Maintaining and Quantifying Drought Stress in Containers

Julie Chard & Bruce Bugbee Utah State University, Crop Physiology Laboratory

Abstract

It has always been difficult to study drought stress in containers because the root-zone water potential changes rapidly. Here we describe techniques for maintaining drought stress in both soil columns and pots of soil-less media. Containers are typically filled with a soil-less media mixture such as peat/perlite to facilitate drainage. Growing plants in soil better approximates field conditions, but it is difficult to avoid flooding and reduced air-filled porosity. Soil columns facilitate drainage and increased porosity. In soil columns, gravimetric measurements of soil water content were compared to measurements of soil water potential made by Watermark sensors. In pots with soil-less media, plants were subjected to steady-state, low root-zone water contents (or negative water potentials). Real-time changes in transpiration rate of plants in soil-less media were gravimetrically quantified at 10-minute intervals using digital balances. See Chard & Bugbee online (www.usu.edu/cpl/research.htm) for additional details.

Objectives

- **To apply and maintain drought stress in containerized plants.**
- **To evaluate drought stress techniques on:**
  - transpiration rate
  - soil moisture content
  - soil matrix potential

Soil Columns

Growth Medium

- **FIELD SOIL**
  - Poorly drained in small containers/pots
  - Gradual changes in root-zone water potential
  - Better approximates the field than potting soil

Growth Container

- **COLUMNS**
  - Support deeper root growth than pots
  - Hold more soil and more plant-available water than pots
  - Like the field, provide a water potential gradient with depth

Methods

- **INSTRUMENTATION (Figures 1&2)**
  - Climate-controlled greenhouse with supplemental HPS lighting
  - Watermark soil moisture sensors (Irrometer, Riverside, CA)
  - Multiplexer (Model AM416) & datalogger (Model CR21X) for recording Watermark & environmental data (Campbell Scientific, Logan, UT)
  - 6" (15.2 cm) diameter x 28.5" (72.4 cm) long PVC columns, 13-L volume
  - Clear PVC water traps and vacuum pump for active water removal
- **COLUMN PACKING IS CRITICAL**
  - Soil moistened prior to packing (Lebron & Robinson, 2003)
    - minimizes settling and sorting of particles, preserves aggregates
    - lower bulk densities (1.18 ± 0.03 g/mL) than dry packing (~1.3 g/mL)
  - Watermark soil moisture sensors packed into columns at three depths
  - Moist soil is scooped and dumped rather than poured into columns
- **COLUMN WATERING**
  - Gradual wetting is essential
    - ponding results in compaction and surface crust formation
    - columns watered once weekly via drip tubing
    - watering takes place over the course of 3 hours
    - watering duration is adjusted as necessary
  - Water traps
    - enable tracking of water in vs water out
    - quantify leaching
    - protect the vacuum pump from water damage
- **CALIBRATION AND USE OF WATERMARK SENSORS**
  - Watermark sensors continuously measure matrix potential **(Figure 3)**.
    - inexpensive (about $24 each)
    - wide measurement range (0 to -2 bars, 0 to -200 kPa)
    - temperature-sensitive (1 to 3% per °C)
    - multiple calibration equations have been generated **(Figure 4)**.
    - calibration coefficients are soil-specific

