The Twinpot Water Management System for potted plants

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The Twinpot Water Management System (TWMS) brings together the unique characteristics of the ANOVApot® (patent pending) and the essential elements of the Pot-in-pot technology (Mathers, 2000) and ''self-watering'' pots. The unit of the TWMS (Figure 1) consists of two ANOVApot®s one sitting inside another (hence ''twin'') in which overhead irrigation, sub-irrigation and controlled drainage are combined to objectively manage an operator-selected range in changing pot water status that optimizes growth while eliminating irrigation (and nutrient) run-off. The system includes the option of automated irrigation that responds directly to plant water use, free of the calibration and interpretative complexities in determining pot moisture contents or the need to include the effects of other micro-environmental variables.

The irony in the evolution of this system is that the original design of the ANOVApot® was intended to minimize root escape from sub-irrigated pots rather than managing water better. It was initially thought that this pot would be unsuitable for overhead irrigation because the patented feature of the pot that of a collar around the central basal hole, would cause water to pond and lead to water-logging. Subsequent tests showed that this did not occur with free water draining completely even though more slowly than in 'normal 'pots. In fact, the slower drainage proved to be a bonus since it meant that the potting mix was better hydrated simply because slower drainage meant it remained wetter for longer.

The other twist in the TWMS is the use of the ANOVApot® as a lower reservoir to store water despite the above claims of good drainage for this pot design. We now know that good drainage relies on the capillary flow through the potting mix, but that in the absence of potting mix, drainage can only occur once the water level exceeds the height of the collar. In the 330mm WaterSaver ANOVApot® this amounts to a reservoir volume of 2L that is utilized in TWMS as a sub-irrigation water resource.

Summary of advantages of the T(A*)WMS A=automatic

- Plant growth
    - Less moisture stress than normally expected
    - Faster plant growth
    - Less root escape and plant shock
    - Healthier root system
- Micro-organisms
    - Less stress induced sensitivity to disease
    - Minimal potential for ground sourced disease spread
    - Minimal air pruning of roots
    - Non-permanent water table interrupts mosquito breeding cycle
- Irrigation
    - Much faster application rates possible without run-off
    - Better water distribution in mix
    - Zero-irrigation run-off possible

    - Major water savings likely
    - Plant water use based automatic irrigation (A*)
    - Dipstick option to monitor water level (and use) and guide irrigation amount and frequency
    - Colour change in potting mix signals irrigation
- Fertilizer
    - Lower rates (30%) likely because of minimal leaching
    - Reduced environmental contamination by nutrients
    - EC of reservoir partially guides pot nutrition
- Potting mix
    - Compatible with most potting mixes
    - Less mix needed because of increased effectiveness
- Pot management
    - Top pot can be removed for sale
    - Top pot much less weathered over time
    - Both upper and lower pots are identical and can be used separately
    - No pot blow over in bracketed system
    - The few roots that emerge through the base of the top pot stay in the pot and are easily removed.
    - Underlying weed mat and pad stay free of roots
    - Pots and pads cleaner
    - Herbicides can be used around pot base
    - No salt encrustation
    - No basal holes available for weed or algal growth
- Miscellaneous
    - Nesting of pots provides considerable insulation of upper pot
    - Placed under trees without tree root competition for water and nutrients
    - Placed inside decorative pots
    - Pots can be separated for swapping or cleaning
    - Pots can be shifted around to capture sunshine

Set-up

Nested pots Figure 1 and Slides 1 and 2 illustrate the TWMS with two 330mm WaterSaver ANOVApot®s, one sitting inside another, but kept sufficiently apart by separators so that the central basal grid of the top pot rests slightly above the top of the collar of the lower pot on the capillary mat. Complete nesting, with the central grid well below the height of the collar was designed to maximize pot packing densities for transport but should not occur in a properly set-up TWMS.

Pot separator or bracket One end of a thin walled 19mm diameter polypipe separator, 45mm long, is squeezed and inserted vertically under the rim of the upper pot. Three separators are inserted equidistantly around the rim and ensure that all the weight of the top pot is supported by the rim of the lower pot. These separators may be replaced by brackets (WindClips™) which again keep the two pots the correct vertical distance apart. These brackets are available in three sizes, 260mm, 140mm and 70mm between pots. The use of currently available brackets forces the grower into a specific spacing distance between pots. The manufacture of adjustable brackets is being considered. Brackets would be preferable where pot stability is important in preventing blow-over.

