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Peculiarities of formation of the forest litter of the water protection pine plantations in the Ukrainian interflue of the Dnipro and Desna rivers

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Abstract. The effective performance of ameliorative functions by water protection plantations is largely determined by the development of the forest litter, its structure, capacity, quality composition, and degree of mineralization. Therefore, the aim of the study was to identify the features of the formation of the forest litter of pine plantations of the Ukrainian interfluves of the Dnipro and Desna. The study of forest litter was carried out on the accounting sites in all age groups of plantations, in which 22 test plots were laid. Litter samples were taken in between rows and directly in rows of forest plantations. During the analysis of the qualitative composition of the forest litter of young plantations, the dominance of the upper horizon of the inactive fraction, which consisted mainly of needles and branches, was revealed. Here, the share of inactive litter in the conditions of moist poor pine site and moist relatively poor pine site was 8.13 t/ha or 85.1% and 12.54 t/ha or 92.1%, respectively. A large amount of dust, which forms the active fraction, was recorded in the lower horizon. Its stocks were 5.3-5.6 times higher than the reserves of inactive litter. In general, in young pine forests in the conditions of moist poor pine site, the stock of inactive litter is 15.10 t/ha (28.1%), while its presence in of moist poor pine site is 17.91 t/ha, 36.5%. In middle-aged pine forests, the share of the active litter fraction increases, which is a consequence of the active action of its decomposition processes. The share of active litter is 79.3% or 155.29 t/ha in mature stands of the conditions of moist poor pine site. This is evidence of the intensification of the processes of mineralization and activation of the circulation of substances. Three horizons are clearly distinguished in the litter of plantations of older age groups, with a strong connection between them. The lower layer of the forest litter of water conservation plantations is permeated with physiologically active roots, which forms its dense type of structure. Under such conditions, during the separation of the lower layer of litter from the upper one, it does not fall apart and its structure remains dense. The presence of strongly intertwined physiologically active roots in the third horizon of the litter is evidence of the activation of microbiological processes, which are also accelerated by the interception of moisture and the accumulation of humus particles of the soil by the lower layers of the forest litter. To prevent the development of flood processes, the effective performance of water regulation and water purification functions, it is recommended to create water conservation plantations with the formation of the identified type of forest litter

Keywords: active and inactive litter, biometric indicators, dust, litterfall, nutrient turnover

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Introduction

Fortest litter is an important structural and functional component of the forest biogeocenosis, which combines its abiotic and biotic components and forms a cohesive system. Forest litter plays an important role both in the processes of circulation of substances and energy in ecosystems, and in soil formation [1-3].

The forest litter, which is formed under the canopy of the forest plantation, in combination with the rhizosphere of the tree-shrub canopy, significantly changes the water, temperature and air regimes of the soil, accumulates in its layer and in the upper horizon of the soil the biodiversity of microflora and fauna. Enriched with nutrients, the decomposition products of forest litter, penetrating into the soil together with atmospheric precipitation, lead to a change in its structure and properties of soil solutions [4; 5].

The formation of forest litter is understood not only for the accumulation of its phytomass. In the litter there are complex processes of decomposition and transformation of organic compounds, which are completed by their full mineralization [3; 6]. Knowledge of the trend of forest litter development is necessary to evaluate its place and role in the biological circulation of nutrients and nitrogen. With the intensive decomposition and mineralization of the litter, the rapid release of ash nutrients is released, which penetrate into the lower mineral layers of the soil. In the case of accumulation of organic matter in humified or semi-decomposed form, the process of transformation of nutrients and nitrogen is slowed down and sometimes stopped.

Quantitative and qualitative analysis of forest litter contributes to a clearer representation of the dynamics of nutrients in forest ecosystems. The mass, structure and chemical composition of the litter depends on many factors, the most important of which include: site conditions [7; 8], species composition [1; 9; 10], age [11-13], density of the stand [14; 15], health condition of planting [3; 15], origin [4; 5], location [8; 16]. Therefore, an important aspect is the formation of such litter, which would ensure rapid rates of its mineralization and, therefore, the circulation of nutrients in the vegetation-soil system, which is of crucial importance for the productivity of forest ecosystems [2; 3].

Particularly multifaceted is the forest amelioration role of the forest litter, in plantations that determines water regulation, water retention, water purification, soil protection, soil formation, soil erosion control and other purposes [12; 17]. Therefore, it is advisable to consider the study of quantitative and qualitative characteristics, stocks and fractional composition of forest litter as an important dynamic component that ensures effective performance of amelioration functions in water protection plantations.

The purpose of the study was to identify quantitative and qualitative indicators characterizing the structural composition of the forest litter and the peculiarities of its formation in water protection pine plantations of the Ukrainian interfluves of the Dnipro and Desna rivers.

The novelty of the research lies in the revealing of a new type of forest litter, which is formed in the pine plantations in moist poor pine site and relatively poor pine site of floodplain landscapes.