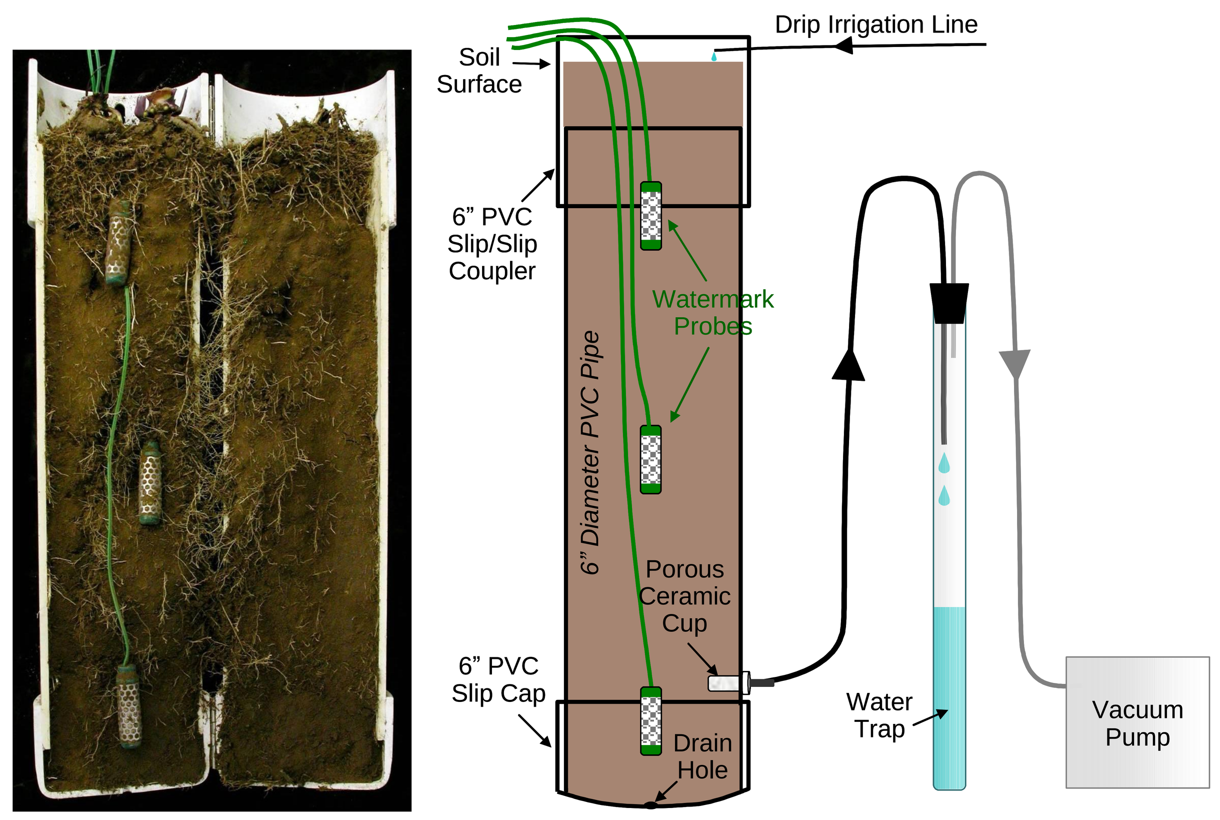

Figure 1. Photo and schematic of a single soil column. Watermark sensors were buried at three depths. A constant suction of 30 kPa (4.5 PSI) was drawn on the column to remove excess water via a 1-bar, high flow, porous ceramic cup. Water was added once a week by extremely slow drip irrigation (over 3 hours) at the soil surface.

