The Twinpot Water Management System: demand (water) driven, automated container irrigation that increases crop turnover, while saving water, nutrients and reducing root escape

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Additional Reference Material

Download document from the website from homepage titled, "Twinpot Water Management System Presentation material."

Abstract

Details are provided of a fully automated water-use based container (pot) irrigation system for the nursery industry. The Twinpot Water Management System (TWMS) utilizes the unique characteristics of the ANOVApot® in combining features of the pot-in-pot technology and 'self watering' container systems. Compared with conventional overhead systems, TWMS promotes 30-40% faster plant growth (and hence more rapid turnover) because of access to a self contained water table. Irrigation run-off can be prevented resulting in substantial water savings, as well as an expected 30% reduction in nutrient loss, while reducing root escape and pot blow-overs. Irrigation management is based directly on individual plant water use, either manually or automatically. Water can be applied to the surface of the top pot at many times the industry recommended maximum without the fear of run-off. Because of the pot-in-pot set up with the ANOVApot® design, the potential for ground based disease entry is virtually eliminated as well as root escape into the underlying soil.

An interactive user-friendly, template based, economic analysis of TWMS, with a detailed list of all the costs and savings that can be customized, was compared with those of two existing systems (unbracketed, single pots and bracketed, pot-in-pot). On the basis of 30% faster crop turnover and a 3% reduction in discards TWMS increased annual profit by about $5.00 per pot. Even with a faster TWMS growth rate of only 9% with no difference in discard rate in the comparisons, profit per pot was still more than a dollar better per year than achieved in the other systems.

Introduction

Without question, irrigation provides the life-blood of pot (container) plant production. Compared to in-ground culture the relatively small amount of available water in a pot quickly becomes a major limiting factor to growth unless the water status is regularly reinstated. With the exception of sub-irrigation, all overhead application systems either apply too little or too much simply because no instrument can provide accurate needs-based information on total pot water deficit. Obviously too little compromises potential growth and leads to ineffective use of potting mix, while too much, wastes water, leaches nutrients and may lead to water-logging.

Less than 6% of the Australian nursery industry (Lane, 2002) has adopted sub-irrigation probably because of high installation costs, perceptions of disease and water logging, major cost escalations as pot density declines with the use of larger pot sizes and the need to use media with adequate capillarity. By contrast, sub-irrigation is the norm (~70%) in Europe perhaps because pot sizes are normally small and peat with its high capillarity is the preferred growth medium. In contrast to most other irrigation systems, properly managed continuous sub-irrigation can maintain optimum water status and hence meet potential plant requirements for smaller pots (say 200mm, 4L or smaller, Beeson, 2002, Hunter et al, 2003)).

We outline a pot irrigation system that utilizes the benefits of sub-irrigation, without the prohibitive costs as pot size increases, and is compatible with existing irrigation systems that actually save water and nutrients as well as promoting more rapid growth than normally achieved with overhead irrigation alone. Importantly, the system can be cost-effectively automated to deliver water on the basis of actual plant water need (self learning capacity incorporated in control software) without run-off, and managed to provide defined water stress as may be required in the hardening up phase prior to sale. The interacting factors of pot water status and evaporative demand in determining water deficits are automatically accounted for without the need for pan evaporation data and specific crop factors as currently recommended in determining irrigation in the general Australian nursery production (Danelon and Hunt, 2008).

The system is an hybrid of ‘self-watering’ wick pot technology, (unchanged in principle since CF Hall (1881) and SJ Rhoades (1885) and Pot-in-pot technology (Mather, 2000), an increasingly adopted system in the US. Fundamental to the cost effectiveness of the hybridization for the wholesale nursery industry has been the use of the unique design features of the ANOVApot® and their effects on pot hydration, drainage and root control (www.anovapot.com).

