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Properties of deluvial soils in Poland and Lithuania and propositions for their classification

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The term *deluvial* is applied to a deposit formed as a result of geodynamic processes in hilly and undulating landscapes by natural and technogenic movement of topsoil or products of weathering down the slope and its accumulation. The properties and distribution of *deluvial* soils are important for agriculture history, soil erosion and water protection.

Deluvial soils are part of national soil classification systems of Poland and until 1999 of Lithuania. In Poland, *deluvial* soils are one of two orders within the fifth division – *alluvial* and *deluvial* soils. Later (Mažvila ir kt., 2003; 2006), deluvial soils in Lithuania have been groused in one unit with *Cambisols* and *Fluvisols*. In France and Germany, the soils on similar deposits are distinguished as *Colluvisols.*

Deluvial soils are mapped, and it is necessary to distinguish them in the first level of classification and to formulate the diagnostic properties of deluvial horizon or deluvial material.

Propositions for the diagnostic properties of *Colluvisols* are given on the base of selected properties of *deluvial* soils in Poland and Lithuania: thickness of more than 30 cm, very fine stratification and irregular distribution of organic carbon, organic carbon content more than 0.5% (of any thicker than 30 cm part of deluvial layer) as well as location on the bottom part of slope in hilly and undulating landscape.

Key words: erosion, deluvial soils, colluvic material, texture, organic carbon, soil classification, WRB

INTRODUCTION

The term 'deluvial' is applied to deposits formed as a result of geodynamic processes in hilly and undulating landscapes by the natural and technogenic movement of topsoil or products of weathering down the slope and their accumulation.

The concept of deluvium and deluvial soils was used by famous Russian scientists A. P. Pavlov, V. V. Dokuchaev (Докучаев, 1950; Павлов, 1888) and others. Instead of *diluvium*, the concept of *colluvium* is used in most European countries and in the American soil science.

At first, the concept of deluvium (colluvium) was used for the definition of mainly water erosion sediments, but after World War II the intensification and mechanization of agriculture led to a high acceleration of erosion. Tillage erosion on arable land can represent up to 50% of total sediment transport (van Oost et al., 2000).

Therefore, in scientific literature of the early 20th century, the notion 'deluvial processes' was used for the definition of the processes that have formed silt-rich surface sediments in extraglacial zones of the Pleistocene period. Recently, it has been proposed to call these sediments as loess and loess-derived material (Švedas, 2003). Thus, the definition of sediments in the extraglacial zones of the Pleistocene period as 'deluvial' is an inaccuracy.

Investigations concerning formation and characteristics of deluvial soils are very important for understanding the human impacts on geomorphic processes in agricultural landscapes and the geomorphic evolution.

The common occurrence of deluvial soils is the main reason for their distinguishing as distinct units (on different levels of classification) in many regional soil classification systems.

Deluvial soils had been part of national soil classification systems of Poland and Lithuania (until 1999).

In France and Germany, soils on similar deposits are distinguished as colluvisols (Почвенный…, 2000).

Human-modified soils in the modern Russian soil classification are classified into a common unit with natural soils in the

order of synlithogenic soils (the order embraces soils with intermittent pedogenesis and accumulation of fresh sediments), and deluvial soils are distinguished under the name of stratozems (Классификация…, 2004).

Colluvisols are spread worldwide. For example, Czech pedologists in Moravia, (*Chernozem* zone) emphase huge volumes of fine-earth fraction and organic materials, and also of some important nutrients such as phosphorus accumulation in thick profiles of *Colluvisols*. Mapping of these new soils could significantly update the system of soil evaluation (Šefrna, Vilímek, 2003).

The systematics of Polish Soils includes seven divisions which are superior units of taxonomy. **Deluvial soils** are one of two orders within the fifth division – **alluvial and deluvial soils.**

The order of **deluvial soils** (VB) includes one type of **deluvial soils** (VB1).

The discussed soils are described as soils which can be found at the foot and in the lower parts of slopes and are influenced by strong erosion. They appear in depressions of hummocky terrains and in small valleys as well as at the edges of larger valleys. The upper sections of slopes and tops of hills are covered with eroded soils where the humus horizon has been thinned by erosion and mixed with the material building the underlying mineral horizons. Such soils can be found especially in cultivated areas exposed to rain-water accelerated erosion. According to the Systematics of Polish Soils (1989), in deluvial soils the accumulated sediment has to be 30 cm or more thick.

The type of deluvial soils is divided into three subtypes:

– proper deluvial soils,

– humous deluvial soils (developed in wet habitats with association of gleyic processes and organic matter accumulation in humous horizons (>5%)),

– brown deluvial soils (with the *cambic* horizon underlying the humous horizon).

