© EVGENIY V. LEBEDEV

Cand. Biol. Sci., Associate Professor,
Department of Forest Plantations,
Nizhny Novgorod State Agricultural Academy (Nizhny Novgorod)

proximus77@mail.ru

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SCOTCH PINE ROOT SYSTEM ABSORPTIVE ACTIVITY AND BIOLOGICAL PRODUCTIVITY IN THE ONTOGENY OF THE TYUMEN REGION

SUMMARY. The purpose of this study is to obtain quantitative data of net photosynthetic, mineral, and biological productivity of Scotch pine (Pinus sylvestris L.) at the level of the organism in different forest types in the ontogeny of the Tyumen region on taxational data. Net photosynthetic productivity was determined by A.A. Nichiporovich, mineral productivity – by V. M. Lebedev, and biological productivity – by the relative weight gain for age period. Growing with age, deficit of elements led to a decrease in the absorbing activities of the roots, net photosynthetic productivity and biological productivity in all types of forests. Adaptive responses of plants to the prevailing conditions has been to increase the active surface of the roots with respect to the surface of the needle, which allowed to increase the supply elements of the aerial parts to maintain vital photosynthesis and the relative stabilization of biological productivity. This regulatory reaction at the level of the organism is marked by the age of 30 years and by the time a tree is 180 years old its adaptive capacity will have been exhausted. The proposed physiological analysis of biomass table's will expand research in the physiology and ecology of forest stands in order to develop technological methods of increasing productivity.

KEY WORDS. Scotch pine, net photosynthesis productivity, mineral nutrition, biological productivity, ontogeny, Tyumen region

Considering the crucial biospheric role of forests in maintaining ecologically safe environment for humans, the interest in studying the biological productivity of forest species in different climatic and sylvicultural conditions has recently increased [1]. To control the production process it is necessary to have the quantitative data on leaf apparatus and root system functioning, as two main sides of a single plant nutrition process. Despite the significant progress in studying of the aboveground part of woody plants morphological and physiological features, the root system is studied relatively poorly, due to some methodological difficulties. The data on forest stands phytomass is largely gathered with the model tree method, when the aboveground part is fractioned into trunks, branches and leaves; and the underground part – using the method of monoliths [2], extracted with big losses in active roots. In such situation we cannot speak about the quantitative aspect of leaf apparatus and root system in different environments and ontogeny. However, there are charts on North Eurasia forest phytomass, compiled by V.A. Usoltsev [3] with organismic-level modeling of large amount of woody plants. Those charts allow us to extend our knowledge on their ontogenic biology, using our data from the microfield model experiments [4], and the data on natural locus [5]. The main goal of the study was to gather the quantitative data of net photosynthetic, mineral and biological productivities, and the nature of the correlation between them in *Pinus sylvestris* in different forest types in Tyumen region ontogeny [3].

Material and methods. The chart data on modal pure pine forests of ledum-cranberry, cranberry and lichen-moss types of forest conditions in the basin of the Konda river in the Tyumen region went through the complex physiological analysis [3, c. 400-402]. The age period was from 20 to 300 years, with a 10-year interval, the length of frost-free period –120 days, precipitation – 530 mm annually, podzolic soil, the climate is continental, photosynthetic active radiation from May to September – 22420 cal/cm^2.

The forest inventory data on the wood of trunks, twigs, leaves and roots was recalculated per plant according to age. The researchers took samples of needles, branches, wood from barks and roots of various diameters in the uneven-aged stands in august, assorted and tested NPK with common agrochemical methods. The surface of needles was tested using the quotients that we had calculated based on the fresh material [6]. There was 90 cm^2 of surface per 1 gram of dry needles. The vegetation period was equated to the frost-free period, because negative temperatures damage the pigmenting system of needles, deteriorating its functioning at the edge of vegetation [7]. The concentration of elements in plant mass was measured considering the organs ratios. The net photosynthetic productivity (NPP) was calculated on the average per each age period [8] according to formula 1:

$$(NPP) = \Delta M/PP,\ g/m^2\ day, \qquad (1)$$

where ΔM – the increment of absolutely dry mass of model plant during the compared period in grams; PP – photosynthetic potential characterizing the needles surface that worked during the age period (formula 2):

$$PP = T(S_1+S_2)/2,\ m^2\ day, \qquad (2)$$

where S_1 and S_2 stand for the surface of needles in the beginning and in the end of the age period, respectively, m^2; T is the length of frost-free period during the age period, day.

