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Influence of superabsorbents on the physical properties of horticultural substrates

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A b s t r a c t. Studies on the physical properties of various horticultural substrates such as: bark, perlit, peat, peat + bark (1:1), peat + perlit (1:1), peat + bark + polyamide PA-6 (1:1:1), with added hydrogels such as: Akrygel - RP and Alcosorb - 400, have been carried out. The influence of the substrate properties with hydrogels added was compared to the control combinations without hydrogels. The following properties were determined in the study combinations: total content of organic matter, substrate reaction, volumetric density, specific surface, porosity and percentage of solid phase. Air and water properties and water-air ratio were determined by means of the pF curve.

Applicability of superabsorbents as components of horticultural substrates was also evaluated. In all the studied substrates a more favourable structure was achieved after hydrogel has been added. Alcosorb - 400 and Akrygel - RP introduced to the substrates has positively influenced their physical properties, considerably increasing retention of water available for plants. They also caused an increase in the specific surface especially in the substrate with perlit and an increase in the pH value in the mixture of peat and bark and peat and perlit. An increase in the applied hydrogel doses from 2 to 6 kg m^{-3} of the substrate improved substrate properties when compared to the control combinations where superabsorbents were not applied. The results obtained showed that it is feasible to apply hydrogels as additions to horticultural substrates as the effects achieved proved that the most favourable conditions for plant development and growth can be created in that way.

K e y w o r d s: horticultural substrates, superabsorbents, physical properties

INTRODUCTION

Horticultural substrates applied in plant breeding in hot houses are characterised by very high variability and changeability that depends on the input materials used and additions applied.

It has been proved that a good substrate is characterised by high porosity and optimum water and air capacity, durable structure during the whole vegetation period and high ability to capture and keep nutrients, as well as good buffer properties [1,10,22]. An ideal substrate should have total porosity of about 85%, air capacity of 20-30% and the same capacity of water available for plants [5]. High comminution of the substrate decreases its water capacity and limits its aeration. The soil becomes sealed and compact, and it becomes difficult for the root to get deeper into the substrate [11].

Superabsorbents are hydrophilic gels, polymer powders that swell in water. Their absorbability is most often expressed in grams of the solution absorbed by one gram of the polymer and depends on many different factors. Degree of the polymer net formation and its comminution and the reaction of water hardness (pH), presence of electrolytes and chemical compounds are the decisive factors here [2,3,4,9, 14-16,21,24].

Water stored in the gel introduced into the soil is effectively utilised by the plants. The potential gradients between gel + substrate and plant roots are adequate to release water from the hydrogel. Hence water is easily available for the plant roots [8,18,24].

Hydrogel in the substrate is breaking continuity of the vertical capillars, which results in the limitation of water evaporation with the simultaneous preservation of soil porosity [12]. Air in the substrate together with the water stored in the hydrogel positively influences plant roots preventing the process of rotting. It is especially important in the case of heavy soils [7].

Studies carried out on various plant species showed that an addition of superabsorbents significantly increased the percentage of water available for plants in the case of sandy soils, prevented stresses caused by long dry periods and minimised the risk of water deficit during sprouting to a considerable degree [6,13,19,20,26].

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Earlier results obtained in the studies on the improvement of the substrate structure by addition of polymers were confirmed [16,17]. Both sprouting, rooting of the cuttings and plant growth were better after addition of hydrogels into the substrate. However, there were some differences in the reaction of individual species to the superabsorbent dose. Rooted cuttings in the substrates with superabsorbent addition were characterised by a considerably higher mass of the root system than the cuttings rooted in the substrates without hydrogel addition.

The articles quoted above show that both the type of substrate and hydrogel applied including the applied doses exert a significant influence on the plant growth, development and yield, as well as their decorative value.

The aim of the present study was to determine variation in the physical properties of various horticultural substrates in relation to different doses of the following superabsorbents: Akrygel - RP and Alcosorb - 400.

MATERIALS AND METHODS

Studies on the physical properties covered six substrates: bark, perlit, high peat (neutralised with chalk up to pH 6.3), peat + bark (1:1), peat + perlit (1:1), peat + bark + polyamide PA-6 (1:1:1). The following hydrogels were added to these substrates: Akrygel - RP made in Poland and Alcosorb - 400 made in England in the powder form at the doses of 2, 4, and 6 kg of hydrogel per m^3 of the substrate. Control combinations were mixtures without hydrogel addition. After sorbents have been thoroughly mixed with the individual substrates, they were wetted with water. The amount of water differed according to the sorbent type and dose. Water in the proportion of 1:100 (100 ml of water per 1g of hydrogel) was added in the case of substrates with Alcosorb - 400, and 1:60 in the case of Akrygel - RP.

