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Physico-Chemical and Physical Properties of some Substrates Used in Horticulture

Physikalisch-chemische und physikalische Eigenschaften einiger im Gartenbau verwendeter Substrate

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Summary

This study was carried out in 2001 using some organic (peat moss, peat, sawdust) and inorganic (perlite, pumice, creek sand) substrates.

pH, electrical conductivity, cation exchange capacity, carbonates, organic matter, particle size distribution, bulk density, water retention characteristics and pore size distribution of substrates were determined.

The amount of water retained at the low tensions (<pF 2.52) in pumice, sawdust, peat moss, perlite, peat and creek sand was 62.6, 59.2, 57.1, 53.7, 53.0 and 28.9 based on % of volume, respectively. However, among the organic-organic, inorganic-inorganic and organic-inorganic mixes, those values were highest in peat : sawdust (60.0 %), perlite : creek sand (40.1 %) and sawdust : perlite (57.2 %).

Among the organic, inorganic, organic-organic, inorganic-inorganic and organic- inorganic mixes, the highest amount of macropores (>100 μm) supply aeration were 56.9 % (sawdust), 60.2 % (pumice), 56.0 % (peat : sawdust), 34.4 % (perlite:creek sand), 52.6 % (sawdust : perlite). The lowest bulk density of substrates were 0.086 g cm^{-3} (peat moss), 0.118 g cm^{-3} (perlite), 0.121 g cm^{-3} (peat moss : sawdust), 0.325 g cm^{-3} (perlite : pumice) and 0.099 g cm^{-3} (peat moss : perlite), respectively.

pH values of substrates varied from 5.1 (peat moss and peat) to 7.6 (pumice). The highest electrical conductivity, cation exchange capacity, carbonates and organic matter values of substrates were 1.065 dS m^{-1} (peat), 206.4 cmol kg^{-1} (peat moss), 0.75 % (pumice) and 95.0 % (peat moss), respectively.

Zusammenfassung

Diese Studie wurde im Jahr 2001 mit einigen organischen (Torfmoos, Torf, Sägemehl) und anorganischen (Perlit, Bimsstein, Flußsand) Substraten durchgeführt. Dabei wurden pH-Wert, elektrische Leitfähigkeit, die Kationen-Austauschkapazität, die Karbonate, der organische Substanz, die Teilchengrößenverteilung, die Schüttdichte, die Wasserspeichereigenschaften und die Porengrößenverteilung der Substrate bestimmt.

Die Wassermenge, die bei den geringsten Spannungen (<pF 2.52) in Bimsstein, Sägemehl, Torfmoos, Perlite, Torf und Flußsand zurückgehalten wurden, betrug 62.6, 59.2, 57.1, 53.7, 53.0 und 28.9 Volumen-%. Bei den organisch-organischen, anorganisch-anorganische und organisch-anorganische Mischungen waren diese Werte bei Torf : Sägemehl (60.0 %), Perlit : Flußsand (40.1 %) und Sägemehl : Perlit (57.2 %) am höchsten.

Die höchsten Werte für das Merkmal Makroporen (>100 μm) waren bei den organischen, anorganischen, organisch-organischen, anorganisch-anorganischen und organisch-anorganischen Mischungen 56.9 % (Sägemehl), 60.2 % (Bimsstein), 56.0 % (Torf : Sägemehl) 34.4 % (Perlit : Flußsand) sowie 52.6 % (Sägemehl : Perlit). Die geringsten Volumengewichte der Substrate betrugen 0.086 g cm^{-3} (Torfmoos), 0.118 g cm^{-3} (Perlit), 0.121 g cm^{-3} (Torfmoos : Sägemehl), 0.325 g cm^{-3} (Perlit : Bimsstein) und 0.099 g cm^{-3} (Torfmoos : Perlit).

