Beyond Hydroponics: Improved procedures for studying rhizosphere effects on plant nutrition

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Abstract

Hydroponic culture has been a cornerstone of plant nutrition since the first studies by Hoagland and Arnon in the 1930's. Liquid hydroponic culture, however, almost completely eliminates rhizosphere effects, which can have an enormous effect on nutrient availability. There are a wide variety of porous substrates, watering methods, and nutrient control methods that might be used to study rhizosphere effects. We refined media and procedures to optimize five root-zone factors: 1) water/oxygen balance, 2) mechanical impedance similar to field soils, 3) buffered pH, 4) precise control of nutrient concentrations, and 5) ease of removal from roots. We tested several growth media and found that the method used to pack the columns is as important as the growth medium. An optimal air/water balance is achieved by using coarse media and watering with small volumes, several times per day, using an automated watering system. Specialized nutrient solutions and pH control can be used to induce specific nutrient deficiencies, and the rhizosphere pH can be manipulated by changing the ratio of NO_3 to NH_4.

Objectives

- **To grow healthy plants in small containers with porous substrates that are easily removed from roots and do not confound plant nutrition studies.**
- **To simulate the field by optimizing the rhizosphere:**
  - water/oxygen balance
  - mechanical impedance similar to field soils
  - buffered pH
  - precise control of nutrient concentrations
  - ease of removal from roots
- **To apply precision stresses to plants.**

Figure 1. Replicate columns growing sunflowers and wheat (foreground) and corn (background) on a greenhouse bench.

Why Columns?

Flexibility

Compact size = room for many treatments & replicates in a single controlled environment (growth chamber or greenhouse, Figure 1).

Reality

Tall, columnar containers are preferable to short, wide pots because they can support deeper root growth. In fine-grained media they provide a water potential gradient with depth that is closer to field conditions.

Growth Media

Standard Potting Mixes

- **SPHAGNUM PEAT + PERLITE OR VERMICULITE:**
  - Well-drained, organic-rich
  - Buffered pH and nutrient exchange
  - Difficult to remove from roots **(Figure 2)**.

Figure 2. Roots of corn grown in (left to right) 50/50 peat/perlite, brown Turface, and vermiculite.

Other Media

- **STYROFOAM BEADS: Lightweight and inert (Figure 3).** Tend to static-electrically stick to surfaces and tend to float, even when mixed with other media (e.g. sand). Mixing with sand reduces bulk density.
- **PERLITE: Lightweight and porous (Figure 3).** Like foam beads tends to float, but less inert and **sticks to roots** due to pores.
- **TURFACE®: Commercially available** calcined clay product (Profile Products, Buffalo Grove, IL). **Easily removed from roots (Figures 2 & 4).** Comes in brown, gray and red. Brown is available in a range of particle sizes. With a **CEC of 33 meq/100 g** (higher than most soils), Turface is **likely to have nutrients associated with its exchange sites.**
- **SAND: Inert and comes in a wide array of grain sizes and shapes (Figures 2 & 5).** Can be layered to optimize the air/water balance in the root zone (Henry et al. 2006). Bulk density can be reduced by mixing with perlite or foam beads.

Column Packing

Moisture is the key!

- Regardless of the growth medium tested, **significantly deeper and more uniform root growth is achieved when the medium is moistened and well-mixed immediately prior to packing (Figure 6).**
- The **target wetness** is one that causes the media particles to stick together.
- **Pre-moistening and scooping/dumping** (as opposed to dry pouring) the media keeps the particle sizes well mixed (Lebron and Robinson, 2003).
- **Tap or tamp the columns identically during packing** to get a uniform bulk density from column to column.
- Column **dry bulk densities** in **Figure 6** ranged from 0.58 to 1.58 **(Table 1)**. The **particle size distribution** also varied widely **(Table 2)**.

Figure 6. Corn roots (above) and soybean roots (right) from columns packed either moist or dry with five different media. We have observed similar results with sunflowers and wheat.

Table 1. Bulk densities of various media.

