Semi-automated, non-weighing, pot-in-bucket (PIB), water management in pot plant culture.

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Abstract

Constant water tables (CWT) in pots have been used in the determination of plant water-use. While the CWT systems eliminate the labour required in watering-to-weight systems, they may be overly wet with the constant water table within the pot itself. A valve in our Pot-In-Bucket (PIB) system maintains the water table at a nominated constant height above, within or below the contents of each test pot. In the latter configuration, the CWT supplies water to an upper ANOVApot® through a capillary tape draped over an upturned pot within the bucket which encloses the valve and supports the upper ANOVApot®. This valve is connected to a remotely located 5L container of water via a medical infusion set. Water-use by a plant/s growing in the ANOVApot® is monitored as changes in water level in the calibrated 5L container. Real time (2-20 minute delay) variation in rate of water-use from plants can be observed (as drips (0.066mL) per second) in the sight glass of the infusion set. Having groups of containers located remotely from the pots they supply, greatly facilitates the ease and speed of the refilling operation and drip rate measurements. Changes in pot weight provide a measure of whole plant biomass and when coupled with water-use enables the non-destructive measurement of water-use efficiency during the crop's lifecycle. This system has worked well in water-use experiments in wheat and rice.

Key Words

automatic, transpiration, fresh weights

Introduction

There is a need to develop simple, well controlled conditions to assess the effective use of water (Blum, 2009) of phenotypes and genotypes of crop plants such as wheat and rice. The use of pot culture in a glasshouse as the screening environment for breeding programs has many advantages over evaluation in the field including: variable soil (water supply and nutrients), variable temperature and humidity and other uncontrolled environmental factors (wind, hail, insect and disease).

A major advantage of sub-irrigation in pots, as outlined by Hunter (1981), and modified by Hammer et al. (1997), O'Sullivan and Ernest (2007) and Hossain (2012), over watering-to-weight systems is the greatly reduced labour and time taken in watering pots. The criticism of overly wet conditions with the constant water table (CWT) within the pot has been dealt with in the development of the Twinpot Water Management System (TWMS, Hunter et al, 2010) of two nested 330mm ANOVApot®s, with the lower pot acting as a reservoir for the upper pot with capillary tape conducting water from the lower water table to the upper pot. The ANOVApot® is unique (US Patent 7743696 B2, 2010) and was designed for the nursery industry to reduce root escape in capillary irrigation based systems.

The ANOVApot® has a single central basal hole covered with a flat grid. Any concavity in the grid, sometimes found in faulty product, reduces capillary transfer. Inside the pot this grid is surrounded by a 40mm collar that greatly reduces root escape by exploiting the positive geotropic nature of roots. Another effect of the collar under overhead irrigation is to slow, but not prevent drainage, ensuring better hydration of potting mix following high volume overhead irrigation (Hunter and Scattini 2009). A version of TWMS with the 200mm ANOVApot® has been developed, but the reservoir capacity of 700mL is insufficient to meet the daily transpirational needs of rice. Our response, reported below, was to nest the 200mm ANOVApot® in a 2.2L bucket with 1.4L effective water storage, hence Pot-In-Bucket (PIB) system, as well as incorporating a valve to maintain a constant water table.

Pot-In-bucket System

Configuration and operation. An upper 200mm ANOVApot® is supported inside a lower 2.2L bucket by an upturned 250mL 80mm tall holed pot over which is draped a capillary tape wide enough (50mm) to cover the width of the grid with both ends extending to the bottom of the bucket (total length 300mm, Figure 1). This small support pot allows the ANOVApot® to fit snugly, but resistance free, allowing its easy removal and weighing in biomass determinations. If necessary broken capillary connections can be reformed by adding a standard amount of water to the top pot that is enough to flow through the capillary cap. A curved 100mm length of polythene tubing is inserted through a hole in the side wall of the bucket, which is level with the base of the upper pot and kept in the 'curve up' position (not shown in Figure 1). Water is added to the upper or to the lower pot either after removing the upper pot or through a piece of tubing inserted between the two pots. Addition of water is stopped once a water level appears in the curved polythene tubing. This tubing is then rotated through 180° to the 'curve down' position. The water that flows from the rotated tubing is captured and the amount subtracted from that added. This process facilitates the accurate management of applied water necessary for water-use studies and closed-pot systems without the need to weigh plant pots. The elimination of weighing saves considerable time and labour as well as minimising the likelihood of back injury resulting from the repeated pot weighing that may occur in watering-to-weight systems.

