

Plant Available and Unavailable Water in Greenhouse Substrates: Assessment and Considerations

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Abstract

Accurate assessment of available water in substrates usually includes a measurement of water unavailable to plants. Plant roots have an ability to pull suctions up to 1.0 to 2.0 MPa, depending on species, with the classic value for unavailability measured at 1.5 MPa. Five samples each of peat moss, pine bark and perlite and a clay soil were placed in a 1.5 MPa porous plate system for 48 hours. The samples were then removed and run in a dewpoint potentiometer then dried for 24 hours at 105°C. The mineral soil potentials averaged 1.39 MPa, but the others were much smaller: peat = 0.38, bark = 0.21 and perlite = 0.28 MPa. Peat and bark were re-tested at 0.3 MPa on the porous plate system then placed in the potentiometer. The peat water potential was 0.33 MPa while the bark was 0.34 MPa, showing good agreement with the porous plate pressures. The samples of highly porous materials of peat, bark and perlite possibly seemed to lose hydraulic continuity between the samples and porous plate above 0.3 MPa of pressure which stopped the flow of water from the samples. This resulted in artificially high values. In a second study, substrate samples (3 peat: 1 perlite: 1 vermiculite, v/v/v) were taken from mature marigold plants in three stages of wilt: Stage 1: light wilt (initial leaf flagging), Stage 2: moderate wilt (leaves wilted to ~45° of vertical) and Stage 3: heavy wilt (leaves wilted and curled to main stem). Water potentials were measured at each stage using the potentiometer. After substrate sampling, each plant was re-watered and level of recovery was noted. Plants at Stage 1 wilt had soil potentials of ~0.6 MPa. Stage 2 wilt was at ~1.55 MPa and Stage 3 wilt was ~2.2 MPa. All plants visually recovered from wilt at all stages. The potentiometer may be useful in determining actual soil water potentials under dry conditions, not normally measurable using the traditional porous plate system. Unavailable water content for horticultural substrates may be overly high using the porous plate system as confirmed with the dew point potentiometer. Measuring water potentials during plant wilt may help to refine the nature of permanent wilt and more precisely determine water is truly unavailable to plants.

INTRODUCTION

The term available water capacity, first defined by Veihmeyer and Hendrickson (1927), describes water held in a soil between field capacity (or container capacity in horticultural substrates) and the permanent wilting point (PWP). Permanent wilt describes the condition where a plant has reached a low enough water potential that there can be no recovery (Taiz and Zeiger, 1996). Richards and Wadleigh (1952) found that the PWP for most agricultural crops is between -1.0 and -2.0 MPa, with the convention of -1.5 MPa to be PWP. Plants do not generally reach permanent wilt at the instant they reach this potential, but instead gradually reduce transpiration until available water is lost. Denmead and Shaw (1962) showed that many plants start to reduce transpiration rate at as low as -0.2 MPa.

In order to determine available water content, container capacity and unavailable water must be measured. To measure UW, Bouyoucos (1929) described an apparatus which produces a suction equal to -1.5 MPa which draws upon a soil sample. This idea was refined by Richards and Fireman (1943) who applied 1.5 MPa of pressure, and

employed the use of porous plates which soil samples are placed upon to allow water to be moved out of the samples until equilibrium is reached with the 1.5 MPa pressure that has been applied. A modified version of Richards and Fireman's pressure plates is currently the most common method of measuring UW, along with the plant-based method using sunflower (Cassel and Nielsen, 1986). The sunflower method was first proposed by Furr and Reeve (1945) and involves growing sunflower seedlings and allowing them to wilt until PWP is reached, and measuring soil water content.

The sunflower method can take long periods of time and due to the non-instantaneous wilt of plants, this method can lack in accuracy. However, inaccuracies have been reported with the use of pressure plates at tensions as high as -1.5 MPa (Stevenson, 1982; Fonteno and Bilderback, 1993; Gee et al., 2002). A possible explanation for the inaccuracies with pressure plates is the loss of hydraulic connectivity, or the lack of an unbroken water column throughout the sample. If the water column between the plate and the length of the sample is broken, pressure will be applied to either end of the sample, and thus result in no net flow of water. Recent research by Curtis and Claassen (2008) has shown the effectiveness of using dewpoint potentiometry to measure the water potential of inorganic amendments with higher precision.

The objectives of this research were: 1) to determine the potentials reached when -1.5 MPa are applied to organic greenhouse substrate components, and 2) to determine soil water potentials of plants grown in container substrates during the wilting process.

