FRACTIONAL COMPOSITION AND FORMATION OF FOREST LITTER IN SCOTS PINE PLANTATIONS ON RAVINE-GULLY SYSTEMS AND THE PLAIN OF THE CENTRAL PART OF UKRAINE

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Abstract

The fractional composition of forest litter was studied in pure and mixed plantations with a predominance of Scots pine aged 14–85 years. The study was conducted in anti-erosion plantations of ravine-gully systems of Dnieper Upland, in parks on Kyiv slopes of Dnieper River, Ovruch Ridge, as well as in the plains of Kyiv and Zhytomyr Polissia. Forest litter is with a thickness of 2.2–2.5 cm in mixed stands and 2.5–3.5 cm in pure stands with a stock of 20.8 and 27.8 $t \cdot ha^{-1}$, respectively. The mass of litterfall in the studied areas is different and ranges from 2.9 $t \cdot ha^{-1}$ in mixed plantations to 14.1 $t \cdot ha^{-1}$ in pure pine ones. Analysis of the fractional composition of litter showed that its active part (leaves, crumbs, fruits) in all experimental areas is in the range from 65 to 82 %, while the inactive part (branches, bark, cones) is 18–45 % of the total mass. The active part in mixed plantations is 73–82 %, pure ones – 65–67 %, and the inactive part is 18–27 and 34–45 %, respectively. The rate of destruction and mineralization of freshly dead phytomass was determined by analysis of litterfall-litter index – the ratio of litter mass to the mass of annual litterfall. Plantations of ravine-gully systems are characterized by strongly inhibited intensity of litter mineralization with an index of 6.2–7.9. The index ranges from 2.9 to 4.5 in park plantations and from 1.1 to 5.5 in the plantations of the plain sites. The mass of water absorbed by litter is 11.0–50.8 $t \cdot ha^{-1}$ and its moisture capacity is in the range of 134–319 %, which is equivalent to 1.6–4.8 mm of precipitation.

Key words: litterfall-litter index, mineralization, moisture capacity, organic litterfall, stock, water permeability.

Introduction

Forest litter is a supersoil formation formed under forest canopy from the litterfall of organic remnants of aboveground forest layers and partially grassy plants (Bogatyrev 1990). Litter decomposition is widely recognized as a vital link between aboveground and underground environmental processes, including soil organic matter formation and nutrient cycling in forest ecosystems (Novák et al. 2013, Semenyuk et al. 2020).

Svyrydenko et al. (2005) consider forest litter to be an independent natural body that is spatially located on the boundary between soil and phytocoenosis, through which dynamic connections and relationships between vegetation and soil take. Forest vegetation properties of the soil are largely determined by the speed of circulation of substances in the soil-plant system. Litter is the main source of returning to soil of organic and ash substances removed from it by plants in the process of life.

Annual litterfall is considered to be fallen leaves, twigs, branches, bark, cones, seeds and other organic residues of forest vegetation. Along with litterfall, the soil surface receives a significant amount of organic matter and nutrients that are in them (Svyrydenko et al. 2005). The amount of litterfall depends on the species composition, age, canopy structure of the forest (Yakuba 2004, Solomatova 2013). Litterfall replenishes the reserves of organic and mineral substances in the litter and affects its physical properties and the formation of various genetic types of forest soils, their productivity.

The proportion of leaves in the litter decreases because they decompose rapidly, the proportion of twigs, fruits, scales and other components (organic residues), which decompose more slowly increases (Parsons et al. 2014). The amount of litter depends on the ratio between its arrival, during litterfall, and consumptions, due to decomposition, which in turn depends on: climate, soil conditions, position, and composition of planting, age and density (Svyrydenko et al. 2005).

Depending on the species composition of stands, different types of forest litter are formed, which differ in power and rate of mineralization (Bogatyrev 1990). It performs a number of different important functions, in particular significantly affects the water regime of soils, delays and retains much of the precipitation, prevents surface runoff and evaporation of water from the soil and thus affects the water, air, temperature, redox regimes of soils (Zhytska 2009). Forest litter plays a significant anti-erosion role, it absorbs 2–6 times more water than its mass; restrains the kinetic energy of rain and protects the soil from destruction; the rough surface of the litter slows down the flow rate and clogs the soil. With the removal of litter, runoff increases and soil water permeability decreases 5–10 times (Gomyyo and Kuraji 2016).

