Estonian Journal of Ecology, 2013, **62**, 1, 6–23 doi: 10.3176/eco.2013.1.02

Humus cover and its fabric depending on pedo-ecological conditions and land use: an Estonian approach to classification of humus forms

Raimo Kõlli[✉] and Indrek Tamm

Estonian University of Life Sciences, Kreutzwaldi 1A, 51014 Tartu, Estonia

[✉] Corresponding author, raimo.kolli@emu.ee

Received 8 October 2012, revised 27 November 2012, accepted 28 November 2012

Abstract. The fabric of humus cover (HC) may be very variegated, depending on local pedo-ecological conditions (origin and composition of deposits, topography, moisture regime, soil climate, plant cover composition). This multiplicity can be expressed by the HC types (or humus forms). On natural areas, where the HC is formed as a result of long-term equilibrated mutual influences of soil cover and plant cover, the fabric and properties of the HC may be used as an ecological indicator in the evaluation of the functioning character and intensity of the soil–plant system (or also the whole ecosystem). In Estonia, besides natural areas, the classifications of HCs are also elaborated for arable areas. Regardless of the profound changes in the fabric of the HC occurring with land-use change (from natural land to arable and vice versa), certain inherited properties are sustained in newly formed HCs. In this paper the fabric and properties (thickness, carbon and nitrogen stocks) of the main HC types (19 in total) are analysed and ecological aspects of HC formation are explained. Data on tree layer taxation, agro-chemical parameters of the soil cover, and ground vegetation productivity are presented with the HC types used as the ecological background. The relationships of soil cover with soil and forest site type are analysed against the background of soil matrix tables and ordination net of forest sites, respectively. Comparative analysis of the Estonian HC classification with the European Reference Base for humus forms (ERB) showed a relatively good correspondence of the Estonian classification of HC types with ERB's humus forms.

Key words: European Reference Base for humus forms, forest site type, humus cover classification, humus cover type, humus form, land-use change, soil cover.

INTRODUCTION

Soil organic matter (SOM) has a pivotal role in the genesis of soil, in the formation of its characteristic properties, and in the functioning of the whole ecosystem (Zonn, 1964; Chertov & Razumovsky, 1980). In the research into soil ecology and the role of organic matter (humus) in it, the accent is on the superficial (rich in SOM) part of the soil profile or on the humus cover (HC), whose fabric may be characterized by the humus profile (Chertov, 1966; Dergacheva, 1985). The soil humus profile consists of the organic matter (humus)-rich soil horizons (forest floor, humus, and organo-mineral and/or peat horizons). According to our understanding, the HC type interpreted by us corresponds almost exactly to the internationally well-recognized term *humus form* (Müller, 1887; Jabiol et al., 1995; Van Delft et al., 2006; Zanella et al., 2010). Knowledge about HC types (pro humus forms) has utmost importance in interpreting the role of soil biodiversity and SOM in ecological processes. In Estonia, besides natural areas, the classification of HC is elaborated also for the arable areas (Kõlli, 2009).

For explaining the specificity of the ecological aspects of HC fabric and formation, comparison of HC classifications with soil types and forest site types is useful. The relationships of HCs with soil and forest site types are analysed respectively against a background of soil matrix tables and an ordination net of forest sites (Lõhmus, 2006; Kõlli, 2009). Besides the characterization of the main Estonian HC types, analysis of their coincidence with the European Reference Base for humus forms (ERB) is important, since it enables to elucidate the adequacy of the ERB to Estonian pedo-ecological conditions and to find possibilities for the harmonization of the Estonian classification with the ERB (Zanella et al., 2012).

The main tasks of the work are (1) to introduce the principles of the Estonian HC classification and to analyse the transformations in it caused by land-use changes, (2) to give a morphological and ecological characterization of the main Estonian HC types, (3) to compare the coincidence of HC types with soil and forest site types, and (4) to analyse differences and similarities in principles and scientific terms of the ERB and the Estonian HC classification.

MATERIAL, TERMS, AND METHODOLOGY

This article is based on materials published by different scientific schools on the fabric and properties of humus forms (Wilde, 1971; Karpachevskij, 1982; Zonn, 1983; AFES, 1998; IUSS, 2007; Galvan et al., 2008; Zanella et al., 2012). The databases Pedon and Catena of field research and laboratory analyses conducted in Estonia (Kõlli, 1987, 2009) as well as experience obtained from collaboration with 'humus people' (Zanella et al., 2009, 2010) were used.

As research into and classification of humus forms (or HC) has a long history in many countries, it is understandable that there exist many different terms and notions, which in fact explain similar or approximately similar features or objects (Koshel′kov, 1961; Rozanov, 1983; Sapozhnikov, 1984; Prusinkiewicz, 1988; Jabiol et al., 1995; AFES, 1998; Van Delft et al., 2006). In some cases they may be taken as notional synonyms, in others, as relatively comparable or similar objects and features.

According to the French school, the soil cover is named *solum*, and its top part (humus profile) is called *episolum* (AFES, 1998). At the same time, in the United States the common names for these are respectively *pedon* and *epipedon* (Soil Survey Staff, 2010). These last terms have been incorporated in the World Reference Base for Soil Resources (WRB) system (IUSS, 2007).

In our earliest works we used many different terms to denote humus form (Kõlli, 1985, 1987, 1992, 2011). In the Estonian language the most convenient term for this was *huumuskate*, the direct translation of which is *humus cover* (i.e. HC). At the same time we called this natural body (i.e. HC) also *humus* *profile* after the Russian school (Chertov, 1966; Dergacheva, 1985) or *epipedon*, which is widely used internationally (IUSS, 2007).

Based on the above approaches, HC is the superficial part of the soil cover, which consists of organic (forest or grassland floor and/or peat) and/or organo-mineral (humus and/or raw humus) horizons, where the greatest part of the carbon cycling of living organic matter (roots, fauna, microorganisms, viruses) is taking place, and the remains of plants and animals (undecomposed, fragmented, bio-degraded to a greater or lesser extent) and molecules of organic matter (exudates, humus acids, proteins, and a multitude of others) are located. HC is formed through the interaction of the soil superficial layer and the ecosystem via the activities of the root system, soil organisms, and decomposers. Changes in pedo-ecological conditions (climate, soil parent material, anthropogenic stress, peculiarities in development) will also cause changes in biocoenosis and thus in the HC. Therefore, the HC concept embraces both the morphological (fabric) and functional (activity) aspects of the natural body in question. A morpho-functional approach to HC enables its ecological essence to be opened more profoundly.

The terms used in the Estonian classification of HC follow the rules of the Estonian language, which does not change at all the essence of the concepts. Two most important differences are (1) the spelling of the names of some HC types, such as *moor* for *mor* and *amfi* for *amphi*, and (2) indices of soil horizons: AT for Aa and Ag; O1, O2, O3 for OL, OF, OH, respectively, and T for H.

In the characterization of HC types, the qualifiers of the WRB were used (IUSS, 2007; Soil Survey Staff, 2010). The materials on the classification of Estonian HC types are published in Estonian (Kõlli 1985, 2009), in Russian (Kõlli, 1987), and in English (Kõlli, 1992). Comparative analysis of the Estonian HC classification with the ERB was carried out using the article by Zanella et al. (2012), but in the elucidation of the peculiarities of our area, many other works were also used (Wilde, 1971; AFES, 1998; Graefe & Beylich, 2006; IUSS, 2007).

