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Evaluation of the pedodiversity, agronomical quality and environment protection ability of the soil cover of Estonian croplands

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Abstract. The diversity, humus status, productivity and environment protection ability of cropland soils were studied in the mild and wet pedoclimatic conditions of Estonia, located in the mixed-forest region of the North European temperate zone. Proceeding from the pedocentric principle, the soil cover is treated as a causal factor largely determining the land use, productivity level, soil management technology and environmental status of the area. The research is based on soil data from seven arable land parcels of three experimental stations, where the *Cambisols*, *Luvisols*, *Retisols*, *Leptosols* and *Gleysols* are dominating. The taxonomic heterogeneity and contrastiveness of arable soils were estimated at the most detailed level of soil taxa. To determine the humus cover types (*pro* humus forms) and to evaluate the agronomical quality of soils, the guidelines elaborated for local pedo-ecological conditions were employed. The environment protection ability of soils was evaluated as a complex indicator, which comprises the biological and physical properties of soil cover, soil climate and the character of soil cover substratum. For quantifying the pedodiversity of soil cover and the contrastiveness of soil taxa, it is recommended to use the mineral soil pedo-ecological matrix with lithogenetic and moisture scalars, and the matrix of top- and subsoil texture. The best indicators of the pedodiversity of arable lands are the soil classification taxa determined at the most detailed level and the statistically elaborated data about their spatial distribution and properties. For the precise land use the evaluation of the agronomical quality of soil cover and its suitability for crops in relation to its whole heterogeneity is indispensable. The most informative pedodiversity indicator of arable soil humus status is the humus cover type. Additionally, the problems connected with pedo-ecological equivalence and soil type-specific biodiversity are discussed. The quantitative indicators of pedodiversity enable arranging the use of croplands in harmony with the pedo-ecological properties soil cover.

Key words: pedodiversity, pedocentric approach, soil taxa, humus forms, soil quality, land use.

INTRODUCTION

The diversity of soil taxa in the soil cover composition (pedodiversity) and the distribution pattern of soils in landscape depend on the diversity of soil parent materials or geodiversity, landscape topography and the climatic conditions of the region (Ibáñez et al. 1998; Ibáñez & Bockheim 2013; Costantini & L'Abate 2016). Estonia lies in the North European temperate zone of the mixed-forest region, which is characterized by mild and wet pedoclimatic conditions (Fisher et al. 2002). This region has a high percentage of forested areas (ca 50%), but a low percentage of croplands (ca 25%) (Kokk & Rooma 1974; Reintam et al. 2005). The soil cover of the region comprises much of the soils suitable mainly for forests (*Podzols*, *Histosols*, *Gleysols*) and/or grasslands (*Fluvisols*, *Gleysols*, *Histosols*). The mineral soil covers with *Cambisols*, *Retisols*, *Luvisols* and *Leptosols* are mainly used as cropland (ELB 2001; Reintam 2002). The typical forest and arable soils include soils suitable for both of these purposes, whose use depends primarily on the needs of the local community and the established land use policy.

For sustainable and successful cropland management the land use based on soil cover properties (the pedocentric approach) is preferred (Blum 2002; Haslmayr et al. 2016). A vital prerequisite for this approach is the availability of know-how on the most detailed level of soil taxa (in the actual work soil species and/or soil varieties) about functioning capabilities of soil and the practice-proven experience on their as good as possible use by forming suitable to soil properties agroecosystems. Besides the availability of large-scale (1:10 000) soil map data, it is also necessary to have information on soil humus and agrochemical status, productivity and suitability for crops. It should be taken into account that certain part of soil properties, which influence the soil productivity level and suitability for crops, are relatively dynamic. Such kind of property is first of all agrochemical and humus status, which may be substantially changed by tillage and in accordance with land management intensity (Rossiter 1996). Also, soil moisture conditions may be regulated by drainage and irrigation.

Besides being a growing medium for crops, arable soils (like all other soils) fulfil many other tasks essential for the sustainable functioning and good health of the surrounding environment (EA 2006). These functions include the decomposition and transformation of soil organic matter (SOM), the conservation of biological diversity, neutralization and rendering harmless of xenobiotic substances and many others (Turbé et al. 2010; Cardinale et al. 2011). Directly connected with soil cover are the carbon cycling intensity, its sequestration capacity and the distribution patterns of its stocks (Garcia-Oliva & Masera 2004).

The biodiversity of the surrounding environment has attracted great attention during the last two decades (Jeffery et al. 2010; Orgiazzi et al. 2016). Soil cover evidently plays a vital role in the biodiversity of areas (Tscharntke et al. 2005; Turbé et al. 2010). Furthermore, the role of soils should not be ignored when treating the biodiversity of any area (Minasny et al. 2010; Ibáñez et al. 2012). Soil biodiversity differs by soil types and land use peculiarities and is different in crop-, grass- and forestlands (Phillips & Marion 2005; Orgiazzi et al. 2016). However, much more information about soil type-specific biodiversity and its relation to different bioclimatic regions is needed (Ibáñez et al. 1998; Guo et al. 2003; Griffiths & Lemanceau 2016). Studies on soil type-specific biodiversity are based on the knowledge of a region's pedodiversity and its correlations with the geodiversity of that area (Serrano & Ruiz-Flano 2007; Ibáñez & Bockheim 2013).

In the present work (1) the indices of pedodiversity, (2) humus status and humus cover types (*pro* humus forms), (3) soil cover productivity (quality) in connection with the suitability of soils for crops and (4) environment protection ability (EPA) of soils are discussed. Additionally, the discussion involves data from our previous work (Rannik et al. 2016) on (1) soil cover composition and the distribution of soil species in it, (2) the particle-size composition of soils by fine-earth and coarse fractions, (3) pedo-ecological conditions of soil cover formation and (4) morphology and genesis of dominant soil species.

In this research the qualifiers of *World Reference Base for Soil Resources* (WRB) (IUSS 2015) were used not only in converting soil names of the Estonian soil classification (ESC) into WRB ones, but also in the comparative analysis of soil properties of different land parcels and in characterizing their pedodiversity. Additionally, the contrastiveness of soils (or contrast of soil species and varieties), pedo-ecological equivalence of soil covers and the role of pedodiversity in the formation of soil type-specific biodiversity and in the planning of field experiments are discussed.

MATERIALS AND METHODS

General remarks on the terms and data used in the study

This study is based on cropland soil data originated from the pedoclimatic conditions of Estonia, representative of the North European temperate zone. At country level, the data used represent three large regions of Estonia, differing from each other in their soil cover and geodiversity (Kokk & Rooma 1974). The studied experimental areas (EAs) belong to Jõgeva Plant Breeding Institute (JEA), Kuusiku Experimental Centre (KEA) and Olustvere Experimental Station (OEA) (Fig. 1). The research comprises seven arable **land parcels** (a land unit used in the Estonian cadastral system) with three parcels in both JEA and KEA and one in OEA. All moist and wet soils of the EAs are artificially drained.

The study considers the **soil cover** as a superficial earth layer or mantle influenced by soil-forming processes and consisting of humus cover and subsoil. **Humus cover** is the superficial part of soil cover, which is characterized by higher biological activity and more intensive carbon cycling as compared with subsoil. The humus cover of mineral agricultural soils consists of humus (A) and/or raw-humus (AT) horizons, but the subsoil includes the eluvial (E) and/or illuvial (B) horizons and is underlain by soil parent material or substratum.

The soil names and codes of the ESC used in tables are given on the level of soil species. The ESC's taxon 'soil species' is identified by soil genesis and is subdivided into 'soil varieties' on the basis of soil species textural composition (Astover et al. 2012). The list of soil species of the ESC is practically identical to the list of soil mapping units of the large-scale (1:10 000) digital soil map of Estonia (ELB 2001).

