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Organic matter of Estonian grassland soils

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Abstract. Soil organic carbon (SOC) and soil organic matter (SOM) contents of Estonian grassland soils are analysed in 20 soil groups using data from the database PEDON and CATENA. The SOC and SOM concentrations (g kg^{-1}) and pools (Mg ha^{-1}) for upland mineral soils (*Leptosols, Cambisols, Luvisols, Albeluvisols, Regosols;* total 9 groups), lowland mineral soils (*Gleysols, Fluvisols;* 9 groups) and wetland organic soils (*Histosols;* 2 groups) are given separately for humus cover (HC) and soil cover (SC). The SOC and SOM pools for the entire Estonian grasslands were calculated on the basis of different soil types, morphological characteristics and distribution superficies. It was concluded that in Estonian grasslands SC 39.9±8.0 Tg of organic carbon is sequestered, 76.2% of which is found in HC and 23.8% in subsoils. Grassland SOC is sequestered in 69.1±12.6 Tg of SOM. A quality analysis of humus covers of grassland soils (evaluated from the pedo-ecological perspective) distinguished 5 quality groups and 15 subdivisions.

Key words: grassland soils, humus status of grassland soil, quality of humus cover, carbon sequestration, SOC and SOM concentration and pools

INTRODUCTION

The sequestration of soil organic matter (SOM) and the soil organic carbon (SOC) in soil organic matter are widely recognized as agents of soil formation and functioning (Lal et al., 1998a; Pulleman et al., 2000; Shaffer & Ma, 2001).

Quantification of SOM and SOC flow and sequestration in soil has tremendous importance (Kern et al., 1998; Bernoux et al., 2002; Nemeth et al., 2002; Zhou et al., 2003). SOC may be sequestered in soil horizons in different forms and in variable relations with nitrogen (Batjes, 1996; DeBusk et al., 2001). The SOM (as well as SOC) flow throughout the soil begins with litter falling on the surface or into the soil, continues with its disintegration, transformation into humus and ends with the disappearance from the soil by its consumption, by soil organisms, by complete mineralization or by illuviation into subsoil or eluviation out of the soil profile. Each soil type has specific characteristics (input => acting and sequestration => output) of SOC flow (Körchens et al., 1998; Yakimenko, 1998; Neill et al., 1998; Genxu et al., 2002). Depending on the soil type and land use, the sequestered carbon may have varying fabrics, properties, quality and residence time in soil the complexity of which can be related to types of humus layers (Kõlli, 1992, 1994).

To determine SOC and SOM sequestered into different grassland soils, a macro-morphological quantitative approach based on horizon samples was used in our research. We have previously determined SOC and SOM pools accumulated into Estonian arable soils (Kõlli & Ellermäe, 2003) and forest soils (Kõlli et al., 2004).

The main tasks of the present work, which fulfils SOC and SOM research gaps in relation to Estonian semi-natural grasslands, were the following: (1) to determine SOC and SOM pools in Estonian grasslands' soil cover (SC); (2) to analyse the humus cover (HC) and subsoil roles in SOC and SOM sequestration into grasslands SC by different soil groups, and (3) to elucidate pedo-ecological regularities of the HC quality of grassland soils.

MATERIALS AND METHODS

The quantitative characteristics of grassland soils originate mainly from the soil profile horizons database PEDON which contains data of 82 grassland experimental areas. PEDON was compiled mainly during 1967–85 and was updated in 1986–95 and in 1999–2002. Data of organic soils were later completed using the humus status research transect data from the database CATENA formed during field studies in 1987–1992.

For the present work, the data on soil morphology (fabric and thickness of soil horizons), bulk density and SOC and SOM concentrations (in the fine earth, ø <1 mm) of humus (A), raw-humuous (AT), histic (T), eluvial (E) and illuvial (B) horizons were used. The carbon concentration for each soil horizon was determined by the Tjurin method (Vorobyova, 1998) based on soil samples taken during field research. For calculation of SOC and SOM pools in the HC and SC of individual profiles (by research areas), the SOC and SOM concentration, soil bulk density and content of coarse fragments in each horizon of the soil profiles were taken into account. The role of rock fragments in soil horizons was determined by their volume in field conditions. The bulk density samples were taken from approximately one third of the profiles. Later the information was generalised and used in the calculation of SOC and SOM pools in different soil horizons and the SC as a whole.

