

ANNA MIECHÓWKA^{1*}, MAREK DREWNIK²

¹ University of Agriculture in Krakow, Faculty of Agriculture and Economics, Institute of Soil Science and Agrophysics, Department of Soil Science and Soil Protection, Al. Mickiewicza 21, 31-120 Kraków, Poland

² Jagiellonian University, Institute of Geography and Spatial Management, Department of Pedology and Soil Geography ul. Gronostajowa 7, 30-387 Kraków, Poland

Rendzina soils in the Tatra Mountains, central Europe: a review

Abstract: The article presents the overview of the rendzinas found in the Polish Tatra mountains based on literature data and unpublished authors results and observations. Particular attention was paid to soil properties related to the high mountain environment in Poland occurring only in the the Tatra Mountains. The influence of soil forming factors on the genesis of rendzinas and their spatial distribution was described. Furthermore the soils properties were analysed in order of distinguished soil units. Finally the proposal for classification of Tatra rendzinas was given.

Key words: Rendzinas, mountain soils, Tatra Mts., humus forms

INTRODUCTION

Tatra Mountains (Tatra) are located in the north-western part of the Carpathian Chain on the border between Slovakia and Poland. These are the highest mountains of the Carpathians in this part of Europe (Gerlach, 2655 m a.s.l.). The geological structure of this area is very diverse (Passendorfer 1996). There is a well-developed vertical geocological zonation (lower and upper montane belt, sub-Alpine and Alpine zone, bare rocky belt) (Kotarba 1996) and a post-glacial relief (Klimaszewski 1996). Due to high natural values and cultural heritage, this area is protected by national parks both on the Polish and on the Slovak side of the border. Those parks had been

jointly entered in the World Network of Biosphere Reserves (UNESCO).

Rendzina soil (rendzinas) are a very important component of the Tatra ecosystems. These soils develop from carbonate rocks and occur in all regions of the Tatra Mountains (Skiba et al. 2015). They predominate in the soil cover of the Regiel Tatra region (subregions: Orawicko-Witowskie Tatra, Kościeliskie Tatra, Zakopiańskie Tatra, Kopy Sołtysie group, Jaworzyńskie Tatra) (regional subdivision of the Tatra Mts. by Balon et al. 2015 is implemented) and in the Belianske Tatra region (Fig. 1). In the Western Tatra region, rendzinas are predominant soils in the Siwy Wierch group, in the Czerwone Wierchy massif (including Giewont Mt.) and in the

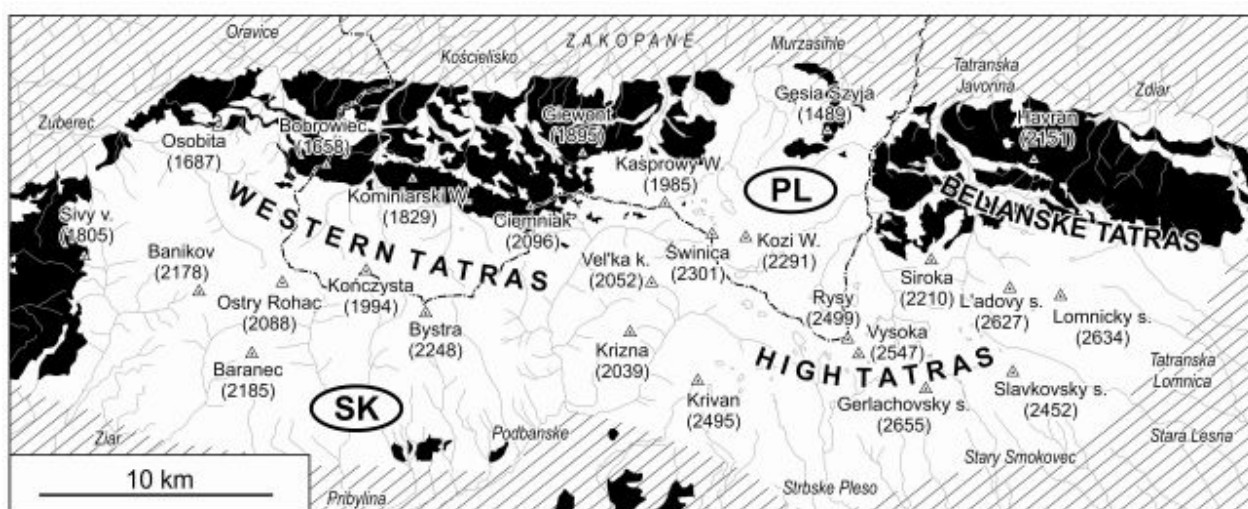


FIGURE 1. Spatial distribution of rendzinas (black coloured contours) in the Tatra Mountains

* Prof. dr hab. A. Miechówka, rrmiecho@cyf-kr.edu.pl

Kominiarski Wierch massif. They also occur in the Osobita-Bobrowiec group (both in the eastern and western part). Rendzinas can also be found in Rohače area (Studený Potok valley) and in the Tomanowo-Jamnickie Wierchy group. In the High Tatra region, these soils are found on a much smaller area – on the northern mountain slopes of Szeroka Jaworzyńska massif, in the north-western part of the Jaworowy-Kieźmarski massif and in the northern mountain slopes of the Waksmundzki massif. In the whole Tatra, rendzinas occupy ~20% of the area (Fig. 1). In the (Polish) Tatra National Park rendzinas occupy about 35% of the soil cover (Skiba 2002).

Rendzinas create natural habitats (mostly protected in the European Union: Habitat Directive, Annex 1) important for the protection of biodiversity in the Tatra. They determine the occurrence of many valuable species of plants and animals (Dyduch-Falniowska 1991, Miechówka and Piękoś-Mirkowa 1998, Piękoś-Mirkowa et al. 2001). 31 endemic species of vascular plants occurring in the Polish part of the Tatra can be found on the rendzinas (of 35 in total), 12 of them growing almost exclusively (over 90% of sites) or exclusively on these soils (Piękoś-Mirkowa et al. 1996).

