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Vesna MARKOSKA,
Velibor SPALEVIC, Kiril LISICHKOV,
Katerina ATKOVSKA and Rubin GULABOSKI

DETERMINATION OF WATER RETENTION CHARACTERISTICS OF PERLITE AND PEAT

SUMMARY

The results of the water retention curves between (pF -2 and -4.2) matric potential for two substrates perlite and peat, are presented in this paper. Perlite is an inorganic, expanded aluminosilicate of volcanic origin. Peat is an organic substrate. For assessing this parameter, the method of bar extractors and Porous plate extractors have been explored. The method is applied on 7 different regimes of pressure (0.1; 0.33; 1; 3; 6.25; 11; 15 bars) in samples composed of perlite and peat present at different volume ratios of 80% Perlite + 20% Peat, 70%Perlite + 30% Peat, 50% Perlite + 50% Peat, 30% Perlite + 70% Peat, 20%Perlite + 80% Peat. The retention capacity of the perlite, at all applied different point of tension, is: 67.88% for 0.1 bar, 58.35%, for 0.33 bar, 47.70% for 1 bar, 39.78%; for 3 bars, 34.84 for 6.25 bars, 30.10% for 11 bars and 26.65% for 15 bars and for the peat are: for 0.1 bar = 89.16%, for 0.33 bar = 74.84%, for 1 bar = 57.94%; for 3 bars = 45.15%; for 6.25 bars = 39.57; for 11 bars = 33.89%; for 15 bars = 23.17%. The peat substrate shows higher retention at all points of tension of 0.1; 0.33; 1; 3; 6.25; 11, with the exception of 15 bars, when the retention is lower than the substrate perlite.

The reason for the higher water retention at peat than at perlite, is the result of the high content of the humus in the peat. Of all the analyzed samples, it can be seen that all curves show a favorable water retention capacity, which is due to the fact that the peat and the perlite as substrates have high porosity. The aim of this paper is to examine the impact of the water retention capacity of both substrates and their mixtures. Also to see the ability which substrate retains a greater amount of water that will be easily accessible to the plants for their proper growth and development.

Key words: perlite, peat, water retention.

[1]Vesna Markoska (corresponding author: vesnemarkoska@yahoo.com), Faculty of Environmental Resources Management, MIT University, Skopje, MACEDONIA. Velibor Spalevic, University of Montenegro, Faculty of Philosophy Niksic, Department of Geography, MONTENEGRO; Kiril Lisichkov, Faculty of Technology and Metallurgy, University Ss. “Cyril and Methodius” Skopje, Republic of Macedonia. Katerina Atkovska, Faculty of Technology and Metallurgy, University Ss. “Cyril and Methodius” Skopje, MACEDONIA, Rubin Gulaboski,Faculty of Agriculture, Faculty of Medical Sciences, University "Goce Delcev" Stip, MACEDONIA;
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INTRODUCTION

Substrates are formulated from various inorganic and organic components to provide suitable physical and chemical properties as required by the specific crop and growing conditions (Bunt, 1988). An important physical property of substrates is air-filled pore space. Individual components of mixed substrates are often chosen considering their properties so that they complement each other and the resultant medium possesses most of the desirable attributes for good plant growth and production. Soil and organic components used in substrate mixes, like peat or compost, often lack coarse particles necessary for adequate aeration and hold moisture relatively tightly around the particles, predominantly by adsorptive forces (Bilderback & Jones, 2001).

Perlite is an inorganic, expanded aluminosilicate of volcanic origin (Nelson, 2003). Perlite is a very lightweight soil amendment perlite is used throughout the world as a component of soil-less growing mixes where it provides aeration and optimum moisture retention for superior plant growth. Expanded perlite has several attractive physical properties for commercial applications including low bulk density, low thermal conductivity, high heat resistance, low sound transmission, high surface area, and chemical inertness.