In the present work the pools of SOC and SOM by soils were estimated for two SC layers: (1) HC or epipedon, which consists of humus, raw-humous and/or peat *(histic)* horizons and (2) SC or solum as a whole, the depth of which reaches from the surface to the unchanged parent material or to C horizon. Therefore the SC consists of HC and subsoil including eluvial (E) and illuvial (B) horizons. The thickness of SC was determined by the depth of the boundary between B and C horizons. In the presence of BC horizon, the solum thickness was measured from the surface to the middle of the BC horizon.

The area of Estonian natural grasslands was 299.5 10^3 hectares during the years 2000-2001, forming 6.6% of the total land or 20.9% of agricultural land of Estonia (Statistical…, 2003). For the calculation of means and for the analysis of variance, the PC program MS STATISTICA 7 was used. The soil group names and codes are given in the system of the World Reference Base for Soil Resources (WRB; FAO et al., 1998). The correlation between the Estonian Soil Classification (ESC) and the WRB for Estonian soils is shown in Table 1 by soil codes.

RESULTS AND DISCUSSION

Overall, the thickness of grasslands sola varies between 25 and 77 cm, with standard deviation 5–20 cm (Table 1). Only the average thickness of *Leptosols (skeletic, rendzic)* and *Fluvisols (salic)* formed on coastal areas is smaller. In most cases, HC thickness is between 19 and 29 cm; but the humus horizons of very young coastal and drought-prone skeletal soils are much thinner. It must be mentioned that for *Histosols,* the unique HC (30 cm) and SC depth (50 cm) was taken arbitrarily.

The average SOC and SOM pools in HC and SC by soil groups were calculated on the basis of profile data of different research areas (Table 2).

In upland grassland soils with automorphic moisture regime, SOC pools in HC are between 40–114 Mg ha^{-1}, and are higher in soils with higher carbonate content. SOC pools that are remarkably lower are accumulated into drought-prone skeletal soils (32 Mg ha^{-1}). SOC pools higher than in automorphic soils are characteristic of *Gleysols*. But the highest pools are those in *Sapric* and *Fluvic Histosols,* the HC of which is peat (*hemic, sapric).* Intensely variegated SOC and SOM pools may be sequestered into the HC and SC of *Fluvisols.* The largest quantities are characteristic of the *Histic Fluvisols* which are situated in riverside areas but are remarkably reduced in coastal *Fluvisols.* For *Histosols* the SOC and SOM pools were recalculated to arbitrary HC (30 cm) and SC depths (50 cm).

Unfortunately, up to now, there has been an absence of exact data about soil distribution on Estonian semi-natural grasslands. However, there is data available from the inventory of grasslands by plant associations (Aug & Kokk, 1983), by land cover types (Meiner, 1999), by wet lands (Paal et al., 1999) and others (Arold, 2005) which help to receive approximate superficies and the precise relative importance of different soil groups on grasslands. With data re: soil distribution for the whole mapped area as well as for forested and arable lands, by R. Kokk (1995), it was possible to find superficies of soils which are used mainly as grasslands. Such soils formed 56% of the total grassland area. The superficies of coastal grasslands, alvars and riverside areas matched well. More problematic are areas with *Cambisols, Luvisols, Albeluvisols* as well as areas influenced by erosion, as these soils may be reforested or turned into arable land. Soil distribution data used in calculation (percentage and superficies) by different grassland soil groups are presented in Table 3. The calculations of SOC and SOM pools of 20 soil groups show that the main SOC accumulators are *Sapric Histosols, Histic Gleysols, Cambisols* and *Luvisols* in Estonian grassland SC.

The main quantitative parameters of soil humus status are HC thickness and morphology (fabric), SOC and SOM concentrations and pools by soil horizons, and HC quality (type). In connection with the absence of thickness and of SOC and SOM pools (Mg ha^{-1}) data for five grassland soil groups in our research areas (see Table 2), the gaps in calculation of total SOC and SOM pools (see Table 3) were filled by using the data presented in Table 4. The data of *Luvisols (cutanic, endogleyic)* and *Saprihistic Gleysols* were used as weighted averages (Mg ha^{-1}) of arable and forest soils (Kõlli, & Ellermäe, 2003; Kõlli et al., 2004).

