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THE ENERGY CONTENT IN THE LIVE BIOMASS COMPONENTS OF SCOTS PINE TREES (*PINUS SYLVESTRIS* L.)

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Results of the development of reference materials for evaluation the energy content in aboveground live biomass of Scots pine trees of the stands of natural and artificial origin of Polissya and Forest-steppe are shown. It is presented the algorithm of the development of reference materials to assess the energy content which is based on the results of modeling the qualitative parameters of live biomass components of trees and their qualitative indicators. The article is based on the results of biometric evaluation of 639 model trees of Scots pine of artificial origin, and 164 model trees of natural origin.

Keywords: *energy, live biomass, reference materials, Scots pine, Polissya, Forest-steppe.*

Current development of world civilization is characterized by rapid population growth that encourages the mankind to find additional sources of food, drinking water and renewable sources of energy. An access to the natural resources, including energy, is an essential stabilizing factor for state economy, as well as an effective instrument for geopolitical influence. At that, the volumes of existing, within the country, energy resources and their sustainable usage in conditions of increasing globalization processes is one of the most important criteria for ensuring national security [5].

In this direction, pine forests, which possess significant amounts of forest energy biomass – stem wood, timber harvested during thinning, logging residues at

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the cutting area of the main use and wastes in wood-processing factories may become one of the key factors for ensuring ecological and economic security of Polissya region of Ukraine.

The aim of the research is the development of regulatory reference support for the evaluation of the energy content in aboveground live biomass of Scots pine trees in stands of various origin of Ukrainian Polissya and Forest -steppe.

Materials and methods of research. Researching energy volumes accumulated in the tree live biomass the primary task is its quantitative and qualitative evaluation. For studying the last was used the method of prof. P. Lakyda, which is described in details in number of scientific papers [1, 3]. The research process of energy content in aboveground live biomass of pine trees includes the following stages [1, 3, 5]: 1 – studying the experience of assessment of tree live biomass and working up the methods; 2 – acquisition, processing and analysis of experimental data; 3 – mathematical modeling of live biomass components of trees and adequacy test of models; 4 – evaluation of deposited carbon content in tree live biomass; 5 – development of standards of energy content in trees live biomass and their verification. For developing of the standards there were used quantitative parameters of energy content in one ton of carbon, deposited in tree live biomass [8]. Herewith, these calculations were based on the following initial data that were gathered by the groups of researchers over the past decade and which represent the reserve experimental base for research aboveground live biomass in the investigated region [4]:

– ***artificial Scots pine stands in Polissya and Forest-steppe*** (116 temporary experiment plots (TEP), where 639 model trees (MT) were cut down with the assessment of components live biomass, for laboratory research were selected 198 samples of experimental cuts of tree stems, 42 samples of crown branches, 303 model branches of tree greenery (TG) and 129 samples of needles);

- ***natural Scots pine stands in Polissya and Forest-steppe*** (26 temporary experiment plots (TEP), where 164 MT were cut down and evaluated; for laboratory research were selected 12 samples of experimental cuts of tree stems, 12 samples of crown branches, 44 model branches of TG and 10 samples of needles) .

The results of the research. To the question of the research of aboveground tree live biomass of the main forest forming stands of the investigated region devoted a number of scientific papers [1, 2, 4, 5, 6], which reflect the systematic realization of complex research of biological productivity of stands for biomass components.

For development of the standards of energy content in live biomass of Scots pine trees was used an algorithm of calculation which is reflected in details in the table. 1.

1. Algorithm of standards development of the energy content of aboveground live biomass components of Scots pine trees of various origins