Each land parcel consists of a certain amount of soil areals with different shapes of patterns and superficies, which are marked by contours on soil maps. The **soil contour** is an areal of soil species and is known as a polygon of the soil mapping unit. In our previous work (Rannik et al. 2016) soil pedons were mostly taken as a basis of pedo-ecological analyses, but in actual work the analysis is mostly based on soil associations (or assemblages of soils). The notion 'status' is used in actual work in a variety of cases and in its larger sense. **Humus status** implies here the management of SOM in

Fig. 1. Location of experimental areas on the map of Estonian counties.

soil cover, which may be quantitatively expressed by the content (concentration and stock) of SOM, soil organic carbon (SOC) or energy captured into SOM. In other words, the humus status characterizes the SOM/SOC flux (input → sequestration → output) via soil cover. **Soil organic matter** is taken here as a whole or a complex component of soil cover, which in addition to the stabilized humus substances dominating in cropland soils, contains also the litter of plants and soil organisms incorporated into the soil, as well as fine roots and microorganisms of the soil living phase. The quantitative analysis of the soil humus status in actual work is based on SOC concentration (g kg^{-1}), humus cover thickness (cm) and SOC stocks (Mg ha^{-1}), but the semi-quantitative analysis is based on **humus cover types** (*pro* humus forms) and humus cover fabric. A similar understanding is used for the **agrochemical status** of soils, which comprises not only NPK, but also the acidity and Ca status of the cropland soil cover. The **environmental status** of soil covers is characterized by the evaluation of its EPA.

Texture of soil covers

The particle-size composition data in Estonian soil databases and on large-scale soil maps are given according to Kachinskij (1965). In this study the fine-earth particle-size composition data were converted into the WRB data. However, coarse fractions are reported in terms of the ESC, because the classification principles of the ESC and WRB cannot be adequately converted (Astover et al. 2013; IUSS 2015).

The ESC uses the following codes and names of coarse fractions (Ø 1–10 cm) in particle-size formulas: r – ryhk (sharp-edged angular fractions of calcareous origin), v – pebble, v^{o} – granitic pebble and p – massive limestone. Their relative content is given in the soil texture formula before fine-earths (Ø <1 mm) by the lower index: 1 – very slightly (2–10% of volume), 2 – slightly (10–20%), 3 – moderately (20–30%) and 4 – strongly (30–50%) ryhky (r) or pebbly (v, v^{o}). The fine-earth codes and names are given according to WRB: S – sand, FS – fine sand, LS – loamy sand, SL – sandy loam, L – loam, SCL – sandy clay loam and SiL – silty loam. Gravel (Ø 1–10 mm by Kachinskij 1965), positioned between coarse and fine fractions by its diameter, is used in the ESC as an additional characteristic at the name of the main fine texture (gravelly loam, etc.). In soil texture formulas the soil layers with a different texture are separated by a single slash (/). Soil texture is a basis for distinguishing soil varieties (i.e. subdivision of soil species) of the ESC.

Methods of laboratory analyses and calculation of parameters

The SOC content was determined by wet digestion of soil with acid dichromate (Arinushkina 1970). Soil reaction (pH_{KCl}) in 1 M KCl (with the soil : solution ratio 1 : 2.5) suspension was measured by a Jenway 3071 pH-meter. Hydrolytic acidity (HA) was determined by extraction with 1 M CH_3COONa and filtrate titration with 0.1 M NaOH (method of Kappen; Arinushkina 1970). The sum of basic cations (SBC) was determined by extraction with 1 M ammonium acetate (pH 7.0) solution (SPAC 1992). The cation exchange capacity (CEC) was calculated by the summation of SBC and HA. The presence of plant available P and K in soil was evaluated by the Mehlich-3 method, whereas the content of P and K in extraction was determined spectrophotometrically. Ca and Mg were determined spectrometrically by the atomic absorption method after their extraction with 1 M ammonium acetate solution (SPAC 1992).

The stocks of SOC ($Mg\,ha^{-1}$) per humus cover were calculated on the basis of humus cover thickness, SOC concentration ($g\,kg^{-1}$) and soil bulk density. The bulk density of humus cover (i.e. humus and raw-humus horizons) was determined by the soil species and texture by means of pedotransfer functions (Suuster et al. 2011).

Methodological principles

To study the actual status of dominant soil species of the EAs, altogether 38 soil profiles (JEA 21, KEA 12, OEA 5) were described (FAO 2006; Astover et al. 2013). Soil samples for laboratory analysis (i.e. for the evaluation of the agrochemical and humus status of humus cover) were gathered in the field from all dominant soil species using the transect method. The main soil humus cover thickness and SOC content were determined at 364 transect points.

In the comparative analysis of soil cover heterogeneity (1) the number of soil species and varieties per area, (2) the mean area of soil contours and (3) the presence (number) of soil layers with varied texture were used as pedodiversity indices. The moisture and lithogenetic heterogeneities of soils (as pedodiversity indices) and the differences (contrast) between various soil types or taxonomical distances of soils (Minasny et al. 2010) were estimated by using the scalars of soil moisture conditions (six stages) and soil genesis (eight stages) of the Estonian normal mineral soil matrix (Kõlli et al. 2008; Kõlli 2017). The heterogeneity and contrast in the stages of the texture of topsoils and subsoils (i.e. differences of soils or pedodiversity from the textural aspect) were estimated on the basis of the soil particle size matrix table, which contains seven varieties of texture for topsoil and eight for subsoil, or a total of 56 units of generalized soil texture varieties (Kõlli 1987).

The heterogeneity scores of soils (as pedodiversity indices, evaluated by the soil position on the scalar) were 1−6 by moisture conditions, 1−8 by genesis and 1−7 (for topsoil) and 1−8 (for subsoil) by texture. Consequently, the contrastiveness or contrast rate of different soil varieties was in the limits 0–5 (min–max) by soil moisture conditions, 0–7 by soil genesis and 0–6 (for topsoil) and 0–7 (for subsoil) by soil texture. The contrast rate zero indicates that there is no contrast or the soils are similar in terms of the property analysed. Contrast 1 means that soils are near or adjacent by this soil property. The higher the rate or number of contrast, the greater their dissimilarity, divergence or contrast. For the evaluation of the soil contrast level the actual (determined by matrices) contrast was compared with the theoretical maximum contrasts, which are given above.

For the evaluation of the actual humus status of arable soil varieties, the Estonian cropland model soil was used as a benchmark (Kokk & Rooma 1978, 1983). Model soil represents the mean characteristics of a certain Estonian soil variety as it was calculated based on data from hundreds of individual profiles. In total, 50 profile models of arable soil varieties are available (Kõlli et al. 2008), from which 12 profile models were used for the evaluation of the humus status of the studied EA soils. The humus cover types (*pro* humus forms) of arable soils were identified based on the local classification (Kõlli 1994).

The agronomical quality of soils was characterized (1) by the soil agro-groups (A – universally suitable, B – moderately suitable and C – with limited suitability), (2) by quality classes (I−X) and (3) by quality points (1−100), using the instructions elaborated for local pedo-ecological conditions (Astover et al. 2013). The highest-quality soils belong to class I and were evaluated by 91−100 points, while the soils with the lowest quality belong to class X and were evaluated by 1−10 points. The suitability of the soils for crops was determined within the 10-point scalar (suitability improving from point 1 to 10) elaborated in a matrix form by soil varieties and agricultural crops. The principles for evaluating arable soils quality and suitability for crops are introduced to the international reader by Reintam et al. (2005).

The EPA of soils was evaluated from four aspects (biological, physical, soil climate and substratum) by using a four-stage scale (0 – absent, 1 – weak, 2 – average and 3 – good): (1) the biological (or active) aspect of EPA was evaluated mainly by soil productivity and intensity of SOM decomposition; (2) the physical (or passive) aspect was estimated by clay and SOM stocks in soil cover, which are tightly correlated with the specific surface area and CEC of soils; (3) the evaluation of soil climate was based on soil cover humidity, aeration and redox regimes and (4) the role of substratum was assessed by its fine-earth texture, content and size of coarse particles, and thickness. Five EPA value classes (I − very good (with total scores ≥12.0), II – good (9.0−11.9), III – satisfactory (6.0−8.9), IV – poor (3.0−5.9) and V − very poor (≤2.9)) were identified on the basis of the sum of the scores of the four aspects (Kõlli et al. 2004, 2009).

In the characterization of soil associations and soil cover composition and properties of land parcels the WRB qualifiers (IUSS 2015), arranged by their importance (occurrence percentage) list in relation to the studied area, were used as pedo-genetical or pedo-diversity indices.

RESULTS

Nomenclature of soil species and soil varieties, and agrochemical status of soil covers

The soil species list of the studied EAs is given in Table 1. To make it more understandable to the international reader, the ESC soil species names were converted into the soil codes and names of the WRB system. The soil species on land parcels of EAs, arranged in decreasing order of their percentage, are given in Table 2. The large-scale soil maps and detailed pedo-ecological characterization of all dominating soils of JEA, KEA and OEA are given in our previous work (Rannik et al. 2016).

