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TOTAL NET RADIATION OF THE MOUNTAIN NORWAY SPRUCE STAND AT BÍLÝ KŘÍŽ (THE CZECH REPUBLIC)

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Abstract

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The presented paper reports results from the comprehensive measurements carried out in the mountain Norway spruce stand at the experimental study site of Bílý Kříž (the Czech Republic). Determination of total net radiation during the growing season is an important information used in an ecophysiological research of the growth processes of a spruce stand under study and it is one of the input value for a description of atmospheric carbon allocation. Four components (incoming and outgoing short-wave radiation and incoming and outgoing long-wave radiation) of the total net radiation were measured and analyzed separately and from these values total net radiation were calculated. Linear relationship between the total net radiation and incoming short-wave radiation was confirmed for the studied stand the whole growing season. Mean daily sums of total net radiation related to the mean daily sums of incoming short-wave radiation during the growing season. Ratio of total net radiation in incoming short-wave radiation was in the interval 0.49 – 0.69. Short- and long-wave radiation balances calculated for the whole growing season amounted 13.72 MJ m^{-2} and -4.31 MJ m^{-2}, respectively.

Key words: incoming and outgoing short-wave radiation, incoming and outgoing long-wave radiation, the growing season

Introduction

Forest stands are exposed to short-wave (solar) radiation, which is regarded as the basic factor affecting the forest microclimate environment. The range of the solar radiation wave-length is from 10^{-1} nm to 1 m and 98% of its energy is in the range of the wave-length from 150 nm to 4000 nm. The part of solar radiation is absorbed in the atmosphere thus the Earth´s surface reaches solar radiation of the wave-length about 280–4000 nm. This reached radiation can be reflected or absorbed by the forest stands or can be transmitted through the ones. In addition, forest stands receive certain amount of long-wave (thermal) radiation (range of wave-length > 4000 nm) from the atmosphere. This type of radiation can be reflected, absorbed or transmitted by the forest stands as well. Because of temperature of the forest stands is above absolute zero, they emit long-wave radiation to their surroundings according to the physical laws. Finally, the amount of radiation absorbed by the forest stand is then the sum of incoming and outgoing short-wave and long-wave radiation. This value is defined as the “net radiation”. Whereas the final value of the net long-wave radiation depends on meteorological conditions, the net short-wave radiation value depends on the geographical position, phenological aspect of the vegetation, on the course of vegetation season and time of day, on the short-wave reflectance of the stand and on the transmission coefficient of the atmosphere and clouds for the short-wave radiation (Tajchman, 1972; Fussler, 1998; Iziomon, Mayer, 2002; Shaw, 2002).

Generally the net radiation is regarded as an important climatic variable since it is: i) only energy input into any surface, ii) driving force in the energy balance at any surface (Anthoni et al., 2000; Irmak et al., 2003) and iii) determines the degree of radiant exchange between the atmosphere and a forest stand. Net radiation significantly affects especially stands evapotranspiration (Fussler, 1998; Betts et al., 1999; Moore et al., 2000; Burba, Verma, 2001). The final estimated values of net radiation are preferentially sensitive to the value of the surface reflection coefficient, surface temperature, and surface emissivity (McCaughey, 1978; Kessler, Jaeger, 1999; Anthoni et al., 2000).

The final value of net radiation at the day-time during the growing season is positive, at night (when it is controlled entirely by long-wave radiation) is negative (Ross, 1975). Very distinctive linear correlation exists between the values of incoming short-wave radiation and net radiation (McCaughey, 1978; Gholz, Clark; 2002, Alados et al., 2003).

The presented paper reports results from the comprehensive measurements of net radiation of a mountain spruce stand carried out at the experimental study Bíly Kříž (the Beskids Mts NE part of the Czech Republic).

Methods

During the year of 2003 total net radiation of mountain Norway spruce stand (*Picea abies* (L.) K a r s t.) was measured at the experimental ecological study site at Bílý Kříž (the Moravian-Silesian Beskids Mts, the Czech Republic). The altitude of the study site is 908 m and its coordinates are 18° 30´ E and 49° 30´ N. Studied spruce stand was planted out in 1981 using four-years old seedlings. Leaf area index of the stand was in 2003 in the interval of values 10 –12 (Marková et al., in press). Total net radiation was measured using the Net – Radiometer CNR 1 (Kipp-Zonen, the Netherlands). The Net Radiometer measures four radiation components separately. Short-wave (solar) radiation is measured by two pyranometers, one for a measurement incoming radiation from the atmosphere, and the second one, which faces downward, for a measurement of the reflected radiation. Long-wave (thermal) radiation was measured by two pyrgeometers, one for a measurement of incoming radiation from the atmosphere, the second one for the Earth´s surface radiation. Values of these four parameters were automatically recorded per 30 seconds and 30-minute averages of these records were stored by Data-Logger (DL 3000, England). Total net radiation and its individual parts was determined for the period of May – October 2003, which is considered to be a period of the growing season for Norway spruce at the study site.