In 1999, a new style of soil classification, harmonized with the WRB, was established in Lithuania. At the beginning of the harmonization, deluvial soils were classified as *Cambisols* (Lietuvos…, 2001), but the *cambic* diagnostic horizon does not occur in most deluvial soils, and deluvial deposits cannot be compared with the underlying buried soil horizons because they have no genetic relation with them. Later it was proposed to classify soils of deluvial origin near river valeys as *Fluvisols* (Mažvila et al., 2003; 2006). According to Referentiel Pedologique (1995), colluvium differs from alluvial deposits by physical properties. Most colluvial material is competentive, i. e. resistant to pressure.

Mapping deluvial soils as *Regosols* or *Umbrisols* is not correct because the information about their anthropogenic (in most cases) origin is lost.

Colluvial deposits are a border case between deposits (sediments) and pedogenic materials. Colluvium (deluvium) itself relates to the same phenomena of transported parent material as alluvium, but is fundamentally different. Colluvium is formed by local wash, mass movement by gravity; its stratification, if present, is usually gross, very poorly sorted, it may comprise clay, silt, sand and coarse materials (typically angular or subrounded). This definition can be used for describing colluvial material (Nachtergaele).

In the WRB 1998, there was no specific qualifier enabling to show the deluvial character of the humus horizon at the lower level units of the WRB. There exists the *Cumuli* prefix, which might be added to the main elements of the soil names to stress the repeated accumulation of soil material up to or over the thickness of 50 cm. However, it cannot be used for accumulative A horizons because the *Mollic* and *Umbric* qualifiers cannot be used for *Chernozems* and *Phaeozems*, as well as *Umbrisols*, as this repeats the information already found in the name of the soil group. As a result, the mentioned prefix was of no use (Charzynski, 2006).

In the WRB 2006, the prefix *Cumulic* was turned into a qualifier, as was proposed in (Charzynski, 2006) and the definition of colluvial material appeared, but the diagnostic criteria of *colluvic* material were not formulated. It seems likely that it was one of the reasons why *Colluvisols* were not distinguished as an individual soil unit. In WRB 2006, *Colluvic Regosols* are established. The only one case of *Colluvic Regosol* is that deluvial deposits are on an extremely eroded soil. In cases when *spodic* or *argic* horizons occur at a depth of <200 cm, it can be *Cumulinovic Podzol* or *Cumulinovic Luvisol*.

The task of this work was to find the place of deluvial soils in modern classification systems (WRB, Polish, Lithuanian) and to examine the possibility of restoring information about deluvial soils in soil maps.

The main questions to be solved were:

1. To establish whether *deluvial* deposits are the same as *colluvium*.

2. To propose additional diagnostic criteria of *colluvic* material for specifying deluvial (colluvial) soils in the first level of soil classification.

3. To solve the problem of the thickness of deluvium necessary for distinguishing deluvial (colluvial) soil.

4. To compare the usefulness of two versions of WRB (1998 and 2006) for the classification of soils of deluvial origin.

OBJECTS AND METHODS

Soil samples in Poland were collected in Chełmno and Brodnica Lake Districts, and in Lithuania samples were taken from all East Lithuanian laky uplands. All the deluvial soils are derived from deposits of Last Glacial Maximum and located between the limits of Brandenburg and Frankfurt glacial periods. The areas of sample collection are shown in Fig. 1. Characteristics of slopes, land use and sequence of horizons are shown in Table 1 and 2.

In Poland, soils on the upper slope position (deluvium alimentation areas) represent *Arenosols* (2 of 7 index plots), *Luvisols* and *Arenosol* (one index plot), and *Luvisols* in other index plots (Table 1). The 1–7 index plots in Lithuania represent soils derived from moraine of different texture (from loamy to clayey), all slope soils were *Luvisols*. The average texture of parent rocks (derived from moraine material, too) of the study objects in Poland were coarser, and more *Umbrisols* were