The importance of rendzinas to the natural environment was the cause of the researchers' particular interest in these soils, both on the Polish and Slovakian part of the Tatra Mountains. Rendzinas of the Polish Tatra have been examined in detail during large-scale soil survey works in the 1970s and 1980s (Komornicki et al. 1975, Komornicki 1977, Komornicki et al. 1984a, 1984b) and described both in the monographs of the Tatra National Park (Strzemski 1956, Adamczyk 1962a, Komornicki and Skiba 1996) and entire Tatra Mountains (Koreň et al. 2010). Finally the spatial distribution of rendzinas in the Tatra in different scales has been shown in the maps (Strzemski 1956, Komornicki et al. 1975, Komornicki 1977, Komornicki et al. 1984a, 1984b, Komornicki and Skiba 1985, Skiba 1999, Skiba et al. 2015).

Detailed scientific studies were carried out on the following topics concerning Tatra rendzinas: the influence of climate on the soil properties and the tendency of vertical soil zonation (Skiba 1983, 1985), the soil geochemistry (Oleksynowa et al. 1977, Miechówka 1989, 1990, 2001), both the properties and forms of humus (Niemyska-Łukaszuk 1977a, Niemyska-Łukaszuk and Miechówka 1996, Miechówka and Ciarkowska 1998, Miechówka 2000, Wasak and Drewnik 2012a, 2012b, 2015, Wasak 2013, 2014) and biological activity of soil (Drewnik 1998, 2006, Miechówka 2000, Miechówka and Ciarkowska 2002, Ciarkowska and Miechówka 2005a, 2005b, Wasak 2014), as well as the concentration of heavy

metals in soil (Miechówka 2000, Niemyska-Łukaszuk et al. 2000, Niemyska-Łukaszuk and Miechówka 2002, Miechówka et al. 2002, Miechówka and Niemyska-Łukaszuk 2004), the concentration of radionuclides in soil (Kubica et al. 2002, 2007, 2010) and their classification (Strzemski 1956, Adamczyk 1962b, Komornicki et al. 1975, Komornicki 1977, Skiba 1983, Komornicki et al. 1984a, 1984b, Komornicki and Skiba 1996, Miechówka 2000). In some of the above-mentioned works the micromorphological investigations were used (Niemyska-Łukaszuk 1977b, Miechówka 2000, Ciarkowska and Miechówka 2005a, Drewnik 2006).

Rendzinas in the Slovakian part of the Tatra were described in monographic studies (Tarábek 1956, Midriak 1971, Pelišek 1973, Koreň 1994, Koreň et al. 1994, Bedrna and Račko 1999). A detailed scientific study, concerning mainly the rendzinas of the Belianske Tatra region, has been carried out on the following topics: the dynamics of the natural and human induced morphogenetic processes affecting the soil cover (Midriak 1983, Barančok and Varšavová 1996, Hreško et al. 2008), chemical properties of soils (Varšavová et al. 1999, Mišovičová 2003) and the problem of their pollution (Barančoková et al. 2009).

The aim of this work was to create an overview of characteristics the rendzinas found in the Polish Tatra mountains, based on literature data and unpublished authors results and observations. Particular attention was paid to soil properties related to the high mountain environment in Poland occurring only in the Tatra Mountains.

Factors affecting the diversity of rendzinas

The rendzinas in Tatra are very heterogeneous soils with respect to the morphological, physical, chemical, physicochemical and biological properties due to the diversity of the parent material, climatic conditions and plant cover in this area.

The carbonate rocks of the Wierchowa and Reglowa series (i.e. structural geological series distinguished in Tatra) are the parent material of the Tatra rendzinas. They are mainly: Triassic limestones and dolomites, Jurassic limestones and marls. There are also Eocene limestones on the border of the Tatra Mts. and Zakopane Basin. The carbonate rocks of the Tatra Mountains differ in their physical and chemical properties, thus their susceptibility to weathering is diverse. They form regolith of varying thickness, varying content of rock fragments, varying textures and chemical composition.

The thickness of regolith is related to the impact of both past and contemporary geomorphological

processes. Present-day morphogenetic processes have the strongest effect on the soil cover diversity above the upper timberline (Skiba 2006). A specific kind of the soil cover variety called 'openwork soil cover' (so-called 'soil cover fragmentation') can be found in the Tatra (Strzemeski 1956, Skiba 2006), which means the occurrence of the complex of well-formed rendzinas soils next to initial soils and next to soilless areas.

The parent material of the Tatra rendzinas is often a mixture of weathered parts of different rocks. For example the upper parts of the talus cone and talus slope in many cases consist of a mixture of carbonate rocks (limestones, dolomites and marls) and non-carbonate rocks (schists, quartzites). Similarly, the majority of rendzinas occurring on the mountain slopes contain some fine-earth admixtures originating from silicate rocks weathering. In fact, Tatra redzinas often develop on slope covers consisting of a mixture of different rocks occurring in the upper part of the slope. Rendzinas on the mountain slopes of Czerwone Wierchy massif are one such case (Miechówka 1998, Drewnik 2008). The huge admixture of granite gravel and fine earths in these soils coming from the 'crystalline cap' located in the top parts of the massif. A very heterogeneous geological material can also be found in soils occurring in many Tatra glades. For example in the border part of glade in the Kościeliska Valley a specific 'mélange' mixture of carbonate and non-carbonate debris of fluvioglacial origin can be found (Miechówka 1994). Finally, it should be noted that admixtures of aeolian-derived silt and clay coming from the weathering of various non-carbonate rocks (including granitoides) are often found in rendzinas. It can be assumed that most soils of the calcareous part of the Tatra originate from non-homogeneous parent material.

As the elevation increases, the mean annual temperature decreases (MAT from $\sim +6^{\circ}\text{C}$ to $\sim -4^{\circ}\text{C}$), the mean annual precipitation increases (MAP from ~ 1200 mm to ~ 1900 mm at ca. 2000 m a.s.l.) and the snow cover period becomes longer in Tatra. There are 5 climatic vertical zones: moderately cool, cool, very cool, moderately cold and cold (Hess 1996). The higher the soils are, the impact of climate on their formation is higher (Strzemeski 1956, Adamczyk 1962a, Skiba 1983). Lower temperature and higher precipitation favour the accumulation of organic matter in soils in higher elevations (Skiba 1983, Drewnik 2006). There is also a greater leaching of basic cations from soils and thus their acidification is stronger (Miechówka and Głąb 1998). The climatogenic character of the Tatra rendzinas is expressed in their zonality. This phenomenon in Polish Tatra was

described by Skiba (1983), after examining the soils of the northern mountain slope of Kominiarski massif. It is not always possible to notice the altitude zonality of rendzinas in each locations due to the relief, the differences in intensity of morphogenetic processes and unequal microclimatic conditions. It should be noticed that slope exposure also shapes the properties of rendzinas (Adamczyk 1962a).

