TEMPERATURE AND OTHER MICROCLIMATE CONDITIONS IN THE OAK FORESTS ON FRUŠKA GORA (SERBIA)

by

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The paper presents the most important data on temperature and other microclimate conditions (solar radiation and light regime) in the 127 year old even-aged pure sessile oak forest in the National Park "Fruska Gora" in Serbia. Data collection was conducted in July 2008, using an automatic weather station "WS-GP1" and a lux meter with a selenium photocell. The study stands are located on the east and west facing sides of a ridge at an altitude of 475 m. The slope inclination is 27° and 32°. The canopy is sparse to complete (0.6-0.7). The paper presents comparative research results for the eastern and western aspect, which are further compared with the data from the reference weather station "Rimski Sancevi". The intensity and trend of microclimate changes depend on the type of forest, its structure, geographical location, canopy closure and other features. Microclimate research results indicate that during the research period the maximum air temperature of the eastern aspect was 24.8 °C, which was 3.6 °C below the maximum measured at the reference station. The maximum air temperature of the western aspect amounted to 31.0 °C, which was 2.8 °C below the value measured in the open. The maximum total solar radiation of the eastern aspect was 769 W/m^2 (at 11.08), and 634 W/m^2 (at 15.31) of the western. The research determined that the east-facing stand had the light intensity of 6,766.3 Lx/m^2, while the light transmission coefficient amounted to 14.8%; the west-facing stand had the light intensity of 9,213.8 Lx/m^2 and the light transmission coefficient of 19.3%.

Keywords: *air temperature, solar radiation, microclimate conditions, illumination, Fruska Gora, oak forest*

Introduction

In the last decades of the 20th century many research studies on the impact of air pollution and climate change on the environment and ecosystems [1-3] were carried out in Central Europe. Increasing fossil fuel burning, forest shrinkage, conversion of forest to agriculture, *etc*., have led to the increase in the concentration of gases that retain heat, and consequently to the cli-

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mate change. The trend and dynamics of the changes are accelerating and as such they impede flexible ecosystem management [4]. Global climate change inevitably causes changes in the climate of microhabitats. Researches on the global climate change impact on microclimate conditions are of great importance in studying dynamics of different ecosystems and environmental conditions. One of the problems of these studies is insufficient number of permanent sample plots for collecting microclimate data and the ensuing lack of microclimate assessments data [5]. Monitoring microclimate data on permanent sample plots in the microhabitats of different ecosystems would provide unique data on the long-term impact of global change on microclimate changes [6]. The key question is how the global climate change affects the microclimate of different ecosystems? Today, there is a growing need for the data collected on such sample plots which could be used for the purpose of monitoring the climate change or adaptation of forest management to the climate change [7].

The scientific debate, would certainly contribute to better understanding of the arguments for and against the so-called global warming, that is, climate changes [8]. According to [9] early understanding of reality of the upcoming global cooling and physical mechanisms responsible for it directly determines a choice of adequate and reliable measures which will allow the mankind, in particular, population of countries situated far from the equator, to adapt to the future global cooling.

Knowledge of microclimate conditions is of great importance in the study of site conditions, bio-ecological characteristics of tree species and natural ecosystems. Although they contribute to better understanding of ecosystem functioning, the available data on microclimate conditions in forest ecosystems are insufficient [10-21]. Therefore, the climate of a forest site is usually defined using data provided by nearby weather stations that are far off the forest and usually in urban areas at lower altitudes, *i. e.* under a considerable influence of the so-called "urban climate". The values of climate indicators obtained from the stations differ from the values of the same elements when measured within forest stands, as indicated by [22-24].

Contemporary studies suggest that the forest ecosystems will in the future be significantly affected by increasing air temperatures, reduced amount of rainfall, rising concentrations of CO_2, wildfires, intensive and extended droughts, wind breakage, extreme precipitation, insects and pathogens [25].