Die pH-Werte der Substrate schwankten zwischen 5.1 (Torfmoos und Torf) und 7.6 (Bimsstein). Die höchsten Werte der Merkmale elektrische Leitfähigkeit, Kationenaustauschkapazität, Karbonate und organische Substant der Substrate waren 1.065 dS m^{-1} (Torf), 206.4 cmol kg^{-1} (Torfmoos), 0.75 % (Bimsstein) und 95.0 % (Torfmoos).

Introduction

Soilless culture is in the process of becoming an important part of world agriculture. There are several advantages of soilless culture compared to conventional soil culture which has poor structure, poor drainage, disease and salinity problems (PADEM et al. 1995, JENSEN 1999).

Among various soilless culture practices, the use of substrates is the easiest to be adapted by growers. A number of materials such as gravel, water, sand, peat, sawdust, pumice (tuff), coir, vermiculite, perlite and rockwool pure or in mixture have been used as growing media. The selection of a particular material for substrate use depends on its availability, cost and local experience on its use (KLOUGART 1983, VERDONCK et al. 1983).

Turkey has a huge pumice and perlite reserves with approximate amount of $3x10^9 m^3$ pumice (SARIIŞIK et al. 1998) and $8x10^6$ tons raw perlite (TUNCER 1997). Turkey is one of the biggest expanded perlite producing countries.

Volume of air and water retention capacity of substrate is generally considered as the quality determining factors for substrates (Brückner 1997, Caron and Nkongolo 1999). A common way to compare substrates is to describe them on the base of their physical properties. Within the physical properties the air-water ratio is most important. The air-water ratio can partly be determined by the granulometry and porosity (Orozco et al. 1997). The relationship between water energy status and water content of the medium is a reflection of the pore size distribution of the medium (Milks et al. 1989). Pore size distribution is valuable for characterising soils for various applications relating to soil-plant interactions, aeration, irrigation, drainage and liquid waste disposal (Topp and Zebchuk 1979).

For horticulture the phase distribution (solid material, water and air) of a substrate is important especially at matric potentials between –1 cm and –100 cm water column as described by many authors (Verdonck and Pennick 1986, Michiels et al. 1993). Air volume and easily available water describe the volume of pores in substrates which released their water when the matric potential is decreased from –10 cm to –50 cm suction level. The matric potential from –50 cm to –100 cm water column is called water buffer capacity and marks the pore sizes from 60 μm to 30 μm. The volume of pores that are retaining their water at a matric potential of more than –100 cm water column contains the less readily available water (Brückner 1997).

Pore sizes have traditionally been divided into macropores, mesopores, micropores and ultramicropores. The macropores (>100 μm) supply drainage and aeration, the mesopores (100–30 μm) supply water conduction and the micropores (30–3 μm) supply water retention (Gemalmaz 1993). The water retained in ultramicropores (<3 μm) is unavailable for plant use (Drzal et al. 1999).

There has been little detailed studies with regard to substrates in terms of their physical and physico-chemical properties especially their water retain characteristics and pore size distribution.

The aim of this research was to determine physico-chemical and physical properties of some pure or mixed substrates used in soilless culture studies in horticulture.

Material and Methods

In this study, pure or mixed substrates widely used in soilless culture studies in Turkey were used as material (Table 1).

Physico-chemical properties of substrates such as reaction, electrical conductivity, cation exchange capacity, carbonates, organic matter and physical properties such as particle size distribution, bulk density, water retention characteristics and pore size distribution of those substrates were determined.

The methods used to determine some physico-chemical and physical properties of substrates are routine methods used in soil analysis but some modifications were made where required.

Particle size distribution values were determined by dry sieving with a mesh sizes of 8, 4, 2, 1, 0.5, 0.25 and 0.09 mm. Soil water characteristics in the laboratory using pressure plates (Demiralay 1993), saturation capacity according to base of weight (Gardner 1986), bulk density with a cylinder volume of 100 cm^3 (Blake and Hartge 1986), reaction with a pH-meter (McLean 1982), electrical conductivity with EC-meter (Rhoades 1982b), cation exchange capacity by sodium acetate method (Rhoades 1982a), organic matter by Smith-Weldon method and carbonates by calcimeter method (Sağlam 1994).