Soil species in the soil covers of each EA are distinct and different. The dominant soil species at JEA belong to *Luvisols* and *Cambisols*. The soil cover species composition is rather different at KEA, where *Gleysols* and more calcareous *Cambisols* are distributed. The soil species of OEA belong mainly to *Retisols*.

The distribution of dominant soil textures (characterized by texture formula) on the land parcels is given in Table 2. Altogether 9, 11 and 3 texture combinations with a substantial area were found in JEA, KEA and OEA, respectively. Besides, 4–6 different texture formulas with a negligible area were additionally found in the soil covers of the EAs.

The data on the agrochemical status of dominant soils are presented in Table 3. The acidity (pH_{KCl}) and Ca content of humus covers are in good accordance with soil genetic properties and texture. Generally Mg contents are low in the well-drained arable soils in KEA and OEA. The plant available P content is high in the well-drained JEA and OEA soils, but low in all dominant KEA soils. The available K contents are high in the soils of KEA.

The agrochemical characteristics of the dominant soils of three EAs revealed that the soil cover of JEA is exceptionally homogeneous, i.e. its heterogeneity from the aspect of agrochemical status is low. Significant differences in agrochemical properties are characteristic of the dominant soils of KEA. The data on the species and textural composition (Table 2) and agrochemical status (Table 3) of OEA soils indicate that the soil cover of OEA is homogeneous but significantly different from those of JEA and KEA.

Humus status and humus cover types (*pro* humus forms)

The data on the humus status of dominant soils are presented in Table 4. The SOC concentration and stocks are significantly higher in the soil cover of KEA, but significantly lower in the soil cover of OEA. This indicates that the SOC concentration of humus cover is the primary factor in determining the SOC stocks of soils. The humus cover thickness is most variable in KEA. From the pedo-ecological aspect, the data on the humus status of soils are in good correlation with their acidity and Ca content (Table 3).

The type of humus cover is a qualitative indicator of soil humus status (Table 5), as it was determined on the basis of soil variety, SOC content, coarse fractions in topsoil and selected agrochemical characteristics (Kõlli 1994). The humus cover types of cropland are derived from both soil cover properties (moisture conditions, calcareousness and soil-forming factors) and management techniques (including the intensity of cultivation, drainage and liming). The humus covers of both JEA and OEA are mostly well drained (or have an optimum moisture regime) and of an *eluvic moder-humic* character. *Neutral mild-humic* cover, which is abundant on parcels I of both JEA and KEA, has excellent agronomical properties.

Table 1. List of soil species codes according to Estonian Soil Classification (ESC) and World Reference Base for Soil Resources (WRB) and soil names according to WRB found in the study areas

Code (ESC)	Code (WRB)	Soil name (WRB)
Kr	LP-jk.rz-hu.pr	*Rendzic Hyperskeletic Leptosol* (*Humic, Protic*)
K	CM-sk.ca-hu	*Calcaric Skeletic Cambisol* (*Humic*)
Ko	CM-ca.skn-lo	*Endoskeletic Calcaric Cambisol* (*Loamic*)
KI	LV-ll.can-lo.ct	*Endocalcaric Lamellic Luvisol* (*Loamic, Cutanic*)
LP	RT-gs.st.fg-go	*Fragic Stagnic Glossic Retisol* (*Geoabruptic*)
Lk	RT-um.ab-hu.qp.arn	*Albic Umbric Retisol* (*Humic, Protospodic, Endoarenic*)
Korg	CM-sk.gln-dr	*Endogleyic Skeletic Cambisol* (*Drainic*)
Kog	CM-ca.gln-lo.dr	*Endogleyic Calcaric Cambisol* (*Loamic, Drainic*)
KIg	LV-ll.gln-lo.dr	*Endogleyic Lamellic Luvisol* (*Loamic, Drainic*)
LPg	RT-gs.gln-ap.dr	*Endogleyic Glossic Retisol* (*Abruptic, Drainic*)
Gk	GL-ca-sk.dr	*Calcaric Gleysol* (*Skeletic, Drainic*)
Go	GL-mo.ca-lo.dr	*Calcaric Mollic Gleysol* (*Loamic, Drainic*)
GI	GL-um-lv.dr	*Umbric Gleysol* (*Luvic, Drainic*)
Go1	GL-hi.sa-ar.dr	*Sapric Histic Gleysol* (*Arenic, Drainic*)

It is impossible to use the *eutrophic* and *mesotrophic raw-humic* covers for crop cultivation without artificial drainage. The quality of *skeleti-calcaric mild-humic* cover is worsened by a high content of coarse textural fractions in it. The skeletic materials are present in an exceptionally high share in *Rendzic Hyperskeletic Leptosols*. Formed on flat lowlands without artificial drainage, *Gleysols* will be subject to paludification (with the formation of *raw-humic* and *peaty* humus covers).

Indicators of pedodiversity and contrastiveness of soils

Pedodiversity becomes obvious in the heterogeneity or variability of properties of soil taxa within soil cover. In Table 6, the soil cover heterogeneity data are quantified by means of pedodiversity indicators. The high soil cover heterogeneity in KEA is proved by a greater number of soil species, varieties and texture combinations. The number of soil varieties per soil species is quite uniform (1−3). The high heterogeneity of KEA is also indicated by a larger number of soil contours (areals) per 10 ha (2.8−5.6) and a relatively small area of the mean soil contour (1.8−3.6 ha). The soil cover of KEA has a five-stage difference in soil genesis and four-stage difference in soil moisture regimes. These differences demonstrate high contrast in relation to these two scalars as they are close to a maximum, being accordingly 5 of a maximum of 7 and 4 of 5. According to this pedodiversity index, the soil covers of JEA and OEA are quite similar.

The contrastiveness of soils was analysed at two levels. At the first level (contrast 100%) all soil varieties were taken into account. At the second level (contrast 90%) only dominant soil species and textures were considered (i.e. the associated soil varieties with a total area of <10% were excluded). The first number in the contrast formula (Table 6) characterizes moisture conditions, the second soil genesis and the third soil texture, whereas both topsoil and subsoil textures were taken into account. The contrast in texture is also the greatest in the soil cover of KEA. Although the soil contrasts of JEA and OEA are similar by the numerical value, their species composition is significantly different. According to the soil cover composition and properties, all EAs represent different board regions of Estonia: KEA soil cover is characteristic of North, JEA of Central and OEA of South Estonian pedo-ecological conditions (Kokk & Rooma 1974; ELB 2001).

The productivity of dominant soil species and their suitability for crops

The dominant soils of JEA have developed on loamy texture. They are well drained, have optimal agronomical properties and high productivity (Table 7). Therefore, based on the agronomical quality, these JEA soils are qualified as the universally suitable soils (belonging to agro-group A). The associated soils (7−11%) of JEA are the moist drained variants of the dominant soils, having a half class lower productivity (Fig. 2).

On the largest KEA parcel (III) the drained *Gleysols* with the drained moist *Endogleyic Lamellic Luvisols* and drained saturated *Sapric Histic Gleysols*, belonging to quality class VI−VII (31−50 quality points), are dominant. The texture of KEA soils varies from sand to loam. The productivity of KEA soils is substantially

Table 2. The composition of the soil cover of experimental areas (EA) by soil species and texture

