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Dynamics of soil temperature and its influence on biomass production of herb layer in a submontane beech forest

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ABSTRACT: The paper summarizes the results of long-term measurements of soil temperature. The measurements were performed at two depths: 5 cm and 20 cm, on a series of five experimental plots with different stocking. The temperature of soil in the submontane beech forest at the Ecological Experimental Site (EES) Kremnické vrchy Mts. reached maximum values in August, minimum ones in February. The obtained data were processed using *t*-test and regression analysis – to evaluate the influence of soil temperature at the discussed soil depths on the biomass production in plants. An important influence of this factor was confirmed at both depths.

Keywords: soil temperature; biomass production; herb layer; beech forest

Soil temperature is an important bio-climatic factor significantly influencing the site character. The appropriate recognition of the intrinsic nature of ecosystems requires understanding of relations between the organisms and the environment as well as within the environment itself. A natural consequence is the requirement for targeted influencing and use of the forest environment. The issue has already been broadly discussed: Petrík (1978, 1988), Střelec (1991, 1992), Smolen (1976), Tužinský (1988), Matějka and Huzulák (1987), Krečmer (1980), Volpers (1989), Ter-Gazarjan (1977), and further exploration is expected.

The soil temperature data are important for the study of root systems in plant communities, of soil microfauna, soil-forming processes, soil water dissociation and vapour condensation – important factors influencing the ecosystem production.

MATERIAL AND METHODS

Research was conducted at the Ecological Experimental Site (EES) Kremnické vrchy Mts. in conditions of submontane beech forests. The ecological site comprises five monitoring plots with adjusted stocking, representing separate phases of shelterwood cutting. The EES is located in the forest district Kováčová, in Kováčová valley, at an altitude of 450–475 m above sea level. The areas of these partial plots (PP) range between 0.5 and 0.41 hectares. The size of all PP is 1.61 ha. The species composition in the EES stand in 1990 was as follows: 85% beech, 3% oak, 2% hornbeam and 10% fir. The locality after the regeneration-felling intervention in 1989 consisted of: plot H – clear cut, stand density 0.0, plot I – intensive felling intervention, stand density 0.3, plot S – medium intensity intervention, stand density 0.5, plot M – moderate intervention, stand density 0.7 and plot K – without any intervention, stand density 0.9. The parent stand is situated on a 17–20° slope, the mean tree height is 28 m, mean tree age 90 years. The details on the individual plots are in Schieber and Kováčová (2000), Kukla (1993), Janík (1996). The soil thermometers were placed at 5 and 20 cm below the soil surface, near standard climate-monitoring boxes. The values were registered at regular 7-day intervals. The collected data were evaluated using a program package Statistika. The production amounts of aboveground and belowground biomass were determined as in Kubíček (1977). The principle consisted in the choice and localization of five representative plots on each partial plot. These plots were used for a non-destructive observation of species diversity and of the number of individuals of the observed species. Sampling was performed close to the representative plots from an in advance marked

