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THE WATER RETENTION OF A GRANITE ROCK FRAGMENTS IN HIGH TATRAS STONY SOILS

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The water retention capacity of coarse rock fragments is usually considered negligible. But the presence of rock fragments in a soil can play an important role in both water holding capacity and in hydraulic conductivity as well. This paper presents results of maximum water holding capacity measured in coarse rock fragments in the soil classified as cobbly sandy loam sampled at High Tatra mountains. It is shown, that those coarse rock (granite) fragments have the maximum retention capacity up to 0.16 volumetric water content. Retention curves of the four particular granite fragments have shown water capacity available for plants expressed in units of volumetric water content of 0.005 to 0.072 in the soil water potential range (0, –0.3 MPa). Available water capacity of stone fragments can contribute to the available water capacity of soil fine earth considerably and help to plants to survive during dry spells.

KEY WORDS: Stony Soil, Rock Fragments, Granite, Water Holding Capacity, Retention Curve, Soil Water, High Tatras.

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Hodnoty vodnej retenčnej kapacity hrubozrnných častíc skeletu v pôdach sa zvyčajne považujú za zanedbateľné. Avšak prítomnosť častíc skeletu v pôdach môže významne ovplyvňovať hodnoty vodnej kapacity pôdy ako aj jej hydraulickej vodivosti. Tento príspevok prezentuje výsledky merania maximálnej vodnej kapacity skeletu obsiahnutého v pôde. Pôdne vzorky boli odoberané v lokalite FIRE, Vysoké Tatry. Podľa meraní, hodnoty maximálnej retenčnej kapacity skeletu dosahovali 0,16 objemovej vlhkosti. Na základe retenčných kriviek pre 4 vybrané žulové kamene môžeme povedať, že hodnoty využiteľnej vodnej kapacity, vyjadrené v jednotkách objemu vody v pôde sa pohybovali od 0,005 do 0,072 pre vodný potenciál pôdy od 0 do –0,3 MPa. Využiteľná vodná kapacita častíc skeletu takto môže významne doplňovať využiteľnú vodnú kapacitu jemnozeme a pomáha rastlinám prežiť suché obdobia.

KĽÚČOVÉ SLOVÁ: skeletovité pôdy, častice skeletu, žula, retenčná vodná kapacita, retenčná krivka, pôdna voda, Vysoké Tatry.

Introduction

In November 2004, spruce stands in High Tatras were seriously affected by a windthrow, during which the strip of the forested area over 12000 hectares was cleared. One of the four chosen sites to be devoted to research, was set in fire next year. The fire burnt out about 200 hectares of fallen area (*Fleischer* et al. 2007). This site was nicknamed FIRE. Soil of the impacted area contain significant part of rock fragments, i.e. solid particles with diameter more than 2 mm.

As reported by *Poesen* and *Lavee* (1994), soils with significant content of rock fragments represent about 30% of West European soils. The share of such soil in Slovakia was not reported, but according to the country morphology, part of stony soils comparable to those in Western Europe can be expected. They are distributed mainly in mountaineous areas. Rock fragments in the soil should affect stony soil properties- soil bulk density, porosity, water retention, hydraulic conductivity, thus influencing water movent in such a soil.

However, literature describing soil water retention and soil water movement properties of stony soils is rather scarce, majority of interest is focused on homogeneous, agricultural soils (*Gusev*, *Novák*, 2007).