Total content of organic matter was determined by burning in the muffle oven at the temperature of 550°C for 3 h. pH of substrates was determined electrometrically. Volumetric density was determined in metal cylinders with the volume 100 cm^3. Specific surface was measured by the Kutilek's method, and porosity and percentage of the solid state phase was evaluated on the basis of density determination of the substrate solid phase and its volumetric density. Water properties were determined by the apparatus for the pF determination [23,25]. Soil water content was determined at all capillary pores saturated to approximately field capacity and the wilting point (pF=4.2). Thus, available water content in the range between pF=1 and pF=4.2 was determined and water content at pF=4.2 was considered as not available to plants. Volumetric ratio of water to air (W/A) was determined on the basis of volumetric water percentage at pF=2.0.

RESULTS

Bark

Chemical and physical properties of substrates from bark in relation to the hydrogel type and dose are presented in Table 1. This substrate contained from 86.0 to 91.6% of organic substance. Hydrogel doses have influenced these properties only slightly. Bark reaction for the control combination was 6.3 pH, and when increased doses of hydrogel were applied to the substrate, its pH level was lowered to 6.1 pH, and in the case of the highest dose of Akrygel to 6.0 pH. Substrate density levels ranged from 0.15 to 0.23 g cm^{-3} with the latter value found for the substrates with the highest dose of Akrygel. Specific surface ranged from 111.2 to 187.2 m^2 g^{-1}. No unique relation between the specific area of the substrate and hydrogel doses was found. However, it was noted that both when the English and Polish sorbents were used, the highest values of this feature were found at the dose of 4 kg m^{-3}. The highest amount of the solid phase was found in the control combination (37.8%). When hydrogels were applied, it decreased and ranged from 17.1 to 19.5%. Change in the porosity was oposite with the lowest value (62.2%) in the control substrate, while in the remaining combinations higher values ranging from 80.5 to 83.9% were found. As far as the porosity was concerned, big coarse in the substrate were the most frequent, and the highest values were observed in the combination with Akrygel - RP in increasing doses. The amount of fine pores ranged from 4.2 to 6.7%. It was found out that when the highest doses of sorbents were applied, contribution of the fine pores increased as compared to the control substrate. When division into individual types of pores was carried out, it was found that this substrate had the highest amount of non-capillary pores (from 22.2 to 44.2%). Substrate water content at pF=0 varied according to the combination and ranged from 218.9 to 311.8% of weight. At pF=2 it was smaller by half, and at pF=4.2 (i.e., at the point of permanent wilting point) it was 25.4-31.4% of weight. Retention of water at pF 0-2 was 117.2-166.6% of weight. Higher values in the range of pF 0-2 were found in bark with the doses of 2 and 4 kg m^{-3} of both English and Polish hydrogel, as compared to 6 kg m^{-3}, where the values of retention were lower than in the control substrates as well. Similar relations were also observed in the pF range of 2-4.2. Retention of water available for plants (pF 2-4.2) was from 70.3 to 115.2%, and of water not available for plants (pF > 4.2) from 25.4 to 31.4% of weight , with the lowest values found in the substrates without hydrogel. Relation between water and air in the discussed substrate was from 1:3.30 to 1:4.59. Slightly lower values were found with the addition of Alcosorb - 400.

