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Soil classification in Belarus: history and current problems

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Abstract. The article contains a brief history of the development of the soil classification scheme of the Republic of Belarus. It comprises the description of the most widely-used (acknowledged) genetic classification of soils, characteristics of basic taxonomic units (type, subtype, sort, kind, and variation), and characteristics of the 13 main types of Belarusian soils. The map of the soil cover of Belarus and the morphological and genetic characteristics of typical and unique soil varieties are presented. The main problems of the national soil classification and its correlation with the international WRB system are shown.

Key words:
taxonomic level,
soil type,
genetic approach,
WRB correlation

Introduction

Classification of soils is an indispensable tool for fundamental and applied research. Soil mapping, comparative characteristics of structure, texture and properties, quantitative and qualitative assessment, suitability for crops, all types of ameliorative impacts on soils and protection from degradation are impossible without a detailed classification of the entire soil diversity with a mandatory set of clear diagnostic features for each soil classification.

In the Republic of Belarus a genetic soil classification developed in 1980 is used, with some updates (Smeyan 2003). State soil services, the Ministry of Forestry, universities and technical schools use it as a working and scientific instrument of soil-cartographic, scientific-methodological and other works that require a scientifically grounded approach to the use of the republic's land resources. A more in-depth study of the republic's soils, accompanied by the accumulation of data on the structure of the profiles, the statistical and dynamic composition and properties, and their role in the functioning of soil systems, shows that the existing classification scheme needs to be improved. Increased international cooperation between soil scientists leads to the need for correlation of the national soil classification scheme and the World Reference Base for Soil Resources (WRB) (IUSS Working Group 2015).

In many countries of Central and Eastern Europe, correlations of the national soil classification with WRB was made. In Poland (Kabała et al. 2016), Latvia (Karklins 2002), Romania (Secu et al. 2008), Hungary (Lang et al. 2013), Russian Federation (Krasilnikov 2002) articles have been published devoted to this problem. This indicates the relevance of this soil classification.

The history of Belarusian soil classification

Soil science as an academic discipline started developing in Belarus only in the beginning of the 20th century.

The problem of soil classification has always been one of the highest priority and the same time most widely discussed topics in soil sciences. The first Belarusian works attempting soil classification include publications in the 1920s and 30s, which was when soil researches began on the territory of the Republic of Belarus (Afanasyev 1997). However, the first comparatively full scheme of Belarusian soil classification was published in 1952 in the monograph "Soils of the BSSR", prepared by a group of authors under the editorship of I.S. Lupinovich and P.P. Rogovoy (1952). Six types of soils were identified: sod, sod-podzolic, including waterlogged, sod-bog, peaty-bog, and alluvial-meadow soils. Sod-podzolic waterlogged include soils formed under the influence of podzolic, sod, and bog soil formation processes.

Classification schemes of that period suggest that the most common soils on the territory of the Belarus were the podzolic and sod-podzolic ones (varying by degree of podsolisation, humidity, type of structure of parent materials and soil texture), and also podzolic waterlogged, peat bog, humus-carbonate and alluvial soils (Kulakovskaya et al. 1974).

The Belarusian soil classification developed by A.G. Medvedev, N.P. Bulgakov and Y.I Gavrilenko published in 1960 already possessed the full structure of hierarchical levels lower than a type (type, subtype, sort, kind and variation). According to this classification worked out based on the material of the first round of large-scale soil researches, the following seven soil types were identified on the territory of Belarus: sod-carbonate, sod-podzolic, sod-podzolic waterlogged, sod waterlogged, peat bog, alluvial sod waterlogged and alluvial peat bog (Medvedev et al. 1960).

In "The guidelines for large-scale soil-geobotanical and agrochemical researches" the classification from 1960 was supplemented with the soils transformed as the result of human activity on different taxonomic levels. In this scheme, cultivated peat-bog soils were singled out on the type level and cultivated sod-podzolic on the lower level. The range of soils on the type level also includes sod-carbonate waterlogged and ancient alluvial soils, but the interim peat-bog soils (Smeyan and Solovey 1973) were excluded from the classification.

The classification published in 1974 was supplemented with brown forest soils (Kulakovskaya et al. 1974).