Maximum water retention capacity (MWRC) of stony soils means sum of MWRC of fine fraction of the soil, and MWRC of the rock fragments (stony part of a soil). Agricultural soils usually contain small part of stones only, therefore its contribution to the soil water retention and movement was (and usually can be) neglected. But, this is not the case of stony soils, where rock fragments form a significant part of such soils. As it can be seen in Fig. 1, at the site FIRE (H. Tatras), the share of stony part of moraine soil was up to 0.47. *Cousin* et al. (2003) reported in clay loam soils up to 0.569 share of rock fragments; it was ranging within 0.219 – 0.569, the lower value was located in the upper soil layer. *Coile* (1953) was probably the first who mentioned the necessity to take into account retention of rock fragments in stony soil to evaluate its water capacity. However, rock fragments contribution to the soil MWRC depends not only on the volumetric part of the rock fragments, but also on their origin, size and shape, on their porosity, on the position of rock fragments in the soil profile, and on degree of their weathering (*Hanson*, *Blevins*, 1979; *Montagne* at al., 1992; *Jones*, *Graham*, 1993; *Poesen*, *Lavee*, 1994; *Brouwer*, *Anderson*, 2000).

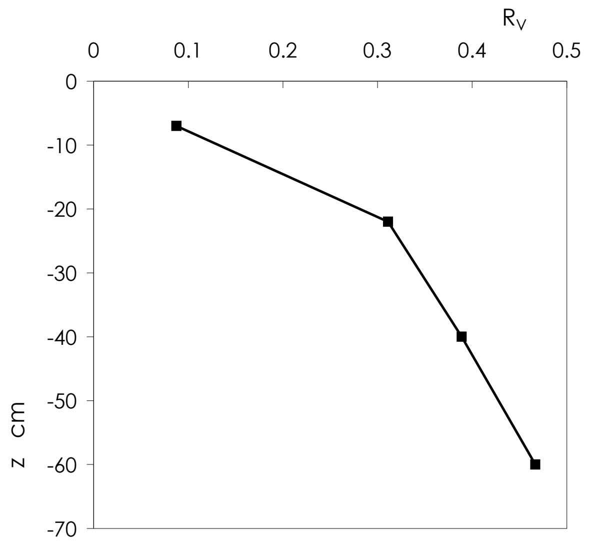

Fig. 1. Relative stone content R_v vertical distribution. Stones with diameter bigger than 1 cm were evaluated (FIRE site, High Tatras).
Obr. 1. Vertikálne rozdelenie relatívneho objemu kameňov R_v s rozmerom väčším ako 1 cm (lokalita FIRE, V. Tatry).

Rock fragments can hold water and act as an accumulation storage (source) during water movement in soil. There is a lot of studies devoted to the hydrophysical parameters of a fine fraction of soil, but a few only, to study the influence of rock fragments on hydrophysical properties of stony soils.

The origin of the rock fragments has significant influence on the soil water holding capacity. As was reported by *Poesen* and *Lavee* (1994), rock fragments of chalk have the highest MWRC, on the contrary, the basalt rock fragments retention capacity is close to zero. In general, rock fragments are decreasing stony soil MWRC. The smaller are the fragments, the more weathered they usually are (*Childs*, *Flint*, 1990), and more water per unite rock volume they can hold. *Childs*, *Flint*, (1990) measured the maximum contribution of rock fragments retention to the available soil water, of plants from 40 soil locations in southwest Oregon. They found their average contribution to the total available water as 0.15 volumetric water content, ranging from 0.016 to 0.52. This retention range is the result of the differences in quality of the above mentioned rock particles.

As it was shown by *Brouwer*, *Anderson*, (2000), *Cousin* et al., (2003), rock fragments are changing their water content with changing water potential, the relationships between rock water content and rock water potential (retention curve) can be determined. The retention of water in this media can contribute to the available stony soil water capacity.

Soils containing rock fragments are strongly influencing even their hydrodynamic characteristics, quantitatively expressed by the soil hydraulic conductivities. The presence of rock fragments usually decrease hydraulic conductivity of soil saturated with water, but in some cases (existence of lacunar pores), it can increase saturated hydraulic conductivity of such soils (*Brakensiek* et al., 1994; *Novák* et al., 2008).

