Rožnovský, J., Litschmann, T. (ed): „Bioklimatologické aspekty hodnocení procesů v krajině“,

Mikulov 9. – 11.9.2008, ISBN 978-80-86690-55-1

ATMOSPHERIC FACTORS INFLUENCING NET ECOSYSTEM PRODUCTION OF NORWAY SPRUCE FOREST IN BESKYDY MOUNTAINS

Klára Taufarová(1, 2), Kateřina Havránková(1), Radek Czerný(1), Dalibor Janouš(1)

(1) Laboratory of Plants Ecological Physiology, Institute of Systems Biology and Ecology, AS CR, Poříčí 3b, 603 00 Brno, Czech Republic. Tel: 00420 543 211 1560,
E-mail:klara@usbe.cas.cz
(2) Mendel University of Agriculture and Forestry in Brno, Faculty of Forestry and Wood Technology

Abstract:

Net ecosystem production results from the potential of ecosystem to sequestrate atmospheric carbon and from its actual growth conditions. Daily net ecosystem production values of Norway spruce forest at Experimental Ecological Research Site Bílý Kříž in Beskydy Mountains were estimated using eddy covariance technique.

Norway spruce forest uptakes CO_2 from the atmosphere during production season. During production seasons 2005-2007 mean daily net ecosystem production was 22 kg C ha^{-1}, and mean production season duration was 240 days.

During production seasons there occurred days with respiration higher than assimilation, thus the forest was source of the atmospheric carbon. There were 45, 68 and 39 days in production seasons 2005, 2006 and 2007, respectively, when the forest was carbon source. It was caused by 1) significant decrease of air temperature and low intensity of PAR at the beginning and end of production seasons; 2) low radiation in overcast days and 3) long dry period with high intensity of direct radiation and high air temperature during production seasons.

Keywords: daily net ecosystem production, eddy kovariance, atmospheric factors

Introduction

Ecosystems are considered an important regulator of global climate. Thus, for predicting climate change it is important to know if ecosystems will be a sink of CO_2 or not (Reichstein et al. 2002).

The objective of this work is to estimate days, when Norway spruce stand was source of CO_2 and to focus on atmospheric factors, which caused inversion from sink to source. Eddy covariance method, which is able to measure carbon fluxes between ecosystems and atmosphere each day continuously through the whole year, was used.

Materials and methods

<u>Experimental site</u>

The Experimental Ecological Study Site (EESS) Bílý Kříž is situated in Moravian-Silesian Beskydy Mountains in a cold region, with abundant dampness and precipitation (Urban et al. 2007). Investigated forest stand was planted in the year 1981 with four years old seedlings of the Norway spruce on the slope with SSW orientation. To the north of the site there is a very shallow W-E oriented mountain saddle. Main characteristics of the forest stand are presented in Tab. 1.

Tab. 1: Site characteristics.

Site	EESS Bílý Kříž, Moravian – Silesian Beskydy Mts.
Country	The Czech Republic
Position	N 49 ° 30’, E 18° 32’ 800-900 m a.s.l.
Topography	hilly
Climate	temperate/continental
Mean annual air temperature	5.5 °C
Annual sum of precipitation	1200 mm
Mean annual relative air humidity	80%
Average number of days with snow cover	160
Prevailing winds	south
Immissions load	mild

Methods of measurement

Standard eddy covariance technique was used for measuring CO_2 fluxes (Insitu-Flux, Sweden and UOE Edinburgh) comprising of research anemometer Gill R3 (Gill, U.K.) and infrared gas analyser Li-7000 (Li-cor, U.S.A.) operating at a 20 Hz sampling rate.

Supporting microclimatic measurement includes wind speed (AN1 Delta-T Devices, U.K.), temperature and humidity (RH1 Delta-T Devices, U.K.) profiles, measurement of incoming photosynthetic active radiation (BPW 21, Telefunken, Germany), net radiation (CNR1, Kipp-Zonen, Holland), profiles of soil temperature (PT 1000, Hit, CR) 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.).