T a b l e 1. Physical and chemical properties of the bark substrate related to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	89.9	89.8	86.0	88.9	89.9	90.7	89.5	91.6
pH	6.3	6.1	6.1	6.1	6.3	6.1	6.1	6.0
Density (g cm^{-3})	0.17	0.15	0.15	0.18	0.17	0.15	0.18	0.23
Specific surface (m^2 g^{-1})	150.7	119.5	187.2	132.4	150.7	111.2	158.7	118.4
Solid phase (% vol.)	37.8	19.0	16.1	17.1	37.8	19.5	18.3	18.3
Porosity (% vol.)	62.2	81.0	83.9	82.9	62.2	80.5	81.7	81.7
Non-capillary pores >3 mm	22.2	42.5	44.2	43.5	22.2	34.7	34.8	28.5
Coarse 3 mm-30 μm	21.4	20.6	21.3	21.1	21.4	24.5	25.1	28.5
Medium 30-0.2 μm	14.4	13.3	13.9	12.7	14.4	16.9	16.5	18.0
Fine <0.2 μm	4.2	4.6	4.5	5.6	4.2	4.4	5.3	6.7
Water content at pF 0 (% weight)	241.2	260.5	261.1	218.9	241.2	311.8	267.9	233.5
2	112.1	121.1	121.4	101.7	112.1	145.2	124.6	108.5
4.2	25.4	31.2	29.8	31.4	25.4	30.0	30.2	29.4
Retention in the ranges of pF 0-2 (% weight)	129.1	139.4	139.7	117.2	129.1	166.6	143.3	125.0
2-4.2	86.7	89.9	91.6	70.3	86.7	115.2	94.4	78.6
>4.2	25.4	31.2	29.8	31.4	25.4	30.0	30.2	29.4
Relation between water and air volume (W/A)	1:3.34	1:4.59	1:4.55	1:4.53	1:3.34	1:3.77	1:3.74	1:3.30

Perlit

Content of organic matter was very low and in the control combination it was 1.9% (Table 2). Addition of the hydrogel increased this value to 2.0-12.2% depending on the combination. Reaction of the control substrate was pH 6.5, the first doses (2 and 4 kg m^{-3}) of hydrogel resulted in a decrease of pH, and the highest doses were the same as in the case of control. Perlit density was from 0.9 to 0.13 g cm^{-3}. Lower values were the same as in the case of combinations with hydrogels. Specific surface was minimal, i.e., 2.8 m^2 g^{-1} in the control combination, and after a medium dose of Akrygel - RP had been applied it increased to 12.7 m^2 g^{-1}. Solid phase of the substrate reached the highest level on the control substrate, i.e., 38.5% and in the remaining combinations, it decreased with increasing hydrogel doses. Hence, porosity of the substrates was increasing with increasing hydrogel doses and ranged from 61.5 to 81.2%. Coarse pores of the substrate occupied from 20.2 to 31.7% and increased with increasing hydrogel doses as well. Similar tendencies were also noted for medium sized pores, but their values were slightly lower. There were only a few fine pores, i.e., from 0.1 to 0.7% with the same relations as described above. Non-capillary pores occupied the volume from 17.2 to 26.4%. Water content of the substrates at pF=0 was increasing with increasing hydrogel doses and ranged from 304% (control combination) to 624% of weight after application of the highest Akrygel - RP dose. At pF 2 and pF 4.2 the same relation was maintained, but the values were considerably lower. At pF 4.2, the values were very small (0.8-7.9% of weight) with the same relations maintained. Retention of water at pH=0 to pH=2 ranged from 162 to 333.9% of weight and these values were increasing with increasing hydrogel doses. Content of water available for plants (pF=2-4.2) was from 141.2 to 288.2% of weight and was increasing with increasing hydrogel dose. A similar relation was found at pF higher than 4.2 and the threshold values ranged from 0.8 to 7.9% of weight. Relation of water to air was from 1:2.77 to 1:3.56 and was decreasing with increasing hydrogel doses.

Peat

Content of organic matter in the substrate with peat was from 85.1 to 90.5% and it was higher in the combinations of hydrogel applications compared to the control (Table 3). Reaction of this substrate was from pH 6.1 to 6.5, and variations were not significantly related either to the hydrogel or its dose. Peat density ranged from 0.070 to 0.086 g cm^{-3}. Specific surface of this substrate was decreasing with increasing hydrogel doses ranging from 258.7 to 299.6 m^2 g^{-1}. Peat solid phase occupied a small volume (4.7-19.1%) and showed a decreasing tendency with increasing hydrogel doses. Similarly to this substrate property, porosity levels were very high and increasing with increasing sorbent doses from 80.8 to 95.2%. With increasing doses, the volume of coarse and medium sized pores was increasing. Fine pores occupied from 2.7 to 4.0% of volume, and the volume of non-capillary pores was decreasing with increasing hydrogel

