to the snow cover. Right after the snow melt (late spring), the production starts to grow rapidly. The production period is relatively short, in the late summer carbon losses already prevail over assimilation. The wetland production is distributed relatively uniformly throughout the vegetation season. Carbon losses are significantly enhanced by methane efflux. Evaluation of carbon losses gives 98% GPP (CO_2 and CH_4) or 74% GPP (CO_2 only). The shape of the cropland site production course is similar to the grassland, however its total respiration losses are smaller (73% at cropland in comparison to 99.5% at grassland). The harvest is a specific feature of the cropland – the grown biomass is taken away in the late summer and the carbon thus bounded is released during food chain utilisation, combusting, and decay.

Key words: eddy covariance, net ecosystem production, forest, grassland, wetland, cropland

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1. Introduction

The changing atmospheric conditions leading to the global climatic change require proper research of carbon cycles. The metabolism of plants, consisting mainly of CO_2 *(Linder et al., 2004)*, is the topic of many impact studies on international or local basis and in various research levels (cell to ecosystem processes) *(Bolin et al., 2000; Linder et al., 2004).*

Various fluxnet networks have been established to study and quantify the CO_2 fluxes between various vegetation types and the atmosphere *(Aubinet et al., 2005; Byrne et al., 2004).*

The Czech Republic is located in the Middle Europe with temperate inland climate. Typical ecosystems for this climate there are coniferous and mixed forests, grasslands and agriculture fields.

Forests play an important role in the global biogeochemical cycles. Reliable estimates of carbon sequestration in forests are crucial, since terrestrial carbon sinks may temporarily postpone the rise in the atmospheric CO_2 concentration. Forests represent the largest terrestrial carbon stock, and forest soils also contain approximately 39% of the global soil carbon *(Bolin et al., 2000).* In the Czech Republic forests cover 33.4% of its area and Norway spruce forest represents 55.2% of these forests (*Ministry of Agriculture, 1997*).

Utilised Agricultural Area (UAA) represents 54.3% of the total area of the Czech Republic. Cropland (i.e., lands used for the production of arable crops) represents approximately 75.7% of UAA (*European Commission, 2002*). Therefore, cropland is a significant ecosystem for CO_2 budget estimation.

Mountain grasslands are an alternative ecosystem to mountain forests. Besides their natural aspect, grasslands have a pure agricultural destination as a primary food source for wild herbivores and domesticated ruminants. Actually, grasslands being a mixture of different grass species, legumes and herbs may act as carbon sinks, erosion preventives, bird directive areas, habitat for small animals and nitrogen fixation *(Carlier et al., 2004).*

Wetland is not a typical ecosystem for the Czech Republic, but we have included it because of its specific features, expecting special behaviour and results. Moreover, global wetlands emit carbon also in a form of methane, and they are considered to be the largest single source of atmospheric methane even when considering all anthropogenic emissions (*Byrne, 2004*).

Net carbon budget of ecosystems is a fine balance between processes of carbon acquisition (photosynthesis, tree and plant growth, forest ageing, carbon accumulation in soils), and processes of carbon release (respiration of living biomass, tree mortality, microbial decomposition of litter, oxidation of soil carbon, degradation and disturbance) (*Malhi et al., 1999*) and expresses the ability of ecosystems to bind atmospheric carbon. These processes operate on a variety of time scales and are influenced by a number of climatic and environmental variables, such as radiation, temperature, moisture availability and frequency of disturbance; also there are large differences between various types of ecosystems.

We have compared the carbon sink in four ecosystems (forest, grassland, cropland and wetland) by eddy covariance measurements in 2005.

2. Materials and methods

2.1. Sites

Our study involves CO_2 flux measurement in four different ecosystem types in the year 2005 (Table 1).

The forest ecosystem is represented by the Norway spruce stand at the Experimental Ecological Study Site (EESS) Bílý Kříž in Moravian-Silesian Beskydy Mountains, situated on the slope (13°) with SSW orientation. Trees are 29 years old.

The mountain grassland at the same locality is situated on the mild slope. It is a mixture of different unmowed grass species, mainly *Holcus*

Table 1. Characteristics of the sites

	Site name	**Position**	**Elevation above sea level**	**Mean annual temperature**	**Annual precipitation**
forest + grassland	Bílý Kříž	N 49°30' E 18°32'	800-900 m	5.5°C	1000 -1400 mm
cropland	Žabčice	N 49°01' E 16°36'	179 m	9.2°C	480 mm
wetland	Mokré Louky	N 49°01' E 14°46'	426 m	7.4°C	620 mm

molis, Nardus stricta, Deschampsia cespitosa, Avenella flexuosa, Juncus effusus and *Carex supina.*

The cropland is located on the flat lowland nearby Žabčice, South Moravia. It is the experimental site of agricultural research and it is composed of small fields with various crops.