The aim of this paper is to present measurements results of the maximum water retention (holding) capacity of rock fragments (granite stones), and its contribution to the available water capacity for plants as a part of the stony soil at site FIRE in the High Tatra region (Slovakia), and thus to demonstrate its significance for hydrological processes, as well as in a general sense.

FIRE site

The site FIRE is located about 1 kilometer to the west of comunity Starý Smokovec, just above the main road to Štrbské Pleso locality. Its altitude is 1000–1200 m a.s.l., oriented to the South-East, with slope about 10 %. Details can be found elsewhere (*Fleischer* et al., 2007; *Fleischer*, 2008).

Basic soil properties

The soil type at the site FIRE was classified (according to the fine- earth material, or soil matrix) as Dystric Cambisol and parental rock is stone centered polygons (*Gömöryová*, et al., 2008). At the site of our excavation it is close to moraine.

The soil contains significant part of stony fraction, the largest part of it can be noted as cobbles (diameter 75–254 mm), (*Soil Survey Staff*, 1975). Even smaller fractions of rock fragments can be found there. The soil matrix (fine fraction) was sampled into metal cylinders, to estimate its characteristics in the laboratory.

Fine fraction

According to the results presented by *Bärwolf* (2006), fine fraction of the soil profile is relatively homogeneous along its depth and, according to USDA classification, it can be noted as gravelly sandy loam (*Soil Survey Staff*, 1975). The soil profiles at site FIRE were found surprisingly similar to the other three sites studied (REF, EXT, NEX), according to the parental rock and texture.

Rock fragments

Because the parent material of soils is a moraine, numerous solid (stony) particles as a part of the soil can be observed there. Because their portion in the soil was significant, it is expected to play an important role in the water retention and movement. Therefore, their share should be estimated in the soil. It was done by excavating and by a carefull separation of rock fragments with diameter larger than 1.0 cm, and by estimating their volume. The sample of square cross section with area of 1.0 m^2 was excavated for separate 15–20 cm soil layers, up to 70 cm below the soil surface. Rock fragments in the soil were of rounded shape with diameters 1––20 cm; more than 50% of all rock particles were of diameters 3.0–10.0 cm. Results of this measurement at the site FIRE is demonstrated in Fig. 1. Fine fraction, pores and the share of stones in the overall soil volume are demonstrated in Fig. 2 (*Novák* et al., 2008).

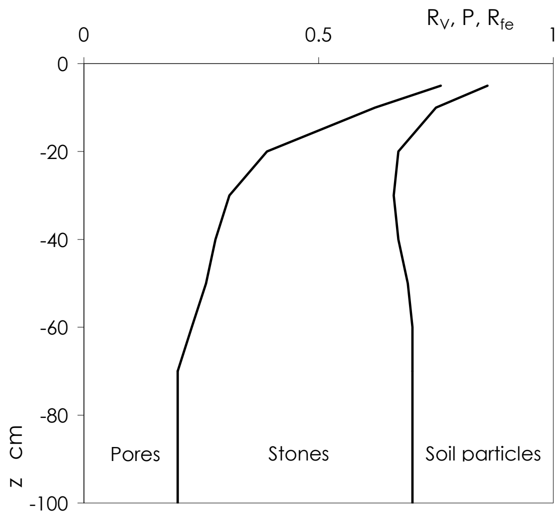

Fig. 2. Relative vertical distribution of three soil constituents (small soil particles, R_{fe}, stones, R_v and pores, P). FIRE site, High Tatras.

Obr. 2. Rozdelenie relatívneho zastúpenia troch zložiek pôdy (jemnozem, R_{fe}, kamene, R_v a póry, P). (lokalita FIRE, V. Tatry).

Methods

Water content of the saturated rock samples

To estimate water content of the rock particles saturated with water, 18 stones were selected from the excavated stony parts. They were 5 cm in the length, approximately of spherical shape, with volumes in the range from 3 to 32 cm^3. They were immersed into the tap water at temperature 20 ºC. It was shown, that being 24 hours in the water, their water content was changing no more. Then their volume was estimated by fast immersion into water in graduated cylinder. Afterwards, their surface was quickly dryed by filtration paper, and weighted followingly. After drying out at 105 ºC for 24 hours, these rock fragments were weighted and volumetric soil water content was evaluated by a standard procedure (*Kutílek*, *Nielsen*, 1994).