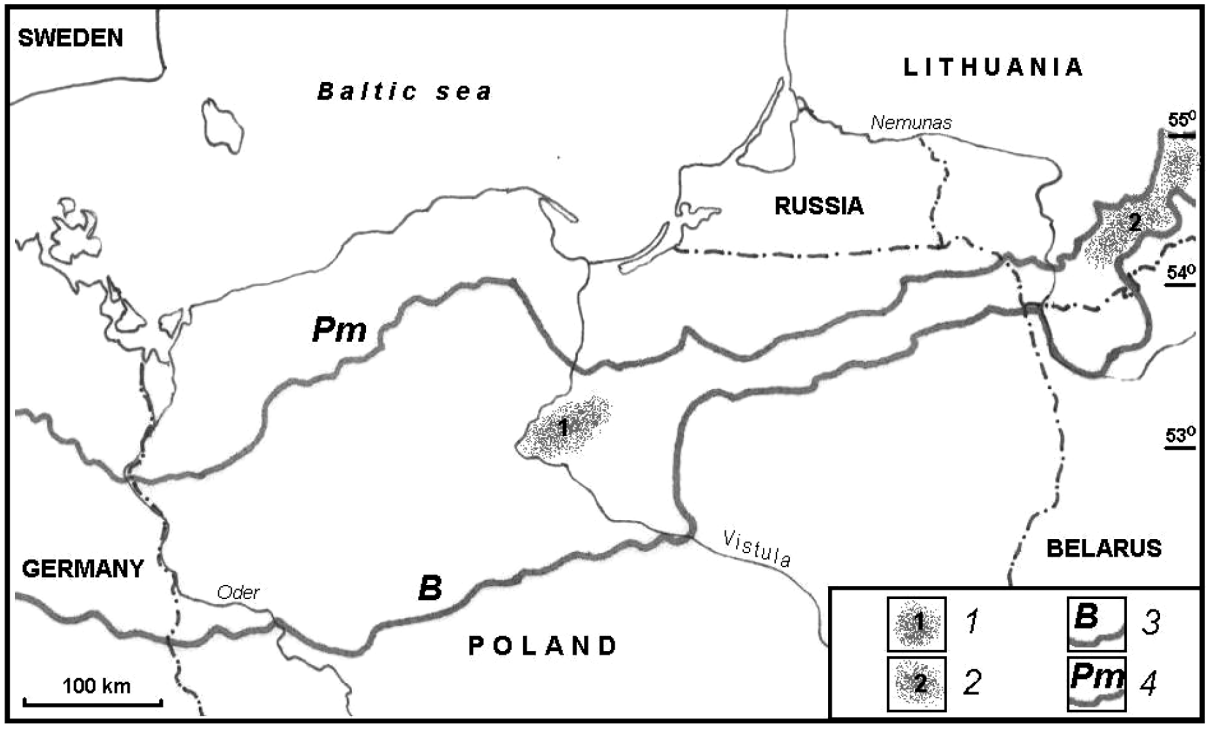


Fig. 1. Areas of soil sampling (*1* – Chełmno and Brodnica Lake District and *2* – East Lithuanian laky Uplands) in Poland and Lithuania in relation with the limits of Last Glacial Maximum (Brandenburg (*3* – **B**) and Pomeranian (*4* – **Pm**) glacial periods). Borders of glacial periods are drawn according to L. Marks (Marks, 2005)

Table 1. **Description of study sites in Poland**

Number and name of study sites	Position on slope	Slope	RSG* (WRB1998/2006) For deluvial soil: profile number and deluvial horizon thickness	Morphology of soil profile**
Brodnica and Chełmno Lake Districts (moraine plateau, undulating or flat) (PL)				
1. Gaj idle land	Crest / upper slope	11°	*Epicutanic Luvisol / Cutanic Luvisol*	ABtp-Bt-Ck
	Middle slope	15°	*Epidystri-Hypoluvic Arenosol / Hypoluvic Arenosol* (*Epidystric*)	Ap-Bw-C-2C
	Lower slope	15°	*1. Regosol / Cumulinovic Arenosol 110 cm*	Adel1-Adel2-Adel3-2Ab-2E-2Bshb
2 and 8 Forest Czyste Błota, reserve Retno	Crest / upper slope	13°	*Hypereutri-Calcaric Arenosol / Arenosol* (*Calcaric*)	ACkp-C1k-C2k
	Middle slope	13°	*Arenosol ./ Arenosol* (*Calcaric*)	Ap-C-Ck
	Lower slope	11°	*2. Regosol / Brunic Arenosol* (*Cumulinovic*), *60 cm*	H-Adel-Bwdel-Cdel-2Hb
	Lower slope	13°	*8. Regosol / Colluvic Regosol, 310 cm*	Adel1-charcoal-Adel2
3. Grzywna arable	Crest	1°	*Areni-Endogleyic Luvisol (Cutanic) / Cutanic Luvisol* (*Arenic*)	Ap-Ee-Bt-2Bt-2Ckg
	Foot	1°	*3. Antric Umbrisol / Umbrisol* (*Novic Anthric*), *85 cm*	Adel1-Adel2-Adel3-2Ab-2Crb
4. Grzywna arable	Crest	1°	*Areni-Endogleyic Luvisol* (*Profondic, Cutanic*) *Gleyic Cutanic Luvisol* (*Profondic, Arenic*)	Ap-Eg-Eg/2Btg-2Btg-2Cg
	Foot slope	1°	*4. Endogleyic Umbrisol / Endogleyic Umbrisol (Novic), 30/35 cm*	Adelp-2Ab(p)-2Crb
5. Sitno arable	Crest / upper	4°	*Epicutanic Luvisol / Cutanic Luvisol*	Ap-Bt-Ck
	Middle slope	4°	*Cutani-Endostagnic Luvisol / Cutanic Endostagnic Luvisol*	Ap-E-E/Btg-Btl-Ckl
	Lower slope	5°	*5. Anthri-Endogleyic Umbrisol / Umbrisol* (*Novic Anthric*), *35 cm*	Adelp-2Ab(p)-2Crb
6. Sitno arable	Crest / upper slope	6°	*Hypereutri-Calcaric Arenosol/ Arenosol* (*Calcaric*)	(A)Ckp-Ck
	Lower slope	6°	*6. Endogleyic Regosol / Colluvic Endogleyic Regosol 70 cm*	Adel1-Adel2-Adel3-2Ab-2Crb
7. Gołoty, garden	Foot slope	13°	*7. Humi-Endogleyic Umbrisol / Endogleyic Umbrisol* (*Novic, Humic Anthric*), *50 cm*	Adelp-2Ab(p)-2Crb

* RSG – Reference Soil Group.

