The ANOVApot®

Origin, development and associated pot irrigation systems

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"more than just another pot"
www.anovapot.com

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Summary

This document provides an overview of the ANOVApot®, a new patented pot (container) for the nursery industry, with innovative features of root and water control. The pot is of value to nursery professionals (and others) seeking to use water efficiently, minimise root escape and reduce labour costs. The reason for its development, its unique design features, its performance when tested, and its use in associated irrigation systems are presented. Results of a survey of 21 industry users are included.

Briefly, the ANOVApot® has a single, mesh covered central basal hole, surrounded internally by a collar. Root escape is greatly reduced and water retention increased (>30%) without water-logging. Growth is promoted. Water retention > 100% occurs when one ANOVApot® is nested in a second ANOVApot®, with the lower pot storing drainage water available to the upper pot via flow through capillary tape (the Twinpot Water Management System, TWMS). The system can be automated via a sensor or valve in the lower pot. The sensor actuates irrigation input at a set water level, while the valve maintains a constant water level in the lower pot. The TWMS eliminates irrigation waste and promotes growth by as much as 45%. Other developments based on the ANOVApot® and using similar concepts are the Pot-in-Bucket, Pot-in-Trough and Split Root systems.

With several notable exceptions, adoption of the ANOVApot® by the Australian nursery industry has been somewhat muted, despite the very positive feedback from survey respondents concerning its performance. Ten percent higher pot costs and limited promotion may be factors in the relatively slow uptake. The ANOVApot® and its associated irrigation systems are now widely accepted by researchers at the University of Queensland, particularly those seeking relatively stress free environments, where water control is important and the study of plant water use efficiency is a particular goal. There are also enhanced opportunities for data collection. Overall, more than 11 million pots of 5 sizes have been sold since 2005 with consistent annual sales indicating a small but established Australian market.

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Table of Contents

Figures

Tables

Introduction

The ANOVApot® is a new type of pot for container plant production, which is very suitable for use in commercial nursery production as well as in a range of plant-based research projects (Figure 1). Its principal attributes in comparison with most other plastic pots are; i) its ability to restrict roots from escaping the base of the pot (root escape); and ii) its slower drainage and consequent benefits in water retention. Its invention was stimulated by the need to control root escape from pots irrigated via capillary mats. The ANOVApot® is covered by US patent no. 7,743,696 B2 (Hunter, 2010, Figure 1); Australian patent no. 2004298289 B2 (Hunter, 2011); New Zealand patent no. 548424 (Anova Solutions, 2010); with a patent pending in Europe.

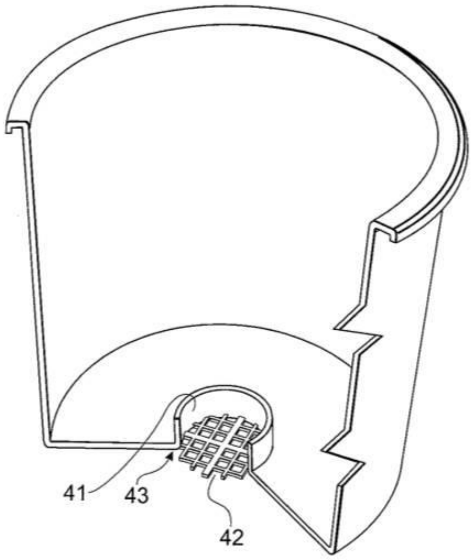


Figure 1. Figure 3 in the US patent 7,743,696B2 depicting the innovative elements of collar (41); and grid (42) covering the basal hole (43) in a plant pot (container). Marketed as the ANOVApot®.

This document provides an overview of the development and performance of the ANOVApot®, including key concepts behind its unique features. Results of tests made under experimental and nursery conditions are presented, together with feedback from a survey of nursery growers. The subsequent development and testing of several innovative irrigation management systems based on the ANOVApot® are also discussed.

Origin of the ANOVApot®

Capillary mat irrigation

Capillary mat irrigation (CMI) supplies water from a moist mat (e.g., needle-punched polyester) to pots with basal holes located on the mat. The pots contain a medium (potting mix) with sufficient capillarity to absorb and transfer water from the water table to the top of the pot. Compared to overhead irrigation, CMI is much more efficient in water use and can be automated to keep the mat continuously moist while virtually eliminating run-off to waste (Goodwin et al., 2003 and many others, including Hunter et al., 2005). It has proved useful for both nursery production and research.

The root escape problem

Because of the relatively stress-free, moist environment of CMI, root growth out through basal holes in both side-holed and bottom-holed pots can be prolific. These roots penetrate and proliferate in the underlying mat (Figure 2) and are almost impossible to retrieve.