By monitoring air temperature in three different time aspects (monthly, daily and hourly) we can determine spatial variability of microclimate conditions [26]. As a result of the climate change, larger fluctuations in daily temperatures can be expected, which would have a negative effect on forest ecosystems especially in the growing season and due to the longevity of woody species [25, 27].

Changes in climatic elements in the horizontal direction on a small forest area are brought about by the changes in forest structure, orography, vegetation and other site characteristics. The term "microclimate" refers to areas, as wide as 0.1-100 m [28]. Therefore, the data obtained from the network of main meteorological stations cannot be applied to all climate conditions in the forest.

The elements of microclimate are interdependent, so that the changes in one of the elements affect other elements. The intensity and the trend of these changes depend on the type of forest, its structure, geographical location, canopy closure and other features. Therefore, forests have their own specific phytoclimates, which clearly reflect the impact of forest vegetation on climatic elements. Lambert's law says that the radiant intensity received by the surface from the Sun is proportional to the cosine of the angle between the direction of the incident light and the surface normal. Therefore, the south and west facing sides are warmer than those facing north and east [29]. It is common knowledge that light has many roles, one of which is the transfer of heat that affects the air and soil temperature regimes in the forest [28, 30]. Optimal forest microclimate conditions (light regime, air and soil temperatures, humidity and solar radiation) are closely related to the main purpose of silviculture, forest tending, methods of natural regeneration, intensity of felling, and productivity growth. Based on the above the objective of this paper was to determine the impact of forests on climate and global climate change on this specific site of Fruska Gora and to compare the available data with the data obtained in the open.

Research area, materials and methods

The research was performed on Fruska Gora, which stretches as a single mountain in the northern part of Serbian Syrmia plain, which is situated in the province of Vojvodina – administrative area of Serbia. Its longitude is λ = 19°5' and the latitude φ = 45°10'. Vojvodina is situated in the area of humid continental climate with specific characteristics that in some areas manifest elements of sub-humid and mesothermal climate [31]. According to [32], bioclimatic classification by Lang shows that the study area has the features of humid climate, while Thornthwaite climate classification defines the climate of Fruska Gora region as predominantly moist sub-humid climate – C2 type. Looking at the overall climate conditions in the territory of Fruska Gora, we can conclude that the mean annual air temperature amounts to 9.9 °C for Iriski Venac.

Data collection was performed on the sampled areas within the sessile oak forest. The measurements were performed within two sample plots, hereinafter designated as SP1 and SP2. The following basic microclimate parameters were measured: air temperature, soil temperature at the depth of 10 cm, solar radiation, light intensity, and the obtained data were used to study microclimate conditions. The data on the stand state of the selected sample plots are shown in tab. 1.

Table 1. Basic data on the 20 m × 20 m sample plots and canopy closure

Sample plot 20 m × 20 m	Altitude [m]	Aspect [°]	Slope [%]	Canopy closure [SS]	Total crown area [m^2]	Average crown area per one tree [m^2]	Average distance between trees [m]	li [Lxm^{-2}]
1	475	E	27	0.6-0.7	366.7	107.0	47.4	12.2
2	475	W	32	0.6-0.7	339.4	76.6	26.0	9.8

Stand canopy varies from sparse to complete (0.6-0.7). The slope inclination is steep and amounts to 27°-32° and the altitude is 475 m.a.s.l. At the stand age of 127 years, the number of trees per hectare is 140 in SP1 and 176 in SP2.

The position of all trees on the sample plots (20 m × 20 m in size) was determined and the horizontal crown projection was taken in order to determine the degree of canopy closure. Stationary isohel method [12] was applied to determine the regime of light in the stands. The measurements were conducted at 36 light regime measurement points within the sample plots (fig. 4). They were carried out in summer *i. e.* in the sunniest month of July – successively from 9 to 11 July. Light intensity was measured every two hours from 6.00 to 18.00 by local time. Lux meter LX-107, Lutron with a range of measurement from 0 to 100,000 Lx and the measurement error ± 5% (fig. 2) was used. The instrument was held in the horizontal position at a height of 1.0 m above the ground.