Table 1. Groups of Estonian grassland soils and mean thickness of soil cover layers.

Group No	Soil or soil association by WRB	Soil code		Profiles n	Thickness (M±SD)[2], cm	
		by WRB	by ESC[1]		HC	SC
I	*Rendzic Leptosols*	LP rz	Kh	4	24±2.4	24±2.4
II	*Skeletic Leptosols*	LP sk	Kr	4	16±9.9	16±9.9
III	*Calcaric&Endogleyic Cambisols*	CM ca gln	K Kg	3	22±3.6	28±5.1
IV	*Mollic&Endogleyic Cambisols*	CM mo gln	Ko Kog	7	27±6.5	53±18.1
V	*Haplic&Endogleyic&Glossic Albeluvisols*	AB ha gln gs	Lk Lkg LP	8	21±2.7	77±15.9
VI	*Calcaric Gleysols*	GL ca	Gk	3	25±8.3	25±8.3
VII	*Mollic Gleysols*	GL mo	Go	4	26±5.7	43±10.6
VIII	*Calcic Gleysols*	GL cc	G(o)	10	29±6.6	39±18.8
IX	*Luvic&Spodic Gleysols*	GL lv sd	GI LkG	3	19±9.1	37±6.6
X	*Epigleyic Fluvisols*	FL glp	AG	7	27±7.8	37±5.7
XI	*Histic Fluvisols*	FL hi	AG1	7	25±7.3	37±19.7
XII	*Salic Gleysols*	GL sz	Gr	4	15±2.5	26±4.2
XIII	*Salic Fluvisols*	FL sz	ArG	4	4±1.3	5±0.4
XIV	*Sapric Histosols*	HS sa	M	3	30±0	50±0
XV	*Fluvic Histosols*	HS fv	AM	8	30±0	50±0

1) For correspondence of ESC soil names and soil codes see Kõlli, Ellermäe, 2003; 2) M - mean, SD - standard deviation, HC - humus cover, SC - soil cover.

Table 2. SOC and SOM sequestration capacity (Mg ha^{-1}, M±SE[1]) of different grassland soil groups.

Group No	Soil code by WRB	n	SOC pools Mg ha^{-1}		SOM pools Mg ha^{-1}	
			HC	SC	HC	SC
I	LP rz	4	114±30	114±30	193±52	193±52
II	LP sk	4	32±8	32±8	61±20	61±20
III	CM ca gln	3	90±18	97±16	156±31	168±28
IV	CM mo gln	7	97±24	120±28	168±41	208±49
V	AB ha gln gs	8	40±4	60±6	67±7	104±11
VI	GL ca	3	97±52	97±52	167±89	167±89
VII	GL mo	4	141±48	157±49	243±84	272±84
VIII	GL cc	10	115±18	119±17	197±32	206±30
IX	GL lv sd	3	74±43	92±37	128±73	158±83
X	FL glp	7	100±12	114±11	172±20	197±18
XI	FL hi	7	125±17	131±25	215±28	225±43
XII	GL sz	4	71±6	84±4	122±6	144±7
XIII	FL sz	4	22±8	24±8	42±14	44±12
XIV	HS sa	3	203±43	338±77	357±44	594±81
XV	HS fv	8	126±16	210±27	218±26	363±45

1) M - mean, SE - standard error, HC - humus cover, SC - soil cover.

Table 3. Total SOC and SOM pools (in Gg) by grassland soil groups (I–XX).