Results

An analysis of 30 minutes average values of total net radiation and incoming short-wave radiation confirmed the linear relationship of these quantities obtained in individual months

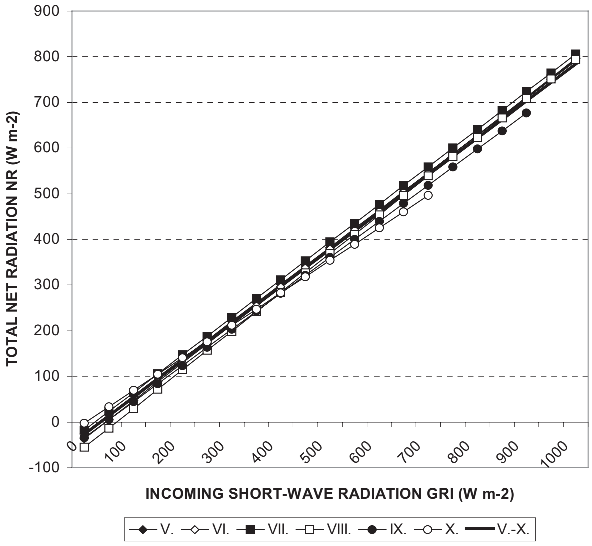


Fig. 1. Linear relationship between total net radiation and incoming short-wave radiation for individual months and for the whole growing season (May–October) 2003 obtained in the Norway spruce stand, Bílý Kříž.

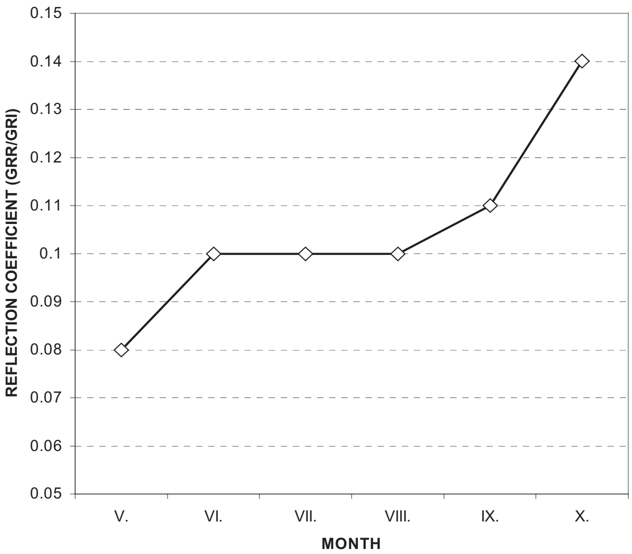


Fig. 2. Reflection coefficient (outgoing short-wave radiation GRR_D/incoming short-wave radiation GRI_D) for individual months of the growing season (May–October) 2003 at the Norway spruce stand, Bílý Kříž.

and during the whole growing season, respectively (Fig. 1). The slopes of the determined linear regression were: 0.81 in May, 0.83 in June, 0.82 in July, 0.85 in August ($R^2 = 0.98$ for all these investigated months), 0.79 in September ($R^2 = 0.96$) and 0.71 ($R^2 = 0.93$) in October and 0.81 ($R^2 = 0.97$) for the whole growing season. Thus, the strong dependency of total net radiation and incoming short-wave radiation was confirmed.

Mean daily sums of incoming short-wave radiation (GRI_D) were strongly related to the seasonal sun elevation, only with the one exception of July. In this period the daily sum of GRI_D was smaller compared to the August value. On the other hand mean daily sums of outgoing (reflected) short-wave radiation (GRR_D) were well balanced during the studied period. Reflection coefficient of short-wave radiation values (GRR_D/GRI_D) strongly distinguished the end of the growing season (Fig. 2).

Mean daily sums of incoming long-wave radiation (LRI_D) and outgoing (emitted) long-wave radiation (LRR_D) follow seasonal sun elevation and were more balanced during the season in comparison to the GRI_D and GRR_D (Table 1a).

Table 1a. Mean daily sums and other chosen statistical characteristics of outgoing (emitted) long-wave radiation (LRR_D), incoming long-wave radiation (LRI_D), outgoing (reflected) short-wave radiation (GRR_D), incoming short-wave radiation (GRI_D) and total net radiation (NR_D) calculated for individual months of the growing season (May–October) 2003 in the N. spruce stand, Bílý Kříž.

