ACCURATELY MONITORING AND MAINTAINING SOIL WATER IN GREENHOUSE CONTAINERS

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Contribution No. 85-49, received 16 October 1985, accepted 22 April 1986

Dwyer, L. M., D. W. Stewart, and **D. Balchin.** 1987. Accurately monitoring and maintaining soil water in greenhouse containers. Can. Agric. Eng. **29**: 89–91.

An efficient method of routinely measuring soil water content in containers, of calculating and recording the volume of water required to bring them to a specified soil water content, and of accurately adding the calculated soil water volume to each container is described. The method, which requires use of a computer, a balance weighing to 0.1 g, and a burette (graduated in 1.0-cm^3 divisions) with reservoir, is a rapid ($\leqslant$3 h for 150 containers), accurate ($\leqslant \pm 1.0$ cm^3) means of monitoring and maintaining soil water content and of estimating and recording evapotranspiration in greenhouse containers.

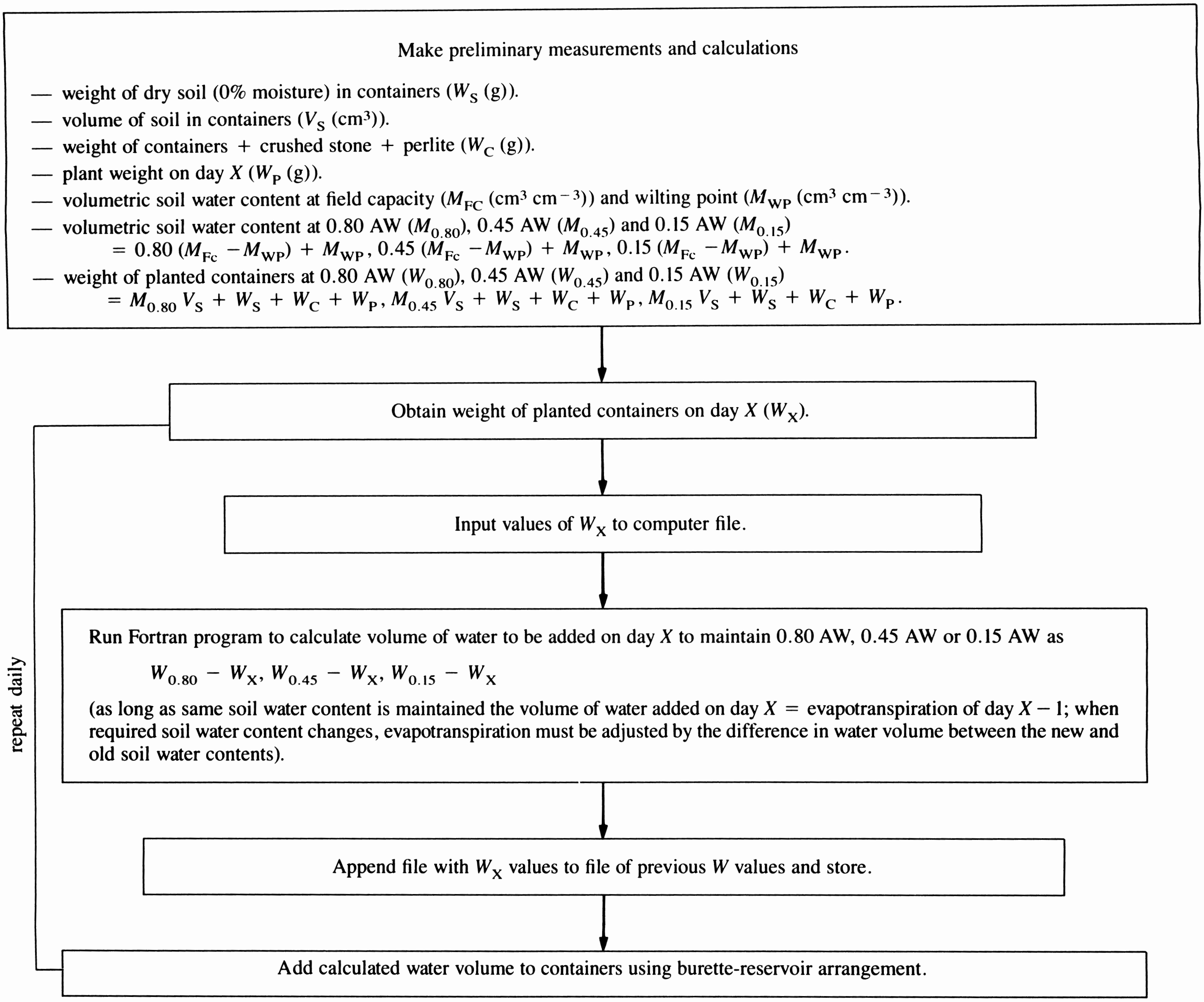
Maintenance of soil water content in replicate plant systems grown in greenhouse containers is a time-consuming requirement of many experiments involving water stress treatments. A common practice has been to weigh the pots at regular intervals and, while the pots are on the balance, add water to bring the soil to a specified water content. Depending on the objective of the experiment, these weights might be recorded by hand for estimation of water loss rates. The problem with this approach is that it is easy to overwater, and unless extreme care and time are taken, accuracy is significantly less than the readability of the balance. In addition, because attention is always directed to the balance, the delivery rate and distribution of water over the pots tends to be erratic and the soil profile is unevenly wetted (although a frequent assumption in container experiments is that water added to the surface diffuses evenly through the container). Finally, although regular weighings may also monitor plant evapotranspiration rates (if soil evaporation is restricted), written records are inefficient for future data manipulation. Therefore, a more accurate rapid means of maintaining soil water content and recording water loss is desirable. A method was devised to routinely monitor soil water content in containers, to calculate and record the volume of water required to bring them to a specified soil water content, and to accurately add the calculated water volume to each container. The method was tested on a barley (*Hordeum vulgare*) experiment that maintained 150 pots (15.2 cm diameter) at soil water levels to produce several water stress treatments.