Natural origin	Artificial origin
$v = exp(-2.592) \cdot d^{1.912} \cdot h^{0.861} / 1000$; $p_b = exp(4.580) \cdot d^{-0.116} \cdot h^{-0.657}$; $v_b = v \cdot p_к / 100$; $q_{tg} = exp(-2.479) \cdot d^{2.493} \cdot h^{-0.881} \cdot P^{-0.333}$; $q_{br1} = exp(-2.621) \cdot d^{3.066} \cdot h^{-1.399} \cdot P^{-0.642}$; $a = exp(2.139) \cdot d^{0.378} \cdot h^{0.253}$; $\rho_{1w}^{st} = exp(5.620 + 0.158\ E\text{-}02 \cdot a) \cdot a^{0.0968}$; $\rho_{1b}^{st} = exp(5.994 + 0.501\ E\text{-}02 \cdot a) \cdot a^{-0.163}$; $m_w^{st} = (v - v_b) \cdot \rho_{1w}^{st}$; $m_b^{st} = v_b \cdot \rho_{1b}^{st}$; $m^{st} = m_w^{st} + m_b^{st}$; $p_n = 66.7$; $s_n = 0.43$; $q_n = q_{tg} \cdot p_n / 100$; $m^n = q_n \cdot s_n$; $q_{br} = q_{br1} + (q_{tg} - q_n)$; $\rho_{1wb}^{br} = exp(5.028 - 0.245\ E\text{-}02 \cdot a) \cdot a^{0.282}$; $\rho_{wb}^{br} = exp(6.003 - 0.694\ E\text{-}02 \cdot a) \cdot a^{0.315}$; $s_\rho^{br} = \rho_{1wb}^{br} / \rho_{wb}^{br}$;	$v = g \cdot h \cdot f / 1000$; $f = 576,482 + 9058.577 \cdot h^{-2.207} - 19.474 \cdot d^{0.545}$; $p_b = exp(3.882) \cdot d^{-0.178} \cdot h^{-0.293}$; $v_b = v \cdot p_к / 100$; $q_{tg} = exp(-1.494) \cdot d^{2.814} \cdot h^{-1.360} \cdot P^{-0.223}$; $q_{br1} = exp(-3.490) \cdot d^{3.457} \cdot h^{-1.423} \cdot P^{-0.809}$; $a = exp(1.292) \cdot d^{-0.197} \cdot h^{1.018}$; $\rho_{1w}^{st} = exp(5.620 + 0.158\ E\text{-}02 \cdot a) \cdot a^{0.0968}$; $\rho_{1b}^{st} = exp(5.994 + 0.501\ E\text{-}02 \cdot a) \cdot a^{-0.163}$; $m_w^{st} = (v - v_b) \cdot \rho_{1w}^{st}$; $m_b^{st} = v_b \cdot \rho_{1b}^{st}$; $m^{st} = m_w^{st} + m_b^{st}$; $p_n = 66.7$; $s_n = 0.43$; $q_n = q_{tg} \cdot p_n / 100$; $m_n = q_n \cdot s_n$; $q_{br} = q_{br1} + (q_{tg} - q_n)$; $\rho_{1wb}^{br} = exp(5.028 - 0.245\ E\text{-}02 \cdot a) \cdot a^{0.282}$; $\rho_{wb}^{br} = exp(6.003 - 0.694\ E\text{-}02 \cdot a) \cdot a^{0.315}$; $s_\rho^{br} = \rho_{1wb}^{br} / \rho_{wb}^{br}$;

Continuation of Table 1.

Natural origin	Artificial origin
$m^{br} = q_{br} \cdot s_{\rho}^{br}$; $m^{cr} = m^{br} + m^{n}$; $m^{tr} = m^{st} + m^{cr}$; $m_C = (m^{st} + m^{br}) \cdot 0.50 + m_n \cdot 0.45$; $e_{br} = m_C^{br} \cdot 35.76$; $e^{st} = m_C^{st} \cdot 35.76$; $e = m_C \cdot 35.76$	$m^{br} = q_{br} \cdot s_{\rho}^{br}$; $m^{cr} = m^{br} + m^{n}$; $m^{tr} = m^{st} + m^{cr}$; $m_C = (m^{st} + m^{br}) \cdot 0.50 + m_n \cdot 0.45$; $e^{st} = m_C^{st} \cdot 35.76$; $e_{br} = m_C^{br} \cdot 35.76$; $e = m_C \cdot 35.76$

