Foliage biomass qualitative indices of selected forest forming tree species in Ukrainian Steppe

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Abstract

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Our study objective was research on the assimilation component of aboveground biomass of trees and its correlation with mensurational indices of trees (age, diameter and height) in stands of the main forest forming species in the Ukrainian Northern Steppe zone – *Pinus sylvestris* L. (Scots pine) and *Robinia pseudoacacia* L. (Black locust). The research was carried out in forest stands subordinated to the State Agency of Forest Resources of Ukraine. We used experimental data collected on sample plots established during years 2014–2016. The main research results prove that the foliage share in the tree greenery biomass structure had a wide range of values. For both investigated species, a positive correlation was found between the dry matter content in the tree foliage and the tree age, height and diameter. The foliage share in tree greenery biomass decreased with increasing mensurational index values. Correlation analysis revealed linear relationships between the mensurational indices and the discussed aboveground live biomass parameters. The closest correlation was observed between the stand age, mean stand diameter, mean stand height and dry matter content in the foliage.

Key words

allometry, Black locust, forestry, mensurational (biometric) parameters, Scots pine

Introduction

Forest ecosystems in the Ukrainian Steppe are important by acting as universal natural filters and by carrying out air protective, recreative, soil protective, and erosion preventive functions (Lovinska and Sytnyk, 2016; Sytnyk et al., 2015).

The essential feature of forest ecosystems productivity is their power to synthesize organic matter. The extent of this power depends on the structure and activity of assimilation components. The foliage share in live biomass defines the basic physiological processes in plants such as photosynthesis, respiration and transpiration, which determine the level of material transformations and energy flows (Clark et al., 2001; Cosmo et al., 2016).

The assimilatory activity of leaves determines plants functioning in general, with particularly strong influence on cambium activity and woody tissue formation. A direct relationship between the size of pro-

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ductive assimilation apparatus and the current annual increment of growing stock has been highlighted in the scientific literature (Albertson, 1988; Jelonek et al., 2009). Reduction of assimilation apparatus size leads to weakening of cambium activity, degradation of conductive system and reduction of annual ring section area (Cosmo et al., 2016). The integral indicator of arboreous plant productivity – biological productivity reflects the above-mentioned statements (Cannell, 1984; Dong et al., 2003; Schlamadinger et al., 2003).

Qualitative parameters of greenery fraction of tree biomass can be used for purposes of environmental monitoring of forest condition and vegetation dynamics (Fownes and Harrington, 1991; Gill et al., 2000; Goudie et al., 2016). Another application of the parameter mentioned above is interpreting annual production estimates, and assessing water retention by arboreous species. It also may form a basis for modeling important processes in forest ecosystems, such as PAR (photosynthetic active radiation) transformation by canopy in stands of various forest-forming tree species, CO_2 gas exchange, determining potential biological productivity of forests, forest stands thinning intensity, etc. (Lauri et al., 2014; Potter et al., 2001).

Research on the biological productivity of forest-forming tree species is obligatory for recognizing the structural and functional patterns of forest ecosystems (Bartelink, 1997; Black et al., 2004). The foliage fraction, as one of the integral tree biomass elements, determines the course of photosynthetic processes, which results in organic matter formation, carbon sequestration and performance of gaseous function of plants – oxygen production (Albertson, 1988; Nakvasina, 2009). The variability of forest stand productivity and its dependence on the site conditions type has already been given appropriate attention (Jelonek, 2009). The research data on assimilation apparatus of forest-forming tree species and their correlation with the main mensurational parameters of the stands can be considered as a basis for modelling the ecological functions of forests (Bartelink, 1997; Küssner and Mosandl, 2000).

We studied two main forest-forming tree species in the Northern Steppe of Ukraine: *Robinia pseudoacacia* L. (Black locust) and *Pinus sylvestris* L. (Scots pine). The black locust is a species introduced from North America (Carter, 2002) and the Scots pine is a species native to the study region (Lovinska and Sytnyk, 2016). The plantations of *Robinia pseudoacacia* in the Northern Steppe region of Ukraine have been created artificially (planted), and their area makes 17,683.7 ha. The corresponding area of Scots-pine-dominated forests is 21,472.9 ha (Lovinska and Sytnyk, 2016; Sytnyk et al., 2015). The formation and evolution of the stand structure, growth and morphogenic development of Black locust trees are mostly controlled by environmental and silvicultural factors.