All the subsequent in-depth studies of Belarusian soils significantly clarified and supplemented the previous classifications. In 1980, on the basis of those studies the new soil classification framework was developed (Smeyan 1980). It reflected natural and anthropogenic aspects of soil forming processes and still remains relevant, taking into consideration the changes and additions made on the basis of studying anthropogenically-transformed soils in the subsequent years. Based on the classification the nomenclature of soils of Belarus including 13 basic soil types (see the Table 1) was created (Smeyan 2003).

Later, in 2006, a new classification of soils of Belarus was developed. It encompasses all the varieties regardless of the degree of anthropogenic transformation, and specifies the new taxonomic units, i.e. a branch, a class, a subclass (Smeyan and Tsytron 2006). Branches are identified according to the degree of anthropogenic influence, classes according to type of hydromorphism, and subclasses according to soil formation process. In this classification there are 52 types of soils: 18 natural ones (soils of natural lands), 17 natural-anthropogenic (meadow lands) and 17 anthropogenic-transformed (arable and technogenically-degraded lands). Despite the positive assessment of this classification by Russian scientists (Dobrovolsky and Zaidelman 2008), it was not accepted by most scientists and specialists in Belarus.

In 2016, a new "natural" classification of soils of Belarus was proposed (Romanova and Berkov 2016). It is an index and digital classification which singles out eight taxonomic levels which describe in detail all the soil properties: class of hydromorphism, type of soil forming process, degree of soil moistening, soil texture and lithology, content of physical clay, presence of peat, mineralogical structure of parent materials, groundwater chemistry, bo-

Table 1. Types and subtypes of soils in Belarusian soil classification (1980)

No	Soil type	Soil subtype
1	Sod-carbonate	Typical Leached Podzolised
2	Brown forest	Residual carbonate
3	Podzolic	Podzolic
4	Sod-podzolic	Sod-podzolic Sod-podzolic eroded Sod-podzolic cultivated
5	Podzolic waterlogged	Podzolic waterlogged
6	Sod-podzolic waterlogged	Surface-gleyed Ground-gleyed Surface-gleyed drained Ground-gleyed drained
7	Bog-podzolic	Peaty-podzolic-gleyed Peaty-podzolic gleyed drained
8	Sod waterlogged	Surface-gleyed Ground-gleyed Surface-gleyed drained Ground-gleyed drained
9	Peat-bog (ground water)	Peat gley Peat Peat-gley drained Peat drained
10	Peat-bog (water from atmospheric precipitations)	Peat gley Peat Peat-gley drained Peat drained
11	Alluvial sod and sod waterlogged	Undeveloped Podzolised Gleyed Gleyed drained
12	Alluvial boggy	Silt-humic-gleyed Silt-peat-gleyed Silt-peat Silt-humus-gleyed drained Silt-peat-gleyed drained Silt-peat drained
13	Anthropogenically transformed	Recultivated Anthropogenically degraded Anthropogenically disturbed Anthropogenically saline Secondary-waterlogged

tanical structure of peat, presence of the processes of deflation and erosion, ameliorative state and degree of cultivation or degradation.

An example classification of a typical Belarusian soil might be "Sod-podzolic, slightly gleyed, middle-cultivated, non-drained loamy soil, developing on light loess-like loams" (Hypogleyic Luvisol). Its class is semi-hydromorphic ($B1_2$), type is sod-podzolic waterlogged, water regime is stagnantly washed (2_3), subtype is slightly gleyed, waterlogged for 20–40 days during the vegetation period (3_3), sort is cohesive rocks (4_2), subsort is loess-like loams, mineralogical composition of medium supply with biophilic elements (5_2), kind is absence of erosion and deflation (6_1), variation is natural water regime, (7_1), variant is medium degree of cultivation (8_3). The genetic code of this soil is $B1_2 2_3 3_3 4_2 5_2 6_1 7_1 8_3$ (Romanova and Berkov 2016).

The developed classification and the coding of main characteristics enabled all the diversity of the Belarusian soils to be presented in a fairly simply scheme. However, nowadays this classification is not used because almost all the all the classifications developed by Belarusian soil scientists have always been of an applied nature, i.e. the main principle for its development is the combination of convenience of use and the genetic approach in singling out the taxonomic units. While the genetic approach is respected, the convenience of practical usage is quite difficult because it requires a large volume of climatic data that are not available for the territory of the country. Also, a lot of factors cannot be determined in the field, which makes it difficult to use this classification in soil mapping. Maybe with the next development of soil science, digital classification will become relevant or will act as a basis for development of a new classification.