Capillary Cap A length of capillary mat (80mm x 200 mm, polyester needle punched hydrophilic geotextile (Global Synthetics, ProFab Geotextile AS500) is attached to the top surface of a 120mm square piece of corrugated plastic cap (Nylex Edge Barrier) that sits on top of the central collar, directly below the grid of the top pot (Slides 1, 2). Two opposite one cm wide edges of the square plastic cap are turned down through 90 degrees to aid in appropriately locating the cap over the collar. (Note that an earlier version of the cap as shown in the slides was round rather than square). The corrugated surface of the cap reduces the risk of sealing, while supporting the mat across the 100mm diameter of the collar. The cap also has the crucial role of shedding drainage water from the top pot into the surrounding reservoir of the lower pot.

Monitoring reservoir water level In the manual version, a 34 cm long bamboo dip stick is inserted through a 9mm diameter hole made in the top rim and slid vertically downwards between the two pots to the bottom of the lower pot (Figure 1). It is removed and the length of wet tip used to monitor water level in the lower pot. A wet length of 40mm would indicate that the reservoir is full. The stick is withdrawn slightly between measurements to rest above the water table to prevent it becoming water soaked and rotten.

A distinctive change in colour or shading is often observed in some media as they dry. Observations in coir and peat based media suggest that a lightening of the overall colour of the top of the mix only occurs when the reservoir becomes dry. Such a change may be used to guide irrigation intervals. Temporary plant wilt during the heat of the day is normally a clear signal of pot water deficit but may also occur where water uptake by the root system has been compromised (e.g. effects of waterlogging and root diseases).

Recent research work has confirmed the utility of a radio connected water level sensor (developed by Senviro P/L) in the lower pot reservoir that automatically triggers irrigation (Figure 1, Hunter et al, 2009). The sensor (patent applied) records the changing electrical signal across two parallel vertical metallic strips as they are progressively submerged in the rising water table in the reservoir. A second pair of strips on the base of the sensor records the electrical conductivity of the solution which is used to adjust the output from the vertical pair as well an indicator of salt concentration (toxic and deficient) of the potting mix above. The sensor automatically triggers a set volume of water (not to exceed pot and reservoir capacity) to be added once the reservoir water level drops to zero.

Automated irrigation in the TWMS is simply based on the level of the reservoir water rather than on potting mix-based probes subject to calibration issues complicated by variability in position, type of potting mix, plant type, root distribution and potting mix degradation. Furthermore, the rate of change of water level accounts for changes in environmental conditions and increasing plant size. There is no need to include pot moisture probe data or any other meteorological information, other than reservoir temperature, in the function of TWMS since it is 'driven' directly by plant water loss and how that responds to environmental conditions. Incorporation of further options in the sensor control software will introduce a 'self-learning' capability that optimises irrigation quantity and frequency for a zero-irrigation run-off condition to meet operator selected plant performance that may vary from potential to levels of sub-potential growth with periods of hardening prior to sale (Hunter *et al*, 2009).

Irrigation management

Since the drop in reservoir level is directly related to plant water use (loss), the trigger in the electronic sensor may be set to go off after a predetermined (by the operator) level of stress. Little stress would be expected if irrigation is triggered while water remains in the reservoir, in contrast to increasing stress the longer the reservoir is left dry before irrigating.

The combination of slower drainage (a characteristic of the ANOVApot® design) and a 2L lower reservoir capacity allows the rapid application of large quantities of water without run-off. Once the reservoir is dry, between 3 and 4 L can be applied within as little as 30 seconds to the surface without loss from the system. Thus the industry rule of thumb of not exceeding irrigation application rates of 15mm/hour (Atkinson and Rolfe, 1995) no longer applies. Water is absorbed in the top pot while as much as 2L can be retained for recycling in the lower reservoir. Not only does this mean that a zero-run-off irrigation regime with water savings can be maintained, a huge reduction of irrigation time is also possible allowing a larger area to be managed with existing irrigation resources.

The loss of soluble nutrients also can be virtually eliminated. Based on results in other closed sub-irrigated systems, as much as a 30% reduction in nutrient addition should be possible in the TWMS as a result of these savings (Handreck and Black, 1994, p169).

[1]While bamboo dipsticks are cheap enough to be included in all pots as a way of assessing water status in each pot, this is not the case with the much more costly electronic sensor. Using a single sensor (in one pot) to manage the irrigation frequency in a number of adjacent pots appears a practical way of reducing the costs of instrumentation. While there is no data on which to select the most appropriate sensor density in a bed, three sensors in a block of 500 pots is currently proving satisfactory.

The success of each sensor as an accurate irrigation trigger for surrounding plants will be affected by evenness of irrigation (spray, dripper), variation in plant size and micro-environment. Some in-house assessment of the effects of such variations could be made with a record of dipstick water status in a block of plants, repeating this exercise a number of times through the crop cycle.