Table 1. Average monthly soil temperatures at 0.05 and 0.20 m depth in 1998–2003

Plot	H		I		S		K		M	
Depth (m)	0.05	0.2	0.05	0.2	0.05	0.2	0.05	0.2	0.05	0.2
1998										
1	1.55	2.20	1.10	2.00	1.40	2.00	1.60	2.10	1.75	1.95
2	0.67	0.80	1.00	0.87	1.20	0.80	1.73	1.00	1.80	1.00
3	2.12	2.48	1.76	2.44	1.76	2.48	1.84	2.36	2.52	2.12
4	6.70	6.70	7.00	7.00	6.65	6.90	6.55	6.90	6.70	7.00
5	9.95	9.90	10.55	10.75	9.80	10.10	9.55	9.85	9.40	9.95
6	13.80	13.32	15.44	15.08	15.52	13.88	14.00	13.28	14.40	13.56
7	14.75	14.30	16.05	15.75	15.25	14.80	15.55	14.25	14.75	14.20
8	15.26	15.48	16.04	16.64	15.00	15.76	14.68	15.02	15.60	15.40
9	12.15	12.80	12.20	12.70	12.00	12.35	11.50	12.00	12.35	12.15
10	10.20	10.85	9.65	10.45	9.50	10.05	9.30	10.00	10.15	10.35
11	3.00	3.96	2.48	3.56	2.40	3.44	2.56	3.72	3.80	4.08
12	0.53	1.20	0.47	1.07	0.33	1.00	0.27	1.13	0.87	1.27
Average	7.56	7.83	7.81	8.19	7.48	7.80	7.43	7.63	7.84	7.75
1999										
1	0.45	0.80	0.35	0.60	0.25	0.70	0.30	0.75	0.70	0.80
2	0.25	0.30	–0.1	0.10	–0.25	0.15	0.05	0.16	0.05	0.20
3	1.72	1.72	1.68	1.72	1.76	2.00	1.96	2.00	1.84	1.92
4	6.95	6.95	7.10	7.35	6.75	6.90	6.70	7.05	7.00	6.80
5	10.44	10.52	10.88	10.96	10.20	10.12	9.60	10.00	9.80	9.56
6	14.33	14.40	15.33	14.73	14.73	14.30	14.53	13.67	14.20	13.40
7	15.90	16.50	16.55	16.70	16.10	15.95	15.75	15.60	15.75	15.70
8	14.66	15.00	14.76	15.32	14.48	14.92	14.52	14.84	14.60	14.60
9	13.85	14.15	13.80	14.35	14.05	14.60	14.25	14.70	13.90	14.35
10	9.55	9.75	9.25	9.65	9.35	8.75	9.05	9.65	9.00	9.45
11	5.32	5.84	5.00	5.40	4.84	5.60	4.80	5.72	4.76	5.84
12	1.60	1.90	1.50	1.45	1.20	1.65	1.40	1.75	1.60	2.10
Average	7.92	8.15	8.01	8.19	7.79	7.97	7.74	7.99	7.77	7.89
2000										
1	–0.10	0.80	–0.30	0.60	–1.10	0.50	–0.70	0.50	–0.10	1.20
2	0.05	0.20	0.25	0.40	0.05	0.50	0.35	0.80	0.30	0.65
3	1.55	1.05	1.35	1.30	1.20	1.35	1.60	1.75	1.45	1.60
4	7.15	7.00	7.00	7.15	6.65	7.10	6.65	7.15	6.85	7.00
5	11.76	11.88	12.08	12.56	11.92	12.16	11.64	11.72	11.64	11.88
6	13.15	13.30	13.50	13.65	13.45	13.65	13.45	13.90	12.95	13.40
7	13.16	13.00	13.52	13.96	13.16	13.48	12.64	13.24	12.84	13.28
8	16.25	16.25	16.65	16.90	16.55	16.70	16.50	16.30	15.95	16.25
9	12.60	12.40	12.50	13.00	12.30	12.75	12.05	12.80	11.95	12.45
10	10.60	10.68	10.20	11.16	10.28	11.04	9.84	11.08	9.96	11.12
11	7.00	7.20	6.90	7.65	6.60	7.45	6.50	7.75	6.85	7.75
12	2.80	3.40	3.00	3.75	2.65	3.50	2.90	3.90	3.00	3.85
Average	8.00	8.10	8.05	8.51	7.81	8.35	7.79	8.41	7.80	8.37