** Soil horizon designations according to FAO Guidelines for Soil Profile Description (FAO 2006) del – deluvial material.

Note. Recent alluvial or aeolian deposits that retain fine stratification are not considered to be an A horizon unless cultivated (Guidelines for Soil Profile Description, 2006). Though, horizons of colluvial (deluvial) origin in Poland and Lithuania are traditionally distinguished as A.

Table 2. **Description of index plots (study sites) in Lithuania. Notes are the same as in Table 1**

Number and name of study sites	Position on slope	Slope	RSG (WRB1998/2006) For deluvial soil: profile number and deluvial horizon thickness	Morphology of soil profile
			Baltic Laky Uplands (LT)	
1. Lindiškės, Vilnius Arable	Middle slope	15°	*Regosol* / *Regosol* (*Calcaric*)	Ap-BCk
	Lower slope	2°	1. *Regosol / Colluvic Regosol 100 cm*	Adel1-Adel2
2. Skudutiškis, Molėtai Arable	Crest / upper slope	8°	*Regosol* / *Regosol* (*Calcaric*)	Ap-BC k
	Lower slope	4°	2. *Regosol* / *Gleyic Albeluvisol* (*Novic*) *80 cm*	Adel1-Adel2-Ab-Eb
3. Čiulėnai, Molėtai	Crest / upper slope	14°	*Regosol* / *Regosol* (*Calcaric*)	Ap-BC k
	Lower slope	4°	3. *Regosol / Colluvic Regosol 205 cm*	Adel1-Adel2- Adel3
4. Aukštadvaris, Arable	Crest / upper slope	11°	*Regosol*	Ap-B-BC
	Lower slope	4°	4. *Endogleyic Umbrisol / Endogleyic Umbrisol* (*Novic*) *58 cm*	Adel1-Adel2-Ab
5. Sudervė, Vilnius Arable	Crest / upper slope	11°	*Endogleyic Regosol* / *Endogleyic Regosol*	Ap-Bng-BC
	Lower slope	4°	5. *Regosol / Colluvic Regosol 67 cm*	Adel1-Adel2-Ab
6. Dusetos, Zarasai Arable - idle	Crest / upper slope	5°	*Luvisol*	Ap-B-BC
	Lower slope	7°	6. *Regosol / Colluvic Regosol 106 cm*	Adel1-Adel2-Ab
7. Daugėliškis, Švenčionys Arable	Crest / upper slope	6°	*Regosol*	Ap-B-BC
	Lower slope	10°	7. *Regosol / Colluvic Regosol 100 cm*	Adel1-Adel2- Adel3-AEb
8–13. Saldutiškis, Utena Arable and idle	Middle slope	4°	*Hypoluvic Calcaric Arenosol / Arenosol* (*Calcaric*)	A-B-Ck
	Crest slope	1°	*Luvisol*	(A)Bp-Bt-Ck
	Middle slope	12°	*Regosol* / *Regosol* (*Calcaric*)	(A)Bp-Ck
	8 Lower slope	1°	8. *Albeluvisol / Albeluvisol* (*Novic*) *35 cm*	Adel1-Adel2-Ab
	9. Lower slope	1°	9. *Luvisol / Luvisol* (*Novic*) *40 cm*	Adel1-Adel2-Ab-Bb
	10. Lower slope	7°	10. *Luvisol / Luvisol* (*Novic*) *43 cm*	Adel1-Adel2-Ab-Eb
	11. Lower slope	3°	*11. Regosol / Colluvic Regosol 82 cm*	Adel1-Adel2- Adel3-Ab
	12. Lower slope	3°	12. *Luvisol / Luvisol* (*Novic*) *40 cm*	Adel1-Adel2-Ab-Bb
	13. Lower slope	1°	13. *Regosol / Colluvic Regosol 54 cm*	Adel1-Adel2- Adel3-Ab
14–20. Vaizbūniškės, Aukštadvaris Arable and idle	14. Crest / upper slope	5°	14. *Regosol / Cumulinovic Luvisol 52 cm*	Adel1-Adel2- Adel3-Ab
	15. Middle slope	6°	15. *Regosol / Cumulinovic-Luvisol 62 cm*	Adel1-Adel2- Adel3-Ab
	Middle slope	8°	*Albeluvisol*	Ap-E-Bt-C
	16. Middle of crest slope	2°	16. *Regosol / Cumulinovic-Luvisol 21 cm*	Adel1-Adel2-Bb
	17. Middle of crest slope	2°	17. *Regosol / Cumulinovic-Luvisol 40 cm*	Adel1-Adel2- Adel3-Ab
	18. Lower slope	5°	18. *Regosol / Colluvic Regosol 81 cm*	Adel1-Adel2- Adel3-Ab
	19. Lower slope	1°	19. *Regosol / Colluvic Regosol 80 cm*	Adel1-Adel2- Adel3-Ab
	20. Lower slope	2°	20. *Regosol / Colluvic Regosol 57 cm*	Adel1-Adel2- Adel3-Ab