Data post-processing

Quality checking

Data (raw data as well as half hourly means) are submitted to the various analysis 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 the means of derived algorithms based on the measured climatological variables (I – incoming PPFD – photosynthetic photon flux density, Ta – air temperature, Ts – temperature of the soil surface).

$$NEE = \underbrace{\frac{\alpha \cdot I + A - \sqrt{(\alpha \cdot I + A)^2 - 4 \cdot \alpha \cdot A \cdot k \cdot I}}{2k}}_{[1]} + \underbrace{\frac{R_{10_{ag}}}{Q_{10_{ag}}^{\left(\frac{10-T_a}{10}\right)}} + \frac{R_{10_s}}{Q_{10_s}^{\left(\frac{10-T_s}{10}\right)}}}_{[2]},$$

with parameters: α – photochemical efficiency of assimilation (mol CO_2 mol^{-1} photon), A – maximal gross primary production (µmol CO_2 m^{-2} s^{-1}), k – convexity (dimensionless), R10 – respiration rate (µmol CO_2 m^{-2} s^{-1}), Q10 – respiration parameter (dimensionless) with indexes: s – soil, ag – aboveground biomass.

Photochemical efficiency (α) and maximal GPP (A) were calculated from dependence of GPP (gross primary production) to measured PPFD using software program Photosyn Assistant 1.1. The response of GPP to incoming PPFD (I) was modeled 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 maximum value.

Respiration rate and respiration parameters were calculated from dependence of measured CO_2 efflux to temperature of respiring part of ecosystem using Raich-Schlesinger equation [2] (Raich et al. 2002). In differentiated ecosystem such as forest, the efflux calculation is divided into soil and aboveground biomass respiration. Course of daily mean R10 from chamber measurements are used for estimation of R10 dynamics in the model.

Results and discussion

Course and length of production seasons 2005, 2006 and 2007 differed due to weather conditions. Annual courses of main atmospheric conditions are in Fig. 1. Mean daily net ecosystem production in these years was 22 kg C ha^{-1} during production season, and mean production season duration was 240 days. More detailed data are in Tab. 2. During production seasons there occurred days with respiration higher than assimilation, so the forest was source of atmospheric carbon (Fig. 2, Tab. 2).

There were 45, 68 and 39 days in production seasons 2005, 2006 and 2007, respectively, when the forest was carbon source. It was at the beginning and end of production seasons caused by 1) significant decrease of air temperature and low intensity of PAR (photosynthetic active radiation); and during production seasons by 2) low radiation in overcast days and 3) long dry period with high intensity of direct radiation and high air temperature.

Length of production seasons 2005 and 2006 was similar. Production season in 2007 was shorter than others due to earlier start of dormant period. There were overcast and rainy days in the second half of October and then followed temperature decline and dormant state of trees in November. Course of NEP (net ecosystem production) during season 2006 differed from the others. There were more “source days” in July due to high ecosystem temperature, drought and high irradiation and in August due to overcast and rainy weather.

Tab. 2: Sink and source analysis of net ecosystem production of Norway spruce forest, 2005-2007. Numbers of days are written.

	2005	2006	2007
Dormant period	**117**	**121**	**139**
Production season	**248**	**244**	**226**
Start of production season [date]	16.3.	12.3.	6.3.
End of production season [date]	16.11.	11.11.	17.10.
Carbon sink	**203**	**176**	**187**
Carbon source	**45**	**68**	**39**
Temperature decline - start and end of production season	3	13	5
Overcast	13	14	4
Overcast and rainy	26	25	28
Sunny and hot	3	13	2
Low irradiation and hot	2	3	0