T a b l e 2. Physical and chemical properties of theperlit substrate in relation to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	1.9	8.1	3.0	12.2	1.9	8.4	2.0	4.6
pH	6.5	6.0	6.2	6.5	6.5	6.3	6.4	6.4
Density (g cm^{-3})	0.13	0.12	0.11	0.9	0.13	0.9	0.9	0.10
Specific surface (m^2 g^{-1})	2.8	4.5	6.7	9.5	2.8	5.9	12.7	11.0
Solid phase (% vol.)	38.5	36.6	28.3	18.8	38.5	35.2	31.2	23.5
Porosity (% vol.)	61.5	63.4	71.8	81.2	61.5	64.8	68.2	76.5
Non-capillary pores >3 mm	22.9	25.2	23.6	26.4	22.9	24.3	22.6	17.2
Coarse 3 mm-30 µm	20.2	20.4	25.9	29.3	20.2	21.7	24.4	31.7
Medium 30-0.2 µm	18.3	17.4	21.8	24.8	18.3	18.5	20.7	26.9
Fine <0.2 µm	0.1	0.4	0.5	0.7	0.1	0.3	0.5	0.7
Water content at pF 0 (% weight)	304.0	321.3	459.5	596.1	304.0	435.6	524.1	624.0
2	142.0	149.3	213.6	277.2	142.0	202.5	243.7	290.1
4.2	0.8	3.3	4.8	7.6	0.8	2.9	5.9	7.9
Retention in the ranges of pF 0-2 (% weight)	162.0	172.0	245.9	318.9	162.0	233.1	280.4	333.9
2-4.2	141.2	146.0	208.8	269.6	141.2	199.6	237.8	282.2
>4.2	0.8	3.3	4.8	7.6	0.8	2.9	5.9	7.9
Relation between water and air volume (W/A)	1:3.34	1:3.56	1:3.21	1:3.18	1:3.34	1:3.49	1:3.24	1:2.77

T a b l e 3. Physical and chemical properties of the peat substrate in relation to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	85.1	87.8	85.8	85.6	85.1	90.5	88.7	86.9
pH	6.3	6.1	6.5	6.5	6.3	6.2	6.4	6.5
Density (g cm^{-3})	0.086	0.073	0.071	0.070	0.086	0.082	0.075	0.078
Specific surface (m^2 g^{-1})	295.3	290.6	293.6	256.7	295.3	299.6	291.0	288.3
Solid phase (% vol.)	16.0	19.1	10.3	10.1	16.0	15.1	11.3	4.7
Porosity (% vol.)	83.9	80.8	89.7	89.9	83.9	84.9	88.7	95.2
Non-capillary pores >3 mm	29.3	25.4	22.7	18.1	29.3	23.9	18.8	16.7
Coarse 3 mm-30 µm	29.2	29.6	35.8	38.4	29.2	32.6	37.7	42.0
Medium 30-0.2 µm	21.4	23.0	28.5	30.7	21.4	25.3	29.7	33.5
Fine <0.2 µm	4.0	2.8	2.7	2.7	4.0	3.1	2.8	3.0
Water content at pF 0 (% weight)	635.0	759.2	944.1	1025.4	635.0	744.1	931.9	1006.3
2	295.2	353.0	438.9	444.9	295.2	345.9	433.2	467.8
4.2	47.6	38.0	38.7	39.7	47.6	37.5	37.2	38.0
Retention in the ranges of pF 0-2 (% weight)	332.8	406.2	505.2	580.5	332.8	398.2	498.7	538.5
2-4.2	247.6	315.0	400.2	405.2	247.6	308.4	396.0	429.8
>4.2	47.6	38.0	38.7	39.7	47.6	37.5	37.2	38.0
Relation between water and air volume (W/A)	1:3.30	1:3.13	1:2.87	1:2.69	1:3.30	1:2.98	1:2.57	1:2.61

doses. Substrate water content humidity at pF=0 was from 635.0 to 1025.4% of weight and decreased when increasing doses of superabsorbents were applied. The same relation was observed at pF=2, whereas this value in the control combination was 295.2% of weight and at the highest Alcosorb dose it was 444.9% of weight. At the highest dose of Akrygel it was 467.8% of weight. Water unavailable for plants (pF 4.2) constituted 37.2-47.6% of weight. The content of water at pF=0 to pF=2.0 was increasing with increasing hydrogel doses, and water available for plants (pF 2-4.2) took up from 247.6 to 429.8% of weight, and was increasing with increasing doses of hydrogels applied. The ratio of water and air content was 1:2.61-1:3.30. These values were decreasing with increasing doses of sorbents.