detected. The Saldutiškis and Vaizbūniškės (numbers 8–13 and 14–20) study sites represent deluvial soils derived from similar parent rock, but under different mezorelief conditions (Table 2).

Selected physical and chemical properties of deluvial soils were examined by standardized methods:

- organic carbon by Tiurin's,
- total nitrogen by Kjeldahl's,
- the texture of Lithuanian deluvial soils was examined in suspension with pipette by Kachinski's and the texture of Polish soils in suspension by the areometric method (of Bouyoucosa, modified by Cassagrande and Prószyński). Methods of texture definition were different and the expression of results was different, too. For the best comparison of Polish and Lithuanian soil properties, the texture is shown on the logarithmic X axis. For data analyzing statistical parameters average and quartiles were used.

SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF DELUVIAL SOILS

Organic carbon content in the studied Lithuanian surface horizon of deluvial soils varied from 0.1 to 3.1% and in the Polish ones from 0.5 to 2.1%. The upper horizon usually contains more organic carbon, but this is not a rule. A high content of organic carbon is the major difference between deluvial soils and most of *Regosols*.

In some cases, a higher content of organic carbon in deeper deluvial horizons (or buried A horizons) than in surface deluvial horizons (Adel1) is observed because the younger surface deluvial horizons contain material coming from deeper (non-humous) horizons of eroded soils.

The average C / N ratio in deluvial soils is qualified as 9–12, and the C / N ratio of slope soils is lower – 6–11 (Fig. 3), because slope soils are different from deluvial ones (strongly eroded

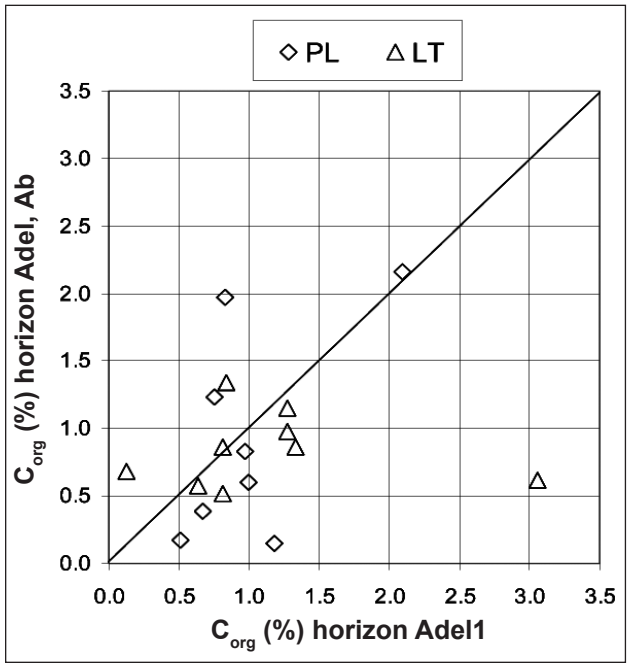


Fig. 2. Comparison of organic carbon content in the top of deluvial horizon Adel1 and in deeper Adel2 (or Ab for shallow deluvial deposits) horizons

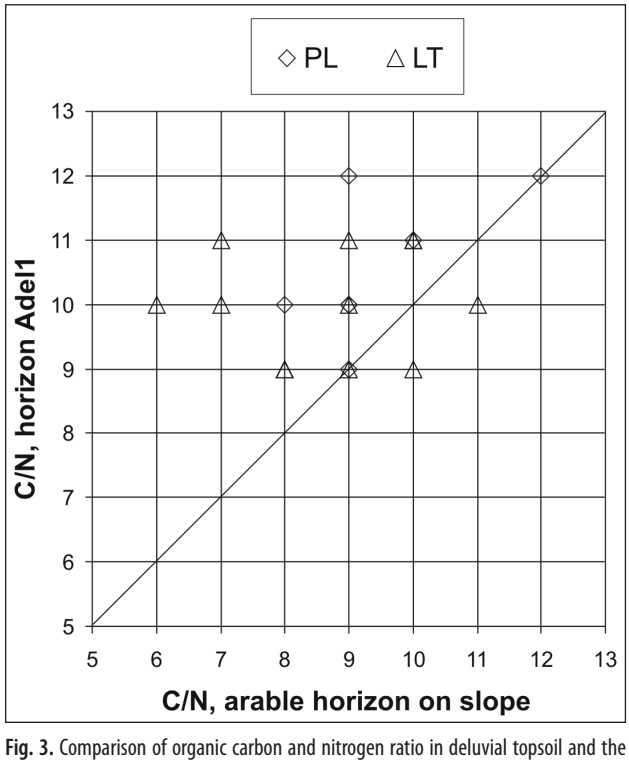


Fig. 3. Comparison of organic carbon and nitrogen ratio in deluvial topsoil and the arable horizon of slope soil