The irony in the evolution of TWMS 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 features of the T(A*)WMS A=automatic

Economics

- As much as $5 increased profitability per pot per year
- Customised template estimates costs and savings for individual nurseries
- Cost of converting to TWMS offset by increased profitability

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 to attract pathogen entry
- Non-permanent water table interrupts mosquito breeding cycle

Irrigation

- Much faster application rates possible without run-off
- Better water distribution in mix
- Managed zero-irrigation run-off
- Major water saving
- Plant water use based automatic irrigation (A*)
- Dip stick option to monitor water level (and use) and guide irrigation amount and frequency
- Colour change in potting mix may signal irrigation frequency

Fertilizer

- Lower optimum rates (30%) likely because of minimal leaching
- Reduced environmental contamination by nutrients
- EC of reservoir solution 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
- Upending lower pots between crops reduces litter and water accumulation
- No pot blow over in bracketed system
- The few roots that emerge through the base of the top pot stay in the lower pot and are easily removed.
- Additional physical and chemical options further reduce or prevent root escape from top pot
- Underlying weed mat and pad stay free of roots
- Pots and pads remain cleaner
- Herbicides can be sprayed around pot base
- Placed inside decorative containers
- Pots can be easily separated for swapping or cleaning

Pots can be shifted around to capture sunshine

No basal holes available for weed or algal growth or salt encrustation

Miscellaneous

Easy to convert from existing PIP systems

Nesting of pots provides considerable insulation of upper pot

Placed in ground under trees without tree root competition for water and nutrients

The Twinpot Water Management System (TWMS)

The hardware

The focus here is the 330mm, 18L WaterSaver ANOVApot® (Slide 1, and 2) (Download additional Twinpot Water Management System Presentation material from website homepage) available from Garden City Plastics (www.gardencityplastics.com), although with slight modification much will also apply to the 200mm 4.0L WaterSaver ANOVApot®.

The 18L ANOVApot®s naturally nest closely together (22mm separation) to minimize volume based transport costs. Nesting of two pots (hence 'twin') is utilized in the TWMS but the vertical distance is increased to 45mm by the use of Windclips (www.windclips.com), an horizontal above ground pot-in pot bracketing system that was invented, developed and promoted in Australia. For unbracketed systems, three 45 mm long Polypipe Spacers, with one end squeezed and placed vertically into the space under and evenly distributed around the top rim, may be used for each pot. These are included with the Conversion Kit (available from Anova Solutions P/L) that also include a Capillary Cap and Dipstick.

The Capillary Cap, a 120mm square indented plastic sheet (Nylex Edge Barrier), is covered with a length of capillary mat (80mm x 200mm polyester needle punched hydrophilic geotextile (Global Synthetics, Profab Geotextile AS500) fixed at one end of the cap with a staple, rivet or glue (Slide 3). The 10mm wide edge of the opposite end of the plastic sheet is turned down at right angles to catch the top of the collar of the lower pot, thus ensuring that the cap stays in position. The capillary tape extends beyond the turned down section of the sheet to rest on the internal base of the lower pot, ensuring a capillary upward pathway for water from the bottom of the lower pot reservoir.

When the two ANOVApot®s are nested and correctly spaced with Windclips or Polypipe Spacers, the grid of the upper pot just comes in contact with the upper surface of the capillary tape, resting on the cap which in turn completely covers the collar of the lower pot. The weight of wet potting mix in the upper pot drops the grid slightly further ensuring that close contact occurs between the capillary tape that connects the lower reservoir and the moist potting mix in the upper pot. The indented plastic sheet of the Capillary Cap ensures that any drainage water from the upper pot is shed into the reservoir of the lower pot, filling it to capacity (2L) before excess drains over the lip of the collar and exits the lower pot. Note that Spacers are unnecessary in the 200mm ANOVApot® with the 18mm tall collar.

A 34mm long thin bamboo stick is included in the Conversion Kit as a water level Dip Stick (Slide 4). It is inserted through a 9 mm hole drilled in the rim of the top pot and slid between the nested pots to the bottom of the lower pot. When withdrawn the length of the wet tip (maximum 40mm) will provide an estimate of the water in the lower reservoir. Withdrawing the Dip Stick between measurements and resting it slightly above the 40mm reservoir level will prevent it becoming water soaked and rotten.

Pot setup

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.

A 330mm WaterSaver ANOVApot® is filled to its brim as normal with potting mix around the transplant and then the pot dropped three times from about 5cm height to settle the mix, being especially important in the central well to ensure good upward capillary flow. Water (2-3L) is added to the transplant but not to excess. It is important not to greatly exceed this volume after potting up since potting mix fines may be washed out of the pot while the capillary tape is not in position. Such fines probably aid capillary connections. This pot is then transferred to the field pad.