Table 1. The substrates used as material in research
Bei den Untersuchungen verwendete Substrate

Substrates	
Pure	Mixed (1:1 by volume)
1- Peat moss	1- Peat moss : Sawdust
2- Peat	2- Peat moss : Perlite
3- Sawdust	3- Peat moss : Pumice
4- Perlite (Expanded)	4- Peat moss : Creek sand
5- Pumice	5- Peat : Sawdust
6- Creek sand	6- Peat : Perlite
	7- Peat : Pumice
	8- Peat : Creek sand
	9- Sawdust : Perlite
	10- Sawdust : Pumice
	11- Sawdust : Creek sand
	12- Perlite : Pumice
	13- Perlite : Creek sand
	14- Pumice : Creek sand

Results and Discussion

Physico-chemical properties

Reaction (pH)

Substrate pH varied from 5.1 (peat moss and peat) to 7.6 (pumice) (Table 2). Plants require different pH ranges in growing medium, but many horticultural plants grow well in a substrate close to 6.5 pH degree (Agaoglu et al. 1995). The chemical composition of media particles, the ratio of media components in the mix, and irrigation and fertiliser practices affect the pH of growing media.

Electrical conductivity (EC)

The EC of organic substrates was higher than that of inorganic substrates (Table 2). On the other hand, among the organic substrates, the highest EC value was obtained from peat (1.065 $dS\,m^{-1}$) and followed by peat moss (0.706 $dS\,m^{-1}$). According to our results, there was no salinity problem the substrates investigated (Bunt 1988, Abad et al. 1989).

Cation exchange capacity (CEC)

The CEC values of organic substrates found higher than inorganic substrates (Table 2). CEC was widely affected by amount of organic matter of substrates. The average CEC value of organic matter is 250 $cmol\,kg^{-1}$ (Ergene 1993). No CEC values obtained from perlite because its surface had not included electrical charges (Kara and Hepaksoy 1992). The low CEC values founded in pumice were close to some clay minerals (Ergene 1993). The low CEC values of creek sand were normally expected.

Carbonates ($CaCO_3$)
According to the analysis results, carbonates value of substrates were less than 1.0 % (Table 2). Therefore, all of the investigated substrates could be classified as lower carbonate substrate groups (ERGENE 1993).

Organic matter (OM)
The highest organic matter content was found in peat moss (95.0 %), while perlite and pumice had not include organic matter (Table 2). Organic materials like peat were not used as source of nutrients. On the contrary mineralization of nutrients is normally not desirable. Their importance is a result of their optimum air capacity at water saturation and the ability to buffer pH, nutrients and salts.

Physical properties

Particle size distribution
The particle size distribution of substrates is shown in Figure 1. In our study, Pumice particles of 2–4 mm were used (SAHIN et al. 1997), therefore, the distribution curve of pumice was not drawn. The particle size of sawdust, creek sand and perlite was 4 mm, while that of peat moss and peat was under 8 mm. The most of particle size of substrates was under 2 mm.

Bulk density
Among the substrates, the highest bulk density was obtained from creek sand (1.491 g cm^{-3}), while the lowest was peat moss (0.086 g cm^{-3}) (Table 3). Therefore, the

Table 2. Some physico-chemical analysis of the pure substrates
Physikalisch-chemische Analysen der Grundsubstrate

Substrates	Analysis				
	pH*	EC** dS m^{-1}	CEC cmol kg^{-1}	$CaCO_3$ %	OM %
Peat moss	5.1	0.706	206.4	–	95.0
Peat	5.1	1.065	93.8	–	41.7
Sawdust	7.1	0.271	71.6	0.15	39.2
Perlite	7.2	0.127	–	0.62	–
Pumice	7.6	0.096	6.4	0.75	–
Creek sand	7.5	0.174	0.6	0.36	0.03

* 1 : 2.5 (soil : water)
** 1 : 5 (soil : water)