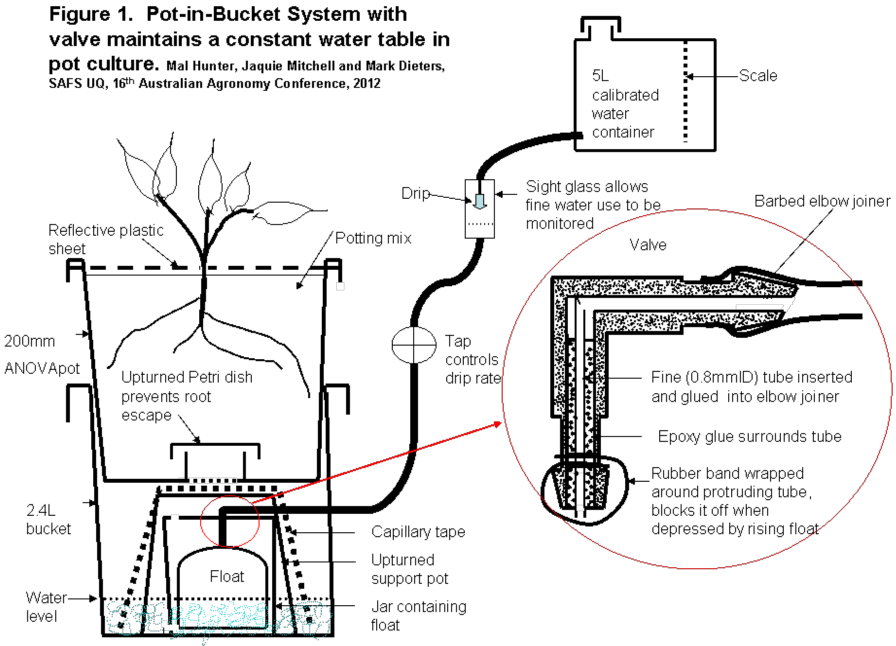

Figure 1. Pot-In-Bucket (PIB) system with valve maintains a constant water table in pot culture.

Float valve and CWT. A very important and useful further development of the PIB system is the inclusion of a simple float valve located within an upturned support pot inside the bucket (Figure 1). This valve is connected via holes in the walls of a small pot and the bucket, through the tubing of a medical infusion set, to a remotely located 5L container. The valve maintains a constant water table in the lower pot, delivering water from the container as the water table falls in response to evapo-transpirational demands. Refilling the container and measuring water level (for water-use) before empty, ensures that the pot water status is maintained. Theory suggests (Marshall et al 1996) that a constant water table will create a constant matric potential within the potting mix, thus providing the option of a non-destructive measurement of whole plant weight as reflected in increasing pot weight. While this concept has been validated in earlier work (in preparation) factors that could cause changes in matric potential have not been studied.

Water table. Changing the height of the float in the valve will change the height of the constant water table in the lower reservoir and hence influence water availability. To create constant water tables at varying heights within the soil block itself (e.g. for rice culture), the valve assemblage (Figure 1) may be attached at varying heights by a side tube from the valve to the side of a non-draining bucket. The ANOVApot® rests inside this bucket with water from the constant level entering through the basal hole of the ANOVApot®.

Calibrated container. The 5L translucent containers rest on a stand preferably along the southern side of the growing bench (in the Southern Hemisphere) to minimise shading, with the shelf about 35cm above the base of the 200mm ANOVApot®. These containers can be very easily and quickly refilled as required. Each container has a calibration strip for easy monitoring of plant water-use, read with an accuracy of about ±

30mL. More accurate water-use determinations are possible by measuring, by weight or calibrated cylinder, the amount of water required to refill each container.

Preventing root escape. The tape on which the ANOVApot® rests may become embedded with the relatively few roots that escape through the central hole. This should be prevented in pots that are weighed. This can be achieved by the placement of an upturned 100mm Petri dish base just above the central well of the ANOVApot® during potting-up (Figure 1). To prevent the interference with moisture flow through the medium accurate placement is important. This can be facilitated by the insertion of a template around the central well (potting mix about 50mm deep), with the dish being pushed into the medium until its base is level with the rim of the template. The template is then removed and the pot completely filled with potting mix. This position of the Petri dish prevents vertical root escape through the central hole and also prevents some of those roots which are moving laterally from entering the well and escaping.

Non-transpirational water loss and cladding. To confine water loss from the system to that from the plant itself, the surface of the pot should be covered with beads or an impervious sheet. Sheet material should be cut to accommodate the stem of the plant and tillers as they emerge. To reduce heat sink effects and the entry of light into the translucent bucket (in promoting algal growth), the whole pot arrangement should be wrapped in a reflective insulation sleeve. This material must not interfere with easy pot removal. A small 20mm long horizontal slit in this material just above the rim of the bucket will allow the access (for solution sampling purposes) to the water table inside the bucket with a stiff tube attached to a syringe.