To further limit root escape, a 15cm square of light-weight plastic film (light-weight poly bags would be a practical option) may be laid flat, centrally in the top pot during the pot filling operation, on the potting mix level with a height some 5 cm above the height of the central well. Further filling of the pot is recommenced. In this position this plastic film will deflect any vertical roots that would otherwise enter and grow through the central well. To reduce environmental plastic contamination, it would be preferable to use plastic film that is degraded in time by bacteria, preferably ones absent from the potting mix so that plastic breakdown does not occur until the root ball is removed from the pot and exposed to such soil bacteria.

In commercial production it is suggested that the lower empty TWMS ANOVApot®s pots be bracketed together on the growing pad, one for each of the filled pots, in units of 9 (slide 5) 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 Polypipe Spacers in keeping the pots the right vertical distance apart. These brackets are available in three sizes of 70, 140, and 260mm which may be joined together in various combinations to give a wide range of spacing options. The pots may be used unbracketed provided Polypipe Spacers are inserted into the rim of the upper pot.

The Capillary Cap (capillary tape) is placed over the collar in each of these empty pots with capillary tape uppermost and tail orientated down the slope of the pad. In the case of unbracketed pots, three 45mm Polypipe Spacers should be inserted (and evenly spread around) under the top rim of the top pot prior to placing these pots inside the unbracketed pots.

The top pot with transplant is placed directly into the bracketed pots. Further irrigation should be applied to the top pot once on the growing pad to completely saturate the top pot as well as completely filling up the lower reservoir with any excess simply draining away through the central well of the lower pot. Dip Sticks inserted into the lower reservoir through the hole in the upper pot and extracted about one hour after adding water are used to assess how well the reservoir has been filled, with further irrigation as necessary.

Routine irrigation and pot management

After the reservoir has emptied following plant water use, 3-4L of water should be added to the surface of the top pot (a flooding application rate is permissible) and reservoir level checked with the Dip Stick one hour later. Provided the reservoir water level is just below the overflow height (40mm) this quantity becomes the reference refill quantity, adjusted up or down according to the quantity recorded in the reservoir: up if the reservoir was only partially filled (less than 90%) and down if overflow occurred. The quantity would thus be adjusted at the next application trigger so that after a number of iterations the capacity of the system is met with no run-off. Obviously irrigation frequency will be determined by rate of plant water use with the interval related to the time it takes to empty the reservoir. A delay in irrigation beyond this time will require an increase in the replacement volume to account for the additional water lost. A delay for a number of days will impose increasing levels of plant water stress which may be desirable response in preparing plants for sale. Imposed stress may also be used in initiating a flowering response.

Overhead irrigation

Surface irrigation can be applied at virtually any rate and still be effective without wastage irrespective of the absorptive characteristics of the potting mix. Because of the unique characteristics of the ANOVApot® design, the volume of the lower reservoir and the effect of internal sub-irrigation on pot water distribution, water can be poured into the top pot at many times the maximum recommended industry standard (15mm per hour, Atkinson and Rolfe, 1995) without run-off. The system we propose is less likely to suffer from channeling, dry patches and water-logging provided the water status of the lower reservoir is used to control irrigation. Any irrigation supply that minimizes pump costs while delivering pot plant needs will be acceptable, including fine or coarse overhead, light or heavy, single or multiple emitters, drippers or spray stakes. The advantage of the combination of overhead irrigation and internal sub-irrigation reduces the likelihood of salt accumulation on the surface. Rapid flow rates from drippers will reduce their likelihood of clogging.

Hand watering

Relatively accurate quantities of pot directed water may be required in retail nursery watering and in water use research. Use of metered delivery nozzles in hand-applying prescribed accurate amounts is preferred but costs of equipment may be excessive. Rapidly hand filling slowly leaking receptacles (bottles, buckets, of known and adjustable capacity) that rest on the top of the potting mix is a practical alternative in research experiments. Capacity of these receptacles may be reduced as required by the inclusion of ‘dead’ space, e.g. a sealed plastic bag of known volume containing sand. As a minimum in retail hand watering, reservoirs should be monitored and regularly refilled to the overflow point.