Obviously, its thermoregulatory role is no less important for forest soils and for the cycle of mineral nutrients. In the process of its decomposition and mineralization, the upper soil horizons are enriched with nutrients (Novák and Slodičák 2009), and therefore are a constant source of modified organic compounds that form humus – the main part of organic compounds that determine the level of forest soil trophic (Brovko et al. 2020, Wei et al. 2020).

The main anti-erosion properties of the litter also include water-absorbing and water-retaining (moisture capacity) ability, which contributes to the transfer of surface destructive runoff into subsoil (Zhou et al. 2018). These properties depend on its thickness and stock. It is known that the litter acts as mulch. The presence of a continuous layer of organic precipitation reduces its heating, evaporation of moisture, inhibits the mechanical pressure exerted by humans and large animals on the upper layers of forest soil, which prevents its excessive compaction.

The main source of trace elements for the forest is organic rainfall. From the point of view of forest productivity, rapid decomposition of precipitation and forest litter is beneficial, because under such conditions the mineral compounds of nitrogen, phosphorus, potassium and other elements are formed.

According to Swift et al. (1979) the rate of mortal decomposition is determined by three groups of factors: physicochemical characteristics of the environment in which the decomposition takes place, the composition of litterfall and the activity of destructive organisms. Thus destruction can be limited both by one factor, and their complex. Excessive accumulation of mortmass indicates incomplete biogeochemical cycles, which is accompanied by a significant decrease in productivity and resilience of forests due to inhibition of the biogeochemical cycle (Chornobay 2000). Studying the rate of circulation through the literfall-liter index is a potential way to assess changes in ecosystems, a priority tool in terms of being able to analyze the cycle, identify changes in individual links, and influence its course by practical measures (Sizer et al. 2000). One of the main indicators of forest litter is its capacity, layer-by-layer analysis of which allows us to assess the rate of accumulation or decomposition of plant precipitation.

Litter plays an important role not only in the processes of circulation of substances in ecosystems, but also in the processes of soil formation and reflects the zonal features of the geographical location of plantations. The meliorate role of forest litter is especially multifaceted, which determines water regulation, water retention, water cleaning, soil protection, anti-erosion and other functions (Yukhnovskyi et al. 2013).

The aim of the study was to analyze the fractional composition of forest litter and the processes of its formation in protective forest stands of Scots pine in the central part of Ukraine.

Material and Methods

The objects of research were Scots pine (*Pinus sylvestris* L.) stands of pure and mixed artificial origin, created in the conditions of ravine-gully territories of Dnieper upland in Forest-Steppe zone, in parks of Kyiv on the slopes of Dnieper River, Ovruch ridge of Polissia. For comparison, plantations growing in the plain conditions of Kyiv and Zhytomyr Polissia were studied (Fig. 1).

Plantations of ravine-gully Rzhyshchiv-Kaniv erosive area are represented by trail plots (TP) 1–4. Plantations are aged from 14 to 38 years. The conditions for the growth of anti-erosion plantations are quite close: slopes' steepness from 12^{o} to 26^{o}, the exposition from south-west to south-east with the location in the middle part of slopes.

On the ravine-gully lands of Ovruch-Slovechna ridge of Polissia zone TP 5 and 6 were chosen in anti-erosion plantations, which grow on sod-podzolic sandy soil. Plantations occupy slope upper part.

Two trial plots (7 and 8) are laid in the park plantations of Kyiv, located in conditions of complex relief. The composition of the mixed plantation is represented by the formula 4*Qr*3*Ps*3*Ap*, pure – 10*Ps*. Their age is 70 years and they grow on the slopes of the southern and northern expositions with a steepness of 20^{o} and 10^{o}, respectively.