Peat + bark

In the substrate of peat and bark with an addition of hydrogels the content of organic matter ranged from 84.1 to 89.4%, and it was the highest in the control sample, i.e., 91.9% (Table 4). The pH values of this substrate were pH 5.7-6.1 and increased slightly with increasing hydrogel doses. Substrate density in the case of peat and bark combination showed a decreasing tendency with increasing hydrogel doses and ranged from 0.105 to 0.091 g cm^{-3}. The specific surface did not show any differences between the studied combinations, and ranged from 228.8 to 297.3 m^2 g^{-1}. The content of substrate solid phase was decreasing with increasing hydrogel doses and was 28.6% in the control substrate and 22.4% with the highest dose of Akrygel. Similarly, substrate porosity increased following the same pattern and was 71.4-77.6%. In the pore structures, non-capillary pores occupied the biggest volume. The content of coarse and medium-sized pores increased with increasing doses of superabsorbents. Fine pores occupied from 2.7 to 3.2%. Substrate water content level at pF=0 was increasing with increasing dose from 387% of weight to 531.4% of weight. Similar relations were observed at pF 2. At pF 4.2, no significant differentiation was observed between the studied combinations. Water content at pF=0 to pF=2.0 was increasing with increasing hydrogel doses from 207.1 to 284.4% of weight. An unambiguous relation between the above values and the doses applied, was observed at pF 2-4.2. The lowest value was noted in the control combination and the highest at the dose of 6 kg of Akrygel - RP. Water to air ratio ranged from 1:3.20 to 1:3.90.

Peat + perlit

In the substrate of peat and perlit the content of organic matter was from 21.0 to 31.7% (Table 5). A decreasing tendency was observed after application of increasing doses of Alcosorb - 400. This relation was not observed when Akrygel - RP was applied. The pH values of this substrate ranged from 6.0 to 6.3. Density of the peat and perlit mixture was from 0.094 to 0.115 g cm^{-3}. The specific substrate surface area ranged from 96.9 to 120.7 m^2 g^{-1}. The highest content of the solid phase was noted for the control substrate, i.e., 34.7%, and the lowest, i.e., 17.2 and 14.7% for the highest doses of Alcosorb and Akrygel. In connection to this latter property,

Table 4. Physical and chemical properties of the peat substrates from peat and bark in relation to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	91.9	88.4	84.1	86.6	91.9	89.4	84.9	85.6
pH	5.7	5.8	5.9	5.9	5.7	5.8	5.8	6.1
Density (g cm^{-3})	0.102	0.093	0.091	0.098	0.102	0.105	0.100	0.098
Specific surface (m^2 g^{-1})	242.5	250.4	228.8	237.3	242.5	253.1	248.9	297.3
Solid phase (% vol.)	28.6	27.4	26.5	24.0	28.6	27.3	27.1	22.4
Porosity (% vol.)	71.4	72.7	74.9	77.6	71.4	72.7	74.9	77.6
Non-capillary pores >3 mm	31.9	30.6	33.1	31.1	31.9	28.9	26.7	25.5
Coarse 3 mm-30 μm	21.2	22.5	22.4	24.9	21.2	23.4	25.8	27.9
Medium 30-0.2 μm	15.2	16.8	16.7	18.8	15.2	17.2	19.5	21.1
Fine <0.2 μm	3.1	2.8	2.7	2.8	3.1	3.2	2.9	3.1
Water content at pF 0 (% weight)	387.0	452.6	459.1	474.6	387.0	417.3	481.2	531.4
2	179.9	210.4	213.4	220.6	179.9	194.0	223.7	247.0
4.2	30.2	30.0	30.2	28.8	30.2	30.2	28.8	31.8
Retention in the ranges of pF 0-2 (% weight)	207.1	242.2	245.7	254.0	207.1	223.3	257.5	284.4
2-4.2	149.7	180.4	183.2	191.8	149.7	163.8	194.9	215.2
>4.2	30.2	30.0	30.2	28.8	30.2	30.2	28.8	31.8
Relation between water and air volume (W/A)	1:3.90	1:3.70	1:3.78	1:3.51	1:3.90	1:3.56	1:3.34	1:3.20