Automatic Irrigation

Many of the requirements (and decisions) of the above manual set up are eliminated when a wireless electronic water level sensor integrated with an irrigation controller is included in the lower reservoir (Slide 6). We have demonstrated that it is possible to automate irrigation based directly on plant water use (Hunter et al 2009). Commercialisation of such a sensor located in the reservoir and connected via a radio head to a computer based irrigation controller is underway. We expect this system to log the filling and emptying of the reservoir, calculate how much of a known volume of added water is retained in the top pot and how much accumulates in the reservoir, thereby optimizing the actual volume added not to exceed system capacity. Such programs will be subject to operator over rides for flushing purposes to minimize the effects of salt build up or to create mild stress for crop production reasons (e.g. hardening off prior to sale, inducing flowering). For 'meaner' irrigation regimes, these data will be used to estimate how much extra water needs to be added for every hour that the nominated trigger is delayed beyond the initial 'empty reservoir' condition.

With its reliance on actual individual plant water use such a system automatically accounts for variation in evapo-transpirational demand, plant size and species. It is not affected by type of potting mix, animal interference or canopy closure where plants actually touch each other. Each sensor will be readily transferable between pots and able to be immediately commissioned, virtually at the touch of a button. Moving them into pots supporting more rapidly growing plants will mean that slower growing plants will tend to be over watered (they are unlikely to catch up), while transferring sensors to slower growers will result in under watering of the bolters. This second strategy may result in a more even crop at point of sale.

To minimize costs, a density of one sensor per hundred pots is currently arbitrarily recommended. The optimum density will be dependent on local environmental variation and variation of plant performance and the actual precision being sought. Selected density may also be dependent on type of irrigation such as individual pot drippers or overhead sprays where wind and canopy type will influence irrigation efficacy.

Water loss and replacement

Evapo-transpiration extracts water from the top pot and the reservoir with relative quantities being determined by the height of the potting mix above the reservoir water table. In the 330mm ANOVApot® (270mm tall) between 40 and 50% of water was lost from the reservoir between 10am and 4pm (bark coir mix) with 4 species, By contrast this value rose to 75 to 82 % for sorghum grown in a 200mm ANOVApot® (195mm tall). As these relative quantities determine the capacity of the whole system if irrigated as soon as the reservoir empties, their actual value is important in deciding on the volume of irrigation that can be applied without run-off. These values do not appear to be affected by plant size or evaporative demand. However, the effect of potting mix composition on relative water holding capacity may also affect the relative losses from the top and reservoir.

Quality of drainage water

The determination of salt content of pot leachate is rarely routinely monitored in practice unless reasons for poor growth are being sought. Even when excessive levels are found, the crop would already have been severely compromised with little effective remediation possible. A major attribute of the automated TWMS is that every reading of a water level includes a current value of the salt content of the reservoir solution. Consequently, elevated salt concentrations above 2dS/m may indicate excessive salt (Handreck and Black 1994), requiring a flushing irrigation, while values similar to the concentrations of the irrigation water itself may indicate inadequate nutrition. However, actual concentrations that impede growth under TWMS needs further evaluation. Recent work with sorghum suggests that considerably higher salt levels may be tolerated because of the non-limiting nature of the water supply compared to normal wetting and dying regimes that lead to very high osmotic effects during the drying phase. Even in the Manual system access to the lower reservoir with a stout hollow probe inserted through the Dip Stick hole can readily draw off enough solution sample for chemical analysis (Slide 7). This approach is much simpler and probably much more definitive (little channeling or pot drying to bias salt extraction) than the Pour Through techniques described by Handreck and Black, (1994) and hence much more likely to be adopted as a routine monitoring tool to detect the onset of toxicity or deficiency.

Sub-irrigation

The system will not absorb water from sub-irrigation capillary mat systems but could work with ebb and flood systems where the flood level rises above the height of the well in the lower pot. However, repeated bottom irrigation without any overhead application may lead to excessive salt accumulation at the top of the capillary fringe.