For the estimation of total phytomass and annual phytoproductivity (APP) of forest ecosystems, the methods employed by the International Biological Program were used (Rodin et al., 1968; Kõlli, 1987). To obtain comparable data on HC and plant cover, the forests selected for sampling had approximately the same age (premature to mature) and stand stock density (0.6–0.9). The phytomass and APP for tree layers were determined using model trees. Test plots were used to determine the total phytomass of the ground vegetation in forests. The APP of herbaceous plants was established by the maximum phytomass of the vegetation period. For statistical analyses, STATISTICA 7 was used.

In the laboratory humus profile samples originating from the databases Pedon and Catena were used for analyses. Organic carbon (OC) was determined by wet digestion of carbon with acid dichromate using external heating, hydrolytic acidity was determined by titration with 0.1 M NaOH after adding 1 M CH_3COONa solution, and soil reaction (pH_{KCl}) in 1 M KCl 1 : 2.5 (Vorobyova, 1998). Total nitrogen (N) was analysed by the Kjeldahl procedure, and the specific surface area by the Puri & Murari method (1964). The content of particles with Ø < 0.01 mm (i.e. physical clay) in soil was estimated according to Katchinsky (1965). The basic cations were determined by the 1 M CH_3COONa extraction procedure (Soil and Plant Analysis Council, 1992). Cation exchange capacity and percentage of base saturation were calculated according to the sum of bases and hydrolytic acidity. The results of analyses are expressed in pools (stocks) per HC on the basis of soil bulk density.

RESULTS

Principles of the Estonian HC classification

The Estonian HC classification was elaborated in the second half of the 1980s (Kõlli, 1985, 1992), or 100 years after the beginning of the pioneering research on forest humus by Müller (1887) and the adoption of the term *mull*. A schema of the classification of the Estonian HC types is presented in Fig. 1. In the elaboration of the schema's scalars, the pedo-centric approach was used, i.e. the HC was not taken as a separate natural body but as a part of the soil cover. Based on this, the

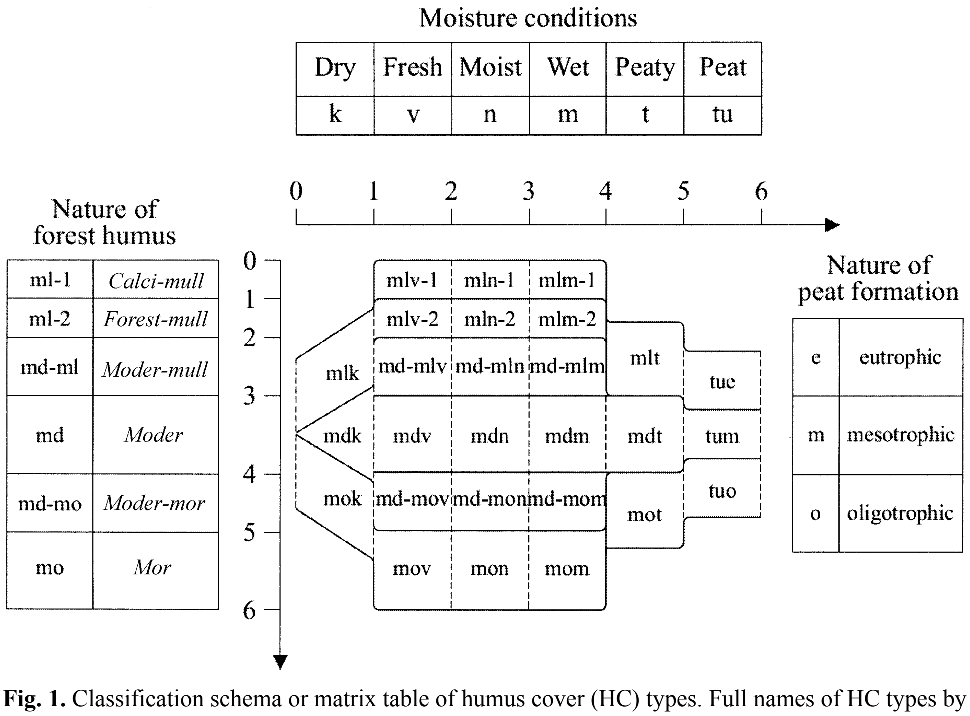

Fig. 1. Classification schema or matrix table of humus cover (HC) types. Full names of HC types by the columns of the matrix are (1) dry types: mlk – *dry mull*, mdk – *dry moder*, mok – *dry mor*; (2) fresh types: mlv-1 – *fresh calci-mull*, mlv-2 – *fresh forest-mull*, md-mlv – *fresh moder-mull*, mdv – *fresh moder*, md-mov – *fresh moder-mor*, mov – *fresh mor*; (3) moist types: mln-1 – *moist calci-mull*, mln-2 – *moist forest-mull*, md-mln – *moist moder-mull*, mdn – *moist moder*, md-mon – *moist moder-mor*, mon – *moist mor*; (4) wet types: mlm-1 – *wet calci-mull*, mlm-2 – *wet forest-mull*, md-mlm – *wet moder-mull*, mdm – *wet moder*, md-mom – *wet moder-mor*, mom – *wet mor*; (5) peaty types: mlt – *peaty mull*, mdt – *peaty moder*, mot – *peaty mor*; (6) peat types: tue – eutrophic peat, tum – mesotrophic peat, tuo – oligotrophic peat.

scalar of moisture conditions of this schema was taken similar to the Estonian soil classification. We presupposed that the water regime of soil cover is reflected more or less adequately in the properties and fabric of the humus profile. The first four (0–4) moisture condition categories characterize the HCs of mineral soils, starting from the drought-prone (*dry*) to permanently overmoist gley (*wet*) soils. The last two categories (5 and 6) characterize pedo-ecological conditions with peat formation, i.e. the latest stages of paludification of mineral soils. The *peaty* soils (stage 5) may be classified as mineral soils with a thin (<30 cm; mostly 10–30 cm) peat (*histic*) layer, but *peat* soils or histosols (6) have a peat layer thicker than 30 cm. For most peat (fen, transitional bog, bog) soils, the peat layer thickness is more than 1 m, as the very thin (30–50 cm) and thin (50–100 cm) peat soils may be taken as transitional peaty soil covers between mineral and organic (peat) soils.

A detailed characterization of the moisture conditions of HC formation (horizontal scalar in Fig. 1) is as follows:

(1) *dry*: mostly coarse-textured automorphic shallow soils that are excessively drained, plant-available water supply in the 75-cm soil layer is <50 mm, during the vegetation period a risk of soil drought may exist;

(2) *fresh*: well-drained and well-aerated automorphic soils, groundwater is located deep (i.e. does not occur in the soil profile), plant-available water is present almost throughout the vegetation period, favourable (typical) conditions for HC formation;

(3) *moist*: moderately well drained, soil is wet (overmoist) for a short time (1–3 months) within the rooting depth during the growing season, semi-hydromorphic gleyed (*endogleyic*) soils, moisture conditions for forest vegetation are close to optimum;

(4) *wet*: somewhat poorly drained, soil is wet at a shallow depth for long periods during the growing season, commonly there is a high water table and/or additional water from catchment seepage, semi-hydromorphic gley (*epigleyic*) soils;

(5) *peaty*: poorly drained hydromorphic peaty gley soils (or histic gleysols), soil is wet in the superficial peat horizon periodically during the growing season or is wet for a long period, free water is commonly persistent at or near the surface;

(6) *peat*: very poorly drained hydromorphic peat soils (or histosols), free water remains at the peat surface during most of the growing season or is permanent.