Genetic soils classification: use and current problems

Due to the convenience of its usage, the most popular and widely used in the large-scale soil mapping is the classification developed in 1980, with some additions (Smeyan 2003).

The main principle of distinguishing soil type is the nature of the soil-forming process. Taxonomic units of a lower level are distinguished by the presence of an additional soil-forming process, genesis of parent materials, soil texture, etc. (see Table 2)

The full name of a soil, according to this classification, can be the following: sod ground-gleyed, thickness of A horizon is less than 20 cm, developed from loam alluvium, changing at a depth of 0.5 m to alluvial sandy loam (Fluvic and Gleysol).

During the second round of large-scale soil research conducted in 1968–1986 cartographic materials were obtained at a scale of 1:10,000 for agricultural lands and 1:25,000 for forest lands, on the basis of which soil maps of all administrative districts of the republic were subsequently created at a scale of 1:50,000, regions at 1:200,000 and the country at 1:600,000. The schematic map showing the soil cover of the Republic of Belarus is shown in Figure 1.

Characterising the soil cover of Belarus, it is worth noting that sod podzolic (27.2%) and sod-podzolic waterlogged (41.1%) soils are predominant in the agricultural and forest lands of the country. Significantly smaller areas are occupied by sod-waterlogged and sod-carbonate waterlogged (8.8%), peat-bog (16.9%), alluvial (flooded) sod waterlogged (2.9%) and anthropogenically-transformed (1.8%) soils. Sod-carbonate soils occupy less than 0.1% of the area.

Sod-podzolic soils are most widely distributed in the Grodno, Mogilev and Minsk regions,

Table 2. Taxonomic units and the criteria for their determination

No	Taxonomical unit	Criteria
1	Type	Leading soil formation process reflected in the structure of the soil profile
2	Subtype	Occurrence of additional soil forming process superimposed on leading one.
3	Sort	Genesis and structure of soil parent materials
4	Kind	Intensity of soil forming process
5	Variation	Texture of soil parent materials