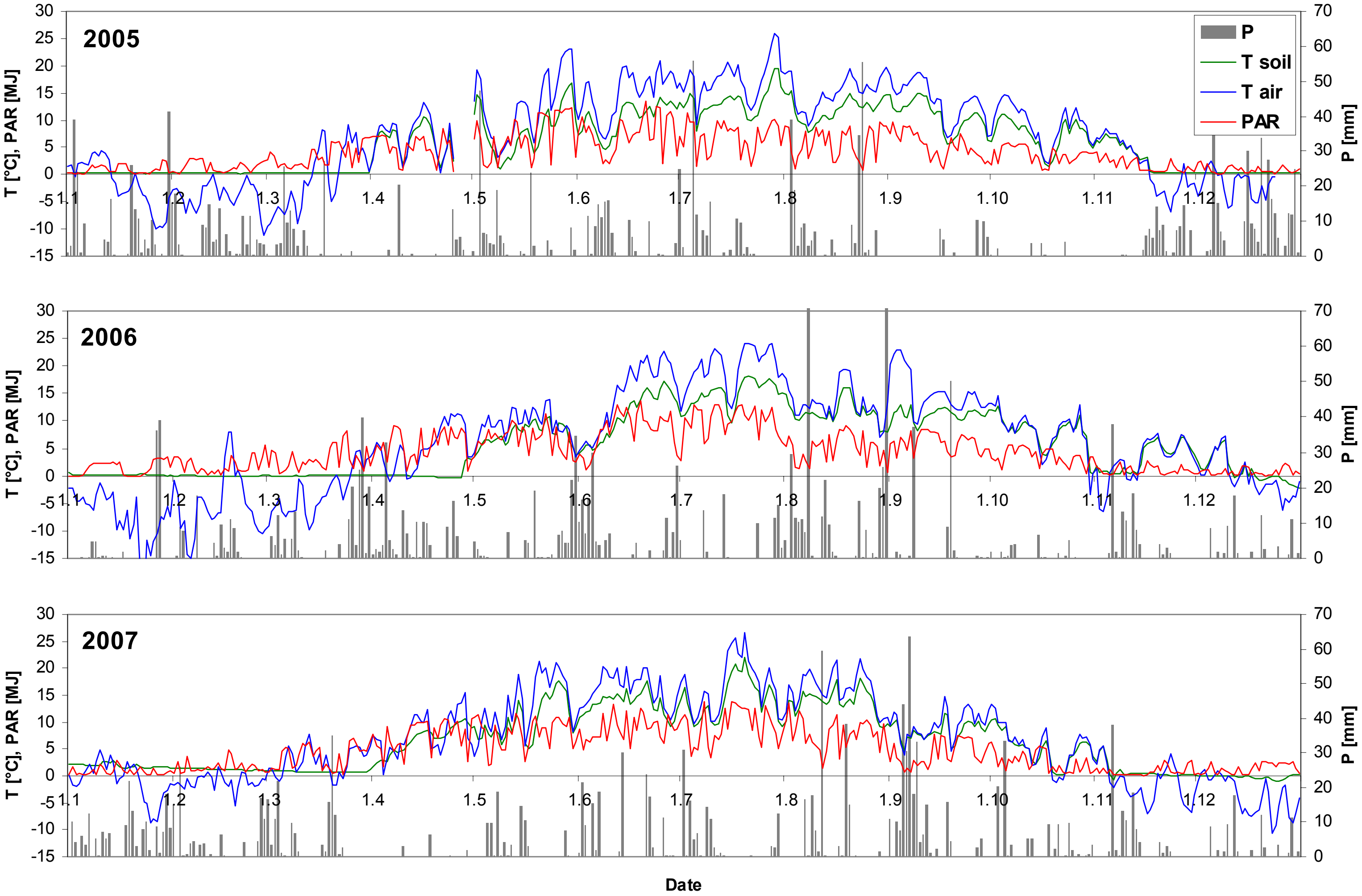

Fig. 1: Atmospheric factors in Norway spruce stand at EESS, 2005-2007. Mean daily values of air temperature (T air) and soil surface temperature (T soil); daily sums of photosynthetic active radiation (PAR) and precipitation (P) are shown.