The well-known humus forms sequence *mull* → *moder* → *mor* was used as the basis of the characterization of the HC types of mineral soils by their formation nature. This three-stage scalar was widened by dividing *mull* types according to the free carbonates content in fine earth of the A horizon into (1) *calci-mull* (*calcic*, *skeletic*), where the A horizon is very rich in calcium carbonates, and (2) *forest-mull*, where only the subsoil is rich in calcium carbonates (*endocalcaric*). Besides that, in order to completely copy the Estonian soil classification's lithologo-genetical scalar (from rendzina to podzols) into the HC forming scalar (from *mull* to *mor*), transitional HC types were used. For describing pedo-ecological conditions of the HC of the (formed on calcareous parent material) leached soils, which are between *mull* and *moder* types, the *moder-mull* stage (type) was added to the scalar. For describing weakly swarded acid sandy podzols formed between podzols and podzolic (sod-, pseudo-) soils, a relevant transitional HC type *moder-mor* was taken into use. As a result, a six-stage humus formation scalar for the HC of mineral soils was obtained. Scalar stages are most clearly visible under *fresh* and *moist* moisture conditions. Such a scalar does not work so well in the case of *wet* mineral soils, as here the hydrological conditions overshadow the normal pedogenetic processes. In the case of *dry* soils a three-stage scalar (*mull* (*calcaric*, *eutric*) → *moder* → *mor* (*arenic*, *dystric*)) should be sufficient. In the case of *peaty* and *peat* soils pedo-environment trophicity (*eu*-, *meso*-, *oligo*-) was taken into use.

Therefore, the basis of the Estonian HC classification is the morphology and sequence of organic and organo-mineral soil horizons and the features of biological activity in them. To these some necessary laboratory analyses (pH, organic carbon content) are added. In the descriptive analysis of the HC fabric, the character of organic remains, the ratio of humus and mineral parts (inside horizons as well as between different horizons), and the activity of soil organisms were of essential importance. Also such inseparably bound to HC features as soil texture and structure, soil moisture conditions and chemical composition, and transitional border between different soil horizons were taken into account. The presence of fungi filaments in half-decomposed litter, which bind the compartments of the forest floor into a united blanket, was used as the indicator of mycogenic decomposition.

Ecological characterization of HC types

The forests sampled were of premature to mature age (between 61 and 109 years). It is notable that on *mull* and *moder* HC types, spruce or deciduous tree species are dominating, but on *mor* pine is prevalent (Table 1). The forest quality class is the highest on HC of *moder* types.

The pedometric and productivity characteristics of HCs by their types are presented in Table 2 and Fig. 2. The OC ratio of the humus horizons and the forest floor shows that in the case of *mull* HC types the OC was accumulated predominantly into the mineral part of the soil profile (mean coefficient is >10), or this type of HC is characterized by endogenic sequestration of SOM. In the case of *moder* HC types this ratio is between 1 and 10, and for the *mor* types it is far lower than 1. Notwithstanding that in HC of *mor* types the OC sequestration is clearly exogenic, it should not be forgotten that large pools of OC have been eluviated from the HC into the subsoil. This phenomenon is characterized by the percentage of OC in the HC of the OC in the whole soil cover. In the case of *mor* HC types this ratio is always <1.

A good parameter for the characterization of HC is also the C : N ratio, which in *mor* HC types is mostly >35 (being in the range 35–50). In the case of endogenic HC types this characteristic is prevalently <19, except for HCs rich in $CaCO_3$ (*calcic*), where the C : N ratio is a little bit higher (20–22). The agro-chemical and physical characteristics of HC presented in Table 3 are given by

Table 1. Average characteristics of tree stands of forest ecosystems by humus cover types

Humus cover type	*n*	Composition of tree stand*, %			BAbh**, $m^2\ ha^{-1}$	Stocking density	Age, years	Stock, $m^3\ ha^{-1}$	Quality class of forest
		Sp	Pn	Dc					
Dry mull	7	71	27	2	20.3	0.72	109	216	V
Fresh calci-mull	6	65	28	6	26.7	0.75	80	301	I–II
Fresh forest-mull	14	66	14	20	24.6	0.74	103	265	II
Wet calci-mull	3	26	1	74	24.1	0.72	79	270	I–II
Fresh moder-mull	7	89	1	10	27.8	0.84	61	310	I
Moist moder-mull	7	34	0	66	26.9	0.85	69	319	I
Wet moder-mull	5	30	0	70	27.3	0.76	80	323	I
Fresh moder	21	60	24	16	29.3	0.80	81	368	I
Moist moder	23	43	30	27	27.9	0.82	76	328	I
Fresh moder-mor	10	8	82	11	29.3	0.88	67	276	I–II
Moist moder-mor	6	9	77	15	23.6	0.74	64	226	II
Wet moder-mor	4	16	72	12	27.1	0.77	102	289	II
Dry mor	5	2	96	2	20.0	0.58	84	188	III
Fresh mor	10	0	96	4	27.3	0.77	93	271	II–III
Moist mor	4	3	89	9	26.4	0.77	71	262	I–II
Peaty mor	11	17	80	3	24.6	0.71	92	248	III
Eutrophic peat	7	21	20	60	17.3	0.65	90	163	III–IV
Mesotrophic peat	3	0	97	3	15.4	0.56	90	88	V[a]
Oligotrophic peat	6	0	100	0	17.4	0.59	89	121	V

* Sp – spruce, Pn – pine, Dc – deciduous tree species.
** BAbh – basal area at breast height.

Table 2. The role of humus cover (HC) in the sequestration of organic carbon (OC) and total nitrogen (N) into the soil cover

Humus cover type	*n*	Percentage of HC in sequestration[a] of		OChh : OCff[b]	C : N in HC
		OC	N		
Dry mull	7	79.2	81.4	13.4	21.1
Fresh calci-mull	6	73.0	56.1	11.1	20.6
Fresh forest-mull	14	64.3	67.5	14.1	15.7
Wet calci-mull	3	89.0	95.1	31.9	12.6
Fresh moder-mull	7	77.5	73.0	13.0	17.0
Moist moder-mull	7	79.3	79.0	14.0	16.0
Wet moder-mull	5	82.2	75.0	10.6	15.2
Fresh moder	21	62.9	40.9	5.7	18.9
Moist moder	23	63.8	53.8	3.9	17.8
Fresh moder-mor	10	41.1	32.7	0.4	35.0
Moist moder-mor	6	37.1	22.2	0.1	49.6
Wet moder-mor	4	26.9	12.5	<0.05	37.8
Dry mor	5	21.9	10.3	<0.05	44.0
Fresh mor	10	40.3	9.5	<0.05	44.7
Moist mor	4	36.7	17.4	<0.05	40.9
Peaty mor	11	39.2	25.9	<0.05	39.3

[a] The percentage is calculated in relation to the whole soil cover.
[b] Ratio of the OC in the mineral soil horizons (OChh) and in the forest floor (OCff), or the coefficient of OC sequestration endogeneity.

