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The Effect of Container Soil Volume on Plant Growth[1]

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***Abstract.* This paper describes a simple laboratory exercise for demonstrating the direct relationship between container soil volume and plant growth in a way that avoids complications caused by soil geometry (shape and depth). This is accomplished by mixing different amounts of gravel into each container soil thereby excluding different volumes of soil from otherwise identical containers.**

The soil[2] volume accessible to a plant's root system determines the water and mineral reservoir potentially available to the plant and therefore, to a large extent, its growth potential, or at least its irrigation requirement. This is an especially important edaphological concept for container-grown plants which have access to only a finite soil volume. Although simple to understand, the effect of soil volume on plant growth is often not clearly demonstrated in the teaching laboratory. The usual exercise to demonstrate this concept uses different size containers of similar or different types to provide a range of soil volumes in which the plants are grown. Unfortunately, this approach also provides an accompanying range of soil shapes and depths, in turn, affecting soil water retention (1, 3) and plant root growth patterns and thereby plant growth. Thus, establishment of a direct relationship between soil volume and plant growth becomes difficult, if not impossible. Another common exercise uses a range of planting densities in greenhouse benches or ground beds to provide a range of available soil reservoirs per plant; however, it also provides a range of photosynthetic radiation and carbon dioxide supplies per plant shoot, again making it difficult to establish a direct relationship between soil volume and plant growth. This paper describes a simple laboratory exercise which clearly and directly demonstrates this important edaphological concept without encountering the problems associated with commonly used exercises. Sample data from such an exercise are also presented.

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[2]'Soil' herein refers to the root zone media.

Laboratory exercise. The objective of this exercise is to demonstrate the probable relationship between soil volume and plant growth. To do this in the most direct manner, it is important to change soil volume between treatments without changing soil depth and shape. Fortunately, this is easily accomplished in practically any container by physical exclusion of soil from the container volume through the incorporation of very coarse textured particles mixed into the soil (Fig. 1) (3, 4). This procedure excludes soil volume equal to the incorporated coarse particles' *solid* (not bulk) volume as long as the particle size of the latter is several degrees of magnitude larger than that of the soil (does not significantly interact with soil particles to affect pore size distribution). The soil volume is thus changed with little or no change in soil depth, shape, or water relations.

In the simplest form, this demonstration requires only a suitable potting mixture (homogeneous, without large chunks of peat, etc.), large, non-porous particles (i.e., washed and sieved "pea" gravel), containers (large enough to provide a range of soil volumes and minimize particle-container interaction), and plants (a species in which growth is easily measured). The first step is to measure the soil bulk volume required to fill the container (container volume). This is the bulk volume upon which subsequent soil volume calculations are based and is simply equal to the volume of water required to fill the container (with its drain holes plugged) (2). Next, the coarse particles solid volume percentage (percent of solid volume in any bulk volume) must be determined so that the bulk volume required to exclude a specified soil volume from the container can be calculated. This is easily done by liquid displacement methods. The water excluded from a water-filled container by coarse particle solid volume can be collected and measured by placing a large pan under the container to catch the water overflow as the coarse particles are added:

$$\text{Coarse particles solid vol \%} = \frac{\text{excluded water vol}}{\text{container vol}} \times 100\%$$

This can also be determined by filling a dry container with coarse particles and measuring the volume of water required to just saturate it (fill all the pore spaces):

$$\text{Coarse particles solid vol \%} = \frac{\text{container vol—sat water vol}}{\text{container vol}} \times 100\%$$

It is best to prepare each container's soil individually to ensure the desired volume of soil is actually excluded from that container. The required coarse particles bulk volume to exclude a given percentage of soil volume:

$$\text{Coarse particles bulk vol} = \frac{\text{excluded soil \%} \times \text{container vol}}{\text{coarse particles solid vol \%}}$$

is placed in the container and soil is mixed into it until no more can be added. The mixture is then poured onto a plastic sheet and remixed (may require moistening) to ensure its homogenity and is replaced into the container. If the final volume is insufficient (and it probably will be unless relatively large containers are used), more soil is added and the procedure repeated.