The containers (without drainage holes) were filled with a 2.5-cm layer of crushed stones and covered with dried sandy loam soil packed to within 5 cm of the top. Additional soil samples packed to the same bulk density were used to measure soil water content at a series of water potentials using pressure membrane apparatus (Sheldrick 1984). All volumes added to each pot were weighed and water was added to bring the soil to field capacity (-0.03 MPa). Barley seeds were planted and thinned to four plants per container. A preweighed aliquot of Perlite formed a 2.5-cm layer on each container to restrict surface evaporation. Containers were kept well-watered (a visual judgement) until the beginning of tillering.

Using data from the pressure membrane apparatus, available water (AW) was calculated as the water held between -0.03 MPa and -1.5 MPa. A Fortran program was written to be run on a VAX computer system, although a microcomputer could have been employed. The program calculated the weight of each pot at specific soil water contents. In our case we were interested in 0.80 AW, 0.45 AW and 0.15 AW, but weights at any number of soil water contents could be determined. Beginning at tillering each container was weighed daily (± 0.1 g). These weights were entered into a computer file in the VAX system. A Fortran program calculated the volume of water required to bring the soil in each container to a specific water content. In addition to determining the water required for each container, the computer program stored the daily weights in a file for future calculations involving plant evapotranspiration. Weighing 150 pots, inputting the data and running the program required about 1 h. Data input required about half of this time. Data acquisition was recently modified with an interface cable that records directly from a balance to cassette or computer, and this additional modification is expected to result in a significant time saving.

At four stages during growth, three containers were destructively sampled and plant fresh weight (above- and below-ground) and leaf area determined. A correlation was found between fresh weight and barley leaf area. Since leaf area per container was measured nondestructively (Kemp 1960) on a weekly basis, soil water calculations could be modified to correct for the contribution of plant fresh weight to the weight of each container at weekly intervals throughout the experiment.

Daily watering was first accomplished with a 100-cm^3 (± 0.20 cm^3) burette with a three-way stopcock that refilled through an inlet tube on the stopcock and automatically adjusted for zero. A large reservoir was positioned so that its water level was above the top of the burette; the base of the burette remained above the level of the containers to be watered. The apparatus was mounted on a cart and wheeled among greenhouse benches. A flexible delivery tube permitted easy access to containers an arm's length from the cart and water could be evenly distributed over the surface of the pots at a rate of approximately 100 cm^3



Make preliminary measurements and calculations

- weight of dry soil (0% moisture) in containers (W_S (g)).
- volume of soil in containers (V_S (cm^3)).
- weight of containers + crushed stone + perlite (W_C (g)).
- plant weight on day X (W_P (g)).
- volumetric soil water content at field capacity (M_{FC} (cm^3 cm^{-3})) and wilting point (M_{WP} (cm^3 cm^{-3})).
- volumetric soil water content at 0.80 AW ($M_{0.80}$), 0.45 AW ($M_{0.45}$) and 0.15 AW ($M_{0.15}$) $= 0.80\,(M_{Fc} - M_{WP}) + M_{WP},\ 0.45\,(M_{Fc} - M_{WP}) + M_{WP},\ 0.15\,(M_{Fc} - M_{WP}) + M_{WP}$.
- weight of planted containers at 0.80 AW ($W_{0.80}$), 0.45 AW ($W_{0.45}$) and 0.15 AW ($W_{0.15}$) $= M_{0.80} V_S + W_S + W_C + W_P,\ M_{0.45} V_S + W_S + W_C + W_P,\ M_{0.15} V_S + W_S + W_C + W_P$.

