

SIMULATING THE FIELD: How to Grow Plants in Soil Columns in the Greenhouse

INTRODUCTION

Why Soil Columns?

In the field of plant research it is often desirable to grow plants under controlled conditions to minimize environmental variability from one treatment to the next. The desired control can be achieved by growing plants in containers in a greenhouse or growth chamber.

Plant growth in soil is straightforward in the field where soils are deep, but soil moisture dynamics are altered significantly in small containers. Drainage in the field results from the depth (thickness) of the soil layer. Gravity alone is not adequate to remove water from agricultural soils in pots.

Soil columns are an improvement over pots because they are deeper and can therefore hold more soil and more plant-available water; the longer the column, the better the water dynamics. A small surface area to depth ratio enables the use of many columns and the application of several randomized treatments within a small area.

Water Dynamics in Soils

The water content of a soil is measured either by weight (gravimetric water content) or by volume (volumetric water content). In unsaturated soils, water is under tension and requires energy for removal. As the water content of a soil decreases from the saturation point, the tension used to hold the remaining water increases. The negative pressure (suction) required to remove water from soil at a given water content is termed the 'matrix potential'. The matrix potential is zero at saturation and decreases (increases in magnitude but becomes more negative) as a soil dries. The relationship between soil water content and matrix potential varies from soil to soil depending on soil texture. The soil water release curve, also called the water retention or soil water characteristic curve, for a particular soil illustrates this relationship. An example curve is shown in Figure 1. For most soils, the water content at field capacity corresponds to a negative pressure of -10 to -30 kPa and 50% of the plant-available water remains at negative pressures ranging from -40 to -200 kPa (Table 1). Wilting point (the point at which plants can no longer extract water from the soil) is -1500 kPa for all soils.

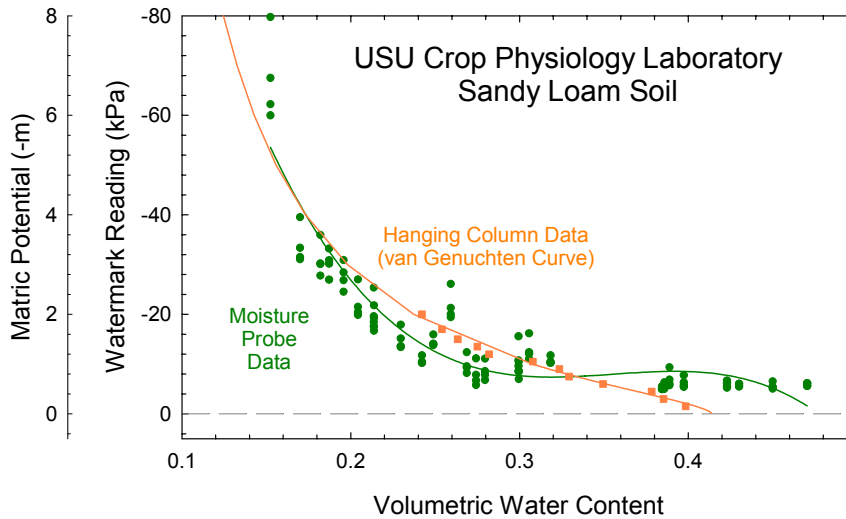


Figure 1. Soil water release curve for a sandy loam soil at the CPL. Two curves were generated. One using hanging column data (orange squares) in conjunction with the van Genuchten (1980) model, and one using soil moisture sensor data (green circles) in conjunction with gravimetric water content measurements.

Table 1. Typical soil water tension for three soil textures.

	Sand	Loam	Silty Clay Loam
	----- Soil Water Tension (kPa) -----		
Field Capacity	10	30	20
50% Available Water Remaining	40	150	200
Wilting Point	1500	1500	1500

EVOLUTION OF THE SOIL COLUMN DESIGN

What we Started With

The soil columns in use at the CPL evolved from pre-existing, 2-Liter PVC columns. The original columns consisted of 46-cm (18") lengths of 7.6 cm (3") diameter PVC pipe. Each pipe was capped on the bottom and a 1/2" drain hole was drilled in the center of each cap. The drain hole was covered with 16-mesh screen to prevent soil leakage. The columns were used in studies where differences in plant growth from treatment to treatment were quantified. In each study, columns filled with our standard potting mix (50:50 peat:perlite amended with lime) served as controls for "good" plant growth. In every case the plants grown in potting mix were larger and more vigorous than those grown in soil, and it became apparent that the columns did not drain sufficiently resulting in waterlogged conditions.

Addition of a Ceramic Cup

In subsequent studies a 1-bar porous ceramic cup was sealed into the side of each column near the bottom to aid in water removal. Ceramic cups have a convoluted network of tiny interconnecting pores that once wetted allow water to move from the outside to the inside (or from the inside to the outside) of the cup. When a wetted cup is in good contact with soil, applying a vacuum of less than 1 bar (14.5 PSI, 1 atmosphere, 100 kPa) to the cup causes water but not air to move out of the soil and into the cup.

