Properties of Lithuanian forest litters

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Having analyzed study material on Lithuanian forest litters over 40 years and taking into account their thickness, fractional composition, decomposition degree, chemical and biochemical properties, forest litters are divided into 3 types: *Mor, Moder* and *Mull*.

Mull is formed on fertile soils in broad-leaved stands. It is relatively thin, containing many ashy elements - Ca, Mg, Mn, P, K and nitrogen, but small amounts of Si and Al, low hydrolytic acidity, high degree of base-saturation, and narrow C:N ratio-range. *Mull* has abundant mesofauna (especially earthworms) and microflora. The poorest according to all these indices is *Mor*. It is usually formed in coniferous (mostly Scots pine) stands, growing on poor acid soils. *Moder* is transitional type of forest litters between *Mull* and *Mor*. It is formed on average fertile soils mainly in mixed stands.

Keywords: forest litters, chemical and biochemical properties, *Mor, Moder, Mull.*

Introduction

Forest litter is an overground organogenic layer of different decomposition degreee peculiar only to forest ecosystems. G.F.Morozov (1949) recorded, that soil chemistry and podzolization process are preconditioned by the properties of forest litters. The latter depend on stand composition, age, stocking level, undergrowth, soil fertility and moisture content, activity of microorganisms and fauna. Forest litter regulates the hydrothermal regime of soils, protects it from compaction and contamination. Products of its decomposition enrich the soil in organic nutrients. Deeper and far decomposed forest litter is a favorable substratum for tree roots development. Studies on forest soils have shown, that in strongly podzolized gleyic (*Gleyic Podzols*) and gleyic soils (*Gleysols*) with clearly expressed eluvial horizon, the main root mass (80-90%) is accumulated in thick ($A_0^{II}+A_0^{III}$ subhorizons sometimes reach 15-25 cm) forest litters. This phenomenon was observed in Curonian Isthmus pine stands by M.Daujotas (1958), in South taiga by A.J.Orlov (1966). Therefore, sometimes even on poor over moisturized soils grow quite productive pine stands. According to forest litter type one can judge about the intensity of the smaller biological circulation of nutrients, soil fertility and their overmoistening degree, humus type. Very often forest litter is called humus. Biomorphogenic studies of forest humus were initiated by P.E.Müller in 1887. Discussions on the question continue up to this day.

According to decomposition degree forest litter is divided into three subhorizons: A_0^{I} – slightly decomposed, A_0^{II} – averagely decomposed, A_0^{III} – strongly decomposed. In the world literature these subhorizons are correspondingly marked as L, F and H (L – litter, F – fermentation layer, H – humus layer). In L subhorizon decomposed organic matter comprises less than 10%, F – 30-70%, while H – more than 70% (Babel, 1971). H.Hesselman (1926) used to determine forest humus according to F+H layers.

Over recent 40 years in Lithuania a lot of data on forest litters has been collected: thickness, mass, biochemical and chemical properties, group-fractional composition, distribution of microflora and mesofauna, relationships of properties with growth sites and stands. These studies proceed by carrying out local and regional monitoring of forest soils.

Materials and methods

Study objects were selected in stands of different species composition and age, taking into account soil genesis and growth sites. Data was collected in the period 1955-1995, by carrying out planned studies, forest soils mapping works (2300 sites) and forest soils monitoring within 8x8 km network (234 permanent observation plots).

Mass of forest litters (234 sites) was determined with the help of metal mould (0.1 m^2) at 10 replications. Samples for chemical analysis earlier (475 sites) used to be taken from 10 places, while after the onset of soil monitoring – from 20 places.

Mesofauna of each investigation plot (45 plots) was studied in 10 places separated by metal moulds. In them manual thorough sorting out of the whole litter was carried out, while later, separately, mineral soil up to 10 cm deep was sorted out and all representatives of mesofauna, found there, were counted up. Unrecognized individuals were placed into formalin solution and kept to be later defined.