T a b l e 5. Physical and chemical properties of the substrates from peat and perlit in relation to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	29.3	27.4	25.4	21.0	29.3	26.4	17.2	31.7
pH	6.0	6.1	6.2	6.3	6.0	6.2	6.3	6.3
Density (g cm^{-3})	0.115	0.107	0.094	0.106	0.115	0.108	0.107	0.105
Specific surface (m^2 g^{-1})	102.7	118.9	119.5	96.9	102.7	117.2	120.7	109.2
Solid phase (% vol.)	34.7	27.2	17.8	17.2	34.7	24.7	19.2	14.7
Porosity (% vol.)	65.3	72.8	82.2	82.8	65.3	75.3	80.8	85.3
Non-capillary pores >3 mm	27.8	34.8	37.2	41.5	27.8	29.1	29.1	37.3
Coarse 3 mm-30 µm	20.1	20.3	23.1	22.1	20.1	24.7	27.7	25.7
Medium 30-0.2 µm	15.3	15.7	20.0	17.2	15.3	19.6	22.3	20.0
Fine <0.2 µm	2.1	2.0	1.9	2.0	2.1	1.9	1.7	2.3
Water content at pF 0 (% weight)	326.3	355.3	500.5	389.9	326.3	427.6	483.1	456.8
2	151.6	165.2	232.5	181.2	151.6	198.8	224.6	212.4
4.2	18.2	18.5	20.2	18.6	18.2	17.2	15.7	22.3
Retention in the ranges of pF 0-2 (% weight)	174.7	190.1	268.0	258.7	174.7	228.8	258.5	244.4
2-4.2	133.4	146.7	212.3	162.6	133.4	181.6	208.9	190.1
>4.2	18.2	18.5	20.2	18.6	18.2	17.2	15.7	22.3
Relation between water and air volume (W/A)	1:3.75	1:4.11	1:3.75	1:4.31	1:3.75	1:3.50	1:3.36	1:3.82

substrate porosity increased with increasing sorbent doses and ranged from 65.3 to 85.3%. Analysis of the pore structure proved that non-capillary pores took up the biggest space volume. Medium-sized pores occupied lower volume, and the fine pores the lowest. Substrate water content level at pF=0 was from 326.3 to 500.5% of weight. When Akrygel was applied, an increase in these values was observed with increasing hydrogel doses. No such relations were observed at pF 2. The content of gravitational water at pF 0-2 ranged from 174.7 to 268.0% of weight. It should be stressed that the two highest values represent the mean doses of both hydrogels applied (4 kg m^{-3}). The same relation was observed in the case of amount of water available for plants at F 2-4.2. Water to air ration ranged from 1:3.36 to 1:4.31. No relationship with the applied hydrogel dose was observed.

Peat + bark + polyamide (PA 6)

The content of organic matter in the substrate of peat, bark and polyamide was from 91.4 to 93.2%, and pH was 5.5 to 5.7 (Table 6). Density of this mixture decreased slightly with increasing hydrogel doses. It was 0.136 g cm^{-3} in the control substrate, and in the combinations with the highest doses of both hydrogels it was 0.113 g cm^{-3}. Specific surface did not show any difference between the combi- nation and ranged from 133.4 to 166.0 m^2 g^{-1}. The content of the substrate solid phase in the control combination was 26.6% and was decreasing with increasing doses of sorbents up to 12.2%. Hence, porosity also increased from 73.4% in the control substrate to 87.8% at the highest dose of Akrygel - RP. Non-capillary pores occupied the volume of 22.7 to 28.2%, whereas the volume of coarse pores increased with increasing hydrogel doses. The volume of medium-sized pores increased with increasing doses of sorbents as well. The applied combinations did not influence the content of fine pores that occupied 3.1-3.4%. Substrate water content at pF=0 was increasing with increasing hydrogel doses up to the value of 337.6% of weight. At pF=2 the above relations were identical, but the values were considerably lower. At pF=4.2 the values were low, and slightly increasing with increasing hydrogel doses. The amount of water content at pF 0-2 was from 180.6 to 288.7% of weight, and these values increased with increasing hydrogel doses. At pF 2-4.2 the content of water available for plants was 133.0% of weight for the control combination and was increasing with increasing hydrogel doses up to 222.7% of weight. The water to air ratio was from 1:2.97 to 1:3.59.