Our ceramic cup assembly consists of a 1-bar, high flow ceramic cup (0652X11-B01M3, Soil Moisture Equipment Corp., Santa Barbara, CA) seated into a modified threaded 1/2" by 1/8" NPT PVC bushing (Figure 2A). The threads are removed from the lower half of the bushing using a grinder or sander. Adhesive-lined heat shrinkable tubing (3:1 shrink ratio) is slipped over the ceramic cup and the threadless section of the bushing and a heat gun is used to seal the tape around the cup/bushing interface (Figure 2B). A 1/8" NPT by 1/4" tube fitting is screwed into the top of the PVC bushing to complete the assembly (Figure 2C).

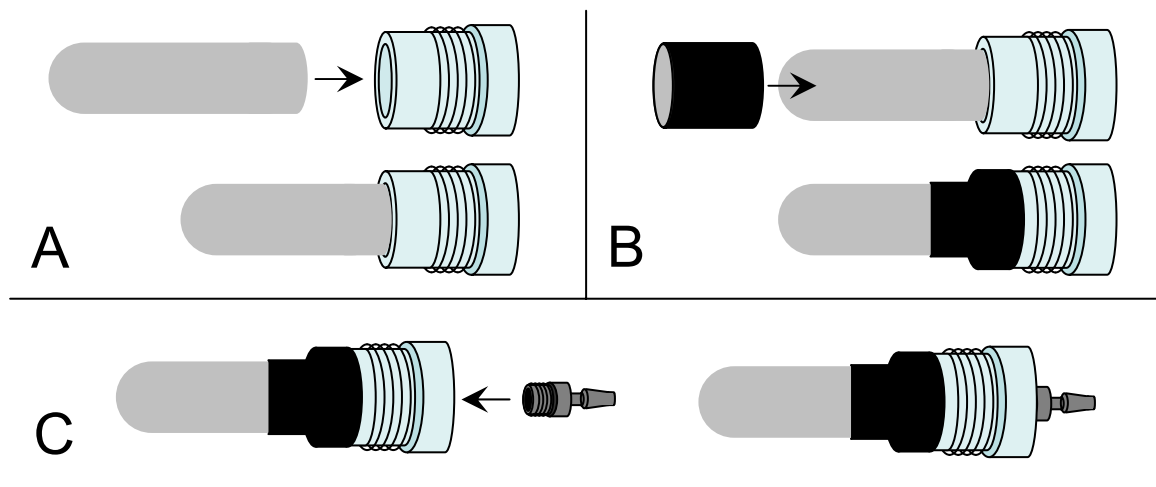


Figure 2. Porous ceramic cup assembly.

A vacuum of -30 kPa (4.5 PSI) is applied to the cup and the water removed from the soil column is collected in a vacuum trap. Removal of water via suction on the ceramic cup appeared to improve water relations in the columns, but plant growth was still sub-standard. We therefore sought to improve the texture of the soil by modifying our column packing techniques.

Soil Packing Techniques

In early studies with the soil columns, air-dry soil was homogenized (for uniform moisture content and aggregate size) in a cement mixer, and then packed into the PVC columns with significant tapping and shaking. The resulting bulk density was high, ranging from 1.3 to 1.5 g/cm³. Packing techniques have since been altered based on discussions with soil physics experts in the Plants,

Soils and Biometeorology Department. Columns are now packed to minimize settling and retain as much of the aggregate structure as possible (see section below on column packing).

Soil Volume

Soil typically has 50% pore space by volume. In a wetted and drained soil, about half of the total pore space (25% of the soil volume) is filled with air and half is filled with water. The amount of plant-available water at field capacity is typically about 20% of the total water in the soil (10% of the total soil volume). A 2-L column at field capacity therefore has about 200 mL of plant-available water; about as much as a crop plant would transpire in a day. The 200 mL is distributed throughout the column, but when columns are packed at high bulk densities (as was the case in our 2-L columns), plant roots tend to proliferate along the inner wall of the PVC and growth into the bulk soil is limited. Improvements in packing and watering techniques have since led to better root exploration of the soil, but a greater volume of plant-available water was also desired.

Soil Column Watering

Plants in soil columns must be watered regularly and thoroughly. Sufficient water must be added to penetrate the entire column and a “pulse” of water is recommended. In our early studies we found that the most time-efficient way to manually water the columns was to pour water on top of the soil surface. The water ponds for a minute or two, then soaks in. Adding water in this manner resulted in loss of soil structure and led to compaction of the bulk soil and a crust at the soil surface. We sought to improve this by using an automated watering system to add frequent, small volumes of water at the soil surface, thereby preventing ponding and soil compaction.