Materials and Methods

The study was carried out in the pine forest stands of the interfluves of the Dnipro and Desna rivers, which grow on a slightly undulating plain dissected by the floodplains of these rivers, which actually determines the landscape structure of this territory. After all, in the valleys of these rivers, marshlands occupy 4.5% of the territory of Chernihiv Polissia. The hydrographic zoning map of Ukraine shows the territory of the Ukrainian interfluves of the Dnipro and Desna rivers, with a total area of about 2 million hectares (Fig. 1). In the landscape structure of the region, the main role belongs to natural complexes dominated by moraine-sand and sandy plains with sod-podzolic soils and pine forests.

Forest coverage of the territory is about 25%. The structure of the forest fund is dominated by pine and oak-pine forests. Forest plantations, in addition to performing important water protection functions, contribute to the accumulation of humus in the soil and form highly productive phytoctnosis, which are characterized by increased water conservation, soil protection, recreational and ecological properties.

The research facilities are located in the State Enterprise “Vyshe-Dubechnia Forestry”. Its land fund is located on the second floodplain terrace of the interfluves. Water protection plantings occupy a dominant position. The forest vegetation conditions of the study site are quite favorable for the cultivation of Scots pine, the plantations of which occupy 18,385.0 hectares, which is 68.6% of the total area of the Forestry [13].

The formation and structure of the forest liter was studied on 22 test plots (TP), which were laid out on the first and second terraces of the Desna River, in the most typical for the region plantations with the participation of Scots pine and birch. Test plots were planted in conditions of moist poor pine site (A2) and relatively poor pine site (B2) in plantations of different ages. The terminology of the typology of forest vegetation sites is given in the publication [18].

Figure 1. Geographical location of the Ukrainian interflue of the Dnieper and Desna rivers on the hydrographic zoning map of Ukraine

The age range of the examined plantations ranges from 21 to 117 years. Their average height is 8.2-40.1 m. Productivity corresponds to I^a-II classes of productivity (site index). It is determined by the conditions of forest vegetation and the location of plantations on different terraces of the Desna River.

Field and laboratory methods. Selection of forest litter samples was carried out at the accounting sites laid in pine forests of different age classes within the test plots. Accounting sites in young and middle-aged plantations were placed between rows and in rows. Depending on the age of the plantation and the thickness of the litter, the area of the accounting sites was determined, which was 0.5 m^2 (0.5x1 m) or 1 m^2 (1.0x1.0 m). The litter was cut along the contour of the accounting site and packed in burlap. In the laboratory, litter was divided into fractions and weighed on electronic scales.

The inactive forest litter consists of branches, bark, cones and needles, the period of complete mineralization of which reaches more than 100 years. The active part of litter includes leaves of tree species and bushes, remains of grasses, buds, remains of entomofauna, debris (dust) and roots. This is consistent with the methodological developments of Y. Chornobai & O. Maryskevich [1], I. Bondar [2], V. Maliuha et al. [15].

The distribution of forest litter into fractions was carried out in laboratory conditions. Tree roots were divided into conducting (thickness over 2 mm) and physiologically active (thickness less than 2 mm). Roots of grass plants were counted separately. The debris was divided into two fractions – coarse and fine. Coarse debris was classified as a dust with dimensions from 1.1 mm to 5 mm, and fine debris was classified as a dust smaller than 1 mm. That is, it is the dust sifted through a one-millimeter sieve, which includes particles of vegetation and soil.

Results and Discussion

A number of factors influence the process of forest litter formation in water conservation pine plantations, namely: species composition with an admixture of deciduous species, age of the tree stand, forest vegetation conditions [1; 7; 10]. That is why a study of litter in planted pine forests, which grow in the most common moist poor pine and moist relatively poor pine sites in the Dnipro and Desna interfluves, was conducted.

Peculiarities of forest litter formation in moist poor pine site (A2)
The general view of young (Fig. 2a) and mature (Fig. 2b) pine plantations, in which profiles were laid and litter samples were taken to determine the fractional composition is shown in Fig. 2. The profile of the litter, which was laid on TP 1 in the inter-row of a 21-year-old pine-birch plantation of the Pirnovo Forestry, is shown in Fig. 2c (block (bl.) 540, unit (un.) 2). The thickness of the litter in the interrows is 1.6-2.6 cm, and in the rows 2.8-3.8 cm. A clear distribution of the litter into horizons is not yet observed, although the half-mineralized lower layer is 1.2-2.8 cm. The upper layer of litter consists of fallen pine needles mixed with birch leaves, and its thickness is 1.1-2.0 cm.