Sensors may be readily shifted from time to time into pots supporting plants that better reflect cropping targets

Water loss, stress and rainfall

The monitored draw down in the reservoir, together with the known quantity of water added, may be used to crudely estimate the rate of water loss and hence expected loss with a change in irrigation frequency. Decreasing frequency and increasing the amount will increase stress. Controlling the level of stress as it affects growth, flowering and quality would be a useful management option.

Changes in water level in response to rainfall would provide information on the pot capture of rain that currently is only guessed at. The shape and size of the plant determines whether rain (or overhead irrigation) is shed or channeled into the pot but its actual quantitative effect on rain effectiveness is poorly understood. Rainfall would be detected as an increase in water level when the capacity of the top pot to store water is exceeded but may also be detected as a delay in the expected emptying of the reservoir following the capture of rain by the top pot.

Pot nutrition

The sensor currently being evaluated includes two horizontal metallic strips to monitor electrical conductivity (EC) of the reservoir solution. Such data is a very useful indicator of pot nutrition. High levels (1.8 dS/m) may indicate the excessive use of fertilizer or excessive nutrient release from controlled release fertilizers (Handreck and Black, 1994, p 276). Increasing irrigation frequency together with leaching amounts of water should quickly ameliorate this problem, with on-going EC monitoring indicating the need to continue this remedial action. Very low EC values, similar to that of

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[1] Sensor information added 10 June 2009

the irrigation water may indicate that nutrient levels in the upper pot are bordering on deficient indicating the need for a side-dressing program. The continual awareness of solution salt status (EC) with appropriate remedial action prevents the emergence of nutritional and toxicity problems and hence lost productivity.

Even without the sensor, regular EC monitoring of the TWMS reservoir solution can be easily carried out. All that is needed to collect a sample is a stiff hollow rod (5mm diameter) that can be attached to a 60mL syringe, inserted vertically through the dip stick hole (after removing the dip stick) and slid down to the bottom of the reservoir. Sampling is done about an hour after an irrigation event and enough solution drawn off for an EC determination.

An interesting option that the TWMS provides is feeding the plant with nutrients added to the reservoir water rather than to the potting mix. This method of nutrition has been conducted in saucer culture (Atkinson and Rolfe, 1995). Research needs to be carried out in this area before recommendations can be made.

Plant growth

The few comparative growth studies conducted with the TWMS indicate that growth is as good as, if not better than that in side holed or basal holed pots. Similar growth was evident in *Grevillea* sp and *Chamodorea seifritzii* (bamboo palm), both considered very sensitive to water logging, a condition expected to be particularly severe in TWMS (Hunter and Scattini, 2009). A replicated and randomized study with 15L side holed and TWMS pots compared the growth of *Syzygium* and *Magnolia* irrigated twice a week with 4L of water on each occasion. When harvested 123 days after transplanting TWMS *Syzygium* and *Magnolia* weighed 913g and 413g respectively in comparison with fresh yields of 453g and 296g for the two species in side holed pots under the same irrigation regime (Least Significant Difference (LSD) 113g, Slides 3 and 4). In a follow up experiment, again with *Syzygium* (Slide 5), fresh shoot weights after 91 days were 1208g for TWMS plants automatically irrigated with a reservoir sensor system, compared with 833g for plants irrigated daily in side holed pots (LSD of 78g, Slide 6). These results support the growth promotion reported for sub-irrigated systems (Hunter et al 2005, Beeson, 2002, Stackhouse, 1993) where plants similarly also had access to an almost continuous supply of water.

Plant species

Many species have now been grown under TWMS conditions with good results in all cases. Species such as bamboo palm (Slide 7) and *Grevillea*, both known for their intolerance of water-logging have grown as well as plants in side or basal-holed standard pots under commercial production nursery conditions (Hunter and Scattini, 2008). Other successfully TWMS grown species include wheat, coffee (Slide 8, 9), potato (Slide 10), parsley, chives, tarragon, rosemary, chervil (Slide 11), lettuce

(Slide 12), *Syzygium* (cvs. Cascade, Aussie Boomer, Hinterland Gold), magnolia (Slide 3), *Spathiphyllum*, kentia palm, golden cane, *Harpulia* , *Lomandra,* Echnida grass, Red Fountain grass, tropical Fuchia, Tiger grass, *Polygala,* sweet potato (Slide 13, 14) and sorghum (Bradley Campbell, personal communication). Two other water-logging sensitive species, avocado and citrus, are growing well (15, 16).