The aim of this research was to estimate the share of foliage in greenery fraction of tree live biomass and to assess the dry matter content in needles of Scots pine and leaves of Black locust growing under conditions of the Steppe zone of Ukraine. In future, these results may be applied for calculation of biological productivity of Black locust and Scots pine stands.

Materials and methods

The research was conducted in forest stands subordinated to the State Agency of Forest Resources of Ukraine (Hulchak, 2011). The stands are located in forested area in the southeastern part of Ukraine – the Steppe zone of Dnipropetrovsk region, within the geographic coordinates: 49°10'N, 48°11'E (Fig. 1). The forests in this region grow on dry black soil. The main climatic indices correspond to the temperate climate: mean annual temperature +8.5°C, mean temperature of the coldest month (January) –5.5 °C, mean temperature of the warmest month (July) +23.5 °C, mean annual precipitation – 425 mm. Thirty model trees (fifteen of Scots pine and fifteen of Black locust) were selected on ten sample plots with an area of 0.25 ha each, established in stands of different age. Data acquisition was conducted in the second half of June, July and in the first half of August, during years 2014–2016.

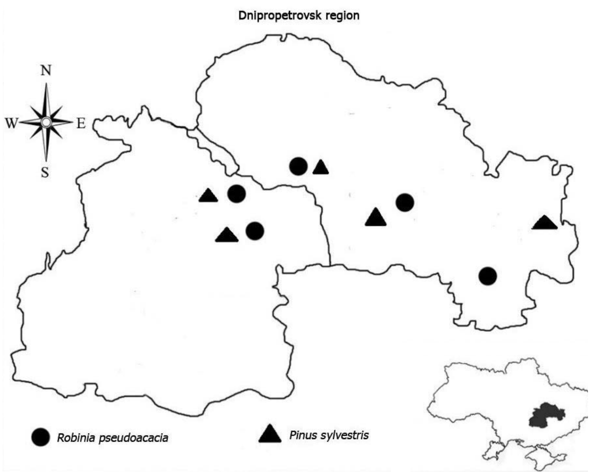


Fig. 1. Location of field experiments in Ukraine.

All studies determining the foliage share and dry matter content in the aboveground live biomass of the studied stands were carried out according to the methodology described by Lakyda (2002), the main guidelines of which are highlighted below.

During the fieldwork, live biomass of each model tree crown was separated into wood (over 1 cm in diameter) and tree greenery (foliage and twigs up 1 cm in diameter), and weighed. The mean foliage share

(P_L, %) was determined with using model tree greenery samples collected randomly. The collected samples were weighed in fresh state, and then re-weighed after manual defoliation. The foliage share was then calculated using the following formula (Turner et al., 2000; Lakyda et al., 2010a):

$$P_L = 100 \cdot (m_f - m_{def}) / m_f,$$

where P_L is foliage share (%), m_f is fresh mass of a model tree greenery sample (g), m_{def} is fresh mass of a model tree greenery sample in defoliated state (g).

Thus, tree greenery fraction was separated into twigs and foliage, and share of foliage in greenery of each model tree was calculated.

After determining the foliage share in the model tree greenery, all the previously separated foliage was collected. From that amount, a series of 10-gram samples was assembled and taken to the laboratory to provide their drying to a constant weight at 105 °C.

The dry matter content (S_L) in foliage was calculated using the formula (Lakyda et al., 2010b; Turski at el., 2008):

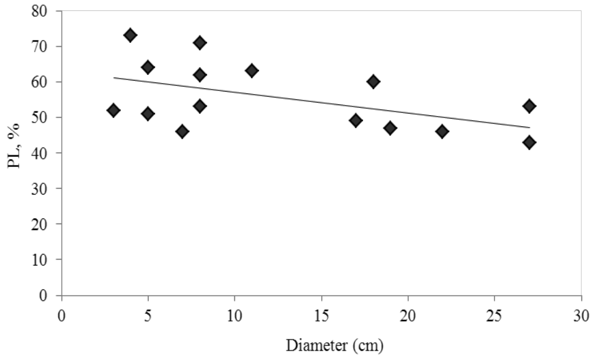
$$S_L = m_0 / m_{nat},$$

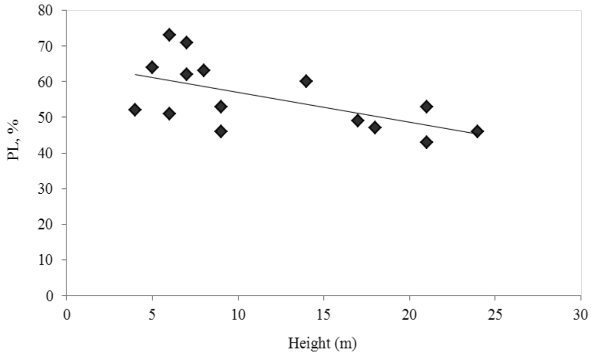
where S_L is dry matter content, m_0 is mass of foliage fraction dried at 105 °C (g), m_{nat} is mass of foliage fraction in fresh state (g).