Shoot 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 in the three pot types was evident in *Grevillea* sp and *Chamodorea seifritzii* (bamboo palm), both considered very sensitive to waterlogging, discounting the idea that the pot configuration of the ANOVApot® limits adequate pot aeration (Hunter and Scattini, 2009, Slide 8). 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 (Slide 9). 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 (LSD 113g, Slide 9 and 10). In a follow up experiment, again with *Syzygium* (Slide 11), 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). These results support the observation of superior growth reported for sub-irrigated systems (Hunter et al, 2005, Beeson, 2002, Stackhouse, 1993) where plants also had access to an almost continuous supply of water.

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 12 and 13). A visual comparison of rootballs of *Chamodorea seifritzii* grown in a range of pot types including two TWMS systems indicated very little difference among treatments even though this species is reputed to be very intolerant of water-logging (Slide 14). The visual comparison of root balls of *Syzygium* and *Magnolia* in the first experiment reported above, again revealed little difference in root appearance (Slide 15). Images of root balls of *Syzygium* in the second experiment above appear in Slides 16 and 17 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 little evidence of ‘poor’ basal root development in the TWMS pots, an otherwise expected response had the system been poorly aerated due to basal water-logging. Roots actually appeared whiter in the TWMS pots, this colour often being associated with a healthy root system. Vigorous and normal root development has also been observed in citrus and avocado after 12, and 11 months respectively under TWMS (Slides 18 and 19).

Root escape and internal coiling

Copper impregnated 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 from the top pot with the slicing action of a sharpened paint scraper over the grid at harvest.

Vertical roots that enter the well from above and then escape may be deflected by a plastic sheet or cap (preferably degraded after the nursery phase), a bit wider than the diameter of the well, placed just above the well at potting up. The cap is completely surrounded by potting mix and should not interfere with capillary water movements. 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 placed in the well (Slide 20) proved effective in preventing root escape in marigold and sunflower. Porous concrete (one part cement, one part water, 10 parts sand, 0.5-1.5mm grain size range, strongly compacted) made *in situ* in the well, about 15 mm thick (Slide 21) can also provide an effective root escape barrier but still allow drainage and upwards capillary flow.

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 22). Copper hydroxide rates of 100g/L in a flat white acrylic exterior paint have been recommended (Handreck and Black, 1994 p 370). Species appear to vary considerably in the sensitivity of their roots to the copper level in this paint.

Plant species

Many species have now been grown under TWMS conditions with good results in all cases. Species such as bamboo palm (Slide 8) 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 (Slides 23 and 24), potato (Slide 25), parsley, chives, tarragon, rosemary, chervil (Slide 26), lettuce (Slide 27), *Syzygium* (cvs. Cascade, Aussie Boomer, Hinterland Gold), magnolia (Slide 9), *Spathiphyllum,* kentia palm, golden cane, *Harpulia* , *Lomandra*, Echnida grass, Red Fountain grass, tropical Fuchia, Tiger grass, *Polygala,* sweet potato (Slides 28 and 29), sorghum (slide 30) and bananas (Slide 31). Two other water-logging sensitive fruit tree species, citrus and avocado, are growing well (Slides 32 and 33).

Potting mix

Most organic matter potting mixes, and even soil, may be successfully used in the TWMS. Because of their much more open structure, rapid drainage and good aeration the former are preferred. 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 and clay content in the case of soils. The height of this rise is not critical in top watered systems and may extend to the surface in coir or peat mixes. The moisture content of such mixes may affect their colour, becoming lighter as the mix dries. This feature may be used to indicate the absence of water in the lower reservoir and hence used as a re-watering trigger.

Water and Nutrient Savings

A major management feature of TWMS is the ability under automated conditions to achieve zero-irrigation run-off. In a recent commercial comparison of two automated systems (Slides 34 and 35), TWMS used 75% less water over a five month period (April-August) than an automatically irrigated side holed pot, fitted with 2L/hr drippers and watered for 2 minutes every 20 minutes over a 5 hour period, except for a total of 29 days without irrigation due to wet weather. Growth was estimated to be some 20-30% faster in TWMS allowing the crop to be marketed 6-8 weeks earlier.

The need to save water by switching irrigation on and off during rainy periods as well as determining the length of the interval, requires decisions based on considerable management experience. Efficiently managing a fixed-schedule automated irrigation system in a nursery environment of many different irrigation blocks that accounts for species diversity and age would be quite onerous. By contrast, such decisions and activity are completely unnecessary in the automated TWMS which automatically takes rainfall, plant size and particular species needs into account.