	LRR_D	LRI_D	GRR_D	GRI_D	NR_D
V.	29.27	23.77	0.23	2.50	2.30
	35.45 ± 12.17	28.68 ± 2.36	1.62 ± 0.80	18.20 ± 8.59	12.01 ± 5.03
	99.04	33.04	2.80	29.58	18.25
VI.	31.17	26.80	0.80	7.33	4.54
	34.74 ± 1.55	29.62 ± 1.58	2.15 ± 0.69	20.64 ± 6.78	13.37 ± 4.42
	37.00	32.82	3.04	30.24	20.71
VII.	31.65	27.71	0.28	2.83	2.33
	34.39 ± 1.69	31.21 ± 1.43	1.49 ± 0.67	14.83 ± 6.72	10.16 ± 4.17
	37.45	33.54	2.71	26.43	16.65
VIII	32.13	26.19	0.53	5.53	3.32
	35.48 ± 1.43	29.42 ± 1.99	2.00 ± 0.51	19.87 ± 5.27	11.81 ± 3.31
	38.00	32.99	2.53	26.19	17.58
IX.	29.86	22.86	0.33	3.18	0.64
	32.63 ± 1.90	27.33 ± 1.95	1.48 ± 0.61	13.23 ± 4.98	6.45 ± 2.29
	36.31	30.53	2.24	19.14	9.92
X.	25.09	19.51	0.10	0.83	0.23
	28.52 ± 1.91	26.82 ± 2.75	0.73 ± 0.64	5.08 ± 3.82	2.65 ± 1.91
	32.70	31.84	2.84	13.63	9.37

MIN
AVG ± STDEV
MAX

(AVG – mean daily sum, STDEV – standard deviation of daily sum, MIN – minimum daily sum, MAX – maximum daily sum)

Table 1b. Day time mean daily sums and other chosen statistical characteristics of outgoing (emitted) long-wave radiation (LRR_D), incoming long-wave radiation (LRI_D), outgoing (reflected) short-wave radiation (GRR_D), incoming short-wave radiation (GRI_D) and total net radiation (NR_D) calculated for individual months of the growing season (May–October) 2003 in the N. spruce stand, Bílý Kříž.

	LRR_D	LRI_D	GRR_D	GRI_D	NR_D
V.	18.52	14.62	0.23	2.50	2.31
	21.35 ± 1.74	18.26 ± 1.65	1.62 ± 0.80	18.20 ± 8.59	13.50 ± 5.79
	24.42	22.17	2.80	29.57	20.94
VI.	21.07	18.09	0.80	7.33	5.71
	23.55 ± 1.13	20.04 ± 1.06	2.15 ± 0.69	20.64 ± 6.78	14.98 ± 4.73
	25.52	22.16	3.04	30.24	21.96
VII.	20.70	18.32	0.28	2.83	2.58
	22.71 ± 1.13	20.58 ± 0.81	1.49 ± 0.67	14.83 ± 6.72	11.22 ± 4.68
	25.41	22.01	2.71	26.43	19.19
VIII	17.62	14.93	0.53	5.53	3.79
	21.63 ± 1.52	17.78 ± 1.37	2.00 ± 0.51	19.87 ± 5.27	14.02 ± 3.61
	23.77	20.41	2.53	26.19	18.96
IX.	15.20	11.75	0.33	3.18	2.24
	17.39 ± 1.09	14.55 ± 1.34	1.48 ± 0.61	13.23 ± 4.98	8.91 ± 2.95
	18.90	16.77	2.24	19.14	12.31
X.	10.68	7.95	0.10	0.83	0.64
	12.88 ± 1.59	12.06 ± 1.82	0.73 ± 0.64	5.08 ± 3.82	3.53 ± 2.34
	16.10	15.51	2.84	13.63	9.74

Mean daily sums of total net radiation (NR_D) related to the mean daily sums of GRI_D. Values of NR_D/GRI_D were 0.66 in May, 0.65 in June, 0.69 in July, 0.59 in August, 0.49 in September and 0.52 in October, respectively.

Comparison of the mean daily sums of LRR_D, LRI_D, GRR_D, GRI_D and NR_D and other statistical characteristics was performed for the light (Table 1b) and night (Table 1c) parts of the day. Mean daily sums of NR_D of the light part of the day were higher compared to the mean daily sums calculated for the whole day. The NR_D values portion of the GRI_D based on the measurements realised only during the light part of the day amounted to 0.74 in May, 0.73 in June, 0.76 in July, 0.71 in August, 0.67 in September and 0.69 in October, respectively.

Short-wave radiation balance (GRI_D – GRR_D), which is possible to obtain only during the light part of the day was always positive (Fig. 3a). Long-wave radiation balance (LRI_D – LRR_D) was always negative (Fig. 3b) indicating the important role of the vegetation and soil surface. The NR_D values were positive during the light part of the day but during the night hours they were negative because of the absence of GRI_D input and because of the LRR_D is higher in comparison to the LRI_D input from stand surrounding.