While processing and developing the standards for evaluation of energy content in aboveground live biomass of trees of the investigated stands there were used the following symbols: d – the diameter of the tree at a height of 1.3 m, sm; h – height of the tree, m; f – old form factor of the tree stem; g – square of the cross-sectional area of the stem, m^2; v – volume of the stem, m^3; v_b – volume of the bark of the stem, m^3; p_b – stem bark percentage, %; q_{tg} – TG live biomass in fresh-cut condition, kg; q_{br1} – crown branches live biomass without fraction of TG in fresh-cut condition, kg; q_{br} – crown branches live biomass of the tree in fresh-cut condition, kg; q_n – live biomass of crown leaves (needles) of the tree in fresh-cut condition, kg; ρ_{1w}^{st} – basic density of the tree stem, kg·(m^3)$^{-1}$; ρ_{1b}^{st} – basic density of stem bark, kg·(m^3)$^{-1}$; ρ_{1wb}^{st} – basic density of wood in the trunk, kg·(m^3)$^{-1}$; ρ_{wb}^{br} – natural density of wood of the branches, kg·(m^3)$^{-1}$; ρ_{1wb}^{br} – basic wood density of branches, kg·(m^3)$^{-1}$; s_{ρ}^{br} – absolutely dry matter content in the bark of the branches; p_n – the percentage of needles in TG, %; s_n – an absolutely dry matter content in the fresh needles; m^{br} – live biomass of wood of branches in an absolutely dry condition, kg; m^{n} – live biomass of needles in an absolutely dry condition, kg; m^{cr} – live biomass of tree crown in an absolutely dry condition, kg; m^{tr} – aboveground tree live biomass in an absolutely dry condition, kg; m_C – deposited carbon in aboveground tree live biomass, kg; e_{br} – energy content in live biomass of crown branches, GJ; e^{st} – energy content in trunk live biomass, GJ; e – energy content in aboveground tree live biomass, GJ.

Moreover, in addition to the results of mathematical modeling of live biomass components parameters and evaluation of their qualitative indicators [4], data from the scientific literature on the percentage of carbon (50 % – wood and bark, 45 % – green fraction) in a weight unit of live biomass in an absolutely dry condition [7] and energy content parameters of one ton of carbon deposited in tree live biomass (35.76 GJ) were used [8].

As a result of realization of the abovementioned algorithm there were received the regulatory reference tables, which provide an information about energy content in aboveground live biomass of Scots pine trees, depending on their mensurational indicators, diameter at a height of 1.3 meters and height. However, taking into account initial experimental data, mentioned regulatory reference tables will give adequate results only in a certain parametric range: for heights from 4 to 32 m; for diameter of 4–44 cm.

The fragments of the standards developed for the assessing the energy content accumulated in live biomass of tree stems are presented in the tables 2 and 3.

2. The energy content accumulated in live biomass of Scots pine tree stems of natural origin, GJ

Diameter, cm	Height, m										
	4	6	8	10	12	14	16	18	20	22	24
4	0.021	0.030	0.043								
6	0.048	0.070	0.091	0.11							
8		0.12	0.16	0.20	0.23	0.27					
10		0.20	0.25	0.30	0.38	0.43	0.48				
12		0.27	0.36	0.45	0.52	0.61	0.68	0.77			
14			0.48	0.61	0.72	0.82	0.93	1.00	1.10		
16			0.64	0.79	0.93	1.07	1.22	1.36	1.50	1.63	
18				0.98	1.18	1.36	1.54	1.72	1.79	1.97	2.15
20				1.22	1.45	1.66	1.79	1.97	2.32	2.50	2.68
22					1.75	1.97	2.15	2.50	2.68	3.04	3.22
24					1.97	2.32	2.68	3.04	3.22	3.58	3.93
26						2.68	3.04	3.40	3.75	4.29	4.65
28						3.22	3.58	4.11	4.47	4.83	5.36
30						3.58	4.11	4.65	5.19	5.54	6.08
32							4.65	5.36	5.90	6.44	6.97
36								6.79	7.33	8.05	8.76

3. The energy content accumulated in live biomass of Scots pine tree stems of artificial origin, GJ

Diameter, cm	Height, m										
	4	6	8	10	12	14	16	18	20	22	24
4	0.029	0.032	0.041								
6	0.064	0.075	0.089	0.11							
8		0.13	0.16	0.20	0.23	0.27					
10		0.20	0.25	0.30	0.36	0.41	0.46				
12		0.29	0.34	0.41	0.50	0.57	0.66	0.75			
14			0.46	0.55	0.66	0.77	0.89	1.00	1.10		
16			0.59	0.72	0.86	1.00	1.14	1.31	1.47	1.64	
18				0.89	1.07	1.25	1.43	1.63	1.79	1.97	2.15
20				1.09	1.31	1.52	1.75	1.97	2.15	2.32	2.68
22					1.56	1.79	1.97	2.32	2.50	2.86	3.22
24					1.79	1.97	2.32	2.68	3.04	3.40	3.75
26						2.32	2.68	3.22	3.58	3.93	4.29
28						2.68	3.22	3.58	4.11	4.47	5.01
30						3.22	3.58	4.11	4.65	5.19	5.72
32							4.11	4.65	5.19	5.90	6.44
36								5.72	6.44	7.15	8.05

What is typical for the trees of various origins that is an increase of energy content in live biomass of stems in bark of trees with an increase in size, which is absolutely consistent with the nature of tree growth.