Microbiological studies of forest litters were conducted in three 50-year-old stands with different litter types: oak stand on *Mull*, spruce stand on *Moder* and pine stand on *Mor* (Dubrava forest). Mean samples of each plot contained samples from 5 places and were analyzed in the laboratory on the same day.

Laboratory analysis of forest litters was done by the following methods: $pH_{(KCl)}$ and $pH_{(CaCl2)}$ – by potentiometer; total N – by Kjeldahl; hydrolyzed N – by Tiurin-Kononova; exchange Ca^{++}, Mg^{++} and H^{+} – by Gedroic; exchange Al^{+++} – by Sokolov; mobile K – by Kirsanov (flame photometer); hydrolytic acidity – by Kapen. Ash analysis was performed by dry burning at +400°C and total amounts were determined by the following methods: Si – by Gedroic; Ca – by Alekseyev (with urotropin); Mg – by Gedroic (with oxyquinoline); K – by flame photometer; P – by Maliugin-Chrenova; Mn – by colorimeter; Al – with trilon B; Fe – by colorimeter with potassium rodanide. Biochemical composition of organic matter was studied by Beltchikova's method. while group-fractional composition – by I.Tiurin's method modified by V.Ponomariova. Heavy metals (Pb, Cd, Cu, Zn, Cr, Ni, Fe, Mn) were defined by atomic absorptiometer-spectrograph (AAS-30) in Center of Agrochemical Investigations of Lithuanian Agriculture Research Institut. The loading of heavy metals on forest litters was determined by taking into account absolutely dry mass of organic matter.

Microflora identification was carried out by sowing diluted suspensions of forest litters on separate nutriculture media, and by distributing microorganisms into physiological and systematic groups:

- ammonifiers on meat-peptone agar (MPA);
- micromycetes on acidified ale mash agar (AMA);
- cellulose-decomposing microorganisms on Hetchinson's agar (HA).

Results

Fractional composition

It is directly dependant on stand species composition, mass of fallings, and conditions of organic matter decomposition.

In coniferous stands the main fraction of forest litter comprise needles (38-57%), as well as twigs (18-27%). Quite a large portion make up more or less decomposed organic residues (10-38%). In the litter of more moist growth sites the amount of needles and twigs decreases but noticeably increases the fraction of semi-decomposed organic recidues.

In the litter of broad-leaved forests prevail twigs (40-58%) and leaves (27-30%). Semi-decomposed organic fractions hardly make up 7-15% (more of them are on moist sites). According to W.Plichta (1981), with increasing forest litter humification, the portion of coarse fractions in it decreases, while that of fine fractions increases. For example, if in L (A_0^{I}) subhorizon the amount of fractions larger than 2-5 mm makes up 54%, then in H (A_0^{III}) horizon – hardly 11%. The amount of the finest (<0.2 mm) fractions is 1.3% and 15.2%, respectively. Smaller differences are observed in the distribution of average fractions (1-1.5 mm): L (A_0^{I}) – 10.7%, F (A_0^{II}) – 25.5% and H (A_0^{III}) – 30.5%.

Thickness and mass

Below there are presented fluctuations of forest litter thickness and mass in Lithuanian forests on automorphic soils of different genesis (Table 1).

Table 1. Dependence of thickness and mass of forest litters on soils and growth sites

Genetic nominations of soils and growth sites	Forest litter	
	thickness, cm	mass, t/ha
Podzols (Na)	3.2(0.8 - 5.0)*	29.3(8.5 - 43.3)*
Podzolic soils (Nb)	3.9(1.0-12.0)	35.7(4.3-110.8)
Sod-podzolic soils (Nc)	3.0(0.3-12.5)	27.8(3.1-112.6)
Forest brown soils (Nd)	1.0(0.3 - 2.0)	10.3(3.0 - 19.7)
Sod-calcareus soils (Nf)	1.2(1.0 - 1.5)	9.7(5.2 - 12.3)