To identify differences in the formation of litter in ravine-beam systems and plain conditions, trial plots 9–12 were laid. Trial plots 9–10 are the pine plantations in Kyiv

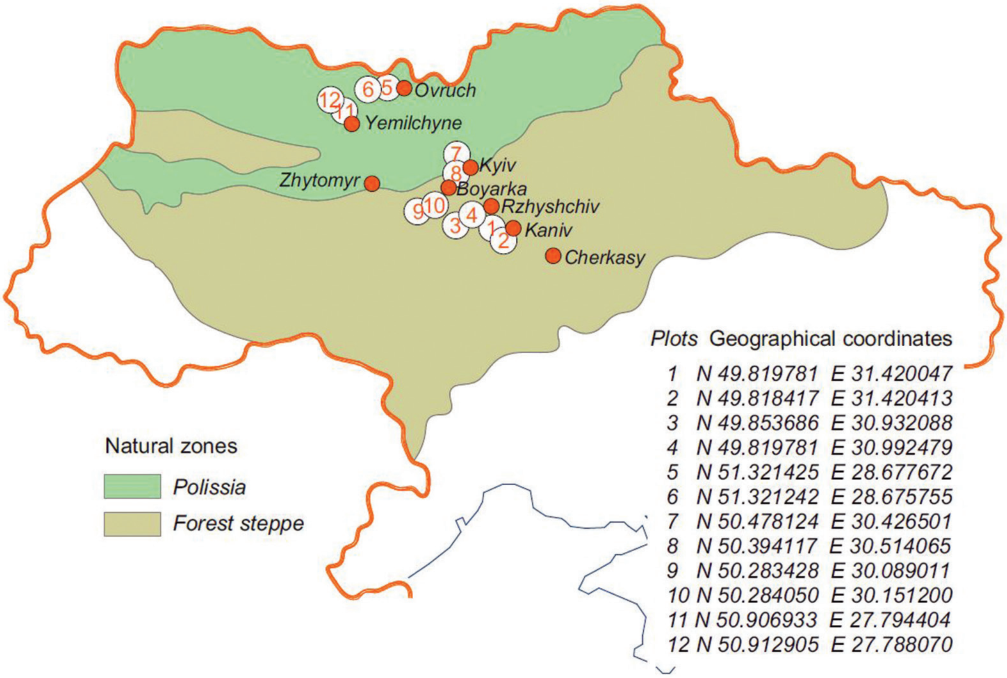

Fig. 1. Locations of research objects.

Polissia, which have reached the V age grade. The plantations are pure in composition, only the stand in TP 9 contains an admixture of red oak (up to 5 % of the total stock).

We also examined water-protected pine plantations growing in Zhytomyr Polissia in TP 11–12. Forest litter was researched in both mixed (9*Ps*1*Bp*) mature plantations and pure pre-mature pine stands growing in TP 11 and 12, respectively.

Trial plots of 11–12 are represented by water protection pine plantations, growing in Zhytomyr Polissia.

The biometric characteristics of plantations were obtained based on the results of processing the 12 test plots, which also described the undergrowth, understory, living above-ground cover and litter. The anti-erosion properties of the litter were studied in the spring (March). Litterfall and litter samples were measured on each trial plot in autumn 2019 in late October or early November. They were collected at the accounting sites using metal trays-intakes measuring 330×140 mm. Litter was taken in 10-fold replicate (a total of 120 samples). According to the recommendations of Karpachevskyi (1981), active and inactive litter fractions were distinguished.

Moisture capacity was determined by soaking the litter intact in water for 8 h. After soaking it was dried to a completely dry state and weighed with an accuracy of 0.01 g, pre-disassembled into active (leaves/needles, crumbs, mummified particles) and inactive (cones, branches, bark) part of the fractions (Hordienko et al. 2000). The capacity, stocks and fractional composition were studied according to the methods of Karpachevskyi (1981) and Vorobeychik (1997). The obtained data were averaged and recalculated per 1 ha.

As an indicator of the speed of destructive processes was used the ratio of litter stock to the annual inflow of litterfall or so-called litterfall-litter index (LLI). It objectively estimates the initial rate of destruction and mineralization of freshly dead phytomass (Basylevich 1983, Ivanyuk 2009). Thus, the higher the indicator, the weaker the intensity of the biological cycle (Rozhak and Kozlovskiy 2013). The turnover intensity was determined by the scale of the biological cycle in plant groups (Ivanyuk 2009). According to this scale, the process of decomposition of litter is divided into stagnant, severely inhibited, inhibited, intense and quite intense, the LLI being in the range of 21>; 6–20; 1.6–5.0; 0.1–1.5 and <0.1, respectively.