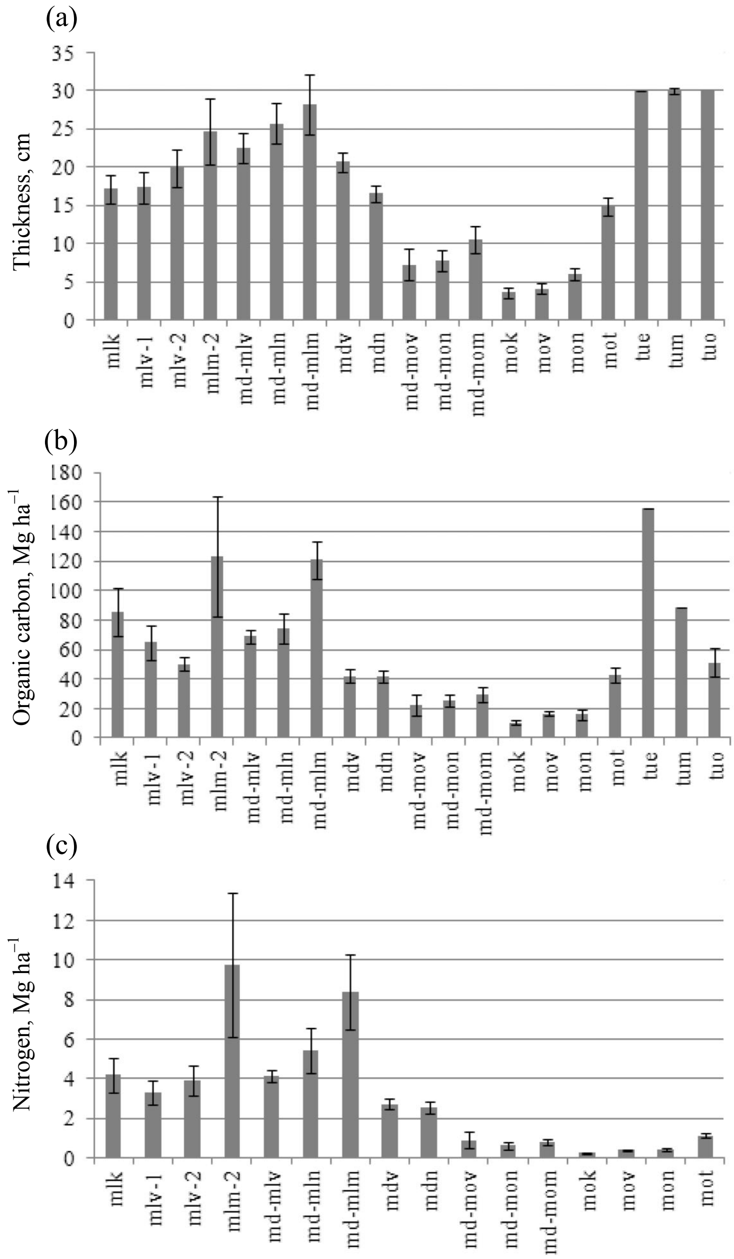

Fig. 2. General characteristics of humus cover (HC) types: (a) thickness, (b) stock of organic carbon in HC, and (c) stock of nitrogen in HC. For full names of HC types see legend to Fig. 1.

pools or stocks in relation to HC or as superficial densities per the whole HC depth. The data on plant cover (areal density of phytomass) and its productivity (APP) by different HC types and by compartments of plant cover are given in Table 4 and Fig. 3.

Table 3. Average quantitative physical and agrochemical characteristics of humus cover types calculated in relation to the thickness of humus cover

Humus cover type	*n*	Clay[a], Mg ha^{-1}	SSA[b], 10^5 m^2 m^{-2}	MA[c], kg ha^{-1}	HA[d]	SB[e]	CEC[f]	BS[g], %
					kmol ha^{-1}			
Dry mull	7	428	203	1	43	517	554	93
Fresh calci-mull	6	568	150	1	35	514	550	92
Fresh forest-mull	14	562	128	5	65	432	496	82
Wet calci-mull	3	777	310	18	185	547	732	58
Fresh moder-mull	7	559	161	43	120	396	516	74
Moist moder-mull	7	742	175	118	165	312	462	65
Wet moder-mull	5	327	203	135	220	511	706	67
Fresh moder	21	407	99	221	194	112	306	36
Moist moder	23	238	68	209	174	80	255	32
Fresh moder-mor	10	36	21	35	73	25	98	20
Moist moder-mor	6	3	24	18	59	14	74	18
Wet moder-mor	4	2	24	56	83	15	97	15
Dry mor	5	1	7	13	24	4	29	14
Fresh mor	10	1	15	13	33	9	42	27
Moist mor	4	2	15	25	43	10	53	23
Peaty mor	11	3	36	47	86	38	125	28

[a] Physical clay or mineral particles with Ø < 0.01 mm;
[b] SSA – specific surface area;
[c] MA – mobile aluminium;
[d] HA – hydrolytic acidity;
[e] SB – sum of exchangeable bases;
[f] CEC – cation exchange capacity;
[g] BS – base saturation.

Table 4. Role of aboveground phytomass (PM) and its annual phytoproductivity (APP) in the functioning of an ecosystem depending on humus cover types

Humus cover type	*n*	PM	APP	PM	APP	Proportion in APP, %	
		of ground vegetation, 100 kg ha^{-1}		of whole ecosystem, 100 kg ha^{-1}		green PM	ground vegetation
Dry mull	7	20.2	9.6	1075	68.1	44.5	14.1
Fresh calci-mull	6	18.5	8.8	1611	91.5	44.7	9.6
Fresh forest-mull	14	19.5	9.7	1474	82.7	45.4	11.7
Wet calci-mull	3	13.8	7.0	1603	96.7	37.6	7.2
Fresh moder-mull	7	16.7	8.1	1569	100.4	39.7	8.1
Moist moder-mull	7	16.5	9.8	1706	120.1	38.4	8.2
Wet moder-mull	5	13.6	8.1	1896	101.0	40.9	8.0
Fresh moder	21	16.5	6.6	1869	89.3	41.1	7.4
Moist moder	23	24.0	8.8	2235	115.6	43.3	7.6
Fresh moder-mor	10	43.7	13.0	1829	84.1	48.8	15.5
Moist moder-mor	6	44.2	12.4	1067	59.1	48.5	20.9
Wet moder-mor	4	55.3	11.1	1759	83.4	42.1	13.3
Dry mor	5	49.0	9.5	1059	47.6	46.1	19.9
Fresh mor	10	49.4	10.0	1294	56.9	43.4	17.5
Moist mor	4	58.1	14.6	1182	62.5	45.4	23.4
Peaty mor	11	62.1	12.6	854	35.3	53.9	35.7