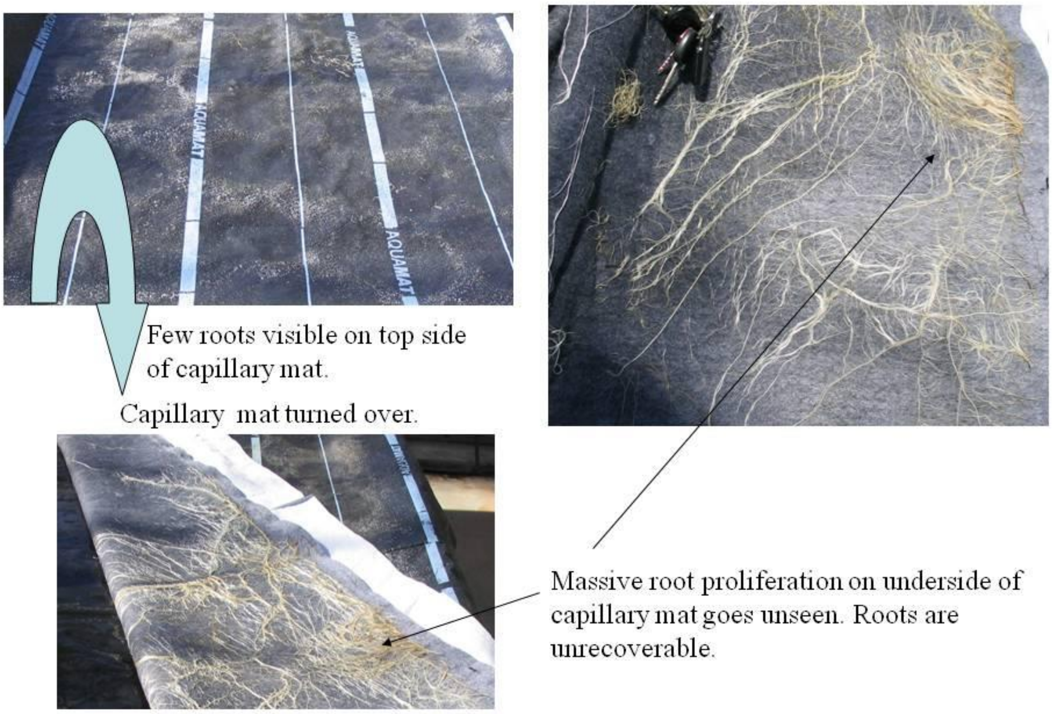


Figure 2. Proliferation of marigold (*Tagetes* sp.) and sunflower (*Helianthus anuus*) roots on underside of capillary mat.

Subsequent pot removal of nursery grown plants will sever these roots and subject the plant to considerable shock, particularly where it has become reliant on escaped roots that have penetrated the underlying waterproof membrane and are actually exploiting the soil below. The inability to retrieve roots also impacts adversely on plant-based research in which root data are essential.

Such a problem confronted Dr Neal Menzies (then leader of the Soils Group, University of Queensland) in his investigation of the supply of phosphorus (P) in a number of soils as it affected the growth of rhodes grass (*Chloris gayana*). Root escape was massive and prevented him collecting useful data on root responses, a plant component particularly important in the assessment of P effects. Although the application of chemical to the underlying mat may prevent root development (Bath and Handreck, 1996; Stafford et al., 1995), the use of chemicals in nutrition studies is unacceptable because of the confounding effects they may have on plant growth responses. Thus a physical solution to the problem was sought, free of chemical use.

Observations of root distribution in pots on capillary mats

Hydrophilic tapes were inserted through horizontal slots made in the wall of a non-holed plastic pot with a top diameter of 140mm (Figure 3). Slots were made 1cm above the base of the pot. A section of the tape was wrapped around the base of the pot with the two ends inserted through the slots on opposite sides of the pot. A second tape running parallel to the first across the base of the pot was inserted in a similar way. A fully fertilised peat and perlite potting mix was carefully poured into the pot to support the capillary tapes in the horizontal position, 1cm above the pot floor, and then to fill up the pot. The tapes provided a conduit for water from the underlying capillary mat into the pot, eliminating the need for holes that are present in other pots, either on the basal rim or distributed on the pot base. Sunflowers (*Helianthus annuus*) were grown for about 30 days in these pots in a glasshouse. Tops were removed. Tapes were cut at the slots where they emerged from the pot allowing the removal of the intact root ball. A 15mm thick basal slice was removed from the root ball and placed on a screen. The potting mix was removed with a gentle stream of water to reveal the basal mat of roots.

As expected, roots massed at the pot base (Figure 4). Most surprising, however, was the almost complete absence of roots in the pieces of tape that had lain horizontally in the pot only 1cm above the basal root mat. As the entry point for all water into the pot, we expected the tapes to be preferentially occupied with roots.

These results were reproduced with maize (*Zea mays,* cv. Pac 424), grown for 34 days in the same type of taped pot with a fully fertilised podzolic soil. This soil medium was used to facilitate root recovery, this being a much more difficult job where particles of the organic medium are invaded by fine roots and difficult to separate. After cutting off the tapes as before and removing the pot, the intact root ball was cut up into horizontal slices 15mm thick. Each slice was placed on a mesh screen and a gentle stream of water applied to remove the soil. After photographing, the slices were dried and weighed and results graphed (Figure 5) to show the distribution of roots in the root ball from the base of the pot to the top. Most roots were present in the basal zone and least in the zone immediately above the basal zone.

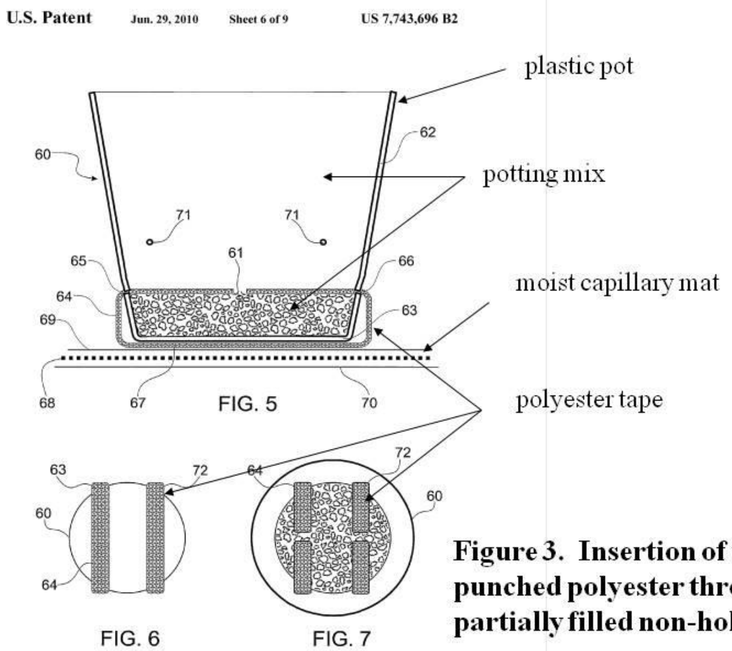


Figure 3. Insertion of tapes of needle punched polyester through the wall of a partially filled non-holed plastic pot.