The studies have shown that physical properties of the tested substrate were different and depended mainly on their composition (structure) and content of individual components. Addition of hydrogels considerably modified the studied properties. The content of organic matter ranged in wide limits in the substrate of bark, peat, and in the combinations of these components, and was above 80%. An addition of polyamide (PA 6) made this value increase above 90%. In the substrate of perlit only 2% of organic substance was noticed. This content increased slightly when hydrogels were applied. In the substrate of peat and perlit, the

T a b l e 6. Physical and chemical properties of the substrates from peat and bark and polyamide PA-6 in relation to the hydrogel type and dose (kg m^{-3})

Studied feature	Alcosorb - 400				Akrygel - RP			
	0	2	4	6	0	2	4	6
Organic substance (%)	91.4	92.7	92.0	93.2	91.4	92.4	92.9	91.5
pH	5.7	5.5	5.6	5.6	5.7	5.5	5.6	5.6
Density (g cm^{-3})	0.136	0.134	0.129	0.113	0.136	0.129	0.129	0.113
Specific surface (m^2 g^{-1})	156.0	133.4	138.8	148.3	156.0	166.0	159.5	159.7
Solid phase (% vol.)	26.6	24.0	21.7	18.3	26.6	24.2	19.4	12.2
Porosity (% vol.)	73.4	76.0	78.3	81.8	73.4	75.8	78.3	87.8
Non-capillary pores >3 mm	28.2	27.4	26.9	22.7	28.2	28.2	24.3	26.8
Coarse 3 mm-30 μm	23.9	26.0	27.5	31.6	23.9	26.5	28.9	32.7
Medium 30-0.2 μm	18.0	19.3	20.5	24.4	18.0	17.8	22.0	25.1
Fine <0.2 μm	3.3	3.3	3.4	3.1	3.3	3.3	3.1	3.2
Water content at pF 0 (% weight)	337.6	362.6	398.3	513.6	337.6	386.7	398.3	539.5
2	157.0	168.6	185.2	238.8	157.0	171.4	185.2	250.8
4.2	24.0	24.8	26.5	26.6	24.0	25.3	26.5	28.1
Retention in the ranges of pF 0-2 (% weight)	180.6	194.0	213.1	274.8	180.6	215.3	213.1	288.7
2-4.2	133.0	143.8	158.7	212.2	133.0	146.1	158.7	222.7
>4.2	24.0	24.8	26.5	26.6	24.0	25.3	26.5	28.1
Relation between water and air volume (W/A)	1:3.44	1:3.36	1:3.27	1:2.29	1:3.44	1:3.59	1:3.21	1:3.10

contribution of organic matter was 20-30% on the average. This differentiation resulted mainly from the composition of this substrate. The highest porosity among all the studied substrates was found in peat and in the mixtures with peat addition. Similarly bark, showed high values of this property. The lowest porosity among all the substrates was observed for perlit. Specific surface of the substrates was very different, it was almost 300 m^2 g^{-1} in peat and in the control combination with perlit it did not reach 3 m^2 g^{-1}. In the mixtures with peat, the level of this value was around 100-250 m^2 g^{-1} on the average. The substrate of bark was also in this range. Addition of hydrogels resulted in a clear increase of water capacity, and in all the studied substrates the amount of water available for plants increased considerably. This increase was strictly related to increasing hydrogel doses reaching up to 100% between the highest hydrogel dose and control combination (perlit, peat). The smallest relative increase of this value was observed in the substrate of bark. The highest dose of Akrygel - RP resulted in higher water capacity than for Alcosorb - 400, except for the substrate of bark where no such difference were found. Hydrogel doses changed the substrate pH only slightly, but the reaction remained in the range considered optimal (pH 5.5-6.5). In the light of the substrate analyses carried out it can be said that their water-air relations were favourable, and the variations observed in individual combinations were mainly related to the substrate type and type and dose of hydrogel applied.

CONCLUSIONS

1. The present studies proved that hydrogels are useful components of horticultural substrates that modify their physical properties. In all the studied substrates hydrogel addition improved their physical properties.

2. Hydrogels Alcosorb - 400 and Akrygel - RP introduced to the studied substrates favourably influenced their physical properties by considerably increasing retention of water available for plants. They also resulted in the increase of specific surface area, especially in the substrate of perlit and in the increase of the pH value in the mixture of bark and peat and peat with perlit.

3. An increase of the applied hydrogel doses from 2 to 6 kg m^{-3} resulted in an improvement of substrate properties when compared to control combinations without supersorbents.

4. The results obtained showed that it is feasible to apply hydrogels as additions to horticultural substrates as that can create the most favourable conditions for plant development and growth.

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