Retention curves of the rock samples

To estimate retention curves of the rock fragments, four of them were selected, with volumes in the range from 16 to 45 cm^3. Those volumes were chosen to allow for the retention curves determination. Because of their irregular shape, they were immersed into fine sand in the metalic cylinder of 100 cm^3 volume (Kopecky cylinder), then saturated with tap water for 24 hours (together with sand). Saturated samples were located first into the sand box for low negative pressures exposure, then into pressure chamber on ceramic plate (product of Soil Moisture Corp.). Three successive pressures (up to 300 kPa) were applied, until soil water content of the samples was in equilibrium. Then, the soil water content of the rock fragments was estimated as before.

Results and discussion

Granite cobbles maximum water content, estimated according to the above described methodology, is presented in Tab. 1. Basic parameters of the four rock fragments used, are in Tab. 2. Frequency distribution of the saturated samples water content (θ_s) at site FIRE, is presented on Fig. 3.

Water content of the saturated rock particles, or their maximum water holding capacity (MWHC) was found in the wide range of volumetric water contents (0.05–0.15). About half of MWHC of the rock samples under study covered the range from 0.06 to 0.1.

Probability exceedance curve of MWHC (or saturated stone water content), at site FIRE, can be seen in Fig. 4. It shows its relatively homogeneous distribution along the whole rock water content range. Retention curves $h_w = f(\theta)$ of four different rock samples (presented in Tab. 2) from site FIRE, are shown in Fig. 5. What can be seen on Fig. 5 ? There are two main features of these retention curves. First, there are large differences in saturated rock sample water contents of individual samples, and decrease of the rock water content in the range of water potentials (0, –0.3 MPa) is remarkable, and is proportional to the saturated soil water content (Tab. 2). The second item is not a surprise, because the larger the pores, the sooner they are emptied during the water potential decrease.

The high water capacity of the sandstone fragments available to plants, was reported by *Hanson* and *Blevins* (1979) – about 0.11, but the shaly fragments contained 0.23 of available water expressed by the soil volume. The available water capacity for plants (AWCP) was evaluated by them as the difference between the water content at field capacity and the water content corresponding to the matrix potential of the wilting point –1.5 MPa. Surprisingly, such dense rock like ironstone gravel as a part of soil (*Brouwer*, *Anderson*, 2000), was containing maximum water content expressed on volumetric basis in the range of 0.166 to 0.361, corresponding to water potential 0.02 MPa. Even the volumetric water content, corresponding to the wilting point (at –1.5 MPa), was evaluated in the range of 0.13 to 0.228), and available water capacity of ironstone gravel ranged from 0.034 to 0.149, as expressed in parts of ironstone gravel volume.

T a b l e 1. Basic characteristics of rock (granite) fragments used to estimate stone maximum water capacity; V – stones volume, MWC (θ_s) – maximum water capacity of stones.
T a b u ľ k a 1. Základné charakteristiky kameňov (žuly), použitých na určenie maximálnej vodnej kapacity; V – objem kameňov, MWC (θ_s) – maximálna vodná kapacita kameňov.