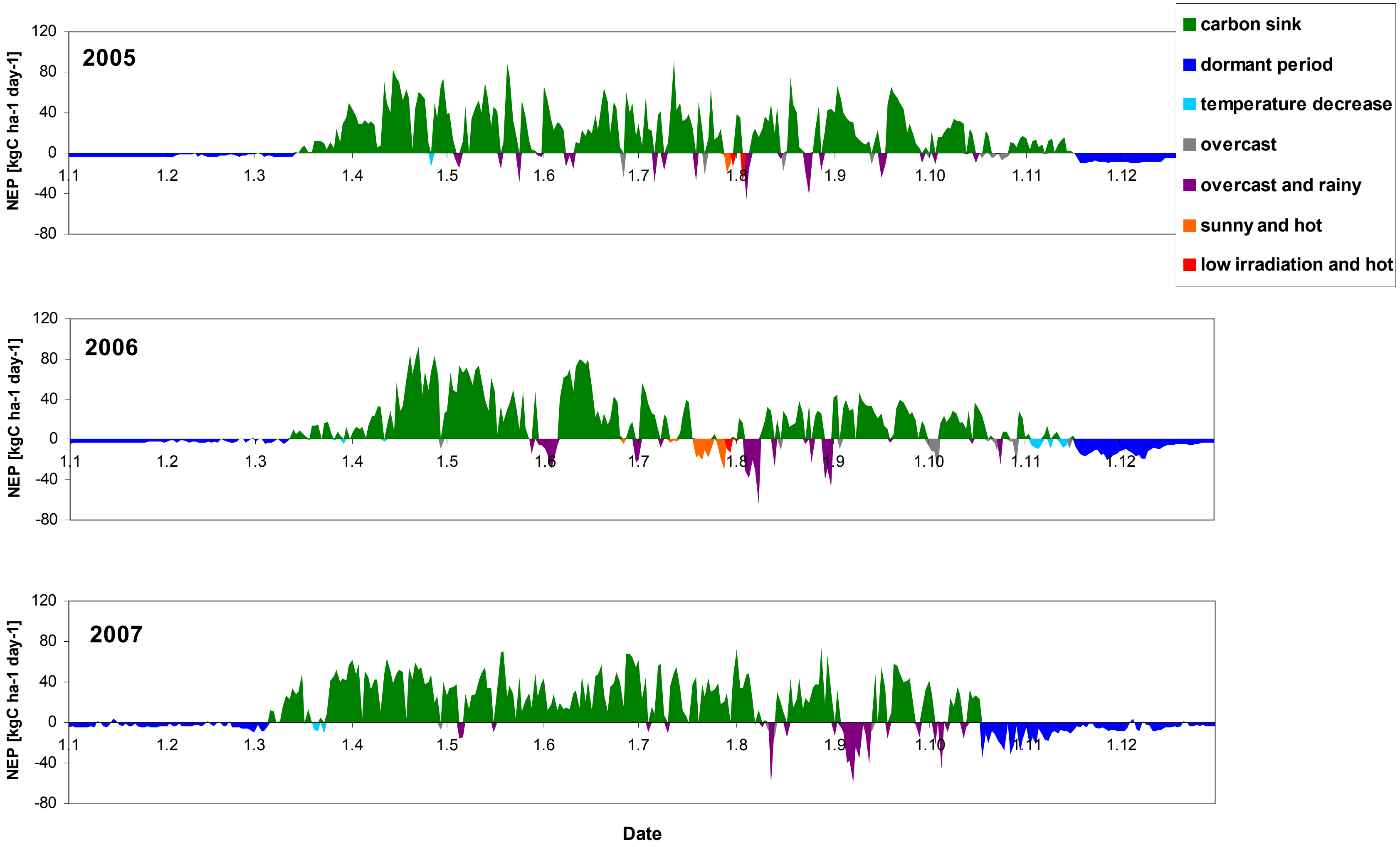

Fig. 2: Annual course of net ecosystem production (NEP) in Norway spruce forest. Daily NEP values are plotted; area above x axis represents carbon sink, area below x axis means carbon release.