1 square meter of needle biomass accumulation was calculated by multiplying NPP by vegetation length. The biological productivity (BP) was considered correlating with the relative increase of model tree biomass, using the data on hundreds and thousands of plants during every age period in ontogeny. To measure the active root surface of the whole plant the researchers used the values of root system specific active surface (RSSAS) and the length of roots per sliver mass unit, measured in model microfield experiments with 1- and 2-year old plants in sod-podzolic and gray forest soils [4, 6]. Due to the highly stable characteristics of active roots per plant (diameter, active root length, RSSAS, relative root length per mass unit of 2-3 mm sliver), the root active surface was calculated by multiplying RSSAS by the

quantity of meters of roots per sliver mass unit and by the mass of root system of the whole plant (as slivers) [9]. RSSAS was considered the active surface per 1 meter of the length of root sliver, cm^2/m. We used the values observed in our experiments: RSSAS – 3.5 cm^2/m, root length per 1 gram of dry sliver – 21 meter. Thereby, 1 gram of dry root sliver mass contains 74 square centimeters of active surface. Since the functioning of leave apparatus and root system are two sides of a single nutrition process, there is always a functional correlation between them. The relation of root potential (RP) to photosynthetic potential (PP) in our experiments [4] for a pine on average equaled 0.20. Functionally it means that 1 square meter of active root surface maintained 5 square meters of needles. Knowing the needle surface of model plant in each age period allows us to calculate the amount of root active surface of the whole plant and the percentage of active part (root lobe) in root system mass. According to our data, root lobes make not more than 3% of the total root system of a plant. This percentage of active roots in root system mass was used in calculations. By Root Productivity we understood the active root surface that worked during the age period (formula 3):

$$RP = T(S_1+S_2)/2,\ m^2\ day, \qquad (3)$$

where S_1 and S_2 stand for active root surface of a whole plant in the beginning and in the end of the age period, respectively, m^2; T – frost-free period during the age period, days.

The RP allows to measure the average mineral productivity (MP) of plants [9], meaning the quantity of mineral elements absorbed by an active root surface unit per day (formula 4):

$$MP = (M_2-M_1)/RP,\ mg/m^2\ day, \qquad (4)$$

where M_2-M_1 is accumulated mineral element within the age period, mg.

The M_1 и M_2 values were found by multiplying the dry mass of a plant within the compared period by the concentration of a mineral element in biomass, that is stable for each species of plant despite the differences in growing conditions, because it is genetically controlled and the metabolism processes are targeted and require strictly normalized number of elements [10]. That is why the NPK concentration in pine biomass that we found can be used at organismic level in different environmental conditions, and they will be approaching the true values [11-12]. The amount of leaf index (LI) and root index (RI) was defined by the ratio of needle and root active surfaces to the area of plant nutrition. The results were then processed with correlation and regression analysis.

Discussion of the results. NPP and BF decrease with aging, becoming 15.4-41.5 and 3.8-6.3 times lower respectively: in ledum-cranberry, cranberry and lichen forest types, respectively (figure 1 a-b). The correlation of NPP and age in the three forest types was negative (from -0.526 to -0.631). The dry mass and its growth (ΔM) in ontogeny were maximal in ledum-cranberry forests, and minimal – in lichen ones. MP dropped with age by 101,5-261,9 (N), 140,8-365,3 (P) and 120,1-311,6 (K) times (figure 1 c-e). The correlation changed from -0.693 to -0.648(N), from -0.606 to -0.648 (P) and from -0.668 to -0.625 (K).