Group No	Soil code by WRB	% from grassland area	Superficies in ha	Sum of SOC pools[1] in Gg ha^{-1}		Sum of SOM pools in Gg ha^{-1}	
				HC	SC	HC	SC
I	LP rz	1.9	5690	649±171	649±171	1098±296	1098±296
II	LP sk	0.3	898	29±7	29±7	55±18	55±18
III	CM ca gln	2.5	7488	674±135	726±120	1168±232	1258±210
IV	CM mo gln	11.6	34742	3370±834	4169±973	5837±1424	7226±1702
V	AB ha gln gs	11.2	33544	1342±134	2013±201	2247±235	3489±369
VI	GL ca	4.3	12878	1249±670	1249±670	2151±1146	2151±1146
VII	GL mo	3.3	9884	1394±474	1552±484	2402±830	2688±830
VIII	GL cc	3.2	9584	1102±172	1140±163	1888±307	1974±288
IX	GL lv sd	5.9	17670	1308±760	1626±654	2262±1290	2792±1467
X	FL glp	2.9	8685	868±104	990±96	1494±174	1711±156
XI	FL hi	2.9	8685	1086±148	1138±217	1867±243	1954±373
XII	GL sz	1.7	5092	362±30	428±20	621±30	733±36
XIII	FL sz	1.6	4792	105±38	115±38	201±67	211±58
XIV	HS sa	9.9	29650	6019±1275	10022±2283	10585±1305	17612±2402
XV	HS fv	3.2	9584	1208±153	2013±259	2089±249	3479±431
XVI	LP gln glp	4.9	14676	1101±220	1101±235	1893±382	1893±411
XVII	LV ct gln	11.3	33844	2369±271	3181±305	4061±474	5483±508
XVIII	GL hi	9.6	28752	4859±1208	5923±949	8367±2070	10178±1639
XIX	RG ai am	4.1	12280	356±12	479±37	614±25	823±61
XX	CM&LV&AB erd CM&LV&AB& GL del	3.7	11082	909±44	1352±133	1563±66	2327±233

1) Soil group area x mean pool in one ha; HC - humus cover, SC - soil cover.

Table 4. Grassland soil groups. Humus status characterization was adapted from other sources.

Group No	Soil or soil association By WRB	% from grass-land area	n	Soil code		Thickness (M±SD)^1, cm		SOC mean (Mg ha^{-1}) ±SE		SOM mean (Mg ha^{-1}) ±SE	
				by WRB	by ESC	HC	SC	HC	SC	HC	SC
XVI	*Endogleyic&Epigleyic Leptosols*	4.9	-	LP gln glp	Khg Gh	20±10	25±12	75±15	80±16	129±26	138±28
XVII	*Cutanic&Endogleyic Luvisols*	11.3	20	LV ct gln	KI KIg	25±5	72±19	70±8	94±9	120±14	162±15
XVIII	*Saprihistic Gleysols*	9.6	6	GL his	G1	22±5	48±12	169±42	206±33	291±72	354±57
XIX	*Aric&Anthric Regosols Cambisols& Luvisols&Albeluvisols (eroded)* ^{1}	4.1	168	RG ai am CM&LV&AB erd	E1 E2 E3	25±6	35±12	29±1	39±3	50±2	67±5
XX	*Cambisols&Luvisols& Albeluvisols&Gleysols (deluvial)*^{2}	3.7	154	CM&LV&AB& GL del	D Dg DG	42±8	96±32	82±4	122±12	141±6	210±21

1) XIX soil group includes severely eroded *Regosols (aric, anthric)* and weakly to moderately eroded *Calcaric Cambisols*, *Humic Luvisols* and *Spodic Albeluvisols;* 2) the XX soil group is composed of deluvial (buried or formed by accumulation of eroded sediments) soils or by WRB from *pachic, cumulic, thaptohumic(-histic)* or *endogleyic Cambisols&Luvisols&Albeluvisols&Gleysols.*

Table 5. Generalized data on SOC and SOM pools in Estonian grassland soils.