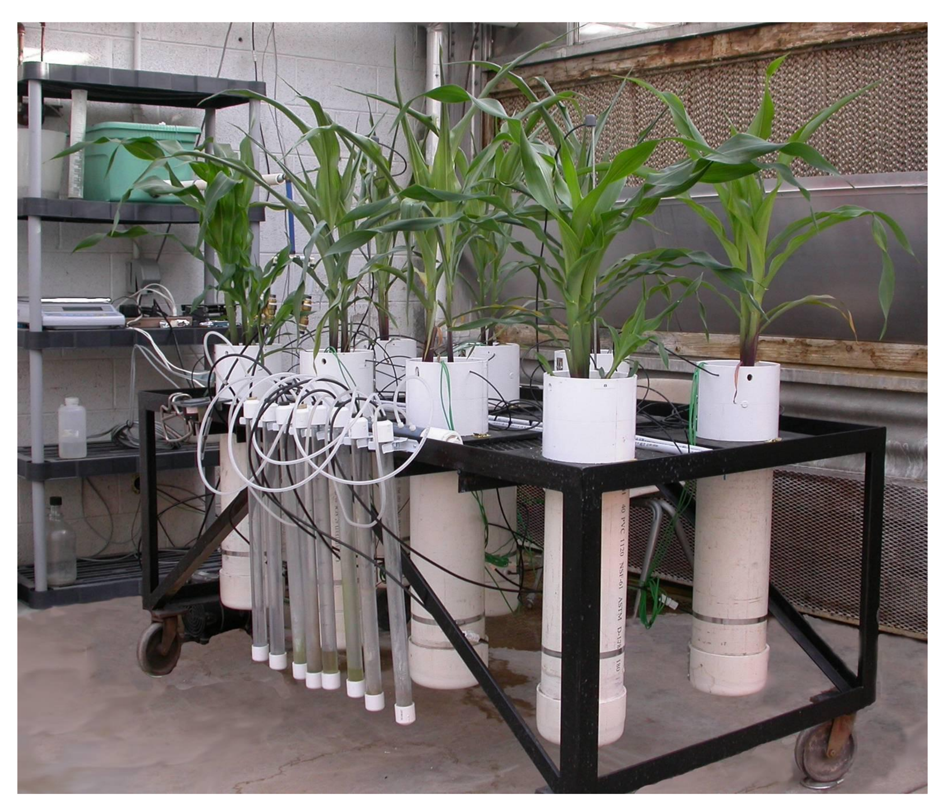

Figure 2. Eight replicate columns in the greenhouse.

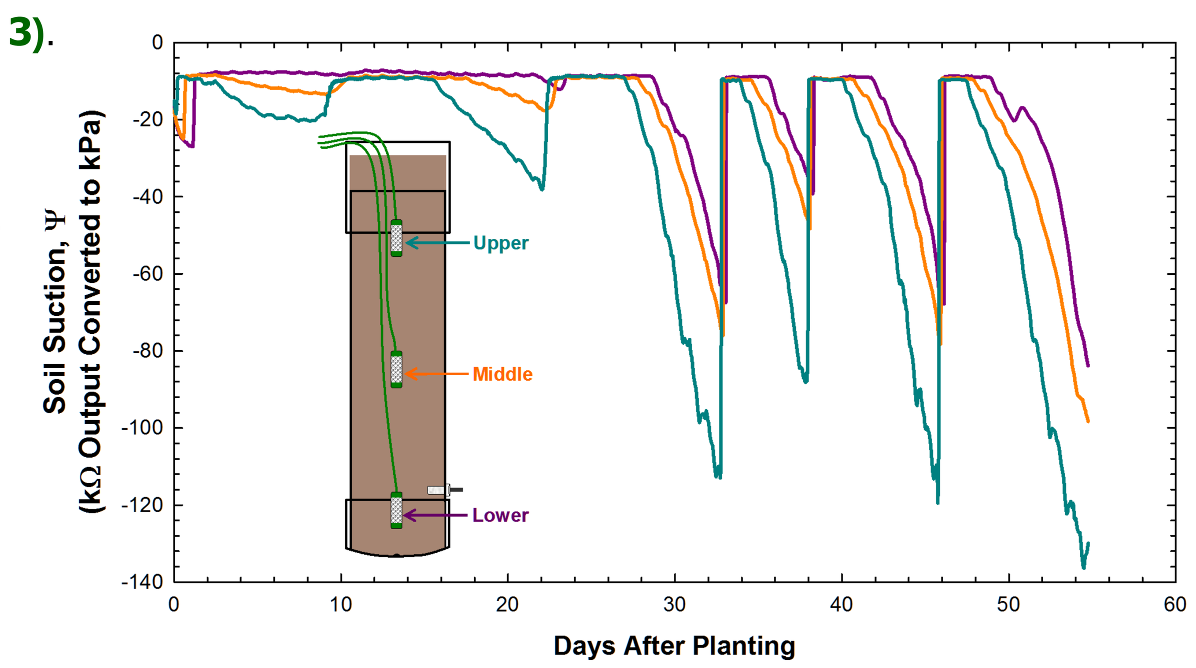

Figure 3. Watermark data at three depths in a single column.