Microclimate studies used a WS-GP1 portable automatic weather station (fig. 1), which allows the measurement of basic meteorological parameters (air temperature, solar radiation) in the desired time intervals at a height of 2 m. The station operates on the principle of radio waves sent by sensors from each measuring instrument. Data are stored in a separate receiver (Data-logger GP1), and transmitted to a mobile computer. These measurements were carried out on each sample plot for three consecutive days in the period from 6.00 to 18.00, at intervals of 1 minutes, which means that in one day the station had 720 measurements of each element. The mean was calculated for each of the measured meteorological elements using 13 daylight measurement terms or every full hour (6.00 a. m. to 6.00 p. m.). Soil temperatures on the sample plots were measured at a depth of 10 cm with a "Lambrecht" link arm geothermometer, every two hours in 7 daylight terms (6.00-18.00). The investigations were carried out in the period from 9 to 14 July, 2008.

Figure 1. "WS-GP1" automatic weather station

Figure 2. LX-107 Lutron Lux meter

Data processing was performed in the standard manner, applying the methods commonly used in forestry research studies for each type of the measurements. AutoCAD 2007 was used to present the spatial distribution of trees with the horizontal projections of the crowns on 20 m × 20 m sample plots. We calculated the total crown area of the sample plots (without overlapping), the average distance between trees, and the average crown area of a (single) tree. AutoCAD Map 6.0 application was used to determine the area between isohels, and the obtained weighted values were used to calculate the average light intensity on each 20 m × 20 m sample plot.

The mean values of the stated climatic elements are graphically represented for each study stand – sample plot separately. The obtained data were compared between the sample plots and with the data gathered in the open at the reference weather station Rimski Sancevi for the termins 7.00, 14.00 and with the max value [33]. The station which provides data on daily values of climate elements is located at 86 m a.s.l.

Results and discussion

Light regime in the study stands

Horizontal changes in the elements of climate that occur on a small area of a forest are brought about by the changes in vegetation, orography and other site conditions. In addition, the impact of global warming causes changes in the light microclimate. The infrared portion

($0.7 < \lambda < 1,000$ μm) of the spectrum of solar radiation carries radiant heat. Changes in the degree of the tree canopy cover in forests change the intensity of solar radiation and consequently change the impact of the infrared portion of the spectrum on the ecosystem functioning.

Light conditions in a forest stand are complex and depend on a number of factors. According to [34], it is difficult to determine the amount of light that a certain point of the forest floor receives because it is not constant. Forest floor receives both direct and diffuse light [29, 35, 24]. Diffuse light is constantly present in the forest, as well as the light that penetrates through canopy gaps (known as sun patches or sun flecks) formed by wind-induced crown swaying and leaf fluttering. The greatest amount of light is received through the canopy openings in the form of direct solar irradiance. The position of the sun in the sky determines the angle under which the sun's rays fall onto the surface. Cloudiness has a large impact on the direct solar irradiance. According to [36], solar irradiance can be potentially without the influence of cloudiness or it can be either absolute or effective under cloudy conditions.

The intensity of solar radiation and the amount of sunlight in the forest are difficult to determine due to the inhomogeneity of vegetation structure [37]. Sunflecks present an additional hindering factor in the measurement of solar radiation in the forests [38, 24]. A sunfleck is the direct sunlight that penetrates through tree crowns onto the forest floor. They usually occur as brief pulses whose position varies with the height and position of the sun. The intensity of the sunfleck light is approximately the same as the intensity of the light in the open. Therefore, it is necessary to take several measurements at different times of the day and take the mean as the actual amount of light in the forest [39].

According to [40], the average daily level of light transmission in sessile oak forests of northeastern Serbia ranges from 19.4% to 50% for different ecological and production units. According to [32], on Fruska Gora it is between 9.6% and 21.9%. These values are within the limits stated by other authors for sessile oak forests.