Characteristic, land use	Unit	Upland mineral soils	Lowland mineral soils	Wetland organic soils	All soils
Grassland superficies	10^3 ha	154.3	106.0	39.2	299.5
	%	51.5	35.4	13.1	100.0
Grassland SOC pools in Tg^1:	Tg				
- in soil cover		13.7±2.2	14.2±3.3	12.0±2.5	39.9±8.0
- in humus cover		10.8±1.8	12.4±3.6	7.2±1.4	30.4±6.8
- in subsoil		2.9	1.8	4.8	9.5
Grassland SOM pools in Tg^1:	Tg				
- in soil cover		23.7±3.8	24.3±6.0	21.1±2.8	69.1±12.6
- in humus cover		18.5+3.2	21.2±6.2	12.7±1.5	52.4±10.9
- in subsoil		5.2	3.1	8.4	16.7
Average SOC pool^2:					
- in soil cover	Mg ha^{-1}	89	134	306	133
- in humus cover		70	117	184	102
- in subsoil		19	17	122	32
Average SOM pool^2:					
- in soil cover	Mg ha^{-1}	154	229	538	231
- in humus cover		120	200	324	175
- in subsoil		34	29	214	56

1) ± Sum of soil groups SE; 2) Weighed (by area) average.

Table 6. Outlines of grasslands HC quality characteristics and distribution.

HC characterization and subdivisions with mean percentage formula by superficies	% from grasslands superficies	% from grasslands SOC pools in		Dominating soils	Characterization of HC on the group level
		HC	SC		
A. Mild- and calci(pebble)-humous: dry:fresh:moist - 10:47:43	21	18	15	LP rz sk gln CM ca mo gln RG ca ai am	Pebble rich (or episkeletic), calcareous or neutral, rich in humus, on sloping areas may be influenced by weak to sever erosion (decrease in humus content[1] > 15%)
B. Mull-moder-humous, with light eluviation features: dry:fresh:moist - 7:44:49	14	11	11	LV ct gln RG eu ai am LV ph del	Slightly acid from superficial layers, under HC features of light eluviation, transition HC between mild-humous and acid-humous HC, on sloping areas may be influenced by weak to severe erosion (decrease in humus content > 15%) or deluvial (colluvial) sediments
C. Moder-humous, moderately or strongly acid: dry:fresh:moist - 14:43:43	14	5	6	AB ha gs gln RG oh ai am AB ph del	Moderately or strongly acid, clear features of podzolization, have Bhf or Ea horizons, on sloping areas may be influenced by weak to severe erosion (decrease in humus content > 15%) or deluvial (colluvial) sediments
D. Raw-humous or wet HC: calcaric:eutric:moder:entic – 27:23:38:12	26	23	20	GL ca mo cc GL lv sd ph sz FL glp sz LP glp	Superficial horizons are organo-mineral or peaty, mainly eu- or mesothrophic character, some areas pebble rich or calcic, periodically inundated areas may contain alluvial or deluvial (colluvial) sediments, on coastal areas may be very shallow (< 3–5 cm)
E. Peats thin:thick - 48:52	25	43	48	HS sa fv GL his FL hi	Superficial horizons are sapric (eutric) or hemic (mesotrophic) peat, which is moderately or well decomposed, on riverside areas may contain alluvial sediments, the thickness of thin peats is 10–30 cm, thick peats > 30 cm (mostly more than 1m)

1) Estimated by concentration (g kg^{-1}) or by pools (Mg ha^{-1}) .

The data about soils influenced by erosion areas (eroded and deluvial soils) were taken from our unpublished work and data about hydromorphic *Leptosols (endo*- and *epigleyic)* from previously generalized postlithogenic soil matrices (Kõlli et al., 2004).

In total, 39.9±8.0 Tg SOC is sequestered (Table 5) in Estonian grasslands SC. Of that, 76.2% is accumulated into the active layer or into HC (i.e. incorporated into stabilised soil humus, raw-humous material or in peat); 23.8% of SOC is located in the passive layers (in E and B horizons) or in subsoil and is characterized therefore by a long turnover time. The generalised SOC and SOM pools (Table 5) are given separately for three sets of soil groups. The role of these three grassland soil group sets in the sequestration of total SOC pools in grasslands is 34.5, 35.3 and 30.2%, respectively; the role of these sets for the total grassland area, (51.5, 35.4 and 13.1%, respectively).

