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ARTICLES

MEDIA PARTICLE-SIZE EFFECTS ON ROOTING[1]

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Sand has been an important rooting medium in the past and still is in widespread use today. A large part of its popularity may be due to its relatively low initial cost and ready availability. Research comparing the effectiveness of sand and other media has had inconclusive and often contradictory results.

Long (3) states that roots produced in sand are coarser, more brittle, and have less branching than those produced in peat moss. Hitchcock (2) using 96 plant cultivars showed only six that produced superior root systems in sand as opposed to those in a peat/sand mixture. Hitchcock (2) and Wells (10) came to entirely opposite conclusions as to the suitability of sand for rooting *Ilex crenata*; Hitchcock indicated that it roots poorly in sand, whereas Wells recommends a sharp sand for *I. crenata*. Pridham (7), in a comparison of cinders, quartz sand, and vermiculite concluded that the type of medium was of less importance than the type of growth regulator used. Similarly, O'Rourke and Dedolph (5) determined that of seven media tested, none was consistently superior.

Sand for rooting cuttings is usually specified only as coarse or medium sand, builder's sand, plasterer's sand, and the like, designations which impart very little information about it. Sand is highly variable in the sizes of its component particles, ranging from 0.05 mm to about 2.00 mm in diameter. Its characteristics as a rooting medium are strongly influenced by whether the predominance is of coarse or fine particles.

The importance of particle size to the characteristics of a rooting medium has been noted by several workers. Pridham (7) observed that 4.8 mm dia quartz sand gave better results than smaller or larger particle sizes. O'Rourke and Maxon (6) compared rooting in sand and fine particle size grades (SF, 1, 2, 3, 4) of vermiculite. Grade 2 (2-3 mm particles) was superior to coarser or finer grades of vermiculite and to the sand which was specified only as a "medium grade construction sand." Both Gray (1) and Robinson (8) noted that propagating media may often be improved by the addition of coarser materials such as perlite or vermiculite.

The particle size of a propagating medium greatly influences the air/water relationship by controlling the pore size. The air/water relationship is a constantly-changing ratio within the pore spaces of the medium. Oxygen in the medium atmosphere is essential to root initiation and development. Water in the medium is initially of minor importance to maintain cutting turgidity but after root initiation and development has taken place, water assumes greater significance in turgidity maintenance.

In a saturated medium, the air content is nearly zero; conversely, in a medium in which the only existing water is hygroscopic the percentage of pore space occupied by air approaches 100%. Neither situation is conductive to rooting and a reasonable balance between air and water is both desirable and necessary. Large pore spaces lose water readily by gravitational force and hold relatively little water while small pore spaces hold water by adhesive and cohesive forces and very little is lost to gravitational drainage. A medium which consists of many different sizes of particles, large and small, is able to hold a larger percentage of water; the smaller particles tend to occupy the pores in among the larger particles, resulting overall in small pore spaces. Spomer (9) notes that in a medium consisting of mixed large and fine particles aeration does not occur until the ratio of coarse/fine particles is greater than a certain "threshold proportion," attained when the amount of fine particles is less than enough to fill the pore spaces among the larger particles.

The percentage of air in the pore spaces gradually increases in a medium to which no further water is added but tends to remain stable under a constant input of water supplied by a mist system. The percent air contained in pore spaces after gravitational drainage is

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[1] 1977 Eastern Region IPPS Student Award paper.

known as the free porosity of the medium, and is a measure of the available oxygen supply for rooting.

Another condition that exists is a propagating medium with regard to the air/water relationship is a perched water layer at the bottom of the flat or bench. This layer is kept saturated if the medium is supplied with excess water as frequently occurs under mist propagation. Matkin (4) observed that the thickness of this layer is determined by pore size of the medium; the layer may be several inches deep if the medium is a fine sand, or only a fraction of an inch in pea gravel. The thickness of this layer for a particular particle size is fairly constant regardless of the depth of the medium. As a result, the depth of the medium in the flat or bench can be very important to avoid sticking the basal ends of the cuttings in a waterlogged, oxygen-deficient zone which would inhibit rooting. Matkin suggests that the medium be as deep as possible and that layers of coarse materials in the bottom of flats or benches not be used as this raises the perched water layer by the exact depth of the coarse material used. Matkin (4) determined the free porosity of various propagating media and arrived at values of 1.2% for "fine sand" and of 9.5% for "typical propagating sand." It is unfortunate that the particle size analysis of these sands was not determined, for purposes of comparison.