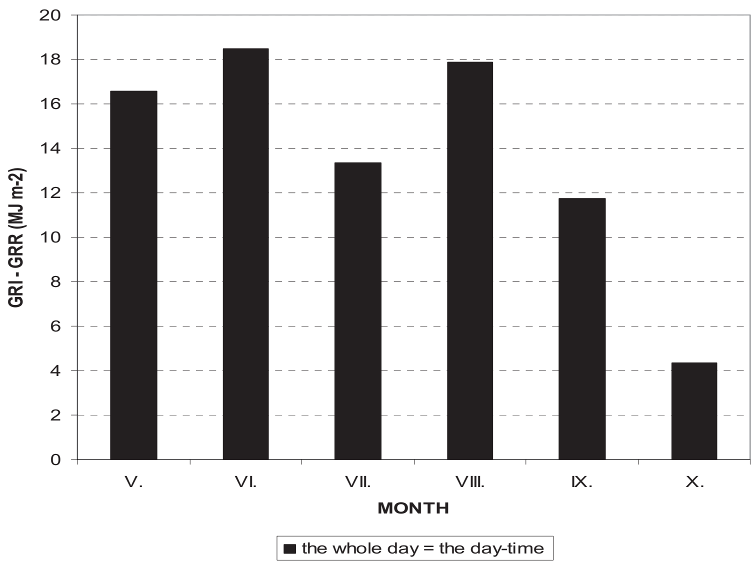
Table 1c. Night-time mean daily sums and other chosen statistical characteristics of outgoing (emitted) long-wave radiation (LRR_D), incoming long-wave radiation (LRI_D) and total net radiation (NR_D) calculated for individual months of the growing season (May–October) 2003 in investigated N. spruce stand, ERS Bílý Kříž.

	LRR_D	LRI_D	NR_D
V.	10.68	10.68	-3.50
	11.89 ± 0.75	10.40 ± 0.75	(-1.49) ± 1.05
	13.31	13.31	-0.01
VI.	10.1	8.65	-2.58
	11.19 ± 0.51	9.58 ± 0.65	(-1.61) ± 0.72
	12.38	11.37	-0.27
VII.	10.46	9.39	-2.53
	11.68 ± 0.87	10.66 ± 0.86	(-1.03) ± 0.77
	13.41	12.53	-0.01
VIII	12.51	9.72	-3.32
	13.85 ± 0.76	11.64 ± 1.17	(-2.21) ± 0.87
	15.49	14.04	-0.38
IX.	13.53	11.11	-4.36
	15.23 ± 1.23	12.77 ± 1.04	(-2.46) ± 1.27
	17.56	14.93	-0.22
X.	13.97	10.78	-4.64
	15.64 ± 0.84	14.76 ± 1.33	(-0.88) ± 1.10
	17.52	17.03	-0.02

The obtained daily sums of LRR_D, LRI_D, GRR_D, GRI_D and NR_D were used for the calculation of mean daily sums for the whole growing season of 2003 (Fig. 4a). Total net radiation amounted to 0.62 of the GRI_D. Short-wave and long-wave radiation balances amounted 13.72 MJm^{-2} and – 4.31 MJm^{-2}, respectively. The same characteristics were calculated for the light part (Fig. 4b) and night hours (Fig. 4c) of the day. During the light part of the day NR_D amounted to 11.02 MJm^{-2} and formed 0.72 of GRI_D. During the night hours values of NR_D amounted only – 1.61 MJm^{-2}. Short-wave radiation balance in the light part of the day fully corresponded to the whole day balance because of the absence of input and reflection of this radiation type. Long-wave radiation balance during the light part and night hours of the day amounted to – 2.70 MJm^{-2} and – 1.61 $MJm^{-2,}$ respectivelly

The determined 30 minutes average values of incoming and outgoing short-wave and long-wave radiation and total net radiation were used for the calculation of the monthly sums for individual months of the growing season (May–October) of the 2003 (Fig. 5a). Comparison of the monthly sums of LRR_M, LRI_M, GRR_M, GRI_M and NR_M for the light part (Fig. 5b) and night hours (Fig. 5c) of the day was done as well. Short-wave radiation (Fig. 6a) and long-wave radiation (Fig. 6b) balance was calculated for individual months of the growing season of the 2003 as well.