In Estonian grasslands 69.1±12.6 Tg SOM is accumulated; approximately half (31.3 Tg or 45.3%) is peat. More than half, 54.7%, of grasslands' total SOM may be qualified as humus with different quality and available for soil edaphon. The majority, 78% (29.5 Tg), of total grasslands' humus is situated in active HC and 22% (8.3 Tg) in passive part or in subsoil. The high proportion of peat in the SOM of Estonian grasslands (approximately half) is caused by the high amount of *Histosols* (13.1%) and *Histic Gleysols & Fluvisols* (12.5%).

The generalised (weighted by area) data about SOC and SOM pools (Mg ha^{-1}) in HC and SC are also presented in Table 5. The comparison of three grassland soil sets shows that subsoils of upland and lowland mineral soils have approximately equal SOC and SOM sequestration capacities, but the average sequestration capacity of SOC in lowland mineral soils' HC (in Mg ha^{-1}) is more than 1.6 times higher than in upland soils. Due to the subsoil richness in SOC, the most powerful SOC accumulators are *Histosols* sola, where an average per one hectare's 50 cm layer sequesters 306 Mg SOC.

In the World Soil Resources Report (FAO, 2001) mean SOC amounts of 0.3 m and 1.0 m soil layers in Boreal Agro-Ecological Zones are 98–102 and 231–240 Mg ha^{-1}, respectively; the 0.3 m layer SOC pool matches our grasslands soil HC weighted average (Table 5). The mean grassland ecosystem soil organic pools according to Lal et al. (1998b) is given as 116 Mg ha^{-1} which is similar to our lowland mineral soils HC pools, and is close to the weighted mean of Estonian grassland SOC amounts.

In the Brazilian Amazon Basin the mean SOC amounts to a depth of 1 m (Rosell & Galantini, 1998) are in a similar range with our data, in *Alfisols* 76–120, *Inceptisols* - 68–76 and in *Mollisols* 95–156 Mg ha^{-1}, if we compare them respectively with *Albeluvisols*, *Lepto-&Cambisols* and *Mollic Cambisols* (Table 2). However, the depth of our sola is thinner, as is characteristic of northern areas.

Comparative studies of meadow and forest soils in the forest zone of Russia (Yakimenko, 1998) have demonstrated the ability of grassland ecosystems to accumulate more SOC in a 50 cm soil layer than in forest ecosystems. For example, 67–88 Mg ha^{-1} SOC is accumulated in grassland soil in the Middle Urals, 66-90 in Leningrad province and in Moscow province 52–81 Mg ha^{-1} SOC, which are accordingly 2–21, 12–22 and 8–29 Mg ha^{-1} more than in the same soils under the forests.

The experiments with annual application of nitrogen and sulphur fertilizers on hayed native grasslands in Saskatchewan, on a *Boralfic Boroll* with sandy loam to sandy clay texture (Nyborg et al., 1998), clearly demonstrated enhancement of SOC storage in grassland soil superficial 37.5 cm layer up to 8 Mg organic carbon per one hectare.

Comparison of Estonian grassland soil SOC pools to a 50 cm layer of soils in the northwestern United States in Mg per ha (Kern et al., 1998) demonstrates the variability of SOC pools with similar limits (CV limits of 20–60%), indicating higher amounts (84–110 Mg ha^{-1}) in *Rendolls, Udolls* and *Borolls* compared with *Udalfs* and *Boralfs* (56–86 Mg ha^{-1}). Soils with *aquic* water conditions in the northwestern United States tend to be similar to pools of Estonian *Gleysols* (varying from 90-200 Mg SOC ha^{-1}).

The humus status of *Histosols* (Tarnocai, 1998) reveals that SOC pools of our *Sapric Histosols* match well with C. Tarnocai's surface (0–30 cm depth) carbon content of *Saprists, Hemists* (*Mesisols* and *Humisols* according to the Canadian Soil Classification) with average SOC amounts of 182 and 217 Mg SOC ha^{-1} respectively. C. Tarnocai (1998) estimated for the Canadian Grassland Ecoclimatic Province a mean SOC content of 122 Mg ha^{-1} which is slightly lower than the value (133 Mg ha^{-1}) found by Post et al. (1982). It is interesting that this is equal to our value for Estonian grassland SOC amounts (133 Mg ha^{-1}; Table 5). But it is clear that the weighted average SOC content of an estimated area depends largely on the presence of *Histosols.*

At present different sources concerning the distribution of SOC and SOM in European soils are available (Rusco et al., 2001; Van-Camp et al., 2004; Zdruli et al., 2004) but in most cases the total SOC and SOM stocks for different countries are computed indirectly and must be updated from time to time. For example, the SOC for Estonian topsoil (0–30 cm) is computed as 1.5 Gt (Van-Camp et al., 2004), however the sources refer to the lack of geo-referenced, measured, harmonised data on SOC available in Europe.