This water saving of TWMS reflects the significant buffering capacity of the 2L lower pot reservoir, the accuracy of the water-use based irrigation trigger and the customized volume of water added that can be automatically adjusted according to volume retained after each irrigation event.

The elimination of irrigation run-off (uncontrolled inputs of rain may still drain) by implication results in the virtual elimination of soluble salt (nutrients and amendments) drainage loss. Based on reported nutrient savings in closed sub-irrigated systems (Handreck and Black, 1994, p 169), as much as a 30% saving in nutrient addition to TWMS should be possible without reducing growth. Not only does this represent substantial cost savings, it also minimizes environmental pollution.

Nutrient Management

Much of the nutrient management in TWMS should be similar to that in conventional systems, bearing in mind the savings suggested above. However, in addition to surface, banded or mixed placement options fertilizer may also be placed in the reservoir. In one short term study of 89 days, rates in the reservoir of Osmocote Extra were only slightly less effective than the same rates of mixed and surface applications (Slide 30). At the heavier rates (4 and 6g/L) differences in growth between reservoir, mixed and surface fertilizer application were fairly small despite very high ECs (11-12 dS/m) that developed in the reservoir solutions in the early stages before rapid water use. Substantial salinity injury while expected was probably avoided as a result of the flushing action of overhead irrigation. The success of reservoir nutrient addition deserves further work as it may allow more timely and accurate nutrient management than currently possible. Research into the efficacy of forms and rates of slow release fertilizers and species compatibilities is warranted.

Pot management

Not only does the absence of any external roots in TWMS allow the use of directed contact sprays around pots for weed control without concern of plant uptake, pads are not contaminated with escaped roots. Furthermore, the absence of side holes reduces potting mix leakage and eliminates sites for weed and algal growth and root death (air pruning) (Slide 36) or the unsightly encrustation of salt deposits around holes.

Bracketed systems resist blow over, while nested pots are insulated from temperature extremes and being less weathered, cleaned more quickly for sale.

When ready, the top pot with plant may be removed and prepared for sale. The few roots that emerge through the base of the top pot can be easily removed with a sharpened paint scraper. If necessary, physical or chemical options can be utilized to reduce or completely eliminate root escape.

The empty lower pot, if left for any length of time, accumulates 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 5). 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 in surfactant solution, dried and stored for further use.

Macro and 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 or the placement of the lower pot on surfaces that seal such as plastic film.

Air-pruning of roots that emerge through drainage holes is common in side holed pots (Slide 36), with these dead and decaying roots attracting root pathogens. Without side-holes in TWMS this concern is minimized.

The water table of TWMS may persist in locations of daily rain long enough for the water phase 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 occurrence of this is yet to be confirmed. The lack of late instar 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 chemical (S-methoprene) that disrupts the normal life cycle or alternatively, bacteria (*Bacillus thuringiensis israelensis*) that produce a mosquito effective toxin would be commercially practical (Russell, 2006). Eliminating habitats for breeding mosquitoes is a very important human health issue particularly in tropical environments where mosquitoes are vectors for disease organisms. The occasional slug, worm and other invertebrates have been noticed in the central well of the lower pot but their potential to do damage is considered low.

Comparison with Pot-in-pot and Self-watering Systems

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 outer 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 above ground with adjoining pots. The major 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 raised 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 larger animals such as toads and snakes taking up residence in empty ‘self watering’ pots with access through the watering hole, an issue that is minimised 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.

Economic assessment *(Extracted from Robinson and Wilson, 2010)*

An Excel Template (ANOVAProfit) was developed to estimate the profitability of installing a TWMS in a wholesale nursery that is currently using either an unbracketed above ground system (US) of stand alone pots or an above ground bracketed system (BS). The template was designed to assess the changed profitability of wholesale nurseries that have continuous output of plants over the year i.e. they do not have seasonal production.