a



b

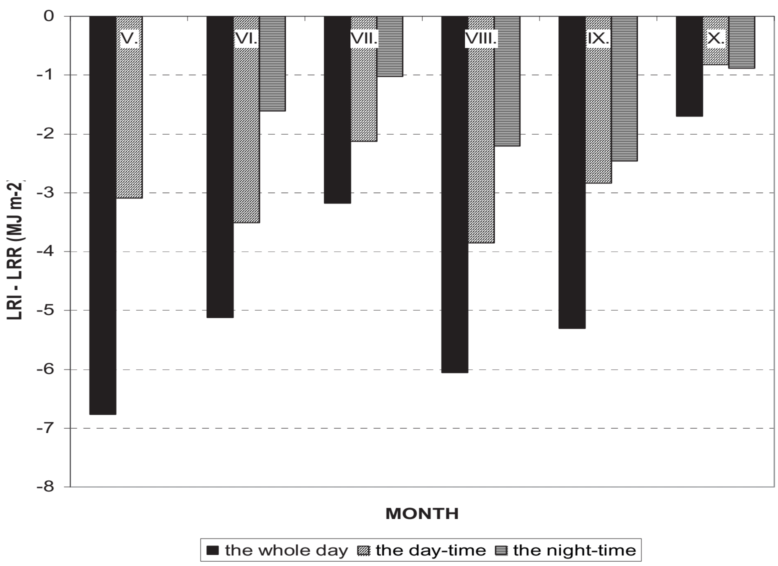


Fig. 3a,b. Short-wave radiation balance (incoming short-wave radiation GRI – outgoing short-wave radiation GRR) – **A** and long-wave radiation balance (incoming long-wave radiation LRI – emitted long-wave radiation LRR) – **B**. Calculated from daily sums for individual months of the growing season (May–October) 2003 at the Norway spruce stand, Bílý Kříž.

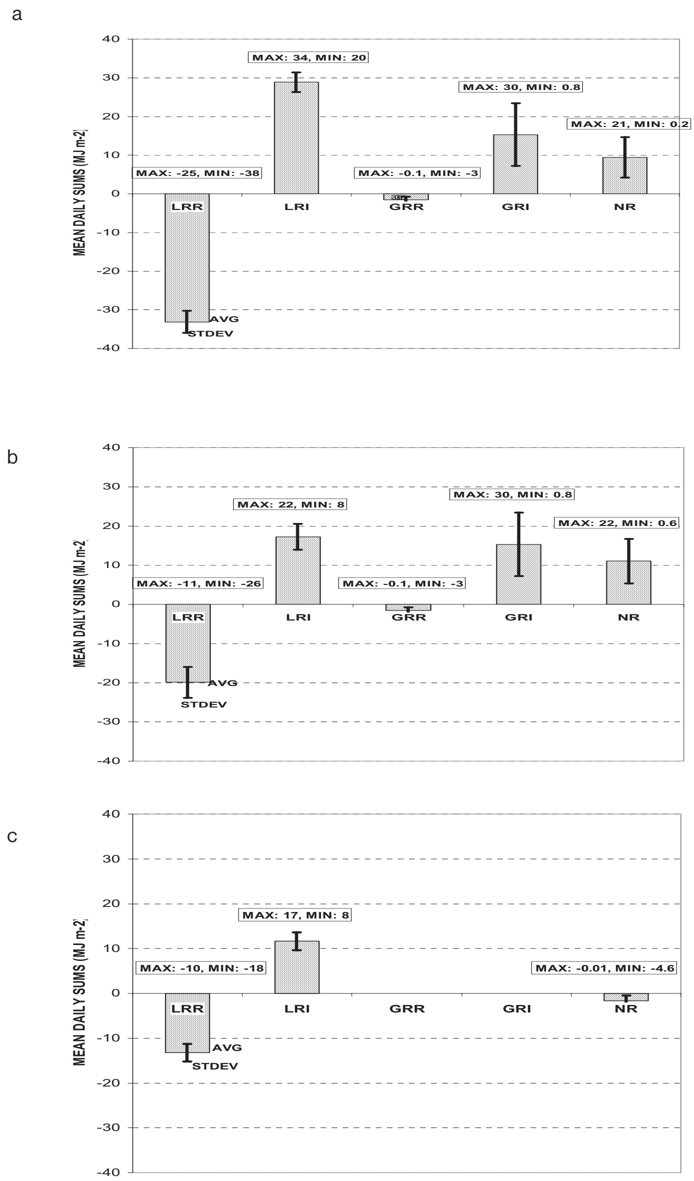


Fig. 4a,b,c. Mean daily sums and other chosen statistical characteristics of outgoing (emitted) long-wave radiation (LRR), incoming long-wave radiation (LRI), outgoing (reflected) short-wave radiation (GRR), incoming short-wave radiation (GRI) and total net radiation (NR) calculated from all daily sums – **A**, for day-time – **B**, for night-time – **C**, during the whole growing season- (May–October) 2003, in investigated N. spruce stand, Bílý Kříž. (AVG – mean daily sum, STDEV – standard deviation of daily sum, MIN – minimum daily sum, MAX – maximum daily sum.