Table 1 to be continued

Plot	H		I		S		K		M	
Depth (m)	0.05	0.2	0.05	0.2	0.05	0.2	0.05	0.2	0.05	0.2
2001										
1	0.08	1.20	0.36	1.12	0.08	0.96	0.56	1.16	0.52	1.08
2	–0.05	0.60	0.15	0.60	0.00	0.45	0.15	0.80	0.10	0.85
3	3.50	3.60	3.95	3.85	3.60	3.40	3.55	3.30	3.20	3.45
4	6.40	6.48	6.44	6.36	6.12	6.36	6.28	6.28	6.08	6.28
5	11.30	11.35	11.45	11.55	11.30	11.20	10.80	11.15	11.40	10.90
6	12.25	12.45	12.55	12.60	12.70	12.30	12.30	12.25	12.30	12.20
7	16.88	16.80	16.76	16.24	16.64	16.44	15.92	15.84	16.28	15.88
8	16.80	17.00	16.90	16.95	16.20	17.20	16.10	17.00	16.50	16.80
9	11.48	12.50	12.00	13.50	10.85	11.90	11.10	11.95	10.65	12.10
10	10.88	11.68	11.08	12.04	10.88	11.40	10.84	11.36	10.72	11.12
11	4.13	5.37	4.73	5.47	3.40	4.47	3.53	5.07	3.13	4.47
12	0.04	1.20	0.32	1.28	–0.48	0.60	–0.20	0.92	–0.24	0.80
Average	7.81	8.35	8.06	8.46	7.61	8.06	7.58	8.09	7.55	7.99
2002										
1	–0.35	0.73	–0.20	0.85	–0.45	0.15	–0.35	0.05	–0.50	0.35
2	1.00	1.40	1.20	1.40	0.85	1.30	1.20	1.45	1.35	1.50
3	3.00	3.20	2.90	3.15	2.65	2.80	2.80	3.15	3.10	3.20
4	6.20	6.52	6.20	6.16	5.64	6.40	5.96	6.80	5.96	6.44
5	12.70	12.70	12.70	12.60	12.70	12.70	12.60	12.45	12.40	12.50
6	14.50	14.20	14.90	14.60	14.95	14.65	14.60	14.65	14.55	14.50
7	15.56	15.36	15.60	15.52	15.48	15.72	15.76	15.88	15.40	15.76
8	16.00	16.50	16.65	16.65	16.45	16.60	16.20	16.60	16.60	16.90
9	11.48	12.72	12.48	12.68	11.88	12.64	11.24	12.68	12.28	13.24
10	7.00	8.15	7.40	8.15	6.90	7.50	6.55	7.80	7.20	8.20
11	4.95	5.63	5.25	5.75	4.75	5.15	4.50	5.45	5.30	6.00
12	1.36	2.00	1.60	2.04	1.24	2.00	0.92	2.12	1.65	2.64
Average	7.78	8.26	8.06	8.30	7.75	8.13	7.67	8.26	7.93	8.44
2003										
1	–0.05	0.20	–0.15	0.10	–0.05	0.05	–0.30	0.10	–0.15	0.30
2	–0.75	0.05	–0.65	–0.05	–0.55	–0.10	–0.90	0.00	–0.70	0.15
3	1.56	1.68	1.36	1.68	1.32	1.68	1.32	1.68	1.28	1.56
4	5.05	5.95	5.10	6.00	4.80	5.90	4.80	6.10	5.00	5.85
5	11.65	11.65	11.85	11.60	11.75	11.65	12.00	11.65	11.75	11.20
6	14.08	14.28	14.64	14.60	14.36	14.44	14.20	14.60	14.72	14.52
7	15.65	15.55	15.85	15.70	15.60	15.65	15.75	15.70	15.90	15.65
8	16.50	16.70	16.84	16.75	16.75	16.80	16.55	16.85	17.15	17.00
9	12.36	13.20	12.52	13.24	12.24	13.04	12.04	13.24	12.92	13.36
10	7.25	7.65	7.20	8.00	6.40	7.60	6.60	8.10	7.45	8.50
11	4.70	5.30	5.15	5.35	4.80	5.35	4.60	5.35	5.15	5.70
12	2.04	2.84	2.24	2.76	2.00	2.80	1.88	2.88	2.24	3.04
Average	7.50	7.92	7.66	7.98	7.45	7.91	7.38	8.02	7.73	8.07