The use of perlite reportedly dates back to the 1800s and modern exploitation of this resource in the United States began in the 1940s (Austin & Barker, 1998; Ennis, 2011; Allen, 1992; Weber, 1963). Expanded perlite is commonly used for herbicides, insecticides, and fertilizer as a carrier (Tekin, 2004), Moreover, it is commonly used in the food industry, filter product, growing of seed, regulating of the soil in agriculture, and in so many other industrial applications (Alihosseini et al., 2010). Perlite has very good physical characteristics. The physical properties of container-growing substrates, particularly air space, container capacity, and bulk density, have a significant impact on plant growth, and knowledge of these properties is essential in properly managing nursery irrigation and fertilization programs (Yeager et al., 2000). As such, physical properties of container-growing substrates and individual substrate components have been investigated and reported in numerous research studies in past years (Bilderback et al., 1982; Bilderback & Lorscheider et al., 1995) and continue to be emphasized in more recent studies (Abad et al., 2005; Bilderback et al., 2005; Blythe et al., 2005; Cole et al., 2005) perlite is one of the best media for growing plants, it is possible to grow most plants in perlite alone and is just as successful as traditional peat mixes. However there are no nutrients in perlite. Perlite on the other hand has been widely used in soil-less cultures. Perlite, is rather inert (low buffering and cation exchange capacities. In general, it has a closed cellular structure, with the majority of water being retained superficially and released slowly at a relatively low tension, providing excellent drainage of the medium and aeration of rhizosphere. Therefore, it requires frequent irrigation to prevent a fast developing water stress (Maloupa et al., 1992).


Figure 1. a) Substrate peat b) Substrate perlite

Peat is an organic substrate. In 1960 the peat as a substrate began to be used in gardening for growing vegetables (Puustjarvi, 1973). There are different types of peat that differ in their degree of decay (Handreck and Black, 2005; Handreck, 1992). Depending on what the peat is formed of, there are different types of peat, from different plant species, created at different climatic conditions, and all of these conditions affect the different characteristics of the peat (Raviv et al ., 2002). Peat is a very porous substrate with excellent water capacity, and therefore is used together with other substrates. Advantages of peat as a substrate have been studied by many authors. Its long-time success is certainly due to the physical properties (slow degradation rate, low bulk density, high porosity, high water holding capacity and the chemical characteristics (relatively high cation exchange capacity, CEC) that makes peat particularly suitable as growing media for a large number of vegetables and ornamentals (Bohlin et al., 2004). Peat is formed as a result of the partial decomposition of plants (Sphagnum, Carex) typical of poorly drained areas (peat bogs), with low nutrients and pH, under low temperatures and anaerobic conditions (Raviv et al., 2002).

Other relevant properties are the high easily available water under conditions of container capacity, i.e. after the end of free drainage and the high oxygen diffusion rate. On the other hand, as negative aspect peat can be a conducive substrate for numerous soil-borne diseases and its sterilization does not solve the problem as it leaves a biological vacuum that can be easily filled by pathogenic fungi (Abad et al., 2001). Peat use in horticulture increased during the last decades, resulting in rising costs and generating doubts about availability of this material in the near future due to environmental constraints. In fact, peat mining has been recently questioned because it is harvested from peat lands, highly fragile wetlands ecosystems with a great ecological and archaeological value, included in the list of natural habitats with a potential degradation. (Barber et al., 1993). Peat also plays an important role in improving groundwater quality, and peat bogs also serve as a special habitat for wild plants and animals. Moreover, these ecosystems represent important carbon dioxide (CO_2) sinks. (Maher et al., 2008). Peat is the most widely used growing media and substrate component in horticulture, currently accounting for 77–80 percent of the growing media used annually in Europe’s horticultural industry (Gruda, 2012a). Seedlings and transplants are grown predominantly in organic substrates based on peat it is also used in horticulture as a raw material for substrates in which container plants are grown (Gruda, 2005). Peat has long been used as a component of standardized growing media; however, research in the1960s showed that it could be used as a growing medium in its own right both for container plants and for vegetable and cut flower production (Puustjarvi, 1973). Peat substrates offer numerous advantages and their nutrient content and pH are easy to control because both are initially low. The purpose of this paper is to see which substrate retains a greater amount of water, and that water to be easily accessible to plants for their proper growth and development. Also to see the impact of the water retention capacity of both substrates and their mixtures. Retention curves have great practical and theoretical significance, because they show data about water properties in substrate. These curves give the opportunity to determinate when and what amount of water the plant needs. In this way we can see the relations among the water, substrate and plants.