The wetland is situated near Rožmberk Lake nearby Třeboň, South Bohemia. This site is characteristic by its temperature and air humidity variations and by strong releasing of carbon in the form of methane as the product of anaerobic processes, as well as in the form of CO_2. Vegetation there is composed of *Phragmites australis, Salix spp., Carex spp., Phalaris arundinacea.*

2.2. Methods of measurement

Standard eddy covariance technique was used for measuring CO_2 fluxes (InsituFlux, Sweden and UOE Edinburgh) comprising of research anemometer (Gill, U.K.) and infrared gas analyser (Li-cor, U.S.A.) operating at a 20 Hz sampling rate.

Supporting microclimatic measurements include wind speed (AN1 Delta-T Devices, U.K.), temperature and humidity (RH1 Delta-T Devices, U.K.) profiles, measurement of incoming PAR (BPW 21, Telefunken, Germany), net radiation (CNR1, Kipp-Zonen, Holland), profiles of soil temperature (PT 1000, Hit, CZ) and soil humidity (Theta Probe, Delta-T Devices, U.K.). Profile CO_2 concentration measurements are carried out in the forest using IRGA Li-820 (Li-cor, U.S.A.).

2.3. Data post-processing

Quality checking

Data (raw data, as well as half hourly means) were subject to various analyses in order to evaluate their quality according to the standard Euroflux methodology (*Aubinet et al., 2000; Falge et al., 2001*). Crucial is the evaluation of good turbulence conditions for the measurement.

Gap filling and data correction

Missing and bad quality CO_2 flux data (net ecosystem exchange – NEE) were substituted by means of derived algorithms based on the measured climatological variables (I – incoming PPFD, Ta – air temperature, Ts – temperature of the soil surface).

$$NEE = \underbrace{\frac{\alpha \cdot I + A - \sqrt{(\alpha \cdot I + A)^2 - 4 \cdot \alpha \cdot A \cdot k \cdot I}}{2k}}_{[1]} +$$

$$+ \underbrace{\frac{R_{10_a}}{Q_{10_a}^{\left(\frac{10-Ta}{10}\right)}} + \frac{R_{10_{sa}}}{Q_{10_{sa}}^{\left(\frac{10-Ts}{10}\right)}} + \frac{R_{10_{sh}}}{Q_{10_{sh}}^{\left(\frac{10-Ts}{10}\right)}}}_{[2]},$$

with parameters: α – photochemical efficiency of assimilation, A – maximal gross primary production, k – convexity, R_{10} – respiration rate, Q_{10} – respiration parameter with indexes: c – canopy, s – soil, a – autotrophic, h – heterotrophic.

Photochemical efficiency (α) and maximal GPP (A) were calculated from the dependence of GPP on measured PPFD (photosynthetic photon flux density) using software program Photosyn Assistant 1.1. The response of GPP to incoming PPFD (I) is modelled by a non-rectangular hyperbola, where the initial slope is the photochemical efficiency (α), the light saturated maximum (A) is the upper asymptote [(Prioul – Chartier equation [1], (*Prioul and Chartier, 1977*)]. An additional parameter (k, convexity) is required to describe the progressive rate of bending between the linear gradient and the maximum value.

Respiration rate and respiration parameters were calculated from the dependence of measured CO_2 efflux on temperature of the respiring part of the ecosystem using Raich-Schlesinger equation [2] (*Raich and Schlesinger, 1992*). In differentiated ecosystems such as the forest, the efflux calculation is divided into soil heterotrophic, soil autotrophic, and canopy respiration.

3. Results and discussion

3.1. Gap filling and data correction

The net ecosystem exchange (NEE) is a sum of different physiological components (according *Aubinet et al., 2000*) acting in opposite directions: the influx of CO_2 in vegetation photosynthesis, and the combined effluxes of CO_2 resulting from autotrophic and heterotrophic respiration.

An example of gap filling and data correction (Fig. 1) shows the measured and modelled daily course of NEE. The highest differences between measured and modelled data occurred during the night-time periods.