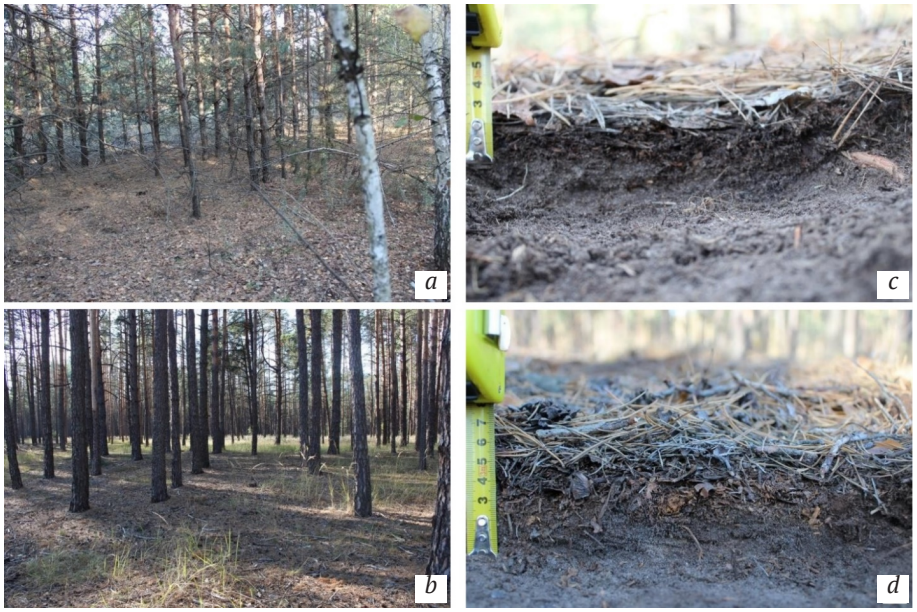

Figure 2. Pine plantations with forest litter profiles: young stand – general view *a*, litter profile *c*; mature stand – general view *b*, litter profile *d*

In the middle-aged pine-birch plantation on TP 6, which is planted in Novosilkiv Forestry in block 795, litter profiles were formed both between rows and in rows. Here, the litter is characterized by clearly defined horizons. In the lower horizon, a semi-decomposed organic mass with a thickness of 1.0-2.6 cm can be traced, and in the middle layer, non-decomposed or half-mineralized remains of needles, birch leaves, and fine pine roots are recorded. The total thickness of this horizon is 1.5-2.3 cm. The upper litter horizon with a thickness of 0.7-2.3 cm is formed by birch, pine needles, and cones. The total thickness of the forest litter in the investigated pine-birch plantation reaches 3.1-4.6 cm.

In the plantations of older age groups, for the study of litter indicators, profiles were laid on TP 3, 8, and 10, which are respectively located in Pirnovo (bl. 579, un. 4), Novosilky (bl. 781, un. 5) and Novosilky (bl. 765, un. 1) forestry's.

The thickness of the forest litter profile is 4.3-5.6 cm in pre-mature pine stands. The bottom layer of litter 1.3-3.2 cm is almost completely decomposed. The middle layer is represented by 1.2-2.2 cm of undecayed twigs, bark, and needles. Fresh annual litterfall from twigs, conifers, and pine cones covers the litter surface with a 1.0-2.0 cm layer.

The litter of a mature pine plantation on TP 10 is represented by well-defined formed layers (Fig. 2d). The thickness of the litter is 4.7-6.6 cm. The profile of the litter shown in Figure 2d, the formed horizons are clearly distinguished. The lower mineralized layer of litter has a thickness of 1.8-3.5 cm. The middle layer of litter is represented by undecayed twigs, needles, bark, remnants of cocoons of entomofauna - pine sawfly, pine silkworm.

Over-mature pine plantations of moist poor pine site accumulate a large layer of litter more than 7.3 cm thick. The lower horizon is clearly defined, mineralized, 1.6-3.7 cm thick. The second semi-decomposed layer of forest litter contains pine roots, conifers, and remains of entomofauna. The upper layer of the litter is the annual litterfall with a small, compared to pines of younger age categories, capacity, which reaches 1.2-2.6 cm.

Generalized data on fractions of forest litter of pine plantations of the II and VI age classes, which grow in A2 site, are given in Table 1. The data of Table 1 indicate that the litter has a two-layer structure in the young plantation. A feature of its structure is the dominant share of dust, which is concentrated in the lower layer of the litter and makes up more than 60% of its capacity. At the same time, the fine part of dust, which is represented by particles smaller than 1.1 mm, exceeds the coarse part of dust by almost two times. The main mass of the litter stock falls on the second layer is 44.13 t/ha. It is more than 4 times greater than the top layer of litter stock (9.55 t/ha).

As the age of the plantations increases, the litter acquires a three-layer structure. This phenomenon is associated with the accumulation of pine needles and cones in the litter. If the stock of cone fraction in young trees was only 0.24 t/ha, then already in middle-aged plantations the stock of cones amounted to 4.01 t/ha, i.e. it was 16.8 times greater. The presence of a significant proportion of cones and needles keeps the bedding substrate in a non coherent and loose state. In general, the litter stock in middle-aged pine stands of moist poor pine site is more than twice the litter stock of young plantation.