Patent no. US7,743,696B2. Figure above copied in full from the published patent application. Numbers are relevant only to the actual patent application.

Again, the tapes that were lying horizontally just above the basal zone were almost devoid of roots (Figure 6), even though they were the only entry point for water. Within the layer of massed basal roots, fewest roots appeared to be located in the central zone. These observations suggested the existence of a ‘sweet’ zone in the centre of the pot, 10-20mm above the base of the pot, which was occupied last by roots as they proliferated throughout the pot volume. Roots block holes in pots and thus interfere with water flow. There seemed to be some potential value in utilising this zone of low root density, as the one and only sub-irrigation water entry point, in reducing this interference.

Such a specific zone of water entry was achieved by cutting a 5cm circular hole in the base of a non-holed pot and glueing a 2cm length of plastic conduit (diameter of 5cm) inside the base of the pot as a collar around the hole. A section of nylon mesh was glued beneath the central hole to retain soil or potting mix within the collar. This pot became the prototype of the ANOVApot® (Figure 7).

Preventing root escape

Maize with the prototype of the ANOVApot®

An experiment was conducted to test the effectiveness of the prototype collar design in preventing root escape, compared with that from taped pots, pots with a basal 100µm screen, pots with porous concrete plugs and ‘normal’ holed pots, again with maize plants.

Figure 4. Sunflower (*Helianthus anus*) roots recovered from base of root ball reveals concentration of roots at base of root ball.

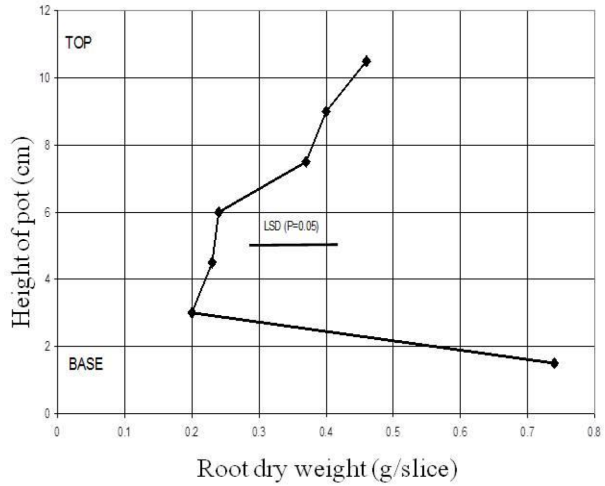


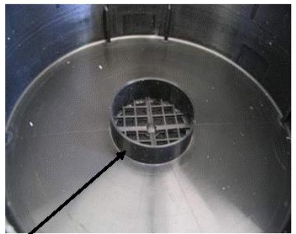
Figure 5. Vertical distribution of maize (*Zea mays*, cv. Pac424) roots after 34 days, meaned over 1.0 L pots with screens and capillary tapes. Each value is a mean of 8 data points.

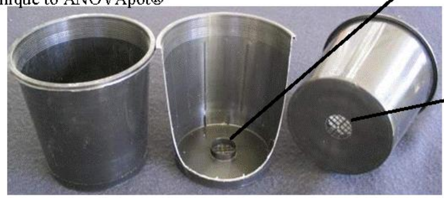
Figure 6. Root recovery in maize (*Zea mays,* cv. Pac424) from basal slice of a 1L pot of Mt Cotton podzolic soil.

ANOVApot®

- **A pot: top 137mm diam, bottom 116mm diam.**
- **Height 140mm**
- **Basal central hole 27mm diameter***
- **Grid of 16 x 3.5 mm square openings and 16 sub-square openings (total opening area of 3 sq cm)***
- **7mm tall and 1mm thick collar around hole***
- **Completely flat smooth base free of projections***
- **Vertical root trainers and spacers on base**
- **Circular raised grip ridges at top**

*Unique to ANOVApot®





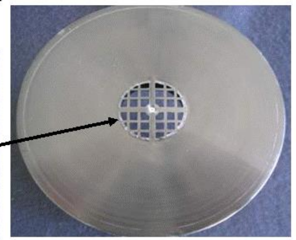


Figure 7. The 140mm ANOVApot®

Pots were sub-irrigated. The results in Table 1 show that in comparison with escape from holed pots, all other water entry modes prevented or greatly reduced root escape (Figures 8 and 9). As expected, a single central hole without a collar was also moderately effective. Importantly, shoot growth of all treatments was not significantly affected by the different designs.

Table 1. Effects of tapes, screens, holes, central wells and concrete plugs on quantity of root escape in maize (*Zea mays*, cv. Pac 424), after 34 days growth.