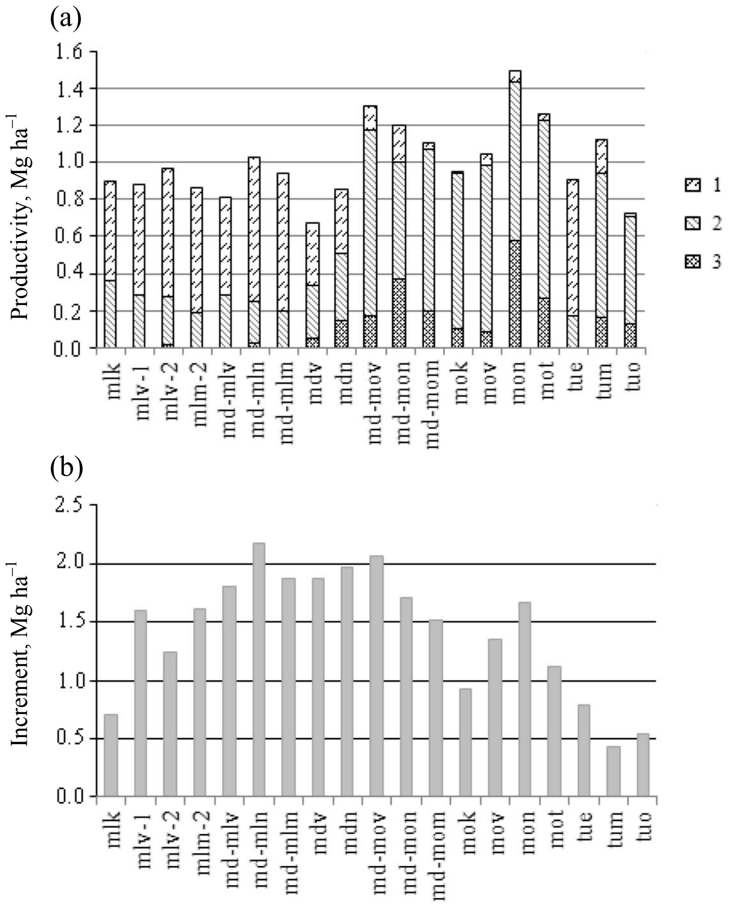

Fig. 3. Annual productivity of some aboveground compartments of ecosystems given by humus cover (HC) types: (a) ground vegetation: 1 – herb layer, 2 – moss layer, and 3 – shrub layer; (b) average annual increment of tree layer stem phytomass. For full names of HC types see legend to Fig. 1.

Correspondence of HC classification to soil and forest site types

Figure 4 presents the HC types on the background of a matrix table of post-lithogenic (normally developed) mineral soils. The vertical scalar demonstrates the congruence between the lithologo-genetical scalar of soil cover and peculiarities of HC formation, where the positions of transitional HC types (*moder-mull* and *moder-mor*) are seen. The difference in the moisture scalars of the two matrices is that in the soil cover matrix there is an additional stage between fresh and moist stages where the soils with weakly developed gleying features are located. Here the matching of HC types with peat soils (or *histosols*) and synlithogenic (abnormally developed) mineral soils is not demonstrated. It may be concluded that the matching between soil cover and HC matrixes is good, but not complete, i.e. there is no one-to-one correspondence.

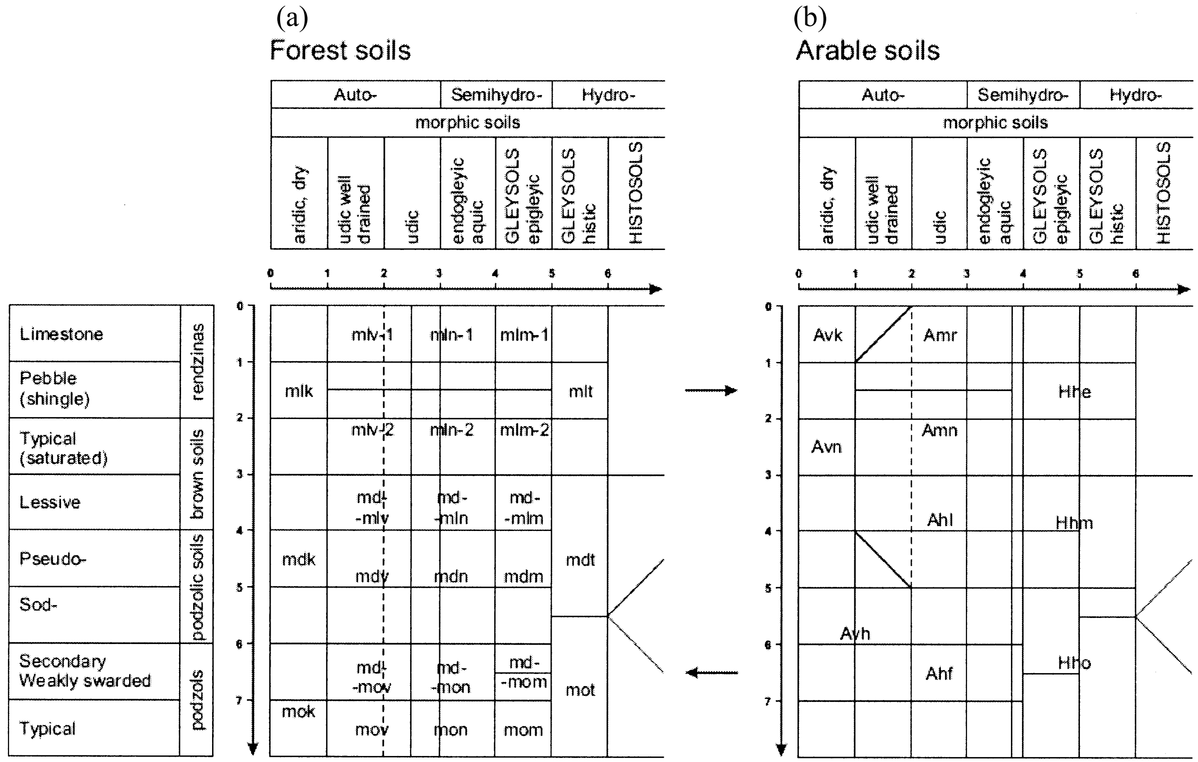

Fig. 4. Disposition of humus cover (HC) types on Estonian soil cover matrices. (a) Disposition of HC types of natural areas (forest); for full names of HC types see legend to Fig. 1. (b) Disposition of HC types of cultivated areas (arable land). The full names of the presented codes and types are: Avk – calcareous low humic, Avn – neutral low humic, Avh – acid low humic, Amr – skeleti-calcaric mild humic, Amn – neutral mild humic, Ahl – eluvic *moder* humic, Ahf – fulvic *moder* humic, Hhe – eutrophic raw humic (or organo-mineral), Hhm – mesotrophic raw humic, and Hho – oligotrophic raw humic.

Figure 4 also describes the correlation between HC types formed in natural conditions and those formed from them as a result of land cultivation in relation to postlithogenic mineral soils. During cultivation the different horizons of the topsoil are mixed and a more homogeneous plough layer (epipedon, humus profile) forms. Notwithstanding the profound changes in the fabric of the HC in connection with land-use change (from natural land to arable and vice versa), a certain number of inherited properties are sustained in the newly formed HC. These are mainly inherited from the soil cover as a whole. On the other hand, as the purpose of land tillage is to form as good as possible growing conditions for crops, the number of HC types needed to characterize the HC of cultivated soils is much smaller than of natural soils (10 and 24, respectively, in Fig. 4).