Table 1. Fractional composition of forest litter of water protection plantations of moist poor pine sites

Layer	Stock, t/ha	Fractions of forest litter, t/ha												
		Inactive part				Active part								
									Roots			dust		
									Tree plants					
		Branches	Bark	Cones	Needles	Leaf	Grass	Buds	Conductive	Physiologically active	Herbaceous plants	Rough part (1-5 mm)	Small fraction (<1 mm)	Entomo-fauna
Young: Composition* – 8Ps2Bp; Age – 15 years; Test plot 4 (block 795, unit 23)														
1st layer	9.553	0.621	0.707	–	6.797	1.037	–	0.027	–	–	–	0.307	0.054	0.003
2nd layer	44.133	0.320	0.877	0.237	5.539	0.715	–	0.112	0.014	0.584	0.082	12.208	23.387	0.058
∑	53.687	0.941	1.584	0.237	12.336	1.752	–	0.139	0.014	0.584	0.082	12.515	23.441	0.061
Middle-aged: Composition – 10Ps; Age – 56 years; Test plot 2 (block 617, unit 2)														
1st layer	16.816	3.837	2.469	3.267	6.650	–	–	0.022	–	–	–	0.290	0.282	–
2nd layer	19.570	2.341	1.949	0.738	4.640	–	–	0.179	–	0.098	–	4.390	5.226	0.010
3rd layer	77.320	0.626	0.715	0.010	0.408	–	–	0.022	0.061	1.366	–	7.723	66.373	0.016
∑	113.706	6.803	5.133	4.014	11.698	–	–	0.224	0.061	1.464	–	12.403	71.880	0.026
Over-mature: Composition – 10Ps; Age – 111 years; Test plot 21 (block 794, unit 11)														
1st layer	13.112	3.828	1.552	1.994	1.914	–	0.440	0.028	–	–	–	1.647	1.679	0.030
2nd layer	109.031	14.927	7.303	4.198	2.009	–	0.345	0.082	0.003	0.228	0.018	12.494	67.281	0.143
3rd layer	121.590	0.903	0.786	3.084	0.403	–	–	0.010	0.786	2.471	–	8.722	104.319	0.104
∑	243.733	19.658	9.641	9.276	4.326	–	0.785	0.121	0.789	2.698	0.018	22.864	173.280	0.277

***Note:** Ps – *Pinus sylvestris* L.; Bp – *Betula pendula* Roth.; Qr – *Quercus robur* L.

Peculiarities of forest litter formation in moist relatively poor pine site (B2)

The moist relatively poor pine sites differ from the moist poor pine sites by richer growth conditions and phytodiversity, which actually affect the formation of the forest litter. Morphometric parameters of litter were studied in the four age groups: young, middle-aged, pre-mature, mature and over-mature. The locations of laying litter profiles on TP 15 and 12 are shown in the Fig 3. They are located in middle-aged and mature pine plantations.

The view of middle-aged and pre-mature plantations, in which the TP 15 and 12 were laid, is shown in Fig. 3a and 3b respectively. The profiles of forest litter are shown in Fig. 3c and 3d.

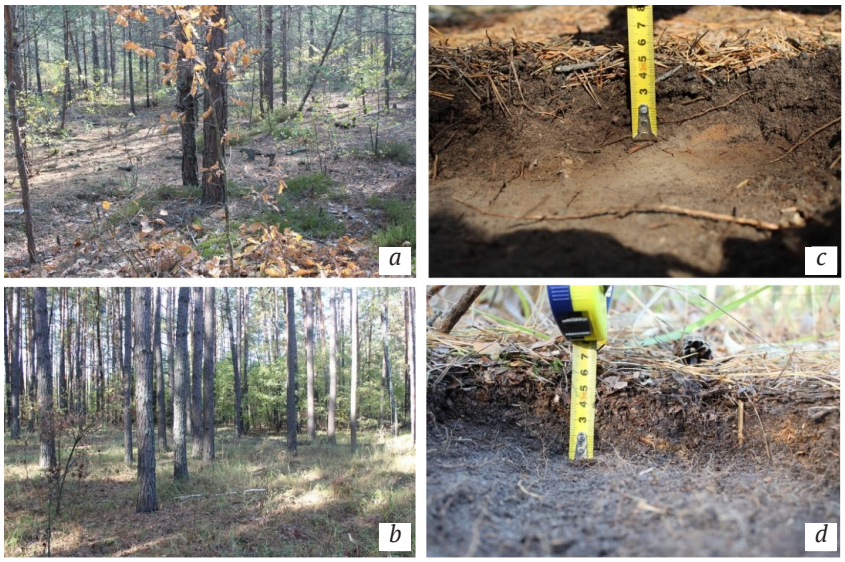

Figure 3. Pine plantations in B2 site with forest litter profiles: middle-aged – general view *a*, litter profile *c*; pre-mature – general view *b*, litter profile *d*

Forest litter of a 26-year-old pure pine plantation growing in moist relatively poor pine site of Novosilky Forestry in the bl. 793, un. 6, reaches a thickness of 2.8-4.7 cm and already forms a thick 1.5-3.4 cm mineralized layer. A more developed living above-ground cover is inherent in a 60-year-old pine planting of the Pirnovo forestry, which grows in the block 539 on the unit 3. Here a layer of litter with a power of 4.8-7.0 cm is accumulated with the formation large thick of stronger annual litterfall, which consists of needles, bark, twigs and cones.