MATERIAL AND METHODS

The experimental part served to determine the retention of moisture of substrates perlite and peat at different pressures. The used perlite originates from Cera Poliana, Mariovo Gradesnica, Republic of Macedonia, and was appled in expanded (commercial) form.

Peat was used in a commercial form. The peat and perlite were analysed in all five of their different ratios: (P: Perlite 20%, 30%, 50%, 70%, 80% by volume) and 100% perlite, (Pe: Peat 80%, 70%, 50%, 30%, 20% by volume) and 100% peat, with the ultimate goal to determine the ability to retain water in the substrate. In laboratory conditions, perlite moisture and peat was determined at higher pressures with application of a pressure limiter with Bar extractor for determination of moisture retention at 0.1 bar (pF - 2); 0.33 bar (pF - 2.54); 1 bar (pF - 3); To determine perlite and peat moisture retention in higher pressures, the Richard Porous plate extractor method was applied, 2.00 bar (pF - 3.3); 6.25 bar (pF - 3.90); 11 bar (pF - 4.04) and 15 bar (pF - 4.2), described by (Belić et al., 2014).

Figure 2. Preparing soil and placing samples on Bar extractor and Porous plate extractor

Figure 3. Substrate and mix- ratio

RESULTS AND DISCUSSION

Keeping water in the peat or perlite is marked as retention. The characteristics of moisture retention include the relations between the matrix potential and the moisture content and can be represented by a retention curve. It shows the moisture content at different tensions. Water retention is the result of two forces: adhesion (attraction of water molecules by the particles) and cohesion (attraction of water molecules to each other). Atheism is much stronger than cohesion. The force with which the water is retained in the substrates, that is, the force it needs to squeeze out of the substrates is denoted as capillary potential and is closely related to the water content. To obtain a clearer representation of the intensity of moisture retention, especially for peat and perlite, the peat along with perlite, the mean humidity values in mass percent tabular and graphic with pF values are displayed, the height of the water column in cm (1 bar = 1063 cm / cm^2).

All examined samples of perlite and peat and their respective ratios were placed on 7 different pressure modes (0,1; 0.33; 1; 3; 6.25; 11; 15 bar) using Bar extractor and Porous plate extractor, and the obtained results for moisture retention in weight percent are presented in Table 1 and Table 2.

	Formulation	**Designation**
1.	100% Perlite (commercial substrate)	(Pe)
2.	100% Peat (commercial substrate)	(P)
3.	80% Perlite + 20% Peat	Pe80/P20
4.	70%Perlite + 30% Peat	Pe70/P30
5.	50%Perlite + 50% Peat	Pe50/P50
6.	30%Perlite + 70% Peat	Pe30/P70
7.	20%Perlite + 80% Peat	Pe20/P80

Table 1. Moisture retention in weight percent % at different tension in substrate perlite and peat at 0.1 bar; 0.33 bar; and 1 bar.

Substrate and mix- ratio	n	**0.1 bar**		**0.33 bars**		**1 bar**	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
100% Perlite	3	67.85	1.88	58.35	1.59	47.70	1.57
100% Peat	3	89.16	0.83	74.84	1.17	57.94	1.03
Pe80/P20	3	72.11	1.07	61.65	1.01	49.75	1.49
Pe70/P30	3	74.25	1.39	63.30	1.80	50.77	0.77
Pe50/P50	3	78.51	0.81	66.63	0.64	52.73	1.12
Pe30/P70	3	82.76	0.64	69.88	0.96	54.87	1.06
Pe20/P80	3	84.89	0.94	71.54	1.34	55.89	1.08

Table 2. Moisture retention in weight % at different tension in substrate perlite and peat at 3 bars; 6.25 bars; 11 bars and 15 bars.