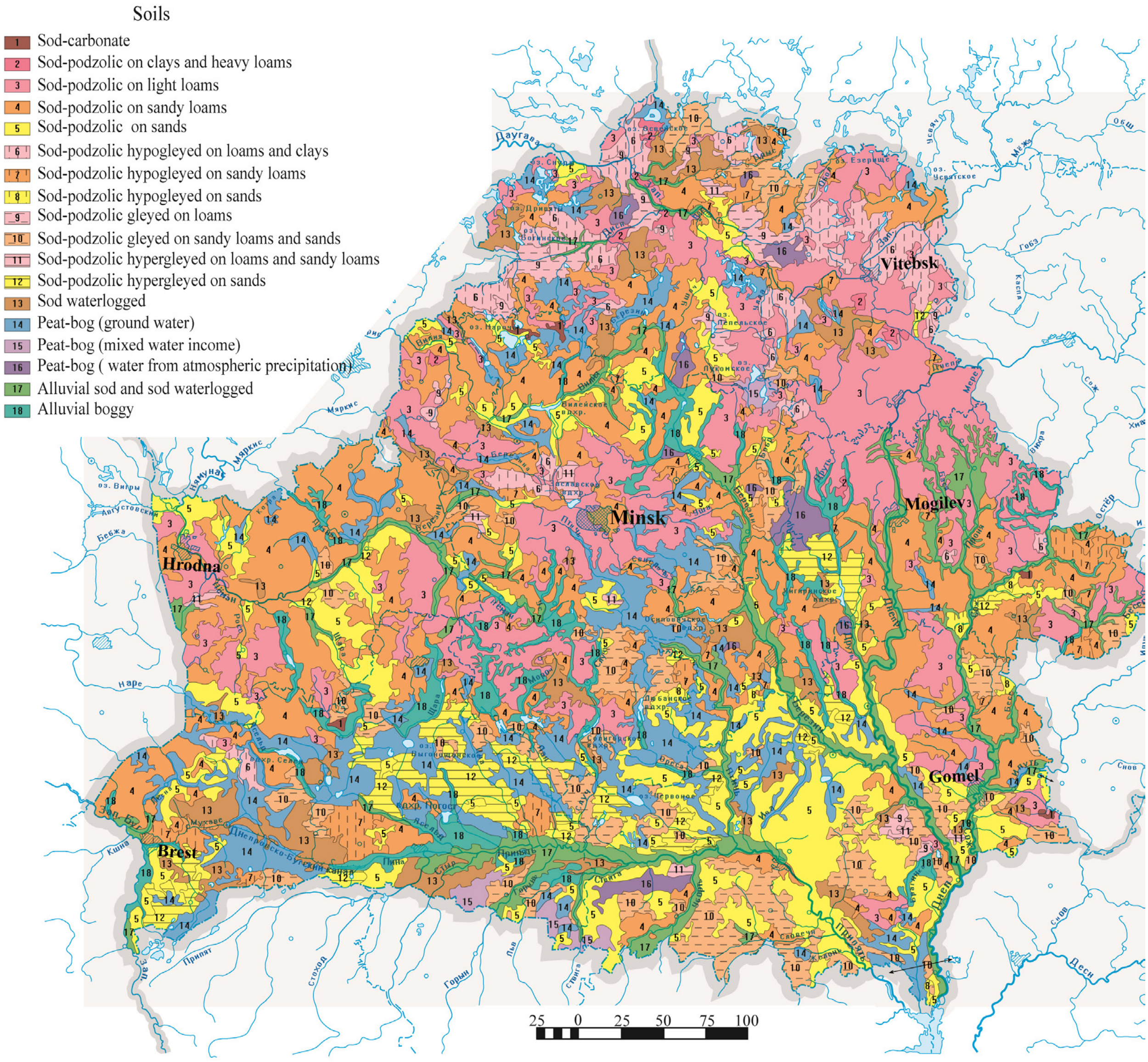


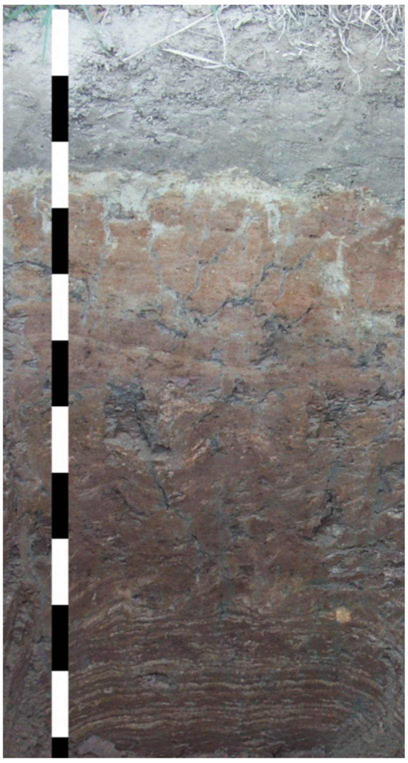
Fig. 1. Soil map of the Republic of Belarus (Lapa and Chernysh 2017)

sod-podzolic waterlogged in the Vitebsk and Mogilev regions, and sod and sod-carbonate waterlogged in the Brest region. The maximum areas of peat soils are concentrated in the Brest, Gomel and Minsk regions. In recent years, the areas of anthropogenically transformed soils have significantly increased, which are mostly degraded peat. The largest areas are situated in the Brest, Gomel and Minsk regions. Flooded (alluvial) sod-waterlogged soils are mostly widespread in the Brest and Gomel regions (Lapa and Chernysh 2017).

Morphological and genetic characteristics of typical soil varieties are presented below on Figures 2–5; Figure 6 shows one of the most fertile soils of the country, and Figure 7 shows degraded drained peat soil.

Despite the extensive use of this classification scheme, there are some problems. The classical definition of the term “soil type” is as follows: the group of soil develops in the similar type-conjugated biological, climatic and hydrological conditions and is characterised by a clear manifestation of the basic soil-forming process, with a possible combination with other processes (Klebanovich 2007).

Sod, podzolic, bog, burozemic, and anthropogenic transformation soil-forming processes were identified on the territory of Belarus. The discussion of the separation of anthropogenic impact on soils and the allocation of cultural soil-forming pro-



$A_P(g)$ 0–25 cm – limnoglacial loam, grey with a bluish mottles, many roots, fresh, slightly compacted, granular structure, abrupt boundary;

BE(g) 25–42 cm – limnoglacial loam, brown with whitish tongues, manganese concretions, fresh, dense, blocky structure, gradual boundary;

BCgk 42–93 cm – limnoglacial clay, brown with grey along the faces of structural segregations, fresh, very dense, blocky structure, effervesces with HCl, gradual and smooth boundary;

Cgk 93–115 cm – limnoglacial clay, brown with grey horizontal interlayers of a thickness of 1–3 mm, fresh, dense, platy structure, effervesces with HCl.