MATERIALS AND METHODS

This experiment required the use of pressure plate extractors (PPE; Soilmoisture Equipment Corp.; Santa Barbara, CA) and a WP4C Dewpoint Potentiometer (Decagon; Pullman, WA). Traditional horticultural substrate components including, sphagnum peat moss (Premier Tech, Canada), aged pine bark, and perlite, were tested along with a clay mineral soil classified as Gerogiaville.

Five rubber rings were placed on each moistened 1.5 MPa pressure plate, and each ring was filled with one of the materials being tested. In total 20 total samples were tested (4 materials, 5 replications). The samples were saturated for 24 h, and placed in PPEs. Flat circular lead weighs were placed on top of each sample, in order apply a slight downward force to ensure connectivity between the plate and the sample. Nitrogen gas (N₂) was then slowly passed into the PPEs until the PPEs were pressurized to 1.5 MPa. The pressure in the PPEs was maintained for 48 h.

The samples were then removed, sealed and measured in the WP4C dewpoint potentiometer. The dewpoint potentiometer uses a chilled-mirror dewpoint technique. Relative humidity is measured until equilibrium is attained between the air in the chamber and the sample. Water potentials were determined using repeated measures until successive readings were equal. Testing the samples from the pressure plate allowed the measurement of water potential rendered after pressures of 1.5 MPa.

Experiment Two – Plant Wilt

Plastic containers of 7.6 cm diameter and 7.6 cm height were filled with a substrate consisting of a mixture of peat: vermiculite: perlite (3:1:1, v/v/v) at a bulk density of 0.13 g/cm³ to ensure uniformity. Marigold (*Tagetes erecta* L.) seeds were sewn directly into the containers, placed into the greenhouse and irrigated as needed. Fertilization was with 200 ppm N (total) in liquid feed once every 2 to 4 days.

Once these plants were mature and flowering the rooting environment (after approximately 8 weeks), each container was saturated, allowed to drain and to begin the wilting process. The plants were observed for wilting until the plant reached one of the three stages of visible wilt (Fig. 1): Stage 1 – initial flagging; Stage 2 – leaves wilted with stems drooping to an angle of 45°; and Stage 3 – all leaves completely wilted. Once at the appropriate wilt stage, plants were photographed and removed from the container.

A soil sample approximately 2 cm wide was removed from the top to the bottom of the substrate. Any visible roots were removed and a portion of the sample was placed

into an aluminum cup and sealed to prevent water loss. The plant was then irrigated and monitored for recovery. Three plants were sampled for each wilt level. Once samples were taken, the substrate samples were measured in the WP4C dewpoint potentiometer for water potential. Measurements took from 20 to 40 minutes to equilibrate and obtain stable readings. Afterwards, the samples were placed in a forced air drying oven at 105°C for 24 h to determine water content. Means separation was performed using SAS, LSD, $p = 0.05$.

RESULTS AND DISCUSSION

The actual water potentials of the substrate components pressurized to 1.5 MPa on pressure plates are shown in Figure 2. The only material to approach the applied -1.5 MPa of pressure was the mineral soil. The horticultural components showed pressures of approximately -0.3 MPa or lower. This is likely due to the highly porous nature of horticultural substrates materials causing a loss in hydraulic connectivity early in the desorption process resulting in a lowering of water content removed from the samples. The volumetric water contents were as follows: 12% for clay soil, 14% for peat, 25% for bark and 27% for perlite.

To help confirm that the conductivity during pressurization was being lost prematurely, the peat and bark were again prepared for the pressure plates but run at 0.3 MPa for 48 hours. The resulting water potentials and volumetric water contents (16% and 24%, respectively) for peat and bark were the same as those at 1.5 MPa. This implies that the peat and bark samples broke hydraulic continuity between 0.2 and 0.3 MPa on the plates. These results indicate that the pressure plate system provided inordinately high values of water content at 1.5 MPa for peat, pine bark and perlite. Furthermore, it seemed that the water contents at 1.5 MPa are actually lower than those produced in the pressure plate. Measuring the soil water potentials for wilting plants was therefore warranted to find more realistic values near permanent wilt.