CURRENT SOIL COLUMN DESIGN

Column Size

Both the surface area and the total volume of our original 2-L columns were increased substantially by the addition of PVC bell fittings (Table 2). The top of each of the original 2-L columns was fitted with a 4” x 6” bell fitting nested inside a 3” x 4” bell fitting (Figure 3).

Table 2. Increase in column volume and surface area with the addition of bell fittings.

Column Component	Surface Area (cm ²)	Surface Area Increase (%)	Added Volume (cm ³)	Total Volume (cm ³)	Volume Increase (%)
Original 3” Column	45.6	0	2145	2145	0.0
3” x 4” Bell alone	81.1	77.8	958	3103	44.7
3” x 4” + 4” x 6” Bells	182.4	300.0	1257	4360	103.3

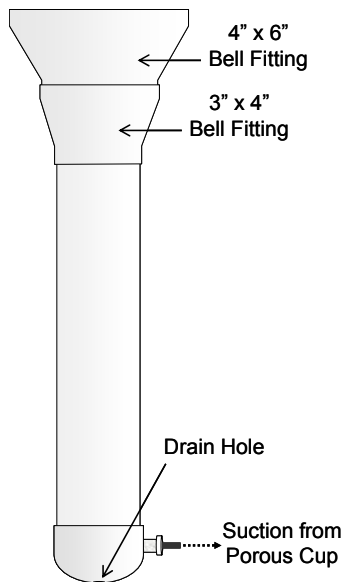


Figure 3. Column construction. The original 3" diameter, 2-L columns were made larger by the addition of a 4" x 6" bell fitting nested inside a 3" x 4" bell fitting.

Column Packing

Lower bulk densities and better soil aggregation may be achieved by moistening the soil prior to packing. We accomplished this by gradually adding water to a pile of bulk soil while mixing the soil with shovels. The target consistency is one that causes the soil particles to stick together, but is not so wet as to cause clumping. Soil that is the consistency of mud or has any free water (glistening or puddling) is much too wet. Thoroughly mixed and uniformly moist soil should be added to each column by scooping and dumping, as opposed to pouring. Pre-moistening and dumping the soil keeps the particle sizes well mixed (Lebron and Robinson, 2003), resulting in a lower and more optimum bulk density.

The dry bulk density of 26 columns packed with a silt-loam soil using this method averaged 1.18 ± 0.03 g/mL. Dry bulk density was calculated by weighing the empty column, then weighing it again once filled to determine the mass of the soil. A sub-sample of moistened soil was dried at 80 °C for 48 hours to determine the moisture content. The moisture was subtracted from the initial soil mass and the resulting dry soil mass (~ 5200 g) was divided by the column volume (~ 4400 mL).

Column Watering

An automated watering system that adds frequent, small volumes of water at the soil surface over the course of an hour or two each watering day can prevent ponding and soil compaction. We have found that applying a saturating pulse of water in this manner every-other day has better results than watering with smaller amounts every day. Our initial automated system consisted of an event timer and a duration timer. The event timer was programmed to signal a solenoid valve to open and allow water to be gravity-fed to the columns several

times over the course of a one- to three-hour period. We were able to change to an every-other day watering regime by controlling the solenoid valve with a datalogger. Water is delivered via a manifold with individual spaghetti tubes plumbed to the soil surface in each column. A small square of Scotch Brite® scouring pad placed beneath the outlet of each tube dissipates the impact of the droplets and prevents cratering of the soil. The watering event duration is set to add just enough water so that ponding does not occur. As the plants grow, the number of consecutive watering events on each watering day is adjusted to be sufficient to cause drainage via the ceramic cup of each planted column. The amount of drainage from each column can be tracked by installing a water trap between the ceramic cup and the vacuum pump (Figure 4).