Vegetation is an important factor affecting the morphology and properties of Tatra rendzinas. The plants in the montane belt and in the subalpine zone (trees and dwarf-pines respectively) influence the stability of the rendzinas. The root systems and low-lying branches mechanically protect soils against water erosion, creep and landslide, therefore soils are less exposed to the influence of morphogenetic processes in these areas (Adamczyk 1962b, Fabianowski 1962, Miechówka 2002). In forest ecosystems, both the species and the age of trees determine the quantity and quality of the accumulating litter, which affects the formation of different forms of soil humus in rendzinas (Wasak and Drewnik 2012a, Wasak 2013, 2014). In non-forest plant communities, vegetation may also have an impact on the diversity of humus forms, for example, there are much thicker organic O horizons in rendzinas under bilberry shrubs than under grasslands in the Tatra glades (Miechówka and Ciarkowska 1998, Miechówka 2000).

Humus forms

All morphological and functional types of humus forms common in calcareous soils described in the European Humus Forms Reference Base (Jabiol et al. 2013) have been found in the Tatra mountains: *mull*, *amphi* and *tangel* types and most of their subtypes. The variety of humus forms present in the rendzinas causes a tendency to treat them, together with depth and the content of stones in the soil body, as the main classification factor due to their diagnostic and habitat functions.

The humus form *tangel* (Kubienna 1953) is common in the rendzinas occurring in the upper montane natural spruce forest and in the rendzinas occurring in the Alpine and sub-Alpine zone under dwarf-pine shrubs, under bilberry shrubs (subtype: *dystangel*) and under calcareous grasslands (subtype: *eutangel*). This humus type is characterized, among others, by the sequence: a well-developed organic O horizons over humus A horizon with thickness no more than of half the O horizon.

Pachyamphi humus form can be found in rendzinas both under the artificial spruce monoculture in the lower montane belt (Wasak 2014), under the

calcareous grasslands and under dwarf-pine shrubs (Miechówka 2002). In these soils, organic O horizon consists of well-humified organic material (OH horizon). The sequence of humus horizons is completed by a biomezostructural A horizon with a thickness of more than half of the OH-horizon thickness. It is assumed that *amphi* humus form is typical for the Mediterranean soil (Zanella et al. 2011), but it has already been described as occurring in soils of Alps (Graefe 2007).

The humus *mull* form occur in rendzinas at different elevations and under different vegetation (beech forests, calcareous grasslands, dwarf-pine shrubs) (Miechówka 2000, 2002, Wasak 2013). An extremely high content of soil organic carbon (SOC) in *mull* humus type is specific to Tatra rendzinas.

In previous works concerning the type of humus in the Tatra rendzinas, classifications of humus other than the European Humus Forms Reference Base (Jabiol et al. 2013) commonly were used: according to the Polish Soil Classification (Niemyska-Łukaszuk 1977a), according to Kubiena (1953) (Miechówka 2000) and according to INRA (1992) (Miechówka 2002). Humus forms in Tatra rendzinas are quite similar to those described by Kubiena (1970) in the Alps (Miechówka and Ciarkowska 1998, Miechówka 2000). Their names were and so far are used in creation of subtypes of rendzinas. An example may be the name „tangelrendzina” used by Skiba (1983) and used also in Slovakia, or the name „rendzina smolista” used by Miechówka (2000), and used for the first time by Tarábek (1956) and then often used by other Slovak soil scientists (Linkeš 1981).

Classification of Tatra rendzinas

The proposal for Tatra rendzinas classification is given in Table 1. Changes as compared to the Polish soil classification (Systematyka gleb Polski 2011) have been done taking into account the specificity of the Tatra rendzinas (especially the impact on the habitats). The translation of Polish soil names into English according to Świtoniak et al. (2016) was done with some changes.

Soils having thickness of less than 40 cm to solid carbonate rock (limestone, dolomite, marl) or soils containing to this depth at least 15% carbonate rock fragments should be classified as rendzinas. Despite carbonate rock under *solum* and/or significant percentage of the carbonate rock fragments in soil body, also rendzinas which do not contain *calcaric* or *dolomitic* material can be found in Tatra. For better characterization, raw-humus rendzinas were divided regarding humus forms in these soils.

Soil description

Raw rocky rendzinas (Rędziny inicjalne skaliste)

Raw rocky rendzinas are found in all geocological zones and belts in the Tatra (lower and upper montane belt, sub-Alpine and Alpine zone, bare rocky belt). These soils are typical for crevices, gaps and ledges in the rocky wall and rocky slopes on outcrops and rocks composed of limestones, dolomites and marls.

Raw rocky rendzinas occurring in crevices and gaps in the rock have specific characteristics due to the fact that they are surrounded by a solid rock at least on two sides. The properties of the soil material

TABLE 1. Key to the Tatra rendzinas classification

Soils having thickness ≤40 cm to solid carbonate rock (limestone, dolomite, marl) or soils containing to this depth at least 15% carbonate rock fragments		
[1]	having continuous carbonate rock starting ≤10 cm	→ Raw rocky rendzina
[2]	having ≥80% (by volume) coarse fragments of carbonate rock to a depth of 40 cm AND combined thickness of O+A+AC horizons ≤10 cm	→ Raw debris rendzina
[3]	having folic* horizon (thickness of ≥10 cm and <40 cm) over A or AC horizon	→ Raw-humus rendzina
[3a]	having <i>tangel</i> humus form**	Subtypes: → <i>Tangel-rendzina</i>
[3b]	having <i>amphi</i> humus form**	→ <i>Amphi-rendzina</i>
[4]	having <i>mollic</i> * horizon	→ Humus rendzina
[5]	having <i>cambic</i> * horizon	→ Brown rendzina
[6]	(others)	→ Proper rendzina
[6a]	having ≥80% (by volume) coarse fragments of carbonate rock to a depth of 40 cm	Subtypes: → <i>Debris proper rendzina</i>
[6b]	(others)	→ <i>Typical proper rendzina</i>

* sensu IUSS Working Group WRB 2015; ** sensu Jabiol et al. 2013.

building these soils depend mainly on the moisture conditions and the size of the gaps. Above upper timberline raw rocky rendzinas are usually very moist or even wet (in many cases water flows through it). Within montane belt, the soil moisture depends on the exposure of the rock wall (or slope). The soils of the northern exposure rock walls are usually very moist or wet, whereas the soil of the southern exposure walls are usually only slightly moist. The content of soil organic carbon (SOC) and carbonates (eqCaCO₃) in those soils is closely linked to moisture conditions (Table 2). In the raw rocky rendzinas found in higher elevations, above upper timberline (profiles 1–3) (Table 2) the SOC concentration is usually >12%, whereas the carbonate concentration is usually <5%. The reaction class of these soils is slightly acidic or

acidic (pH in water 5.2–6.7). Raw rocky rendzinas occurring in lower elevations, within montane belt, are more diverse in terms of SOC and carbonate content, and they are characterized by a neutral or slightly alkaline reaction (pH in water 6.6–7.8) (profiles 4 and 5) (Table 2).