Treatments (water entry modes)	Fresh weight (g/plant) of escaped roots				Shoot fresh weight (g/plant)
	Rep 1	Rep 2	Rep 3	Mean	
Tapes	0	0	0	0	85.8
Screen (100μ)	0	0	0	0	85.9
Pot with 5 holes	2.25	2.29	1.07	1.87	87.4
Pot with 24 holes	1.37	0.94	0.59	0.97	79.0
Pot with 8 Holes	2.03	1.22	0.49	1.25	82.1
Central Hole (CH)	0.19	0.22	0.11	0.17	72.0
CH + 2 cm tall well	0	0	0	0	73.8
CH + 3 cm tall well	0.01	0	0.01	<0.01	80.3
10mm tall plug[1]	0	0	0	0	80.2
20mm tall plug[1]	0	0	0	0	88.8
30mm tall plug[1]	0	0	0	0	81.3
20mm tall plug[2]	0	0	0	0	91.8
LSD (P=0.05)				0.45	NS (16.8)
Coeffecient of Variation (%)				94	12.4

[1]38mm diameter; [2]62mm diameter

These results clearly show that the prevention of root escape from pots can be achieved by a range of physical means without having to resort to the use of chemicals as proposed by Bath and Handreck (1996).

The success of the prototype design of the ANOVApot®, of the central hole surrounded by a collar, exploits the strong geotropic nature of a root system as it fans downwards. It appears that lower order roots have little if any ability to grow upwards and then downwards in moving from the floor of the pot to the top of the collar and then downwards to escape.

Again, in support of earlier observations, there seems little evidence that these roots are preferentially attracted to the origin of the potôs water supply as it enters the pot through the central basal hole. While this was counter to our initial expectations, it may simply reflect the already high, relatively static, moisture content of the medium, sub-irrigated by a constant water table, in which strong moisture gradients that may influence root direction are unlikely to develop.

Any lower order roots (primary or secondary) that arrive at the ósweet zoneô immediately above the collar opening may continue their downward path unheeded through the basal hole and escape. Although this occurrence is relatively rare, such roots can be deflected away from the collar by an impervious flat surface, e.g., an upturned base of a Petri dish (Appendix 2, p. 43). Careful positioning of the dish above the collar is critical to ensure that it does not also impede water flow.

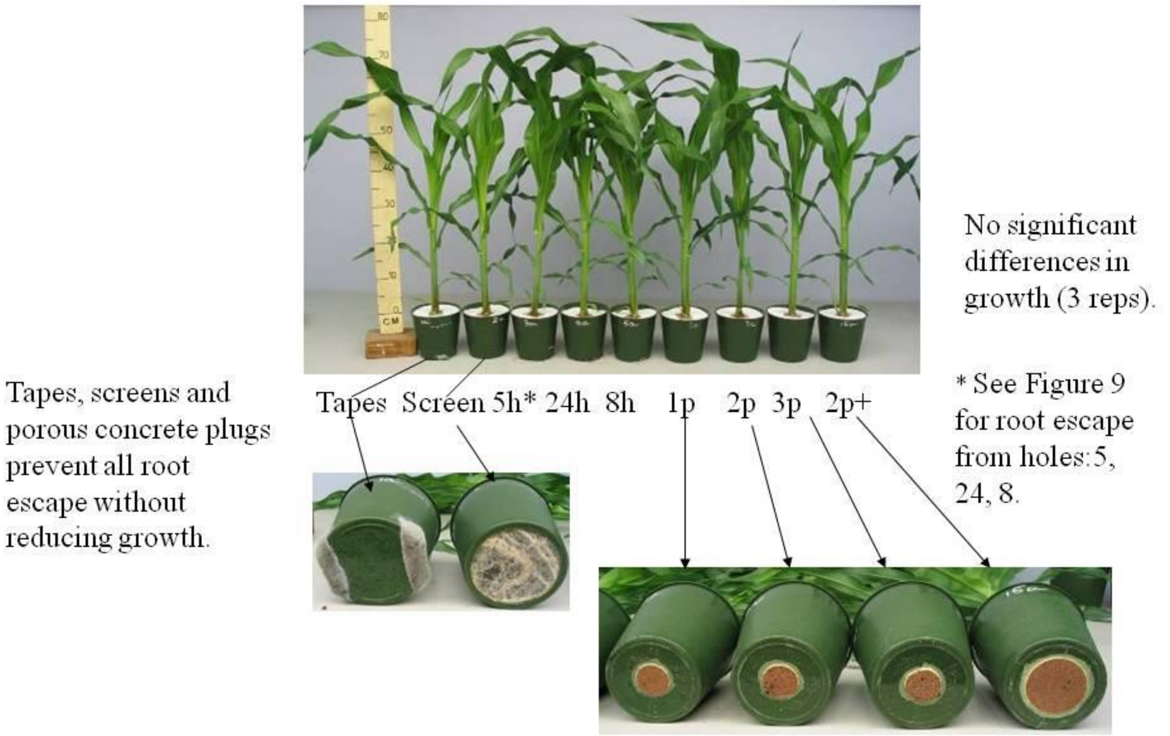


Figure 8. Effects of tapes, screens and various sizes of porous plugs (p) on growth and root escape of maize (*Zea mays*, cv.Pac 424) after 34 days.

