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REED CANOPY TRANSPARENCY UNDER DIFFERENT LEVELS OF DIFFUSE RADIATION*

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Abstract: Diffused solar radiation increases ecosystem productivity. One of the explanations for this phenomenon is the fact that this type of radiation penetrates the vegetation layer more efficiently, thus changing radiation conditions under the plant canopy. The study of reed transparency under different radiation diffusion conditions makes it possible to estimate the amount of radiation energy that reaches plants living under the reed canopy. The presented radiation parameters were obtained using the SS1 probe (Delta-T Devices Ltd. UK.). The measurements were carried out in September 2014 in a reed canopy in the Rzecin peatland (52°45′N, 16°18′E, 54 m a.s.l.). Analyses showed that the transparency of the reed canopy (*Tr*) is directly proportional to the degree of diffusion (*D**) of the radiation which reaches the plant surface and the reed *Tr* value is always greater at cloudy conditions than during periods of low radiation diffusion. At the same time, *Tr* is inversely proportional to the leaf area index (*LAI*). Under high diffusion of radiation the plants growing under the reed canopy gain approximately 38% radiation energy in comparison with periods characterised by low values of *D**.

Keywords: diffuse radiation, reed, leaf area index

INTRODUCTION

Solar radiation is a form of energy that is absorbed by green plants in their basic life process, i.e. photosynthesis. Therefore, solar energy is the basis for the existence of all living organisms.

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The amount of carbon dioxide absorbed by plants largely depends on the amount of solar radiation that reaches the terrestrial ecosystems. The amount and diffusion level of solar energy which reaches the Earth's surface is determined by such meteorological elements as cloudiness, the type of clouds and their location in the sky in relation to the Sun disc (Matuszko and Soroka 2009), as well as the type and quantity of aerosols and gases that are both suspended and dissolved in the atmosphere (Hoyt 1978, Roderick *et al*. 2001).

Diffuse radiation enhances the ability of plants to absorb CO_2 from the atmosphere (Gu *et al*. 2002, Mercado *et al*. 2009). Among other things, it results from the fact that this type of radiation easily penetrates into the vegetation layer (Dengel and Grace 2010). The value of the plant layer transparency (*Tr*) is also directly determined by the value of the leaf area index (*LAI*). This parameter describes the number of leaves per unit area of land (Leśny *et al*. 2007). At the same time, the *Tr* value depends on the value of the diffusion index (D^*) of the radiation reaching the plant community surface. Thus, the process of scattering solar radiation in the atmosphere increases the amount of radiant energy which is transmitted through the plant canopy.

Wetlands, frequently overgrown by reeds, are important elements of global carbon balance (Gorham 1991). In the developed canopy of reeds the value of diffuse radiation should affect the amount of radiant energy that is available under the canopy, thus determining the development of plants, e.g. *Sphagnum spp.*, that grow under reeds.

The aim of this study was to assess the radiation conditions under the canopy of reeds at different levels of diffuse solar radiation.

METHODOLOGY

Description of measurement system

The SunScan Canopy Analysis System SS1 (Delta-T Devices Ltd. UK.) was used during the measurements. The measurement system consists of the following elements: a SunScan Probe type SS1-RL4 linear sensor (1 m long array of 64 photodiodes) used to measure transmitted Photosynthetic Photon Flux Density (*PPFD*) – (*Rtr*); a BF3 sunshine duration sensor that measures both total *PPFD* (*Ri*) and diffused *PPFD* (*Rdiff*) that reach the vegetation surface; a BF-RL4 Radio Module (transmitter); a palmtop PDA – a handheld data collection device (Delta-T Devices Ltd, 2008). The SunScan system provides non-destructive measurements, e.g. *LAI*, and these measurements can be carried out under various weather conditions (Uździcka *et al*. 2012).

Experimental site description

The measurements were taken at the Rzecin peatland (Chojnicki *et al*. 2007) (52°45'N, 16°18'E, 54 m a.s.l) in the north-western part of the Wielkopolska Region, Poland. This site is located about 80 km N-E of the city of Poznań. This peatland is covered by abundant vegetation that is typical of wetlands (Wojterska 2001), while the rush where the dominant species is common reed (*Phragmites australis)* is located in the north-central part of the site (Barabach and Milecka 2013). At the time of the study the site substrate water pH was 4.9 and electrolytic conductivity was 52.8 μS cm^{-1} (Romanowska 2015). The mean annual precipitation is 526 mm, mean annual air temperature in Rzecin is 8.5°C, while the mean length of the vegetation period in this region is 220 days (Farat 2004).

