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Peculiar Influence of Nitrogen on the Daily Growth and Photosynthesis of Scots Pine in the Far North

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Abstract. The study covered the Scots pine stands in the forest zone adjacent to tundra at the northern border of the coniferous forests range (66°45'N) and, in particular, the 33-year-old lichen pine forest which was analyzed for the dynamics of its physiological processes and the daily growth of longitudinal shoot. It has been found that both the physiological processes and daily growth can be intensified by using nitrogen fertilizer on the plantings. The research has further found that the daily growth of pine in the Far North is at its highest during twilight and night hours and that the greatest intensity of physiological processes occurs during daytime. It is during the indicated time periods that plants, due to intense photosynthesis, synthesize a significant amount of growth substances, which are then realized in the form of height increment during the twilight hours. Unlike the taiga zone (66°45'N), where the climate is more temperate, in severe climatic conditions of the Extreme North pine grows much slower and has a lower rate of physiological processes within 24 hours in comparison with the north taiga zone. The low rate of growth and physiological processes in the pine trees in the Far North are explained by low and fairly dynamic average daily temperatures. Nitrogen has a positive effect on the rate of growth and physiological processes in pine. Nitrogen exposure causes the daily longitudinal growth and its daily duration to increase in plants, the photosynthesis increasing significantly (1.4-fold) and the water regime normalizing the process. These positive changes lead to an improvement in the functional activity of pine and an increase in the productivity of pine stands.

1. Introduction

The forests and the open woodlands adjacent to tundra climate zone perform a number of important biospheric and ecological functions. Their geobotanical nature is disclosed in many publications but, in biological terms, they remain underexplored: the available scarce data is ambiguous and often very contradictory. It is believed that the vehicle for plants to adapt to the soil and climatic conditions of the Far North lies in the specific changes in their metabolism.

Therefore, the studies into biological characteristics of the plant communities of the forested area in question are becoming more and more relevant due to the unceasing intensification of the development of natural resources in the area and the increase in anthropogenic load on its natural ecosystems. Such studies are of considerable interest both from cognitive, scientific point of view on woody plants' development in different climatic zones and also in connection with the applied problems of trees mineral nutrition. Such studies are also important for better understanding the biochemical processes



that determine growth and physiological processes in trees within 24 hours and during the vegetation season. They are necessary also in terms of determining how forest stands productivity could be controlled based on climatic conditions and places where they grow, as well as on diverse man-caused impact. Located in the climatic zone bordering on treeless tundra, many plant species are on the border of ecological tolerance. The short growing season (56-63 days), the low summer temperatures under 10-13°C in the warmest month (July), the increased solar exposure, the frequent natural forest fires, the excessive precipitation, and the low soil fertility have their specific, marked effect on the biology and productivity of plant communities in this climatic zone. The growth here is largely determined by thermal conditions of the growing season [11. Tsvetkov V.F., Semenov B.A. "Pine Forests of the Far North". M., 1985. Ch. 1. pp. 7-13]. Therefore, even a minor man-caused impact complemented by adverse climate factors can be damaging and even lead these highly vulnerable plant communities to death.

The aim of the study was to analyze the physiological processes and the daily growth dynamics in the longitudinal stem of the Scots pine growing at the northern border of its distribution range, as well as the potential for controlling these processes by means of nitrogen fertilizer.

2. Objects and methods of the study

Our study covered the northern border of Scots pine distribution range, which is 120 km off the Arctic Ocean in the zone bordering on treeless tundra, in the territory of Nenets Autonomous Area, namely, its N. Pyesha – Taratinskoye stow (66°04'N). The main object of the study was a 33-year-old lichen pine forest of pure composition, that emerged on the site previously burned by fire; our additional object was a 60-year-old lichen pine forest located in close proximity. The composition of the 33-year-old forest was 10 P with density of stocking of 3,000-4,000 pines per 1 ha. The pines had a height of 1.5–2.0 m and grew on sandy podzol on blanket sand of ancient origin. Species-wise, the composition of the ground layer was uniformly represented by green mosses and fruticose lichens, small synusia of butterbur, alpine and common bearberry, and dwarf birch thickets.