Interrelationships between Estonian HC types and forest site types are presented on the background of the forest site types ordination schema of Lõhmus (2006) in Fig. 5. This ordination schema is currently the main tool for characterizing Estonian forest growing conditions. The matching of these two classifications is far from a one-to-one correspondence, which is evident also from the significant difference in the number of the types (19 forest site types and 27 HC types).

(a) (b)

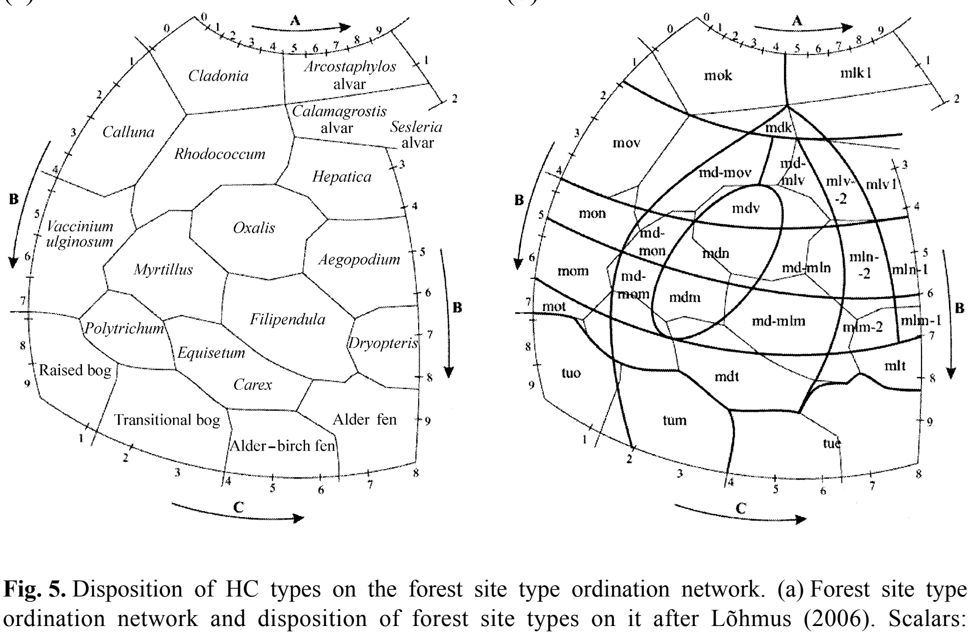

Fig. 5. Disposition of HC types on the forest site type ordination network. (a) Forest site type ordination network and disposition of forest site types on it after Lõhmus (2006). Scalars: A – increasing calcareousness of soils; B – water regime: increasing water-holding capacity of soil and decreasing groundwater level from the surface; and C – amelioration of plant nutrition conditions (from oligothrophic to eutrophic). (b) Disposition of HC types on the forest site type ordination network; for full names of HC types see legend to Fig. 1.

Comparative analysis of the ERB and Estonian HC classifications

Comparison of the Estonian HC classification with the ERB (Zanella et al., 2012) shows that the used diagnostic horizons, which in the ERB are determined according to the latest WRB version (IUSS, 2007), coincide well with those used in the Estonian classification. Organic horizons (OC content >20%) are forest floor with its subdivisions: O1 – litter (fresh, old), O2 – partially decomposed, fragmented, and/or fermented layer, O3 – humus or well humified litter or muck, and T – peat in different stages of decomposition (*fibric*, *mesic*, *sapric*).

As to the organo-mineral horizons (OC <20%), the Estonian classification separates the humus (A, OC <7%) and raw-humus (AT and AO, OC 7–20%) horizons. At the same time, they are not divided (in a more detailed way) according to the absence or presence of soil organisms or by the soil structure, as it is done in the ERB. In both classifications the presence of fungi filaments and fine roots is important.

Comparison of the Estonian classification of HC types (Fig. 1) with the ERB humus forms (Zanella et al., 2012) on the basis of moisture conditions revealed the following correspondence: (1) Estonian *dry* HC types (which form <2% of the area of forest soils) correspond to ERB *enti* humus forms, (2) *fresh* and *moist* (altogether 21%) types correspond to *terro*, (3) *wet* (31%) types to *hydro*, (4) *peaty* (9%) types to *epihisto*, and (5) *peat* (37%) types to *histo* humus forms. This means that the ERB *terro*-humus forms form ca 23% of the Estonian forest soils area in the order: *moder* > *moor* > *mull*. Estonian forest land is predominantly (77%) overmoist; of this area 40% has mineral gley (*epigleyic*) soils and 37% peat soils or *histosols*.

The ERB *mull*, *moder*, and *mor terro*-humus forms coincide well with *mull*, *moder*, and *moor* HC types in the Estonian classification. ERB *amphi terro*-humus forms are approximately equal to Estonian *moder-mull* types (mainly in their calcareousness). Of the ERB *enti* humus forms, *lithomull* (on limestone rendzinas), *peyromull* (on pebble rendzinas), and *psammomor* (on podzols) are present in Estonia. Also the ERB *para* humus forms (*rizhomull*, *rizhomoder*, *lignomoder*, *lignomor*, and others) are present in Estonian forest soil cover, although in a very modest (<0.5%) quantity. *Tangel* humus form, which develops in the conditions of high altitudes, is absent in the Estonian classification.

The limitation of the ERB for reflecting Estonian pedo-ecological conditions in detail is revealed firstly in relation to the transitional area between *mor* and *moder*, i.e. in the case of humic and secondary podzols. The ERB does not include equivalents for Estonian *fresh moder-mor* and *moist moder-mor* or for normally moist and gleyed weakly swarded (*humic*) and secondary podzols, while in the Estonian classification there are no equivalents for the ERB *tangel*, *amphi* (*hydro*-, *epihisto*-, *histo*-), and *anmoor* (*epihisto*-, *histo*-) humus forms.

The advantages of the ERB are as follows: classification is based on the composition and activity of soil organisms, the fabric of decomposable organic matter and soil aggregates are observed in a detailed way (using a magnifier), and the WRB modifiers are used for characterizing humus forms. The Estonian classification has the following advantages: strong connection of HC types with soil varieties and forest site types, ordination of HC types, which reveals the position of each HC type among others; and explanation of the changes connected with land-use change (cultivation).

The shortcoming or weakness of the ERB, in our opinion, is its insufficient systematization and specification of humus forms formed under North European conditions. The shortcoming of the Estonian classification is its weak treatment of the role of soil organisms in the formation of HC.

DISCUSSION

In studying humus forms (humus cover types) both the ecosystem and pedocentric approaches are promising. In optimal or in good forest growing conditions according to moisture conditions (i.e. *fresh* and *moist*) the character of the *detritic* chain depends first of all on the mineral–chemical potential of the soil's mineral part. In permanent overmoist conditions (*wet* and *peaty* HC types) of mineral soils the character of HC formation depends much more on the nourishing water. The water causing overmoisture may be of catchment origin (*allochthonous*), mounted from groundwater (rich in carbonates), and, to a lesser extent, precipitation, where the readily soluble substances (originating from the local soil) are present. In all these cases the influence of *autochthonous* (local) mineralogy is overshadowed by *allochthonous* materials.