MATERIALS AND METHODS

For this study, 1000 g samples of two sand types were mechanically analyzed by sieving; a "coarse builder's sand" and a "medium" yellow sand used for propagating by several Tennessee nurseries. Particle size distribution curves are shown in Fig. 1. The yellow sand has more fine particles than the builder's sand. The free porosity of five particle-size grades of sand, an ungraded coarse "builder's sand," coarse perlite, and vermiculite was determined by means similar to that described by Matkin (4). Five grades of sand were sieved from the "builder's sand" into separates based on the U.S.D.A. soil separate classification system (Table 1).

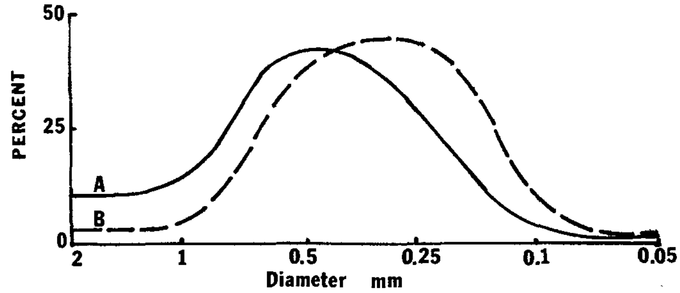


Figure 1. Particle size distribution of (A) coarse builder's sand and (B) Tennessee yellow sand.

Table 1. Classification of Soil Separates (adapted from U.S.D.A.)

Separates	Dia. Limits of Separates (mm)	Avg. Part. Size (mm)	Grade
Gravel, very coarse sand	Above 1.00	1.5	1
Coarse sand	1.00-0.50	0.75	2
Medium sand	0.50-0.25	0.38	3
Fine sand	0.25-0.10	0.18	4
Very fine sand	0.10-0.05	0.08	5*
Silt	0.05-0.002	0.026	-
Clay	Below 0.002	--	-

*Some silt- and clay-sized particles included in Grade 5

Cylinders were constructed of plexiglass tubing, 5 cm inside dia and 20 cm in ht with a single hole 6.3 mm drilled in the center of the bottom. The holes were plugged with rubber stoppers and a disc of fine mesh brass screen was placed over the hole to prevent loss of medium when unstoppered.

Table 2. Bulk density, free porosity, and available moisture of porpagating media studied.

Medium	Bulk Density (g/cc)	Free Porosity (% vol.)	Available Moisture (% vol.)
Sand (gr. 1)	1.61	30.7	10.0
Sand (gr. 2)	1.57	23.7	19.0
Sand (gr. 3)	1.54	9.2	34.3
Sand (gr. 4)	1.53	1.0	40.6
Sand (gr. 5)	1.45	0.04	41.2
Sand (unsieved)	1.78	2.1	33.6
Vermiculite	0.09	24.0	37.8
Perlite	0.14	39.6	24.1

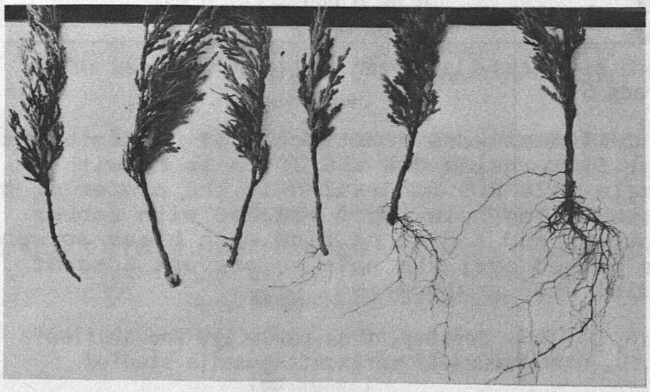
Three hundred cc of each medium to be tested was weighed. A volume of water was also weighed and enough added to the medium to cover it entirely. The wet medium was carefully spooned into the cylinders and gently stirred to remove trapped air bubbles and assure uniform saturation. When all 300 cc of medium had been added to the cylinders, the water level was brought down level with the surface of the medium. The water removed was weighed and the amount of water remaining in the medium at total saturation was determined by subtraction.