MP decreased with age by 101.5-261.9 (N) times, 140.8-365.3 (P) and 120.1-311.6 (K) times respectively (figure 1 c-e). The correlation varied from -0.693 to -0.648 (N), from -0,606 to -0,648 (P) and from -0,668 to -0,625 (K). To make the analysis more convenient, the BP, NPP, MP (N) and the correlation between root potential and NPP (RP/PP) in the ontogeny are displayed on the same scale, as percentage of maximums (figure 2). The physiological values were compared with the absorption of N – the main nutrition element. The correlation between MP and NPP was highly positive in all forest types (0,867-0,844, 0,800-0,824 and 0,820-0,842 for N, P and respectively). The decrease of MP and NPP affected BP (the correlation between MP and BP was highly positive and made for N, P and K: 0,965-0,993, 0,984-0,999 and 0,977-0,997 respectively). But numerically, the decrease of BP was not so sharp as that of NPP and MP, due to the plants' regulatory reaction for decreased mineral nutrition, leading to the growth of RP/PP by 7.5-8.6 times with age – in all forest types. The correlation between RP/PP and age was highly positive in all forest types (from 0,876 to 0,903). The functional connection of root system and leaf apparatus decreased with age, and an active root surface unit would maintain less needle surface. The decrease of N absorption was accompanied by an increase in RP/PP (highly negative correlation: from -0,896 to -0,847). The correlation of RP/PP with NPP and BP were also negative: from -0,959 to -0,985 and from -0,699 to -0,842 respectively. The regulatory function of the plants in all forest types was active since the age of 30 years, when N, P and K daily absorption was at the level of 120-156, 39-54 and 46-62 mg/m^2 respectively. Naturally, the concentration of those elements in soil solution is 10^{-3}-10^{-4} M, and P – 10^{-5}-10^{-6} M [13]. Water-soluble N, P and K only partly fulfill the needs of the plants by transpiration. Most part of the elements move towards the root by diffusion which often limits the speed of absorption [14-15], especially in cold soils [16]. The number of absorbed elements depends on the concentration of soil solution, speed at which it moves by the root surface with diffusion, the size of active root surface and the intensity of its functioning. With low concentration and speed of diffusion, the plants can significantly increase the absorption, that is why the relative upbuilding of active roots is the adaptive reaction for increasing the supply of the elements to the above-ground part, in order to maintain photosynthesis at vital level. Due to that regulation the decrease of BP in the ontogeny in all forest types was less sharp than that of NPP and MP. The leaf index (LI) in the ontogeny in different forest types varied by 1.9-2 times, and root index (RI) – by 12.7 – 14.2 times. The LI value in all forest types grew till the age of 150, and RI – to till the age of 180 years, after which the values would decrease sharply (figure 3). Absorbing N, P and K at the level of 3.8-5.0, 0.9-1.2 and 1.301.6 mg/m^2 daily, the regulatory activity of the plants at organismic level would drain its capacities. The growth of dry mass (ΔM) would increase in ledum-cranberry forest till the age of 150, and then would decrease sharply. In lichen-cranberry and lichen forests ΔM would decrease by the age of 125-130. There was always a positive correlation between LI and RI in all forest types (from 0.487 to 0.647). The correlation between LI and ΔM was higher (from 0.743 to 0.893). The correlation between RI and BP was negative (from -0.677 to -0.866).

