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METHOD FOR THE RAPID DETERMINATION OF SOIL PHYSICAL PARAMETERS OF EXTENSIVE GREEN ROOFS

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ABSTRACT

Optimization of soil mixes used for extensive green roofs is essential in a long-term, well-functioning system design and implementation. One of the key elements of this is determining the soil physical characteristics of the used components with the following critical elements: rock mass, rock volume, space between particles, water absorption and water retention capacity, surface water retention. In our research we developed a new method for rapid identification of soil physical performance characteristics of extensive green roofs. The performance indicators were divided into three groups: 1. density-related indicators: loose density, wet loose density, rock material density, wet density of the rock, crystal structure density, rock mass per unit rock volume; rock volume per unit rock volume, rock mass per unit wet rock volume, rock mass per unit wet rock mass. 2. Water content related indicators: water content (porosity) per unit mass of wet rock, water content (porosity) per unit wet rock volume, water content per unit volume of wet granules, surface water per unit volume of granules, surface water per unit mass of granules. 3. Indicators related to space between particles: space between grains per unit volume of granules, space between grains per unit mass of granules. During the development of the procedure and method it was important for us that the parameters should have been determined simply and easily. Further advantages of the developed method are that they are fast, cheap and reasonably accurate and help rock/soil mixture characterization and quantitative comparability. We illustrate the method and the system of performance indicators on examples of growing media mixes for extensive use.

Keywords: soil physics parameter, performance indicators, extensive green roof, rapid identification

INTRODUCTION

In general, green roofs are defined as flat or slightly sloped roof with a waterproofing membrane, a load carrier layer, and a soil layer of a certain thickness to provide the vegetation to be planted with an environment to live in. From the static, heat and humidity control point of view, green roofs are sized and installed with insulation for rainwater; with the vegetation and insulating layers constituting an integrated system (FLL, 2002; WERTHMANN, 2007).

In technical literature, there is a distinction between extensive green roofs and intensive green roofs, categories from agriculture. An extensive green roof is basically a roof with an ecologically active vegetation protective layer, typically unsuitable for regular access. The design is close to nature, relying on undemanding plant material corresponding to the natural cycles and processes. Taxa are drought-tolerant, rockery succulents and other plant materials well-adapted to extreme conditions. The other category is that of intensive green roofs, or roof gardens, which require a high level of maintenance, regular replenishment of nutrients, typically with irrigation systems installed, with selectively bred taxa and a higher proportion of covered surfaces. Hybrid solutions of the two categories are rare in practice as the planned use of the green roof determines the type to be implemented. The decision between an extensive or an intensive green roof is influenced by the designated use, maintenance needs, irrigation, the acceptable load, the depth and the species to be used (HIDY et al., 1995). *Table 1* provides a comparison between extensive and intensive green roofs.

Table 1. A comparison of extensive and intensive green roofs

	Extensive	**Intensive**
Use	no access, ecological protective layer	suitable for regular access
Maintenance	low maintenance costs	requires care
Irrigation	usually not used	not installed without irrigation
Weight	1.6-24 kN/m^2	2.0-15.0 kN/m^2
Structural depth	10-15 cm	25-100 cm
Plant material	stonecrop, wildflowers, grass	perennial ornamental plants, woody plants, herbaceous plants

Source: HIDY et al., (1995)

The growing medium on extensive green roofs is to meet special requirements. Intensive roofs do not get regular maintenance, no pesticides are used, even irrigation is not available, and therefore the composition of the low-depth mix must take these factors into account. The composition, the physical and chemical parameters of substrate mixes used on extensive roofs are determined by the local climate (exposure, humidity, wind uplift etc.) and by the planted vegetation. Nevertheless, the mixes for extensive roofs need to comply with multiple requirements. A layer with a depth of only a few centimeters is to provide, at the same time, a balanced nutrient supply, a stable heat system, good water management, it is to have the appropriate, not too heavy weight, while it is supposed to retain water but also control storm-water runoff. Low volumetric weight (0.2-0.8 g/cm^3) biomass materials are often used in growth media as they provide not only good water management but are also excellent for improving soil life and biological activity. Examples of such materials are peat, wood chips, sawdust etc. (FORRÓ, 1998; FORRÓ, 2001).