Comparison of SOC and SOM retaining (sequestration) capacity of grassland HC and SC by soils groups and soil sets with those for arable and forest soils (Kõlli & Ellermäe, 2003; Kõlli et al., 2004) enables us to elucidate some pedo-ecological regularities. First of all, arable, forest and grasslands clearly differ by their soil types and texture composition. On arable land, more fertile upland mineral soil types (with loamy texture) are dominant (altogether 72%); on forest lands there is a greater share of organic (37%) and lowland mineral soils (39%); consequently both differ from grassland composition (see Tables 3 and 5). A clear difference is observed in HC thickness, which is highest in arable soil, and in the fabric of HC where a clearly formed forest floor is observed in forest soils. In arable soils the organic superficial layer is absent all together, but may occur on some grasslands that have low biological activity. With regard to grasslands SOC and SOM amounts, their weighted averages are slightly higher on upland mineral and lowland mineral soils when we compare them with arable and forest lands.

Our study reveals that we must not decide carbon sequestration capacity only on SOC and SOM concentration, but first of all on the basis of SOC or SOM. Many researchers have clarified (Kern et al., 1998; Körchens et al., 1998; Percival et al., 2000; FAO, 2001) that SOC- and SOM-retaining capacity depends on the soil moisture regime, physical clay and carbonate content in fine earth, and soil management character. Land use and/or tillage technology have a substantial influence mainly on the humus status of superficial soil layers. SOC sequestration in subsoils depends greatly on the thickness of the solum. In subsoils of mineral grasslands, an average of 17–19 Mg ha^{-1} SOC or 29–34 Mg ha^{-1} SOM may be found. That may be treated as a buried resource. Thick *Histosols* and various soils with *pachic, cumulic* and *thaptohumic* epipedons formed in mineral soils by accumulation of eroded (deluvial) and alluvial sediments are especially rich in sequestered SOC.

The characteristics of humus quality are presented in Table 6, where a rough estimation of the share of different HC types is shown. The first three divisions (A, B and C) belong to upland mineral soils (see Table 5). Raw-humous HC is developed on lowland mineral soils; the exceptions are *Histic Gleysols* and *Histic Fluvisols,* the HC of which is peaty. By area, the peat type HC (25%) can be divided almost equally between thin peat (peaty soils) and thick peat (real organic (peat) soils). A remarkable share of HC (23% by pools and 26% by area) belongs to raw-humous or wet HC, which is potentially fertile, but suffers from water logging during spring and autumn. These HC are relatively well humified in *Gleysols* with calcareous and neutral reaction, rich in nutrition elements. The portion of acid raw-humous HC with features of podzolization is not high (< 6% by area) but the quality of this kind of SOM is low from the ecological, and especially from the edaphic, viewpoint. Although the soils of upland grasslands form more than half, (51.5%), of the total grassland, their SOM pools account for only about one third, (34.3 %). A comparison of qualities of Estonian forest and grassland HC's show that biologically more active epipedons or HC are characteristic of grassland.

CONCLUSIONS

Sequestration capacities for each soil type of grassland characteristic SOC and SOM have developed. They are determined mainly by soil thickness, moisture regime, as well as by carbonate and clay content. Depending on composition of individual site specific soil properties, the SOC and SOM contents and pools in humus cover and sola may vary greatly.

In Estonian grassland soils 39.9±8.0 Tg SOC is sequestered. The latter is accumulated as 69.1±12.6 Tg of SOM (humus, raw-humous material, peat) in different soil horizons and layers. 76.2% of SOC is located in the biologically active humus cover and 23.8% in less active subsoil. Epipedons formed on grasslands are biologically more active and have better ecological quality than on forest lands.

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