The plug in the bottom of the cylinder was removed and the gravitational water which drained out was weighed. Since 1 cc of water equals approximately 1 g (100 cc of water was found to weigh 99.7 g under the conditions of these tests) the amount of free porosity and available water can be determined on a volume basis. The procedure was repeated three times for each medium tested. The data is summarized in Table 2.

"Builder's sand" was sieved into five particle-sizes to test the effect of particle size upon the rooting of cuttings. The unsieved sand was also tested.

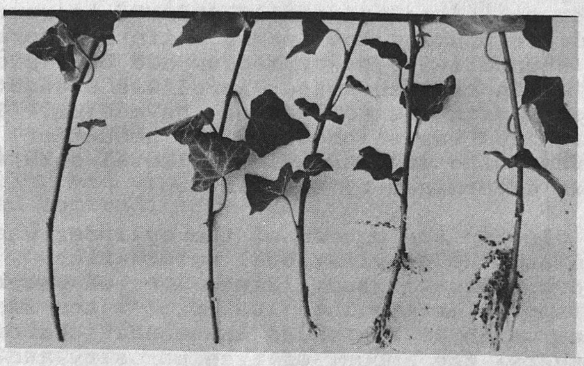
A mist bed with 6 sec mist/6 min interval, from 8 am to 4:30 pm was used for rooting. Two flats each of the five grades and of the unsieved sand, filled to a depth of approximately 3 inches, were randomly distributed on the propagating bench.

Forty-five cuttings each of *Juniperus horizontalis* 'Plumosa,' *Pyracantha* x'Shawnee,' and *Hedera helix* were stuck in each flat at appropriate dates. All cuttings were pulled on 3/3/76 (Table 3).



Juniperus horizontalis 'Plumosa'

Pyracantha x 'Shawnee'



Hedera helix

Figure 2. Visual classification scale used for each type of cutting studied.

Table 3. Time cuttings were allowed to remain in the propagating media.

Plant Species	Date Stuck	Days in Media
J. Horizontalis 'Plumosa'	11/13/75	112
P. x 'Shawnee'	12/ 8/75	87
H. helix	1/26/76	38

The cuttings were classified on a scale of 0-5; 0 = dead or no callus or root initiation, 1 - callus with no root initiation, 2 = root initiation, 3 = some rooting, 4 = fair rooting, and 5 = good rooting (Fig. 2). The data were evaluated both quantitatively and qualitatively. For a quantitative comparison, classes 2-5 were combined as "cuttings showing evidence of rooting" (Table 4). For a qualitative analysis, the number of cuttings in each class were summed, and divided by the total number of cuttings for all classes (Table 5). By this latter method the higher the number the better the overall quality of rooting.

Table 4. Quantitative evaluation of rooting.

	Percent of cuttings showing evidence of rooting				
Grade	*J. horizontalis* 'Plumosa'	*Pyracantha* x 'Shawnee'	*Hedera helix*	Average Rooting, Percent	**
1	11.3	36.5	17.5	21.7	a
2	89.8	72.0	85.2	82.3	bc
3	80.9	77.2	78.9	79.0	bc
4	94.4	89.5	88.8	90.9	c
5	49.2	51.4	82.1	60.9	b
Mix	94.5	87.3	92.1	91.3	c

** Mean separation by Duncan's multiple range test, 5% level performed on arcsine transformations.

Table 5. Qualitative evaluation of rooting.

	Rooting index means				
Grade	*J. horizontalis* 'Plumosa'	*Pyracantha* x 'Shawnee'	*Hedera helix*	Average	**
1	0.41	1.64	0.49	0.85	a
2	4.29	2.82	3.24	3.45	bc
3	3.77	2.84	2.92	3.18	bc
4	4.30	3.25	3.38	3.64	c
5	2.04	1.86	2.84	2.25	b
Mix	4.15	3.41	3.51	3.69	c

** Mean separation by Duncan's multiple range test, 5% level.

Grade 1, particles greater than 1 mm diameter. Cuttings in this medium gave the poorest rooting response both in quantity and quality of rooting. Most of the cuttings died as a result of dessication, becoming defoliated or brown and brittle. However Pridham (7) preferred a coarser grade, using a uniform particle size of 3/16 inch (4.8 mm), commenting that sizes much larger or smaller did not give satisfactory results. It is possible that satisfactory rooting would result with more frequent mistings or increased duration of mist.