The weight of the growth media is important for the load of the roof structure, for the compaction factor and erosive processes. The water retention, water drainage capacity, the nutrient retention and supply features etc. of growth the media are much more important for the vegetation to be planted. Several substrate types have been developed for extensive green roofs (DEUTSCHER, 1995).

In the construction practice for extensive roofs, single-component substrates of mineral origins are common for their short-term structural characteristics and relative low cost, but in the long run their use may result in increased acidity and the build-up of toxic materials. Acidity increases the risk of pathogens and pests, while the buffer capacity of those substrates is minimal. The humus materials and clay-humus complexes used in the mixes provide sufficient nutrient reserves for the plants. The nutrient release rate protects the plants from overconsumption (FORRÓ, 2002).

The optimization of substrate mixes used on extensive green roofs is essential for the design and implementation of system well-functioning in the long run. A key component in that effort is to determine the soil mechanics characteristics of components used, with the

following critical items: unit weight, unit volume, pore space, water absorption and water retention capacity, water retention on the surface.
The main objective of this study is to develop a new method/procedure for prompt determination of performance characteristics for extensive green roofs. A subsidiary objective of the study is closely related to the first objective, to illustrate the procedure through examples of extensive media mixes.

MATERIAL AND METHOD

The conceptual procedure for determining the parameters is as follows. The rock sample is gently dried at 70 ˚C for 24 hours in a drying cabinet. Then the sample is cracked to particle sizes in the 0.5-1.0 mm range and graded. Required equipment: graduated cylinder, scales, water, dry, fine quartz sand or corundum of known particle size. For accuracy, preciseness and reliability of measurements, 10 parallel measurements are conducted at the same time.
The procedure for the measurement is as follows: Determine the tare weight of the empty graduated cylinder. Place some sample material into the cylinder and measure the net weight (loose/m). Read the volume (loose/v). Pour the sample onto a sheet of paper. Place some quartz sand into the cylinder, measure the net weight (por/m), and read the volume (por/v). Add the previous sample from the paper, and shake with the quartz sand. Knock on the cylinder and if the particles are not covered in sand, while continuously knocking the cylinder, add more sand so that the sample particles are covered. Measure the combined net weight (mix/m) and read the combined volume (mix/v). Pour the material from the cylinder and fill with a certain amount water (of known volume), measure the net weight of the water (for accuracy, water.m = water.v). Add some sample material to the water and measure the net weight of the suspension (susp/m).Wait for 10 minutes for the suspension to settle, than read the combined volume for the suspension (susp/v). Remove the excess water from the rock particles, close the opening of the cylinder, turn it upside down and wait for the remaining water to trickle away (0.5-1 hour).Turn the cylinder back to its normal position and measure the weight again (wet/m). As the last step, compact the wet material by gently hitting against a hard surface, then read the wet volume (wet.v). Table 2 explains the calculation of the parameters.
The results are statistically evaluated in several steps. Based on the 10 parallel measurements, the arithmetical average and variation for each physical performance indicator is determined for the media. Using the averages, profile diagrams are created for the media for visual representation. Using single-factor variation analysis, it is determined whether there are two samples significantly different for the given characteristic. Where there is a significant difference, the least significant difference (LSD) approach is used for comparison in pairs in the post hoc test.

The procedure and the evaluation is illustrated using the following mix:

Mix No. 1: zeolite 17 %, clay granulate 17%, river sand 20%, Florasca 'A' substrate 40 %, Hanság peat 5%.
Mix No. 2: ground brick 25 %, ground ytong blocks 25 %, Hanság peat 15%, zeolite 20 %, meliorite 15%.
Mix No. 3: Florasca 'A' substrate 50%, Hanság peat 20%, sand 15%, meliorite 15%.