Sample plot 1 and its stand

The stands within which the sample plots are located stretch along both sides of a ridge road. The stand in which sample plot 1 is located faces east. It has a sparse to complete canopy of 0.6-0.7. The slope inclination is steep and amounts to 27°. The altitude is 475 m. The total canopy cover (tab. 1) of sample plot 1 is 366.7 m^2 (92%), while the double and triple crown overlap amounts to 107 m^2. The crown area of an individual tree is about 47.4 m^2, with the average distance between the trees of 12.2 m (fig. 4). The average light intensity on the plot is 6,545 Lx, with the mean light intensity per unit area of 6,766.3 Lx/m^2.

The largest part of the plot, 231.2 m^2 or 57.8% (fig. 3), is illuminated with 5,000 Lx to 10,000 Lx, while a large part of its area, 117.1 m^2 or 29.3%, has the illumination below 5,000 Lx. This plot receives a lot of light on the part of the plot not covered by crowns near the opening. This area of the plot exposed to a greater quantity of light amounts to 45.8 m^2 or 11.5%, but the light intensity is moderate (12,500 Lx). Strong light penetration, which covers approximately 6 m^2, has the intensity of 17,500 Lx and 22,500 Lx. This is due to the proximity of the ridge road just above the sample plot.

The maximum illumination on this plot occurs after local noon, at 14.00, and amounts to 13,868.6 Lx (fig. 6), while the light transmission coefficient reaches its maximum of 19.7% at 8.00 (fig. 5). The average value of the light transmission coefficient (ltc) is 14.8%. Figure 5 shows that the average daily flow of ltc for this plot has a steady increase in the morning when it culminates, which is due to the eastern aspect of the stand and its slope inclination. This is the stage when the greatest light reaches the understory. The light transmission coefficient is high and constant till 14.00, when it starts to decrease.