No.	V [cm^3]	MWC (θ_s)
1	18.0	0.06
2	6.3	0.08
3	10.0	0.09
4	9.0	0.09
5	10.0	0.14
6	19.0	0.06
7	5.5	0.15
8	5.8	0.08
9	9.0	0.15
10	8.3	0.09
11	19.0	0.05
12	32.0	0.08
13	11.0	0.10
14	3.7	0.12
15	12.3	0.07
16	6.2	0.11
17	6.9	0.15
18	11.0	0.12

T a b l e 2. Basic characteristics of stones used to measure their retention curves; m_d, m_w – mass of dry stones/stones saturated with water, V – stones volume, θ_s – the water content of saturated stone, AWC – available water capacity as the difference between θ_s and SWC at water potential –0.3 MPa.
T a b u ľ k a 2. Základné charakteristiky kameňov použitých na meranie ich retenčných kriviek; m_d, m_w – hmotnosť suchých kameňov, resp. kameňov nasýtených vodou, V – objem kameňov, θ_s – vlhkosť vodou nasýtených kameňov, AWC – využiteľná vodná kapacita ako rozdiel medzi θ_s a SWC, zodpovedajúca vodnému potenciálu pôdy –0.3 MPa.

Stone number	m_d [g]	m_w [g]	V [cm^3]	θ_s	θ_{AWC}
1	118.06	118.51	45	0.0100	0.005
2	49.31	50.76	20	0.0725	0.058
3	41.32	42.95	16	0.1090	0.072
4	43.34	44.54	18	0.0667	0.047

Conclusions

The maximum water capacity of rock (granite) fragments in High Tatra forest soil was measured. Measurements have shown coarse rock (granite) fragments with surprisingly high maximum reten-

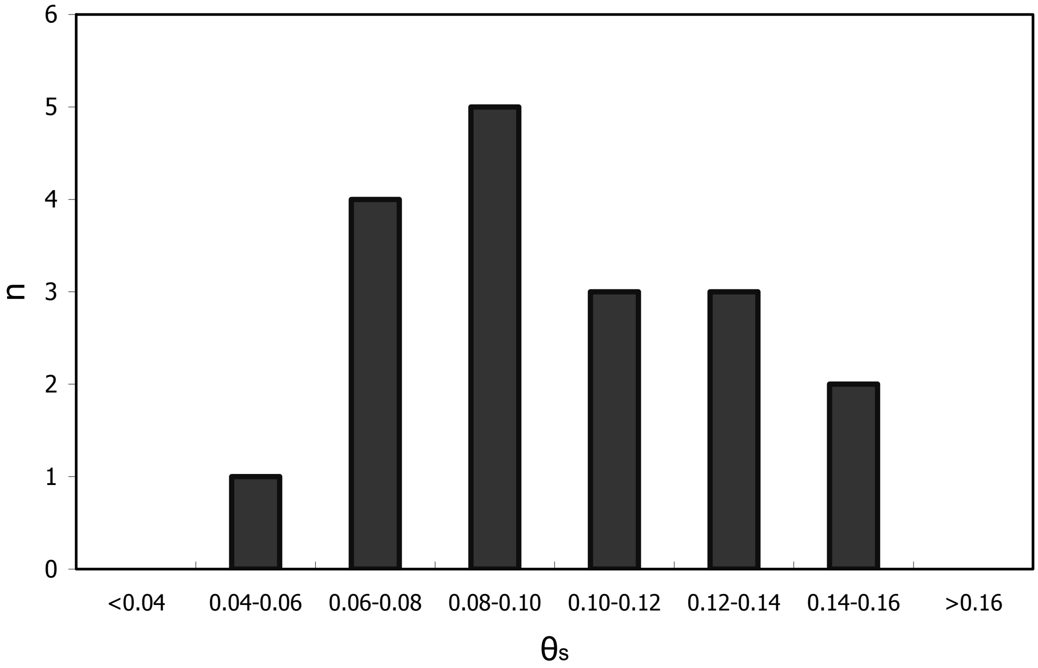

Fig. 3. The frequency distribution of saturated stones water content (θ_s) at site FIRE, High Tatras.
Obr. 3. Rozdelenie početností objemových vlhkostí vodou nasýtených kameňov (θ_s) v lokalite FIRE, V. Tatry.