*in brackets – ranges of thickness and mass fluctuations

Data show, that the thicknest forest litter is found on averagely fertile podzolic soils (*Podzols*). With increasing trophicity, average depths of forest soils decrease and reach their minimum in the most fertile sod-calcareus soils (*Leptosols*). Analogical to soils is the distribution of forest litter mass. Fluctuations are very large, especially on sod-podzolic (*Podzoluvisols*) and podzolic (*Podzols*) soils. There is no direct relation between litter thickness and mass, as far as mass is also dependent on fractional litter composition and organic matter humification degree.

On gleyic soils of different genesis the thickness and mass of forest litters increases (2-3 times). Only on gleyic brown (*Cambisols*) and sod-gleyic (*Luvisols*) soils the differences, as compared to automorphic soils of the same genesis, are insignificant. The greatest thickness and mass of forest litters on peat bof soils (*Histosols*) are approximately equal to those of automorphic soils. Maximal indices are peculiar to drained transitional bog soils (*Fibric Histosols*, growth site – Pc°).

Formation regularities

Our special studies in Dubrava forests (1995) show, that the thickness of forest litter changes moving from tree trunk towards the periphery of its crown. Though these fluctuations are especially distinct only under the crowns of coniferous trees. The thickest litter is found very close to pine or spruce trunk. Already at a distance of 1 m and further towards the crown periphery litter thickness remains almost the same. In broad-leaved stands (namely oak stand) changes of litter thickness under crowns are very small. It depends on the distribution of fallings, their mineralization intensity, precipitation, reaching litter, and chemical properties. Due to this reason, the most acid forest litters, independent of tree species, are closer to tree stems and in the periphery of crown projections. Knowledge on these regularities is necessary in taking samples for laboratory analysis and for the determination of their thickness and mass.

Types and properties

From olden times foresters distribute litter (humus) into: *Mor* (Rohhumus), *Moder* and *Mull*. They greatly differ by the amount of total nitrogen and ashy elements (Table 2).

Table 2. Chemical composition of different forest litter types

Types of forest litters	Amount of ash, %	% from abs.dry matter								N, %
		Si	Ca	Mg	Fe	Al	P	K	Mn	
Mor	3.4	0.37	0.20	0.06	0.12	0.11	0.04	0.08	0.04	1.50
Moder	5.3	0.33	0.51	0.09	0.15	0.11	0.05	0.12	0.06	1.72
Mull	7.0	0.24	1.53	0.14	0.16	0.10	0.07	0.15	0.08	1.90

Mor forest litters contain the least amounts of ash, calcium, magnesium, phosphorus potassium, manganese and nitrogen, but they accumulate more Si. These are generalized data. In every concrete case chemical composition of forest litters depends on their fractional composition.

Great changes in chemical composition of forest litters is observed under increasing humification degree (Table 3).

Table 3. Fluctuations in chemical composition of forest litter subhorizons in spruce stands growing on sod-podzolic gleyic soils (*Gleyic podzoluvisols*)

Subhorizons of forest litter	Ash, %	Ash elements, %								N, %
		Si	Ca	Mg	Fe	Al	P	K	Mn	
A_0^{I} (L)	4.8	0.46	0.48	0.05	0.07	0.08	0.06	0.08	0.10	1.57
A_0^{II} (F)	6.5	0.74	0.55	0.05	0.13	0.08	0.07	0.08	0.10	1.96
A_0^{III} (H)	8.4	0.94	0.52	0.03	0.12	0.09	0.04	0.07	0.11	1.98

Data shows, that with increasing decomposition of forest litter, increases its ashiness, more nitrogen, Fe and Si are accumulated, slightly rise Ca, Al and Mn quantities, while P and Mg amounts decrease.

With greater soil fertility of the same stands significantly change physico-chemical properties of their litters (Table 4).

Biochemical composition of litters in separate forest stands is relatively stable (Table 5).