Results

Experimental plantations with the participation of the main forest-forming species of Scots pine, both pure and mixed in composition with different proportions of related species of woody plants: birch, maple, oak have an age range from 14 to 85 years. All plantations have high quality performance indicators – I–I[b] productivity classes. The range of basal areas of all presented plantations is from 5.1 (at 16 years) to 50.8 $m^2 \cdot ha^{-1}$ (at 66). Quantitative indicators of productivity of experimental plantations taking into account the sums of basal areas of stands range from 38 (at 16 years) to 568 $m^3 \cdot ha^{-1}$ (at 66 years) (Table 1).

Table 1. Biometric indicators of plantations in different regions.

No of trial plot	Stand com-position*	Age, years	Average		Number of trees, ha^{-1}	Sum of basal areas, $m^2 \cdot ha^{-1}$	Class produc-tivity	Stock, $m^3 \cdot ha^{-1}$
			Height, m	Diameter, cm				
Rzhyshchiv-Kaniv dislocations (Forest-steppe)								
1	5*Ps*5*Bp*	16	7.2	8.8	837	5.1	I	38
2	10*Ps*	14	5.9	7.6	2750	12.5	I	42
3	8*Ps*2*Ap*	36	17.0	20.0	1120	35.2	I[a]	291
4	10*Ps*	38	17.2	21.0	1218	42.2	I[a]	348
Ovruch-Slovenian ridge (Polissia)								
5	9*Ps*1*Bp*	35	16.0	17.0	1830	41.5	I[a]	330
6	10*Ps*+*Bp*	20	12.0	14.0	1761	27.1	I[b]	160
Park plantings of Kyiv (Forest-steppe)								
7	4*Qr*3*Ps*3*Ap*	70	25.0	47.0	210	36.4	I	370
8	10*Ps*	70	23.9	30.2	570	40.8	I	437
Kyiv Polissia								
9	10*Ps*+*Qr*	43	19.5	20.6	481	16.0	I[a]	153
10	10*Ps*	40	17.0	16.5	987	21.1	I	178
Zytomyr Polissia								
11	9*Ps*1*Bp*	85	27.0	31.5	300	23.4	I	290
12	10*Ps*	66	25.0	32.1	628	50.8	I[a]	568

**Ps* – *Pinus sylvestris* L., *Bp* – *Betula pendula* Roth., *Qr* – *Quercus robur* L., *Ap* – *Acer platanoides* L.

Given the fact that to study the anti-erosion properties of the litter presents a wide geographical range of experimental material, the analysis of the presented indicators, which are obtained by the same method, we will consider differentiated. The characteristics of forest litter of protective stands are given in Table 2.

Table 2. Characteristics of forest litter of protective stands.

No of trial plot	Stand composition*	Relief			Litter			
		Steepness	Exposition	Part of slope	Thickness, cm	Stock, $t \cdot ha^{-1}$	Part of litter, %	
							active	inactive
1	5*Ps*5*Bp*	26°	N-S	middle	2.2	20.8	82	18
2	10*Ps*	16°	S-W	middle	2.5	22.5	67	33
3	8*Ps*2*Ap*	15°	S-E	middle	2.5	27.8	73	27
4	10*Ps*	12°	S	middle	3.5	23.5	66	34
5	9*Ps*1*Bp*	10°	N-W	upper	2.6	27.4	69	31
6	10*Ps*+*Bp*	3°	E	upper	1.3	12.2	65	35
7	4*Qr*3*Ps*3*Ap*	20°	S	upper	1.5	19.0	80	20
8	10*Ps*	10°	N	upper	1.0	20.9	70	30
9	10*Ps*+*Qr*		plain		2.4	13.5	65	35
10	10*Ps*		plain		1.5	8.4	55	45
11	9*Ps*1*Bp*		plain		6.0	77.0	72	28
12	10*Ps*		plain		6.0	64.8	64	36

Note: *as in Table 1.

