Influence of the light conditions on the undergrowth of Siberian stone pine (*Pinus sibirica*) in forests of different types

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The adaptive mechanism of a plant organism in response to the influence of different ecological factors has been studied. Regularities have been revealed in the leaf apparatus of the undergrowth of Siberian stone pine under different light conditions in the understory of different forests.

The basic research of the influence of light conditions on the ecological status and biology of development of the plant organisms in the understory of a forest are still disputable. One of the significant features of conifers is the presence of multiple-aged and wintering groups of modified leaves – needles. The environment exerts permanent influence on the plant organism and, to survive, the plant should adequately respond to irritants.[1] In the case of increasing adverse, it is more advantageous for a plant to stop the growth, including the structure changes, combining the principles of the maximum power and optimization, and then to reconstruct it quickly under the optimal conditions, to maintain it at the given level due to the high power inputs.[2] The study of features of the interaction between different components of the phytocenosis aimed at the preservation of valuable forest species is impossible without the knowledge of regularities of physiological processes, proceeding under the influence of climatic and soil conditions. Therefore, the aim of this work was to reveal the effects of morphological and physiological features of the leaf apparatus on the undergrowth of Siberian stone pine, growing in forest communities near Tomsk under different ecological conditions.

The object of our study was the undergrowth of Siberian stone pine (*Pinus sibirica* Du Tour), growing in the nettle birch grove, forb pine forest, and forb deciduous-pine forest. Sample areas were chosen in the Timiryazevo forestry. The stand age was 60 years, the pine height was 22–27 m, and the birch height was 17–19 m. The undergrowth in the amount of 400–1100 species/ha was represented mostly by the Siberian stone pine; it was also possible to found pine trees and some species of birch, spruce, fir, and larch. The mean height of the Siberian stone pine undergrowth was 1.3 m (0.1–4.1 m). The understory trees were represented by mountain ash, arrow-wood, and bird cherry of low and medium density. The ground cover consisted of different motley and tall grasses. The seasonal growth and phenology of the Siberian stone pine and the species of the ground cover were studied using commonly accepted techniques.[3–6]

In this study, we used one-year needles as an organ most sensitive and responsive to the effect of different ecological factors. The pigment complex of the photosynthetic apparatus was determined in accordance with the Shlyk's recommendations.[7] The water conditions of the leaf apparatus and field humidity of the upper soil level were determined by the commonly accepted techniques.[8] The temperature of the soil and air was measured with a thermometer. The light conditions of phytocenoses were determined with a luxmeter, set at a height of 1.3 m above the ground.

The stand density, phenological state, species composition, tree height, crown shape and size characterize, ultimately, the plant layer, transforming the solar energy and being an inhomogeneous optical medium for it. The optical properties of this layer depend on both the biological features of the plants and the layer geometry.[9] Our results have shown that three stages can be separated in the seasonal development of the components (stand, understory trees, undergrowth, grass cover). At the first stage from late April to early June, the crown of the upper-layer trees (birch and aspen) and bushes (bird cherry tree, mountain ash, arrow-wood, and others) and the grass cover are formed. In this period, high illumination (20–40 10^3 lx at a height of 1.3 m) and high humidity of the ground litter and the surface soil layer (40–84%) are observed under the forest canopy. Then the temperature increases and reaches the values, characteristic of summer. For example, the soil temperature at the depth of 5 cm reaches 13–15°C and higher (Table 1).

The temperature of the soil and air until late September usually is within the average long-term values. The period of sprout growth is critical in the plant's life with respect to the deficit of water and elements of root nutrition. In the period of latent

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growth, the initiation, differentiation, and growth of buds occur and organic substances are accumulated in a plant.

Table 1. Light, temperature, and humidity conditions of sampled areas

Date	Light, 10^3 lx	Temperature, °C		Soil humidity, %
		air	soil	
Forb pine forest				
June 26	42±36	20.18±3.41	15.82±3.61	39
August 4	8.07±4.14	23.27±2.32	16.82±1.73	38
September 27	4.53±1.02	21.11±3.57	15.82±2.52	45
Forb deciduous-pine forest				
June 26	19.77±8.89	19.07±1.51	14.31±3.91	51
August 4	5.02±3.21	21.19±1.09	15.01±2.11	45
September 27	2.58±0.6	20.01±1.49	14.70±3.41	49
Nettle birch grove				
June 26	32±29	18.34±3.93	13.52±3.64	84
August 4	15±16	20.37±1.71	14.72±3.24	65
September 27	5.53±2.12	19.34±2.74	14.12±2.64	74

It is known that water comes to a plant through the gradient of the water potential between the soil and the root system of plants. Inside a plant organism, the water circulates through xylem and phloem vessels, distributing the dissolved substances over tissues. The atmospheric humidity affects the processes of water evaporation. This process also depends on the degree of stoma opening.[10] The state of water potential is affected by the soil humidity, that is, the amount of water per unit soil volume. The water contained in the soil strongly affects the soil properties from the bearing capability (permeability) and to the thermal conductivity.[11]

In the period of the needle growth, the wet weight of needles in the nettle birch grove was doubled due to the every-year stagnation of water from melted snow in this type of a forest as compared to the needle weight of plants of other communities. As the needle growth ceases by late June, the dry mass begins to accumulate in needles of plants of all communities, which is likely indicative of the activation of growth processes. The fall decrease in the dry mass of needles indicates the outflow of organic substances from the leaf apparatus to other tissues of a plant (Table 2).