The investigations were conducted in this reed canopy, with the first step (12th of September, 2014) consisting in the analysis of the biotic parameters of the vegetation layer. In five experimental plots of 1m x 1m each non-destructive *LAI* measurements (SunScan SS1-RL4, Delta-T Devices Ltd. UK) were realized, followed by destructive biomass collection. The mowed reeds were dried, separated and weighed in the laboratory.

Table 1. Biophysical parameters of reed at five experimental sites in the Rzecin peatland, 12.09.2014. Where: AVG – mean value; SD – standard deviation; Min – minimum value, Max – maximum value.

Parameter	AVG	SD	Min	Max
Total stem density (stem m^{-2})	127.80	21.71	110.00	164.00
Green stem density (stem m^{-2})	46.40	9.56	31.00	56.00
Plant height (m)	1.93	0.07	1.86	2.04
LAI m^2 m^{-2}	2.52	0.87	1.50	3.30
Total biomass (g m^{-2})	1313.20	115.25	1205.00	1446.00
Green biomass (g m^{-2})	689.00	157.16	518.00	885.00

A 20-m long transect was located in the reed area, where 20 measuring points were established, spaced at a distance of 1 m from each other. A single campaign consisted of *Rtr* measurements at each measuring point, and this action was realized in sequential mode. One measurement series was obtained during approximately 5 minutes. 81 campaigns were done within the period from 15th to 25th October 2014, under various levels of incoming diffused *PPFD*.

A single measurement involved a simultaneous measurement of *Ri*, *Rdiff* (BF3 sunshine duration sensor) outside the reed area, and *Rtr* (SS1-RL4 linear sensor) under the plant canopy. During this measurement the radiation probe SS1 was placed horizontally to the ground surface at about 20 cm above the peatbog surface at each measuring point. The BF3 sensor was installed on a tripod and transmitted measured values to the PDA. The recorded data were stored in the PDA and then transferred to the computer memory for further analyses.

Data analysis

In this study the transparency of the surveyed reed canopy was calculated using the following formula:

$$T_r = \frac{R_{tr}}{R_i} \quad (1)$$

where: T_r – transparency (–); R_{tr} – transmitted *PPFD* (μmol m^{-2} s^{-1}); R_i – total *PPFD* (μmol m^{-2} s^{-1}).

The values of the diffuse radiation index *PAR* were calculated according to the formula (Spitters *et al*. 1986):

$$D^* = \frac{R_{diff}}{R_i} \quad (2)$$

where: D^* – diffusion index (–); R_{diff} – diffused *PPFD* (μmol m^{-2} s^{-1}).

RESULTS AND DISCUSSION

Transparency of reed vs. diffuse radiation

The transparency of reed canopy (*Tr*) in the entire transect was analysed in terms of the diffusion index (*D**) value (Fig. 1.). *Tr* was found to be proportional to the *D** value and this relationship can be described by the following linear equation:

$$Tr = 0.0732\, D^* + 0.0434;\ R^2 = 0.2792 \quad (3)$$

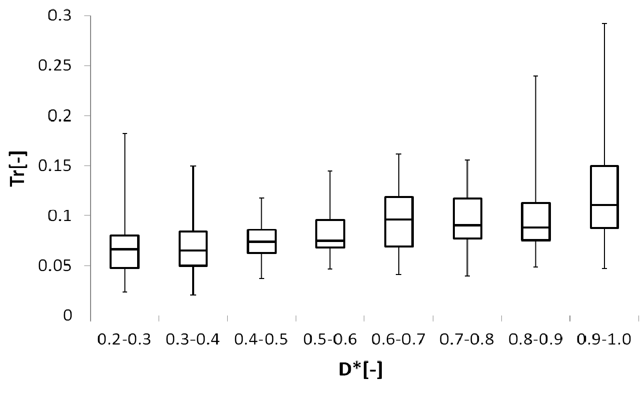

Fig. 1. The dependence of reed canopy transparency (*Tr*) on *PPFD* diffusion index (*D**)

The similarity tests of the transparency values of reed canopy in different diffusion radiation conditions was applied in the next step of data analysis. The *Tr* dataset was divided into 3 groups in terms of different values of the radiation diffusion index: low diffusion (D^* = 0.0-0.3), medium diffusion (D^* = 0.3-0.7) and high diffusion (D^* = 0.7-1.0) (Urban *et al.* 2007). The normality of distribution for these groups was assessed using the Shapiro-Wilk test. The test showed a lack of normal distribution for the studied *Tr* populations.