The obtained results enabled us to perform correlation and regression analyses. The first was aimed at determining the driving factors for P_L and S_L from among the mensurational parameters (age, mean diameter and mean height of forest stands). The second enabled us to express the dependencies of P_L and S_L on the identified driving factors in a mathematically formalized form.

Results

The research results show that the foliage share in the Black locust greenery fraction, as a part of the aboveground biomass structure, had a significant variation range: 43.0–72.8 % (Fig. 2).





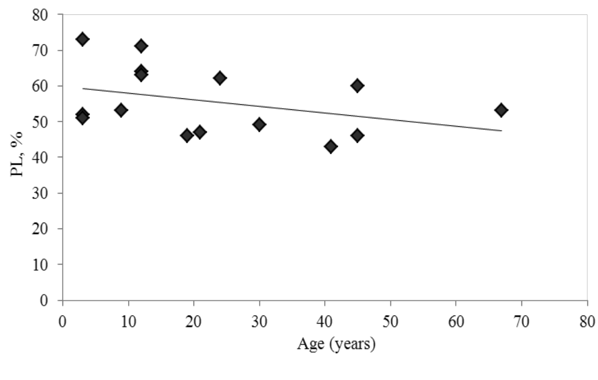
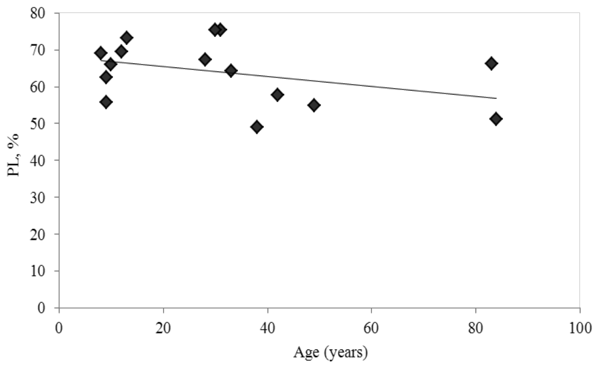


Fig. 2. Dependence between mensurational parameter values and foliage share (P_L) in Black locust greenery.

The minimum value of this parameter was recorded in a 41-year old overmature *Robinia pseudoacacia* stand, while the maximum was found in a 3-year old stand. The information collected on the Black locust samples shows that there is no statistically significant dependency of the foliage share in the tree greenery fraction on the tree age, diameter or height.

The foliage share in the tree greenery of the Scots pine model trees varied in a range of 49.1–75.4 % (Fig. 3). The lowest value of this parameter was recorded in 38, 49 and 84-year old stands, and the maximum value was in a 30-year old stand. The dependency of foliage share on tree age, diameter and height showed trends decreasing with increasing mensurational parameters of trees.



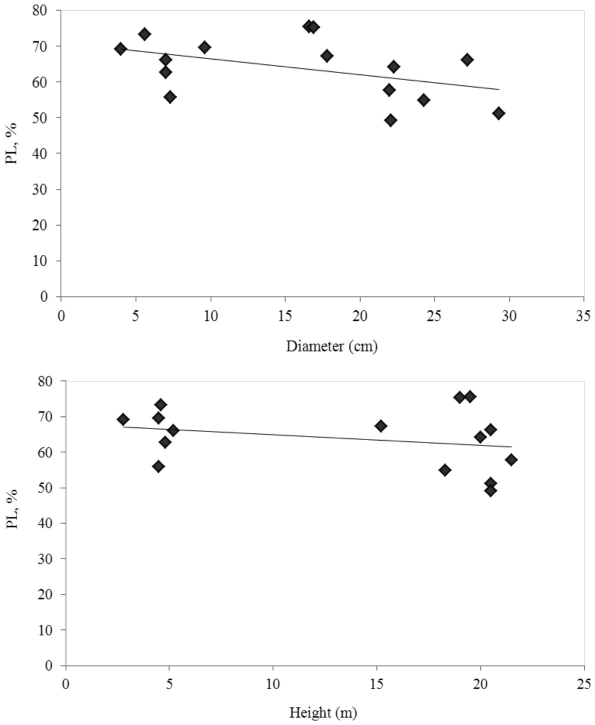


Fig. 3. Dependence between mensurational parameter values and foliage share (P_L) in Scots pine greenery.