Cuttings or transplants are grown in the treatments under normal cultural practices through that plant's normal life cycle or until obvious growth differences occur (depending on available time). The most obvious growth effect should be on plant size. Treatments should be irrigated at identical intervals with a standard fertilizer solution. Care should be taken during irrigation to minimize particle separation by washing. Actual differences between treatments in soil water storage can be determined by measuring the volume of water applied to and drained from each at irrigation. Stored water equals the difference between

Table 1. Sample data from laboratory exercise.

	Gravel					Partition	
Treatment (Relative volume)	Total root zone (cm^3)	Gravel bulk vol[z] (cm^3)	Excluded soil vol (cm^3)	Retained soil vol (cm^3)	Growth[y] (cm)	Total root vol (cm)	Growth[y] (cm)
1.0	1780	0	0	1780	50	1780	50
0.8	1780	552	356	1424	48	1424	52
0.6	1780	1104	712	1068	43	855	45
0.4	1780	1655	1068	712	32	342	34

[z]Particle diameter = 0.7 cm, solid volume = 0.645 × bulk vol.
[y]Avg height of 5 plants after 10 weeks (rounded to nearest cm).

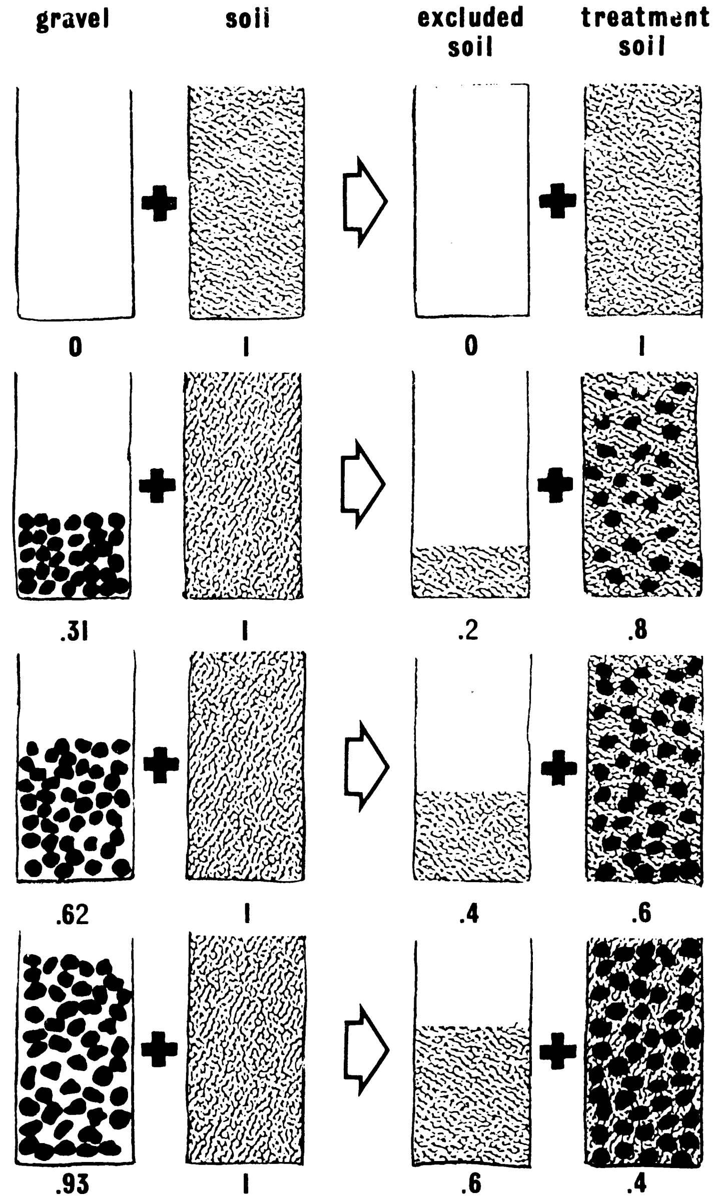

Fig. 1. Diagram of example soil volume treatments where soil reservoir volume is excluded from a container by incorporating gravel into the soil. With this method, soil shape, depth, or extent are not changed from the control. The numbers refer to the fraction of the container volume. Treatments consisted of 1, 0.8, 0.6 and 0.4 container volumes of soil.