Roots

No quantitative data are available on root production. However, visual inspection of the rootball of TWMS coffee at 3 and 9 months revealed the presence of numerous white (healthy?) roots distributed throughout (Slides 17, 18 and 19). A visual comparison of rootballs of *Chamodorea seifritzii* grown in a range of pot types including two twin pot systems indicated very little difference among treatments even though this species is reputed to be very intolerant of water-logging (Slide 20). The visual comparison of root balls of *Syzygium* and *Magnolia* in the first experiment reported above, again revealed little difference in root appearance (Slide 21). Images of root balls of *Syzygium* in the second experiment above appear in Slides 22, 23 and 24 and illustrate root distribution on the base and the side of the root ball. While not definitive, more roots appear in the TWMS particularly on the base of the root ball than in side holed pots. Thus, there was no evidence of 'poor' basal root development in the TWMS pots, an otherwise expected response had the system been prone to basal water-logging. Roots actually appeared whiter in the TWMS pots, this colour often being associated with a healthy root system.

Root escape and internal coiling

Internal mat linings are used to minimize root escape in the PIP (Mathers, 2000). No roots will escape out of TWMS pots although they do escape from the top pot into the capillary mat and reservoir of the lower pot. These roots are all contained within the lower pot and easily removed at harvest.

This root escape from the top pot can be prevented by a barrier in the well of the top pot. This barrier can be a layer of porous concrete (one part cement, one part water, 10 parts sand , 0.5-1.5mm grain size range, strongly compacted) made *in situ* about 1 cm thick in the well (Slide 25). Alternatively, a layer of copper hydroxide or oxychloride impregnated coir (0.2-0.5% Cu as a suspension used to wet up the coir), or fabric may be placed in the well (Slide 26). Species variation in root response to copper may be expected.

Basal root coiling may be prevented with a two cm band of copper impregnated paint applied to the lower corner of the upper pot (Slide 27). Copper hydroxide rates of 100g/L in a flat white acrylic exterior paint have been recommended (Handreck and Black, 1994 p 370).

Comparison with other systems

Pot-in-pot and Self-watering Neither Pot-in-pot (PIP, Mathers, 2000) nor self watering pot technology is new but the combined aspects of each as developed in the TWMS is unique. Both PIP and TWMS protect the inner pot from temperature extremes and pot surface deterioration (important in preparing for sale). In-ground or bracketed TWMS and PIP systems provide great pot stability from blow-over.

The top pot of the PIP system nests in the bottom pot which is sunk in the ground or bracketed together with adjoining pots. The only real difference between PIP and TWMS is that both PIP pots are holed and not designed in any way to hold water or slow drainage. So labeled 'self-watering' pots (they still need to be watered) incorporate a lower reservoir and a core of potting mix that extends down into the lower water table. A false floor with slots keeps most of the potting mix above the water table but does not prevent root growth into the lower reservoir. Water is added through a side hole into the lower well. The plant relies on capillary flow upwards through the cores of potting mix, the rate of which must change as the potting mix degrades and becomes filled with roots. The success of potting mix rehydration from the lower reservoir if the reservoir completely dries and the potting mix becomes hydrophobic is questionable, especially after the characteristics of uptake have changed over time. There is a chance of unwelcome animals such as toads and snakes taking up residence in empty 'self watering' pots with access through the watering hole, an issue that is avoided with TWMS. Few, if any, 'self-watering' pots can be readily separated, an important issue in wholesale production and in cleaning reservoirs especially in plants grown permanently in the pot. 'Self watering' pots are not commonly used in production nurseries.

Pot management

Details of how to set up the TWMS is provided in Hunter and Hunter (2009) as guidelines in assembling and managing the pot, provided with the Conversion Kit. This kit includes a capillary cap, polypipe spacers and a dip stick for each 330mm WaterSaver ANOVApot®. Pots are available from Garden City Plastics and kits from Anova Solutions P/L

In commercial production it is likely that the lower TWMS pots will be bracketed together in units of 9 or 16, to maximize pot stability and minimize the incidence of blow over. The dimensions of the WindClips™ (Windclips Australia P/L) bracket allow it to substitute for the spacers in keeping the pots the right vertical distance apart. These brackets are available in three sizes of 70, 140, and 260mm. When ready, the top pot with plant may be removed and prepared for sale. This leaves the empty lower pot, if left for any length of time, as a receptacle for dust, leaves and water. This problem may be avoided by upending and turning over these pots while bracketed together in their units of 9 (Slide 28). Upturned, these pots become a heat sink with high temperatures likely to kill any resident pathogenic micro-organisms. Before turning, capillary caps should be retrieved, disinfected in bleach, rinsed, dried and stored for further use.