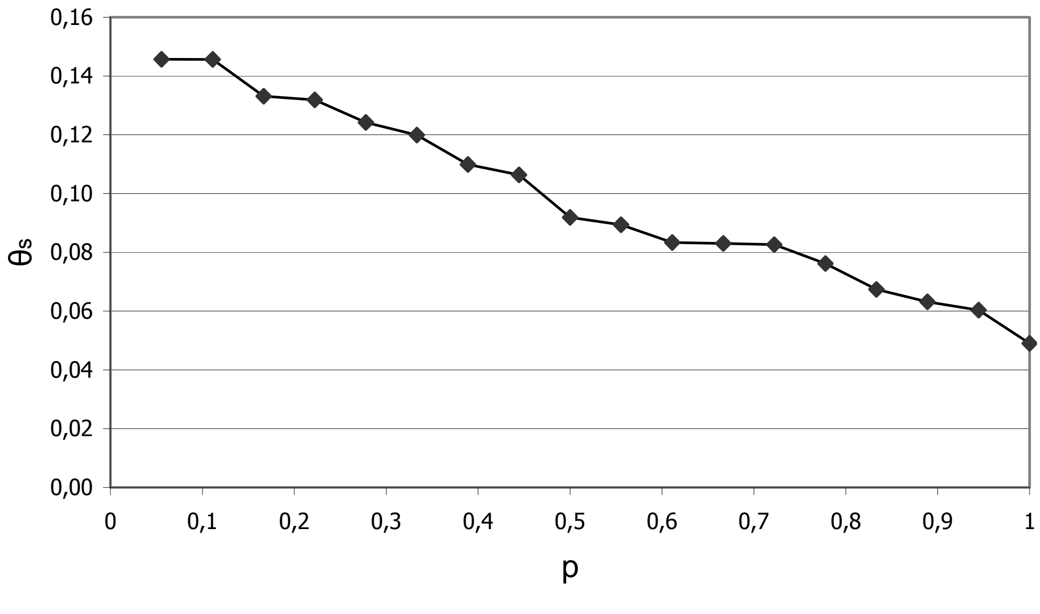

Fig. 4. Probability exceedance curve of saturated stones water content (θ_s) at site FIRE, High Tatras.
Obr. 4. Čiara rozdelenia pravdepodobností objemových vlhkostí vodou nasýtených kameňov (θ_s) v lokalite FIRE, V. Tatry.