EA[a]	Land parcel		Decreasing orders of soil species and soil texture (%)[b]
	No.	Area (ha)	
			Decreasing orders of soil species[c]
JEA	I	222	LV-ll.can (56) > CM-ca.skn (27) > LV-ll.gln (8) > RT-gs.st.fg (7) > GL-mo.ca (1) > CM-ca.gln (1)
	II	138	LV-ll.can (47) > CM-ca.skn (36) > LV-ll.gln (16) > GL-mo.ca (1)
	III	24	LV-ll.can (74) > CM-ca.skn (13) > CM-ca.gln (12) > CM-sk.ca (1)
	I–III	384	LV-ll.can (54) > CM-ca.skn (30) > LV-ll.gln (11) > RT-gs.st.fg (4) > GL-mo.ca (1) > CM-ca.gln (<0.5)
KEA	I	57	CM-ca.skn (43) > CM-sk.ca (26) > LP-jk.rz (12) > CM-sk.gln (7) > LV-ll.gln (5) = RT-gs.st.fg (5) > CM-ca.gln (2)
	II	4	LP-jk.rz (88) > CM-sk.ca (12)
	III	126	GL-mo.ca (64) > LV-ll.gln (17) > GL-hi.sa (10) > GL-um (5) > GL-ca (3) > CM-ca.gln (1)
	I–III	187	GL-mo.ca (43) > CM-ca.skn (13) = LV-ll.gln (13) > CM-sk.ca (8) > GL-hi.sa (7) > LP-jk.rz (6) > GL-um (3.3) > CM-sk.gln (2.1) > GL-ca (2.0) > RT-gs.st.fg (1.4) > CM-ca.gln (1.2)
OEA	I	63	RT-gs.st.fg (87) > RT-um.ab (9) > RT-gs.gln (3) > GL-mo.ca (1)
			Decreasing orders of dominating soil texture formula[d]
JEA	I–III	349	$\mathbf{v_1}$L/$\mathbf{v_1}$SCL/$\mathbf{r_1}$L (45) > $\mathbf{v_1}$L/$\mathbf{r_2}$L (32) > $\mathbf{v_1}$L/SiL/$\mathbf{r_1}$L (5) = $\mathbf{v_1}$SL/$\mathbf{r_1}$L (5) > SL/SiL (4)
KEA	I–III	166	FS (28) = LS/FS (28) > $\mathbf{v_1}$L/$\mathbf{r_2}$L (11) > LS (7) > $\mathbf{r_3}$SL/r (6) > ($\mathbf{v_{1\text{-}2}}$)S (5) > $\mathbf{r_2}$L/$\mathbf{r_{3\text{-}4}}$SL (4)
OEA	I	62	$\mathbf{v°_1}$SL/$\mathbf{v°_1}$SCL (67) > $\mathbf{v°_1}$L/$\mathbf{v°_1}$SL/SCL (23) > $\mathbf{v°_1}$LS/S (9)

[a] Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere. [b] Percentage soil distribution is given in brackets after soil species codes or soil texture formulas. [c] For soil names by WRB codes see Table 1. [d] For soil texture's formula see the part 'Texture of soil covers'.

Table 3. The agrochemical status[a] of the humus covers of dominant soil species by experimental areas (EA)

EA[b]	Soil	n[c]	pH_{KCl}	Ca^{2+}	Mg^{2+}	P	K^+	HA	SBC	CEC
				mg kg^{-1} ± SE[d]				cmol$_+$ kg^{-1} ± SE[d]		
JEA	LV-ll.can	11	6.2 ± 0.1b[e]	1404 ± 51b	158 ± 10c	137 ± 18b	164 ± 24b	1.8 ± 0.2c	8.4 ± 0.3b	10.2 ± 0.2b
	CM-ca.skn	7	6.3 ± 0.2b	1395 ± 57b	167 ± 12c	180 ± 18bc	175 ± 12b	1.6 ± 0.3c	8.4 ± 0.4b	10.1 ± 0.2b
KEA	GL-mo.ca	4	7.1 ± 0.1c	1779 ± 124c	197 ± 13d	45 ± 11a	307 ± 60c	1.0 ± 0.1b	10.6 ± 0.9bc	11.5 ± 0.9bc
	CM-ca.skn	4	6.5 ± 0.3b	1385 ± 162b	91 ± 10b	36 ± 14a	646 ± 164d	2.3 ± 0.9c	9.0 ± 1.0b	11.1 ± 0.4b
	CM-sk.ca	4	7.1 ± 0.1c	1616 ± 69c	83 ± 4b	56 ± 10a	263 ± 26c	0.7 ± 0.1a	10.4 ± 0.4bc	10.9 ± 0.6b
OEA	AB-gs.st	5	5.3 ± 0.4a	877 ± 181a	63 ± 8a	140 ± 13b	95 ± 26a	2.8 ± 0.7d	5.1 ± 0.9a	7.9 ± 0.4a

[a] HA, hydrolytical acidity; SBC, sum of basic cations; CEC, cation exchange capacity. [b] Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere. [c] n, number of soil samples. [d] mean ± standard error (SE). [e] Letters behind the data indicate significant difference at the P <0.05 level.

Table 4. The humus status of dominant soil species of experimental areas (EA)

EA[a)]	Soil	n	SOC content,[b)] g kg^{-1} ± SE	Thickness of humus cover,[b)] cm ± SE	SOC stock,[b)] Mg ha^{-1} ± SE	Mean bulk density, Mg m^{-3}
JEA	LV-ll.can	110	13.9 ± 0.55b[c)]	32.2 ± 0.59c	66 ± 4.1c	1.48
	CM-ca.skn	70	13.9 ± 0.25b	29.0 ± 0.00b	58 ± 1.2b	1.44
KEA	GL-mo.ca	21	24.4 ± 0.81e	38.0 ± 0.87e	76 ± 4.1d	0.82
	CM-ca.skn	12	19.1 ± 0.28c	29.0 ± 1.39b	77 ± 4.6d	1.39
	CM-sk.ca	15	22.2 ± 1.05d	26.5 ± 0.64a	77 ± 5.2d	1.31
OEA	RT-gs.st	25	8.6 ± 0.31a	36.0 ± 0.96d	45 ± 2.9a	1.44

[a)] Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere. [b)] mean ± (SE) standard error, estimated on the basis of soil species, horizons and texture. [c)] Letters indicate significant difference at the P <0.05 level. n, number of samples.

Table 5. Humus cover types and their distribution by land parcels (%)

Humus cover type	JEA			KEA			OEA	Total
	I	II	III	I	II	III	I	
Eluvic moder-humic	71	63	74	10	–	17	90	54
Neutral mild-humic	28	36	26	52	–	1	–	24
Eutrophic raw-humic	1	1	–	–	–	77	1	16
Skeleti-calcaric mild-humic	–	–	–	38	100	–	–	4
Mesotrophic raw-humic	–	–	–	–	–	5	–	1
Fulvic moder-humic	–	–	–	–	–	–	9	1

Humus cover types are given according to the classification of Estonian arable soils humus cover types (Kõlli 1994). Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere.

lower than that of JEA soils (Fig. 2). The lower productivity is also characteristic of the soils of OEA, when compared with JEA soils. Besides the universally suitable soils (agro-group A), the moderately suitable soils (B) are also present in OEA. In KEA, a small quantity (13%) of soils with limited suitability for crops is present apart from the universally and moderately suitable arable soils. These soils have the quality under 40 points, belonging to quality class VII or to the soils of poor quality.

The value of soils was also assessed by their suitability for specific crops (barley, potatoes and field grasses). Depending on the crops, the suitability of the EAs' soils varied from 4 to 10 (Table 7). The dominant soils of JEA and OEA have a high suitability (9–10) for barley and potato. Some soil varieties of KEA are also highly suitable for the same crops, but unfortunately they are not dominant soils. It is seen that soils of all EAs are highly suitable for field grasses, whereas in only some cases it is recommendable to use the alternatives to conventional plant species (more suitable for these soil types): melilot and alfalfa for calcareous and skeletal soils and lupine for acid soils.

The environment protection ability (EPA) of soils

Different aspects of the EPA of EAs' soils were characterized on the basis of soil functions (Fig. 2). It is seen that the role of soil cover substratum in total EPA is the lowest in skeletal soils, but the role of soil climate is low both in epigleyic soils and leptic soils. According to the summarized data, the soil cover of JEA has a very good EPA (class I), i.e. a higher quality compared with the other two EAs (Table 7). The well-structured, well-drained loamy soils of JEA have the highest total values of EPA, due to the neutral to slightly acid reaction, optimum SOC contents, high CEC, sufficient soil depth and excellent physical properties of subsoil. The EPA of the OEA soil cover is generally good (class II). Lower ability (i.e. satisfactory to good EPA, classes II–III) is characteristic of KEA. The EPA of the KEA soil cover is lower than those of the other EAs due to the high content of rock fragments in soil and low biological activity within epipedons. The relatively low EPA of KEA is also related to its skeletal substratum. In KEA, the hydro-ameliorative system used on *Gleysols* promotes soil aeration by eliminating the excess water,

Table 6. Indicators of pedodiversity and soils contrastiveness by land parcels and experimental areas