Substrate and mix-ratio	n	**3 bars**		**6.25 bars**		**11 bars**		**15 bars**	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
100% Perlite	3	39.78	2.58	34.84	2.66	30.10	2.40	26.65	2.75
100% Peat	3	45.15	1.07	39.57	1.18	33.89	1.07	23.17	1.45
Pe80/P20	3	40.85	1.21	35.78	1.15	30.86	1.03	25.94	1.12
Pe70/P30	3	41.40	1.20	36.25	1.40	31.24	1.26	25.60	1.21
Pe50/P50	3	42.46	0.55	37.21	0.17	31.96	0.52	23.86	0.20
Pe30/P70	3	43.54	0.18	38.15	0.72	32.75	0.51	23.16	0.17
Pe20/P80	3	44.07	0.33	38.62	0.81	33.13	0.40	23.83	0.57

To understand more clearly the intensity of moisture retention in peat with perlite, the mean moisture values in weight percent are shown. The experimental data presented in Table 1 and 2 show that the peat substrate has the largest retention capacity in all variants and at all points of pressure tension such as: at pressure of 0.1 bar with an average value of 89,16% at pressure of 0.33 bar with an average value of 74,84 %, at pressure of 1 bar – 57,94%; 3 bars – 45,15%; 6.25 bars - 39.57; at pressure of 11 bar - 33.89%; except at pressure of 15 bars - average value of 23.17%.

The retention capacity of the perlite is lower than the peat in at all applied pressures of different tension: for 0.1 bar = 67.88%, for 0.33 bar = 58.35%, for 1 bar = 47.70%; for 3 bars = 39.78%; for 6.25 bars = 34.84; for 11 bars = 30.10%; for 15 bars = 26.65%. In other analysed ratios, where the peat was represented by 20%, 30% and 50% 70%, 80% in the analysed sample, the perlite retention capacity is increased dramatically. The retention pressure of other ratios such as Pe70/P30 and Pe50/P50, Pe30/P70, P80/Pe20, is presented in Table 1 and Table 2. From the presented data, it is obvious that the addition of a larger percentage of peat to perlite, always resulted in increase of the sample retention pressure.

Figure 1, 2, 3, 4, 5, 6, and Figure 7 represent the retention curves of the analysed samples of substrate perlite and the peat respectively. The ability of the substrate to retain and maintain moisture is crucial for improving the efficiency of water use for growing crops in closed (greenhouses) and open-field conditions. According to (Richards 1955), retention curves have great practical and theoretical importance, because they show all important data about water properties and management in soil and substrates. Moisture retention curves (MRCs) in soilless substrates were first described by (Bunt, 1961). However, the suction range is generally conducted at lower tensions (0 to 30 kPa) than in mineral soils, because soilless mixes are more porous and normally have larger diameter pores, enabling water to drain at lower tensions. Moisture retention curves provide data about substrate capacity for available moisture, with the upper limit of field water capacity and the lower limit of the coefficient of the set.

For estimation of substrate moisture, using capillary potential quantified, pF-(soil moisture tension), values were determined, whereby the water force in the substrate was expressed through the height of the water column in cm (1 bar = 1063 cm/cm^2) (Vućić, 1987).

Filipovski (1996), also explains that retention of moisture in various tensions is closely related to the content of humus, clay, dust and mineral clay composition. According to (Kutilek and Novak, 1998) the hydrological characteristics such as water retention and the rate of water movement, depend, to a large degree on the total porosity and pore-size distribution of the material. The moisture content depends on the percentage of pores in the perlite itself, higher porosity- higher moisture content.

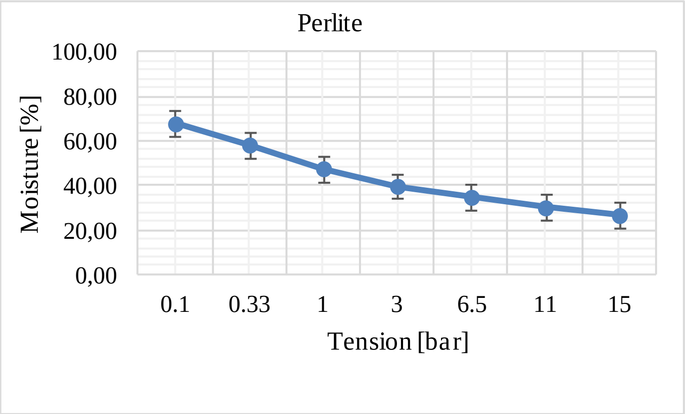

Figure 1. Moisture retention curve of substrate perlite.

Figure 1 shows the results of the retention curve of the substrate perlite. The analysis shows higher water retention at points of tension of 0.1, 0.33, 1 up to 3 bars with a percentage of moisture of 67.88, 58.35, 47.70 and 39.78 vol.%, respectively. At higher pressures of 6.25, 11, and 15 bars the percentage of moisture drops from 34.84, 30.10 to 26.65 vol.%, respectively. The curve of retention has slight slope, where the percentage of moisture gradually decreases at higher tensions.