H – clear cut area, I – intensive felling intervention, S – medium intervention intensity, K – control plot, M – moderate intervention intensity

Table 2. Statistical characteristics of average soil temperature at a depth of 0.05 m and 0.20 m in 1998–2003

	Partial plots, depth (m)									
	H		I		S		K		M	
	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20
Valid	6	6	6	6	6	6	6	6	6	6
Mean	7.8	8.1	7.9	8.3	7.7	8.0	7.6	8.1	7.8	8.1
Median	7.8	8.1	8.0	8.3	7.7	8.0	7.6	8.1	7.8	8.0
Sum	46.6	48.6	47.7	49.6	45.9	48.2	45.6	48.4	46.6	48.5
Std. dev.	0.20	0.20	0.17	0.20	0.16	0.20	0.17	0.30	0.13	0.30
Min.	7.50	7.83	7.66	7.98	7.45	7.80	7.38	7.63	7.55	7.75
Max.	8.00	8.35	8.06	8.51	7.81	8.35	7.79	8.41	7.93	8.44
Range	0.50	0.52	0.40	0.53	0.36	0.55	0.41	0.78	0.38	0.69
V_x%	2.60	2.50	2.50	2.40	2.13	2.40	2.20	3.75	1.54	3.75
Std. err.	0.08	0.08	0.07	0.08	0.07	0.08	0.07	0.10	0.05	0.10

Std. dev. – standard deviation, Std. err. – standard error, V_x% – coefficient of variation

transect. Plant communities of the plots H, I, K belong to the association *Carici pilosae Fagetum* and those of the plots S and M to the association *Dentario bulbiferae Fagetum*. Observing the belowground biomass production, we applied the method according to Fiala (1987). The method was based on the separation of rhizosphere from the aboveground part at the place of interface between the atmosphere and the soil surface. Removing the undesired mixtures, the laboratory processing and calculation per unit area were used to obtain the data on production abilities of the observed plant species. The impact of temperature on biomass production in herbs was evaluated using analysis of variance and regression analysis.

RESULTS AND DISCUSSION

As we can see in Table 1, the soil temperature in the submontane beech stand at the EES reached maximum values at both soil depths mainly in August. Minimum temperatures were measured in February. The only exception was 2002, when the minima on all partial plots were recorded in January. Minus values to –1.1°C were measured only in the upper 5cm layer. At the 20cm depth minus values were observed in February 2003, on plots I and S. Smolen (1976) stated that the forest soil got frozen only in its uppermost 2cm layer, the other soil layers maintaining positive values all the year round. The author also reported that the soil freezing was dependent on its heat conductivity. Measurements proved that the day heat transport into deep soil layers was substantially higher on an open area compared to the forest stand. On the other hand, the reverse flow in night was also more intensive on the open area. The snow cover thickness also plays an important role. Ten years after the cutting, we can see that the differences in temperature in the upper 5cm soil

Table 3. Student's t-test between partial plots and between the years 1998–2003

Plots	1998		1999		2000		2001		2002		2003	
Depth (m)	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20
H:I	1.2	1.66	0.74	0.45	0.71	4.7^{++}	1.09	1.05	3.0^{++}	2.0^{++}	2.5^{++}	1.3
H:S	0.57	0.29	1.58	0.48	1.75	4.2^{++}	1.92	0.92	0.33	1.27	0.57	0.3
H:M	2.3^{++}	0.91	1.75	1.39	1.73	3.2^{++}	1.93	3.1^{++}	1.59	0.05	1.65	2.2^{++}
H:K	0.77	2.1^{++}	1.82	2.3^{++}	2.4^{++}	4.2^{++}	2.1^{++}	3.8^{++}	1.57	1.97	2.6^{++}	1.63
I:S	2.5^{++}	3.3^{++}	2.7^{++}	0.35	3.9^{++}	3.2^{++}	1.15	0.88	4.9^{++}	1.69	3.1^{++}	1.68
I:M	0.12	2.2^{++}	1.86	1.25	2.9^{++}	0.28	1.18	2.8^{++}	3.3^{++}	0.38	4.5^{++}	3.1^{++}
I:K	1.97	2.6^{++}	1.67	1.51	2.0^{++}	1.1	1.19	3.5^{++}	2.3^{++}	1.62	1.3	1.2
S:M	2.3^{++}	0.43	0.59	0.82	0.17	1.16	0.29	0.99	0.95	2.2^{++}	1.32	2.6^{++}
S:K	0.6	1.68	0.22	1.1	0.04	0.21	0.65	1.03	2.0^{++}	3.1^{++}	2.8^{++}	1.67
M:K	2.5^{++}	2.2^{++}	0.37	1.46	0.1	0.99	0.25	1.59	2.1^{++}	2.0^{++}	3.5^{++}	0.67