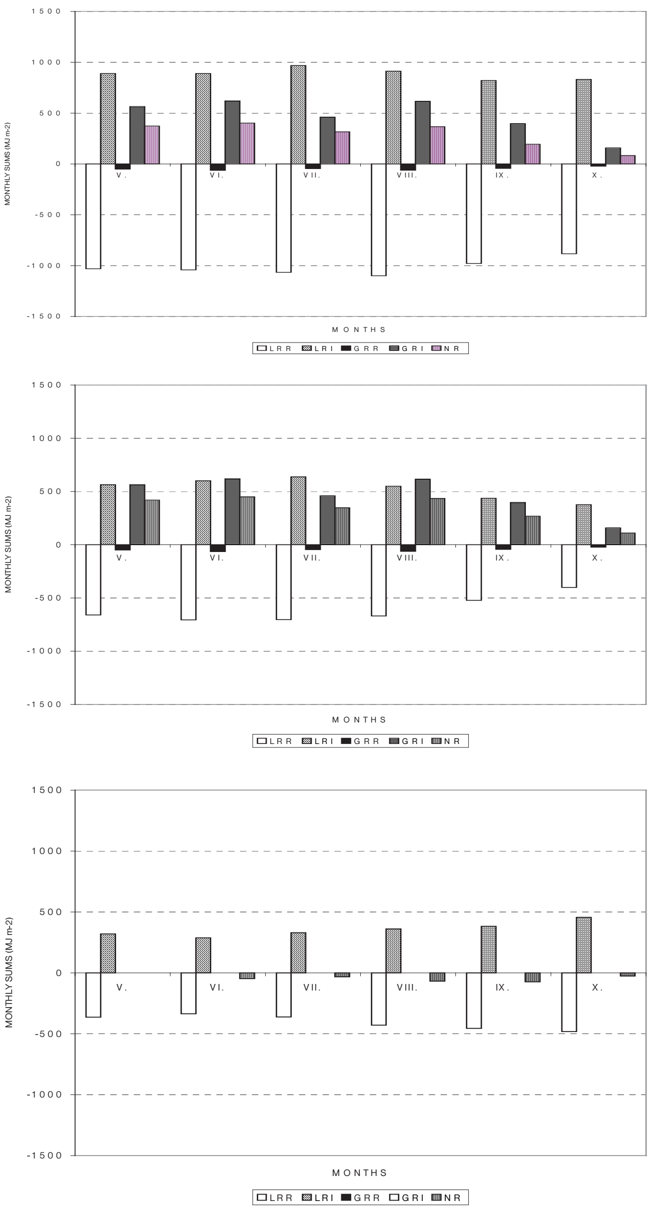
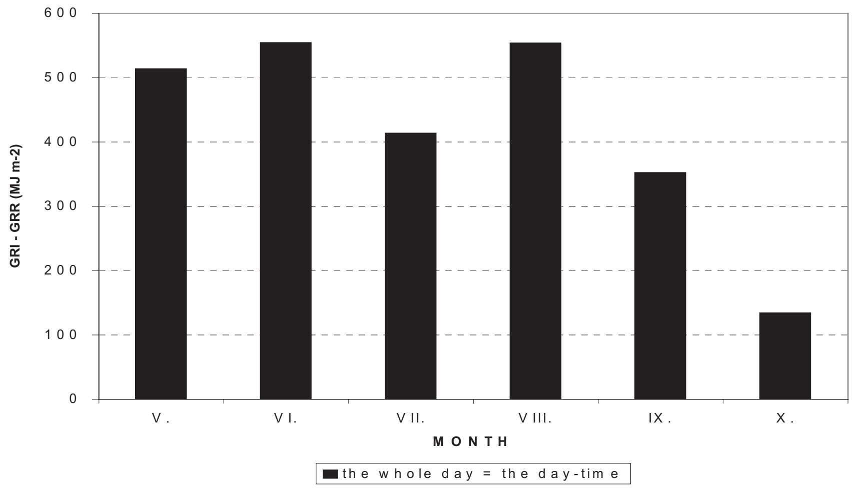


Fig. 5a,b,c. Monthly sums of outgoing (emitted) long-wave radiation (LRR), incoming long-wave radiation (LRI), outgoing (reflected) short-wave radiation (GRR), incoming short-wave radiation (GRI) and total net radiation (NR) calculated from all 30 minutes average–A, for day-time –B, the night-time values of individual months during the whole growing season (May–October) 2003 at the Norway spruce stand, Bílý Kříž.

a



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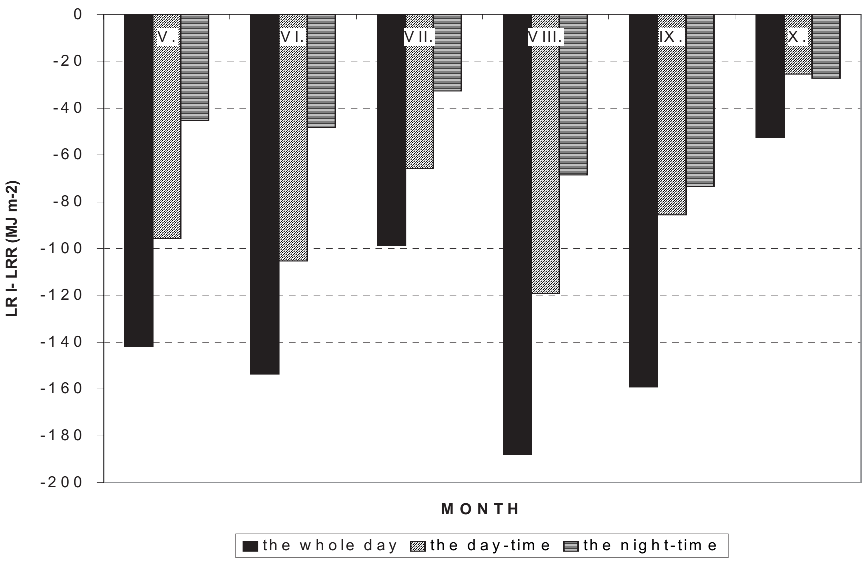

Fig. 6a,b. Short-wave (A) and e-long-wave (B) radiation balance (GRI – GRR) calculated from monthly sums for individual months of the growing season (May–October) 2003 in the N. spruce stand, Bílý Kříž.

