Aeration Adequacy In Greenhouse Soils

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As a general rule, the smaller the particles that make up a soil, the greater the suction required to remove water. In greenhouse soils, the suction in the upper soil surface at cessation of drainage is equal, but opposite, to the pressure at the bottom of a water column of the same depth. In a 7-inch soil layer (18 cm), the suction in the upper surface is equal to 7 inches of water at completion of drainage. If, as the result of small particle size, the suction required to drain the pores exceeds 7 inches water: then the aeration status of the soil is dependent upon rate of water removal by the plant and evaporation (evapotranspiration). In some insances, continual disruption of the soil surface (hand watering with a heavy stream) may lead to crust formation. Higher suction may be necessary to displace water with air. The shallower a given soil, the less likelihood of air entry. In some artificial media with porosities approaching 90%, large amounts of water may be retained. Good aeration will depend upon plant use. The slower the rate of evapotranspiration (low light, cool temperatures, small plants), the more likely is undesirable response.

The past 4 years, we have examined various root media by means of special laboratory equipment called the Haines apparatus. Two objectives were in mind: 1) comparison of water release by different media between suctions of 0 and 64 cm water (equivalent to a maximum soil depth of 26 inches), and 2) determination of air entry values for these mixtures. The results obtained with 16 media are presented.

Method

In N.Y.S.F.G. Bulletin 192, the method for studying air entry was described. Briefly, the Haines apparatus permits a definite suction to be exerted on a small soil sample, and the amount of water removed at that suction to be measured. The results when plotted as a graph (suction versus water removed) constitutes a *soil-water characteristic curve.* The different media examined are presented in Table 1. Each mixture was steam sterilized, sifted through a ¼ inch screen, and packed into the sample holder under nearly identical conditions. The sample was then wetted from below and allowed to stand, saturated, for 12 to 24 hours. Starting at 0 suction, the pressure was decreased 3 cm water, the sample allowed to stand until water ceased flowing (4 to 12 hours) and the amount of water removed measured. A platinum electrode was inserted into the sample and the rate of oxygen supply determined. Suction was then increased, slowly, to 8 cm water, allowed to equilibrate, the water removed and oxygen supply rate determined. This same procedure (in

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TABLE 1:

Materials examined for determination of air entry values.

NAME	REMARKS
Peat moss	German peat, unshredded
Peat-perlite	Equal parts german peat and coarse perlite
Peat-sand (C)	Equal parts peat and coarse quartz sand
Peat-sand (F)	Equal parts peat and fine quartz sand
Eel silt loam	High organic matter, good aggregation
Fulton silt loam	Field soil with 20% clay
Hempstead silt loam	Week structured soil from Long Island
El-1-1	Equal parts Eel, sand and peat
Fl-1-1	Equal parts Fulton, sand and peat
Hl-1-1	Equal parts Hempstead, sand and peat
Peat-beads	Equal parts peat and uniform glass beads of the following size diameter ranges: 0.105mm and less 0.210 to 0.105mm[a] 0.35 to 0.177mm 0.50 to 0.35mm 0.71 to 0.42mm 1.19 to 0.71mm

[a] 25.4mm (millimeters) equal 1 inch.

5 cm increments) was repeated up to a maximum suction of 64 cm water.

At the end of a run (64 cm), the amount of water remaining in the sample was determined. Assuming no entrapped air at 0 suction, and negligible soil shrinkage, the amount of water and air at each suction was ascertained by adding the water removed to that remaining at 64 cm. Table 2 presents typical results for 3 determinations in a Hempstead silt loam.

TABLE 2:

Typical data resume for one root substrate, Hempstead silt loam. Figures, averages of 3 determinations.

Suction[a]	Water removed[b]	Water[c] (%)	Air[c] (%)	0_2[d] Flux
0	0	52	0	4
3	3	51	1	3
8	6	48	4	3
13	5	46	6	3
18	3	45	7	3
23	6	42	10	5
28	7	39	13	6
33	4	38	14	9
38	3	36	16	6
43	3	35	17	9
48	2	34	18	18
53	2	34	18	39
58	2	33	19	31
64	2	32	20	31

[a] Suction in cm water
[b] Average cc's water removed from 3 samples
[c] Percent of total volume
[d] 0_2 flux as g/cm²/min x 10^{-8}

Results and Discussion

Air-entry—In Bulletin 192, *air entry value* was defined as the minimum soil moisture tension (suction) required in a soil to cause displacement of water by air in significant amounts. Ideally, the suction at which the largest amount of water was removed, could be designated as the air entry value in inches of soil depth required to achieve that suction in the upper soil surface.

The determination of air entry values on this basis was found to be impractical in some cases. As can be seen in Figures 1 and 2, and Table 2, some water was removed at all suctions. Usually, the larger the particle size (Fig. 1–2), and the more uniform those particles (Fig. 2): the easier to base air entry on water removal. In heterogenous, small particle mixtures (field soils, smallest glass beads and peat), it was not possible to give a positive air entry value.