$^{++}$ statistically significant ($\alpha = 0.05$)

Table 4. Average biomass production of herb layer in kg/ha

Partial plots	H	I	S	K	M
Aboveground biomass	1,931	735	382	127	234
Belowground biomass	2,272	661	488	157	477

layer reach 0.5°C, rarely 1°C, between the individual plots. No difference higher than 1°C was recorded. A very similar situation is at a 20cm depth where we recorded even smaller differences. Larger differences were between the years: at 5cm depth they ranged between 0.36 and 0.5°C, at 20cm depth 0.52–0.69°C. Table 1 presents mean annual temperatures at depths of 5 and 20 cm. It is evident that the year 2000 can be considered the warmest on almost all partial plots. Higher values were measured only in 2002 at both depths on plot Střelec (1991) reported that in 1990 (one year after the cutting) maximum temperatures were on clear-cut plot H measured in August – up to 17°C. One year later, minimum soil temperatures at 20 cm were recorded in February –0.7°C, maximum in August – over 16°C. The mean annual temperature on the clear-cut plot reached 7.6°C. We can conclude that the damping impact of forest stands on temperature extremes compared to unforested area is considerable. On the other hand, the differences between mean annual temperatures of the soil are not significant. Petrík (1988) reported that the differences in soil temperature in forest stands compared to clear cut could reach 5.1°C for maximum values, 2.5°C for minimum ones. The differences in amplitude can reach 5.1°C. Similar results were obtained in the primeval forests Badín and Dobroč.

Table 2 summarizes the statistical measures of amount and symmetry. Key important is variation in mean annual temperatures whose values did not exceed 4% at both the tested depths. The Student's *t*-test did not reveal any significant differences in soil temperature on the same plots between the years. On the other hand, there were highly significant differences between the plots even in the same year. The largest differences were found between the clear-cut and the forested plots. All the testing results are summarized in Table 3. Regression and variance analyses were also tools for assessment of the influence of soil temperature at depths of 0.05 and 0.20 m on biomass production in herbs. The obtained differences revealed the high significance of the examined factor. The results are presented in Tables 4 and 5.

CONCLUSION

We can summarize that the minimum soil temperature values at 0.05 and 0.20m depths were recorded in February, maximum ones in August. The soil gets frozen only to the depth of 0.05 m, exceptionally to 0.20 m – in dependence on the snow cover. It has been shown that the time factor is determinant for mitigation of extreme values of soil temperature, primarily on the open area. One year after the intervention, the maximum mean temperature of soil, about 17°C, was in August at 0.05 and 0.20 m, 10 years later, 7–8°C. This phenomenon was caused by the succession of plant species at the site, and by the creation and growth of successive parent stand. Such phenomena have mitigating effects on extreme values of temperature characteristics. The differences between the years on the same plots are not significant; on the other hand, there are significant differences

Table 5. Analysis of variance of the influence of average soil temperature on the aboveground and belowground biomass production of herb layer