The thickness of the forest litter in the mature 81-year-old pine plantation in the Vyshche-Dubechnia Forestry in block 568, un. 16 was 4.4-7.8 cm with formed three-layer structure. The upper layer up to 2.5 cm is represented by the annual litterfall of woody and herbaceous vegetation with implicit signs of the beginning of the mineralization process. The middle layer consists of semi-decomposed remains of coniferous litter, bark, and twigs with 1.5-3.5 cm thickness. The lowest third layer of litter with a thickness of 1.7-4.0 cm is mineralized organic mass.

Over-mature plantations in Pirnovo Forestry on TP 22 (bl. 562, un. 17) accumulate a thick litter with three-layer structure and the thickness of 8.7-9.8 cm. The thickness of all layers is almost the same and ranges from 2.5 to 4.0 cm.

It is found out a feature of litter formation in water protection plantations between the Dnipro and Desna rivers. It is the fact that the lower horizon, saturated with intertwined fine roots, is characterized by increased density. During separation from the litter of the middle layer, it does not crumble, preserving its structure. Such a phenomenon was not detected in similar forest vegetation conditions of the pine forests of Kyiv Polissia.

The generalized data on the distribution of forest litter by fractions in pine plantations of different age groups of the moist relatively poor pine site are given in Table 2. Qualitative and quantitative indicators of the forest litter of young, pre-mature and over-mature plantations are given below. Such a wide range of research made it possible to determine regularities in the complete cycle of formation of pine plantations in B2 site. Almost the same total mass of litter is accumulated in young pine plantations, the stock of which is 49.098 and 53.87 t/ha, respectively. However, the inactive part of the forest litter in B2 site has more branches and cones in its composition, and in the A2 site the cones was not yet noticeable in the litterfall. This is evidence of the intensive development of young pine plantations in conditions the moist relatively poor pine site. There is a noticeable predominance of root remains in the lower layer in the active part of the litter of young stands of A2 site that indicates the development of the upper soil horizons. The mass of physiologically active roots in the litter of young pine plantations was 0.582 t/ha in A2 site and only 0.162 t/ha in B2 site.

Table 2. Fractional composition of forest litter of water protection plantations of moist relatively poor pine sites

Layer	Stock, t/ha	Fractions of forest litter, t/ha												
		Inactive part				Active part								
									roots			dust		
									tree plants					
		Branches	Bark	Cones	Needles	Leaf	Grass	Buds	Conductive	Physiologically active	Herbaceous plants	Rough part (1-5 mm)	Small fraction (<1 mm)	Entomo-fauna
Young: Composition – 8Ps2Bp;Age – 18 years; Test plot 11 (block 547, unit 5)														
1st layer	13.621	4.566	1.803	0.682	5.491	0.264	–	0.019	–	–	–	0.597	0.198	–
2nd layer	35.477	0.984	1.464	0.128	2.794	0.030	–	0.085	–	0.162	–	4.792	24.786	0.253
∑	49.098	5.550	3.267	0.810	8.285	0.294	–	0.104	–	0.162	–	5.389	24.984	0.253
Pre-mature: Composition – 10Ps+Qr; Age – 60 years; Test plot 12 (block 539, unit 3)														
1st layer	20.032	5.195	1.872	4.987	4.243	0.298	1.382	0.093	–	–	–	1.685	0.275	0.002
2nd layer	13.181	1.187	1.133	1.744	0.570	0.029	0.109	0.078	–	0.042	0.120	5.102	3.038	0.029
3rd layer	90.422	4.162	0.898	3.838	0.208	0.027	0.142	0.066	0.040	0.541	0.643	23.101	56.696	0.061
∑	123.635	10.544	3.902	10.570	5.021	0.354	1.634	0.237	0.040	0.582	0.763	29.888	60.010	0.091
Over-mature: Composition – 10Ps; Age – 101 years; Test plot 22 (block 562, unit 17)														
1st layer	23.874	6.760	3.168	5.502	6.758	0.090	–	0.053	–	–	–	1.165	0.378	–
2nd layer	31.632	4.085	2.846	3.138	1.965	0.029	–	0.232	–	0.155	–	6.427	12.702	0.053
3rd layer	140.242	1.456	1.642	2.834	0.301	–	–	0.070	0.637	4.350	–	15.806	113.067	0.078
∑	195.747	12.301	7.656	11.474	9.024	0.118	–	0.355	0.637	4.506	–	23.398	126.147	0.131

The accumulation of forest litter in middle-aged pine plantations also has a similar pattern, which is characteristic of young plantations. The total stock of litter in middle aged plantations is 2-2.5 times greater than the mass of litter in young plantations, regardless of forest vegetation sites. This is explained by the different intensity of leaf fall, as well as different rates of its mineralization, which is characteristic of pure pine plantations.