Examined the physical properties of the perlite and tested the moisture retention by methods from the manual by (Fonteno & Harden, 2010) with Volumetric Pressure Plate Extractors with (-Kpa), which yielded similar results with ours, the percentage of moisture in the perlite substrate was 66% per 0.1 bar, 43% per 1 bar and 31% of moisture per 10 bars. The water retention curve of perlite shows moderate hysteresis (Bures et al., 1997b; Wever et al., 1997) reported that the saturation of perlite was very rapid, independent of its initial moisture.

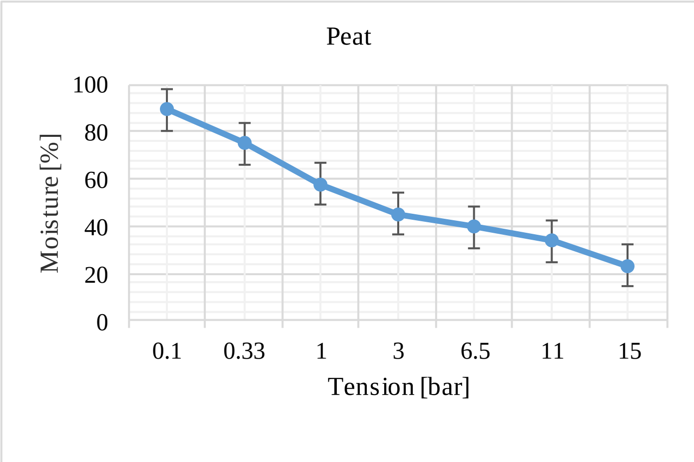

Figure 2. Moisture retention curve of substrate peat.

Figure 1 shows the results of the retention curve of the substrate perlite. The analysis shows higher water retention at points of tension of 0.1, 0.33, 1 up to 3 bars with a percentage of moisture of 67.88, 58.35, 47.70 and 39.78 vol.%, respectively. At higher pressures of 6.25, 11, and 15 bars the percentage of moisture drops from 34.84, 30.10 to 26.65 vol.%, respectively. The curve of retention has slight slope, where the percentage of moisture gradually decreases at higher tensions.

Figure 2 shows the results of the retention curve of the substrate peat. From the results it can be seen that the peat shows higher retention of water than perlite. The curve has sharp slope starting from 0.1, 0.33, 1, 3, 6.25 and 11 bars, except with a mild drop in a lower retention of moisture at 15 bars. The reason for the higher retention of the substrate peat than the perlite is due to the high content of organic matter in the peat. Comparing the two substrates, it can be ascertained that the peat substrate has higher moisture retention from the perlite at all points of tension except at 15 bars. The moisture in the perlite that is stored at 15 bars, which is higher than the peat, has an approximate value of the point or humidity wilting range.This means that under conditions wilting range, the substrate perlite retains higher percentage of moisture than the peat. Similar results as ours, received authors (Fields et al., 2004), where the percentage of moisture in the substrate peat, at a point of tension of 0.1 to 3 bars is around 40-90 vol.%. At the point of tension of 3 to 15 bars, the percentage of moisture ranges from 50-27 vol.%, while the substrate perlite at a point of tension of 0.1 to 3 bars has moisture percentage of 67-40 vol.%, and at tension of 3 up to 15 bars the retention curve of moisture ranges from 40-30 vol.%. According to the author (Raviv et al., 2002), the total pore space in the plant growth substrates should range from 60-90% by volume.

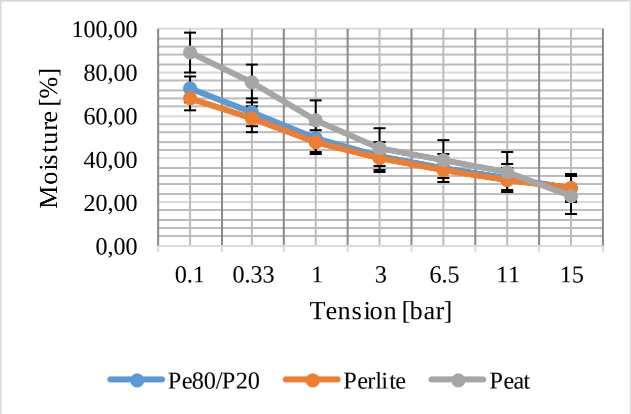

Figure 3. Moisture retention curve of substrates peat, perlite and mix ratio Pe80/P20.