Raw rocky rendzinas as described above create habitats for plant communities specific for rocky gaps (e.g. *Drabo-Artemisietum petrosae*, *Asplenio viridis-Cystopteridetum*, *Asplenium rutae murariae-trichomanis*) and for plant communities typical for calcareous grasslands (*Festuco versicoloris-Seslerietum tatrae*, *Carici-Festucetum tatrae*). Raw rocky rendzinas occurring in crevices and gaps are relatively poorly investigated due to difficulties in obtaining research material (narrow gaps) and due to legal restrictions (protection of habitats and plant species).

TABLE 2. Basic properties of raw rocky rendzinas

Horizon	Thickness > 2 mm cm	> 2 mm %v/v	pH (H ₂ O)	pH (KCl)	SOC %	C/N	eqCaCO ₃ %	BS	Reference / Remarks
1. Stoły, 1,920 m a.s.l., crevice within rock wall 60°S, <i>Festuco versicoloris-Seslerietum tatrae</i> , Somerirendzic Nudillithic LEPTOSOL (Hyperhumic)									
A	0–10	0	6.2	5.6	13.99	17.7	0.55	90.6	Piękoś-Mirkowa et al. (2001)
2. Stoły, 1,900 m a.s.l., crevice within rock wall 45°SWW, <i>Festuco versicoloris-Seslerietum tatrae</i> , Eutric Nudillithic LEPTOSOL									
O	0–9	0	5.3	4.8	23.85	13.7	0.27	n.d.	/ very moist
3. Długi Giewont, 1,650 m a.s.l., rock wall 80°N, <i>Carici-Festucetum tatrae</i> , Hypereutric Nudillithic LEPTOSOL									
OC	0–5	0	6.7	6.4	24.50	14.5	1.07	93.4	/ very moist
4. Krokiew, 1,050 m a.s.l., rock wall 80°N, <i>Asplenium trichomano-rutae-murariae</i> , Hypereutric Nudillithic LEPTOSOL									
A	0–1	0	7.5	n.d.	n.d.	n.d.	n.d.	n.d.	(unpublished)
5. Kopieniec Mały, 1,160 m a.s.l., slope 20°S, <i>Carici-Festucetum tatrae</i> , Hypereutric Nudillithic LEPTOSOL (Hyperhumic)									
AC	0–9	10	7.5	7.3	5.16	13.6	24.39	97.4	/ very moist
6. Ciemniak, 2,025 m a.s.l., slope 5°NW, calcareous alpine grasslands with calcifuge species, Dystric Hypersekeletal Lithic LEPTOSOL (Hyperhumic)									
AC	2–10	80	5.7	5.2	5.47	11.6	0.64	41.4	(unpublished)
7. Kopa Kondracka, 1,257 m a.s.l., rock slope 75°NEE, <i>Seslerietalia varia</i> with calcifuge species, Eutric Skeletal Lithic LEPTOSOL (Humic)									
AC	10	50	5.9	5.2	1.32	9.4	0.73	66.3	/ admixture of granitic parts (unpublished)
8. Kobylarz, 1,820 m a.s.l., rock slope 50°NNW, <i>Festuco versicoloris-Seslerietum tatrae</i> , Lithic Calcaric LEPTOSOL (Hyperhumic)									
A	2–10	5	6.7	6.1	19.57	15.5	4.93	81.2	(unpublished) very moist
9. Stoły, 1,730 m a.s.l., ledge within rock wall 30°N, <i>Carici-Festucetum tatrae</i> , Hyperskeletal Lithic Calcaric LEPTOSOL (Hyperhumic)									
AC	0–5	80	7.2	6.9	8.93	11.2	60.07	97.9	Piękoś-Mirkowa et al. (2001)
10. Przednia Kopka, 1,055 m a.s.l., summit part 25°NE, <i>Carici-Festucetum tatrae</i> , Lithic Calcaric LEPTOSOL (Hyperhumic)									
A	0–8	0	7.1	6.8	18.17	13.4	3.39	84.01	(unpublished)
11. Pióro (Nosal), 950 m a.s.l., ledge within rock slope 20°N, <i>Erico-Pinetalia</i> , Eutric Lithic LEPTOSOL (Hyperhumic)									
O	2–10	0	5.6	5.0	48.17	28.0	n.d.	n.d.	(unpublished)

Raw rocky rendzinas occurring on ledges in the rocky walls and on the rocky slopes are also diverse. In the vicinity of mountain tops, they are usually very shallow, because they are frequently eroded. Soil material moves to lower lying places, where deeper soils are formed. Within rocky wall the thickness of these soils depends on the size of the ledges. Mostly they are classified as raw rocky soils. These rendzinas are usually poorly stabilized (loose and friable consistency). Their physical and chemical properties mostly depend on the moisture conditions and the properties of a material deposited on the ledge. Both the SOC and carbonates concentration in rendzinas is lower in the case of substantial admixture of granitoides and metamorphic schists originating in higher positions in slope (profiles 6 and 7) (Table 2) in comparison to rendzinas developed from ‘pure’ calcareous parent material (profiles 8 and 9) (Table 2).

Both organic O horizons and humus A horizons with a high content of SOC (profiles 10 and 11) (Table 2) formed ‘in situ’ can also be found on ledges in the rocky wall and on the tops of calcareous rocks. Such soils occur, among others, in the relict pine forests (*Erico-Pinetalia*), which are very important plant communities for the biodiversity of the Tatra Mountains. Raw rocky rendzinas developed on ‘pure’ calcareous parent material create habitat for plant communities typical for calcareous grasslands (*Festuco versicoloris-Seslerietum tatrae*, *Carici-Festucetum tatrae*), whereas in the case of substantial admixture of non-calcareous parts in soil some acidophilous plant species can be observed.