Fractional composition of forest litter

In addition to quantified indicators determination of litter distribution by area, aggregation, and fractional composition was studied. It was found that the distribution of litter by area was generally uniform.

Differences in the thickness and stocks of forest litter in rows and between rows of pine plantations are not observed already in pre-mature plantations from the VI age class. The thickness of the litter in the rows exceeds the similar values between rows by 1.0-1.5 cm in young plantations. This is especially clear in plantations with wide (2.0-2.5 m) rows (Fig. 4).

Figure 4. Characteristics of litter profiles in rows (*a*) and between rows (*b*) in pine plantations of the III age class

Thus, in the moist relatively poor pine site, the forest litter of 22-year-old of mixed pine planting (9Ps1Bp) in rows has a thickness of 4.0-5.0 cm, and in the interrows its thickness reaches 3.6 cm (Fig. 4). The composition of the forest litter is marked by a coherent three-layer structure in the older age groups. It consists of the branches, bark, cones, pine needles, leaves, buds, roots, rough and fine dust, entomofauna remains.

The "cones" fraction appears in the middle-aged plantations of the moist poor pine site. It is concentrated in the top layer of litter. Its weight is 4,014 t/ha. The total mass of cones is 10,570 t/ha in the plantations of the moist relatively poor pine site. It is usually almost evenly placed on the separated horizons. This reaffirms the early and intensive reproductive activity of pine plantations of B2 site. The proportion of roots in the litter of A2 site is 5-5.5 times higher than the proportion of roots in the litter of pines growing in B2 site. The content of physiologically active roots in the litter almost doubles their content in the upper 10-centimeter layer of mineral soil, which is respectively 4,506 t/ha and 2,403 t/ha [5].

The small fraction of forest litter, with particles size <1.1 mm, is actively accumulated in the lower layers. If in young plantations it dominates in the second layer of litter, then in the plantations of the older age groups it accumulates in the third layer. Its mass in the forest litter in mature plantations of B2 site is 126,147 t/ha, which is 64.4% of its total mass. This indicates the active course of decomposition processes in the thickness of the litter and intensive mineralization processes in its lower layers. Generalized data of stocks in the forest litter fractions are given in Table 3.

Table 3. Stocks and fractional composition of litter of water protection plantations

Age groups and composition of plantations	Layer of litter	Litter stock, t/ha	Fractions of litter, t/ha				
			Branches	Bark	Cones, needles	Leaf, grass, buds	Roots, dust, entomofauna
Plantations of moist poor pine site (A2)							
Young stand: 8Ps2Bp; A–15 years; TP 4	1st layer	0.955	0.62	0.71	6.80	1.06	0.36
	2nd layer	44.13	0.32	0.88	5.78	0.83	36.33
	∑	53.69	0.94	1.58	12.57	1.89	36.70
Middle-aged stand: 10Ps; Age – 56 years; TP 2	1st layer	16.82	3.84	2.47	9.92	0.02	0.57
	2nd layer	19.57	2.34	1.95	5.38	0.18	9.72
	3rd layer	77.32	0.63	0.72	0.42	0.02	75.53
	∑	113.71	6.81	5.14	15.72	0.22	85.82
Over-mature stand: 10Ps; Age – 111 years; TP 21	1st layer	13.11	3.83	1.55	3.90	0.47	3.36
	2nd layer	109.03	14.92	7.30	6.21	0.43	80.17
	3rd layer	121.59	0.90	0.79	3.49	0.01	116.40
	∑	243.73	19.65	9.64	13.60	0.91	199.93

Age groups and composition of plantations	Layer of litter	Litter stock, t/ha	Fractions of litter, t/ha				
			Branches	Bark	Cones, needles	Leaf, grass, buds	Roots, dust, entomofauna
Plantations of moist relatively poor pine site (B2)							
Young stand: 8Ps2Bp; A–15 years; TP 4	1st layer	13.62	4.57	1.80	6.17	0.28	0.80
	2nd layer	35.48	0.98	1.46	2.92	0.12	29.99
	∑	49.10	5.55	3.27	9.09	0.40	30.79
Pre-mature stand: 10Ps+Qr, Bp; A – 60 years; TP 12	1st layer	20.03	5.20	1.87	9.23	1.77	1.96
	2nd layer	13.18	1.19	1.13	2.31	0.22	8.33
	3rd layer	90.42	4.16	0.90	4.05	0.24	81.08
	∑	123.64	10.54	3.90	15.59	2.22	91.37
Over-mature stand: A – 101 years; 10Ps; TP 22	1st layer	23.87	6.76	3.17	12.26	0.14	1.54
	2nd layer	31.63	4.08	2.85	5.10	0.26	19.34
	3rd layer	140.24	1.46	1.64	3.13	0.07	133.94
	∑	195.75	12.30	7.66	20.50	0.47	154.82