During stable night-time conditions, an underestimation of CO_2 fluxes measured with the eddy covariance method frequently occurs. Non-turbulent transport processes usually cause the storage of CO_2 in the air space below the measurement height and consequent drainage by advection (*Aubinet et al., 2005*). Advection, however, can cause underestimation, as well as overestimation of the night-time CO_2 fluxes.

The night-time fluxes correction is thus necessary for the right flux evaluation and it is performed on the basis of ecosystem CO_2 efflux models and correct night-time CO_2 flux measurements obtained during windy periods with a suitable friction velocity.

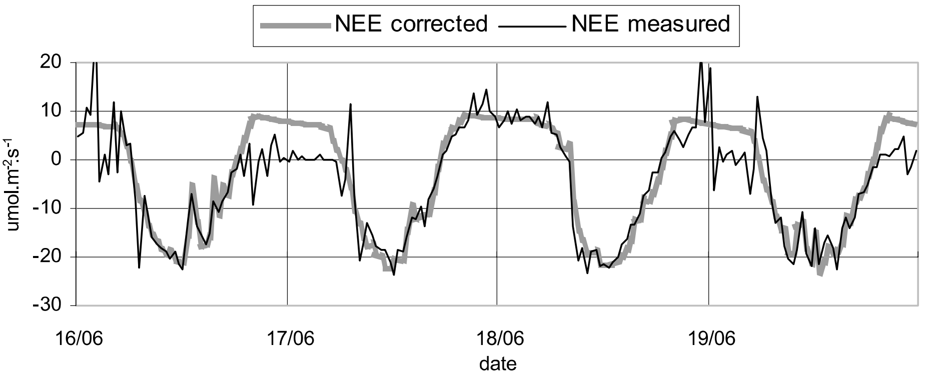

Fig. 1. Example of NEE data gap filling and data correction at wetland, 16^{th}-19^{th} June 2005.

3.2. Gross primary production – light response curve

The light response curve was modelled for selected clear and sunny days for each ecosystem (Fig. 2) to estimate differences of assimilation efficiency. The highest value of α for grassland (Table 2) represents the short and fast start of photosynthesis, when PPFD increases. At the cropland the start of production is slow in comparison with other ecosystems, but the production is not limited by its maximum.

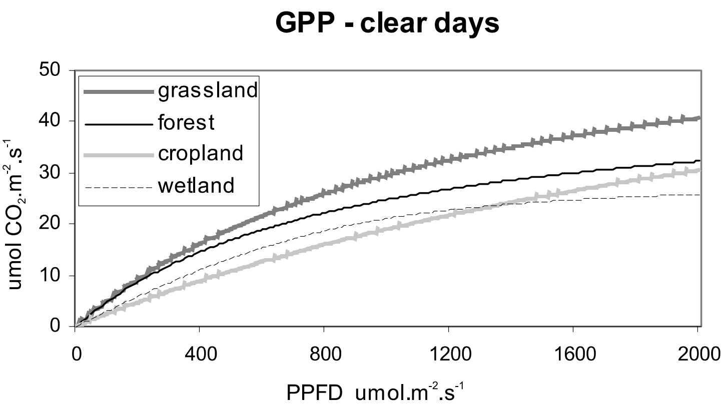

Fig. 2. Gross primary production – light response curve for clear days. PPFD – photosynthetic photon flux density.

Table 2. Parameters of light response curve of gross primary production: alfa – photochemical efficiency, k – convexity, GPPmax – maximal gross primary production

	alfa	k	GPPmax umol $CO_2.m^{-2}.s^{-1}$
forest	0,0402	1,76.10-4	46,1
grassland	0.0538	9,21.10-6	65,5
cropland	0.0253	1,32.10-4	76,9
wetland	0.0307	0,831	29,0

3.3. Net ecosystem production evaluation

Ecosystems differ significantly in net ecosystem production (Fig. 3, Table 3). The spruce forest has the longest growing season in comparison to the other ecosystems, which results in its high productivity potential. Its activity starts early in the spring, when the soil is still covered with snow and the buds do not germinate yet. Such activity is mainly caused by the convenient temperature conditions of the crown layer. The forest in EESS Bílý Kříž is a young stand with high production.