Source of variation		Between groups	Residual	Total
Sum of squares	A-biomass	335,295	1,979,028	2,314,323
	B-biomass	82,070	2,232,253	2,314,323
Degree freedom	A-biomass	1	3	4
	B-biomass	1	3	4
Mean squares	A-biomass	353,294.9	659,676.0	
	B-biomass	820,069.7	744,084.0	
F-ratio	A-biomass	10.508		
	B-biomass	15.110		
P level	A-biomass	0.50		
	B-biomass	0.70		

$F_{0.05}$ = 10.13, $F_{0.01}$ = 34.12 – critical values of *F*-ratio, A-biomass – aboveground biomass, B-biomass – belowground biomass between the individual plots – primarily between the clear-cut plot and forest stands of different density. Regression analysis revealed a very close dependence of biomass production in herbs on the soil temperature. Nevertheless, as for the statistical tools, I feel necessary to add that the nature of all the studied processes is exclusively biological; they cannot be planned or repeated identically. We are aware of possible problems connected with the result misinterpretation. However, they can provide us with tools for evaluation and forecasting of some events and causal relations and then setting them under a conscious control. We would like to reach with this paper a contribution to a more complex understanding of individual environmental phenomena and processes.

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Dynamika teploty pôdy a jej vplyv na produkciu biomasy bylín v podmienkach podhorských bučín

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ABSTRAKT: V práci uvádzame výsledky šesťročného výskumu merania teploty pôdy v hĺbke 5 a 20 cm na sérii piatich plôch s rozdielnym zakmenením. Maximálne teploty pôdy v podhorských bučinách Ekologického experimentálneho stacionára (EES) Kremnické vrchy boli v auguste, minimálne vo februári. Testovaním a regresnou analýzou sme vyhodnotili vplyv teploty pôdy v uvedených hĺbkach na produkciu biomasy bylín. Bola preukázaná veľmi významná miera vplyvu tohto faktora, a to v obidvoch sledovaných hĺbkach.

Kľúčové slová: pôdna teplota; produkcia biomasy; rastlinná vrstva; bukový porast

Cieľom príspevku bolo uviesť výsledky šesťročného výskumu merania teploty pôdy v hĺbke 5 a 20 cm. Výskum bol uskutočnený v podmienkach bukového Ekologického experimentálneho stacionára (EES) Kremnické vrchy. Teplotu pôdy sme zaznamenávali na sérii piatich plôch s diferencovaným stupňom zakmenenia pomocou ortuťových teplomerov. Z výsledkov uvedených v tab. 1 je vidieť, že maximálne teploty pôdy v oboch sledovaných hĺbkach boli zaznamenané v letných mesiacoch – prevažne v auguste, v ojedinelých prípadoch v júli. Minimálne teploty boli namerané vo februári, a to na všetkých sledovaných čiastkových plochách a počas celého obdobia. Z výsledkov je tiež zrejmé, že pôda v hĺbke 20 cm pod ochranou materského porastu v podstate nezamŕza. Premŕzanie v hĺbke 5 cm bolo zaznamenané v mesiacoch január a február (len v nepatrnej miere). Produkčné schopnosti sledovaného lesného ekosystému sme posudzovali pomocou metódy nepriameho odberu podľa Kubíčka (1977). Najvyššie hodnoty vyprodukovanej tak nadzemnej, ako aj podzemnej biomasy bylín sme zaznamenali na ploche H, kde bol uskutočnený holorub (1 931 kg nadzemnej a 2 272 kg podzemnej biomasy bylín). Najnižšie produkčné schopnosti vykazovala plocha K – kontrólna bez zásahu (127 kg nadzemnej a 157 kg podzemnej biomasy bylín). Pomocou Studentovho *t*-testu a metódy regresnej analýzy sme hodnotili vplyv teploty pôdy v oboch sledovaných hĺbkach na produkciu nadzemnej a podzemnej biomasy bylín. Z výsledkov uvedených v tab. 5 bola preukázaná významná miera vplyvu tohto faktora, a to v obidvoch sledovaných hĺbkach.

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