The age-conditioned decrease of foliage share in the tree greenery fraction can be explained by physiological state of needles, branch structure, crown density and general light availability.

Analyzing the variation in dry matter content in the Black locust fresh foliage, we see that this parameter varies from 0.321 to 0.524 g, with the extreme values in young trees (Fig. 4).

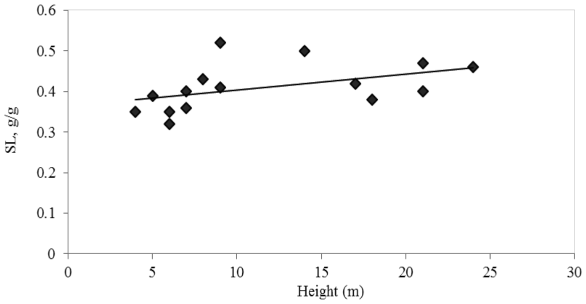
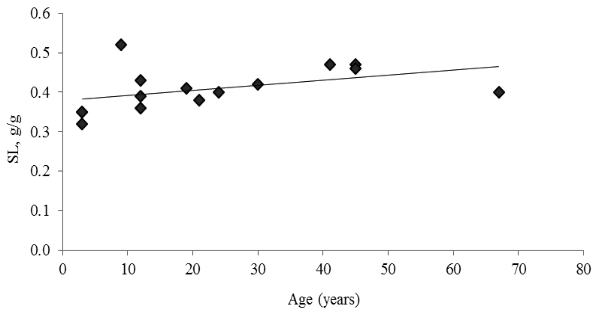
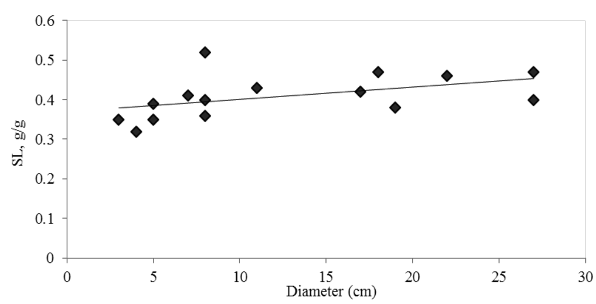


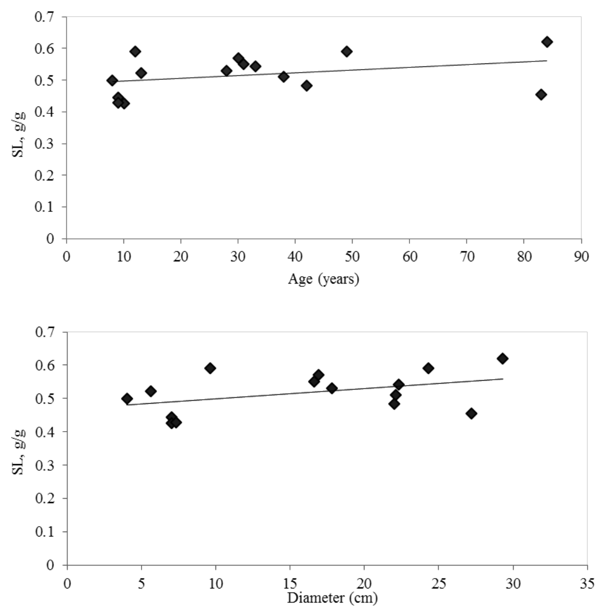
Fig. 4. Dependence between mensurational parameter values and dry matter contents (S_L) in leaves of Black locust.

There is a significant fluctuation in the absolute values of this parameter, even for the same age, height and trunk diameter. However, the trend line shows a tendency towards an increase in dry matter amount in foliage with increasing tree mensurational parameters. In the same way as for the foliage share, there has not been obtained a statistically significant dependency for dry matter content on age, height and trunk diameter.

On contrary, the dry matter content in the Scots pine foliage tended to increase in relation to these three parameters (Fig. 5). The analysis of dry matter content in needles shows a substantial variability of values from 0.426 to 0.620, while the mean for the majority of sample trees is 0.500. Significant fluctuations of the analyzed parameter values have been obtained for age, height, diameter at breast height. In general, according to the data provided, the trend line shows an overall increase in dry matter content with increasing mensurational parameters values.