Arenosols and *Luvisols*). Organic carbon and nitrogen ratio in deluvial topsoil A horizons in most cases is higher or equal in comparison with that on the slope, i. e. soils from which deluvial material was derived. The cause for such a low C / N ratio in the surface horizon of eroded soils (on the slope) is rejuvenation of their A horizons.

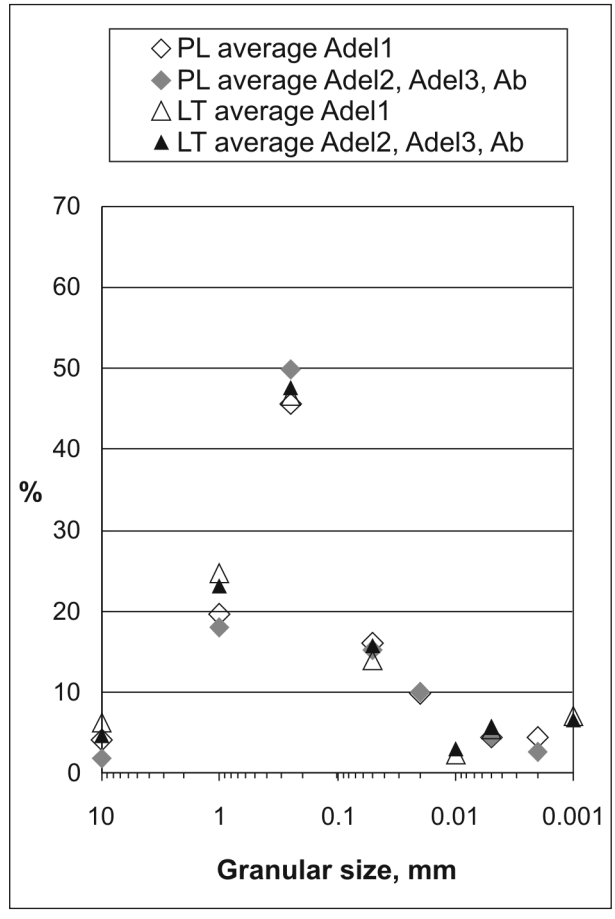


Fig. 4. Averages of particle size content in the upper and bottom horizons of deluvial soil. Numbers of index plots in Poland 1–8, in Lithuania 1–7

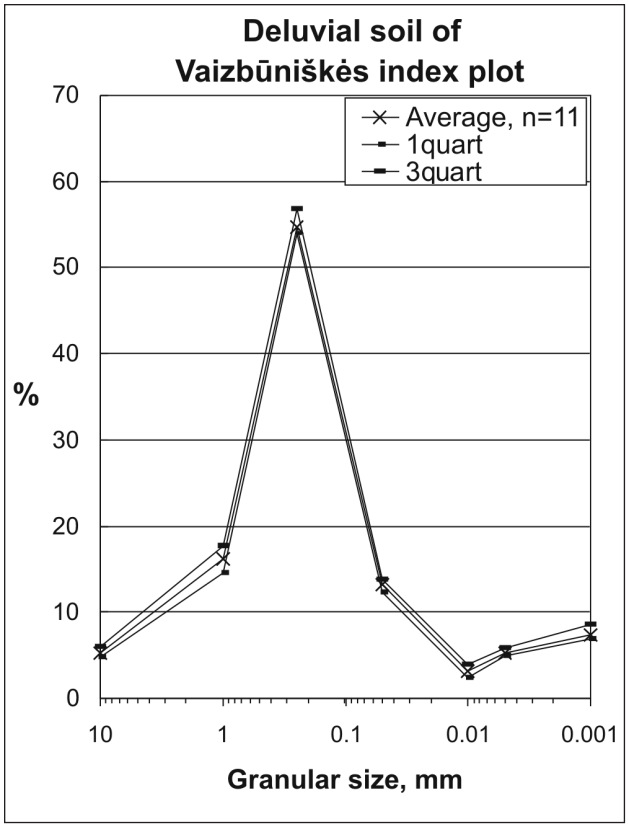
There is no relation between the content of organic carbon and the thickness of the deluvial horizon.