Grade 2, particle size range 0.5-1.0 mm diameter. Cuttings in this medium showed fairly good rooting response. *Juniperus horizonatlis* 'Plumosa' cuttings had nearly 90% rooting and a higher rooting index mean than any grade except 'Plumosa' in grade 4.

Grade 3, particle size range 0.25-0.50 mm diameter. Cuttings in this medium gave only a fair rooting response in both quantity and quality. However, it should be noted that the replicates for this grade showed the greatest variance from their mean with one flat having 88.5% rooting and the other with 70.1% rooting. This would seem to indicate that possibly the flat with the lower percentage had been located on a section of the mist bench having a less favorable microclimate. If the points represented by the rooting percentages of the four other uniform particle-size grades are plotted on a graph, the curve obtained indicates a value for grade 3 of approximately 90%.

Grade 4, particle size range 0.10-0.25 mm diameter. Cuttings in this medium showed good overall rooting. Both the J. 'Plumosa' and the P. x 'Shawnee' gave better rooting percentages in this grade than in any other grade, although the rooting index mean for Pyracantha was slightly higher in the flats of unsieved sand. This grade was one of the two grades showing the highest quantity and quality of rooting; in fact, the differences between this grade and the unsieved sand are so small as to be easily accounted for by error.

Grade 5, particle size range 0.05-0.10 mm diameter. Cuttings in this medium showed poor overall rooting. Hedera helix had the highest rooting percentage but a relatively low rooting index mean. Because of the small particle size most of the pores are of capillary size and the percent moisture held in the pores is very high. Consequently, aeration is poor, resulting in inhibition or rooting. In addition, when the cuttings were pulled, callus tissue was soft and spongy, indicating a waterlogged condition in the medium.

Unsieved "builder's sand" (analysis-15% grade 1, 13% grade 2, 42% grade 3, 29% grade 4, and 4% grade 5 or less). Cuttings in this medium showed a higher overall rooting percentage and rooting index mean than any other grade, but only slightly higher than grade 4.

Matkin (4) noted that for optimum rooting response a propagating medium should have at least 20% free porosity. On the basis of these results with sand good rooting may be obtained with as little as 1.0% free porosity for some species. However, in determining free porosity for the particle-size grades of sand, the inclusion of a perched water layer at the bottom of the cylinders was unavoidable; the free porosity of the medium above this layer is therefore higher than indicated in Table 3. Matkin did not indicate whether his free porosity values includes this layer, but as it would be extremely difficult if not impossible to remove, the figures obtained by Matkin and those in this report are probably similar.

An increase in the free porosity of a medium would probably be beneficial as long as enough water is applied to prevent dessication. This should be done by adjusting the mist system cycle or duration. A medium of primarily capillary pores cannot be as easily improved by regulating the moisture supply, as the water tends to be held in the pores and does not drain. The free porosity of a medium with predominantly fine particles may be increased by addition of coarser particles, or by removal of particles less than 0.10 mm diameter. However, Spomer (9) indicates that in the addition of coarse to fine particles the point at which the fine particles are insufficient to fill the spaces among the coarse particles (threshold proportion) and good aeration is obtained in approximately 3:1.

From the free porosity and moisture content data obtained for grades of sand it is possible to derive equations of these functions. The curve representing the free porosity of a nonabsorptive uniform particle-size medium is obtained from the equation

$$y = 42-35.413e^{-0.90228(x-0.18)}$$

where y = free porosity and x = average particle size for a particle size range. Similarly, the expected moisture content of the medium for a given average particle size is represented by the equation

$$y = 39e^{-1.06(x-0.18)}$$

where y = moisture content and x = average particle size for a particle size range. The data points obtained from the experimental procedure and the theoretical curves using the two equations are shown in Figure 3. As the particle size increases, the moisture content tends to approach 0, being held only over particle surfaces, and that the free porosity tends to approach the total pore space. Conversely, if average particle size decreases to less than 0.2 mm, capillary forces tend to keep the medium in a nearly saturated state. It is expected that these curves would hold true not only for sand but also for other nonabsorptive particulate media.