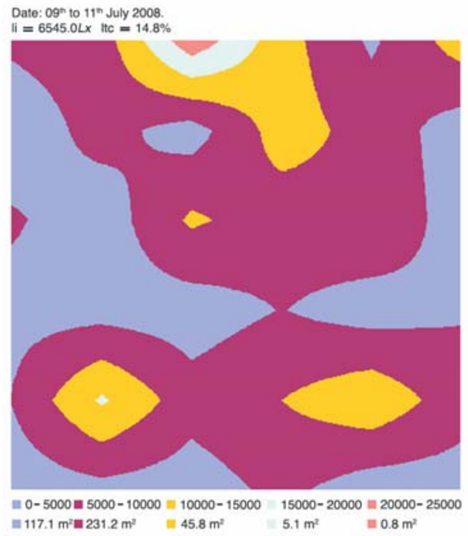

Figure 3. Average daily light intensity

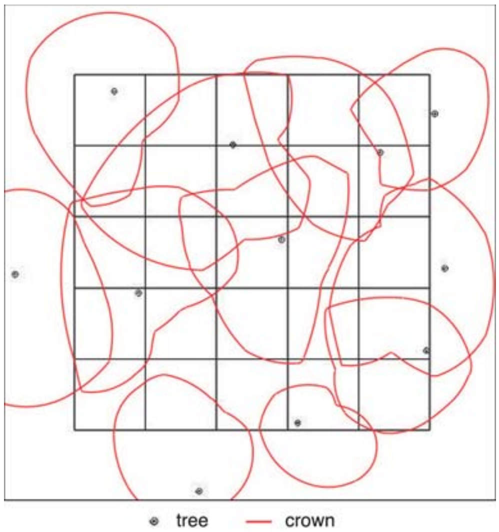

Figure 4. Canopy cover on sample plot 1

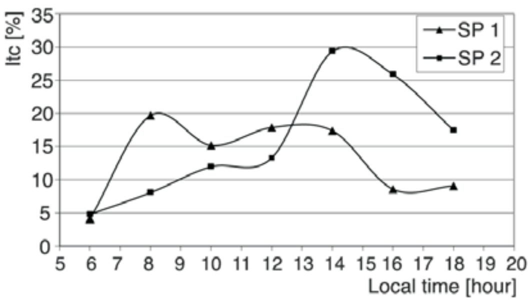

Figure 5. Average daily flow of the light transmission coefficient

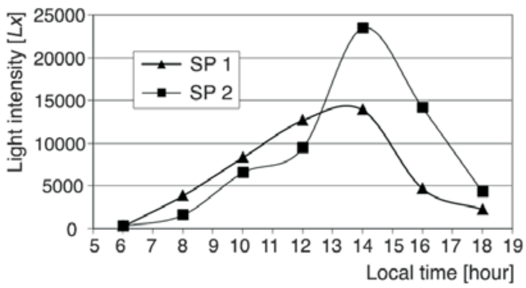

Figure 6. Daily course of the light intensity

The daily course of light intensity shows a strong influx of light from early morning hours throughout the entire morning (fig. 6) until it reaches its peak at 14.00. The light intensity curve has a pronounced right asymmetry. Like in the case of air temperature, it decreases after the culmination (fig. 9), which is directly related to the aspect and slope inclination.

Sample plot 2 and its stand

The stand in which sample plot 2 is located faces west and has the same stand canopy of 0.6-0.7 as the previous stand. The slope is a bit steeper and amounts to 32°. The altitude is the same. The plot has a slightly lower canopy cover (tab. 1) compared to the previous sample plot. It amounts to about 339.4 m^2 (85%), with the double and triple crown overlap of 76.6 m^2. The crown area of an individual tree is about 26 m^2. The average distance between the trees is 9.8 m (fig. 8).

The mean daily light intensity per unit area is 9,213.8 Lx/m^2, which is significantly higher than in the previous stand. The impact of global warming in this stand may have a greater effect on vegetation than in the previous stand. The largest part of the plot, *i. e.* 243.8 m^2 or 60.9%, is illuminated with the light intensity between 5,000 Lx and 10,000 Lx (fig. 7). The light of higher intensity is received by a significant part of 92 m^2 or 23.0%. This intensity is 12,500 Lx on average and occurs as a result of a large lateral opening on the southwest edge of the plot and a smaller gap within the plot. Strong light of the average 17,500 Lx occurs in 6.1% of the area within the large lateral opening, and 2.3% of the plot area has the light intensity above 20,000 Lx.

Figure 7. Average daily light intensity

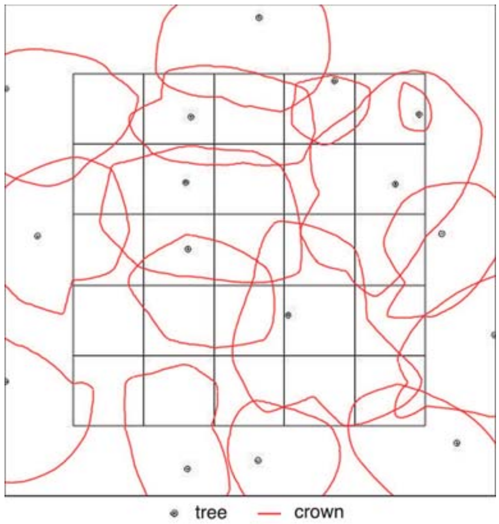

Figure 8. Canopy cover on sample plot 2

Due to the stand aspect, the maximum average light intensity occurs after local noon, at 14.00 and amounts to 23,452.2 Lx (fig. 6). The maximum light transmission coefficient (29.4%) also occurs at 14.00. (fig. 5). The average light transmission coefficient is 19.3%, with the minimum value of 4.8% that is measured at 18.00. Figure 5 shows that ltc for this plot has low values in the morning, then experiences a sharp rise after local noon when it reaches its maximum. After the culmination, ltc gradually decreases, but keeps high values till late afternoon, which is mostly due to the western aspect of the plot.

The average daily course of light intensity in this stand is shown in fig. 6. In the early morning, before 8.00, light intensity is extremely low. Morning values do not exceed 10,000 Lx. Light intensity becomes higher after local noon, at 14.00, when it reaches the maximum. Such course of light intensity is typical of west-facing stands and steeper slopes.