Estimated profitability of installation of TWMS in a 10,000 pot commercial nursery

Size of nursery (No. of pots)	10,000	
Value of sales/plant ($)	$25	
	TWMS pots	**US or BS pots**
Months for plants to reach saleable size (No.)	4.6	6.0
Pots produced per year (No.)	26,087	20,000
Throw outs (%)	5.0%	8.0%
Plants sold per year (No.)	24,783	18,400
Annual gross sales ($)	$619,565	$460,000
Summary	**TWMS cf. US**	**TWMS cf. BS**
Change in annual gross sales	$159,565	$159,565
plus annual materials & services savings	$1,720	$1,720
plus annual labour savings	$5,462	$3,031
Sub total	$166,747	$164,317
less extra materials & services annually	$97,547	$90,347
less extra labour annually	$20,821	$19,988
Change in annual profit	$48,379	$53,981
Change in profit/pot (Nursery size)	$4.84	$5.40

These estimates show that the annual profits of the 10 000 unit nursery should increase by around $50,000. The increased profit in the case of an existing BS is slightly higher than for the US because it requires less investment in additional equipment.

As the increased profits are very sensitive to changes in turnover rate and the reduction in the percentage of discarded plants, sensitivity analyses in changes of these parameters was also carried out. Even with a increased growth rate of only 9% and the same discard rate (8%) as the other two systems, annual profit per pot compared with the other two systems is still more than a dollar.

Estimated increase in profit per pot ($) under varying plant growth and discard scenarios in changing from a BS system

	Percentage discards			
Months to reach saleable size:	5%	6%	7%	8%
4.6	5.40	4.75	4.09	3.44
5.0	2.99	2.39	1.79	1.19
5.5	0.48	-0.06	-0.61	-1.15
6.0	-1.61	-2.11	-2.61	-3.11

The template does not assess the profitability of any of the systems on a whole enterprise basis. The intent is to calculate the change in profitability in moving from either total "steady state" US or BS systems to a total "steady state" TWMS. The change in annual net profit was the criterion used to assess the change in profitability. The template does not explore the cash flow implications of moving from one system to another. Many of the template inputs can be customized to better reflect the actual operations of an individual nursery.

Installation of the TWMS has the potential to increase the profitability of the order of $5 per pot. However, improvements in profitability are highly dependent on achieving improvements in technical efficiency especially that of appropriate. Irrigation management.

Because of the nature of the technology, nursery operators who are interested in installing TWMS could do it on a small trial basis to find out for themselves whether they are able to achieve the improvements necessary for it to be profitable in their situation.

Availability of the Excel Template ANOVAProfit

Nursery operators who wish to obtain a copy of the Template to customize inputs that better reflect their enterprise should contact Dr Mal Hunter of Anova Solutions Pty Ltd. Email: mhunter@powerup.com.au Phone: 0408764459

Adoption of TWMS

As of May 2010, TWMS has been implemented commercially in a tree nursery in the ACT to better manage limited water of marginal quality. It is a key cultural component in the Peanut Company of Australia’s speed breeding program, with the use of 330mm ANOVApot®s promoting rapid peanut crop turnover rates within 85 days and the production of very high quality kernels necessary in their single seed descent back-crossing work (G. Wright, personal communication). TWMS provides the cultural basis for the University of Queensland’s speed breeding wheat program using modified 140mm ANOVApot®s, which again promote rapid crop turnover rates (70 days) and the production of high quality pollen and grain (M. Dieters, personal communication). As a system that better controls water and roots while promoting excellent growth, the TWMS is being utilized at UQ in sorghum physiology research (temperature and genotype, G. Hammer, personal communication). TWMS is being successfully used by many home gardeners in the culture of herbs, vegetables and fruit trees. The system is available from Nova Gardens, The Gap, Brisbane, ph. 07 33004161, www.novagardensnursery.com.au.

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 and Polypipe Spacers 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 drainage loss (62mm/hour, Poulter 2009). Frequency of irrigation will also be substantially decreased with savings in labour. Again, pots may be sold separately or in the Twinpot 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 (Slide 37, 38 and 39).

Plant Hire The 2L capacity of the TWMS in the 330mm WaterSaver ANOVApot® should 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 rediected from time to timewith a hand operated bilge pump. The ease of swapping species about while leaving the lower pot in position is a useful option.

Domestic The TWMS is attractive in the fully exposed 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 Dipstick 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.

The TWMS may be applied to decorative pots and managed on patios without run-off. The wet length of the Dip Stick would indicate how much water can be added without exceeding the capacity of the reservoir.

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