Raw debris rendzinas and debris proper rendzinas (Rędziny inicjalne rumoszowe i rędziny właściwe rumoszowe)

That group of rendzinas includes soils developed on talus cones and talus slopes. They occur presumably above timberline, in the Alpine and sub-Alpine zone in Tatra (profiles 12–14) (Table 3). The largest patches of raw debris rendzinas and debris proper rendzinas can be found in valleys: Litworowa, Mułowa and Wielka Świstówka in the Czerwone Wierchy massif. A much smaller talus cones are located in the forest belt (profile 15) (Table 3). A characteristic feature of raw debris rendzinas is the very high content of stones (even boulders) with varying thickness of *solum*. They often have a significant thickness, but simultaneously they have poorly (raw debris rendzinas) or moderately (debris proper rendzinas) developed soil genetic horizons. The variety of their physical and chemical properties is related to: (1) the content and size of the stony material, (2) the content and spatial distribution of fine-earth particles in *solum*, (3) the relief position of soil, (4) the moisture condition, and (5) the degree of surface stabilization (Miechówka 2000).

In the rendzinas occurring on talus slope directly at the foot of the rocky wall (profile 13) (Table 3) the content of SOC is usually higher, whereas the concentration of carbonates in the fine soil is usually lower in comparison to rendzinas occurring at higher distance from rocky wall (profiles 12, 14 and 15), although this phenomenon also depends on the degree of surface stabilization (Table 3). Plant communities such as: *Silenietum prostratae*, *Oxyrio*

TABLE 3. Basic properties of raw debris rendzinas and debris proper rendzinas

Horizon	Depth cm	> 2 mm %v/v	Colour (moist)	Texture	pH (H ₂ O)	pH (KCl)	SOC %	C/N	eqCaCO ₃ %	BS	Reference
12. Krzesanica, 2,090 m a.s.l., talus cone 20°W, <i>Thlaspietalia</i> , Calcaric Hyperskeletal LEPTOSOL											
AC	0–15	80	10YR 7/2	–	7.8	7.6	1.87	8.9	74.48	94.8	(unpublished)
13. Małolączniak, 1,940 m a.s.l., talus cone 10°NWW, <i>Thlaspietalia Oxyrio digynae-Papaveretum tatrici</i> , Hyperskeletal Rendzic LEPTOSOL (Loamic, Hyperhumic)											
AC1	0–14	80	10YR 2/1	–	7.5	7.1	8.26	17.6	5.05	97.9	(unpublished)
AC2	14–31	90	10YR 3/1	SL	8.0	7.2	8.91	–	3.41	98.5	
2AC	31–40	75	10YR 2/1	SL	8.1	7.1	6.84	–	1.36	98.9	
14. Mała Świstówka, 1,360 m a.s.l., talus cone 10°NE, <i>Seslerietalia varia</i> , Calcaric Hyperskeletal LEPTOSOL (Humic)											
AC	0–16	85	10YR 4/3	–	7.7	7.3	2.30	13.5	17.45	97.8	(unpublished)
Cca	16–(33)	90	10YR 5-4/3	–	7.9	7.4	1.67	–	20.11	97.8	
15. Jastrzębia Turnia, 1,080 m a.s.l., debris slope 15°W, <i>Carici-Festucetum tatrae</i> , Hyperskeletal Rendzic LEPTOSOL (Humic)											
AC	0–23	70	10YR 2/1	–	6.9	6.7	6.47	15.0	63.90	96.7	Niemyska-Łukaszuk and Miechówka (1996)
Cca	23–43	95	10YR 4/4	–	7.2	7.0	1.21	6.3	88.34	97.9	

digyna-*Papaveretum tatricum* and *Cerastio latifolii-Papaveretum tatricum* are developed on relatively mobile, active parts of talus cones. In contrast there are species characteristic for typical calcareous grasslands (forming plant communities such as: *Festuco versicoloris-Seslerietum tatrae*, *Carici-Festucetum tatra*) in the stabilized parts of talus cones, usually on the debris proper rendzinas. Raw debris rendzinas and debris proper rendzinas can also be found in the forest belt. They were described in coniferous spruce forest in the talus cone and talus slope in Wantule in Miętusia valley (Skiba et al. 2011). Thick ectohumus horizons cover a huge (calcareous) boulder and stones in this area. The content of rock fragments in

soils reaches 90%, and voids between them are partially filled by fine-earth particles containing up to 75% of soil organic matter (Skiba et al. 2011).

Typical proper rendzinas and humus rendzinas (Rędziny właściwe typowe oraz rędziny próchniczne)

Typical proper rendzinas and humus rendzinas occur at different elevations and under different vegetation (Table 4). They create habitats for plant communities such as: dwarf-pine shrubs (*Pinetum mugo carpaticum*), grasslands (*Seslerietalia varia* and *Arrhenatheretalia elatioris*), both natural broadleaf and coniferous forests (*Dentario glandu-*