Our sampling plots were flat, forested areas. The manual drilling of soil exposed groundwater was at a depth below 1.5 m from the soil surface. For the purpose of our research, three most viable pine trees of the first and the second growth classes (Kraft classification), sharing similar annual increment patterns in their stems, were selected and registered on both the experimental and control plots. Unsheltered by their mother trees, all the trees under study were well lit and did not have fierce root competition. Nitrogen fertilizer (carbamide), in which the nitrogen concentration was 46%, was applied to the stands in different doses. In our study a dose of nitrogen equaled 180 kg/ha of active substance. The fertilizer was applied to soil two times when it was wet, on May 29, 1987 before the beginning of the growing season – manually by spreading over surface of 20x20 m plots. The soil analyzes showed that the total nitrogen content in the soil of the test pine forest was extremely low: in 0–10 cm deep layer it was no more than 0.93%, in 10–20 cm deep layer only traces of it were found. After the nitrogen fertilizer had been applied, the nitrogen content in these soil layers increased up to 1.30% and 0.05%, respectively.

The daily linear growth of the stem was studied by direct measure using a ruler with clearly marked graduation line which was attached to the tree stem tightly. Additionally, a pole caliper was made use of. The intensity of photosynthesis was measured using the radiometric method [2. Voznesensky L.V. et al., "Research Methods for Photosynthesis and Plant Respiration," M-L., 1965, 305 P.], [9, Mokronosov A. T. "Issues of Plant Physiology and Geobotany". Proceedings of Sverdlovsk All-Union Botanical Society. Sverdlovsk, 1969. Issue. 4. pp. 3-13.]; the transpiration rate using the weighing method [4. Ivanov L.A. et al., Botan. Zh., 1950, V. 32, No. 2. pp. 171-185]; and the shade density using a Yu-116 M lux meter. The measurements were performed every 4 hours in parallel. Concurrently, measurements were taken of the air and soil temperature. The repeated research was carried out in the year following fertilization – on June 20 and partly on June 21, 1988 when the daylight was the longest. It should be noted that on the days before and during the measurements, the weather was unusually warm, sunny, and cloudless, with temperatures of 23°C–25°C. However, on

the following day, as the evening neared, the measurements had to be stopped: the weather changed under the influence of the Arctic cyclone that came totally unexpected from the Arctic Ocean and brought cold drizzling rain. The weather as unfavourable as that remained until the end of the month, leading to weak seasonal growth of pine. Please see the Table for summarized results.

3. Discussion

The studies showed that the fertilizer had increased, in the first place, the vitality of the root system in pines. On fertilized grounds, the roots began to disengage 1.4 times more CO₂ than the roots of the control pines [7. Konovalov V.N., Listov A.A., "Lesnoy Journal, IVUZ", 1989. No. 4. pp. 15-19]; [8. Konovalov V.N., Zarubina L.V. "Ecological and Physiological Characteristics of Coniferous on Fertilized Soils", 2011. Ch. 4.1. pp. 139-147]. Improved, the viability of the roots had activated other functions of the root system, such as absorbing, synthetic, and growth functions, and had a positive effect on the processes in the aerial organs of the trees, particularly, on the productivity of single trees and the entire stand.

The analysis of the potential daily photosynthesis rate showed that the speed of this process in pine under the conditions of the Extreme North, regardless of the long light day (22 hours), is subjected to significant fluctuations and is heavily reliant on the dynamics of light conditions and, to a lesser extent, air temperature. Within 24 hours on June 20, 1988 the maximum levels of photosynthesis in pines were observed in the period between 8 a.m. and 8 p.m. (with illumination of 49.5–76.0 thousand lx). In last year's needles, the levels of photosynthesis were peaking at 18.7–32.9 mg of CO₂ per 1 g of dry needles an hour (compared to the 16.5–22.2 mg of CO₂ on the control plot) on the plots with high nitrogenous nutrition. On plots with increased nitrogenous nutrition, the photosynthesis rate in pine was 12%–48% higher than in control trees. In the evening and the early morning hours, the rate of photosynthesis was significantly reduced and was almost 5 times lower compared to daytime rates. Between 12 a.m. and 3 a.m. and between 10 p.m. and 12 a.m., due to low light conditions (no more than 4, 0 thousand lx), the photosynthesis rate in pine could almost stop. A similar daily pattern of potential photosynthesis rate in young pine forest was also observed in the northern taiga zone of Arkhangelsk Region (Leshukonsky District) but with higher absolute values [8. Konovalov V.N., Zarubina L.V., 2011. Ch. 4.7. pp. 206-214].

In the morning hours, a significant rise in photosynthesis usually began at about 6 a.m. with illumination of 18–22 thousand lx in the test and control trees, simultaneously. In the test plants, the growth in photosynthesis occurred at a more significant rate than in the control plants. In the midday hours (12 p.m.) the trees experienced a slight depression in photosynthesis regardless of their root nutrition. Since higher air temperatures (above 25°C) are not common in this area, the assumption can be made that the water regime of the trees could have been disrupted during that period under the influence of adverse exposure to high temperatures (25°C) and illumination (76 thousand lx).