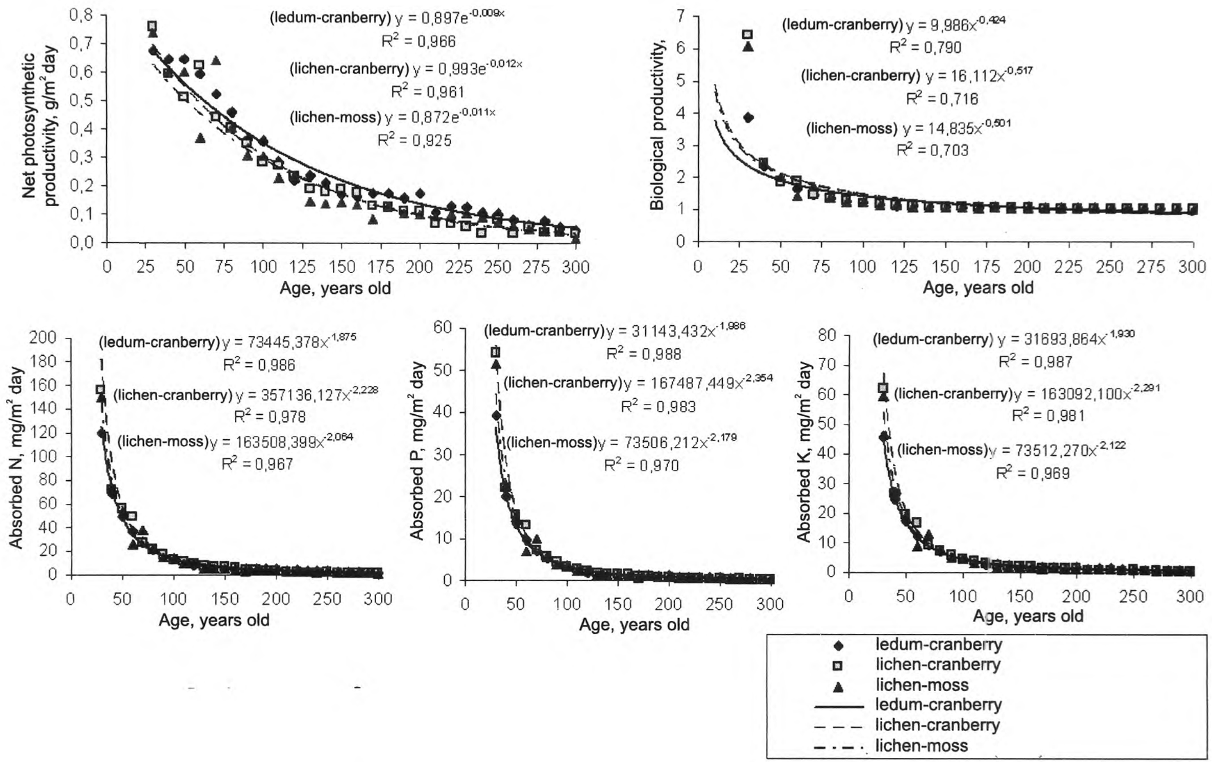

Fig. 1. Net photosynthetic productivity, biological and mineral productivity of Scotch pine in different forest types in the ontogeny of Tyumen region

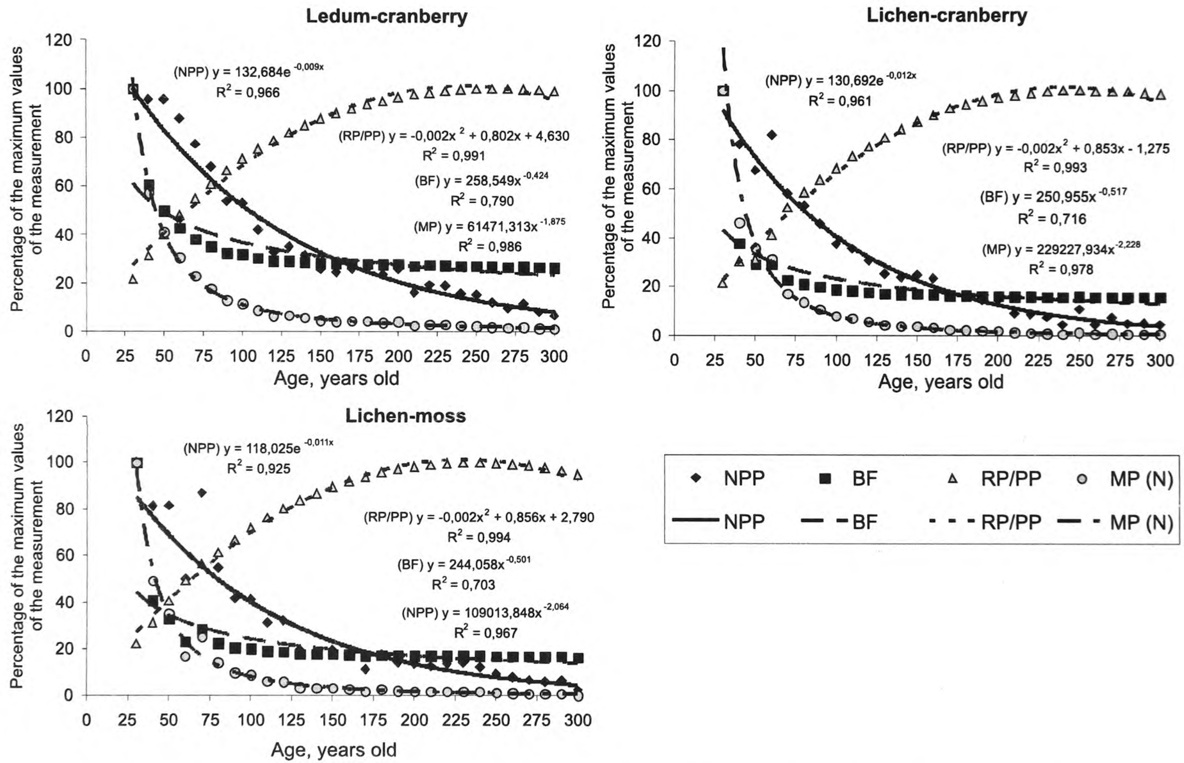

Fig. 2. The character of connections of basic physiological measurements of pine forests in different forest types in the ontogeny of Tyumen region