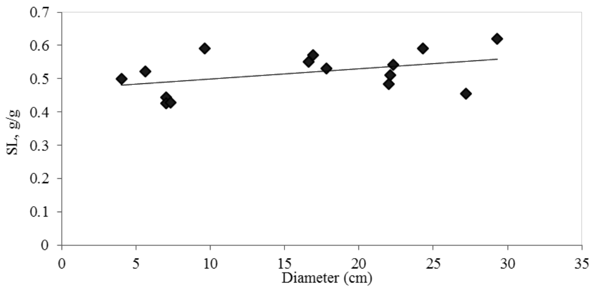


Fig. 5. Dependence between mensurational parameter values and dry matter contents (S_L) in foliage of Scots pine.

The correlation values for the foliage share in the tree greenery fraction and dry matter content in foliage to the tree age, mean height and mean diameter are presented in Table 1. The statistical analysis of the models developed showed that they did not provide a complete description of the empirical research material. This statement is evidenced by relatively low determination coefficients (R^2 = 0.12–0.21). In addition, the models evaluating the foliage share in tree greenery are less accurate compared to the models estimating the dry matter content in foliage. Thus, dependencies of the investigated aboveground live biomass indices on the tree age, diameter and height are expressed with equations with determination coefficients of 0.08–0.16 for foliage share, and 0.16–0.21 for dry matter content for Scots pine, and 0.14–0.41 and 0.31–0.36 for Black locust, respectively.

To understand the relationship between the researched qualitative indices of crown live biomass and mensurational parameters of trees, the respective correlation coefficient values were calculated (Table 2). The analysis of the correlation coefficients obtained for the Black locust suggests a conclusion that there is a moderate correlation of P_L to tree age (r = –0.42) and a significant correlation to tree diameter (r = –0.59) and tree height (r = –0.67). The correlation is inverse and, among the three analyzed mensurational parameters, the most significant for tree height. As for the resultant index S_L, direct moderate correlations to tree age (r = +0.42), height (r = +0.46) and diameter (r = +0.47) were registered.

Table 1. Allometric relationships between mensurational parameter values and indices of aboveground biomass

Index/ Parameter	*Robinia pseudoacacia* L.		*Pinus sylvestris* L.	
	Foliage share in tree greenery	Coefficient of determination	Foliage share in tree greenery	Coefficient of determination
Age (years)	$P_L = 64.9\ a^{-0.05*}$	$R^2 = 0.14$	$P_L = 76.37\ a^{-0.06}$	$R^2 = 0.12$
Height (m)	$P_L = 81.43\ h^{-0.16**}$	$R^2 = 0.41$	$P_L = 71.16\ h^{-0.05}$	$R^2 = 0.08$
Diameter (cm)	$P_L = 71.54\ d^{-0.11***}$	$R^2 = 0.27$	$P_L = 78.77\ d^{-0.08}$	$R^2 = 0.16$
		Dry matter content		
Age (years)	$S_L = 0.326\ a^{0.07}$	$R^2 = 0.36$	$S_L = 0.415\ a^{0.07}$	$R^2 = 0.21$
Height (m)	$S_L = 0.304\ h^{0.12}$	$R^2 = 0.31$	$S_L = 0.443\ h^{0.06}$	$R^2 = 0.16$
Diameter (cm)	$S_L = 0.318\ d^{0.10}$	$R^2 = 0.34$	$S_L = 0.416\ d^{0.08}$	$R^2 = 0.19$

*age; **mean height; ***mean diameter.

Table 2. Coefficients of correlation of foliage share in tree greenery fractions (PL) and of dry matter contents in foliage (SL) with mensurational indices of trees

Parameter/ Index	Age	Diameter	Height
Pinus sylvestris L.			
P_L	–0.391 ± 0.174*	–0.454 ± 0.167*	–0.280 ± 0.179
S_L	0.354 ± 0.176*	0.443 ± 0.166*	0.401 ± 0.173*
Robinia pseudoacacia L.			
P_L	–0.422 ± 0.170*	–0.670 ± 0.138***	–0.590 ± 0.152***
S_L	0.421 ± 0.170*	0.461 ± 0.167**	0.463 ± 0.167**

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

For the Scots pine, correlation indices of foliage share (P_L) had negative values in relation to all the three impact factors. Thus, for tree age and diameter a moderate correlation was observed with values of –0.39 and –0.45, respectively. There was also a weak inverse correlation to tree height (r = –0.28). The value of foliage share parameter decreased with increasing age, tree height and diameter. Direct correlations of dry matter content to tree age (r = 0.35), diameter (r = 0.44) and height (r = 0.40) were found indicating an increase of this index along with increasing mensurational parameter values.