In this work only normally developed soils were analysed. However, in the case of synlithogenic or abnormally developed mineral soils, solid sediments (deluvial, alluvial) are added to water-soluble substances. In the Estonian HC classification features of this kind are determined by adequate qualifiers (*colluvic*, *fluvic*, *transportic*, and others). In droughty soil moisture conditions (*dry* HC types) the decomposition of SOM is modest and it takes place during a very short period; therefore the role of the biological activity (plant cover as well as soil organisms) is also modest.

Comparative analysis of the normally developed mineral soil cover lithogenetic sequence rendzina → brown soils → podzolic soils → podzols and the HC sequence *mull* → *moder* → *mor*, which is presented in Fig. 4, shows an equally highest diversity in the case of *fresh* and *moist* HC moisture conditions. Caused by mineral composition, the diversity of HC types decreases in the direction of both *dry* and *wet* (soil, HC) moisture conditions. The transitional HC types between mineral and organic soils are very scantily researched.

The fabric and properties of main HC types were previously analysed on the background of the HC classification schema by using generalized (interpolated) isolines (Kõlli, 1992). Such treatments (graphical models) demonstrated graphically the trends of HC ecological parameters in relation to the HC classification schema or the response to changed pedo-ecological conditions.

The connectedness of humus forms (or HC) of natural and cultivated areas has been treated modestly to date. In our opinion, such research would help us to more profoundly understand the ecology of HC and the role of soil cover in its formation (Kõlli, 2009). The list of HC types of cultivated soils may be easily improved by the use of the WRB list of A horizons and diagnostic properties and materials qualifiers together with suitable specifiers (IUSS, 2007). The WRB principles and terms may be regarded as a good source for developing and harmonizing HC (or humus forms) classifications.

In the course of the determination of HC types, besides humus status indicators (composition and humification stage of SOM, fulvic/humic humus ratio, humus saturation stage, and others) also the character of the SOM decomposition chains and, connected with this, the composition and functioning character of soil organisms is taken into account. Unfortunately, soil organisms and their role in the formation of HC have not yet been researched and relevant data have not been systematized sufficiently.

The HC types are good complex indicators for characterizing ecosystem functioning. The *fresh* and *moist mor* types of HC demonstrate domination of mycogenic decomposition in the topsoil. In this case, the falling litter is poor in ash and nutritient elements, the C : N ratio is large (>35), and the formed decomposition products are acid and nonsaturated by basic cations. Under such conditions mostly non-zoogenically (prevalently mycogenically) formed HC types are present. *Fresh* and *moist mull* HC types refer to quick bacterial decomposition of the litter, which is rich in nitrogen and nutritient elements; the formed products are from slightly acid to neutral and of a high base saturation stage.

During the last 20 years great success has been achieved in harmonization and unification of soil classifications (IUSS, 2007). At the same time only the first steps have been taken in HC treating–researching methods and the harmonization–unification of its classifications. The most remarkable step in this direction was the accomplishment of the first version of the ERB (Zanella et al., 2012). Biological type is taken as the main unit of the ERB classification. In the centre of this is the biotransformation of dead organic matter, because it reveals the character of energy binding into the soil and its later release. The reflector of this kind of life expression is humus form. The ERB is compiled for forest soils, but humus forms of grasslands influenced to a greater or lesser extent by man and wetlands are also treated (Zanella et al., 2010; Kõlli, 2011).

CONCLUSIONS

In the formation and fabric of HC (or humus forms) regional peculiarities caused by soils and climatic conditions are clearly visible. In complex research of soils, determination and analysis of humus cover types (or humus forms) should be conducted.

HC type may be used as a complex indicator that reflects the functioning and character of the biological turnover of the whole ecosystem as well as its compartments (soil cover). Besides the functioning of the soil–plant system, the detritus food chain deserves special interest. Adequate knowledge of the detritus food chain and of the decomposer community forms the basis for understanding the ecology of soil processes and for sustainable use of soil cover.

The ERB's *mull*, *moder*, and *mor terro*-humus forms coincide very well with *mull*, *moder*, and *mor* HC types in the Estonian classification. The ERB's *amphi* humus form corresponds well to the *moder-mull* type in the Estonian classification. The high altitude *tangel* humus forms, which are absent in Estonia, are an exception.

A shortcoming of the ERB in relation to the Estonian soil cover is the absence of possibilities for more profound characterization of *mor* and *moder-mor* HCs formed in *fresh*, *moist*, and *wet* pedo-ecological conditions (i.e. weakly swarded and typical podzols) and of *wet moder* (i.e. podzolic and pseudopodzolic gley soils). Therefore the ERB should be amended from the aspect of the humus forms of northern areas, and its bias towards the Mediterranean pedo-ecological conditions should be avoided.

REFERENCES

AFES. 1998. *A Sound Reference Base for Soils: The "Referential Pedologique"*. INRA, Paris.

Chertov, O. G. 1966. About characterization of humus profile types of podzolic soils in Leningrad Province. *Pochvovedenie*, **3**, 26–37 (in Russian).

Chertov, O. G. & Razumovsky, S. M. 1980. On ecological trends of soil forming processes. *Journal of General Biology*, **XLI**(3), 386–396 (in Russian).

Dergacheva, M. I. 1985. *Soil Organic Matter, Statics and Dynamics*. Nauka, Novosibirsk (in Russian).

Galvan, P., Ponge, J.-F., Chersich, S. & Zanella, A. 2008. Humus components and soil biogenic structures in Norway spruce ecosystems. *Soil Science Society of America Journal*, **72**(2), 548–557.

Graefe, U. & Beylich, A. 2006. Humus forms as tool for upscaling soil biodiversity data to landscape level? *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft*, **108**, 6–7.

IUSS [IUSS Working Group WRB]. 2007. *World Reference Base for Soil Resources 2006*. 2nd edn, first update 2007. World Soil Resources Reports 103. Rome.

Jabiol, B., Brêthes, A., Ponge, J.-F., Toutain, F. & Brun, J.-J. 1995. *L'Humus sous toutes ses formes.* ENGREF, Nancy.

Karpachevskij, L. O. 1982. Modern approaches to classification of forest litter. In *Biogeotsenologicheskie issledovaniya v lesakh yuzhnoj Sikhote-Alinya* [*Biogeocenological Studies in Forests of Southern Sikhote-Alin*], pp. 5–12. Vladivostok (in Russian).

Katchinsky, N. A. 1965. *Soil Physics*. Vol. I. Moscow State University, Moscow (in Russian).

Koshel′kov, S. P. 1961. Formation and subdivision of litters in southern taiga forests. *Pochvovedenie*, **10**, 19–29 (in Russian).

Kõlli, R. 1985. *Metsamullateaduse välipraktika* [*Field Practice on Forest Soil Science*]. EPA, Tartu (in Estonian).

Kõlli, R. 1987. *Pedoecological Analysis of Phytoproductivity, Biogeochemical Fluxes of Substances and Humus Status in Natural and Cultivated Ecosystems*. Doctoral thesis. Estonian Agricultural Academy, Tartu (in Russian).

Kõlli, R. 1992. Production and ecological characteristics of organic matter of forest soils. *Eurasian Soil Science*, **24**, 78–91.