Temperature and other microclimate conditions in the stands

The results of the research are presented comparatively for the eastern and for the western aspect. The resulting values are compared with the data obtained in the open outside the forest.

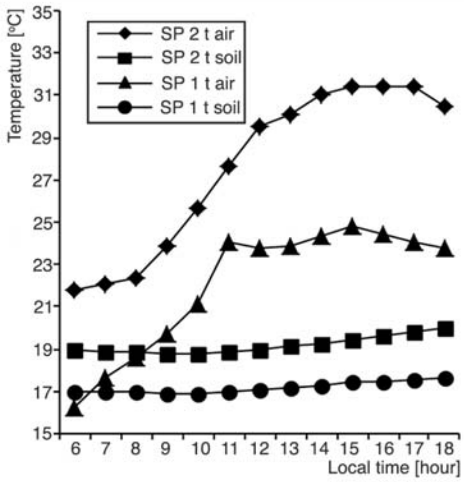

Figure 9. Daily course of air and soil temperatures

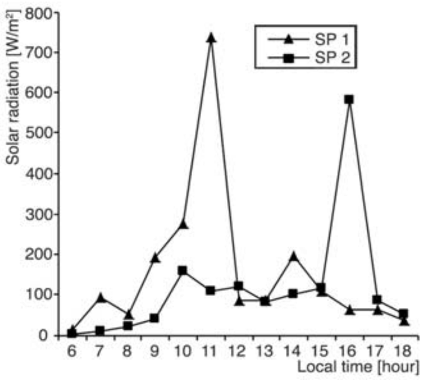

Figure 10. Daily course of solar radiation

Sample plot 1 and its stand

The average daily courses of air temperature, soil temperature, and solar radiation for the east-facing sample plot are shown in figs. 9 and 10. The study stand has the average daily course of air temperature that is characteristic of east-facing terrain and stands. An intensive air temperature rise is observed from early morning hours till the secondary culmination, which occurs at about 11.00, when the temperature amounts to 24.1 °C. Air temperature then decreases by about 0.5 °C and does not change till 14.00 (fig. 9). After that, air temperature slightly rises until reaching its primary maximum of 24.8 °C at about 15.00. The maximum temperature for the same period measured in the open outside the forest is 28.4 °C, which is higher by 3.6 °C. The determined values are lower than the ones stated in earlier studies because this research area is characterized by helophytic tree species and incomplete canopy. Many earlier studies indicate that summer daylight air temperatures in a forest can be lower by up to 5 °C (2.5 °C on average) than in open areas [29, 28, 41]. The average temperature in the study stand is 22.0 °C. The primary air temperature maximum occurs one hour later compared to the light intensity culmination, while the secondary temperature and solar radiation maximums (fig. 10) occur three hours before the light intensity maximum (fig. 6), which is primarily due to the eastern aspect of the stand and the steep slope of the terrain.

The average daily course of soil temperature, measured at a depth of approximately 10 cm, shows that the study stand experiences the lowest temperature of 16.9 °C between 9.00 and 10.00 (fig. 9). After that, soil temperature constantly shows an increasing trend until late afternoon when it reaches its peak value of 17.6 °C. The average daily soil temperature is 17.2 °C, with the amplitude of only 0.7 °C. The same trend of daily soil temperature, measured at the same depth, with the culmination between 17.00 and 18.00 was recorded by [11] in the fir-spruce stand. According to [18], the maximum soil temperature in a fir-spruce stand near Drinić, in the western part of the Republic of Srpska, measured at a depth of 10 cm, occurs at around 18.00 and amounts to 14.8 °C.