On the other hand, rates of oxygen supply often showed notable increases at particular suctions. In some instances, an increase of 5 cm suction resulted in a hundred-fold increase in 0_2 supply. But, this most often occurred with large, uniform particled soils. With small particle, heterogeneous soils (for example Hempstead silt in Table 2), the rate doubled several times but did not coincide with the suction at which the greatest amount of water was removed.

Thus, it was decided that designation of a definite air entry value either on basis of water removal and/or increase in 0_2 supply was not justifiable for all substrates.

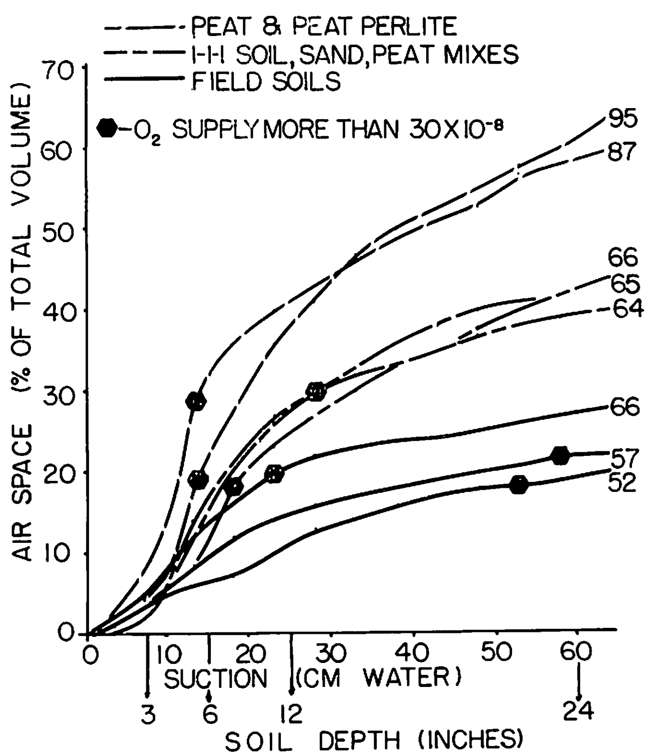

Figure 1: Soil water characteristic curves from 0 to 64 cm water suction for selected media plotted as a function of air-filled pore space. Soil depth refer to the equivalent soil depth necessary to achieve an equal suction in the upper surface of that soil. Figures on the right are total pore space present in the respective mixtures.

However, examination of the data (Fig. 1–2) indicated some important points. At equivalent soil depths of 3 inches. free pore space in all mixtures was less than 10%.

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The larger the particles of a given medium, and the more uniform those particles: the greater the effect of depth on water removal and 0_2 supply. In soil consisting of small particles, soil depth varied widely without having a noteworthy effect on amount of water and air. In artificial mixtures, however, changes in depth of 2 inches sometimes resulted in more than 50% of the total pore space being emptied.

Adequacy of aeration—The question shifted to determining the soil depth necessary to assure adequate aeration for plant growth. We have presented evidence in N.Y.S.-F.G. Bulletin 210 that moisture contents in excess of 40% and free pore space less than 50% may reduce growth of snapdragons. We also know from other research, that oxygen supply rates less than 30×10^{-8} grams of oxygen per square centimeter per minute (g $0_2/cm^2/min$) will usually result in root death. With this information, it became possible to look anew at the data.

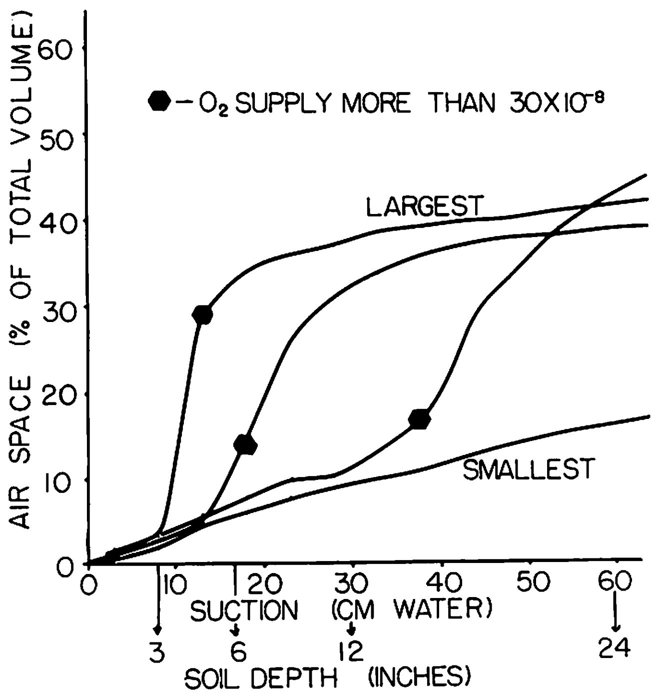

Figure 2: Soil water characteristic curves from 0 to 64 cm water suction for media consisting of different diameter glass beads and peat moss. Plotted as a function of air-filled pore space.