Indicators	JEA[a]				KEA				OEA
	I[b]	II	III	I–III	I	II	III	I–III	I
Quantity of species	7	6	5	10	8	2	8	14	5
Quantity of varieties	15	12	8	28	19	2	16	36	6
Quantity of textures	7	6	4	10	9	2	11	19	4
Varieties per one species	2.1	2.0	1.6	2.8	2.4	1.0	2.0	2.6	1.2
Quantity of contours per 10 ha	1.6	1.7	4.1	1.8	5.6	4.6	2.8	3.7	1.4
Mean area of contour (ha)	6.2	6.0	2.4	5.6	1.8	2.2	3.6	2.7	7.0
Cntr-100%[c], formula[d]	2.8/3/2.2	2.8/2.2/1	2/2/1.6	2.8/3/2.2	3/4/2.5	1/0/0.5	4/2/3.6	5/4/6	2.8/3.2/3
Cntr-100%, total[e]	8	6	5.6	8	9.5	1.5	9.6	15	9
Cntr-90%[c], formula[d]	2/1/0.1	2/1/0.5	0/1/0	2/1/0	2/1/2	1/0/0.5	2/1.2/3	4/2/4	1/1/1.2
Cntr-90%, total[e]	3.1	3.5	1	3	5	1.5	6.2	10	3.2

[a] Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere. [b] Land parcels. [c] Cntr: soil contrastiveness (Cntr-100% – all soils were taken into account; Cntr-90% – only 90% of the soil area was taken into account). [d] Formula of soil contrastiveness: moisture/genesis/texture. [e] Total soil contrastiveness.

Table 7. The productivity and suitability of dominant soil species of experimental areas for crops

Characteristics	JEA[a]			KEA							OEA	
	LV[b] ll.can	CM ca.skn	LV ll.gln	GL mo	CM ca.skn	LV ll.gln	CM sk.ca	GL hi.sa	LP jk.rz	GL um	RT gs.st	RT um.ab
Agro-group[c]	A	A	A	B	A	B	A	C	C	B	A	B
Quality class[d]	IV	IV	V	V	IV	VI	V	VII	VII	VI	V	VI
Suitability for barley	10	10	9	7	10	8	9	6	6	7	9	6
Suitability for potato	9	9	8	8	9	8	8	4	4	8	10	7
Suitability for grass leys	9	9	9	9	9	8	7/10[e]	10	4/8[f]	9	9	5/9[g]
EPV class[h]	I	I	II	III	II	II	II	III	III	III	II	II

[a] Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere. [b] Abbreviated soil code by WRB (see Table 1). [c] Agro-group: A, universally suitable; B, moderately suitable; C, with limited suitability. [d] Soil quality class: IV, good; V, VI, average; VII, poor. Suitability for [e] melilot, [f] alfalfa and [g] lupin. [h] EPV class: I, very good; II, good; III, satisfactory.

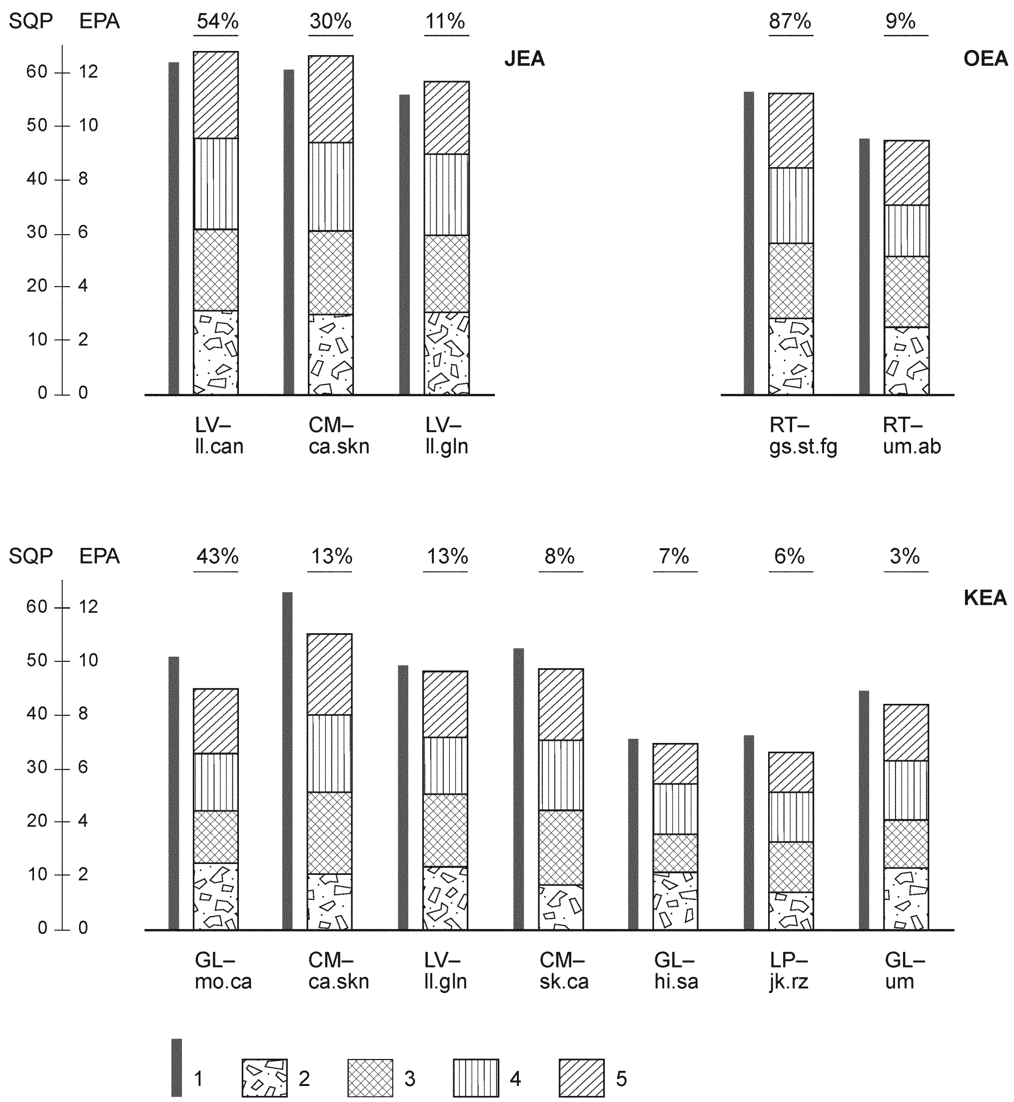

Fig. 2. Soil quality points (SQP) and environment protection ability (EPA) of soil species. Experimental areas: JEA, Jõgeva; KEA, Kuusiku; OEA, Olustvere; for soil names see Table 1; percentage above bar charts – proportion of soils in the soil cover of the experimental area. Legend: 1, SQP; 2−5, the proportion of different properties in the total EPA score (2, substratum; 3, soil climate; 4, physical status; 5, biological activity).

which also improves the soil redox regime and therefore considerably increases its EPA.

DISCUSSION

Soil cover representativity and pedo-ecological equivalence

The soil covers of JEA, KEA and OEA are representative of the pedo-ecological and soil-forming conditions of the European temperate-zone mixed-forest region (Fisher et al. 2002; Jones et al. 2005; Rannik et al. 2016). On the country level the soil cover of KEA well represents North Estonia, JEA Central Estonia and OEA South Estonia (Kokk & Rooma 1974; ELB 2001). From the territorial aspect, these three EAs characterize ~70% of Estonian landscapes enfolding among others the best agricultural areas (Arold 2005). The rest of the areas (~30%) include the regions where soil cover is dominated by the *Histosols* in association with wet Podzols (~15%) or with histic and epigleyic *Gleysols* on flat coastal landscapes (~7%) (Kokk & Rooma 1974). In these areas there are also present stony-rich podzolic soils between the sea and North Estonian klint (escarpment) (~3%) and erosion-affected soils on glacially deposited mounds (~5%) in South Estonia, which are markedly different from the studied EAs' soils (GSE 1999).