Figure 3 shows the water potentials of the Marigold plants at the different wilting stages. At Stage 1, the plants were at -0.6 MPa. Plants at Stage 2 were at -1.55 MPa, which is currently considered as the permanent wilting point. Stage 3 showed even higher potentials of -2.2 MPa. Volumetric moisture contents were 12.8% for Stage 1, 6.0% for Stage 2 and 4.8% for Stage 3. The water contents for Stages 1, 2 and 3 were much lower than those obtained from the pressure plate study. This would indicate that actual water contents of substrates at water potentials near permanent wilt are perhaps much lower than previously reported using pressure plates- perhaps nearer 5 to 10% rather than 25% for 1.5 MPa. At all three wilting stages, all plants appeared (visual observation only) to make full recoveries within 24 hours after re-watering, most within a few hours. It is probable, but unknown that changes in evapotranspiration or photosynthesis may have occurred as a result of the stress.

These data warrant other points of discussion. The loss of hydraulic continuity shown in the pressure plate work may also be happening at initial wilt. Both values were approximately 0.3 MPa, indicating that initial wilt could be caused by a loss of continuity, preventing a redistribution of water content within the substrate profile. This is perhaps due to the coarse nature of substrate components compared to mineral soils. This would also imply that there may be little redistribution of water after drainage in substrates, especially as the plant begins to take up water. This would underscore the need for a root system to fully explore the substrate to reduce the potential for wilt. For this reason, plants were grown for 8 weeks to develop root systems that were visually well developed and encompassed the entire substrate.

Another point of discussion is the complexity of the term, “available water.” Available water is a function of water volume, the (matric) tension in which it is held, and the hydraulic conductivity between where the water is held and the root exerting tension. Measuring these parameters in the 1970’s involved tension tables, tensiometers and pressure plates. De Boodt and Verdonk (1972) used tension tables to define “easily available water” and “watering buffering capacity”. These tables had a working tension of

~10 kPa before they broke tension. These values were correlated with plant production where water tensions measured with tensiometers showed a decrease in plant production after 10 kPa. However, classic soil science with mineral soil shows available water defined from field capacity to permanent wilt. For containers that would be defined as from container capacity to unavailable water.

Our approach is to use the latter definition of available water. This would include water content for both production and marketplace/consumer survival- from container capacity to permanent wilt. From these data, it seems clear that the moisture contents previously reported for unavailable water (≥ 1.5 MPa) using pressure plates may be artificially high. Also, the water potentials reached in this experiment as well as others (not shown) indicate that substrates may easily reach potentials of -1.5 MPa or higher during the wilting process and recover after irrigation. This would mean that the available water content may be only 5 to 10% less than the substrate container capacity. The wilting experiment also suggests that the soil water potentials during water stress may reach lower values than currently thought. This may also be true for ultimate limits for plant survival. More work is needed to verify these results and more fully explore the substrate water potentials and plant stress.

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Figures

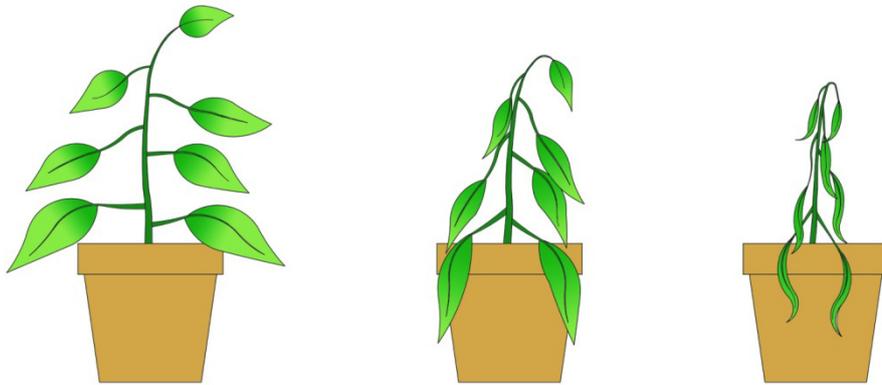


Fig. 1. Diagram of wilting stages: Stage 1 (Left) Initial wilt, Stage 2 (Center) Moderate wilt, Stage 3 (Right) Heavy wilt.