1) Significant decrease of ecosystem temperature and low intensity of PAR

Start of production season depends on air temperature. Even when snow is still within the forest, photosynthesis can start, when air temperature is convenient. We registered start of carbon sink, when air temperature in the forest reached 3,5°C. This situation occurred in the first half of March in all investigated years (Tab. 2). When air temperature decreased significantly after start of production season, forest became source for these days (Fig. 3). After next warming, the carbon sink was higher then the previous one.

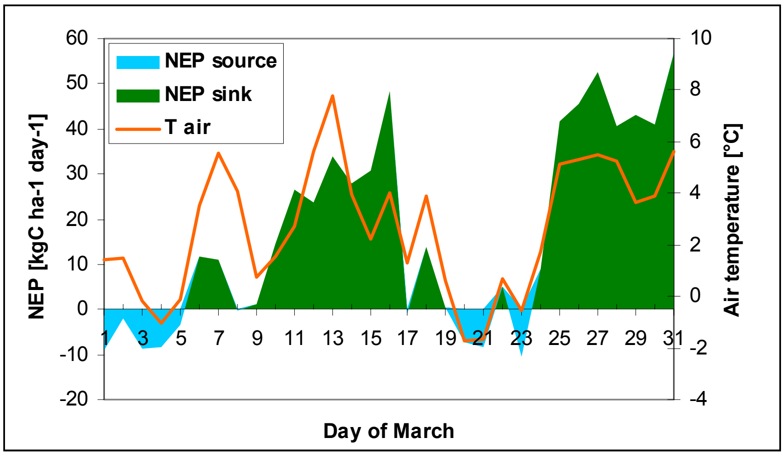

Fig. 3: Monthly course of net ecosystem production (NEP) and air temperature.

2) Low radiation in overcast days

The photochemical efficiency of the stand is higher during cloudy periods (with fraction of diffuse radiation 0,8-0,9) than during clear periods (with fraction of diffuse radiation 0,2-0,3) and NEE values are higher during cloudy periods at the same incident PPFD (than during clear periods (Urban et al. 2007). Nevertheless, in clear periods there was more radiation coming to the ground, thus carbon sink was higher during clear periods.

The main presumption of carbon sink is that the assimilation of the forest stand is higher than ecosystem respiration. To estimate the sufficient amount of photosynthetic active radiation for carbon sink, dependence of daily net ecosystem production on incoming PAR (daily sum) was plotted (Fig. 4). Data from days without rain from intensive production periods (June – August) of all years were used. Nonrectangular hyperbolic function was fitted to the data. For days with incoming PAR smaller than approximately 4 MJ we can say, that the Norway spruce forest is source of atmospheric carbon. Assimilation is not so high to compensate ecosystem respiration.

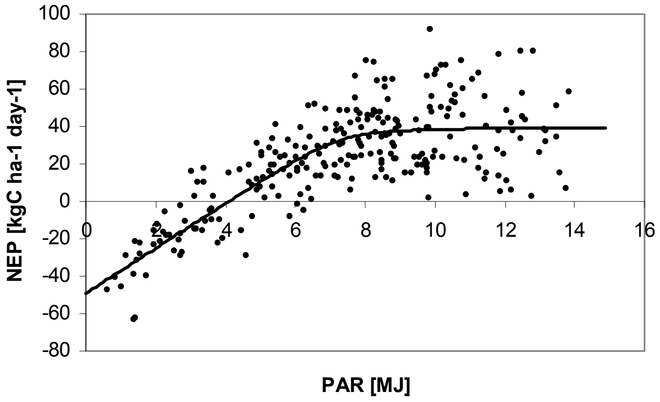

Fig. 4: Daily sum of net ecosystem production (NEP) in relation to incoming photosynthetic active radiation (PAR). Nonrectangular hyperbolic function according the Prioul – Chartier equation was fitted to the data.

3) Long dry period with high intensity of direct radiation and high air temperature

In the summer, when the production activity of forest is the highest, there occurred periods with high intensity of direct radiation, high air temperature and low soil moisture. Trees were stressed and they closed their stomata due to water deficiency. Due to stomata closure the gas exchange between plant and atmosphere was inhibited.