Table 3. Bulk density of substrates
Schüttdichte der Substrate

Substrates	γ (g cm^{-3})	Substrates	γ (g cm^{-3})
Peat moss	0.086	Peat : Sawdust	0.165
Peat	0.207	Peat : Perlite	0.150
Sawdust	0.117	Peat : Pumice	0.381
Perlite	0.118	Peat : Creek sand	0.981
Pumice	0.431	Sawdust : Perlite	0.120
Creek sand	1.491	Sawdust : Pumice	0.327
Peat moss : Sawdust	0.121	Sawdust : Creek sand	0.876
Peat moss : Perlite	0.099	Perlite : Pumice	0.325
Peat moss : Pumice	0.276	Perlite : Creek sand	0.851
Peat moss : Creek sand	0.872	Pumice : Creek sand	1.081

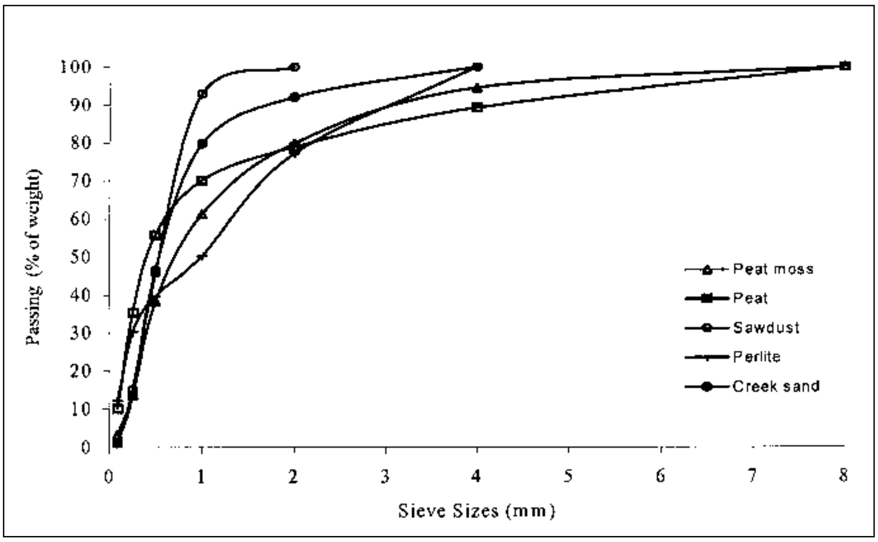

Fig. 1. Particle size distribution of substrates
Teilchengrößenverteilung der Substrate