Depending on the composition of parent materials of soils (geodiversity) and water conditions in the soil covers of the studied EAs, the processes of argillization, eluviation, podzolization, gleyification and paludification are taking place (GSE 1999; Reintam 2002). The arable soils of these EAs may be characterized by the WRB (1) principal qualifiers – *rendzic/mollic/umbric*, *cambic*, *luvic*, *albic*, *glossic/retic*, *reductic*, *spodic*, *gleyic/stagnic*, *calcaric*, *fragic*, *skeletic*, *sapric/hemic*, *leptic*, *eutric/dystric* and *haplic* and (2) supplementary qualifiers – *arenic/loamic/clayic*, *humic*, *aric*, *drainic*, *abruptic/geoabruptic*, *cutanic* and *calcic* (IUSS 2015). Some of these qualifiers were used as the identifiers of WRB reference soil groups and land use – *luvic*, *glossic*, *cambic*, *reductic*, *retic*, *albic*, *spodic* and *aric*. Some of them (*luvic*, *skeletic*, *abruptic*, *eutric/dystric* and *calcic*) were used as principal qualifiers for some soils, but as supplementary qualifiers for others. As a conclusion we suggest that the WRB qualifiers are good informative indices for characterizing the properties of whichever soil cover (land parcel, soil association in the landscape) and pedogenesis. For example, the most important qualifiers for the characterization of parcel JEA-I are *luvic–cambic–endocalcaric–endoskeletic–humic–loamic–cutanic*, for KEA-III *reductic–luvic–mollic–eutric–gleyic–sapric–arenic–drainic* and for OEA-I *retic–umbric–glossic–stagnic–fragic–abruptic–loamic*.

In the decreasing order of 6–10 qualifiers it is possible to demonstrate both the similarities and differences between the soil covers of land parcels and EAs from the genetic, taxonomic, textural and other aspects. These orders may be taken also as a good basis for elucidating the pedo-ecological equivalence between soil covers of large regions.

The knowledge of the pedo-ecological equivalence of soil covers is necessary for introducing research results and selecting areas for field experiments. In the management of soil resources it is important to look for and to use the findings received in the other (but pedo-ecologically equivalent) regions. Regarding soil cover properties, inappropriate land use leads to either or both of the inefficient exploitation and destruction of land resources and related social problems (Tscharntke et al. 2005).

In Estonia, the croplands of the agricultural regions are represented by different combinations (patterns) of forest- and grasslands (ELB 2001). As a rule, the latter lands are distributed on soils of lower productivity, which are unsuitable or less suitable for crops. Regarding the large districts (agro-districs, counties) of JEA, KEA and OEA location (Fig. 1), the percentages of the associated soils are quite similar (Kokk & Rooma 1974). On average about 16–24% of the aggregate territory of agro-districts is influenced by paludification. About 31–35% of mineral soil cover is found in hydromorphic soils, 0.7–3.0% in *Fluvisols* and 0.5–2.5% in eroded soils.

The study of landscape components (Arold 2005), comparison of soil maps with Quaternary sediment maps (GSE 1999), agro-districts soil cover composition with different types of geological maps (Rannik et al. 2016) and finally the composition of our EAs' soil associations with EAs' geology show the great influence of geodiversity not only on the pedodiversity (Krasilnikov et al. 2007; Kasparinskis & Nikodemus 2012), but also on the plant cover diversity (Köster & Kõlli 2013). This proves the statement that the basis of the pedodiversity of any territory is its geodiversity (Serrano & Ruiz-Flano 2007; Ibáñez & Bockheim 2013). The influence of geodiversity on soil cover diversity and through this on plant cover diversity is outlined in Fig. 3.

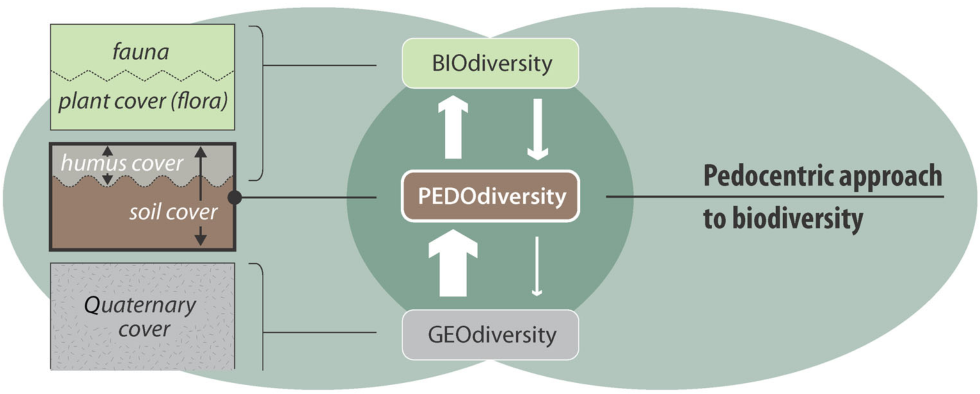

Fig. 3. The pedocentric approach to the formation of the biodiversity of a plant association and edaphon. Soil and humus covers may be taken as a transitional space between geo- and bio-components of the terrestrial ecosystems; pedodiversity, which has been formed according to area's geodiversity, has a decisive role in the development of both soil cover and the biodiversity of its humus cover.

Comparative analysis of the humus status of cropland soils

Soil humus status is an important indicator of soil quality (Garcia-Oliva & Masera 2004). For the evaluation of the humus status of EAs' soils (Table 5) its main indices were compared with Estonian cropland model soils (Kokk & Rooma 1978, 1983; Kõlli et al. 2008). We support the statement that soil humus status is soil type-specific (Schmidt et al. 2011). We suggest that the humus status of soil species (varieties) be evaluated by the scalars of SOM or SOC concentrations elaborated according to the calcareousness, texture and moistening conditions of soils (Astover et al. 2012). These scalars enable estimating whether the SOM or SOC concentrations in humus cover are sufficient for the normal functioning of soil or under the critical content or, on the contrary, in surplus. We are of the opinion that the humus status should be estimated not only by the SOM or SOC concentrations in soil, but also by their stocks per area given in relation to certain soil layers or horizons. The low humus content of *Stagnic Glossic Retisols* of OEA (Table 4) indicates humus deficit, which may be caused by the mixing of the A-horizon with a deeper horizon, poorer in humus. The SOC stocks of 42–48 Mg ha^{-1} may be qualified as quite normal for this soil species. Relatively large SOC stocks in KEA's *Calcaric Cambisols* and modest stocks in *Mollic Gleysols* are caused by regional soil peculiarities. The low SOC stock of *Mollic Gleysols* results from soil drainage, which promotes intensive SOM mineralization (Rousevell et al. 2005). Each arable soil type has a humus sequestration capacity varying within certain limits. The stocks of SOM and SOC (Mg ha^{-1}) in humus cover depend primarily on soil species SOM and SOC concentration (g kg^{-1}) and secondly on humus cover thickness or the quantity of fine-earth in soil cover.

A good pedodiversity indicator of the humus status of arable soils is their humus cover type (*pro* humus form). The European classification of humus systems and humus forms was recently elaborated by Zanella et al. (2017). It shows that the humus forms of the European classification match well with Estonian humus cover types (Kõlli 2017). We support the proposal of Zanella to use the notion 'humipedon' in relation to humus form.

As usual, the arable soils have mostly well-aerated or aeromorphic humus covers (Table 6). The dominant part (54%) of EA humus covers belongs to the *eluvic moder-humic* type, which needs periodical liming. The best agronomical quality on EAs have the *neutral mild-humic* humus covers, which do not require liming at all. However, the *fulvic moder-humic* cover of OEA needs systematic liming. The quality of *skeleti-calcaric mild-humic* humus cover, present on parcels I and II of KEA, is a bit lower than that of *neutral mild-humic* cover due to its high content of coarse skeletal fractions. Regarding the unstabilized *raw-humic* humus covers, the dominant part of them are of *eutrophic* character. The pedodiversity analysis of arable soils based on their humus cover types shows their differences/similarities in watering conditions, trophic status, calcareousness, acidity, content of humus and richness in skeletal fractions. Therefore, we suggested the use of the humus cover types not only for characterizing natural soils but also for arable soils. The local classification of humus cover types of arable soils (Kõlli 1994) correlates well with the Estonian natural areas' humus cover types (Kõlli 2017) and with the European humus forms classification (Jabiol et al. 2013). It should be mentioned that the humus cover may be characterized also by A-horizons types and some WRB qualifiers (such as *mollic*, *umbric*, *anthric*, *drainic* and others) (IUSS 2015).