Today in many European countries branch wood is recognized as an important additional source of raw materials that are widely used not only in pulp and paper industry, but also in bioenergy production. In Ukraine, wood and bark of branches are considered as illiquid raw materials, hardly used, and mainly are left in the forest after logging. Considering the global trends in the development of alternative energy sources and taking into account the experience of European countries, such as Finland and Austria, in Ukraine wood and bark of the branches can serve as one of the sources of thermal energy that requires an appropriate regulatory reference support to assess their energy potential.

The fragments of the standards developed for assessing energy content accumulated in live biomass of tree branches are presented in the tables 4 and 5.

4. The energy content accumulated in live biomass of Scots pine tree crown branches of natural origin, GJ

Diameter,	Height, m										
cm	4	6	8	10	12	14	16	18	20	22	24
4	0.007	0.005	0.004								
6	0.025	0.014	0.011	0.007							
8		0.036	0.025	0.020	0.014	0.013					
10		0.068	0.048	0.036	0.029	0.025	0.021				
12		0.12	0.082	0.063	0.050	0.041	0.034	0.030			
14			0.13	0.098	0.079	0.066	0.055	0.048	0.043		
16			0.20	0.15	0.12	0.098	0.082	0.072	0.063	0.055	
18				0.21	0.17	0.14	0.12	0.10	0.089	0.079	0.072
20				0.29	0.23	0.20	0.16	0.14	0.12	0.11	0.10
22					0.30	0.25	0.21	0.18	0.16	0.14	0.13
24					0.41	0.34	0.29	0.25	0.21	0.20	0.17
26						0.43	0.36	0.30	0.27	0.25	0.21
28						0.54	0.45	0.39	0.34	0.30	0.27
30						0.66	0.55	0.48	0.43	0.38	0.34
32							0.68	0.59	0.52	0.45	0.41
36								0.84	0.73	0.66	0.59

5. The energy content accumulated in live biomass of Scots pine tree crown branches of artificial origin, GJ

Diameter,	Height, m										
cm	4	6	8	10	12	14	16	18	20	22	24
4	0.007	0.005	0.004								
6	0.029	0.016	0.011	0.009							
8		0.041	0.029	0.020	0.016	0.013					
10		0.082	0.055	0.041	0.032	0.027	0.023				
12		0.15	0.10	0.075	0.059	0.048	0.041	0.036			
14			0.17	0.12	0.10	0.080	0.066	0.057	0.052		
16			0.25	0.20	0.15	0.12	0.10	0.089	0.079	0.070	
18				0.29	0.21	0.18	0.15	0.13	0.11	0.10	0.091
20				0.39	0.30	0.25	0.21	0.18	0.16	0.14	0.13
22					0.43	0.34	0.29	0.25	0.21	0.20	0.18
24					0.57	0.46	0.39	0.34	0.29	0.27	0.23
26						0.61	0.50	0.43	0.38	0.34	0.30
28						0.77	0.64	0.55	0.48	0.43	0.39
30						0.97	0.80	0.70	0.61	0.54	0.48
32							1.00	0.86	0.75	0.66	0.59
36								1.27	1.11	0.98	0.88

It is worth to be mentioned, that within one degree of the thickness, the live biomass of Scots pine tree branches decreases with the increasing of height, accordingly the same trend remains in the standards of the energy content in the tree branches.

The use of the above mentioned regulatory reference tables is effective in case when wood and bark of tree trunks of investigated stands will be used as an energy resource and the live biomass components of crowns will remain on the cutting areas (for further rotting) in order to minimize the impact on the stability of ecosystems. Also, in case of procurement of industrial assortments as for energy purposes can be used only felling residues in the form of branches [6].

For necessity of the assessment of the energy content in aboveground live biomass of trees in general, can be used regulatory materials, fragments of which are given in the tables 6 and 7.