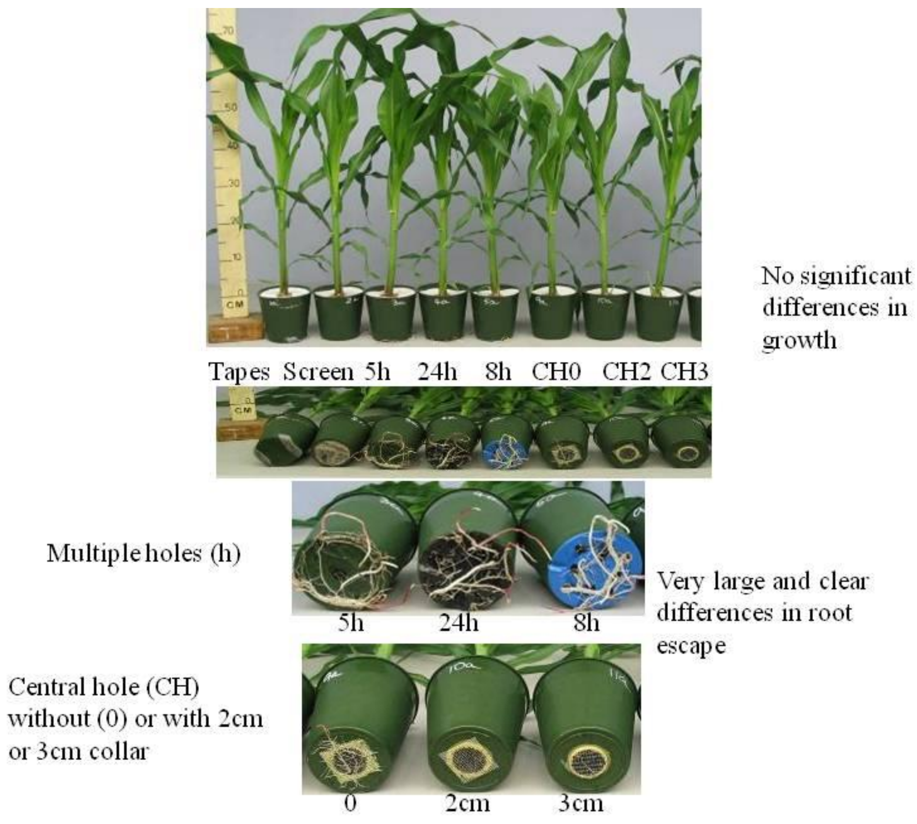


Figure 9. Effects of tapes, screens and various hole arrangements on growth and root escape of maize (*Zea mays*, cv. Pac 424) after 34 days.

Commercialisation: selecting the ANOVApot®

It was clear that root escape could be greatly reduced and even prevented altogether in a number of physical ways. Converting any of these into a commercial product, able to compete cost-effectively with existing plastic pots, required an assessment of the likely manufacturing costs. The decision to select a pot with a single basal, centrally located, mesh covered, collared hole (Figure 7) was based on the feasibility of its manufacture as a one-pass, injection-moulded pot at a competitive price. The ease and likely cost of its manufacture outweighed its slightly lower ability to prevent root escape compared with the other alternatives. Pot price is an up-front cost in nursery production and often appears as the single most important arbiter in the choice of pots of similar volume.

Root retention in sunflower and marigolds with the ANOVApot®

Figure 10 with sunflowers (*Helianthus annuus*) and Figure 11 with marigolds (*Tagetes sp.*) show the effectiveness of the ANOVApot® in reducing root escape under commercial irrigation conditions. A compacted plug of copper treated coir in the central well was effective in reducing even further the small number of roots that escaped the ANOVApot®. Compacted but porous concrete is also effective, supporting results found with maize (Table 1 and Figure 8). The use of the cap, while effective, is restricted to overhead irrigation.

Unreplicated measurements are provided in Figure 11 for the time taken to prepare pots for retail sale (particularly root removal), indicating the potential saving of some 4 seconds and 16 seconds in the ANOVApot® compared with bottom-holed pots (Europots) and the side-holed pots (Slimline), respectively. At commercial labour rates of $40/hr, a 4 second difference is equivalent to 4.4 cents, a cost saving that more than covers the extra cost of ANOVApot®s compared to conventional pots of the same size.

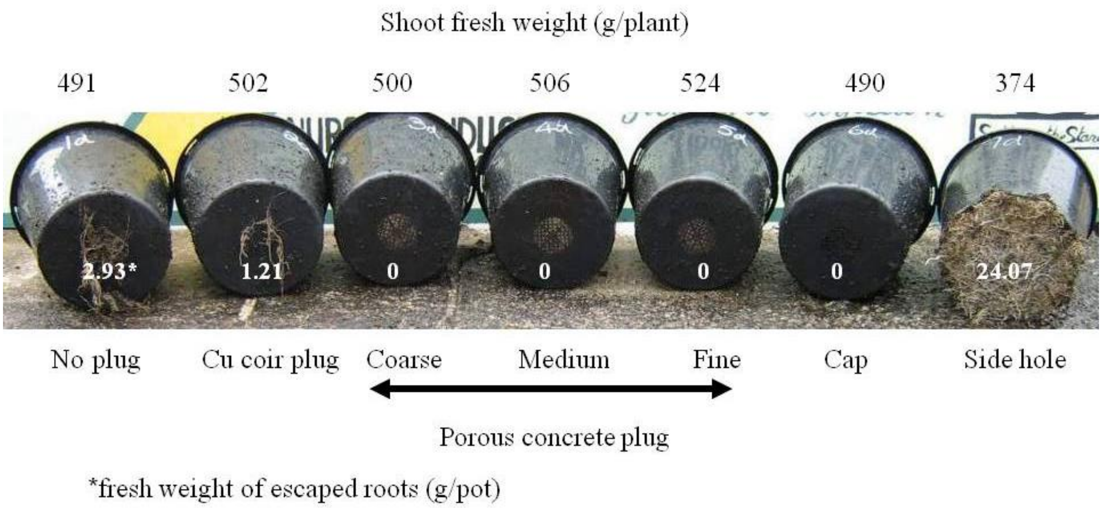


Figure 10. Root escape* of overhead irrigated sunflower (*Helianthus annuus*, cv. Hysun 38). After 87 days, comparison between a side-holed pot and capped, unplugged, or plugged 200mm Anovapot®s (3 grades of porous concrete plugs and copper impregnated coir plugs).