The analysis of the active and inactive litter fractions showed that the upper layer of the litter of young pine plantations the inactive component of the litter is dominated, which contains a large proportion of branches and needles. Their share in the A2 site and B2 site is 8.13 t/ha (85.1%) and 12.54 t/ha (92.1%), respectively. In the second layer of the litter, in young plantations, the active part with a large amount of dust is already dominant, which is 5.3-5.6 times greater than the inactive part of the forest litter. The trend towards an increase in the active part of the litter is confirmed by the research of C. Prescott [19], which indicates the possible humification of the litter in suboptimal conditions (low temperatures or excessive humidity).

In general, the stock of inactive litter in the young plantations of A2 and B2 sites is 15.10 t/ha or 28.1% and 17.91 t/ha or 36.5% respectively. It is noted that a significant mass of the inactive part of the litter accumulates in the upper layer. Moreover, the share is greater in plantations of B2 site due to the more active course of growth and development processes. At the same time, in young pine plantations of A2 site, the inactive part of the forest litter of the second layer already dominates this indicator in the litter formed under conditions of B2 site, which indicates the activation of microbiological processes and its accelerated decomposition.

An increase in the active part of the litter can be achieved by introducing it to pine plantations of deciduous species. This is confirmed by the research of P. Sewerniak [3] and other scientists. It is known that pure conifer monocultures are much more likely than broad-leaved or mixed forests to be affected by factors such as fires, pathogens, pests, and windstorms. This thesis is confirmed by the research conducted in the pure coniferous forests of the Dolomites, in Gallio, Asiago and Cansiglio. In particular, P. Sewerniak [3] recommends converting pine monocultures into mixed forests by conventional planting of deciduous species into middle-aged monocultures. The problem of rational management of clean coniferous plantations is currently urgent and important. After all, the frequency of forest damage has increased in recent decades [20]. It is also predicted that in the future, ongoing climate changes may cause a serious loss of the economic value of European forests.

In pine stands of the VI age class, the litter accumulation and its fractional composition is similar general regularity to that of young stands. However, the tendency to increase the fraction of active litter is clearly visible It indicates the active processes of mineralization.

With age, stocks of active litter increase (Table 4). In mature stands of A2 site, its share reaches 82.4%, which is 200.82 t/ha. Somewhat lower values of the share of active litter were recorded in B2 site – 79.3% or 155.29 t/ha, which is explained by the acceleration of the processes of mineralization and circulation of substances.

Table 4. Distribution of stocks of active and inactive litter in water protection pine plantations

Age group	Layer of litter	Litter stock, t/ha	Fractions of litter			
			Inactive		Active	
			t/ha	%	t/ha	%
Plantations of moist poor pine sites						
Young	1st layer	9.56	8.13	85.1	1.43	14.9
	2nd layer	44.13	6.97	15.8	37.16	84.2
	∑	53.69	15.10	28.1	38.59	71.9
Middle-aged	1st layer	16.82	16.22	96.5	0.60	3.5
	2nd layer	19.57	9.67	49.4	9.90	50.6
	3rd layer	77.32	1.76	2.3	75.56	97.7
	∑	113.71	27.65	24.3	86.06	75.7

Age group	Layer of litter	Litter stock, t/ha	Fractions of litter			
			Inactive		Active	
			t/ha	%	t/ha	%
Over-mature	1st layer	13.11	9.29	70.8	3.82	29.2
	2nd layer	109.03	28.44	26.1	80.59	73.9
	3rd layer	121.59	5.18	4.3	116.41	95.7
	∑	243.73	42.91	17.6	200.82	82.4
Plantations of moist relatively poor pine sites						
Young	1st layer	13.62	12.54	92.1	1.08	7.9
	2nd layer	35.48	5.37	15.1	30.11	84.9
	∑	49.10	17.91	36.5	31.19	63.5
Pre-mature	1st layer	20.03	16.30	81.4	3.73	18.6
	2nd layer	13.18	4.63	35.2	8.55	64.8
	3rd layer	90.43	9.11	10.1	81.32	89.9
	∑	123.64	30.04	24.3	93.60	75.7
Over-mature	1st layer	23.87	22.19	92.9	1.68	7.1
	2nd layer	31.63	12.03	38.0	19.60	62.0
	3rd layer	140.24	6.23	4.4	134.01	95.6
	∑	195.74	40.45	20.7	155.29	79.3

A similar trend regarding the layer-by-layer accumulation of forest litter can be seen in middle-aged and mature water protection plantings. The ratio of litter in young, pre-mature and over-mature stands of B2 site is 1:2.5:4.0 or 49.10, 123.64 and 195.74 t/ha, respectively. With age, there is an increase in the mass of litter, which at the maturing of pine stands is 4 times greater than the litter stocks of young plantations. The same regularity was found in the distribution of litter fractions. In particular, the share of active litter increases with age and reaches 79.3% in over-mature stands. In pre-mature and over-mature pine plantations, the active litter of the third layer is 89.9% and 95.6%, respectively, which indicates active processes of its mineralization.