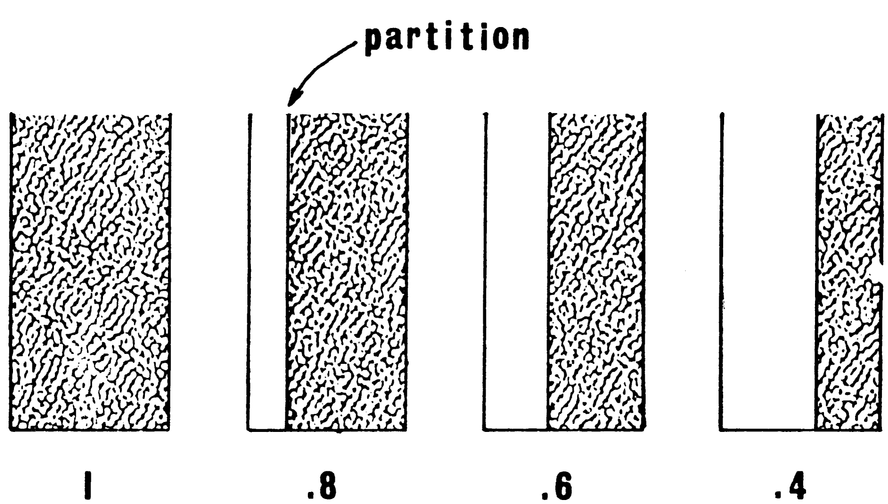

Fig. 2. Diagram of soil volume treatments where soil reservoir volume is excluded from a container (in identical amounts to those in Fig. 1) with vertical partitions placed in the container. With this method soil shape and extent are changed from the control.

applied and drained volumes and should be proportional to the amount of soil retained (inversely proportional to the soil excluded). An additional exercise may be set up to vary irrigation interval to compensate for soil volume differences. For example, gravel treatments excluding 20, 40, and 60% of the soil would be irrigated at t/4, t/3, and t/2 intervals where t = the irrigation interval of the 0% excluded soil treatment. More frequent irrigation would be expected to compensate for reduced soil volume because the main effect of the soil volume treatments is on water storage and availability; however, this concept has been difficult to demonstrate, apparently because of poor aeration or excessive nutrient leaching in the most frequent irrigation treatments. This optional exercise, therefore, is not always successful. It seems to work best under conditions of high water use.

When a suitable container (such as a half-gallon milk carton) is used, parallel treatments may be added using vertical barriers to reduce the soil's volume to the same extent as the gravel treatments (Fig. 2). Drainage depth remains the same and root zone extent is reduced along with soil volume. The restricted root zone usually has little or no effect on the growth of most species in this situation; however, the longer the growth cycle, the more likely an effect will be observed. The nearly identical growth observed between parallel treatments demonstrates the observed growth response in the gravel treatments is indeed caused by soil exclusion (Table 1). This comparison also may be used to further demonstrate the effect of soil physical amendment (2).

A reduction in growth does not occur until the soil's water reservoir becomes limiting relative to the plant's water requirement. The latter depends largely on plant size and on environmental conditions. Under a given environmental condition, differences in growth usually do not appear until the plants become large enough that their water requirement exceeds soil storage capacity. Differences in growth may not appear at all if the soil reservoir and irrigation interval of the smallest-volume treatment are sufficient to meet the plant's water requirement. Growth differences will occur sooner and be more significant when treatment soil volumes are relatively small and evapotranspiration rates relatively high.

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