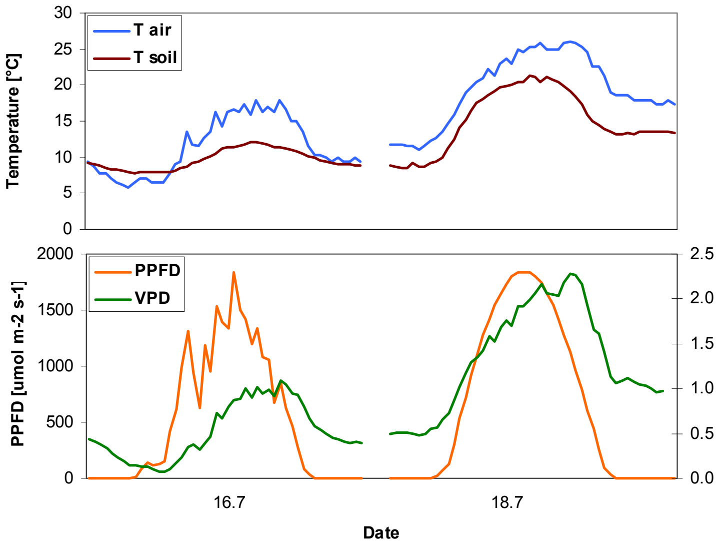

Fig. 5: Weather conditions in Norway spruce forest, July 16 and 17, 2006. T air – air temperature, T soil – soil surface temperature, PPFD – photosynthetic photon flux density, VPD – vapor pressure deficit.

In weather conditions, which do not limit the growth of Norway spruce, the light response curve looks like July 16 in Fig. 6. Production was not limited, and NEE values under the same irradiation were similar in a.m. and p.m. hours. On the opposite, at July 18, air and soil surface temperature and vapor pressure deficit increased. It was clear day (Fig. 5). In the morning till PPFD reached 500 µmol m^{-2} s^{-1} NEE had the same dependence as at July 16. Then spruce stand was light saturated and in the afternoon NEE (p.m. values) was very low. In days with atmospheric conditions like at July 18, the forest is the source of carbon.

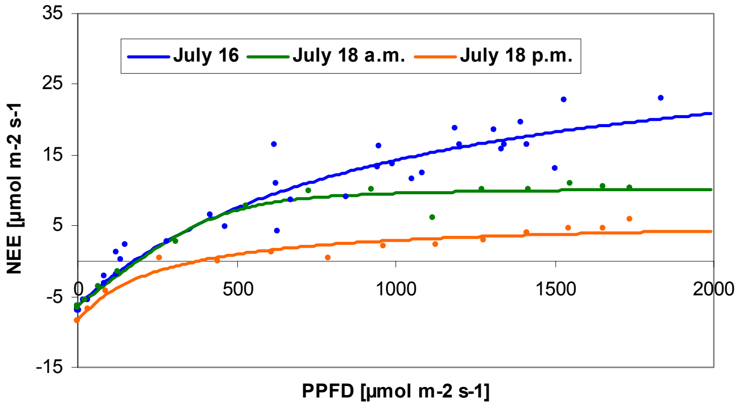

Fig. 6: Net ecosystem exchange (NEE) in relation to photosynthetic photon flux density

Conclusion

Atmospheric factors determine if Norway spruce forest becomes sink or source of atmospheric carbon at each day. 1) Significant decrease of air temperature and low intensity of PAR at the beginning and end of production seasons, 2) low radiation in overcast days and 3) long dry period with high intensity of direct radiation and high air temperature during production seasons caused, that ecosystem respiration was higher than assimilation and forest became source of CO_2. There is supposed that within global climate change weather extremes will occur more frequently than these years and this can lead to occurrence of more source days and hence to lower carbon sequestration into the ecosystem.

Acknowledgement

This work was supported by the grants MSMT 2B06068 Interviron and MZP SP/1a6/108/07 CzechTerra.

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