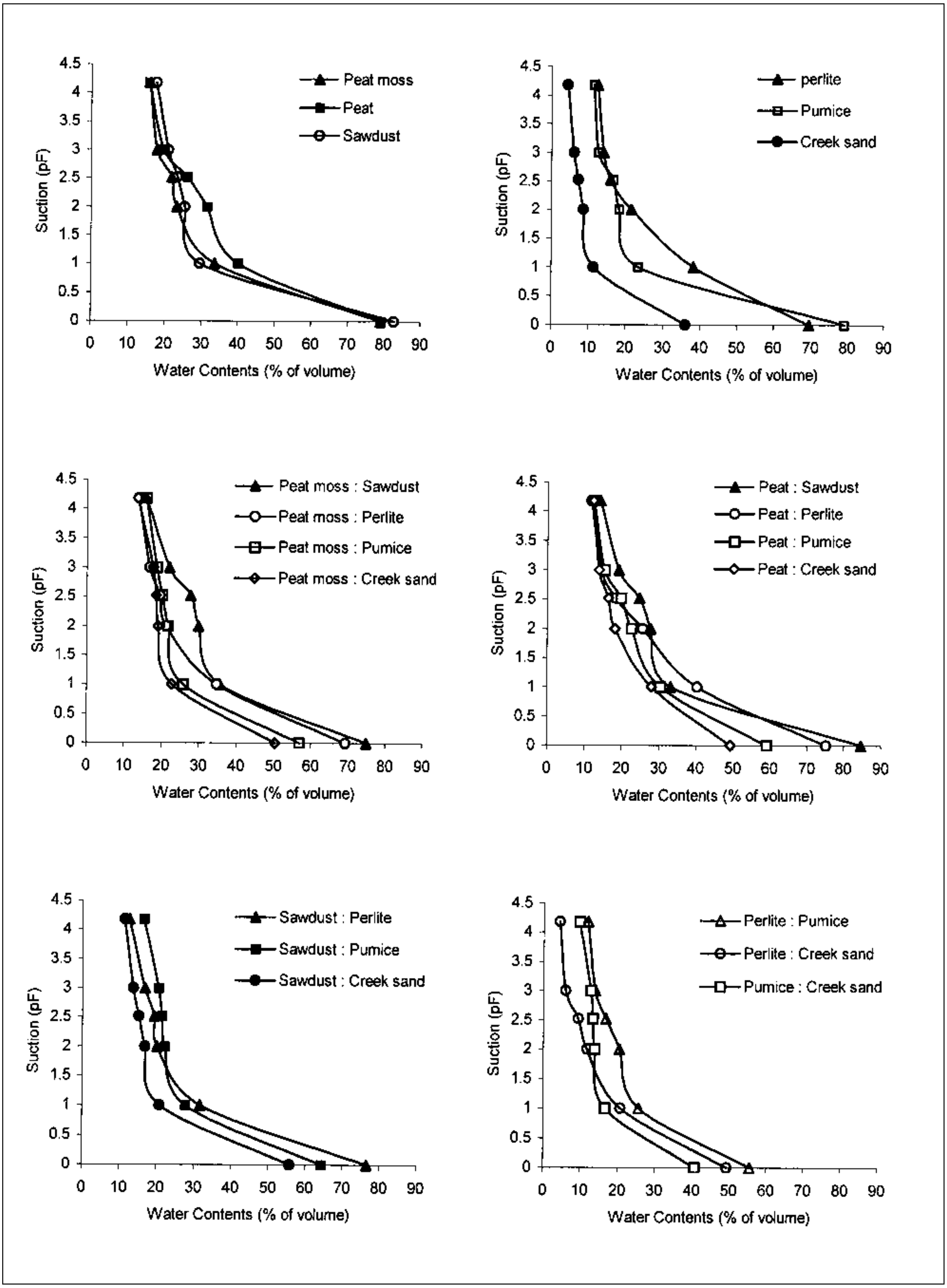

Fig. 2. Water retention characteristics curves
Wasserspeichervermögen der untersuchten Substrate