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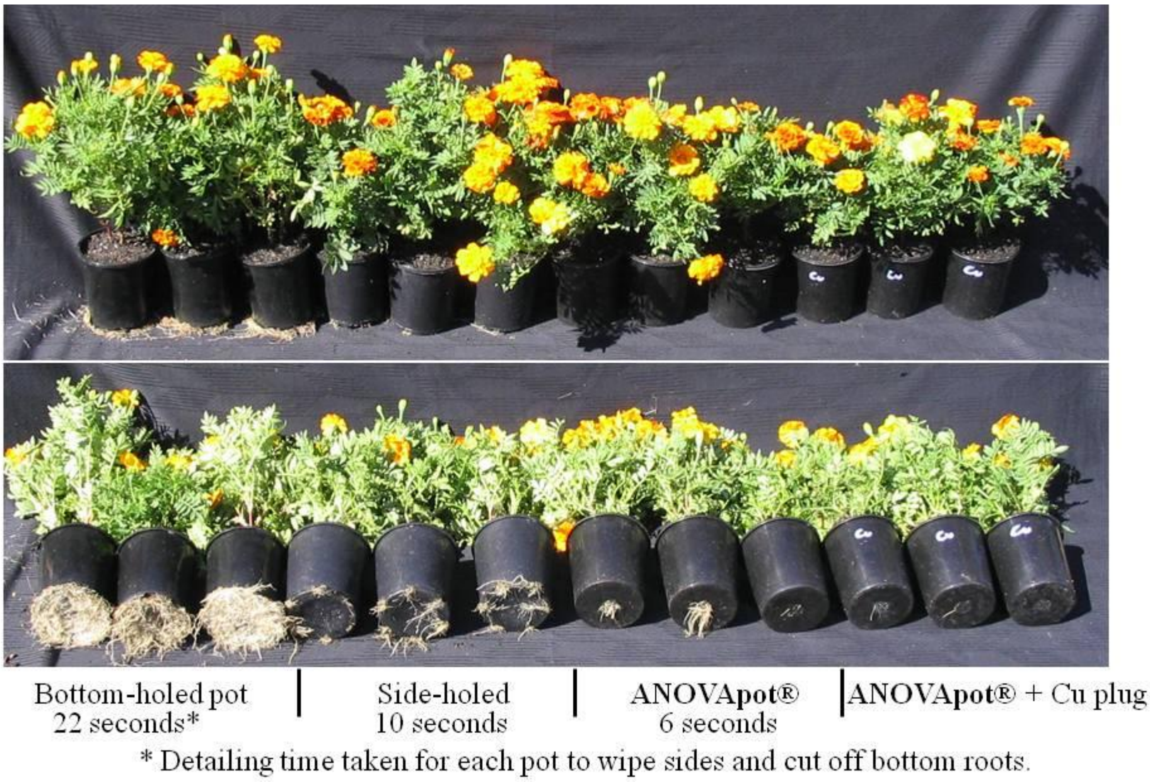


Figure 11. Effect of pot type (and Cu coir plug) on escaped roots in Marigold (*Tagetes* sp.). Comparison made 47 days after placement of pots on capillary mat.

Drainage in the ANOVApot®

While the collared system was selected for capillary mat irrigation we had considerable concerns about its drainage if used without protection from rain. We assumed that the collar would trap overhead water to the level of the collar and ultimately lead to severe basal water-logging and subsequent disaster for any water-logging sensitive species. However, a simple examination of a cut-away pot with medium in place showed that the free water actually drained, but more slowly than in a common pot. Drainage not only occurred to the bottom of the pot but actually continued further if the grid was in contact with a capillary mat below the base of the pot (see drainage video on www.anovapot.com). Others speculate that drainage is superior to that in side-holed pots in which perched water tables are common (Handreck and Black, 2004).

Short term drainage experiment: 36 hours

To confirm these observations a replicated experiment was set up to measure drainage rate. Drainage was compared in two commercial pots, the Slimline (a 4.5L side-holed pot) and the Europot (bottom-holed 4L pot), and a 4L ANOVApot® with an 18mm tall central collar. These three pots were allowed to drain freely, while a second ANOVApot® rested on a hydrophilic capillary tape lying on a plastic cap on top of the 18mm collar of another ANOVApot® (the Twinpot configuration; see p. 12 and Figure 14). The end of the tape lay on the bottom of the lower ANOVApot® a distance of 18mm from the base of the upper pot. Drainage from this pot accumulated in the pot below. These four pots were filled with the same volume of close-to-saturated bark/coir potting mix (about 1600g) which was then consolidated by dropping each pot four times from a height of 10cm. Three hundred mL of water was then poured rapidly onto the surface of the mix in each pot and the increasing weight of drainage water measured over the next 36 minutes. Results appear in Figure 12.