Figures 3, 4, 5, 6, and 7 represent the moisture retention curves of the analyzed samples of substrates perlite and peat and their mixtures of different volume ratios Pe80 / P20; Pe70 / P30; Pe 50 / P50; Pe30 / P70; Pe20 / P80. The pF curves of moisture retention of substrate perlite and substrate peat is the same as in Figures 1 and 2, while for other mixtures of perlite and peat there are some differences between the retention curves. In the analyzed sample of the mixture with ratio Pe80 / P20 retention curve shows moderate decline in the retention of moisture, starting from 0.1 bar to 15 bars with a moisture content of around (71 to 25 vol.%).

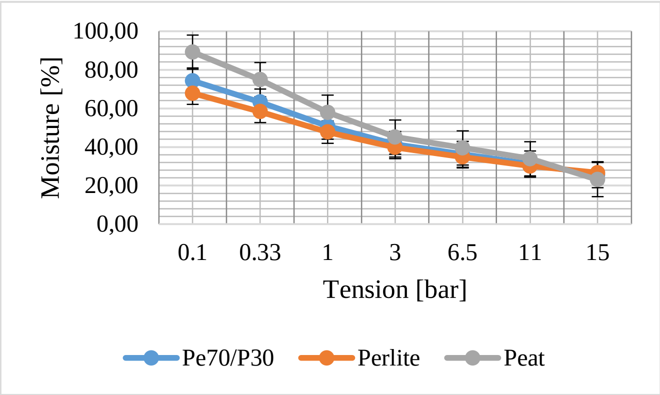

Figure 4. Moisture retention curve in substrates peat, perlite and mix ratio Pe70/P30

The curve of retention on Pe50/P50 shows a slightly more noticeable decline in values between 0.1 and 3 bars when percentage of moisture decreases from (78.51 to 42.46 vol.%), and then up to 15 bars tension it decreases moderately to 23.86 vol%.

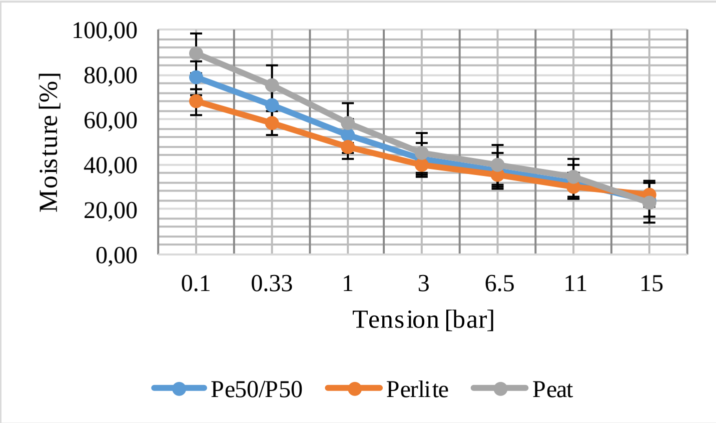

Figure 5 Moisture retention curve in substrates peat, perlite and mix ratio Pe50/P50.

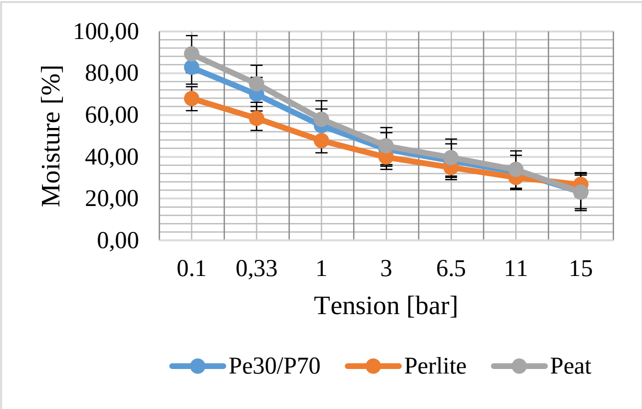

Figure 6. Moisture retention curve in substrates peat, perlite and mix ratio Pe30/P70.