Table 3. Net ecosystem production in the year 2005. NEP – net ecosystem production, GPP – gross primary production, Re – respiration, Re/GPP – respiration-production ratio

	NEP kgC.ha^{-1}	GPP kgC.ha^{-1}	Re kgC.ha^{-1}	Re/GPP %
forest	-5 000	-19 300	14 300	74
grassland	-20	-16 340	16 320	99.5
cropland	-4 600	-17 200	12 600	73
wetland	-4 300	-16 600	12 300	74
wetland with methan	-300	-16 600	16 300	98

On the contrary, the growing season of mountain grassland is restricted to the snow cover. Right after the snow melts (late spring), the production starts to increase rapidly. The production period is relatively short, in the late summer carbon losses already prevail over assimilation. Grassland is an old steady ecosystem, thus the assimilation and respiration are balanced – respiration-production ratio is 99.5%.

The growing season of cropland starts earlier than at grassland, because cropland is located at lowland in South Moravia, which is known as the warmest region in the Czech Republic (Table 1). This ecosystem also produces a lot of biomass (corn, sunflowers) in a short time and it results in high CO_2 flux into the ecosystem. The shape of the cropland site production course is similar to the grassland, however, its total respiration losses are smaller (73% at cropland in comparison to 99.5% at grassland). Harvest is a specific feature of the cropland – the grown biomass is taken away in the late summer and the carbon thus bounded is released during food chain utilisation, combusting and decay. Several studies *(Smith et al. 2004; Anthoni et al., 2004)* maintain that agricultural areas showed moderate net CO_2 uptake, but with the harvest taken into account they were a carbon source.

The wetland production is distributed relatively uniformly throughout

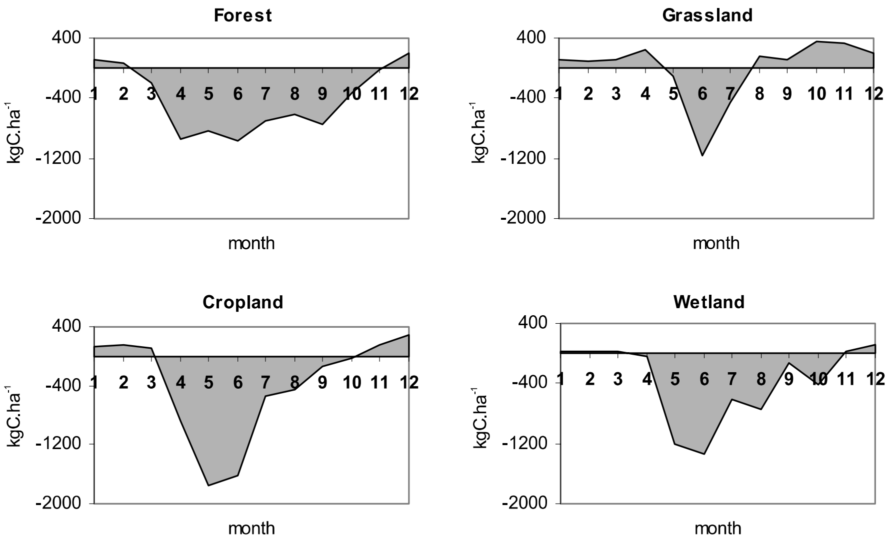

Fig. 3. Net ecosystem production in the year 2005.

the vegetation season. Carbon losses are significantly enhanced by methane efflux in wetland ecosystems. Evaluation of carbon losses gives 98% GPP (CO_2 and CH_4) or 74% GPP (CO_2 only). Losses of carbon in the form of methane were guessed, because the methane efflux measurement was not implemented directly in the footprint of the eddy flux measurement.

4. Conclusions

The CO_2 flux (NEE) was measured using eddy covariance technique for four different ecosystems. Data were checked for their quality, and gaps filled using the model derived from measured climatological data (PAR, temperatures). Gross primary production and respiration losses were calculated.

Forest, grassland, cropland, and wetland ecosystems differ in their net ecosystem productions. The forest ecosystem has got the longest production season in comparison to other ecosystems, and it resulted in the biggest sink of CO_2. The carbon uptake from this analysis was 5 $t.C.ha^{-1}.yr^{-1}$. This value is within the range of 2–7 t.C.ha^{-1}.yr^{-1} reported recently for several techniques (*Lindner et al., 2004; Papale and Valentini, 2003*). Evaluation of respiration losses is small in the forest (74%), carbon production and losses in the grassland are nearly the same. Evaluation of carbon losses in the wetland gives 98% GPP (CO_2 and CH_4) or 74% GPP (CO_2 only). In the cropland, respiration losses are small as well (73%), but this value does not include harvested carbon.

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