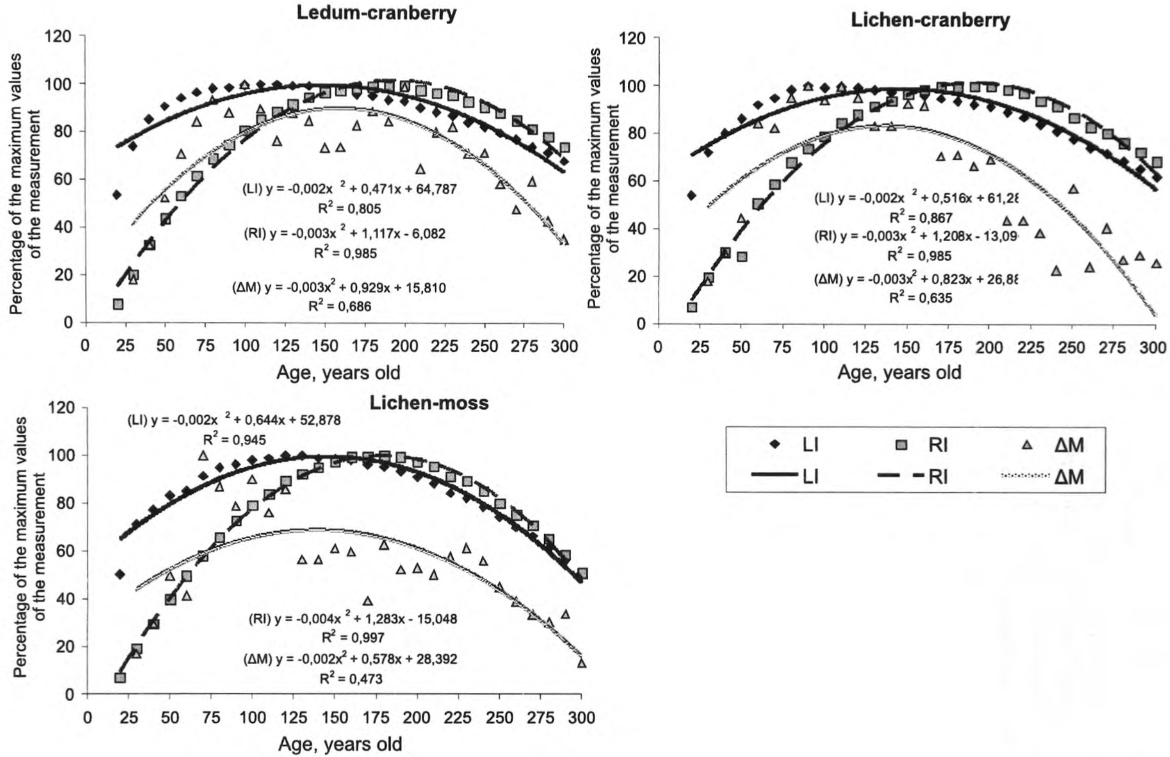

Fig. 3. The changes of leaf (LI) and root (RI) indexes and the growth of the absolutely dry biomass of pine forests in different forest types in the ontogeny of Tyumen region

Conclusions

The main factors limiting the growth processes of Scotch pine in different site conditions of the Tyumen region were the lack of nutrition elements, growing with age, that led to the decrease of root absorptive activity and the fall of net photosynthetic productivity and biological productivity.

The growing deficit of nutrition elements initiated the mechanism of non-specific adaptation of the plants, which, as stress response, increased the active root surface compared to the needle surface, which helped to provide the above-ground part of plants with nutrition elements, maintain the vital photosynthesis and stabilize the biological productivity from the age of 75 to 300. The regulatory activity at organismic level was in process since the age of 30, absorbing (mg/m^2, daily) 120-156 N, 39-54 P and 46-62 K; and by the age of 180 absorbing 3.8-5.0 N, 0.9-1.2 P and 1.3-1.6 K mg/m^2 daily the regulatory capacity was exhausted.

The suggested comprehensive physiological analysis of phytomass forest tables allows to gather quantitative data on the leaf apparatus and root system functioning in the ontogeny at organismic level; define the correlations, which would allow to expand the studies in the field of tree-stand physiology and ecology, and can be the theoretical basis for developing technological methods of crop productivity enhancement.

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