The retention curve of the analyzed sample with volume ratio Pe30/P70, for tension from 0.1 to 3 bars shows higher moisture percentage from 82 to 53 vol. %. Then the retention curve gradually drops in a horizontal fall, when the percentage of moisture slightly decreases from 38 to 23 vol.%.

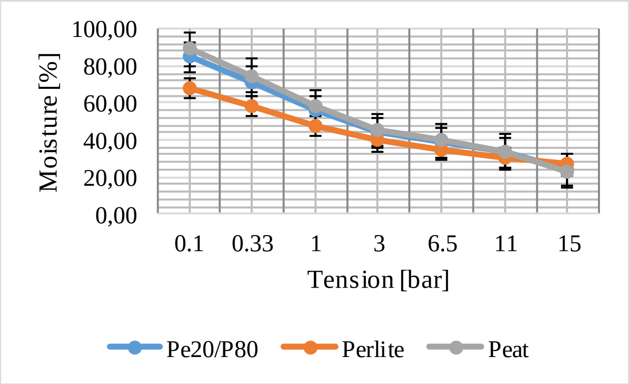

Figure 7. Moisture retention curve in substrates peat, perlite and ratio Pe20/P80.

Table 3. Correlation coefficients between the tension points of 0.33, 1, 3, 6.25, 11, 15 bars and humus content.

Correlation coefficients	**0,1 bar**	**0,33 bars**	**1 bar**	**3 bars**	**6.25 bars**	**11 bars**	**15 bars**	**Organic mater**
0,1 bars	1	0.996**	0.959**	0.912**	0.879**	0.772**	-0.664**	0.645**
0,33 bars		1	0.953**	0.926**	0.894**	0.781**	-0.649**	0.640**
1 bar			1	0.830**	0.811**	0.828**	-0.720**	0,627**
3 bars				1	0.975**	0.611**	-0.401**	0,566**
6.25 bars					1	0.570**	-0.326**	0,537**
11 bars						1	-0.750**	0,514**
15 bars							1	-0,510*
Organic mater								1

Based on the correlation analysis for the investigated properties in different ratios of the perlite substrate and the peat, it can be noted that there is a positive significant correlation in almost all of the retention constants, the highest is r = 0.996. High positive significance correlation (r = 0.645) exists between organic matter and all points of tension except at 15 bar (r = - 0.510).

CONCLUSIONS

Based on the data from laboratory investigations for moisture retention in the substrate perlite and the peat substrate and their mixtures with ratios Pe80 / P20, Pe70/P30, Pe50/P50, Pe30 / P70, Pe20 / P80 ratio, the following can be concluded: Most of the moisture at all the analyzed samples is run out at lower pressures of 0.1 to 3 bar around 85-40 vol.%. A smaller percentage of moisture is run out to higher pressures of 6.25 to 15 bar (40-20%). However, for the plants, the most important is the physiologically available moisture that in all the analyzed samples ranges somewhere around 71-34 vol.%. The total amount of moisture from 0.33 bar to 15 bar ranges from 31.7 % in perlite, 51.72% at peat and in the mixtures of substrate perlite and the peat substrate with Pe20/P80 ratio the total available moisture is approximately 47.72%.

Comparing the retention curves of the perlite and the peat, they are relatively close to each other. There are certain differences at the peat, where the peat unlike the perlite shows a higher moisture retention capacity, from 0.33 bars to 11 bars and the slightly decreasing of water retention occurs at higher pressure of 15 bars. Higher retention curves in the peat substrate are due to the higher percentage of organic matter (humus). Also, the perlite substrate shows the optimum water retention capacity, which has slightly higher value at tension of 15 bars compared to that of peat. The perlite retains more water at 15 bars, because that moisture in the substrate perlite is retained by very large retentive forces. This is particulary important because the moisture content is retained in the substrate under conditions when the plant is at wilting range at 15 bars. pF curves of moisture retention provide data on the capacity of the available moisture, which gives us the opportunity to draw conclusions when and what amount of water the plant needs. That is the best way to understand the relationship between water, substrate and plants. For each water content, its holding strength in the substrate can be determined.

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