Therefore the significance analysis was conducted using the nonparametric Wilcoxon test. The pairwise analysis of these *Tr* populations in different ranges of D^* values was performed and the level of significance for this test was assumed to be 0.05. The tests showed that medians of the *Tr* populations were significantly different.

Reed canopy transparency vs. leaf area index

The value of plant cover transparency depends on both the diffusion level of *PPFD* and plant leafage size. In this case *LAI* was used as the parameter of the reed leafage status.

The sets of *Tr* and *Rtr* values which were measured during the periods with low ($D^* \leq 0.3$) and high (D^* = 1.0) degrees of diffuse *PPFD*, respectively, were selected from the whole data set.

The values of these two parameters were analysed in the context of various *LAI* values at each measurement point (Fig. 2).

The values of *LAI* in each measurement point were recorded at cloudless sky ($D^* \leq 0.3$), since the SS1 probe application methodology requires sunny conditions. The additional measurements that were carried out at these measuring points were used for the study of *LAI* impact on both *Rtr* and *Tr* values.

Under both low and high diffusion of *Ri* the values of *Tr* (Fig. 2a) and *Rtr* (Fig. 2b) in the reed canopy are inversely proportional to *LAI*. The studied reed canopy (with *LAI* values ranging from 2.9 to 3.8) is always more transparent at complete diffusion of radiation (D^* = 1.0) than in cloudless periods ($D^* \leq 0.3$). These findings correspond to results presented in the literature (Shulski *et al*. 2004, Dengel *et al*. 2015). In other words, at the time of complete diffusion of *Ri* at the point where *LAI* = 3.8 the lowest *Tr* value was 0.1212, while under low *Ri* diffusion where *LAI* = 2.9 the highest *Tr* value was 0.0746 (Fig. 2a), respectively. The amount of radiation energy which reaches the peatland surface under the plant canopy characterised by the specified value of *LAI* is always higher under high diffusion of *Ri*; however, the impact of the higher diffusion on the *Rtr* value can be reduced by a higher *LAI*. For example, the same value of *Rtr* = 49.2 μmol m^{-2} s^{-1} is observed under the canopy during low diffusion for *LAI* = 2.9 and high diffusion conditions for *LAI* = 3.5.

The differences of *Rtr* values approximated with linear equations (Fig. 2b) are in the range from 20.2 μmol m^{-2} s^{-1} (*LAI* = 2.9) to 22.3 μmol m^{-2} s^{-1} (*LAI* = 3.8), 29 to 49% of *Rtr* relative gain respectively. In other words, the plants below the reed canopy obtain additional 38% of radiant energy in the average.