Medium	Dry Bulk Density (g/cm³)
Sand	1.4 to 1.7
Calcined Clay (Profile/Turface)	0.50 to 0.66
Peat/Perlite (50/50, v/v)	0.14 to 0.18

Table 2. Particle size distribution of 100-g samples of various media.

		g retained (also % retained) in each size class					
Sieve Size	Actual Size (mm)	Angular Sand	Angular Sand	Ottawa (Round) Sand	Profile	Brown Turface	Gray Turface
< 30	< 0.6	59.4	59.3	0.0	16.2	0.0	0.0
25 - 30	0.6 to 0.7	18.6	21.8	3.3	16.6	0.2	0.2
18 - 25	0.7 to 1.0	13.7	12.1	96.1	67.0	0.8	2.0
12 - 18	1.0 to 1.7	6.2	5.7	0.0	0.1	14.7	49.4
> 12	> 1.7	0.3	0.2	0.0	0.0	83.8	47.9

Column Construction

- **Larger diameter column = more water-holding capacity; longer column = deeper roots.**
- **Column dimensions** should reflect water-holding capacity and expense/availability of the rooting media, size and rooting depth of the plant species, and the intended study duration. Our columns are scaled for studies of 2 to 6 weeks with a rapidly-growing crop such as corn.
- Our columns **(Figure 7)**: **12" long, 2" diameter PVC pipe**, **volume ~600 mL**. Bell-shaped reducer fitting secured to bottom of PVC pipe stabilizes column and secures a **mesh screen**. Mesh screen supports rooting media while also allowing water to drain by gravity.

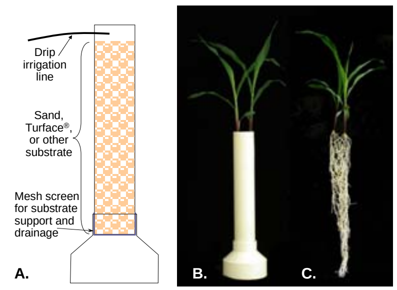


Figure 7. A) Column construction. B) Corn plants growing in a column. C) Roots grew to the bottom of the column and were easily separated from the Turface substrate.

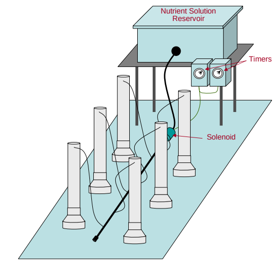


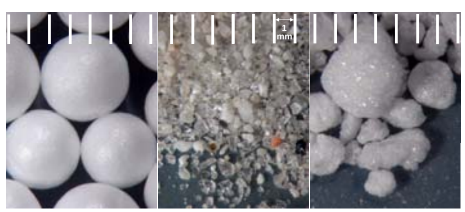
Figure 8. Gravity-feed nutrient solution delivery system with time clocks, solenoid, and drip irrigation lines.

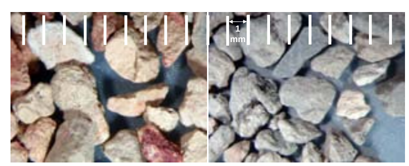
Watering

- **Air:water in pore spaces varies from top (more air) to bottom (more water).**
- **Fine media can be watered less frequently (2 to 3 times/day), coarse media need to be watered more frequently (12 to 18 times/day)**
- **Automated watering system** delivers nutrient solution to each column **(Figure 8)**:
  - Event timer controls the number of watering events each day (fine media/small plants = 2 to 6, coarse media/large plants = 10 to 20)
  - Duration timer controls the length of each watering event (enough to keep tops moist with little leaching).
  - Elevated 50-L reservoir supplies nutrient solution to columns via gravity feed.
- **Nutrient solution** recipes are customized to meet objectives of individual studies.
- Sometimes appropriate to mix in **nutrients in solid form** (pellets or granules) during packing.

pH Management

- **Solubility and plant availability of mineral nutrients is closely coupled to pH.**
- **Rhizosphere pH can be manipulated by changing the form of N supplied.**
  - When N is supplied as nitrate (NO_3^-), N uptake results in a rising rhizosphere pH.
  - When N is supplied as ammonium (NH_4^+), N uptake results in a decreasing pH.
- **Bulk column pH can be buffered ~8 with calcium carbonate ($CaCO_3$).**
  - Powder should be thoroughly mixed with a moistened, fine-grained medium such as sand.
  - 10 g per 600-mL column is adequate for a 4-week study without excessive leaching.
  - Each watering event perturbs the carbonate equilibrium.





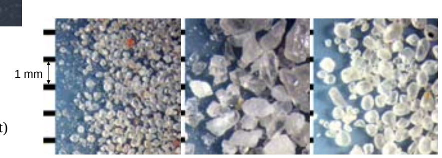


Figure 3. (Above) A closer look at (left to right) styrofoam beads, an angular sand, and perlite.

Figure 4. (Above right) A closer look at brown (left) and gray (right) Turface Pro-League®.

Figure 5. (Right) A closer look at three kinds of sand: (left to right) round sand, angular sand, and round Ottawa sand.

Cited References

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