Table 1: The influence of nitrogen on daily growth in height and intensity of physiological processes in 33-year-old lichen pines, June 20–21, 1988.

Processes in 55-year-old larch pine, June 20-21, 1988.										
Time, h	Temperature, °C	Illumination, K lux	Control		N180		Photosynthesis, mg CO ₂ /g*h		Transpiration, mg H ₂ O/(g*h)	
			Stem length, cm	Increment, cm	Stem, cm	Increment, cm	Control	N180	Control	N180
June 20										
000	7,3	1,5	7,7	0	14,7	0	1,1	1,0	-	-
400	10,0	3,9	7,8	0,1	14,9	0,2	4,9	5,8	80	73
800	18,6	49,5	8,0	0,3	15,3	0,6	22,2	32,9	106	89
1200	24.8	76.0	8.2	0.5	15.5	0.8	21.2	30.5	228	197

Time, h	Temperature, °C	Illumination, K lux	Control		N180		Photosynthesis, mg CO2/g*h		Transpiration, mg H2O/(g*h)	
			Stem length, cm	Increment, cm	Stem, cm	Increment, cm	Control	N180	Control	N180
June 20										
1600	22,2	52,0	8,4	0,7	15,8	1,1	19,6	28,3	280	248
2000	18,5	22,6	8,5	0,8	16,3	1,6	16,5	18,7	130	103
2400	7,7	2,0	8,9	1,2	17,2	2,5	0,7	1,3	38	35
June 21										
400	10,9	3,6	9,2	1,5	17,5	2,8	4,8	5,9	22	20
800	19,1	40,7	9,5	1,8	18,0	3,3	20,1	31,7	113	103
1200	23,4	60,5	9,7	2,0	18,2	3,5	21,8	32,1	219	189

The analysis of the diurnal transpiration rate, a significant change in the intensity of photosynthesis was observed in pine within 24 hours that depended on the availability of nitrogenous nutrition. Under our conditions, the maximum transpiration intensity in pine remained in the daytime, 12 p.m. to 8 p.m., ranging in control trees between 130 mg and 280 mg H₂O/(g*h) and in the trees receiving nitrogen nutrition between 103 and 248 mg H₂O/(g*h). In test trees, the transpiration was 12%–20% lower than in the control ones. At night and before dawn, in both control and test trees the transpiration was practically zero. M. A. Abrazhko [1. Abrazhko M. A., "Structure and Productivity of Spruce Forests of Southern Taiga." M., 1973. pp. 170-191] and G. K. Vsevolozhskaya [3. Vsevolozhskaya G. K. et al. Collection of Research Papers "The Physiology of Woody Plants", M., 1962. pp. 81-92] notes in their publications that the intensity of transpiration in woody plants is determined by a set of co-factors in the phytogenic medium, the most influencing being solar radiation and mineral nutrition.

In our experiment, the effect of each of these factors (illumination. nitrogen) on transpiration was not unambiguous. As can be seen from the table, the greatest influence on the intensity of transpiration is rendered by illumination and, to a much lesser extent, additional nitrogenous nutrition. If we compare the effect of these two environmental factors on the intensity of transpiration in pine under the illumination range of 52–23 thousand lx (the air temperature did not change much), then it can be seen that at a 2-times lower illumination the intensity of transpiration in the control trees decreased two-fold, and in the nitrogen-fed trees, under the same illumination range, only by 20%. G.K. Vsevolozhskaya et al. [3. Vsevolozhskaya G. K. et al., 1962. pp. 81-92] found that the reason for transpiration in plants under the action of fertilizers to tend to decrease is the increased accumulation in the leaves of osmotically active substances - sugars and protein substances known to absorb water and prevent it from evaporating from the cell. It is believed that the reduction in the transpiration water levels under the action of mineral elements has a positive effect on plants, allowing them to minimize the unproductive waste of water and energy resources needed for creating the organic matter and making the process of transpiration more economical in terms of energy [8. Kononov V.N., Zarubina L.V., 2011. Ch. 4.2. pp.147-157].

In the last year's needles of test and control trees, the respiration intensity varied within 24 hours slightly, equaling 0.6–1.0 mg of CO₂/(g*h), while the respiration rate in younger shoots was higher, ranging from 7.6 to 9.5 mg of CO₂/(g*h).