TABLE 4. Basic properties of typical proper rendzinas and humus rendzinas

Horizon	Depth cm	> 2 mm %v/v	Colour (moist)	Texture	pH (H ₂ O)	pH (KCl)	SOC %	C/N	eqCaCO ₃ %	BS	Reference / Remarks
16. Bobrowiec, 1,630 m a.s.l., slope 5°N, <i>Pinetum mugo carpaticum</i> , Dolomitic Skeletic Leptic REGOSOL (Loamic, Humic)											
OL	0–1.5	0	–	–	3.7	3.7	40.45	39.3	0.00	21.6	Miechówka (2001)
Of	1.5–3.5	0	–	–	4.2	3.8	21.96	15.4	1.29	19.5	
A1	3.5–10	0	10YR 3/3	L	4.9	3.9	7.14	13.2	1.09	45.2	
A2	10–19	15	10YR 4/3	L	6.0	5.8	4.74	10.5	2.59	86.9	
AC	19–40	90	5Y 6/1	L	7.3	6.8	2.28	15.2	49.32	95.3	
17. Kopa Królowa Wielka, 1,530 m a.s.l., slope 8°N, <i>Seslerietalia</i> , Skeletic Somerirendzic LEPTOSOL (Loamic, Humic)											
A1	0–6	20	10YR 3/2	SiL	6.6	6.2	8.30	10.2	3.25	92.7	Miechówka (2001)
A2	6–11	20	10YR 3/3	SiL	7.1	6.6	5.92	9.0	5.02	96.3	
Cca	11–23	85	10YR 4/4	SiL	7.6	7.0	1.74	7.6	58.95	97.1	
18. Opalony Wierch, 1,430 m a.s.l., slope 60°S, <i>Caricetum firmae</i> , Dolomitic Somerirendzic Skeletic LEPTOSOL (Loamic, Hyperhumic)											
Of	0–1	0	–	–	5.8	5.3	21.62	18.0	1.70	–	Miechówka (1989)
A	1–8	0	10YR 2/1	–	6.7	6.0	10.42	12.0	1.23	–	
AC	8–18	40	10YR 3/2	–	7.2	6.4	6.31	11.0	3.84	–	
Cca	18–25	80	10YR 6/4	SiL	7.9	7.1	0.49	6.0	68.02	–	
19. Bobrowiec, 1,485 m a.s.l., slope 60°S, <i>Caricetum firmae</i> , Skeletic Endoleptic Rendzic PHAEOZEM (Loamic)											
A1	0–12	5	10YR 2/2	–	6.8	6.5	10.64	13.6	13.20	94.6	Miechówka (2001) / very moist
A2	12–23	15	10YR 3/3	SL	7.2	6.9	4.42	7.4	20.16	98.6	
AC	23–34	60	10YR 3/4	SL	7.3	7.0	2.34	4.4	76.09	97.3	
Cca	34–52	90	10YR 4/4	SL	7.4	7.1	0.75	4.7	86.23	96.4	
20. Głębowiec, 1,280 m a.s.l., slope 45°NW, <i>Piceetum tatricum</i> – windthrow, Dolomitic Skeletic Epileptic Rendzic PHAEOZEM (Loamic)											
A1	0–2	0	–	–	7.1	6.4	16.11	15	3.52	–	Miechówka (1989) / very moist
A2	2–12	0	10YR 2/1	–	7.4	6.5	14.30	13	3.00	–	
AC	12–22	30	10YR 3/2	–	7.6	6.9	7.44	12	24.75	–	
Cca	22–42	80	10YR 5/4	SiL	8.0	7.0	0.84	9	80.91	–	
21. Polana Jaworzynka, 1,240 m a.s.l., slope 10°NW, semi-natural meadows with elements of calcareous grassland, Skeletic Epileptic Rendzic PHAEOZEM (Loamic)											
A	0–10	5	10YR 3/2	SL	7.4	7.1	6.38	12.5	16.2	89.0	Miechówka (1994) / very moist
AC	10–33	60	10YR 3/3	SL	7.6	7.3	2.68	9.6	22.43	89.0	
22. Polana Smytnia, 1,115 m a.s.l., slope 20°WNW, <i>Gladiolo-Agrostietum</i> , Calcaric Skeletic Endoleptic PHAEOZEM (Loamic)											
A1	0–13	5	10YR 3/2	–	6.6	5.9	8.62	8.9	1.09	82.7	Miechówka (1994) / very moist
A2	13–23	20	10YR 3/3	SiL	7.1	6.7	4.82	11.4	14.16	94.4	
Cca	23–66	90	10YR 4/3	SiL	7.5	7.2	1.86	8.5	22.32	95.3	

losae-Fagetum, *Sorbo-Aceretum*, *Polysticho-Piceetum tatricum*) and artificial spruce monocultures.

In these soils, various subtypes of *mull* and *amphi* humus types are present (*sensu* Jabiol et al. 2013). A relatively large amount of well-humified organic matter in humus horizons gives them a black colour (Table 4). Proper rendzinas and humus rendzinas are different in thickness of humus horizons (Table 4). However, regardless soil type, some of them have neutral or slightly alkaline reaction in whole *solum* (pH in water 7.1–8.0) (e.g. profiles 20 and 21) (Table 4), whereas some others are acidic in the uppermost part of soil (lower pH, less carbonates content or even lack of them). A well-pronounced acidification of humus horizons is evident in the rendzinas under the coniferous forests and under dwarf-pine shrubs, in circumstances such that soil is covered by low thickness litter (profile 16) (Table 4). The slightly acidic, neutral or slightly alkaline reaction (pH in water 5.6–7.8) can also be found in some soils of grasslands (including glades) (profiles 17, 18 and 22) (Table 4). Detailed chemical and micromorphological studies of soils with acidic uppermost part of *solum* carried out by Miechówka (2000) have shown that these soils are characterized by (1) high biological activity; (2) soil plasma formed microforms typical for brown rendzinas (*skel-lattisepic*, *lattisepic*) and (3) a higher content of aluminosilicate iron in comparison with other rendzinas.

Raw-humus rendzinas (Rędziny butwinowe)

Raw-humus rendzinas occur in places favouring the accumulation of organic matter on the soil surface (litter). Those are usually high-elevated areas, with high precipitation and low temperature, fully covered with vegetation cover, where the intensity of morphogenetic processes is negligible. Thick organic soil horizons develop under such conditions. Conventionally rendzinas with *foliic* horizon (thickness of ≥ 10 cm and < 40 cm) over A or AC horizon are classified as raw-humus rendzinas. These soils occur in the Alpine and in the sub-Alpine zone, as well as in the montane belt. Vegetation has a crucial role in shaping thickness, biological activity and chemical properties of organic O horizons in these soils.

Rendzinas with *tangel* humus usually occur under natural upper-montane coniferous spruce forests (*Polysticho-Piceetum*). In these soils, called tangel-rendzinas, the thickness of organic O horizons is more than twice the thickness of humus A horizons (Table 5). Organic O horizons consist of both well-pronounced poorly-humified organic matter (horizons: Ol, Of) and

well-humified organic matter (horizon Oh) (profile 23) (Table 5). The organic O horizons in these soils are acidic or strongly acidic (pH in water < 5.5) and do not contain carbonates.

Raw-humus rendzinas with *pachyamphi* humus type occur under the calcareous grasslands *Seslerietalia varia* (profiles 24, 25 and 26) (Table 5). These soils, called amphi-rendzinas, can be also found under the artificial spruce monoculture (profile 27) (Table 5). They have relatively thick organic O horizons, dominated by well-humified organic matter (Oh horizon). Below occurs humus A horizon with a thickness of more than half the thickness of Oh horizons. The pH values in the organic horizons of amphi-rendzinas are usually higher than in tangel-rendzinas. Under dwarf-pine shrubs both tangel-rendzinas (profile 28) (Table 5) and amphi-rendzinas can be found (profile 29) (Table 5). Due to special genetic conditions raw-humus rendzinas are recognized in Alps and Tatra as high-mountainous variants of rendzinas.