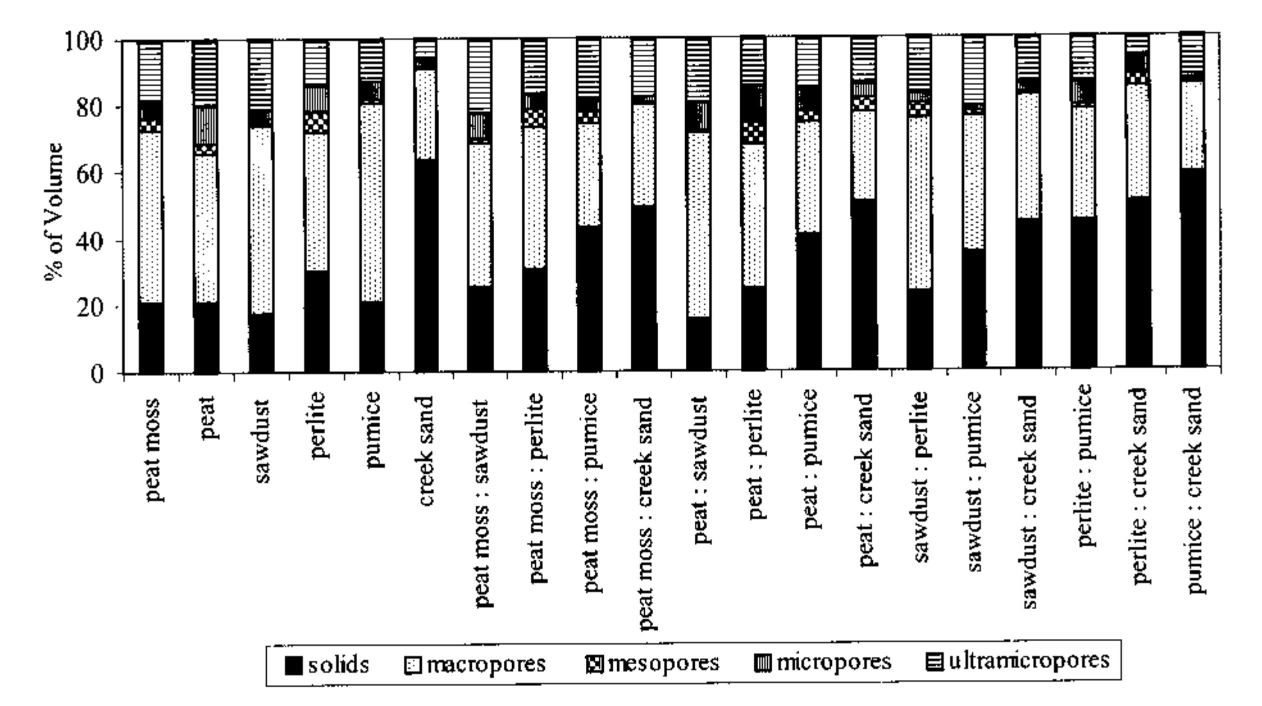

Fig. 3. Pore size distribution
Porengrößenverteilung

substrates mixed with creek sand had a higher bulk density value. The organic matter had a decreasing effect on bulk density. Thus, the bulk density value of organic substrates was lower. Perlite and pumice also had lower bulk density values because of its expansion structure. In greenhouse, usually lower bulk density is desirable due to easier handling and less root losses during the pick up and transportation (WILSON 1983).

Water retention characteristics
Results of the water retention analysis are shown in Figure 2. The highest saturation percentage was obtained from peat : sawdust (84.6 %), while the lowest was from creek sand (36.1 %). Most of the water was retained at the lower tensions in substrates. The larger amount of macropores increased amount of water retained at low tensions (Figure 3).

Among the pure substrates used in this research, the highest water retention capacity at the low tensions (<pF 2.52) was obtained from pumice (62.6 %). On the other hand, among the mixed substrates, the highest water retention capacity obtained from peat : sawdust (60.0 %). Organic matter had increased water retention capacity. The expandable structure of pumice and perlite had also increased water retention capacity. Higher water retention capacity at the low tensions is very important for optimal plant growth (SAHIN et al. 1997).

The highest water retention capacity between pF=2.52–4.18 was obtained from peat moss : sawdust (11.9 %) and followed by peat (10.6 %) and peat : sawdust (10.5 %), respectively.

Pore size distribution
Figure 3 shows pore size distribution of substrates. The highest macropores (>100 µm) obtained from pumice (60.2 %). Perlite had highest mesopores (100–30 µm). The highest micropores (30–3 µm) determined on peat (11.9 %). However, the highest ultramicropores (<3 µm) obtained from peat moss : sawdust (22.0 %).

Substrates include more pore size gave higher yield (BRÜCKNER 1997, CARON and NKONGOLO 1999). The amount of pore space of media is a critical physical characteristic which influences water and nutrient absorption and gas exchange by the root system. Pore space is related to the shape, size and arrangement of media particles. For sufficient gas exchange, drainage, and water-holding capacity, the proper proportion of macropores to micropores is necessary.

Media containing the greatest amount of medium-sized pores had the potential to hold more readily available water. Among the organic, inorganic, organic-organic, inorganic-inorganic and organic-inorganic substrates, the highest medium-sized pores obtained from peat (14.6 %), perlite (13.9 %), peat : sawdust (9.5 %), perlite : creek sand (9.1 %) and peat : perlite (17.3 %), respectively (Figure 3).

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