The absence of any external roots in TWMS allows the use of directed contact sprays around pots in weed control without concern of plant uptake.

Furthermore, the lack of side holes eliminates sites for weed (Slide 29) and algal growth or the unsightly encrustation of salt deposits around holes.

Potting mix

Most potting mixes, and even soil, may be successfully used in the TWMS. However, the extent of capillary rise of water from the lower reservoir may vary considerably depending on the proportion of the fibrous component, such as peat or coir, in the mix. The height of this rise is not critical in top watered systems and extends to the surface in coir mixes.

The moisture content of such mixes greatly affects their colour, becoming lighter as the mix dries. This feature may be used as an indicator of water in the lower reservoir and hence as a re-watering signal.

Microorganisms

Excess water flow from the TWMS occurs only outwards thereby minimizing the likely entry of any ground sourced disease pathogens or disease transfer from pot to pot. This assumes that free drainage from pots occurs. This is likely to be compromised on flat pads under flood conditions.

The absence of air-pruning of roots, common in side holed pots (Slide 29) eliminates these dead and decaying roots in TWMS as an attraction for root pathogens.

The water table of TWMS may persist in locations of daily rain long enough for the water component of a mosquito's life cycle to be completed. While there is a 2mm gap between the walls of the two 330mm WaterSaver ANOVApot®, the few observations of mosquito larvae in the lower reservoir suggest that it is not readily accessible. Not only do mosquitoes have to get down between the pots and into the water table to lay eggs, the emerging adults have to then find their way out, a vertical distance of 22cm between two plastic surfaces 2-4mm wide. The likelihood of this is yet to be confirmed. The lack of larvae (wrigglers) is also probably due to the intermittent nature of the water table with the dry phase causing larval death. In the event of significant mosquito habitation in TWMS, the addition to the reservoir of a mosquito life cycle disrupting chemical (S-methoprene) or toxin producing bacteria (*Bacillus thuringiensis israelensis*) would be commercially practical.

Providing habitats for breeding mosquitoes is a very important human health issue particularly in tropical environments where mosquitoes are vectors for disease organisms.

Utility

Wholesale In the wholesale nursery only the top pot of TWMS is removed for sale, with the system being suited to all sorts of overhead irrigation, including the huge application rates of hand watering. The TWMS is suitable for ebb and flood systems provided the water level rises above the height of the internal collar in the flood phase to fill the lower reservoir. It is not suitable for capillary or sand bed irrigation systems.

A retail request for the Twinpot setup itself may be met by simply placing the upper harvested pot into a new one with capillary cap in place rather than removing both pots and disturbing the bracketed lower pot setup on a pad.

Retail A major advantage of TWMS emerges in the retail sector where hand watering predominates since large quantities of water can be rapidly applied without loss (62mm/hour, Poulter 2009). Frequency of irrigation will also be substantially increased with savings in labour. Again, pots may be sold separately or in the twin pot configuration.

Landscape The TWMS allows the culture of shade loving species under trees without their water or nutrient supply being compromised. This should considerably expand the choice of species options for landscape designers in dry environments where large tree demand and competition for water and nutrients would otherwise make it impossible to grow plants successfully in their footprint.

Plant Hire The 2L capacity of the TWMS in the 330mm WaterSaver ANOVApot® would be of interest to the plant hire industry. Such capacity should have substantial effect on reducing the frequency of watering. Any added water in excess to the capacity of the Twinpot would collect below the TWMS and have to be removed from time to time. The ease of swapping species about while leaving the lower pot in position would also be useful.

Domestic The TWMS is attractive in the domestic environment because of much lower watering frequency (e.g. once every two days rather than twice a day for a large plant), with large quantities being applied without run-off. Such control is further enhanced with the use of the dip stick to monitor water level.

The value of converting home garden vegetable, herb and fruit production to the TWMS is evident where direct sunlight is limited, varying greatly with season. Pots may be moved around as needed to take greatest advantage of sunlit positions.

The curse of tree roots in garden beds and their severe impact on the water and nutrient budget is completely eliminated with the TWMS. This is particularly important where water restrictions apply.

Weed control of potted plants is also much easier than in beds. Timely hand control is simple. Mulches of various sorts on the pot surface will also greatly reduce weed growth. Being confined within a pot, running species such as Wandering Jew won't get out of hand.

The TWMS may be placed within decorative pots and managed on patios without run-off. The wet length of the dip stick will indicate how much water can be added without exceeding the capacity of the reservoir.

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