The thickness of the litter in mixed plantings is slightly less than in pure ones and represents 2.2–2.5 cm and 2.5–3.5 cm, respectively. The stock of litter, taking into account its capacity, composition and age of plantations, is from 20.8 to 27.8 $t \cdot ha^{-1}$. The active part of the fractional composition of mixed plantations is 73–82 %, pure – 66–67 %, and the inactive part – 27–18 % and 34–33 %, respectively (Fig. 2).

According to the species composition of woody plants on TP 5 and 6, the difference is small (9*Ps*1*Bp* and 10*Ps*+ *Bp*), but the age is 15 years, which affected the indicators of litter. Thus, the thickness of forest litter of mixed and pure pine stands is 2.6 and 1.3 cm, respectively, and the stock of litter is 27.4 and 12.2 $t \cdot ha^{-1}$. The fractional difference is insignificant.

Mixed planting on TP 7 has a slightly greater thickness of the litter than pure planting on TP 8, which is 1.5 and 1.0 cm, respectively. However, the stock of litter has a different pattern and reaches 19.0 and 20.9 $t \cdot ha^{-1}$, respectively, which is caused by the difference in the composition of the litter. Mixed planting also has a higher percentage of the active part.

The water-regulation functions of litter play an important role in the plantations in the ravine-gully areas of Rzhyshchiv-Kaniv dislocations (TP 1–4) and Ovruch-Slovechno ridge (TP 5, 6). In some pine curtains of water protection plantations (TP 11 and 12), which grow in lowland wet conditions, a large share of forest litter accumulates. As for melioration, anti-erosion and water protection functions of pine plantations are more than obvious, as the litter provides water

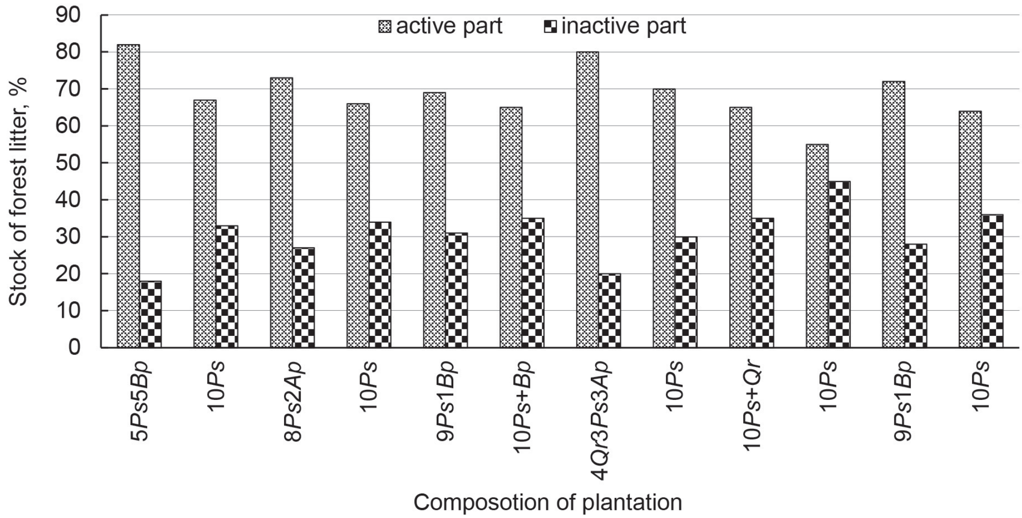

Fig. 2. The ratio of litter fractions depending on the plantations' composition.

collection from adjacent slopes, transferring surface runoff into deep, and most importantly – is the primary stage of soil formation processes (Novak and Slodičák 2009, Gomyyo and Kuraji 2016, Brovko et al. 2020, Wei et al. 2020).

In the plain conditions of Polissia zone at TP 9–12, the difference in capacity and stock of litter is caused mainly by plantations' age. The tendency regarding the fractional composition of the litter persists – in pure plantations its active part is inferior to the mixed ones.