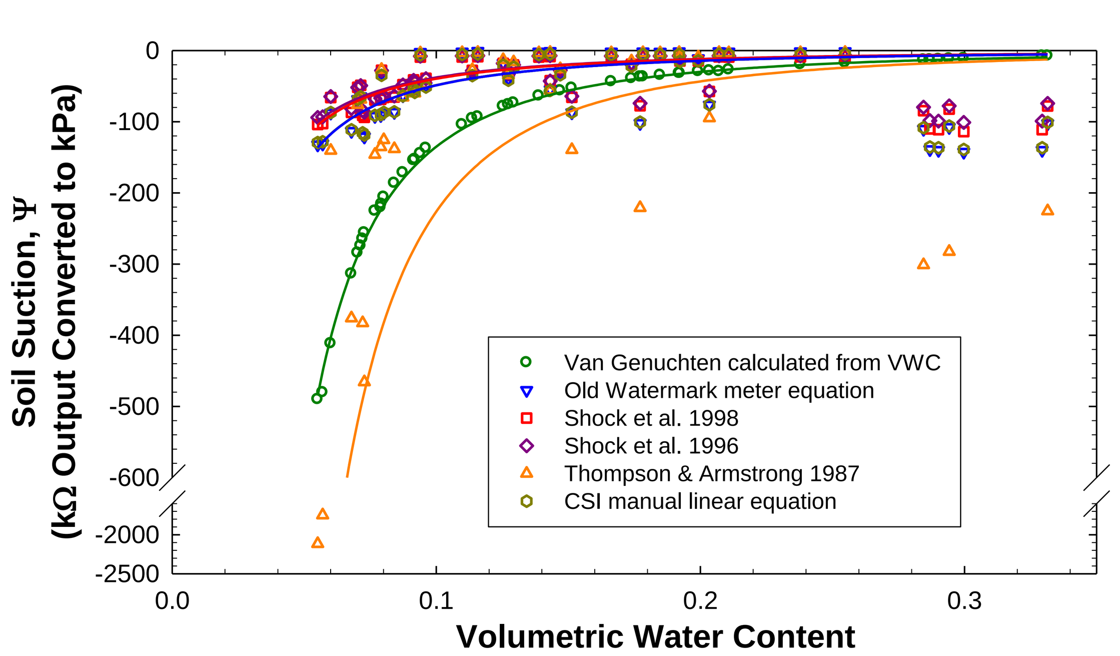

Figure 4 (left). Watermark sensor output as a function of volumetric water content. Sensor output was converted to kPa using four different calibration equations. See Chard & Bugbee online (www.usu.edu/cpl/research.htm) for details.

Gravimetric

Growth Medium

- **SPHAGNUM PEAT + PERLITE/VERMICULITE**
  - Well-drained, organic-rich
  - Ideal for small containers/pots

Methods

- **INSTRUMENTATION (Figures 5&6).**
  - Growth chamber to obtain constant radiation and temperature
  - Electronic-output scales (Models ALC & Vicon, Acculab, Edgewood, NY)
  - Datalogger for recording data and running the controller & multiplexer (Model CR1000, Campbell Scientific, Logan, UT)
  - Multiplexer to provide enough input channels to read many balances at once (Model AM416, Campbell Scientific, Logan, UT)
- **REAL-TIME MESUREMENT OF TRANSPIRATION**
  - Plant/pot weight continuously measured and recorded
  - Transpiration rates calculated on 10-minute intervals
  - Stomatal conductance calculated from transpiration & VPD
- **AUTOMATED WATERING**
  - Water lost via transpiration replaced once per hour
  - Individual solenoids open/close as signaled by the datalogger
- **INDUCTION OF DROUGHT STRESS (Figures 7&8).**
  - Weight setpoints lowered in datalogger program
  - Transpiration reduced by ~50% & maintained at steady state.