Obtain weight of planted containers on day X (W_X).

Input values of W_X to computer file.

Run Fortran program to calculate volume of water to be added on day X to maintain 0.80 AW, 0.45 AW or 0.15 AW as

$$W_{0.80} - W_X,\ W_{0.45} - W_X,\ W_{0.15} - W_X$$

(as long as same soil water content is maintained the volume of water added on day X = evapotranspiration of day $X - 1$; when required soil water content changes, evapotranspiration must be adjusted by the difference in water volume between the new and old soil water contents).

Append file with W_X values to file of previous W values and store.

Add calculated water volume to containers using burette-reservoir arrangement.

Figure 1. Steps required to monitor and maintain soil water in greenhouse containers.

TABLE I. SAMPLE FORTRAN OUTPUT OF DAILY WATERING VOLUMES AND EVAPOTRANSPIRATION

Days from planting	Container	Soil water content (% AW)	Required container weight (g)	Actual container weight (g)	Volume of water to be added (cm^3)	Evapo-transpiration per container (cm^3 day^{-1})
33	1	80	3520.4	3424.8	95.6	95.6
	20	45	3417.9	3332.9	85.0	85.0
	59	15	3358.8	3313.6	45.2	45.2
34	1	80	3520.4	3395.2	125.2	125.2
	20	45	3417.9	3319.4	98.5	98.5
	59	15	3358.8	3305.7	53.1	53.1
35	1	80	3520.4	3389.9	130.5	130.5
	20	45	3417.9	3314.4	103.5	103.5
	59	15	3358.8	3326.7	32.1	32.1

min^{-1}. Specific soil water contents could thus be maintained within narrow tolerance limits and a slow even delivery assured that the water was well distributed. Using this technique 150 pots could be watered in less than 2 h. As the plants grew and daily water losses increased to over 100 cm^3 a 250-cm^3 (± 1.0 cm^3) burette was modified to accommodate a three-way stopcock and to automatically zero.

Figure 1 illustrates the sequence of steps required to monitor and maintain soil water in greenhouse containers using this procedure. Table I shows a sample of output from the Fortran computer program for

5-wk-old plants. Daily water loss (evapotranspiration) per container is obtained directly from calculation of the volume of water to be added. Regular monitoring of leaf area permitted calculation of average evapotranspiration per leaf area. For the 3 days shown, calculated evapotranspiration ranged from 0.099 g cm^{-2} day^{-1} for container 1 on day 35 (a sunny winter day, midday greenhouse quantum radiation (Q) = 589.9 μE m^{-2} s^{-1}) to 0.061 g cm^{-2} day^{-1} for container 59 on day 33 (overcast, midday greenhouse Q = 158.0 μE m^{-2} s^{-1}). Instantaneous measurements of evapotranspiration made with a steady state porometer (Li-Cor model 1600) during the same period were 1.352 μg cm^{-2} s^{-1} at Q = 580.0 μE m^{-2} s^{-1}, and 0.658 μg cm^{-2} s^{-1} at Q = 175.0 μE m^{-2} s^{-1}. Extrapolating these values over a 16-h photoperiod and the leaf areas of containers 1 and 59, respectively, results in a daily evapotranspiration of 102.6 cm^3 (0.078 g cm^{-2}) on a sunny day and 28.0 cm^3 (0.038 g cm^{-2}) on an overcast day. Although these estimates fall below daily water rate loss calculated from container weights (Table I), the discrepancy is reasonable in a forced-air greenhouse environment which is conducive to evaporation through the dark hours and the weight changes can be used to monitor evapotranspiration on a daily basis.

REFERENCES

KEMP, C. D. 1960. Methods of estimating the leaf area of grasses from linear measurements. Ann. Bot. **24**, 491–499.

SHELDRICK, B. H. (ed.) 1984. Analytical methods manual. Agriculture Canada, Land Resource Research Institute, Ottawa, Ont. Contribution no. 84-30, Section 3.5.