Table 4. Physico-chemical properties of forest litters in pine and oak stands growing on soils of different fertility

Stand	Soils and growth sites	A_0 sub-horizons	$pH_{(KCl)}$	Exchange		Hydrolytic acidity	Base saturation, %
				$Ca^{++}+Mg^{++}$	$H^{+}+Al^{3+}$		
				cmol+/kg			
Pine stands	Podzols, Na	A_0^{I}	3.5	42.9	21.7	55.1	44
		A_0^{II}	2.7	40.6	29.7	129.4	24
Pine stands	Podzolic, Nb	A_0^{I}	4.0	51.4	16.9	52.6	45
		A_0^{II}	3.4	47.5	24.3	92.6	34
Pine stands	Sod-podzolic soils, Nc	A_0^{I}	4.0	79.9	14.6	48.2	63
		A_0^{II}	3.9	79.5	12.8	45.1	56
Oak stands	Forest brown soils, Nd	A_0^{I}	5.3	66.5	6.7	49.8	54
		A_0^{II}	5.4	119.3	4.6	36.9	76
Oak stands	Sod-calcareus soils, Nf	A_0^{I}	5.2	75.5	5.6	41.5	64

The table 5 demonstrates, that in the studied forest litters prevailed lignin, cellulose and hemicellulose. Proteins were also abundant.

Table 5. Biochemical composition of forest litters (% from dry ashless matter)

Soil and stands	Water-soluble substances				Substances extracted with spirit-benzol	Hemicellulose	Cellulose	Non-hydrolyzed remnant lignin	Albumens (proteins)
	dry remnants	including							
		reducible substances	C	N					
Forest brown soils (aspen stands)	6.0	0.1	2.9	0.1	4.7	15.4	19.1	32.4	5.8
Loess forest brown soils (oak stands)	9.6	0.1	3.6	0.3	5.6	12.3	15.8	40.2	11.9
Loess forest brown soils (birch stands)	6.8	0.2	3.3	0.1	6.0	14.9	17.6	36.3	7.1
Loess gleyic forest brown soils (oak stands)	8.3	0.2	3.2	0.2	4.8	15.1	15.4	39.3	7.6

Analysis of group-fractional composition of litter organic matter indicates, that forest litters on more fertile soils contain narrower C:N range, they are richer in nitrogen, and accumulate less bitumens (Table 6).

Under greater decomposition of forest litters, the ratio C:N decreases, and noticeably increases the amount of both humic and fulvoacids (the latter prevail). In humic acids prevails the 3rd fraction, binded with stable uncombined oxides. Minimal is the 2nd fraction, i.e. binded with calcium. In fulvoacids almost equal quantities comprise the 1st and 3rd fractions. The 1st

Table 6. Group-fractional composition of forest litter of pine stands, % from org. C

Subhorizons of forest litters and thickness, cm		%		C:N	Bitumen, %	Fractions of humic acids				Fractions of fulvoacids					$C_{h.a.} + C_{f.a.}$	$\frac{C_{h.a.}}{C_{f.a.}}$
		C	N			1	2	3	total	1a	2	3	3	total		
		Shallow podzol sandy soils, growth site Na														
A_0^I(L)	0-1	48.0	0.8	63.1	21.4	2.8	1.4	7.6	11.8	1.8	7.5	1.2	9.3	19.8	31.6	0.60
A_0^{II}(F)	1-4	32.2	1.0	31.3	19.1	9.5	0.4	9.5	19.4	1.4	12.4	0.5	11.4	25.7	45.1	0.75
		Sod podzolic slighty podzolized binded sandy soil on leam, growth site Nc														
A_0^I(L)	0-1	48.6	1.2	40.5	11.1	3.1	1.1	5.3	9.5	1.2	8.6	0.8	4.8	15.4	24.9	0.62
A_0^{II}(F)	1-3	44.2	1.5	30.5	12.6	6.7	1.5	6.9	15.1	1.0	12.4	0.0	9.1	22.5	37.6	0.67

fraction is binded with the 1st fraction of humiacids, which is abundant in uncombined oxides, especially Fe_2O_3. The 3rd fraction of fulvoacids is binded with the 3rd fraction of humiacids, i. e. also with stable uncombined oxides. A very small percentage of the 2nd and 1st fractions are found in fulvoacids. The 1st fraction is binded with free and mobile uncombined oxides, while the 2nd fraction – with the 2nd fraction of humiacids, containing calcium.