Brown rendzinas (Rędziny brunatne)

Brown rendzinas have been found in all climatic and vegetation zones in the Tatra Mountains, with the exception of bare rocky belt. They occupy the largest area in the montane belt (Komornicki 1977), including glades (Miechówka 1994). Brown rendzinas above the upper timberline are located in the elevation zone ca. 1550–1750 m a.s.l. (Miechówka 2000). They are most often located on southern exposed slopes, where the admixture of aeolian material is significant. They have also developed on the slope covers containing a significant amount of non-carbonate rocks admixture (Table 6).

The weathering process leading to formation of Bw horizon, correlated with *cambic* horizon (so-called 'brownification'), may occur in Tatra even in soil containing up to 30% carbonates in the fine-earths provided that: (1) the proportion of active carbonates is small (0–10%), (2) they contain the appropriate amount of iron, and (3) the biological activity of soils (including soil meso-fauna) is high (Miechówka 2000). Brown rendzinas can be found in forests often under the broadleaf *Dentario glandulosae-Fagetum*, and under grasslands such as a *Gladiolo-Agrostietum* plant community (e.g. profiles 30 and 31) (Table 6). Above the upper timberline, these soils form habitats for calcareous grasslands *Seslerietalia varia* (e.g. profile 32), grassland *Calamagrostietalia villosae* (e.g. profile 33) and dwarf-pine shrubs *Pinetum mugo carpaticum* (e.g. profile 34) (Table 6).

TABLE 5. Basic properties of raw humus rendzinas

Horizon	Depth cm	> 2 mm %/v/v	Colour (moist)	Texture	pH (H ₂ O)	pH (KCl)	SOC %	C/N	eqCaCO ₃ %	BS %	Reference / Remarks
23. Dolina Miętusia, 1,170 m a.s.l., slope 20°E, <i>Polysticho-Piceetum</i> , Dolomitic Skeletic Folic Leptic REGOSOL (Loamic)											
Olf	0–3	0	–	–	5.7	5.2	37.48	22	2.95	–	Miechówka (1989) / Humus form: Eutangel
Oh	3–20	0	10YR 2/1	–	5.7	5.2	31.29	19	1.11	–	/ very moist – wet
A	20–24	30	10YR 3/2	SL	7.5	6.9	7.16	15	44.91	–	
Cca	24–39	90	10YR 4/4	SL	7.7	7.0	1.52	11	75.82	–	
24. Stoły, 1,940 m a.s.l., shoulder 25°W, <i>Festuco versicoloris-Seslerietum tatrae</i> , Dolomitic Folic LEPTOSOL (Humic)											
Oh	0–11	0	10YR 3/1	–	6.0	5.6	20.62	12.6	0.00	–	Niemyska-Łukaszuk and Miechówka (1996) / Humus form:
A	11–18	0	10YR 3/2	–	6.9	6.2	7.62	10.0	0.00	95.4	Pachyamphi
Cca	18–24	90	10YR 6/2	–	7.8	7.7	1.35	15.0	88.39	98.6	/ very moist
25. Kominiarski Wierch, 1,829 m a.s.l., summit 3°W, mixed high-mountain grassland, Folic Endoleptic Rendzic PHAEZEM (Hyperhumic)											
Oh1	0–13	0	10YR 2/1	–	5.4	4.9	30.42	16.0	0.00	77.4	Niemyska-Łukaszuk and Miechówka (1996), Miechówka (1998) / Humus form:
Oh2	13–26	0	10YR 2/1	–	5.8	5.0	23.32	21.0	0.02	69.3	Pachyamphi
AC	26–63	60	10YR 2/1	–	6.5	6.1	14.84	19.7	5.91	91.1	/ very moist
26. Mnichy Chochołowskie, 1,470 m a.s.l., slope 75°S, <i>Seslerietalia variae</i> , Calcaric Folic Hyperskeletic LEPTOSOL (Arenic)											
O	0–13	20	10YR 2/1	–	7.3	7.0	26.70	25.0	47.34	98.1	Miechówka (2001) / Humus form:
OC	13–22	70	10YR 3/1	–	7.5	7.2	19.05	19.2	70.00	97.6	Pachyamphi
AC1	22–40	85	10YR 4/4	S	7.8	7.4	4.52	8.5	91.57	93.7	
AC2	40–57	90	10YR 5-4/4	S	8.1	7.7	2.79	6.8	95.32	94.8	
27. Dolina Białego, 980 m a.s.l., middle slope – flat, spruce monoculture, Calcaric Skeletic Folic Endoleptic PHAEZEM (Hyperhumic)											
O1	0–1	0	–	–	5.5	5.0	53.83	–	–	–	Wasak (2013, 2017) / Humus form:
Of	1–7	0	–	–	4.6	3.7	52.32	24	0.00	29	Pachyamphi
Oh1	7–14	0	–	–	6.3	5.7	32.48	22	0.19	15	
Oh2	14–24	5	7.5YR 1.7/1	–	7.2	6.7	21.03	19	19.43	86	
AC1	25–30	50	7.5YR 1.7/1	–	7.2	6.7	16.63	20	24.61	97	
AC2	30–40	60	10YR 1.7/1	SiL	7.3	6.8	8.77	16	37.86	92	
AC3	40–50	75	10YR 2/2	–	7.4	6.9	5.78	11	29.09	–	
28. Dolina Kondracka, 1,560 m a.s.l., bottom of valley 5°N, <i>Pinetum mugo carpaticum</i> , Folic Epileptic Somerirendzic PHAEZEM (Hyperhumic)											
O1	0–1	0	–	–	–	–	–	–	–	–	Drewnik (1998) / Humus form: Dystangel
Ofh	1–16	0	10YR 2/2	–	4.2	3.6	37.51	30	–	32	
Oh	16–25	0	10YR 1.7/1	–	4.6	4.0	31.04	–	–	–	
Ah	25–35	10	7.5YR 2/1	–	7.3	6.9	5.83	–	–	–	
29. Kominiarski Wierch, 1,825 m a.s.l., middle slope 8°N, <i>Pinetum mugo carpaticum</i> , Skeletic Folic Epileptic Rendzic PHAEZEM (Hyperhumic)											
Olf	0–2	0	–	–	5.1	4.0	37.05	20.6	0.00	17.2	Miechówka (2002) / Humus form: Pachyamphi
Oh1	2–4	0	10YR 2/2	–	5.8	4.7	28.57	13.8	1.11	48.1	
Oh2	4–14	0	7.5YR 2/1	–	6.7	6.7	27.02	19.7	1.32	95.9	
AC	14–39	90	7.5YR 2/1	–	7.3	6.8	12.72	18.9	2.95	98.0	