The daily course of solar radiation (fig. 10) in the study period has a clearly expressed maximum before local noon, at 11.00, and amounts to 739.0 W/m^2, while the minimum occurs at 6.00 and amounts to as much as 15.0 W/m^2. The maximum solar radiation coincides with the secondary air temperature maximum, which is primarily the result of the terrain aspect. The stand receives the absolute maximum solar radiation between 10.15 and 11.20, when it reaches 769 W/m^2 (11.08). The average solar radiation for the study period in the stand amounts to 154.7 W/m^2.

Sample plot 2 and its stand

The average daily course of air temperature for the study period (12-14.07.2008) in the sample plot 2 stand differ from the previous sample plot because the temperature rise during early morning hours is very small (fig. 9). The rise is intensified between 9.00 and 10.00 and this trend continues until reaching the maximum value of 31.4 °C at about 15.00. After the culmination, the temperature has approximately the same value till 17.00, and then gradually decreases. The temperature measured in the stand at 7.00 was 22.1 °C, which was by 1.8 °C lower than the temperature measured in the open area, while at 14.00 the stand temperature measured 31.0 °C which was 2.8 °C below the temperature measured in the open (Rimski Sancevi). The average air temperature in the stand during the study period was 27.6 °C. This temperature trend is primarily due to the impact of the stand`s western aspect and its steeper terrain.

The daily course of soil temperature (fig. 9) in the study stand has an almost identical flow as the previous sample plot. Early-morning temperatures are low as the result of intensive night radiation of forest soil with the lowest soil temperature of 18.8°C occurring between 9.00 and 10.00. It is followed by a constant increase which lasts till late-afternoon hours when the highest value of 20.0 °C is measured. The average daily soil temperature in the stand is 19.2 °C.

Figure 10 presents the daily course of solar radiation for the study period. The expressed afternoon maximum of 581.0 W/m^2 that occurs at 16.00 is due to the western aspect of the terrain and the stand. The minimum value occurs in the early morning and amounts to only 4.0 W/m^2. The average for the investigated period is 114.3 W/m^2. The stand receives the absolute maximum solar radiation between 15.30 and 16.20, when it reaches 634 W/m^2 (at 15.31).

Conclusions

Global climate change inevitably causes changes in the climate of microhabitats. Researches on the global climate change impact on microclimate conditions are of great importance in studying dynamics of different ecosystems and environmental conditions. By monitoring temperature and other microclimate conditions in the microhabitats of different ecosystems we can get unique data on the long-term impact of global climate change on microclimatic changes.

Detailed comparative research of temperature and other microclimate conditions in the east and west facing stands produced the following results for the given research period.

- The absolute maximum solar radiation in the east-facing stand was 769 W/m^2 (at 11.08), while it was 634 W/m^2 in the west-facing stand (at 15.31).
- The maximum air temperature of the east-facing stand was 24.8 °C, which was 3.6 °C below the maximum value measured in the open.
- The western aspect had the maximum air temperature of 31.0 °C, and it was by 2.8 °C lower than the temperature measured in the open.
- Soil temperature reached the highest values in the late afternoon. The highest value measured on sample plot 1 was 17.6 °C, while it was 20.0 °C on sample plot 2.
- The average daily soil temperature on sample plot 1 was 17.2 °C while it was 19.2 °C on sample plot 2. The amplitude was only 0.7 °C.
- By using the stationary isohel method we found that the average light intensity of the eastern aspect was 6,766.3 Lx/m^2, with light transmission coefficient of ltc = 14.8%; the western aspect had the light intensity of 9,213.8 Lx/m^2, and the light transmission coefficient ltc = 19.3%.

The obtained results of the measurements indicate a significant impact of the forest on the change in microclimatc conditions compared to the microclimate conditons in the open. The temperatures in the given forest conditions are lower by 2.8-3.6 °C compared to the open conditions.

Hilly-mountainous areas usually have an insufficient number of weather stations, which is the case with Fruska Gora. Similar research stiudies should be conducted at several locations in different ecosystems, which would provide a clearer picture of the impact of forests on the mitigation of the ongoing climate change. Furthermore, similar comparative research studies should be conducted at higher altitudes which currently lack available data. More investigations of this kind should be carried out in future.

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