Mesofauna and microflora

Forest litter, formed from annual fallings and dead grass cover, is at once inhabited by more or less numerous populations of mesofauna and microorganisms. Some of them mechanically chop plant residues and mix them, others change chemical composition of the residues by letting them through their organism. The intensity of all the processes depends both on the chemical composition of fallings, moisture and temperature conditions, as well as on the diversity of mesofauna and microflora, and on their abundancy. All these factors predetermine the formation of different forest litter types.

Mesofauna differences in separate forest litter types is illustrated by data in Table 7. Total number of fauna representatives in mor is twice less than in the other types. Mull, as compared to other two, is significantly thinner, therefore, mesofauna abundancy, calculated per m², is somewhat less than in *Moder*. Best reflecting soil fertility, exchange of organic matter, and inducing the activity of microorganisms are considered to be earthworms (*Lumbricidae*) (Linden 1992). They are 8 times more abundant in *Mull* than in *Mor* and almost twice more numerous than in *Moder*. Knowing that annually an earthworm passes through his organism 200 times more organic matter than his own mass (Atlavinytė 1975) one must acknowledge the importance of its activity. Other mesofauna representatives are also most numerous in *Mull*. Only ants (*Formicidae*) are less abundant in *Mull*, as far as they prevail in poor sites of coniferous forests.

Microflora, like mesofauna, is most abundant in *Mull* (Table 8). Here the total number of microorganisms is almost 8 times greater than in *Mor*. As far as the largest portion of microorganisms comprise non-spore bacteria, their distribution regularities are the same. They participate in the initial stages of organic matter decomposition. In *Mull* and *Moder* these bacteria make up 90%, while in *Mor* – 70%. This testifies, that mor contains less easily decomposed organic matter, but in it prevails complex organics, easily assimilated by spore bacteria. Here they are relatively more numerous. However, the activity of spore bacteria in *Mor* is not very intensive, for even 20% of them are in the state of inactivity. Spores in *Moder* of spruce stands comprise even 40%, while in *Mull* of oak stands – hardly 3.5% from the total amount of spore bacteria.

Very contrasting is the distribution of cellulose-decomposing microorganisms. In *Mull* they are almost 100 times more abundant than in *Mor*. From this viewpoint *Moder* is closer to *Mor*. As far as cellulose in the composition of litter makes up 50%, the role of these microorganisms is very important. If *Mull* is decomposed by bacteria as well, then decomposition of *Mor* is achieved only by fungi.

Table 7. Mesofauna in forest litters (number, spec./m²)

Types of forest litters	*Lumbricidae*	*Elateridae*	*Curculionidae*	*Tipulidae*	*Julidae*	*Grylloblattoidae*	*Gastropoda*	*Blattodae*	*Arachnoidae*	*Formicidae*	*Carabus*	*Campodeidae*	Other fauna	Total
Mull	20.0	1.2	1.4	2.8	1.6	2.8	8.6	0.2	17.4	5.8	2.4	32.4	27.0	123.6
Moder	11.7	1.1	0.4	1.9	1.0	2.6	2.2	0.2	19.2	12.1	1.5	42.6	29.3	125.8
Mor	2.6	1.9	0.2	0.1	0.3	2.1	0.6	0.5	11.5	9.6	1.1	18.3	17.3	66.1

Table 8. Soil microflora in forest litters (number, thou./g)