Media such as sand and perlite are similar in that they are nonabsorptive particulate materials, whereas media such as vermiculite and peat moss absorb water internally. Perlite particles, while technically nonabsorptive, have rougher surfaces that retain a greater proportion of moisture than sand particles of the same diameter. Additionally, broken perlite particles are capable of absorbing water into internal capillary pores. An expanded mica such as vermiculite absorbs water into the interior of the particle while retaining a particulate shape, giving it the ability to hold a greater amount of water for a given particle size while retaining the same amount of free porosity as a sand or other nonabsorptive medium of the same particle size composition. Peat moss has no particulate structure and is able to retain water in the capillary pores and additionally to absorb water within the fibers themselves, giving it one of the highest water retention capabilities of any medium. Finely shredded peat moss has smaller pores spaces than peat moss which is allowed to remain somewhat chunky and therefore has less free porosity. Free porosity of a medium often is reduced by rough handling or packing of the material. Relatively fragile media such as vermiculite are easily broken down into smaller particles by rough handling with resultant lowered free porosity. Packing or tamping of a medium compresses the material and causes the particles to fit more closely

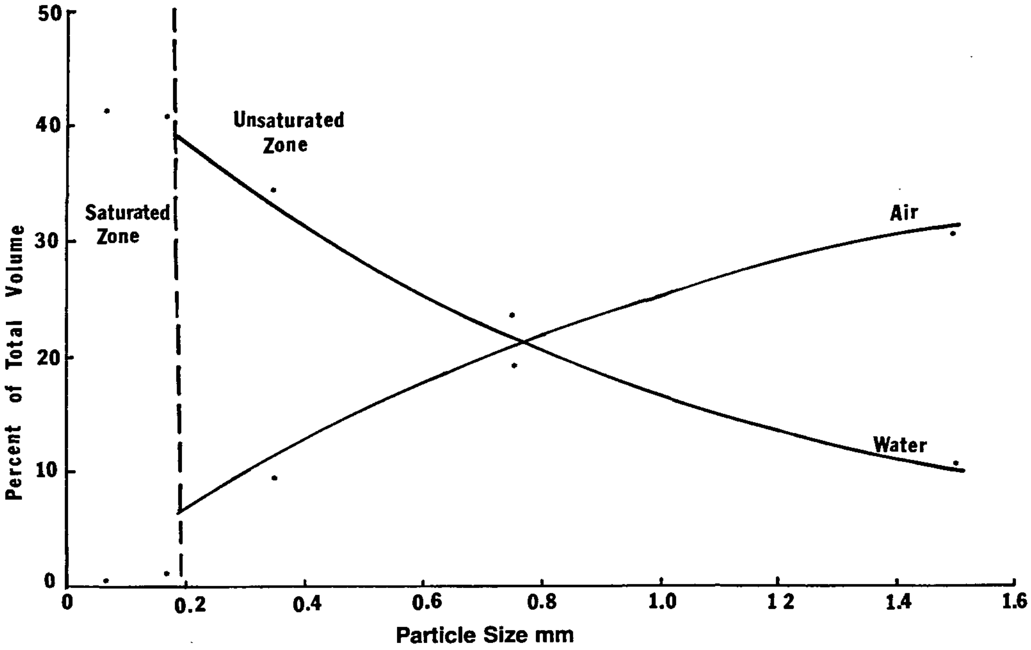


Figure 3. Theoretical curves of percent air and water in particulate nonabsorptive media and measured values (*).

together with attendant reduction of pore size and therefore less free porosity.

The research concerning the value of free porosity of a medium is not yet conclusive except that a certain amount is necessary to provide oxygen for root initiation and development. The optimum free porosity may be and probably is variable according to the type of plant, and possibly as to whether it is xerophytic or hydrophytic. Differences in rooting response of different species in the same medium may be due in part to different oxygen requirements.

Further research needs to be done to determine the desirable range of free porosity for a propagating medium to maximize positive rooting response. One possible direction for continued investigation would be into combinations of various particle sizes to provide a specific mean pore size or free porosity. Another area which requires looking into is measurement of medium oxygen content. Studies of any particulate medium should include particle-size analysis to facilitate comparison by different investigators.

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EFFECTS OF REFRIGERATION, CO_2 AND PHOTOPERIOD ON THE INITIAL AND SUBSEQUENT GROWTH OF ROOTED CUTTINGS OF *Ilex cornuta* Lindl. AND Paxt. cv. Burfordii

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Abstract. Dormant *Ilex cornuta* 'Burfordii' cuttings were subjected to cold temperature treatment by refrigeration prior to forcing in