Fig. 2. Sod-podzolic hypogleyed loamy soil, developed from limnoglacial loam on limnoglacial clay (WRB: Hypostagnic Retisol; Lapa and Chernysh 2017)

A_P 0–31 cm – morainic sandy loam, brownish grey, many plant roots in the upper part, fresh, slightly compacted, granular structure, small stone fragments, clear boundary;

BE 31–42 cm – morainic sandy loam, whitish with reddish-brown mottles, fresh, friable, massive structure, gradual and smooth boundary;

B_1 43–67 cm – morainic loam, red-brown with yellow mottles, moist, loose, massive structure, gradual boundary;

B_2 67–95 cm – morainic loam, yellow-brown, moist, loose, massive structure, gradual boundary;

B_3Cg 95–115 cm – morainic loam, light brown and brownish-yellow layers, moist, loose, massive structure.

Fig. 3. Sod-podzolic sandy loamy soil, developed from morainic sandy loam on morainic loam (WRB: Luvisol; Lapa and Chernysh 2017)

A_P 0–25 cm – fluvioglacial sand, dark grey: in the lower part, light spots of the underlying lower horizon, many roots, fresh, slightly compacted, single grain structure, abrupt boundary;

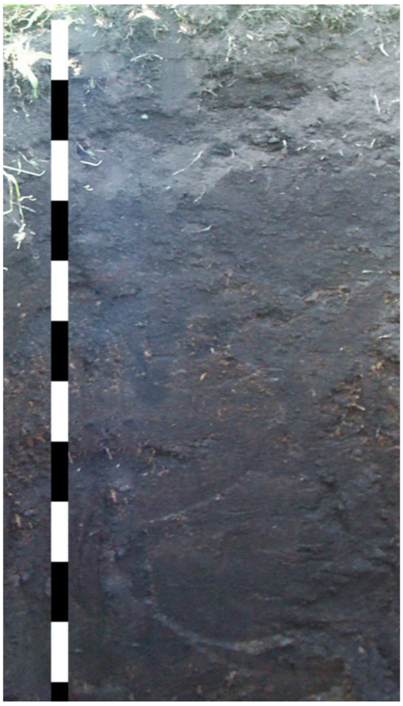
E(g) 25–37 cm – fluvioglacial sand, grey, many black concretions of manganese, moist, compact, single grain structure, gradual and smooth boundary;

BEg 37–52 cm – fluvioglacial sand, yellowish grey with a bluish tongues, moist, compacted, single grain structure, gradual and smooth boundary;

Bg 52–87 cm – fluvioglacial sand, bluish with brown mottles, moist, compacted, single grain structure, gradual and smooth boundary;

Cg 87–100 cm – morainic loam, reddish brown with grey mottles, wet, dense, massive structure.

Fig. 4. Sod-podzolic hypogleyed sandy soil, developed on fluvioglacial sand on morainic loam (WRB: Planosol; Lapa and Chernysh 2017)



H_1 0–36 cm – highly decomposed peat, dark grey, many roots in the upper part, fresh, loose, granular structure, gradual boundary;

H_2 36–66 cm – weakly decomposed reed-sedge peat, dark brownish grey, moist, granular structure, gradual boundary;

H_3 66–120 cm – weakly decomposed reed-sedge peat, brownish-dark grey, wet, blocky structure, clear boundary;

G 120–135 cm – fluvioglacial sand, greyish brown, wet (groundwater level at a depth of 1.2 m), single grain structure.