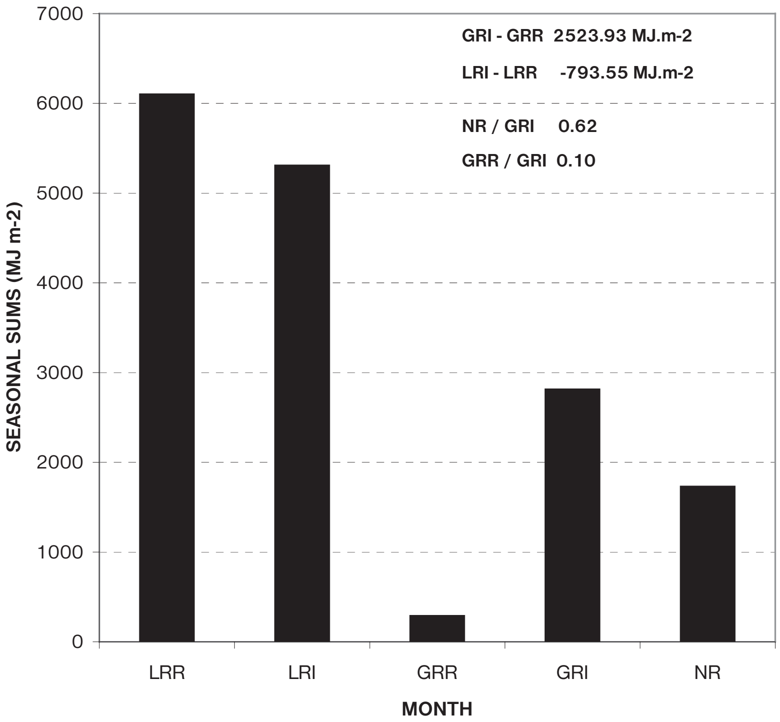

Fig. 7. Seasonal sums of outgoing (emitted) long-wave radiation (LRR), incoming long-wave radiation (LRI), outgoing (reflected) short-wave radiation (GRR), incoming short-wave radiation (GRI) and total net radiation (NR), short-wave radiation balance (GRI – GRR), long-wave radiation balance (LRI – LRR), portion of total net radiation in incoming short-wave radiation (NR / GRI) and reflection coefficient of short-wave radiation (GRR / GRI) calculated from all 30 minutes average values of the whole growing season (May–October) 2003 in the N. spruce stand, Bílý Kříž.

In the end seasonal values of incoming (GRI_S) and outgoing (GRR_S) short-wave radiation, incoming (LRI_S) and outgoing (LRR_S) long-wave radiation, total net radiation (NR_S), short-wave radiation (GRI_S-GRR_S) and long-wave radiation (LRI_S-LRR_S) balance and reflection coefficient of short-wave radiation (GRR_S/GRI_S) were calculated (Fig. 7).

Discussion

The obtained linear relationship between total net radiation and incoming short-wave radiation is supported by the literature sources. Jarvis et al. (1975) reported the values of the slope of this relation which amounts the interval 0.7–0.9 for coniferous, Tajchman (1972) reported for Norway spruce stand the values from the interval 0.61–0.75.

Determined average daily sums of incoming short-wave radiation (GRI_D) classsifies the study site as an area of higher location (Vaníček, 1994; Marková et al., 2003). These locations are typical with the effect of orography on the cloudiness in summer months, which decreases the values of incoming GRI. Vaníček (1994) reports the highest long-term average daily sum of incoming GRI_D for areas of higher location for July (18.2 MJm^{-2}) followed by May (16.5 MJm^{-2}), June and August (16.1 MJm^{-2}), September (10.9 MJm^{-2}) and October (7.7 MJm^{-2}). On the other hand Marková et al. (2003) report the highest long-term average daily sum of incoming GRI_D for the study site of Bílý Kříž in June and July (15.9 MJm^{-2}) followed by May (15.2 MJm^{-2}), August (14.4 MJm^{-2}), September (10.2 $MJm^{-2,}$), October (6.8 MJm^{-2}).