The mass of litterfall in anti-erosion plantations of Rzhyshchiv-Kaniv dislocations (TP 1–4) is from 2.9 to 3.8 $t \cdot ha^{-1}$. A similar value of precipitation mass was also observed in the plantations of Ovruch-Slovechna ridge on TP 5, 6. Here, the annual litterfall in mixed and pure plantations acquires values of 4.0 and 3.7 $t \cdot ha^{-1}$, respectively. In park plantations on complex relief the difference turned out to be bigger. Here the litterfall in the mixed plantation was 4.2 $t \cdot ha^{-1}$, and in the pure – 7.2 $t \cdot ha^{-1}$ (Table 3).

It is known that the increase in litter capacity in forest stands is due to the receipt of dead plant remains during the extinction of aboveground plant phytomass. Decomposition and movement of litter material in the lower soil horizons reduces the capacity of the litter, which depends on the ratio of litterfall and removal of mineralization products in the lower soil horizons (Novák et al. 2014).

The intensity of litter decomposition in TP 1–4 is set as strongly inhibited with the LLIs from 6.2 to 7.9. The same intensity of litter decomposition was determined at TP 5 with the LLI 6.8. Trial plot 6 has an inhibited intensity of decomposition of the litter with a rate of 3.3. In park plantations on complex terrain, the intensity of decomposition is considered to be inhibited with fluctuations of LLI from 2.9 to 4.5 at TP 8 and 7, respectively.

In the plain conditions of Polissia zone, the mass of litterfall in 43- and 40-year-old plantations was 10.1 and 7.6 $t \cdot ha^{-1}$, respectively. The mass of litterfall in 66-year-old pure plantations in TP 12 was 12.2 $t \cdot ha^{-1}$, and its maximum was recorded in 85-year-old plantations in TP 11.

Table 3. Water-physical indicators for protective plantations.

No of trial plot	Stand composition*	Mass of litterfall, t·ha^{-1}	LLI	Mass of absorbed water, t·ha^{-1}	Moisture capacity of litter, %	Precipitation retained by litter, mm
1	5*Ps*5*Bp*	2.9	7.2	48.3	319	4.8
2	10*Ps*	3.6	6.2	22.5	189	2.2
3	8*Ps*2*Ap*	3.5	7.9	26.4	235	2.6
4	10*Ps*	3.8	6.2	22.2	190	2.2
5	9*Ps*1*Bp*	4.0	6.8	19.7	156	2.0
6	10*Ps*+*Bp*	3.7	3.3	15.6	134	1.6
7	4*Qr*3*Ps*3*Ap*	4.2	4.5	45.2	375	4.5
8	10*Ps*	7.2	2.9	29.4	244	2.9
9	10*Ps*+*Qr*	10.1	1.1	11.0	246	1.1
10	10*Ps*	7.6	4.1	23.1	133	2.3
11	9*Ps*1*Bp*	14.1	5.5	50.8	420	5.1
12	10*Ps*	12.2	5.3	46.7	386	4.7

Note: *as in tables 1 and 2.

As for the experimental plots of Polissia zone, with the exception of TP 9, the intensity of decomposition is also inhibited. Forest litter is formed according to certain patterns, at a certain age of young plantations it is formed, gradually its mass accumulates, then stabilizes, and after felling it disappears (Voron et al. 2018). The reason for the intensive decomposition of litter at TP 9 can be explained by the thinning in 2016 with a pulling out of 15 % of the stock, the active role of undergrowth of mountain ash and buckthorn brittle.

The mass of absorbed water by all experimental plots ranges from 11.0 to 50.8 t·ha^{-1}. In terms of anti-erosion, the role of litter in the absorption and retention of moisture is extremely important. Thus, its moisture content in those plantations, which are 14–38 years old, ranges from 134 to 319 %, which in terms of delayed precipitation is 1.6–4.8 mm. Park plantings on difficult terrain at the age of 70 provide a moisture content of 244–375 % or 2.9–4.5 mm. The litter of the plantations of the plain relief is characterised by a moisture content of 133–420 % or 1.1–4.7 mm of precipitation.