Pedodiversity and soil type-specific biodiversity

The pedodiversity and heterogeneity of soil cover may be explained from different aspects. In our previous work (Rannik et al. 2016) we studied them on the same EAs from the qualitative aspect, i.e. by taxonomical units (soil species/varieties and texture) and by soil-forming processes, which were reflected in the fabric of soil genetic horizons and profiles. That study revealed that the soil covers of JEA and OEA are relatively homogeneous in soil species and textures of topsoils, but differ substantially in subsoil calcareousness.

The current study analysed, in addition to the previous work, the agrochemical and humus status of dominant soils, presence and character of humus cover types, agronomical quality of soils, suitability of soils for crops and EPA of the EAs' soil covers. The analysis revealed variation in the total number and nomenclature of pedodiversity indicators. The best indicators of soil cover pedodiversity of cropland are the local soil classification taxa determined in the most detailed level. In Estonia, soil species and varieties are used for this purpose. We suggest using additional indicators, such as the number of soil varieties per soil species, the number of soil areals (contours) per certain land area and the mean area (superficies) of one soil areal.

We recommend quantifying the cropland pedodiversity and soil species contrastiveness (i.e. from the genetical aspect) by the litho-genetic and moisture scalars of soil species of soils pedo-ecological matrix. For quantifying the pedodiversity and contrast of soil varieties (i.e. from the aspect of soil texture), we suggest the use of the top- and subsoils fine- and coarse-particle distribution matrices. The quantitative data on the position of each soil on the scalars of soil species and soil texture matrices may be used as the quantitative basis for calculating the contrastiveness among soils in any soil association or land parcel. This kind of treatment of soil heterogeneity (pedodiversity) is in good accordance with the concepts of McBratney & Minasny (2007) stating that a suitable and effective measure of pedodiversity is a mean taxonomic distance between soil types.

The more stable agrochemical properties of dominant soils may be used as pedodiversity indices as well. The contents of plant available nutrients (NPK), however, are unsuitable for this purpose as they depend mainly on the agrotechnology used in the course of the actual vegetation period. The area inclination certainly belongs to the soil cover properties (Oueslati et al. 2013), therefore, the relief of the soil areal is one additional index of soil cover pedodiversity. On arable lands, most of the soil diversity indicators have a smaller amplitude of variability than those of natural areas. The main cause of this is the antecedent selection of the best areas for arable lands, which eliminated a lot of natural pedodiversity as unsuitable for crop management. It should be mentioned that during land use change (from natural land to cropland) the influence of the most soil type-specific properties persisted to a great extent in low-input soil management, and in perceptional extent as well in the case of conventional soil management, but not at all in the case of high-input soil management (Marcinkonis et al. 2015). According to our research, it seems that for the evaluation of the region-specific pedodiversity of arable soil covers the investigated area should be over 50−100 ha. But of course this depends largely on the region's geomorphology and its substratum geodiversity.

The main reason for discussing soil biodiversity in connection with soil pedodiversity is that very commonly the studies on floral and faunal diversities give insufficient information about site conditions, i.e. about soils. At the same time many investigations have proved that the floral composition of plant cover and its functioning have changed distinctly in accordance with changes in the properties of soil cover (Swift et al. 2004; Köster & Kõlli 2013; Marcinkonis et al. 2015). The same has been proved in relation to faunal diversity (Topoliantz et al. 2000; Jeffery et al. 2010; Beylich et al. 2015). Therefore, those studies on biodiversity which have been conducted in concordance with soil cover pedodiversity are highly appreciable (see Fig. 3).

Arable land management and tillage affect mainly the diversity of humus cover (spatial distribution and vertical fabric) by changing humus cover more homogeneous or by decreasing its pedodiversity. To some extent, this is proved by the comparison of the classifications of the humus covers of Estonian arable and natural mineral soils, where the normally developed mineral cropland soils are characterized by 10 but the soils of natural areas by 24 humus cover types (Kõlli et al. 2008; Kõlli 2017).

The information about soil cover pedodiversity should be taken as a basis in the interpretation of research data about soil biodiversity. Cardinale et al. (2011) and Ibáñez et al. (2012) concluded that the existing linkages between biodiversity and pedodiversity are not yet fully explored. Still more, the conservation and maintenance of biodiversity require a better understanding of the linkages between geodiversity, pedodiversity and biodiversity (McBratney & Minasny 2007).

General aspects of soil biodiversity are relatively well studied, however, investigations on soil type-specific biodiversity are still very rare (Topoliantz et al. 2000; Beylich et al. 2015). Research on ecosystem functions in a pedocentric perspective can provide valuable information on matching local environmental heterogeneity with soil type-specific biodiversity. Data on soil cover composition and distribution (or pedodiversity) and its related biodiversity (Fig. 3) are necessary not only in planning suitable technology for soil management, but also in other activities relating to the health and sustainability of the surrounding environment (Swift et al. 2004; Rousevell et al. 2005; Ibáñez et al. 2012). Only these plant associations which are well matched with soil cover heterogeneity and properties of its main components are sustainable. The most detailed characterization of the pedodiversity of land parcels or certain territories is very important in introducing precision agriculture and understanding the mechanism of the formation of biodiversity suitable for soil cover (Landis 2017).

The importance of the obtained results in everyday practice

A comprehensive knowledge of soil cover properties and quality is the main prerequisite for developing an environmentally-friendly management of local land resources (Rossiter 1996; Panagos et al. 2010). The composition of cropland soil cover by soil types (species, varieties) is the main factor influencing the suitability of land for crops (Reintam et al. 2005). Matching the crops with soils suitable for their growth is a prerequisite to the effective and sustainable use of croplands (Rousevell et al. 2005; Panagos et al. 2010).

The evaluation of the representativity of the studied EA soils of the region and their suitability for field experiments was done by comparing their dominant soil properties with model soils representing the region (Kokk & Rooma 1974, 1978, 1983). It revealed that according to their agronomical properties, soil covers of all EAs are suitable for regional field experiments: KEA soil cover represents well North Estonia, JEA Central Estonia and OEA South Estonia.

The role of soils in sustaining the good status of the environment needs much more attention (Blum 2002; EA 2006; McBratney et al. 2014). Numerous authors have justifiably emphasized the pivotal role of soils (or soil cover as a whole) in the functioning of terrestrial ecosystems (Blum 2002; Griffiths & Lemanceau 2016). In this connection much attention is paid to the protection of soils and their functioning (Montanarella 2003). The dominating opinion among soil scientists seems to be an agreement that soil cover composition, functioning and protection strategies are very different depending on the pedo-ecological conditions of the region (Fisher et al. 2002). Therefore region-specific studies on soil functioning capabilities and peculiarities by the dominating soil types and land use manners should be carried out.

It seems to us that the functioning capacity of soil cover, which is the basis of an alternative approach to environment protection, has been left without merited attention. This approach consists in giving a more important role to soil cover in reaching the sustainable state of the ambient environment. But unfortunately very frequently the role of soils is underestimated in the functioning of ecosystems. To our understanding soil cover should be taken as an active component of the functioning of any terrestrial ecosystem. The soils (their species/varieties) determine not only (1) the floral and faunal composition and diversity, (2) the productivity level and related influx of fresh organic matter into the soil, (3) the SOM decomposition intensity and (4) the biological turnover of chemical elements, but also the transforming of areal macroclimatic conditions into the soil (micro)climate, on which an inducing/stagnating intensity of inputted SOM decomposition and transformation depends (Astover et al. 2012). In connection with all interrelated functions, soil cover acts in concordance with its formed soil type properties and therefore, maintains the surrounding ambient environment healthy and in sustainably functioning status.

Since 2004 (Kõlli et al. 2004, 2009) and also in this work we have been trying to evaluate quantitatively the EPA of some soil types dominating on Estonian croplands from four aspects (Fig. 2; Table 7). All these aspects of EPA are distinctly different and quantitatively measurable. As a feedback the data about different aspects of EPA indicate the possibilities of enhacing these abilities or finding ways for preventing the decrease in the real existing levels of functioning.

We analysed the capacity of arable soil covers in order to either maintain or enhance, or both, the environmental quality of an area by their EPA. The soil cover acts as a filter, but its plasma as a colloid complex (i.e. humus and clay particles) is able to absorb different harmful substances. This ability of soils may be regulated by improving the soil humus status and proper tillage. The actions that increase the soil biological activity and crops productivity increase also the EPA value of soil.