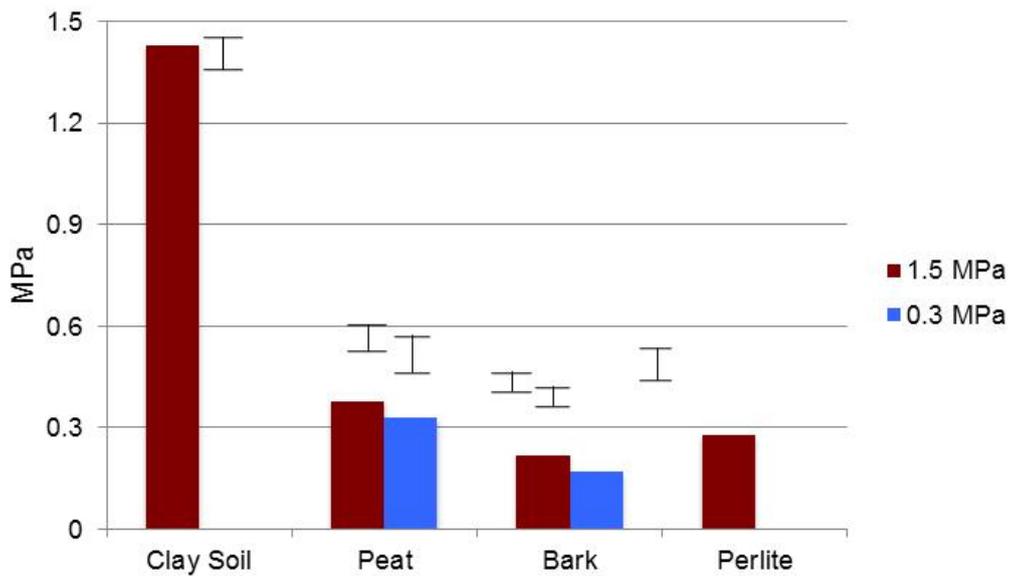


Fig. 2. Water potentials of materials measured by dewpoint potentiometer after being pressurized to 1.5 MPa. Peat and bark were also run at 0.3 MPa on pressure plates.

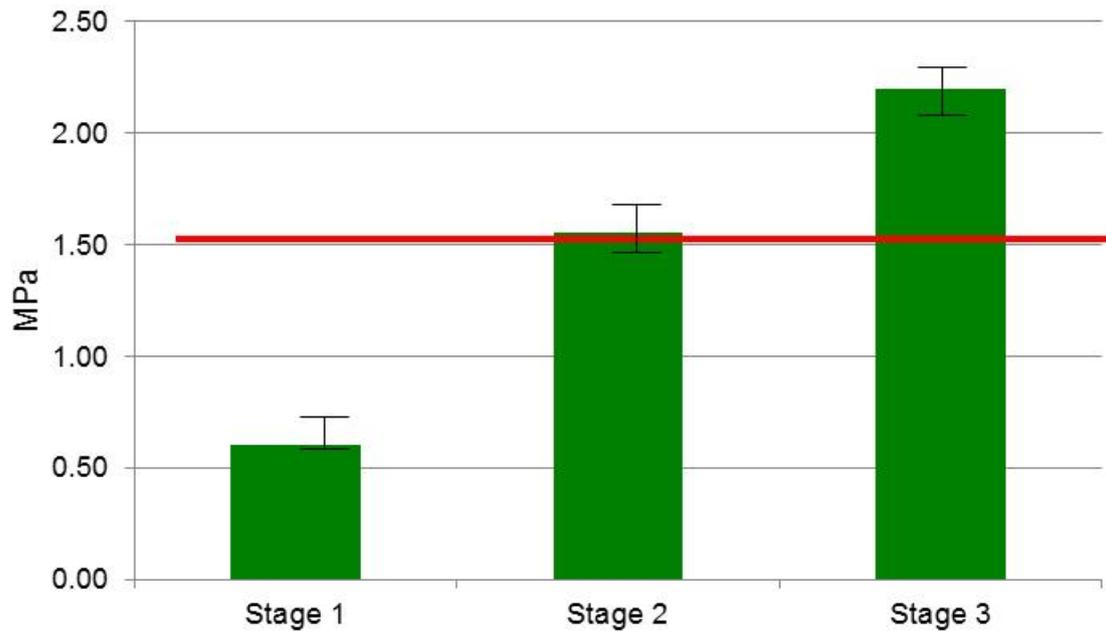


Fig. 3. Substrate (3 peat: 1 perlite: 1 vermiculite) (v:v:v) water potential of plants allowed to dry down to stage 1) initial flagging, stage 2) moderate wilt, and stage 3) all leaves completely wilted. Thicker line at -1.5 MPa represents value considered to be permanent wilt point. Volumetric moisture contents were 12.8%, 6.0% and 4.8% at Stage 1,2 and 3, respectively.