Fig. 5. Peat lowland medium drained soil, developed from reed-sedge peat, underlain by sands (WRB: Murshic Sapric Histosol; Lapa and Chernysh 2017)

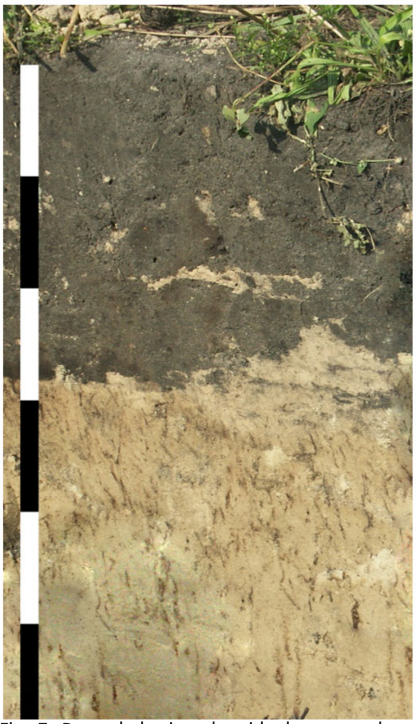
A_p
0–23 cm – old alluvial loam, dark grey, moist, compacted, granular structure, smooth and gradual boundary;

A_1
23–73 cm – old alluvial clay loam, dark brownish grey, moist, compacted, granular structure, effervesces with HCl in the lower part, smooth and gradual boundary;

BCк
73–91 cm – old alluvial clay loam, grey, moist, granular structure, effervesces with HCl, smooth and gradual boundary;

Cкg
91–130 cm – old alluvial sand, bluish grey colour with rusty-brown mottles, moist, effervesces with HCl.

Fig. 6. Sod-carbonate leached soil, developed from old alluvial sediments (WRB: Gleyic Chernozem; Lapa and Chernysh 2017)



Ap(H)
0–26 cm – mixture of sand with the remains of highly decomposed peat, dark grey, many pale yellow mottles, dry, friable, abrupt and irregular boundary;

Bg
26–50 cm – sand, light yellow with whitish mottles, lot of rusty-brown and black rooting patterns, moist, single grain structure, gradual boundary;

Cg
50–110 cm – fluvioglacial sand, brownish yellow with a bluish and rusty brown mottles, moist, single grain structure.

Fig. 7. Degraded mineral residual-peat sandy soil, underlain by fluvioglacial sand (WRB: Gleyic Umbrisol; Lapa and Chernysh 2017)

cesses (significant improvement in the natural properties of agricultural soils and the appearance of the new type of soil: agrozems (Smeyan and Tsytron 2006)) and degradation (degradation of soil properties) was largely disputed because of the classification scheme of 2006.

A brief description of the soil-forming processes is given below.

The podzolic process proceeds under conditions of a washing or partially washing water regime under coniferous forests, mainly on non-carbonate parent rocks. As a result of the forest vegetation, plant residues of low thickness formed on the surface of the soil every year, which decomposed by a fungal micro flora, forming a light-colored organic acid. This acid destroys the soil minerals and takes the products of that destruction into the lower part of the soil profile or beyond it (Kulakovskaya et al. 1974).

The sod process developed under the influence of grass flora, which annually accumulates a significant amount of overground and underground biomass. Under the influence of microorganisms, the dead plant remains decomposed with the formation of darkly coloured humic acids, which leads to enrichment of the upper soil horizon with humus. Accumulation of humus significantly weakens the leaching process and enriches the upper horizon with mineral elements. As a result of this process, a dark humus horizon with a lumpy or granular structure is formed (Kulakovskaya et al. 1974).

On the territory of Belarus, the sod and podzolic processes usually occur together, which leads to the formation of sod-podzolic soils.

The bog process occurs in conditions of excessive soil moistening, caused either by shallow groundwater occurrence, or by the retention of atmospheric precipitation by waterproof rocks (clay, loam). The characteristic features of the marsh process are peat formation and gleying. In depressions, the bog process is genetically associated with sod and podzolic processes, which as a result leads to the formation of sod-podzolic waterlogged soils (Kulakovskaya et al. 1974).

Burozemic soil formation takes place under conditions of the washing water regime under deciduous forests, where the process of silt accumulation predominates. The process comprises a metamorphic transformation of minerals, the accumulation of silt *in situ* without leaching it through the soil profile (Kulakovskaya et al. 1974).

Anthropogenic transformation of soils is a combination of processes that results in a significant change in the natural properties of soils. In the course of transformation, the productivity of soils can be improved (cultivated soils of agricultural lands), or catastrophically degraded (soils of quarries) (Kulakovskaya et al. 1974).

When using this classification scheme there are problems. If one strictly abides by the principles of genetic isolation of soil types, then there are doubts about the logical separation of some of the existing 13 soil types.