Discussion

Most information on allometry of tree live biomass can be found in several scientific works (Tobin et al., 2006; Turski et al., 2008), but these articles do not address the aboveground live biomass of the main forest forming tree species growing within artificially created Steppe forest stands. As far as we know, studies concerning this issue are lacking.

The results of our study indicate that the aboveground live biomass parameters of stands dominated by the Black locust and Scots pine depended on mensurational indices of these trees and forest stands. Thus, for *Robinia pseudoacacia* the highest foliage share is typical for young-age trees and decreases with increasing tree age. Our findings correspond to the results obtained by Lochmatov and Gladun (2004) who observed that the Black locust stands dynamics was characterized by a rapid growth in the early years, especially in favorable conditions. Early, at around 5–7 years of age, these stands come closer to their maximum levels of shoot-forming capacity, foliage biomass production and foliage area. There is also an early and substantial dieback of canopy base branches due to lacking light and moisture, especially in dry conditions.

According to our results, the foliage share of Black locust decreased with increasing tree age, height and trunk diameter. Our findings may be explained by the fact that with increasing age the share of big branches in the crown increases with simultaneous decrease of share of small twigs, where leaves are formed.

For the Scots pine, the parameter of foliage share reached the highest values in mid-aged stands around 30 years. These findings are comparable with data referred by Usoltsev (2013) who explains this phenomenon by peculiarities in the stand structure and plant physiology in young and mid-aged stands. Young trees utilize photosynthetically active radiation and other abiotic ecological factors with the highest possible efficiency, due to their cenotically unstable condition. Instability of their status is reasoned by continuous natural selection, which is manifested in tree differentiation according to their growth and development. Their further ecological strategy is determined by efficient use of space. In such case, the efficiency of photosynthetic activity decreases.

According to the results of this study, the dry matter content in Black locust leaves does not show a correlation to mensurational indices, although there was a weak tendency to increase with increasing driving factors. These findings are probably linked to the physiological activity of plants and development of their root systems supplying the tree foliage with water and with dissolved minerals. For the *Robinia pseudoacacia* stands, we observed a rapid growth of their root systems and crowns in the early years and subsequent reduction of growth intensity in the following years. A high level of growth potential acting in moist conditions and limited growth possibilities in dry and extremely dry conditions lead to an early differentiation of trees according to their size, architectonics, and position of root systems in the soil. As a rule, the root systems of Black locust do not grow deep into the soil. Interestingly, they do not form a taproot at young age, instead tending to form side roots. This peculiarity may affect moisture supply to vegetative organs as well as it may influence dry matter content in fresh tree foliage.

For both studied species, the correlation between the foliage share, share of dry matter and mensurational indices, examined by regression analysis, was statistically insignificant ($P < 0.05$). Our findings agree with the results of Hungerford (1987) and Thompson (1989), who found that the parameters of aboveground live biomass were not affected by tree age, diameter and height.

Tree diameter is a convenient parameter for estimating foliage share and dry matter content for the two species: Scots pine and Black locust. Tree age and height cannot be applied in allometric equations to estimate the aboveground live biomass parameters. Fownes and Harrington (1991) also report similar findings in their research.

Our semigraphical and statistical analyses resulted in finding that in the Black locust stands the parameter of foliage share in tree greenery fraction of live biomass varied substantially, ranging 43.0–72.8%. The variability of this parameter for the Scots pine stands was also considerable, ranging 49.1% to 75.4%. There was an inverse correlation between the foliage share in tree greenery and tree age, height and diameter for both species under conditions of the Northern Steppe near the Dnipro River.

As for analyzing the variation in the dry matter share in the fresh foliage, its index varied from 0.321 to 0.524, and the extreme values were observed in trees belonging to the young age group. There was a trend of increasing dry matter content in fresh foliage of the studied species with increasing mensurational tree parameters.

In our opinion, assimilatory active live biomass production in Scots pine and Black locust stands can be enhanced by regulating the influence of the strategic silvicultural and forest management factors during the stages of stand creation and formation. Further research is required for establishing dependencies of the resulting parameters on the type of forest site conditions and on the technologies of formation of forest stands of these species in the Steppe zone of Ukraine.

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