a

b

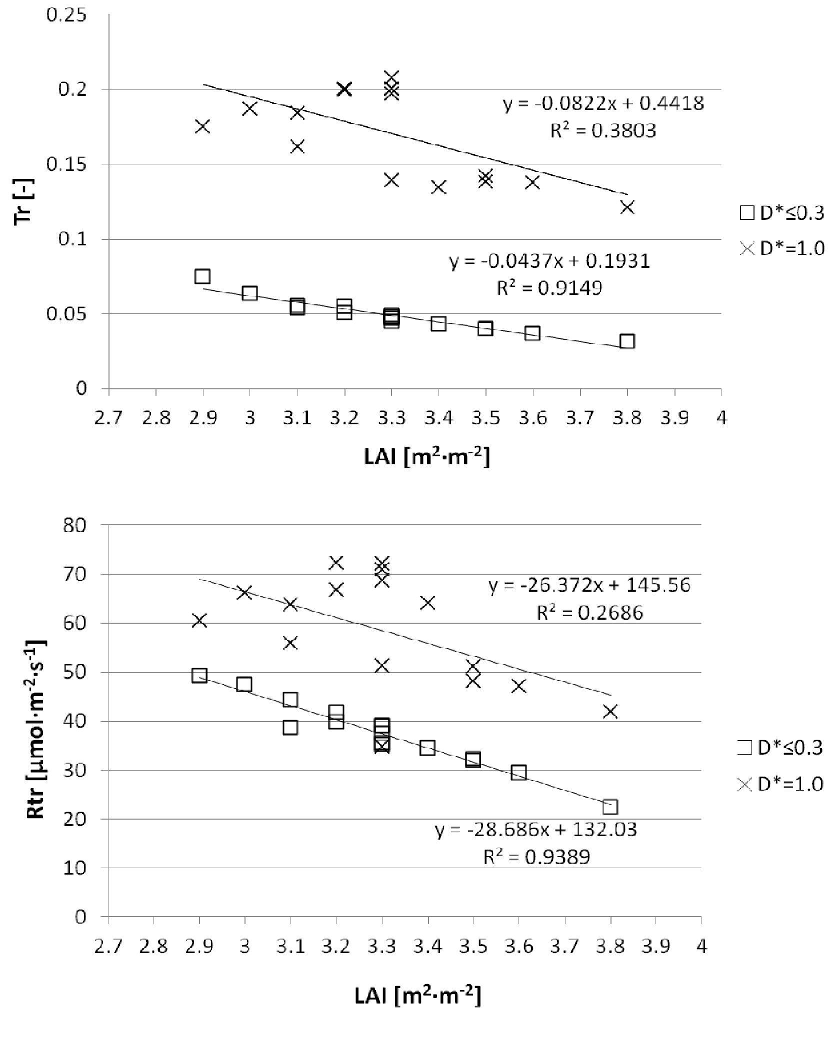

Fig. 2. The dependence of transparency (*Tr*) (a) and transmitted radiation flux density (*Rtr*) (b) on *LAI* of the reed canopy at Rzecin peatland

CONCLUSIONS

The results presented above allow to draw the following conclusions:

1. The reed canopy (*LAI* 2.9-3.8) transparency is directly proportional to the diffusion index (D*) and its value ranges from 0.05 (D* = 0.1) to 0.11 (D* = 1.0);

2. The differences between the median values of reed *Tr* observed under three different ranges of D* values are statistically significant ($D^*_{0,0-0,3} - D^*_{0,3-0,7}$ ***; $D^*_{0,3-0,7} - D^*_{0,7-1,0}$ ***; $D^*_{0,0-0,3} - D^*_{0,7-1,0}$ ***).

3. The transparency of the studied reed canopy is inversely proportional to *LAI*; however, under full diffusion conditions (cloudy sky) *Tr* is always higher than transparency under low diffusion *Ri* (clear sky).

4. The amount of radiation energy under the reed canopy depends both on the *LAI* value and on the degree of *Ri* diffusion. However, the increase of reed *Tr* under high *Ri* diffusion conditions can be reduced by a higher value of *LAI*.

5. The above conclusion is crucial for plants that grow under the reed canopy, e.g. peat mosses. At diffused radiation greater amounts of radiation energy reach these plants than during the cloudless periods. We may thus assume that peat mosses growing under the reed canopy gain an additional portion of radiation energy (approximately 38%) during cloudy periods. At the same time, the measured *Rtr* values at D* = 1.0 ranged from 22.4 to 72.3 μmol m^{-2} s^{-1} and they did not exceed the threshold value of moss photoinhibition (Murray *et al*. 1993). Therefore we can expect that the growth rate (productivity) of peat mosses under the canopy of reeds will be increased during cloudy sky conditions.

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PRZEZROCZYSTOŚĆ TRZCINOWISKA W RÓŻNYCH WARUNKACH ROZPROSZENIA PROMIENIOWANIA SŁONECZNEGO

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S t r e s z c z e n i e. Rozproszone promieniowanie słoneczne powoduje wzrost produktywności ekosystemów. Jest to spowodowane między innymi tym, że ten rodzaj promieniowania lepiej penetruje roślinność, zmieniając tym samym warunki radiacyjne pod okapem roślin. Badanie przezroczystości trzcinowiska w różnych warunkach rozpraszania promieniowania pozwala na określenie warunków (ilości docierającej energii promienistej) bytowania roślin żyjących pod okapem trzcin. Prezentowane dane są wynikiem pomiarów wykonanych za pomocą sondy SS1 firmy Detla-T służącej do oceny warunków oraz parametrów radiacyjnych roślin. Badania przeprowadzono we wrześniu 2014 r. w łanie trzcin na torfowisku w Rzecinie (52°45′N, 16°18′E, 54 m n.p.m.). W wyniku przeprowadzonych analiz stwierdzono, iż przezroczystość trzcinowiska (*Tr*) jest wprost proporcjonalna do stopnia rozproszenia promieniowania docierającego do powierzchni roślin (D^*), a jej wartość jest zawsze większa w warunkach $D^* = 1.0$ od wartości *Tr* w okresach o małym rozpraszaniu promieniowania. Jednocześnie *Tr* jest odwrotnie proporcjonalne do wartości współczynnika ulistnienia (*LAI*). W warunkach pełnego rozproszenia ilość energii promienistej docierającej do roślin znajdujących się pod okapem trzcin wzrasta średnio o ok. 38% w porównaniu do okresów o niskich wartościach D^*.

S ł o w a   k l u c z o w e: promieniowanie słoneczne rozproszone, trzcinowisko, współczynnik ulistnienia