Kõlli, R. 2009. *Pedo-ecological characterization of Estonian soils*. http://mullad.emu.ee/cd-d/CD-4/DATA/index_eng.htm (visited 03.10.2012).

Kõlli, R. 2011. Euroopa huumusvormide klassifikatsiooni väljatöötamisest [About elaboration of European humus forms' classification]. In *Agronomy 2010/2011*. EMI-EMÜ-JSI, Saku (in Estonian).

Lõhmus, E. 2006. *Eesti metsakasvukohatüübid* [*Estonian Forest Site Types*]. Eesti Loodusfoto, Tartu (in Estonian).

Müller, P. E. 1887. *Studien über die natürlichen Humusformen und deren Einwirkung auf Vegetation und Boden*. Springer, Berlin.

Prusinkiewicz, Z. 1988. *Multilingual Dictionary of Forest Humus Terms*. Panstwowe Wydawnictwo Naukowe, Warszawa.

Puri, B. & Murari, K. 1964. Studies in surface-area measurements of soils, 2. Surface area from a single point on the water isoterm. *Soil Science*, **97**, 341–343.

Rodin, L. E., Remezov, N. P. & Bazilevich, N. I. 1968. *Methodological Instructions for the Study of Dynamics and Biological Turnover in Phytocoenosis*. Nauka, Moscow (in Russian).

Rozanov, B. G. 1983. *Soil Morphology*. Moscow University Press, Moscow (in Russian).

Sapozhnikov, A. P. 1984. Forest litter: nomenclature, classification, and indexing. *Pochvovedenie*, **5**, 96–105 (in Russian).

Soil and Plant Analysis Council. 1992. *Handbook on Reference Methods for Soil Analysis*. Athens, Georgia.

Soil Survey Staff. 2010. *Keys to Soil Taxonomy*, 11th edn. USDA-NRCS, Washington.

Van Delft, B., de Waal, R., Kemmers, R., Mekkink, P. & Sevink, J. 2006. *Field Guide Humus Forms, Description and Classification of Humus Forms for Ecological Applications*. Alterra, Wageningen.

Vorobyova, L. A. 1998. *Chemical Analysis of Soils*. Moscow University Press, Moscow (in Russian).

Wilde, S. A. 1971. Forest humus: its classification on a genetic basis. *Soil Science*, **111**(1), pp. 1–12.

Zanella, A., Jabiol, B., Ponge, J. F., Sartori, G., de Waal, R., Van Delft, B. et al. 2009. Toward a European humus forms reference base. *Studi Trentini di Scienze Naturali*, **85**, 145–151.

Zanella, A., Jabiol, B., Ponge, J. F., Sartori, G., de Waal, R., Van Delft, B. et al. 2010. *A European Reference Base for Humus Forms: Proposal for a morpho-functional classification*. http://hal.archives-ouvertes.fr/docs/00/54/14/96/PDF/Humus_Forms_ERB.pdf (visited 01.10.2012).

Zanella, A., Jabiol, B., Ponge, J. F., Sartori, G., de Waal, R., Van Delft, B. et al. 2012. A European morpho-functional classification of humus forms. *Geoderma*, **164**, 138–145.

Zonn, S. V. 1964. Soil as a component of forest biogeocenosis. In *Osnovy lesnoj biogeotsenologii* [*Fundamentals of Forest Biogeocenology*], pp. 372–457. Nauka, Moscow–Leningrad (in Russian).

Zonn, S. V. 1983. *Modern Problems of the Genesis and Geography of Soils*. Nauka, Moscow (in Russian).

Huumuskate ja selle ülesehitus sõltuvalt pedo-ökoloogilistest tingimustest ning maakasutusest: huumusvormide klassifikatsiooni Eesti versioon

Raimo Kõlli ja Indrek Tamm

Huumuskatte tüübi mõiste (langeb praktiliselt kokku rahvusvaheliselt tuntud huumusvormi mõistega) all käsitatakse muldkatte (mullaprofiili) pealmist osa, mis koosneb orgaanilistest (metsa- või rohumaade kõdu, turbad) ja/või organo-mineraalsetest (huumus- ja/või toorhuumuslik) horisontidest, kus ringleb valdav osa elusaine (juured, fauna, mikroorganismid, viirused) süsinikust, paiknevad loomade ja taimede jäänused (lagunemata, fragmenteerunud, suuremal või vähemal määral biodegradeerunud) ning orgaanilise aine molekulid (eritised, huumushapped, proteiinid ja paljud teised). Sõltuvalt asukoha pedo-ökoloogilistest tingimustest (geoloogiliste setete päritolu ja koostis, maa-ala reljeef ning veerežiim, mullakliima, taimkatte koostis) võib huumuskate olla väga erineva ehituse ja koostisega, mille mitmekesisust saab väljendada huumuskatte tüüpide (*pro* huumusvormide) kaudu. Pikaajaliste taim- ja muldkatete vastastikuste mõjude tõttu moodustub looduslikel aladel teatud kindla ülesehituse ning omadustega huumuskate (huumusprofiil). Tasakaalustunud huumuskatte tüüpi võib käsitleda kui ökoloogilist indikaatorit, mille järgi saab hinnata taim-muld-süsteemi (kui ka kogu ökosüsteemi) talitlemise iseloomu ja intensiivsust. Eestis on huumuskatete klassifikatsioon koostatud peale looduslike alade veel ka haritavate alade kohta. Vaatamata põhjalikele muutustele huumuskatte ülesehituses ja omadustes seoses maakasutuse muutustega (looduslike alade kultuuristamine ning, vastupidi, kultuurmuldade söötijätmine), säilivad teatud päritavad omadused ikkagi ka uuesti formeerunud huumuskattes. Töös on esitatud 19 huumuskatte tüübi ülesehitust ja omadusi (tüsedus, süsiniku ning lämmastiku varu) kajastavad andmed. Selgitamaks huumuskatte formeerumise ökoloogilist tagapõhja, on esitatud huumuskatte tüüpide kaupa uurimisalade keskmised puurinde takseerimisandmed, muldkatte agrokeemilised näitajad ja alustaimestiku produktiivsuse koostise ning taseme näitajad. Huumuskatte tüüpide kokkulangevust mullataksonitega on analüüsitud normaalse arenguga mineraalmuldade maatrikstabeli taustal ja teisest küljest nende kokkulangevust metsakasvukohatüüpidega E. Lõhmuse Eesti metsakasvukohatüüpide ordinatsiooniskeemil. Eesti huumuskatte klassifikatsiooni võrdlus Euroopa huumusvormide referentsbaasiga (ERB) näitas, et ERB huumusvormid langevad hästi kokku Eesti huumuskatte tüüpide klassifikatsiooniga automorfsete ja poolhüdromorfsete taksonite osas, st et ERB *mull*-, *moder*- ning *mor terro*-huumusvormid on sarnased Eesti klassifikatsiooni *mull*-, *moder*- ning *moor*-huumuskatte tüüpidega. ERB *amfi terro*-huumusvorm on praktiliselt võrdne Eesti *moder-mull*-tüübiga. ERB-s puuduvad võimalused Eesti olude *moder*'i ja *moor*'i üleminekualal (huumuslikud ning sekundaarsed leedemullad) kujunenud huumuskatte määratlemiseks.