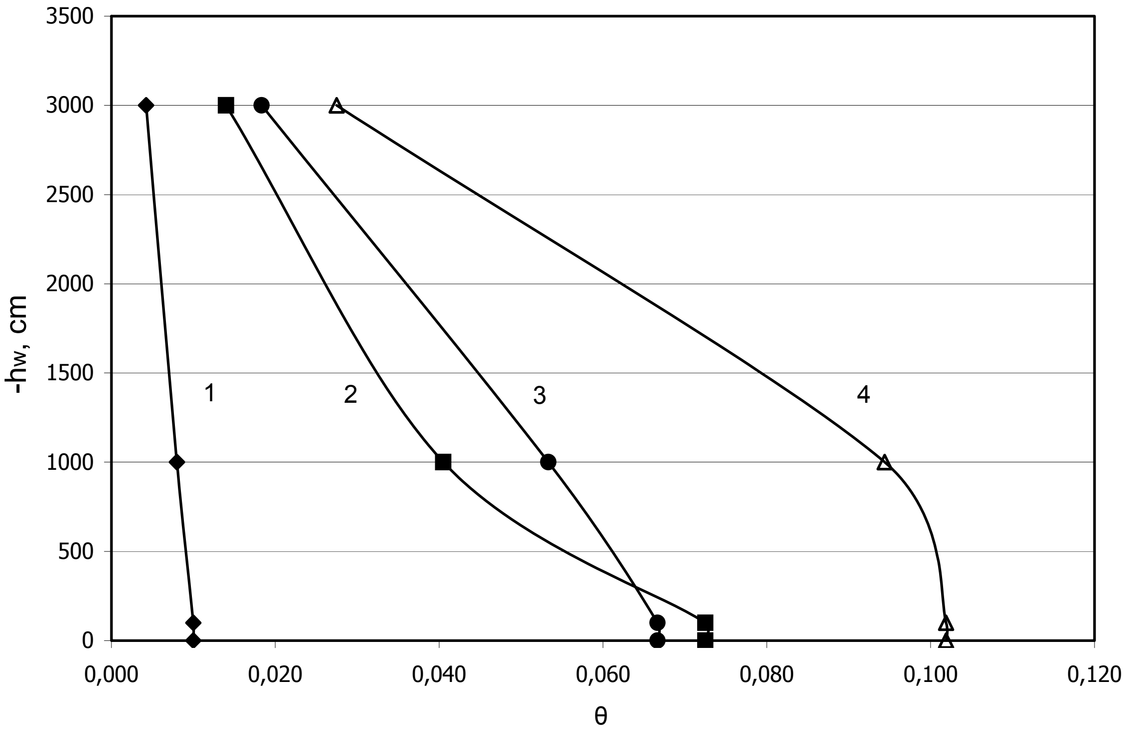

Fig. 5. Retention curves $h_w = f(\theta)$ of four different stones (see Tab. 2) from site FIRE, High Tatras.
Obr. 5. Retenčné krivky $h_w = f(\theta)$ štyroch rozdielnych kameňov (pozri tab. 2) v lokalite FIRE, V. Tatry.

tion capacity. The volumetric water content was within a wide range from 0.02 to 0.16.

The original method of rock water retention curves determination has been elaborated. It is based upon the procedure of submerging the irregular rock samples into the fine sand in metal cylinders, then using the standard method of processing. The rock water retention curves of granite cobbles demonstrated high variability among particular cobbles (Fig. 5), as well as high available water capacity for plants up to 0.109.

Available water capacity of the rock fragments in High Tatra forest soil, containing granite cobbles, can help trees to survive during dry spells. Contribution of water, contained in the rock fragments to the available soil water capacity expressed in volumetric units, was found in the range of 0.005 to 0.07. Relatively low water conductivity of the rock fragments allows for conservation (storage) of water for a relatively long time.

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RETENCIA VODY ŽULOVÝMI ČASTICAMI SKELETU V SKELETOVITÝCH PÔDACH OBLASTI VYSOKÝCH TATIER

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Meraním bola určená maximálna vodná kapacita skeletu (žula) ako súčasti lesnej pôdy Vysokých Tatier. Z výsledkov meraní vyplýva prekvapujúco vysoká maximálna retenčná kapacita skeletu (žuly), ktorá sa pohybovala v rozmedzí od 0,02 do 0,16 objemovej vlhkosti.

Bola navrhnutá originálna metóda merania retenčných kriviek skeletu, ktorá je založená na uložení nepravidelných fragmentov skeletu do jemného piesku v kovových valcoch; potom bola použitá štandardná procedúra merania retenčných kriviek. Vlhkostné retenčné krivky žulových kameňov demonštrujú výraznú variabilitu medzi nimi (obr. 5), podobnú, ako bola variabilita obsahu vody dostupnej pre rastliny v jednotlivých kameňoch, tá v jednom prípade dosiahla hodnotu 0,109 objemovej vlhkosti.

Využiteľná vodná kapacita žulových kameňov v lesných pôdach Vysokých Tatier obsahujúcich kamene môže stromom pomôcť prežiť najmä v suchých obdobiach. Príspevok vody obsiahnutej v kameňoch k vodnej kapacite skeletovitej pôdy využiteľnej rastlinami bol zistený v rozsahu 0,005 až 0,07. Relatívne nízka hydraulická vodivosť kameňov umožňuje retenciu vody v nich počas relatívne dlhého obdobia.