Conclusions

The distribution of forest litter within the pine plantations of water protection purposes is quite uniform in terms of area. The difference in its thickness and stocks in rows and between rows of artificial pines is not observed after the VI age class. The thickness of the litter in the rows exceeds the similar indicators between the rows by 1.0-1.5 cm only in young plantations. This is especially clear in plantations with 2.0-2.5-meter rows.

In terms of composition, the studied forest litter is coherent with a three-layer structure in older age groups. The litter of over-mature pine plantations of a moist relatively poor site is characterized by a large thickness (8.7-9.8 cm) with a clearly defined lower mineralized layer 2.5-4.0 cm thick. The second semi-decomposed layer of the litter is saturated with small pine roots, needles, and remains of entomofauna. The annual litterfall has a much lower capacity than in the plantations of younger age groups.

A feature of litter formation in water protection plantations is the fact that its lower horizon, saturated with small roots, has a dense structure. During separation from the litter of the middle layer, it does not crumble, and its structure is not destroyed. This phenomenon was not detected in pine plantations growing in similar forest vegetation conditions of the Kyiv Polissia.

The presence of a significant proportion of physiologically active roots in the third layer of litter indicates the active course of microbiological processes in it. The content of physiologically active roots in the litter almost doubles their content in the upper 10-centimeter layer of mineral soil, which is respectively 4.5 t/ha and 2.4 t/ha.

For an in-depth study of the water regulation and water purification functions associated with the formation of forest litter in pine plantations of floodplain landscapes, a perspective trend is the analysis of the chemical composition of the litter in dynamics to complement the mechanism of its mineralization.

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Особливості формування лісової підстилки водоохоронних соснових насаджень Українського межиріччя Дніпра і Десни

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Анотація. Ефективне виконання меліоративних функцій водоохоронними насадженнями значною мірою визначається розвитком лісової підстилки, її структурою, потужністю, якісним складом, ступенем мінералізації. Тому метою дослідження стало виявлення особливостей формування лісової підстилки соснових насаджень Українського межиріччя Дніпра та Десни. Дослідження лісової підстилки проведено на облікових майданчиках у всіх вікових групах насаджень, у яких закладено 22 пробні площі. Зразки підстилки відбирали у міжряддях і в рядах лісових культур. Під час аналізу якісного складу лісової підстилки молодняків виявлено домінування верхньому горизонті неактивної фракції, яку складали переважно хвоя і гілки. Тут частка неактивної підстилки в свіжих лісорослинних умовах бору і субору становила відповідно 8,13 т/га або 85,1 % і 12.54 т/га або 92,1 %. У нижньому горизонті зафіксовано велику кількість трухи, яка формує активну фракцію. Її запаси у 5,3–5,6 раз перевищують

запаси неактивної підстилки. Загалом, у молодих сосняках свіжого бору запас неактивної підстилки становить 15,10 т/га (28,1 %), у той час коли її наявність у насадженнях свіжого субору – 17,91 т/га 36,5 %. У середньовікових сосняках частка активної фракції підстилки збільшується, що є наслідком активної дії процесів її розкладу. У стиглих насадженнях свіжого субору частка активної підстилки становить 79,3 % або 155,29 т/га. Це є свідченням інтенсифікації процесів мінералізації і активізації колообігу речовин. У підстилці насаджень старших вікових груп чітко виділяються три горизонти, із міцним зчепленням між собою. Нижній шар лісової підстилки водоохоронних насаджень пронизаний фізіологічно активним корінням, що формує її щільний тип складання. За таких умов під час відділення нижнього шару підстилки від верхнього він не розпадається і його структура залишається щільною. Наявність сильно переплетеного фізіологічно активного коріння у третьому горизонті підстилки є свідченням активізації мікробіологічних процесів, які також пришвидшуються перехватом вологи і нагромадженням гумусових часток ґрунту нижніми шарами лісової підстилки. Для запобігання розвитку паводкових процесів, ефективного виконання функцій водорегулювання і водоочищення рекомендується створення водоохоронних насаджень з формуванням виявленого типу лісової підстилки

Ключові слова: активна і неактивна підстилка, біометричні показники, труха, опад, кругообіг речовин