At the beginning of the vegetative season, the crowns of the birch community had a loose structure and well transmitted the solar radiation. The mixed forest due to the high density of the crowns of wood species even in the spring created a shade under the forest canopy. The forb pine forest occupied an intermediate position. The decreasing dynamics of the illumination is connected with the blooming and growth of laminas of adult trees. At the highest density of leaves, we observed the period of unstable illumination, characteristic of all phytocenoses. The maximum density of crowns prevented transmission of solar radiation to the undergrowth. This stage is characterized by the mosaic illumination under the forest canopy. In this case, the photosynthetic apparatus of the undergrowth of Siberian stone pine experiences a significant overload, because the illumination can change for a short time from minimum values (shading) to the maximum ones, which can cause the inhibition of the photosynthesis.[12]

Table 2. Characteristics of one-year needles of model species of Siberian stone pine

Date	Length, mm	Surface area, mm^2	Humidity, %	Weight, g	
				green	dry
Forb pine forest					
June 26	73±5	126.6	42.0	0.027±0.00	0.015±0.00
August 4	117±13	–	35.1	0.038±0.00	0.021±0.01
September 27	121±19	283.1	62.1	0.042±0.01	0.016±0.00
Forb deciduous-pine forest					
June 26	63±9	98.5	36.3	0.027±0.00	0.016±0.00
August 4	104±29	–	43.3	0.034±0.01	0.017±0.01
September 27	107±16	207.9	64.6	0.032±0.01	0.011±0.01
Nettle birch grove					
June 26	73±9	138.1	57.4	0.050±0.01	0.019±0.00
August 4	105±13	–	49.7	0.033±0.00	0.017±0.01
September 27	106±11	207.11	62.9	0.034±0.05	0.013±0.00

Note. All the data are calculated per one needle.

At the same time, the shading of the lower layers has individual features. In the nettle birch grove even at the calm weather, leaves permanently change their position in space, which favors the penetration of solar rays to the undergrowth and the grass cover. The illumination in the forb pine forest depends, to a significant degree, on the understory wood, consisting of mountain ash, which occupies a considerable space. In the mixed forest, the low illumination is explained, most likely, just by the species composition of the tree canopy. The crowns of trees make a denser layer, which favors the shading of the lower layer of the forb deciduous-pine forest.

The content of pigments of the photosynthetic system of the plant leaf apparatus can serve a significant index, characterizing the adaptation of a plant to light conditions. It has been found that, in response to adverse natural factors, the chloroplast can transform the energy with a rather high efficiency and fast adapt to changes in the environment.[13] Against the background of the illumination lability, in August the increase of the ratio of chlorophyll *a* to chlorophyll *b* is indicative of the partial destruction of chlorophyll *b*. The analyzed pigment takes part in the system, accumulating the light quanta to be transferred to the reaction center. Under the intense illumination, it can undergo partial destruction. These facts are indicative of a sufficient degree of illumination of the Siberian stone pine undergrowth just in this vegetation period.

Carotinoids serve to preserve the chlorophyll molecules from the irreversible photooxidation. In the summer period, the amount of carotinoids in all types of forests remained virtually unchanged. In the fall, the amount of these pigments increased in the leaf apparatus of the undergrowth of Siberian stone pine (Table 3).

Table 3. Pigment complex of one-year needles, mg/g green mass

Community	Chl *a*	Chl *b*	Chl *a* + chl *b*	Carotinoids	Chl *a* / Chl *b*	Chl *a*+ chl *b* / carotinoids
			August 4			
Pine forest	0.83 ± 0.05	0.26 ± 0.01	1.09 ± 0.06	0.18 ± 0.01	3.2	5.8
Deciduous-pine forest	0.82 ± 0.02	0.25 ± 0.07	1.07 ± 0.03	0.18 ± 0.02	3.2	6.0
Birch grove	0.79 ± 0.03	0.26 ± 0.03	1.05 ± 0.04	0.18 ± 0.01	3.0	5.8
			September 30			
Pine forest	0.97 ± 0.02	0.35 ± 0.01	1.32 ± 0.02	0.27 ± 0.02	2.8	4.8
Deciduous-pine forest	0.85 ± 0.01	0.33 ± 0.01	1.18 ± 0.01	0.23 ± 0.002	2.6	5.1
Birch grove	0.87 ± 0.01	0.33 ± 0.01	1.20 ± 0.01	0.26 ± 0.01	2.6	4.5

Note. Chl stands for chlorophyll.

The illumination is closely related to the temperature conditions. The soil temperature at a depth of 5 cm in spring warms up more intensely in the forb pine tree, which is likely connected, in the first turn, with the heating of the bark of adult pine trees. The fall decrease of the illumination under favorable temperature conditions in the soil favored the increase of the total chlorophyll. The observed change in the *a*-to-*b* ratio of chlorophylls toward a decrease indicates just the adaptation reactions of the pigment complex of the leaf apparatus in needles of the Siberian stone pine undergrowth to the external factors. The seasonal increase of carotinoids by the fall is a physiological norm (see Table 1).

Thus, at the maximum density of the crowns of the tree canopy in different types of the forest, the accumulation of photosynthetic pigments in the undergrowth of Siberian stone pine was roughly at the same level. In the period of the fall of leaves in the birch grove, the processes characteristic of the needle ageing were observed in the undergrowth of Siberian stone pine. Consequently, the undergrowth of Siberian stone pine has a flexibility in response to the changing environment and can adapt to different conditions of the growth.

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