Assuming 30×10^{-8} as being the absolute minimum for plant survival, we compiled Table 3, showing the soil depth required to obtain a diffusion rate equal to, or in excess of, 30×10^{-8} in the upper surface. Some of these values are plotted in Figures 1 and 2. Two items may be noted: 1) the minimum depth for any mixture was 5 inches and, 2) the minimum free pore space for any mixture was not less than 10%. The order in which the different root media fall coincides with general expectation. That is, the smaller the particle size, the greater the depth necessary to achieve minimum 0_2 supply values.

TABLE 3:

Aeration adequacy for different soils on the basis of depth of soil at which oxygen supply reached or exceeded 30×10^{-8} g $0_2/cm^2/min$.

Root medium	Depth of soil (in.)	Suction (cm water)	Air (%)[a]	Water (%)[a]
Peat moss	5	13	11	84
Peat-perlite	5	13	29	58
Peat-sand (C)	5	13	43	38
Peat-sand (F)	7	18	34	52
Hl-1-1	7	18	18	47
El-1-1	11	28	22	44
Eel silt loam	11	28	30	36
Fl-1-1	11	28	30	34
Hempstead silt loam	21	53	18	34
Fulton silt loam	23	58	22	35
Peat-beads (1.19)	5	13	29	28
(0.71)	7	18	26	32
(0.50)	7	18	14	37
(0.35)	9	23	19	37
(0.21)	16	38	17	44
(0.105)	28	69	18	36

[a] Percent of total soil volume

Unfortunately, determination of aeration adequacy on this basis does not indicate that maximum growth would be obtainable. We know that in some soils, 0_2 supply rates in practice may approach values of 30×10^{-8} without drastic, deleterious plant responses. Whereas, in other substrates, 0_2 rates near 80×10^{-8} g/cm^2/min may occur simultaneously with severe chlorosis. It is necessary to consider the actual amount of water present in the mixture. For example, in Table 3, 84% of the peat moss medium at a 5 inch depth consisted of water as contrasted

TABLE 4:

Aeration adequacy for different soils on the basis of soil depth at which moisture content was less than 40% of total volume and 0_2 supply exceeded 30×10^{-8} g $0_2/cm^2/min$ in the upper surface.

Root medium	Soil depth (in.)	0_2 flux[a]	Air[b] (%)
Peat-sand (C)	5	106	43
Peat-sand (F)	11	116	52
El-1-1	11	37	50
Hl-1-1	11	66	27
Fl-1-1	11	42	36
Peat-perlite	16	125	49
Peat-moss	21	150	58
Hempstead silt loam	21	39	18
Eel silt loam	23	77	27
Fulton silt loam	23	45	22
Peat-beads (1.19)	5	116	29
(0.81)	7	153	26
(0.50)	7	166	14
(0.35)	9	181	19
(0.21)	16	267	27
(0.105)	28	51	18

[a] 0_2 flux in g/cm^2/min x 10^{-8}

[b] Air as percent of total soil volume

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to quantities less than 40% for all field soils at greater depths but similar O_2 supply. Using the value 30×10^{-8} as the *minimum* O_2 supply, *and* a moisture content of 40% as the *maximum* moisture content, Table 4 was compiled. Contrary to expectation, the minimum soil depth for peat-perlite was 16 inches and peat moss 21 inches. The peat-coarse sand mixture remained at 5 inches (Tables 3–4), whereas the peat-fine sand mixture increased to 11 inches. The depth required to achieve aeration adequacy was not what we might think it to be. It is fortunate that plants do use substantial amounts of water, and that evaporation occurs. Otherwise, we might experience more trouble.

Summary

The results have indicated that soils containing large amounts of pore space are not always an unmitigated blessing. Where such mixtures are employed in shallow depths (less than 6 inches), the attempt should be made to increase water loss by: 1) increasing temperature, 2) increasing air circulation, 3) increasing light intensity, 4) using large plants with vigorous, well-established root systems, and 5) possibly decreasing the total pore space through judicious packing. Where not all of these practices can be followed (for example small plants during the winter), the use of a soil naturally possessing a low total pore space might be considered. It is obvious, that as *total* pore space decreases in a given volume of soil, the smaller the *total* amount of water that can be retained. Thus, the frequency of irrigation may be higher for a soil possessing a small total pore space as contrasted to one having a porosity exceeding 80 or 90%. In any root medium, depths less than 6 inches are dangerous and require precautions to avoid difficulty.