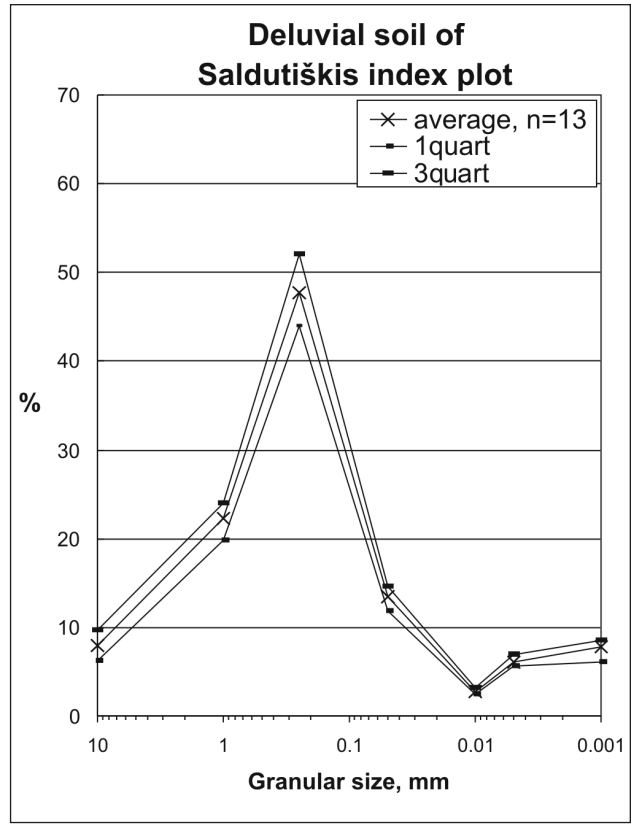
The pecularities of texture of deluvial soils are very similar in Lithuania and Poland. The texture of deluvial horizons does not differ much. On average, the upper deluvial horizon contains more gravel and 0.25–1 mm fraction, because it is formed from deeper layers of normal slope soils (less weathered); on the contrary, the content of fine fraction in deeper deluvial horizons is higher than in the upper horizon of deluvial soil (Fig. 4).

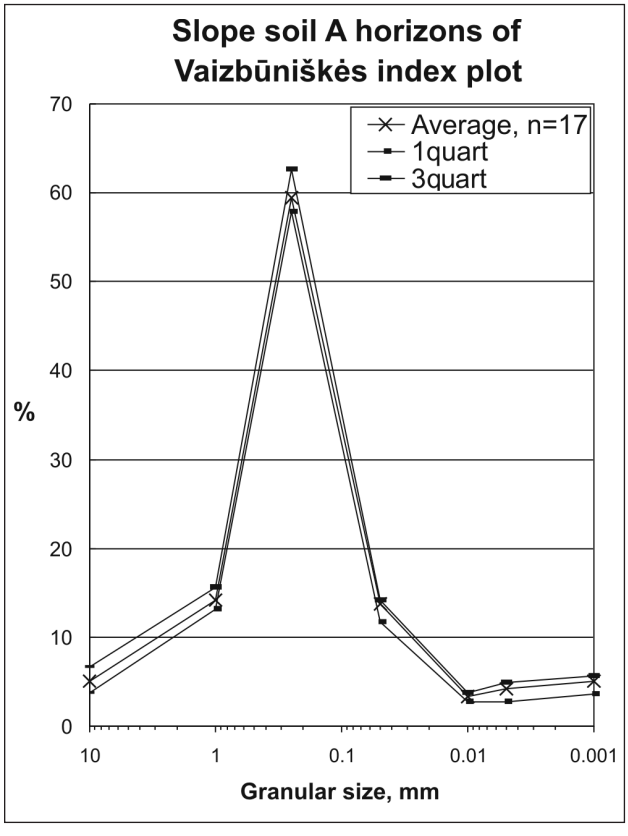
Lowest contents are typical of fractions 0.002–0.01 mm, but <0.001 mm fraction (detected in Lithuania) on average increases both in the upper and in the bottom deluvial horizons.

The very fine clay fraction (<0.001 mm) may accumulate in the matrix of deluvial material from fluxes of muddy interior soil water and surface water which soaks into deluvial soils after flowing down the slope. Thus, deluvial layers play a role of a filter, partially cleaning the water from fine solid particles and colloids. The same result was reported by Russian scientists (Козловский *и* др., 2000).

The index plots of detailed investigations demonstrate the same result. A comparison of statistical parameters of particle size composition shows a higher content and a lower scattering of the very fine fraction in deluvial soils than in arable horizons of slope soils (Fig. 5).