So, often when describing podzolic soils, the presence of low-activity A (humus) or AE (humus-eluvial) horizons are indicated, which automatically excludes the presence of a separate type of soil. In addition, in the literature there is no clear criteria for the separation of bog podzolic and podzolic waterlogged soils. After all, the soil-forming processes in them are overall the same. Even if the presence of a peat horizon is considered a necessary criterion of the difference, and guided solely by the genetic approach, it turns out that these types of soils should contain be no humus horizon. However, no such soil variety is described in the literature (Klebanovich 2007).

In addition, correlating between the national soil classification and the international WRB system is highly problematic.

The classification of soils in the international WRB system is of particular interest in connection with the growing international cooperation of soil scientists and the increasing role of soil in the modern world. In the Atlas of European soils (Jones et al. 2005), only four taxonomic units have been identified on the territory of the Republic of Belarus. There were: sharply dominant Albeluvisols (now replaced with Stagnosols, Planosols, and Retisols, which are equivalents of sod-podzolic and sod-podzolic waterlogged), Histosols (peat-bog), Fluvisols (alluvial) and Podzols (podzolic being part of sod-podzolic waterlogged and bog-podzolic). This map is undoubtedly very schematic and does not correspond to reality.

The main problem of the correlation between the Belarusian and international soil classifications is the difference in the approaches to the allocation of taxonomic units. In the WRB system, classifying is done based on diagnostic horizons, without taking into account the factors of soil formation and the features of the soil-forming process. In the national classification of Belarus, the leading principle of soil type identification is the genetic approach, in which emphasis is placed on the conditions of soil formation.

The most widely discussed correlation of the Belarusian soil classification and the WRB system was created by the scientists of the department of soil science and land information systems of the Geographical Faculty of the Belarusian State University. The most famous and respected specialist in this institution is N.V. Klebanovich. They published a soil map of Belarus in the WRB classification, based on a medium-scale map in the national classification (Klebanovich et al. 2011), which reflects the features of the country's soil cover much more accurately. The revised version after the changes in the classification of WRB was also published (Klebanovich 2015). This map shows 13 taxonomic units, partially corresponding to the genetic types of soils of the Belarusian classification. The map also reflects the greatest distribution of Retisols (Arenic), Gleyic Retisols and Luvisols (Siltic) in the soil cover of Belarus.

The proposed approach to the correlation of genetic soil types in the Belarusian classification to the soil groups WRB is shown in Table 3 (Klebanovich 2015).

Conclusions

Historically developed and actively used in soil mapping in the Republic of Belarus, the genetic classification of soils, in which 13 soil types are identified, is quite complete and informative for the country. However, the separation of some types of soil is controversial. From the stand point of unification and generality of understanding in the selection of soil types, the optimal solution is to rely on the classical definition of soil type, implying the association in a given taxon of soils with a combination of properties and characteristics due to the course of a particular set of soil-forming processes.

It is advisable to think about separating out the anthropogenically transformed soil type–allocating a cultural soil-forming process that forms soils of a particular type. The processes of soil changes under negative anthropogenic impact towards their deterioration should be generalised as a degradation process and regarded as antipode to another anthropogenic soil-forming process.

Further improvement of the nomenclatural list of soils of Belarus at the level of the type should first of all be based on the presence or absence of general soil-forming processes (types of soil formation) and, if possible, correlated with the international soil classification scheme to improve cooperation opportunities with soil scientists of other countries.

Table 3. Correlation between international WRB and Belarusian soil classification systems (Klebanovich 2015, modified)

Belarusian soil classification scheme (1980)	**International WRB scheme (2015)**
Sod-carbonate (developing on ancient alluvium)	Chernozems/Phaeozems
Sod-carbonate (other)	Leptosols
Brown forest	Luvisols
Podzolic	Podzols
Sod-podzolic (fine textured)	Luvisols
Sod-podzolic (coarse textured)	Retisols/Planosols
Podzolic waterlogged	Gleyic Podzols
Sod-podzolic waterlogged (depending on the subtype)	Stagnosols/Planosols Gleyic/Stagnic Retisols
Sod waterlogged (depending on the subtype)	Gleysols/Stagnosols
Peat-bog (ground water)	Hemic Histosols
Peat-bog (water from atmospheric precipitations)	Fibric Histosols
Alluvial sod and sod waterlogged	Fluvic Gleysols
Alluvial boggy	Fluvic Histosols
Anthropogenically transformed	Various units

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