The day-and-night observations of the daily growth in pine height showed that the maximum increment in stem growth occurs in the evening and at night (from 4 p.m. to 8 a.m.). In our experiment, it was 2.2 cm in the test trees and 1.1 cm in the control ones. In the daytime the extra growth in the stems of all sample trees was small, reaching 4 mm in the control trees and 5 mm in the test ones over the period from 8 a.m. to 4 p.m., on average. This data indicates that under the climatic

conditions of the Far North the most intense longitudinal growth occurs in pines in the twilight and darker time of the day, slowing down in the daytime. At the same time, this data proves convincingly that the processes of stretching and dividing cells in pines tends to be at its highest under favorable climatic and soil conditions. Our calculation of the increment in stem growth per each hour during the indicated intervals (from 8 a.m. to 4 p.m., and from 4 p.m. to 8 a.m.) showed that in the control trees the stem growth rate equaled 0.5 mm/h and 0.63 mm/h, and in the test trees 0.69 mm/h and 1.34 mm/h, respectively. During the daytime, in our experiment, the pine trees tended to grow in height equally slowly on both the plots fertilized with nitrogen and on the control plots. What happened during the daytime was active accumulation of spare growth substances (carbohydrates) as a result of the increased photosynthesis, which were then realized by plants at night as an additional increment in shoots. H. Lear [9. Lear H. et al., 1974. "Physiology of Woody Plants", M., 1974. Ch. 10, p. 10. pp. 322-326] determined, by making use of an auxonograph, that in Scots pine, Douglas fir and other coniferous species the growth begins before noon, reaches its maximum at about 8 p.m. and remains intense in the dark hours. However, this information is true about the forest located in relatively low geographic latitudes, where there is a clear change of day and night, and the duration of dark night periods is very long. In the areas of the Far North, where our observations were carried out, the duration of light period in June can be as long as 22 hours and there is practically no pronounced dark nighttime in clear sunny weather, or long twilight period sets in, during which the photosynthesis rate in plants is close to 0.

The comparison of the physiological and growth processes of pines of lichen forests in the climatic zone of the Far North and in the taiga zone, shows that in the taiga areas where the climate is more favourable for trees temperature-wise, pines tend to show higher daily levels of physiological and growth processes, as compared to near-tundra forests with more severe climate and much lower temperature in vegetation season. In the Far North – within the areas bordering on open tundra – the pine grows by 1.2 cm daily under favorable weather conditions in June and by 2.5 cm under the influence of the N180 dose; in the northern taiga zone (Leshukonsky Raion, latitude 66 degrees 45 minutes N.) it does so 1.9 cm and 2.9 cm, respectively. In the near-tundra area, the pine shows lower intensity rate of its physiological processes, as well as weaker seasonal growth [6. Konovalov V.N. "Problems of Pre-Tundra Forestry". Proceedings / AILiLKh. 1995. pp. 78-89], [8. Konovalov V.N., Zarubina L.V., 2011, Ch. 5. pp. 242-255], as compared to the northern taiga zone.

According to literature [4. Zakharin A. A. The Journal "Plant Physiology." 1993. V. 40, No. 6. pp. 940-946], the average growth rate in the majority of trees is 0.3–1.0 mm per hour. In the Far North, the 33-year-old lichen pine forest grows at a rate of 0.5 mm/h under favorable weather conditions and 1.04 mm/h, which is twice faster and meets the average daily growth rate in cultivated plants, under the influence of a nitrogen dose (180 kg/ha), as compared to the control trees. The relatively weak daily growth, noted by us in the pines growing in the Far North, compared to the pines in the northern taiga zone, is explained by lower average daily summer temperatures which tend to vary greatly during the day [11. Tsvetkov V. F., Semenov B. A., 1985, Ch. 1, pp. 7-13].

Thus, the analysis of the obtained data on the daily dynamics of physiological processes and the growth rate in terminal shoots of the pine trees growing in the Far North, indicates that these processes tend to be very dynamic in the climatic zone in question, which is due to the specific light and temperature patterns. Our study has shown that in the Far North – in the near-tundra forests and open woodlands – the main physiological processes in pines occur more actively during the daytime when the environmental factors are most intense, whereas the daily growth in height is at its highest in the twilight and early morning hours. Nitrogen is a factor that enhances daily growth processes and photosynthesis in plants. At the same time, low summer temperatures, combined with frequently adverse weather, tend to limit the daily and seasonal growth, as well as the rate of physiological processes in pine trees. These unfavorable factors lead to lower productivity of pine forests in this climatic zone [11. Tsvetkov V.F., Semenov B. A., 1985, Ch. 6, pp. 83-104].

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