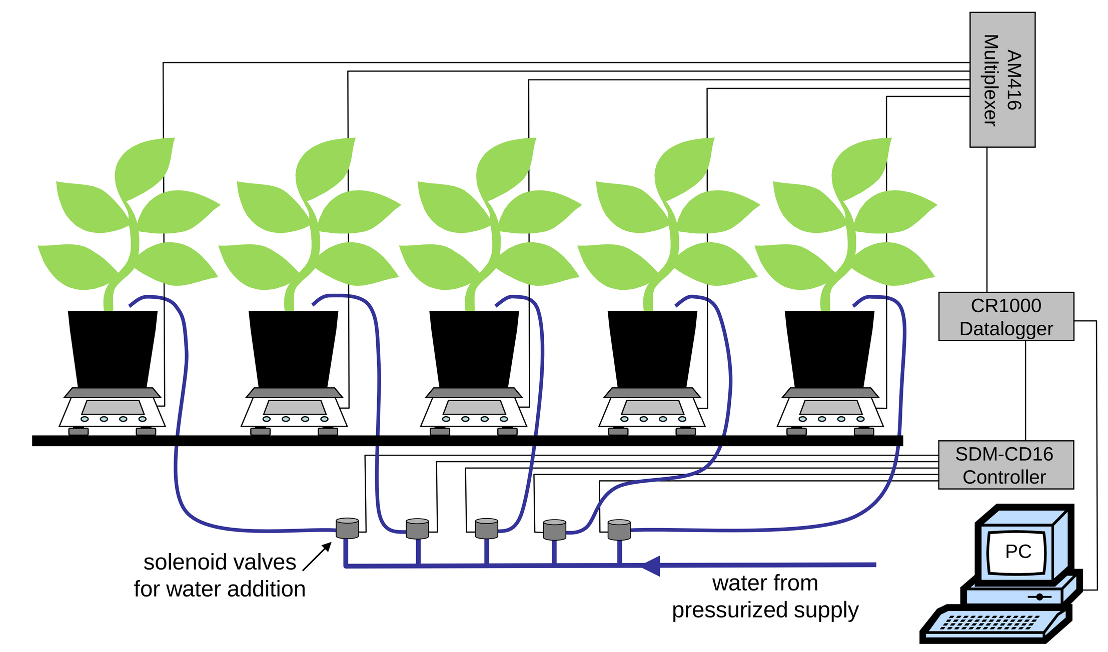

Figure 5. Schematic of the automated system used to impart precision drought stress on potted plants. Scale weights are continuously monitored using a datalogger and multiplexer. Transpiration rates are calculated on 10-minute intervals. Weights are compared to programmed setpoints once per hour. The datalogger signals a controller to open solenoids and add water to pots with weights below their setpoints. Weights are maintained within 5% of their setpoint.

Figure 6 (below). Cotton plants on scales in the growth chamber. The leaf contact in this photo sometimes interfered with accuracy.

Figure 7 (above). Roots of well-watered (left) and drought-stressed (right) soybean plants. Water distribution and root growth are uniform even with limiting water.