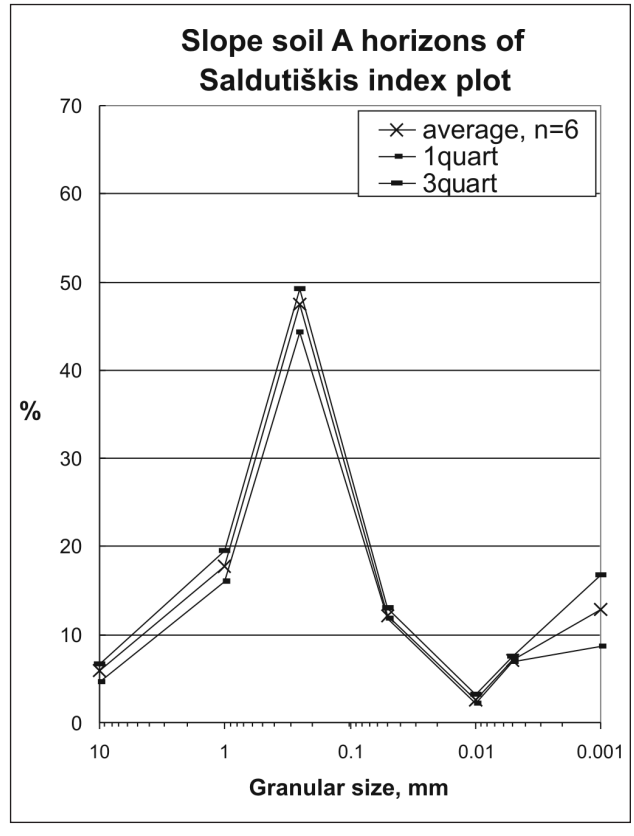


Fig. 5. Averages, 1st and 3rd quartiles of particle size content in deluvial and slope soil horizons in Vaizbūniškės index plot of complex investigations

CONCLUSIONS

1. By WRB (1998), deluvial soils studied in Poland and Lithuania were *Regosols, Luvisols* and *Umbrisols.* The qualifiers *anthric* and *endogleyic* could be used.

2. In the latest version of WRB (2006), for the definition of deluvial soils in the second level of classification, the qualifiers *colluvic* and, with the usage of specifier cumuli, *cumulinovic, cumulimollic* are used. The 2006 version of WRB is more useful for enhancing the deluvial origin, what was not possible in the older version of WRB.

3. The moderately high organic carbon content, irregular distribution in profile, the C / N ratio features and a specific texture of deluvial deposits make it necessary to classify deluvial soils separately from *Regosols, Luvisols* and *Umbrisols* or other RSG distinguished in WRB.

4. The definition of colluvial (deluvial) soil material can be improved by adding the diagnostic properties:

– thickness more than 30 cm;

– organic carbon content more than 0.5% in any part of deluvial layer more than 30 cm thick.

5. It is not necessary for national Polish or Lithuanian soil classifications to change the term 'deluvial soils' to 'colluvial soils' or *Fluvisols.*

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DELIUVINIAI DIRVOŽEMIAI LENKIJOJE IR LIETUVOJE BEI PASIŪLYMAI JŲ KLASIFIKACIJAI

Santrauka

Sąvoka deliuvinis vartojama apibūdinant nuosėdas, susiformavusias veikiant geodinaminiams procesams, kalvotame ir banguotame kraštovaizdyje, kuriam būdinga skurdi augalijos danga bei technogeninio poveikio metu paviršiniam dirvožemio sluoksniui arba dūlėjimo produktams judant šlaitu žemyn ir kaupiantis šlaito apatinėje dalyje. Deliuvinių dirvožemių savybės ir paplitimas yra svarbūs žemės ūkio istorijos, dirvožemio erozijos tyrimams bei vandens apsaugai.

Deliuviniai dirvožemiai yra Lenkijos ir Lietuvos dirvožemių klasifikacijos dalis. Lenkijoje deliuviniai dirvožemiai yra vienas iš dviejų sąnašinių dirvožemių (aliuvinių ir deliuvinių) potipių. Nuo 2001 m. Lietuvos dirvožemių klasifikacijoje deliuviniai dirvožemiai yra salpžemių grupėje, bet tai nekorektiška, nes deliuviniuose dirvožemiuose sluoksniuotos aliuvinės medžiagos paprastai nėra. Prancūzijoje ir Vokietijoje dirvožemiai ant deliuvinių nuogulų yra vadinami *Colluvisols.*

Deliuviniai dirvožemiai yra sukartografuoti, todėl juos būtina išskirti pirmajame klasifikacijos lygmenyje, ir, pagal tarptautinės dirvožemių duomenų bazės reikalavimus (WRB), turi būti suformuluotos diagnostinės savybės.

Pasiūlymai diagnostinėms deliuvinių dirvožemių savybėms yra pateikiami pagal Lenkijos ir Lietuvos dirvožemių savybes: deliuvinės kilmės sluoksnio storis – daugiau negu 30 cm; labai smulkus sluoksniavimasis; organinės anglies kiekis >0,5% kuriame nors storesniame nei 30 cm dirvožemio pahorizontyje.

Raktažodžiai: erozija, deliuviniai dirvožemiai, koliuvinė medžiaga, granuliometrinė sudėtis, organinė anglis, dirvožemių klasifikacija, WRB