Mean daily sums of GRI_D obtained in the individual months of the growing season of 2003 were higher comparison to the long-term values (only the July and October were exceptions). Obtained values of reflection coefficient (outgoing short-wave radiation / incoming short-wave radiation) were in agreement with literature sources. Reflection coefficient values obtained in a tall Norway spruce forest amounts to 0.05 (Tajchman, 1971), for coniferous forest the reflection coefficient value 0.07 is accepted (Jarvis et al., 1975). McCaughey (1978) presented this value for a mature balsam fire stand, amounted to 0.07, Kessler and Jaeger (1999) and Gholz and Clark (2002) presented reflection coefficient value to 0.1 and 0.18 for a mature pine forest, respectively.

The mean daily sums of incoming long-wave radiation (LRI_D) were fully realted to the meteorological conditions. Seasonal course of this parameter was related to the temperature conditions, which were dependent on the GRI input. The high LRI_D value observed in July were caused by the large presence of clouds, it is confirmed by the lower value of GRI.

Presence of clouds influences markedly both short-wave and long-wave radiation (Tajchman, 1972; Betts et al., 1999; Alados et al., 2003). Daily mean sums of outgoing long-wave radiation (LRR_D) were, such as the values of LRI_D, in correspondence to meteorological conditions. However, these values could be affected by the physiological status of the forest stand such as the leaf area index seasonal changes (Burba, Verma, 2001; Law et al., 2001).

The LRR values determined during the growing season were always distinctive higher in the light part of the day. It is because of higher LRI and GRI input. The GRI input is missing during the night hours. Only one exception was found, the measurement in October. During this month the night value of LRR were lower compared to the light part of the day. The main reason was discovered in the low GRI input during this part of the day. Thus, studied spruce stand received small amount of energy which can be utilised to the stand warming subsequent followed by the LRR output to the stand surrounding.

Obtained values of the total net radiation (NR) and NR/GRI ration were in accordance to the published literature sources. Tajchman (1972) presents for a Norway spruce stand mean daily value of NR 8.33 MJm^{-2} in May, 13.10 MJm^{-2} in June, 11.81 MJm^{-2} in July, 10.93 MJm^{-2} in August and 7.45 MJm^{-2} in September and NR/GI in the interval 0.61-0.75. Jarvis et al. (1975) published NR/GRI ration for coniferous stand in the interval 0.70-0.90. The high values of NR/GRI are the results of lower reflection coefficient of conifers (Jarvis et al., 1975; Kessler and Jaeger, 1999). The NR values determined during the light part of the day were higher compared to the whole day ones. A distinctive absence of short-wave radiation producing higher radiation losses during the night hours was responsible for this phenomenon.

On the basis of these results the values of the monthly sums of LRR_M, LRI_M, GRR_M, GRI_M and NR_M obtained for the individual months of the growing season (May – October) and seasonal sums of LRR_S, LRI_S, GRR_S, GRI_S and NRS obtained after the whole growing season of the 2003 expressed as on the whole day, on the light part of the day or on the night hours were in accordance to results obtained as mean daily sum of individual measured characteristics.

Conclusion

Linear relationship between total net radiation and incoming short-wave radiation was confirmed for the studied mountain Norway spruce stand during the whole growing season (May–October) in the 2003.

Mean daily sums of incoming and outgoing long-wave radiation were fully related to the meteorological conditions during the growing season, which are considerably influenced by the short-wave radiation input. However, values of outgoing long-wave radiation could be affected by the physiological status of the studied stand as well. Ratio of total net radiation in incoming short-wave radiation was observed in the interval 0.49–0.69. Short- and long-wave radiation balances calculated for the whole growing season amounted 13.72 MJ m^{-2} and -4.31 MJ m^{-2}, respectively.

Translated by the authors

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Marková I., Janouš D., Marek M.V.: **Celková radiační bilance horského smrkového porostu na Bílém Kříži (Česká republika).**

V předložené práci jsou uvedeny některé výsledky rozsáhlého výzkumu, který probíhá v horském smrkovém porostu na ekologickém experimentálním pracovišti Bílý Kříž (Moravskoslezské Beskydy). Během vegetační sezóny (květen – říjen) roku 2003 byly samostatně měřeny a analyzovány čtyři součásti celkové radiační bilance (dopadající a odražená krátkovlnná radiace a dopadající a vyzářená dlouhovlnná radiace) a z těchto hodnot byla vypočítána celková radiační bilance porostu. Pro studovaný porost byla během celé vegetační sezóny potvrzena lineární závislost mezi celkovou radiační bilancí a dopadající krátkovlnnou radiací. Průměrné denní sumy celkové radiační bilance odpovídaly během vegetační sezóny průměrným denním sumám dopadající krátkovlnné radiace. Podíl celkové radiační bilance v dopadající krátkovlnné radiaci se pohyboval v intervalu 0.49–0.69. Hodnoty bilance krátkovlnné a dlouhovlnné radiace vypočítané pro celou vegetační sezónu byly 13.72 MJ m^{-2} a -4.31 MJ m^{-2}.