Water quality and water table height. Because of the small size of the tube (0.8mm diameter) in the float valve, applied reservoir water needs to be free of particles that may cause blockages. Thus, the water supply should be filtered and preferably deionised. The filter in the medical infusion set may be very fine (15µ screen in one version) and may quickly become blocked with colloidal material. It should be disabled at the outset to allow unimpeded water flow. Covering the reservoir with reflective insulation to exclude light is only necessary if non-deionised water is used. Algae will grow in domestic water supply. Water tables may be monitored with a dipstick inserted between the nested pots to the base of the lower pot.

Salt accumulation and sampling. To reduce the accumulation of salts at the extreme of the capillary fringe (surface of pot) a measured amount water (say 500mL) may be applied to the surface of each pot every 7 to 10 days. Salt accumulation is unlikely when the surface is covered to prevent evaporation. Extracting (by syringe) a sample of the reservoir water and assessing for pH and salt level allows adjustments to be made if either condition is considered unsuitable. Additional analyses for nutrients would be very useful in nutritional and salinity research.

Drip rates. The medical infusion set includes a sight ‘glass’ (polyethelene) that allows the drip rate of water flow into the pot to be monitored. Each drip has a volume of 0.066mL. Thus, recording drip rate provides a measure of transpiration that is occurring close to the time of measurement (actually delayed by 2–20 minutes). Drip rate may be a useful ‘real-time’ descriptor of the performance of different genotypes and their reaction to changes in radiation, temperature, humidity, wind and other environmental factors. Drip rates can be automatically recorded (see below) allowing the continuous monitoring of plant water-use.

Imposing water stress. To assess the effects of water stress a sliding switch on the infusion set can be adjusted to limit water supply. A slowly developing stress in the PIB is more likely to mimic field stress than stresses applied in watering-to-weight systems in which all available water is consumed within one or two days. A reduced drip rate may not diminish total water consumed each day since dripping will continue through the night until the pot matric potential has been restored, even though transpiration may have ceased with darkness and stomatal closure. However, flow may be reduced even further by adjusting the flow rate controller to take this into account. Alternatively, a percentage of the previous day’s total water-use as measured in non-stressed pots (container connected), can be added manually to pots disconnected from the calibrated container external while the stress regime is imposed. Such amounts may be easily calculated from daily changes in water levels in the reservoirs of the non-stressed pots. However, repeatability of these moisture stress effects can only be ensured under relatively well controlled environmental conditions where variation in water loss from day to day is only slight.

Automation as a future development. To fully automate watering, individual infusion sets may be plugged into a pressure regulated communal water supply. While this option foregoes the manual monitoring of total water lost from individual pots, the measurement of drip rates for each pot will still provide a relative measure of water-use rate. Drip monitors ($250 each) attached to the sight glass of individual pots could continuously record rate and total water-use. Pot weights can also be monitored electronically with load cells avoiding the problem of broken capillary connections. Increases in weights (theoretically a constant water table maintains a constant matric potential within the pot) would be a direct measure of increases of whole plant biomass allowing the direct calculation of water-use efficiency (whole plant weight increase per unit water loss over the same interval). We have measured changes in environmental effects as differences in drip rates delivering as little as 0.01mL/minute. Results of further studies on the value of drip rate monitoring may justify the development of cheaper versions of drip rate monitors specifically for the PIB system.

Experience. The PIB system has recently been successfully used in an experiment to determine water-use efficiency (WUE) of six wheat genotypes, including within crop cycle biomass determinations. The system, with and without the valve, has also been successfully used in a number of experiments investigating the effects of variable water tables on production and WUE in a number of rice genotypes (these proceedings, Sourideth et al 2012).

DIY. Construction of the system is relatively simple without the need for specialised equipment. Components are readily available. The cost of materials for each completed unit is about AUS$8 with construction time per unit of about 15 minutes. Bulk purchases and batch production reduce costs.

Benefits. The material and labour costs of PIB are relatively small compared to the labour costs incurred in the alternative of watering-to-weight systems for water-use and closed pot (nutrition) experiments. Weekend work is eliminated. In addition, the PIB system provides an accurate and non-destructive estimate of water-use efficiency as well as a real-time plant water-use response (as drip rate) to changes in environmental conditions such as temperature, radiation, humidity, wind speed, nutrition and salinity. Importantly, the PIB system can be set up at different levels: (1) as a basic unit without a valve to greatly improve accurate water management or (2) with a valve for much more efficient WUE assessments or (3) wholly automated. The first two set-ups have been confirmed while the third requires further resources for development and testing.

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