Discussion

The capacity of the litter, the rate of its decomposition and release of chemical elements depends on the type of forest, its age, the density of the stand, climatic and soil conditions, edaphotope features (soil conditions, water and heat regime, etc.), participation in the stand, except conifers, deciduous tree species, the presence or absence of grass or moss cover, the amount of annual precipitation. In contrast to deciduous forests, a characteristic feature of the rhythm of litter accumulation in coniferous forests is its year-round and uniform replenishment throughout the year due to litterfall. At the same time, according to Chornobay (2000), winter litterfall can be from 39 to 82 % of its total annual mass. Litterfall and litter formation are key parts of the substance cycle in the forest ecosystem (Meentmeyer et al. 1982). The amount of litterfall depends primarily on the species composition of the stand, level of productivity, density and closure of the crowns and physic-chemical properties of the soil.

Differences in the conditions of litter formation are manifested in the late stages of decomposition of organic matter, which is reflected in the thickness of soil horizons, and organic matter is significantly reduced. Researchers (Voron et al. 2018) when studying the fractional composition of forest litter layers in sections emphasize that the proportion of twigs predominates near the trunks and under the crowns, and the leaves – in the inter-crown zone.

According to Minder et al. (2019) the middle and lower parts of the slope with 10^{o} have approximately the same litter stock compared to the plain conditions (respectively 25.2 and 24.9 t·ha^{-1}), and in the upper part of the slope there is a smaller litter stock – 20.9 t·ha^{-1} (Table 3).

Litter in pine stands decomposes slowly and the rate of its mineralization decreases with age, as evidenced by the studies of Çömez et al. (2020), Corter (1998), Voron (2004) and others.

Accelerated process of litter mineralization is observed in plantations of Scots pine with an admixture of common oak and related species – Hornbeam and Maple, which cannot be said about the litter of red oak plantations (TP 9). There is a slowing down of the mineralization process of litterfall due to the lack of specific mycorrhizal fungi that occur in the forests of North America (Dickie et al. 2020) and the presence of dense litterfall from the leaves of single red oak trees.

It is known that the rate of decomposition of organic matter of forest litter depends on the ratio of its active and inactive parts, and therefore we calculated the reserves of these parts of forest litter protective plantations in comparison with the composition of plantings, which are given in Table 3, and their percentage is illustrated in Figure 2.

As can be seen from Figure 2, the active part of the litter of pure plantations is inferior to mixed, which indicates the positive role of impurities of deciduous species and significantly depends on their participation in the composition of plantations. A review of litter decomposition in forest ecosystems in Krishna and Mohan (2017) showed that the mineralization of litter of deciduous plant species occurs faster than coniferous and hardwood. Moreover, the litter of leaves disappears much faster than twigs and branches, i.e. the inactive part of the litter.

The inactive part of the litter of clean stands in most of the experimental plots is in the range from 30 to 36 %, which does not indicate a significant discrepancy. The exception is pure pine plantation in TP 10, where this figure reaches 45 %. This flow of organic matter was caused by intensive thinning of the stand and the removal of a significant amount of phytomass from the site The effect of thinning on the reduction of organic matter in the litter is indicated in the works of Czech scientists Novák and Slodičák (2009), Novák et al. (2020).

Thus, the studied pine stands with an admixture of birch, oak, maple in Polissia and Forest-Steppe of Ukraine form significant reserves of forest litter, and their meliorate properties significantly improve the ecological and edaphic conditions for the development of biogeocenotic processes in these ecotopes.

Conclusion

Regardless of the region and research conditions, the trend regarding the fractional composition of litter persists – in pure plantations, its active part is inferior to mixed stands; most of it in the fractional composition of the litter had a positive effect on increasing its moisture content.

In different climatic conditions and under the cover of different plants, as well as under different conditions of natural drainage of the terrain, the intensity indices of the biological cycle of organic-mineral substances vary very significantly from 1.1 to 7.9.

It is established that the studied protective forest plantations are characterized by inhibited and very inhibited types of biological cycle (literfall-litter index is 2.9–7.9 in plantations on complex relief, and 1.1–5.5 in plain conditions).

In experimental plantations on complex terrain, which perform anti-erosion functions, the moisture capacity of forest litter varies in the range from 134 to 319 %, and depending on the species composition of woody plants and their age, the litter can hold from 1.6 to 4.8 mm of precipitation.

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