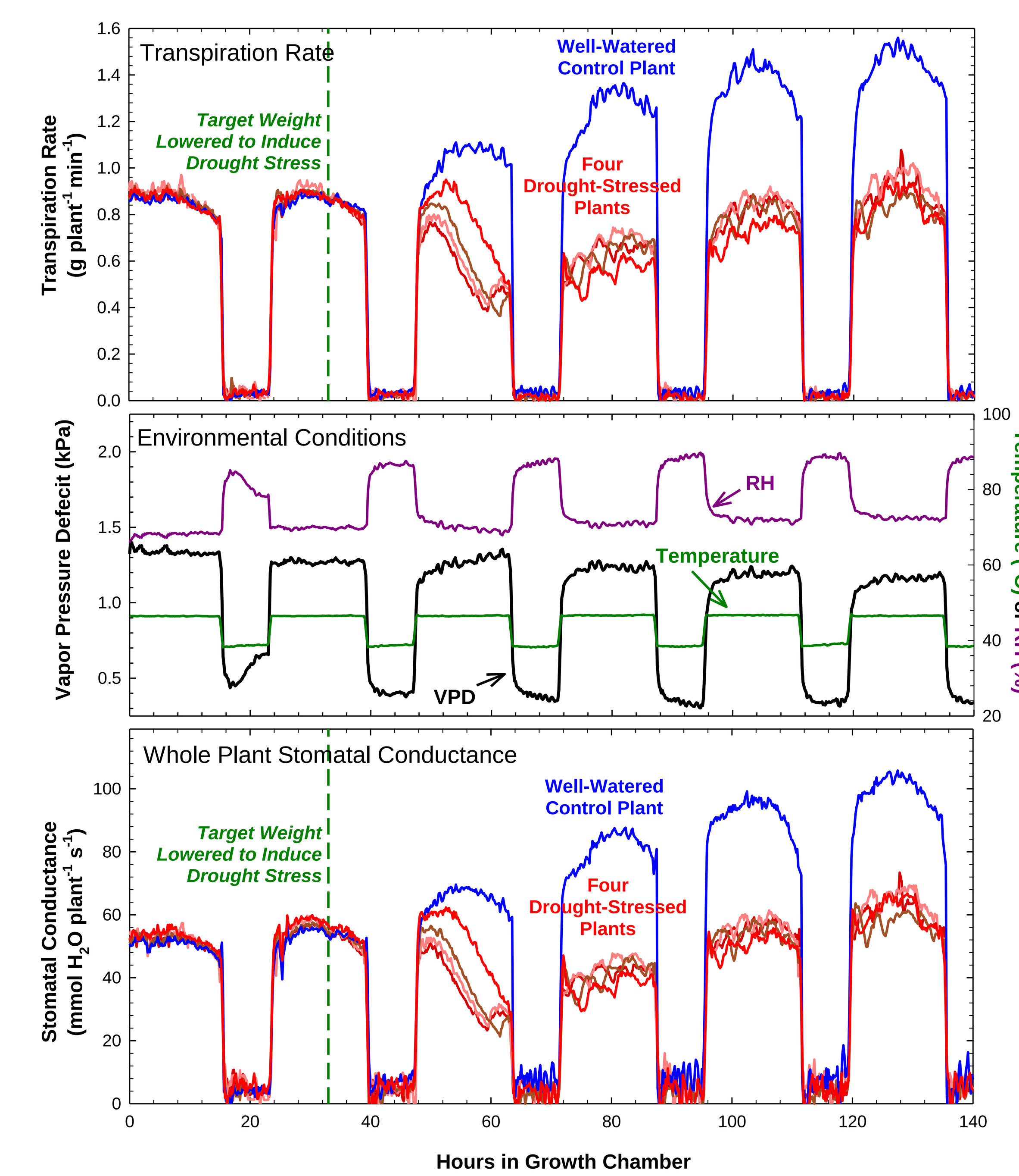

Figure 8. Sample data. Temperature and relative humidity data are used in combination with transpiration data to calculate whole-plant stomatal conductance. The weight setpoints were reduced to induce a ~50% reduction in transpiration.

Conclusions

Soil – Changes in soil water content are gradual, so drought stresses imposed using this method are not steady-state. The transient nature of the stress better for approximates field conditions. None of the published calibration equations for Watermark sensors matched the water retention curve for our soil.

Gravimetric – Drought stresses imposed gravimetrically are relatively steady-state and can be used to continuously measure transpiration. This technique can also be used with plants grown in soil (Earl, 2003).

References

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Earl, H.J. 2003. A precise gravimetric method for simulating drought stress in pot experiments. Crop Science 43(5):1868-1873.