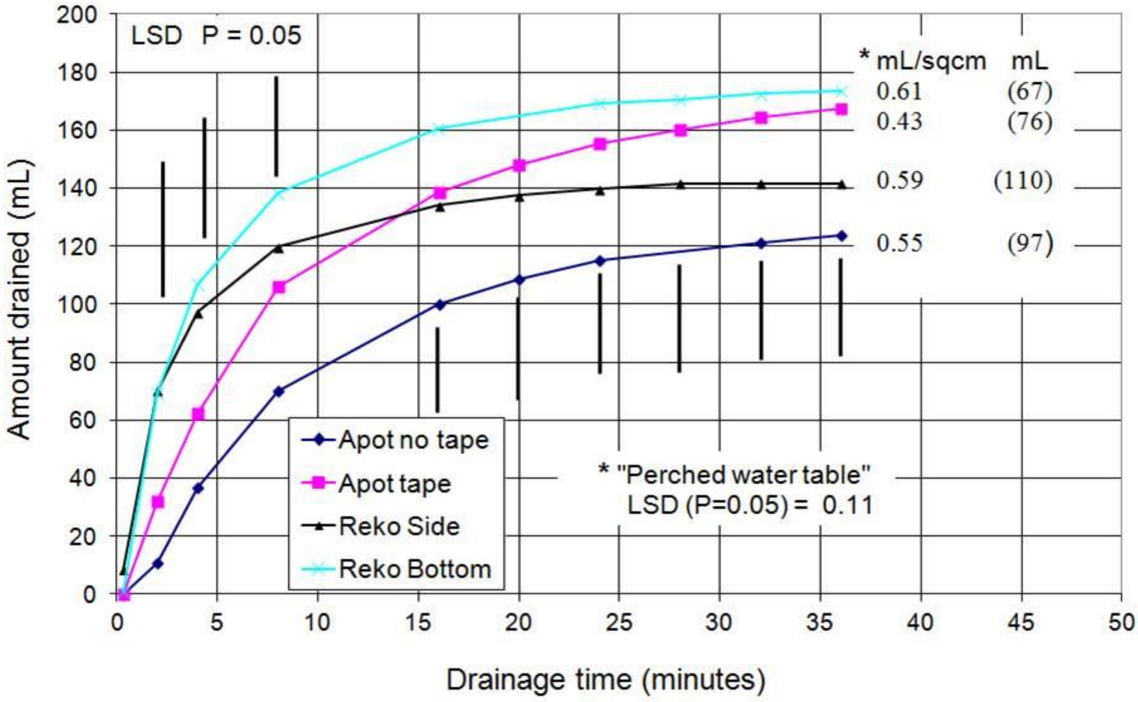


Figure 12. Comparison of drainage patterns in two commercial pots (Reko Side = Slimline, Reko Bottom = Europot); and two ANOVApot®s, without capillary tape and with tape, in the Twinpot configuration (3 replicates).

While there was no significant difference in volumes drained between the Slimline and the non-taped ANOVApot® after 36 minutes, earlier drainage rates were slower in the latter. The Europot drained initially much more rapidly than all the other pots but yielded no more in total volume than found in the taped ANOVApot®. In fact, drainage from the taped ANOVApot® although slow to start with matched the Europot drainage rates within 4-8 minutes. Its rate after 36 minutes was still maintained compared with the plateau expressed in the Europot plot. As the ANOVApot®s were made of transparent plastic it was possible to observe the macro-pores becoming evident at the base of the pots towards the end of their drainage period. Interestingly, the so called ñperched water tableò was less evident in the two ANOVApot®s than the two industry pots. (The ñperched water tableò (PWT) is defined here as the additional water that drains through a 6mm hole drilled in the basal rim of all pots (unnecessary in the Slimline), when the pot is shifted from a vertical to a 45^0 position).

It is likely that the drainage of water below the collar in the ANOVApot® was facilitated by the adhesion and cohesion forces residing in the potting mix, which are responsible for capillary flow. The slowness of early drainage in the ANOVApot® suggested that the potting mix may in fact retain more water after each irrigation event than occurs with the industry standard pots. This was tested.

Longer term drainage experiment: 40 days

The drainage characteristics of an 8mm collared 4L ANOVApot® and a 40mm collared 4L ANOVApot® were compared with that of a side-holed Slimline pot (as above) over 40 days. Maize was the test plant, grown in two potting mixes (boiled bark, peat/sand mix), with drainage water recycled or flowing to waste. Again pots were free draining. Comparisons of drainage between the Slimline (an Australian industry standard pot) and ANOVApot®s with the two collar heights appear in Table 2 and Figure 13.

Increasing collar height significantly ($P<0.05$) delayed drainage but not the total volume on day 39. However, over the 40 day period, 14% more drainage actually occurred in the ANOVApot®s than in the Slimline pot. Although shoot weights and total evapo-transpiration were not significantly different, their trends converted into a small, but significant, increase in water use efficiency in the 40mm collared ANOVApot®.

Following harvest at 40 days, all root-balls were dried to constant weight and then irrigated by hand from above. After an hour, the Slimline had retained only 22% of the water added, while the 8mm and the 40mm ANOVApot®s had retained 52% and 70%, respectively. Much of this difference was probably related to the position of the drainage holes in the Slimline pot, which were immediately accessed by water as it flowed off the surface of the root ball and down the side of the pot. This illustrates the efficacy of the ANOVApot® in reinstating pot water status where root-balls have been inadvertently allowed to dry out, thereby decreasing the wetting ability of the medium.

Thus, under hand-watering regimes when insufficient water is added to completely rehydrate the root-ball, more water is likely to be retained in ANOVApot®s. When adequate amounts are added this benefit may only be marginal.

Table 2. Comparison between the Slimline pot and two collar heights of 4L (200 mm) ANOVApot®s on drainage, water use and growth of maize (*Zea mays*, cv. Pac464) after 40 days in a glasshouse[1].