Table 2. Calculation of parameters in the procedure

Loose density	$\rho_{\mathrm{loose}} = m_{\mathrm{loose}} \div V_{\mathrm{loose}}$
Wet, loose density	$\rho_{\mathrm{wet\ loose}} = m_{\mathrm{wet}} \div (m_{\mathrm{susp}} - m_{\mathrm{water}}) \times \rho_{\mathrm{loose}}$
Rock density	$\rho_{\mathrm{rock}} = m_{\mathrm{mix}} - \rho_{\mathrm{por}} \times V_{\mathrm{por}}) \div (V_{\mathrm{mix}} - V_{\mathrm{por}})$
Rock density, wet	$\rho_{\mathrm{wet\ rock}} = m_{\mathrm{wet}} \div (m_{\mathrm{susp}} - m_{\mathrm{water}}) \times \rho_{\mathrm{rock}}$
Crystal structure density	$\rho_{\mathrm{crystal\ structure}} = (m_{\mathrm{susp}} - \rho_{\mathrm{water}} \times V_{\mathrm{water}}) \div (V_{\mathrm{susp}} - V_{\mathrm{water}})$
Rock weight, in unit volume	$m_{\mathrm{rock/V}} = \rho_{\mathrm{rock}}$
Rock volume, in unit volume	$V_{\mathrm{rock\ /Vrock}} = \rho_{\mathrm{rock}} \div \rho_{\mathrm{rock}}$
Rock weight, in unit wet volume	$m_{\mathrm{rock/}}v_{\mathrm{wet\ rock}} = \rho_{\mathrm{rock}}$
Rock weight, in unit wet weight	$m_{\mathrm{rock/}}m_{\mathrm{wet\ rock}} = (1 \div \rho_{\mathrm{wet}}) \times \rho_{\mathrm{rock}}$
Water content (porosity), in unit wet weight	$m_{\mathrm{water/}}m_{\mathrm{wet}} = 1-(1 \div \rho_{\mathrm{wet}}) \times \rho_{\mathrm{rock}}$
Water content (porosity), in unit wet volume	$m_{\mathrm{water/Vwet}} = (\rho_{\mathrm{wet}} - \rho_{\mathrm{rock}})$
Water content, in unit wet granulate volume	$m_{\mathrm{water/V\ unit\ wet\ granulate}} = \rho_{\mathrm{wet\ loose}} - \rho_{\mathrm{loose}}$
Surface water, in unit granulate volume	$V_{\mathrm{surface\ water/}}v_{\mathrm{\ granulate}} = \rho_{\mathrm{loose}} \div \rho_{\mathrm{rock}} + m_{\mathrm{water}}/v_{\mathrm{unit\ wet\ granulate}}) - 1$
Surface water, in unit granulate weight	$V_{\mathrm{surface\ water/m}} = V_{\mathrm{surface\ water/}}v \div \rho_{\mathrm{wet}}$
Pore space, in unit granulate volume	$P_{\mathrm{space}}/v_{\mathrm{unit\ granulate}} = 1-(\rho_{\mathrm{loose}} \div \rho_{\mathrm{rock}})$
Pore space, in unit granulate weight	$P_{\mathrm{space}}/m_{\mathrm{unit\ granulate}} = P_{\mathrm{space}}/v_{\mathrm{unit\ granulate}} \div \rho_{\mathrm{loose}}$

Source: own construction based on KOCH et al. (1966)

RESULTS

The procedure can be used to simply and rapidly determine those parameters of the rock sample/substrate mix that are required most often for design and implementation efforts on the technical side: density, the volume of cavities in the volumetric unit of the rock, the density of the crystal structure constituting the rock etc.

As a result of length limitations, the results presented herein are only highlights from the substrate mixes. For the accuracy, preciseness and reliability of the measurements, averages are calculated from 10 parallel measurements.

The results indicate that the substrates represent a typical pattern. Every density parameter (loose density; wet loose density, rock density, wet; crystal structure density) resulted in a series of descending values for Mix 1, Mix 3 and Mix 2. *Figure 1* shows parameters directly corresponding to density, while *Table 3* presents the results of the post hoc test for the density parameters of the mixes.

This summary table evidences corroborates that Mix 1, then Mix 3, then Mix 2 took the highest values for every density parameter for every mix, at least to 95 %.