The most suitable climate for soil organisms is in the soil that is sufficiently warm, well aerated and with sufficient water content. Better soil aeration favours oxidation processes, including fresh litter decomposition. The drainage of waterlogged soils improves soil EPA due to redox processes and impedes paludification. The substratum of soil cover acts as an additional protective filter. Filtered water may comprise groundwater contaminating nitrates and water-soluble organic substances. The substratum renders contaminants harmless or sequesters pollutants for prolonged periods.

The following groups of pedodiversity indices (their total number, used in actual work, is given in brackets behind the group name) were counted on three cropland EAs with seven land parcels: **(1)** ESC taxa and their indices: soil species (14), soil varieties (42) and the formula of soil texture (21); **(2)** humus status of soils: quantitative data calculated on the basis of SOC (3) and humus cover types of croplands (6); **(3)** agrochemical and physical status, and topography: agrochemical indices (8), physical index (1) and the inclination or slope of soil cover (1); **(4)** soil cover genesis or main characteristics of its functioning processes and features: soil-forming processes (evaluated on the basis of soil pedo-ecological matrix; Astover et al. 2012) (11); **(5)** WRB qualifiers counted by their groups: reference qualifiers (8), principal qualifiers (15) and supplementary qualifiers (10) (IUSS 2015); **(6)** soil productivity, evaluated according to local classifications, i.e. indirectly (3): by agro-groups, quality classes and quality points; **(7)** soils suitability for three groups of crops (3): cereals, potato and grasses; **(8)** characterization of soil species/varieties areals (or contours on a large-scale soil map) (2): mean number of areals/contours per 10 ha and mean area of one contour; **(9)** the position of soil taxa on the scalars of soil pedo-ecological matrix (2): by the moisture regime and the litho-genetic character; **(10)** the diversity of soil cover may be additionally characterized by its environment protection ability using the scores of soils on its biological activity, physical status, soil climate and subsoil character (4).

Thus, soil cover diversity may be evaluated from different aspects. The above-presented list of pedodiversity indices groups includes more than 150 indices, which can be used to characterize the pedodiversity of soil cover. The choice of the pedodiversity evaluation aspect depends not only on soil cover composition, but mostly on the availability of the evaluation methods and instructions adequate for local conditions. The holding of local legacy data on soil cover properties and on methods of their pedodiversity evaluation is justified until more improved comprehensive methods are available. The current multitude of pedodiversity determination methods should not be taken as a shortcoming or weakness but, on the contrary, as a strength. It should be mentioned that no universally suitable complex indices for the characterization and evaluation of the pedodiversity of cropland soil covers have been elaborated yet.

CONCLUSIONS

(1) The best indicators of cropland pedodiversity are the soil classification taxa determined at the most detailed level (in Estonia soil species and soil varieties), data about the spatial distribution of taxa (by the soil map at a scale of at least 1:10 000) and the size of statistically elaborated indices (properties).

(2) For quantifying the pedodiversity and contrastiveness of soils, it is recommended to use the lithogenetic and moisture scalars of soil pedo-ecological matrix from the aspect of pedogenesis and the top- and subsoils fine- and coarse-particle matrix from the aspect of soil texture.

(3) The most informative pedodiversity indicator of the humus status of cropland soils is the humus cover type (*pro* humus form), which involves not only the influence of the plant cover, but also the influence of its soil edaphon.

(4) For the precise land use the evaluation of the agronomical quality of soil cover and its suitability for crops in relation to its whole heterogeneity is indispensable.

(5) The integrated environment protection ability of cropland soils consists in the cumulative influence of their biological and physical properties, soil climate and character of soil cover substratum.

(6) Cropland use should be arranged in harmony with soil cover pedodiversity, i.e. soil properties found in it.

(7) The biodiversity of both plant cover and consortium of living organisms should be evaluated in accordance with properties of soil cover or its pedodiversity.

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Eesti haritavate maade muldkatte mitmekesisuse, agronoomilise väärtuse ja keskkonnakaitselise võimekuse hindamine

Kaire Rannik ja Raimo Kõlli

Haritavate maade mullastikulist mitmekesisust, huumusseisundit, produktiivsust ja muldkatte keskkonnakaitselisi omadusi uuriti Eesti mullastik-klimaatilistes tingimustes. Laiemas plaanis esindavad uuritud alad Põhja-Euroopa parasvöötme segametsade levila pehme ja niiske kliimaga mullastiku tingimusi. Töös püstitatud ülesannete lahendamise aluseks on võetud muldkeskse käsitluse (pedotsentriline) printsiip, mille järgi käsitletakse muldkatet (ja seda moodustavaid muldasid) kui peamist ökosüsteemide talitlemise põhjuslikku tegurit. Sõltuvad ju muldkatte koosseisust ja omadustest suurel määral maakasutuse viis, produktiivsuse tase, maaharimise tehnoloogia ning ka regiooni keskkonnaseisund.

Andmed põllumuldade omaduste kohta pärinevad Jõgeva, Kuusiku ja Olustvere katsejaamades tehtud sügavkaevete uurimisest (koos proovide võtmise ja analüüsiga). Andmestik mullaliikide ja erimite leviku kohta on aga saadud meie korrigeeritud mullastikukaartidelt. Töö aluseks olev seitsme maamassiivi mullastiku andmestik (tabelid 1 ja 2) on meie poolt eelnevalt üldistatud ja avaldatud ajakirjas Geoderma Regional (2016, 7, 293–299). Antud töös, mis on sisu poolest selle artikli jätk, on käsitletud: 1) erinevate mullastiku mitmekesisuse näitajate kasutamist, 2) huumusseisundi ja huumuskatte tüüpide määramist, 3) muldkatte produktiivsust (kvaliteeti, headust) seoses kasutussobivusega põllukultuuridele, 4) muldkatte tähtsust ümbritseva keskkonna hea seisundi tagamisel.

Haritavate muldade taksonoomilist heterogeensust ja kontrastsust on käsitletud kvantitatiivsete näitajate abil võimalikult detailsel, s.o mullaliikide ja/või mullaerimite tasandil. Põllumuldade huumusseisundit, huumuskatte tüüpe (ehk huumusvorme), sobivust põllukultuuridele ja ümbritsevat keskkonda heas talitlemiskorras hoidmise võimet on analüüsitud seoses pinnakatte (sh mullalähtekivimi) geoloogilise mitmekesisuse, muldade kujunemise ökoloogia ning muldade majandamise võtetega. Põllumuldade huumuskatte tüübid on määratud ja nende agronoomiline väärtus on hinnatud Eesti mullastikutingimuste kohta koostatud juhendite järgi. Muldkatte keskkonda hoidvat või aineringete tasakaalustunud seisu säilitavat või parendavat võimet on hinnatud komplekse näitajaga, kus on arvesse võetud mulla bioloogilisi ja füüsikalisi omadusi, mulla kliimat ning muldkatte all asuva substraadi (pinnase) geoloogilist päritolu ja koostist. Muldade kontrastsust on hinnatud mullaliikide ja lõimiste maatriksite alusel, määrates mullaliikide ning -erimite (lõimisevariantide) taksonoomilise distantsi skalaaride suhtes. Lisaks sellele: 1) on selgitatud muldkatete mullastik-ökoloogilist ekvivalentsust ja selle arvestamise vajadust katsepõldude planeerimisel ning uurimistulemuste rakendamisel, 2) on rõhutatud vajadust arendada mullaliigi- (-erimi, -tüübi) põhise mulla bioloogilise mitmekesisuse uurimist, sest mulla bioloogiline mitmekesisus sõltub suurel määral mullaliigist, lõimisest ja maakasutuse viisist, 3) on käsitletud WRB kvalifikaatorite kasutamist maamassiivide omaduste võrdlemisel ja nende mullastiku mitmekesisuse hindamisel.

Töö tulemusena soovitatakse mullastiku mitmekesisuse näitajate ja mullataksonite kontrastsuse kvantifitseerimisel kasutada: 1) mullamaatriksi litoloogilis-geneneetilist ja niiskustingimuste skalaari, 2) pealis- ja alusmulla lõimiste kompleksmaatrikseid, 3) muldade levikuareaalide kvantitatiivseid näitajaid. Haritavate maade huumusseisundi informatiivseks (ja heaks) näitajaks on huumuskatte tüüp ehk huumusvorm. Mullastiku mitmekesisuse kvantitatiivsed näitajad on heaks aluseks haritavate muldade kestlikule kasutamisele kooskõlas muldkatte mitmekesisuse, agronoomiliste omaduste ja talitlemise potentsiaaliga.