CONCLUSIONS

Tatra rendzinas are diverse soils in terms of both morphology and properties (physical, chemical and biological ones). They are a base of various biotopes and they have a great importance in shaping the biodiversity of the Tatra Mountains, creating a number of important habitats. The diversity of these soils is

determined by spatially varied and changing with altitude factors such as: parent rock, geomorphological processes, climatic conditions and vegetation. Due to the strong influence of morphogenetic processes and climatic factors, a special attention has been paid to the specific pattern of the Tatra rendzinas soil cover ('open-work' type). Another important feature of the Tatra rendzinas is the extremely high content of SOC

TABLE 6. Basic properties of brown rendzinas

Horizon	Depth cm	> 2 mm %v/v	Colour (moist)	Texture	pH (H ₂ O)	pH (KCl)	SOC %	C/N	eqCaCO ₃ %	BS %	Reference
30. Polana Stoły, 1,350 m a.s.l., slope 15°E, <i>Gladiolo-Agrostietum</i> , Calcaric Epileptic											
CAMBISOL (Loamic, Humic)											
A	0–12	0	10YR 3/3	SiL	5.4	4.7	5.63	10.6	0.00	59.4	Miechówka (1994)
Bw	12–23	0	10YR 4/3	SiL	6.6	6.4	1.84	–	9.75	85.8	
BC	23–37	80	10YR 4/2	SiL	7.4	7.2	0.75	–	54.29	94.9	
31. Przystań Mętusi, 1,100 m a.s.l., slope 20°SW, <i>Gladiolo-Agrostietum</i> , Calcaric Skeletic Endoleptic											
CAMBISOL (Loamic, Humic, Raptic)											
A	0–27	5	10YR 4/4	–	6.8	6.5	7.49	–	2.20	92.3	Miechówka (1994)
Bw	27–40	15	10YR 5/8	L	7.6	7.0	1.74	–	9.93	97.2	
2BC	40–79	90	10YR 5/3	SiL	7.9	7.4	0.40	–	46.25	99.1	
32. Mała Świstówka, 1,570 m a.s.l., ledge in the rock wall, 80°SSE, <i>Seslerietalia varia</i> , Eutric Epileptic											
CAMBISOL (Loamic, Humic, Raptic)											
A	0–10	30	10YR 2/2	SL	6.5	6.2	7.74	12.5	0.00	90.0	Miechówka (2001)
2AB	10–22	20	10YR 3/4	SL	7.0	6.5	5.37	12.2	0.00	91.1	
2Bw	22–35	20	10YR 5/4	SL	7.1	6.7	2.12	7.9	0.30	87.1	
33. Zawrat Kasprowy, 1,610 m a.s.l., slope 60°N, <i>Calamagrostietalia villosae</i> , Eutric Leptic											
CAMBISOL (Loamic, Humic)											
Ah	0–10	0	10YR 3/2	–	5.2	4.5	7.22	7.7	0.25	60.2	Miechówka (1998)
AB1	10–30	10	10YR 4/4	SL	5.8	4.8	2.95	7.6	0.32	64.9	
AB2	30–50	70	10YR 4/4	SL	6.7	6.0	2.17	7.5	0.61	–	
34. Kominiarski Wierch, 1,545 m a.s.l., slope 60°SSE, <i>Pinetum mugo carpaticum</i> , Calcaric Skeletic Epileptic											
CAMBISOL (Loamic, Hyperhumic)											
O1	0–3	0	–	–	4.3	3.7	44.58	45.9	0.00	17.5	Miechówka (2002)
Ofh	3–4.5	5	10YR 2/2	–	4.4	3.9	26.30	17.4	1.32	30.7	
A	4.5–10	30	10YR 3–2/2	–	5.9	6.0	13.29	9.5	1.70	89.5	
AB	10–20	50	10YR 4/1	–	6.6	6.1	10.57	9.1	2.32	94.8	
BC	20–45	85	10YR 5/6	SL	7.6	7.0	1.84	7.7	30.84	98.5	

and the occurrence of all types and subtypes of humus, which distinguishes the Tatra region from other parts of Poland.

Rendzinas in Tatra (especially variants called ‘high-mountainous rendzinas’) differ from rendzinas occurring in lowlands with respect to the content and the distribution of carbonates in soil body. In some rendzinas despite the high content of stones consisting of limestones, dolomites or marls in *solum*, carbonates are absent in fine earth material. In some cases, despite the high content of carbonates in fine earth, the process of weathering typical for *cambic* B horizon is taking place, possibly due to the low content of active carbonates.

Tatra rendzinas are widely studied soils (probably the best researched rendzinas in Poland). Despite this, they are still an interesting object of research. The problem of their classification is still under discussion. The unique characteristics of some rendzina units makes it problematic to allocate them to the established divisions. The proposal given in this paper could be an input in this debate.

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Rędziny Tatr – praca przeglądowa

Streszczenie: Artykuł zawiera przegląd wiedzy na temat rędzin tatrzańskich występujących w polskiej części Tatr w oparciu o dane literaturowe oraz niepublikowane wyniki i spostrzeżenia autorów pracy, ze szczególnym uwzględnieniem właściwości rędzin wysokogórskich, które na obszarze Polski występują tylko w Tatrach. Omówiony został wpływ czynników glebotwórczych na genezę i przestrzenne zróżnicowanie tych gleb oraz została przedstawiona charakterystyka wyróżnionych jednostek taksonomicznych: rędzin inicjalnych (skalistych i rumoszowych), rędzin próchnicznych (typowych i rumoszowych), rędzin butwinowych (tangel-rędzin i amphi-rędzin) i rędzin brunatnych. Zaproponowano też klucz do klasyfikacji rędzin tatrzańskich.

Słowa kluczowe: rędziny, gleby górskie, Tatry, formy próchnicy