Type of litter	Total amount of mic-roorga-nisms	Non-spore bacte-ria (MPA)	Spore bacte-ria (MPA)	Amount of spores (MPA+ AMA)	Amount of micro-scopic fungi (AMA)	Amount of cellulose-decomposing microorga-nisms (HA)
Mull	68437	61499	6411	223	15	288
Moder	12972	11640	870	372	66	20
Mor	8980	6227	2109	405	234	3

Microscopic fungi prefer acid media, therefore, they are most numerous in *Mor* (234 thou. /g). In *Moder* they are 3.5 times, while in *Mull* – even 15 times less abundant. Fungi, as compared to bacteria, decompose a wider range of organic matter, but the process is much slower. Therefore, greater abundancy of fungi in *Mor* slows down the ratio of its decomposition.

Discussion and conclusions

Acquaintance with the properties of forest litters may lead to a logical question on what effect they may have on forest growth. Our long-term studies show, that the height of pine stands at a certain age, despite soil fertility and overmoistening degree, increases with greater thickness of the litter. This is confirmed by regression equations of pair correlation in normal and temporarily overmoistened soils. Relations expressed by hyperbola are averagely resilient.

Soils of normal moistening:

$$y = 26.40 + \frac{1.32}{x},$$

where y – height of pine stands (m) x – tickness of forest litter (cm) in growth site: Na – 2.55±0.19
Nb – 3.96±0.16
Nc – 2.46±0.09
La – 9.33±1.80
Lb – 9.96±0.31
Lc – 5.14±0.28

$\eta = 0.61$

$n = 119$

Soils of temporal overmoistening:

$$y = 26.87 + \frac{6.34}{x}$$

$\eta = 0.61$

$n = 26$

Greater thickness of forest litter has negative impact on the growth of spruce, oak, ash, birch, aspen and black alder stands. Resilience of these relations differs, but the general tendency is quite distinct.

In general, the thinnest (1-1.2 cm) and best decomposed *Mull* is formed in deciduous forests, growing on forest brown soils (*Cambisols*) and sod-calcareus soils (*Leptosols*). Their thickness is quite even, they are rich in ashy elements and nitrogen, have small hydrolytic acidity, high degree of base saturation, narrow C:N ratio.

Mor is formed in coniferous stands, growing on poor gleyic soils. Its thickness in on an average 3-4 cm significantly increasing close to tree trunk. Mor is acid ($pH_{(KCl)}$ 2.7-4.0), relatively poor in chemical elements, slowly decomposed. A major role in its decomposition, as compared to *Mull* and *Moder* is performed by fungi, while bacterial fauna in them is not abundant, few are found mesofauna representatives, especially earthworms.

With increasing decomposition degree of forest litters, their C:N ratio range narrows down, increases ashiness and the amount of humic and fulvoacids.

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Свойства лесных подстилок Литвы

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Резюме

На основании анализа данных за 40-летний период по мощности, фракционному составу, степени разложения, п химическим и биохимическим свойствам лесных подстилок, они разделены на 3 основные типа: грубые, переходные и мягкие Мягкие лесные подстилки формируются в лиственных насаждениях, произрастающих на плодородных почвах. Он сравнительно маломощные, содержат много зольных элементов – Ca, Mg, Mn, P, K и азота, но мало Si и Al характеризуются небольшой гидролитической кислотностью, высокой степенью насыщенности основаниями, узким отношение C:N. В этих подстилках много представителей мезофауны (особенно дождевых черней), обильна микрофлора. По всем эти показателям самыми бедными являются грубые лесные подстилки. Они обычно формируются в хвойных лесах (чаще всего сосняках) на низкоплодородных и кислых почвах. Переходного типа лесные подстилки занимают промежуточное место межд мягкими и грубыми лесными подстилками. Они формируются на среднеплодородных лесных почвах в смешанных хвойно лиственных лесах.

Ключевые слова: лесные подстилки, химические и биохимические свойства.