6. Energy content in aboveground live biomass of Scots pine trees of natural origin, GJ

Diameter, cm	Height, m										
	4	6	8	10	12	14	16	18	20	22	24
4	0.032	0.039	0.046								
6	0.082	0.093	0.11	0.13							
8		0.18	0.20	0.23	0.25	0.29					
10		0.29	0.32	0.36	0.43	0.46	0.50				
12		0.43	0.46	0.54	0.61	0.68	0.72	0.82			
14			0.68	0.75	0.82	0.93	1.00	1.11	1.22		
16			0.89	1.00	1.11	1.22	1.32	1.47	1.61	1.72	
18				1.29	1.39	1.54	1.72	1.86	1.93	2.07	2.25
20				1.61	1.75	1.93	2.00	2.18	2.50	2.65	2.83
22					2.15	2.32	2.43	2.75	2.90	3.25	3.40
24					2.50	2.79	3.08	3.40	3.50	3.93	4.29
26						3.25	3.50	3.93	4.29	4.65	5.01
28						3.93	4.29	4.65	5.01	5.36	5.72
30						4.29	5.01	5.36	5.72	6.08	6.44
32							5.36	6.08	6.44	7.15	7.51
36								7.87	8.22	8.94	9.66

7. Energy content in aboveground live biomass of Scots pine trees of artificial origin, GJ

Diameter, cm	Height, m										
	4	6	8	10	12	14	16	18	20	22	24
4	0.043	0.043	0.046								
6	0.12	0.11	0.11	0.13							
8		0.20	0.21	0.23	0.26	0.29					
10		0.34	0.35	0.39	0.43	0.46	0.50				
12		0.54	0.50	0.54	0.61	0.64	0.72	0.82			
14			0.75	0.75	0.82	0.89	1.00	1.11	1.22		
16			1.00	1.04	1.11	1.22	1.32	1.43	1.57	1.75	
18				1.36	1.43	1.54	1.68	1.82	1.97	2.11	2.29
20				1.72	1.79	1.90	2.07	2.25	2.40	2.54	2.86
22					2.22	2.29	2.40	2.72	2.83	3.15	3.47
24					2.65	2.65	2.90	3.18	3.47	3.93	3.93
26						3.22	3.43	3.93	4.29	4.29	4.65
28						3.93	4.29	4.29	4.65	5.01	5.72
30						4.65	4.65	5.01	5.36	6.08	6.44
32							5.72	5.72	6.44	6.79	7.15
36								7.51	7.87	8.58	9.30

The regulatory reference tables that are proposed in this article can be used for quantitative evaluation of the areas allocated to different types of logging for determination of energy potential, procured at their carrying of wood biomass. Taking under consideration, that the forests of the investigated region perform important ecological functions, use of wood and logging wastes for energy purposes should be based on the principles of sustainable development.

Conclusions. Thus, the results obtained in the research will contribute to the practical implementation of development of regional bioenergy programs as one of the most perspective areas for solving the existing energy problems of investigated regions. In addition, development of reference support can be used in the scientific, ecological, forestry, technical and economic study of expanded use of forest energy resources of pine stands in Ukrainian Polissya and Forest-steppe.

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Наведено результати розробки нормативно-інформаційного забезпечення для оцінки вмісту енергії в надземній фітомасі дерев сосни звичайної у деревостанах природного та штучного походження Полісся і Лісостепу. Запропоновано алгоритм розроблення нормативно-довідкових таблиць для оцінки вмісту енергії, який базується на результатах моделювання кількісних параметрів компонентів *фітомаси дерев та їх якісних показниках. В основу роботи покладено результати біометричної оцінки 639 модельних дерев сосни звичайної штучного походження та 164 модельних дерева – природного походження.*

Ключові слова: *енергія, фітомаса, нормативно-інформаційне забезпечення, сосна звичайна, Полісся, Лісостеп.*

Приведены результаты разработки нормативно-информационного обеспечения для оценки содержания энергии в надземной фитомассе деревьев сосны обыкновенной в древостоях естественного и искусственного происхождения Полесья и Лесостепи. Предложен алгоритм разработки нормативно-справочных таблиц для оценки содержания энергии, основанный на результатах моделирования количественных параметров компонентов фитомассы деревьев и их качественных показателях. В основу работы положены результаты биометрической оценки 639 модельных деревьев сосны обыкновенной искусственного происхождения и 164 модельных дерева – естественного происхождения.

Ключевые слова: *энергия, фитомасса, нормативно-информационное обеспечение, сосна обыкновенная, Полесье, Лесостепь.*