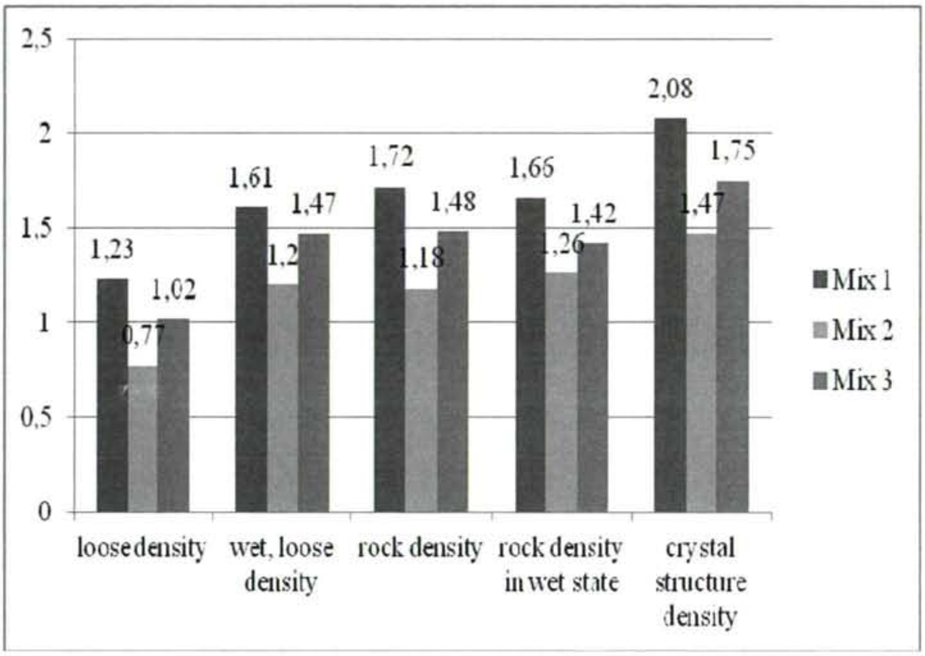

Figure 1. Density Parameters of the Mixes Tested

Table 3. Matrix for Significant Differences in Density Parameters for the Mixes Examined

loose density wet, loose density rock density rock density in wet state crystal structure density	**Mix 1**	**Mix 2**	**Mix 3**
Mix 1	–	99% 99% 99% 99% 99%	99% 95% 99% 99% 99%
Mix 2	0.46 0.47 0.54 0.40 0.61	–	99% 99% 99% 95% 99%
Mix 3	0.20 0.14 0.24 0.24 0.33	0.25 0.27 0.30 0.16 0.28	–

CONCLUSIONS AND DISCUSSION

Currently, a number of Hungarian National Standards cover testing for soil quality and soil mechanics characteristics: MSZ-08-0205:1978 – Determination of physical and hydro-physical properties of soils; MSZ-08-0480-1:1981 – Horticultural soil mixtures. Qualitative requirements; MSZ-08-0480-2:1982 – Horticultural soil mixtures. Laboratory analyses; MSZ-08-1788:1984 – Field measurement of hydraulic conductivity of soil. One must note that these standards were primarily developed for soil and not substrate mixes to be used under special extensive conditions. It is also known that detailed and lengthy tests should be carried out primarily in accredited laboratories, relying on the appropriate skillest and equipment.

The procedure is designed in a manner that would provide as many parameters as possible through a few very simple and interlinked weight and volume measurement. The entire system models the scenario of rainwater falling onto the extensive green roof, so the particles absorb as much water as the hydration shell around them, the rest drains away. These measurements are often required, and they are carried out without being comprehensive, however, with much more effort invested in the process than it would be necessary. The lack of a system and the incomprehensive nature of the process would very often renders the comparison of samples tested for different parameters at different times impossible, and the result is the loss of valuable information. The procedure described here is designed to prevent that loss of information, while at the same time it is a useful tool to better understand the behaviour of a substrate, rock material, or filtering particles. A disadvantage of the procedure is that it is of limited use with fine grains. Profiling physical parameters of mixes has the primary advantage that it provides the comparability of samples through a detailed, almost comprehensive description of the materials.

The profiles can be considered as fingerprints for rock/medium features, very characteristic to the samples tested. The profile polygon is unambiguously determined by the area/perimeter (A/P) ratio and the profile polygon centre of gravity (GC). It would be a useful step to adapt that methodology to extend the procedure described (KOLLÁR-HUNEK et al., 2008).

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