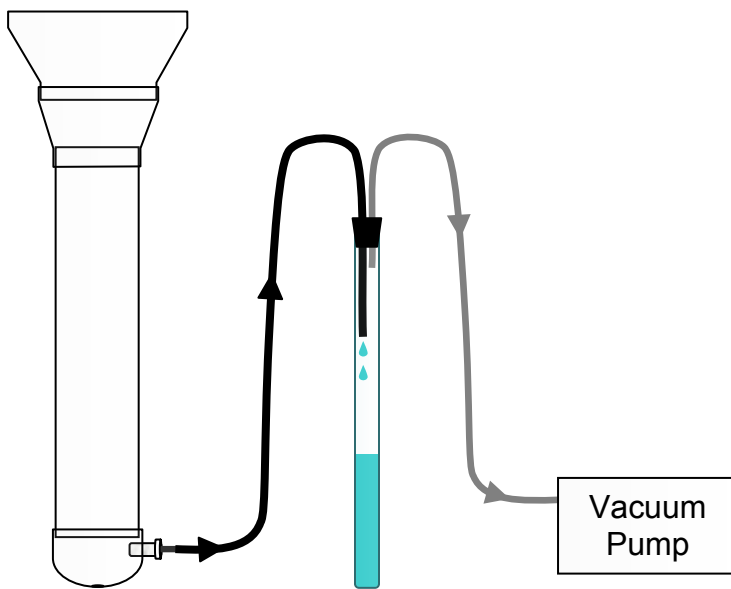


Figure 4. A water trap positioned in-line between the ceramic cup and the vacuum pump collects drainage water. Traps are constructed of clear PVC to allow visual confirmation of column drainage.

WATER DYNAMICS WITH NEW COLUMN DESIGN

In order to grow healthy plants in small containers filled with soil, it is necessary to start with *and to maintain* low bulk densities and good drainage. We have improved our soil column design as well as our techniques for packing and watering the columns. As a result, we have been able to grow plants that are almost as vigorous as those growing in peat/perlite control columns (Figure 5).



Figure 5. Red robin tomato plants grown in peat/perlite potting mix (left) and sandy loam soil (right).

An every-other day watering regime seems to work well. Columns are watered with a saturating pulse of water which is applied over the course of two or three hours, then allowed to drain and surface dry for 48 hours before water is re-applied. Ideally the surface soil will dry faster than the soil toward the bottom of the column, as is the case with the three tomato columns in Figure 6. The automated system works well for plants of similar transpiration rate, so long as individual water emitters deliver similar volumes of water from column to column. Figure 5 shows Watermark readings from three columns planted with tomatoes. Though the plants are the same age and size, Tomato 2 appears to dry the fastest. This was due either to a lower volume of water being applied to this column at each watering event, or to a difference in transpiration rate between this plant and Tomato plants 1 and 3.

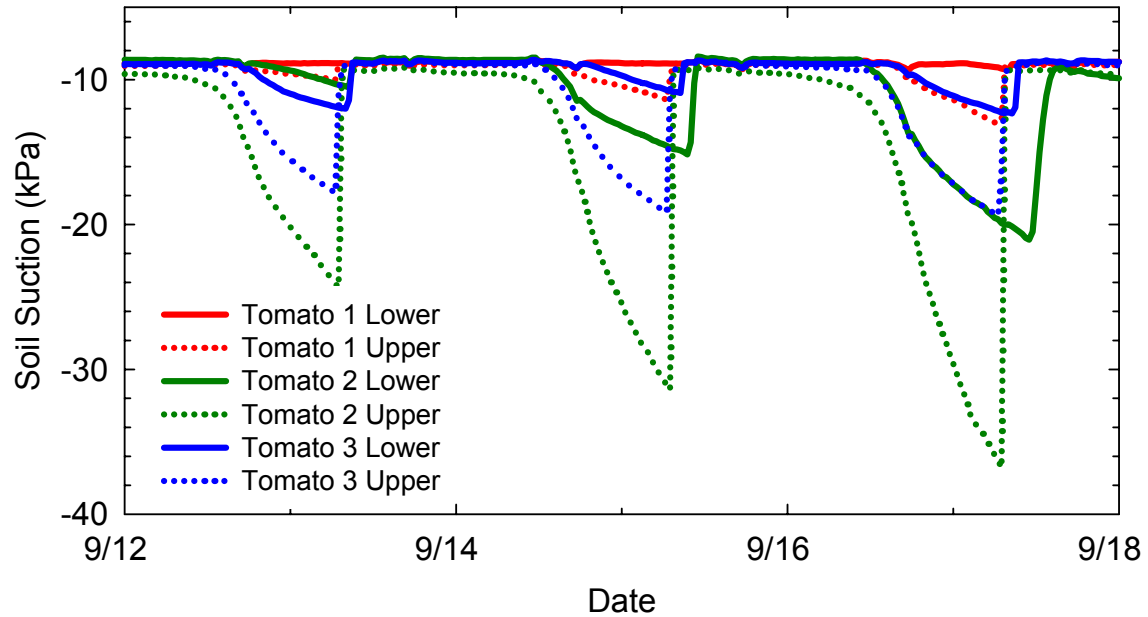


Figure 6. Watermark readings in three different columns planted with Red Robin tomatoes and watered every-other day. Each column is equipped with a Watermark probe 10 to 15 cm below the soil surface (upper probe) and 10 to 15 cm above the bottom of the column (lower probe).

REFERENCES

- Lebron, I. and D.A. Robinson. 2003. Particle size segregation during hand packing of coarse granular materials and impacts on local pore-scale structure. *Vadose Zone Journal* 2:330-337.
- van Genuchten, M. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* 44:892-898.