Collar height (mm)	Drainage on day 39 after adding 1.4L water		All water drained over 40 days (mL)	All evapo-transpir-ation over 40 days (mL)	Water retention after one hour[2] (%)	Shoot dry weight (g/plant)	Water Use Efficiency[3] (mg/mL)
	After one minute (mL)	Total when ceased draining (mL)					
0[4]	96 a	141	1980 a	9917	22 a	40.40	4.07 a
8	23b	173	2147ab	9788	52 b	39.95	4.08 a
40[5]	3 b	166	2260 b	9683	70 c	40.44	4.18 b
P	<0.0001	NS	<0.05	NS	<0.0001	NS	<0.05
LSD (P= 0.05)	16		223		11		0.09

[1]Results are means from a three factor experiment (3 collar heights, 2 potting mixes, 2 effluent recycling) replicated three times (n=36); column values that share common letters are not significantly different ($P<0.05$); [2]Retained proportion (%) of the amount of water added to the harvested dried root-ball; [3]Calculated on a shoot dry weight basis; [4]4.5 L Slimline pot with 8 basal side holes; [5]40mm section of 50mm diameter conduit glued onto existing collar of the 4L ANOVApot®.

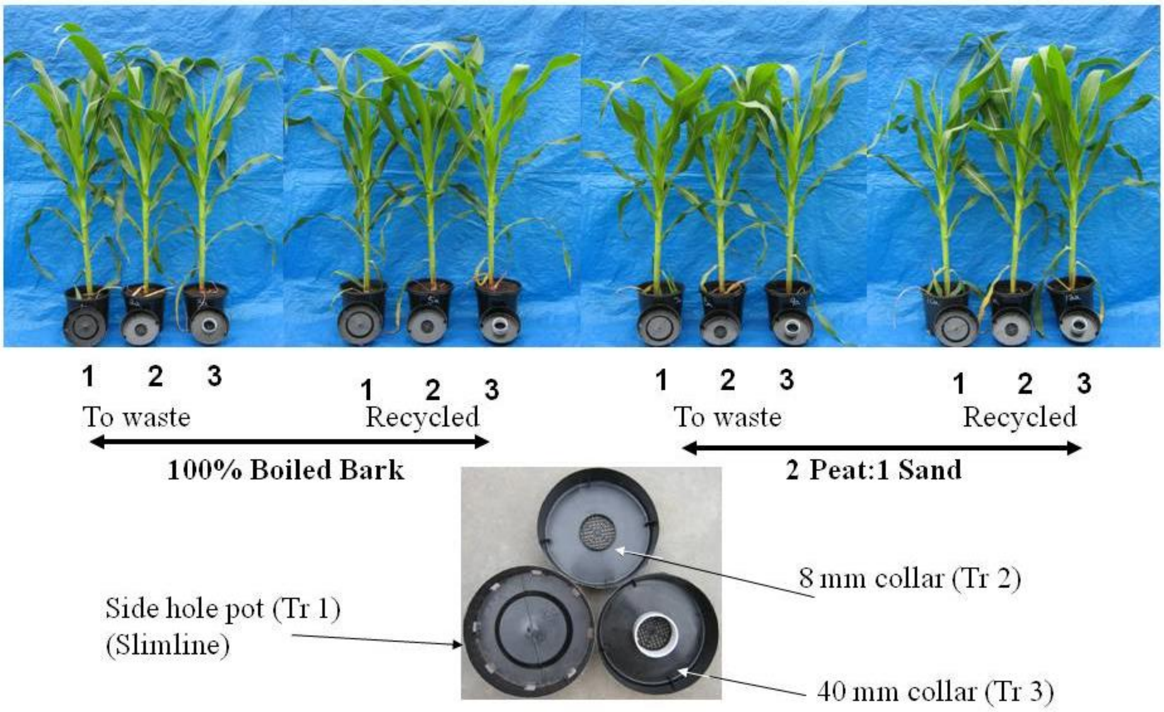


Figure 13. Effect of three basal pot configurations (1=side hole, 2=8 mm collar, 3=40 mm collar) on growth of maize (*Zea mays*, cv. Pac424) in two potting mixes, on day 36, with effluent drained to waste or recycled. Cut back sections of each pot reveal differences in basal drainage configuration.

These results are generally in line with those from the short term experiment above, which indicated little difference in final drainage volumes. There was also little difference here in plant growth despite substantial differences in pot configuration. It may be concluded that the slower drainage of the ANOVApot® is not an indication of inadequate drainage but may enhance greater root-ball water retention to the benefit of the plantôs on-going water status.

Twinpot Water Management System (TWMS)

The Twinpot

As the name implies, this system is based on two ANOVApot®s configured as a single unit, with one ANOVApot® nesting in another identical ANOVApot® (Figure 14; Hunter et al., 2010). The upper pot supports the plant in a suitable medium while the lower one collects and recycles drainage water from the top pot through a capillary tape that connects the two. An impervious loose fitting plastic cap resting on the internal collar of the lower pot supports the tape and upper pot, while diverting drainage water from the upper pot into the space around the collar. Once the free water storage capacity of the lower pot (1.5L in the 320mm ANOVApot®) is exceeded, excess water overflows the central collar in the lower pot and runs to waste. Drippers connected to irrigation lines may be placed in each pot and set to regularly deliver nominated amounts of water based on measured water levels in a number of representative pots. Under- or over-watering can be minimised by adjusting the duration of irrigation times based on dip-stick monitored water levels in the lower pot. However, inadvertent over-watering will not cause water-logging since the water table cannot rise above the base of the top pot. Examples of commercial use of the Twinpot are illustrated in Figures 15 and 16.

Note: when in position, the top pot is supported by the capillary cap of the lower pot.

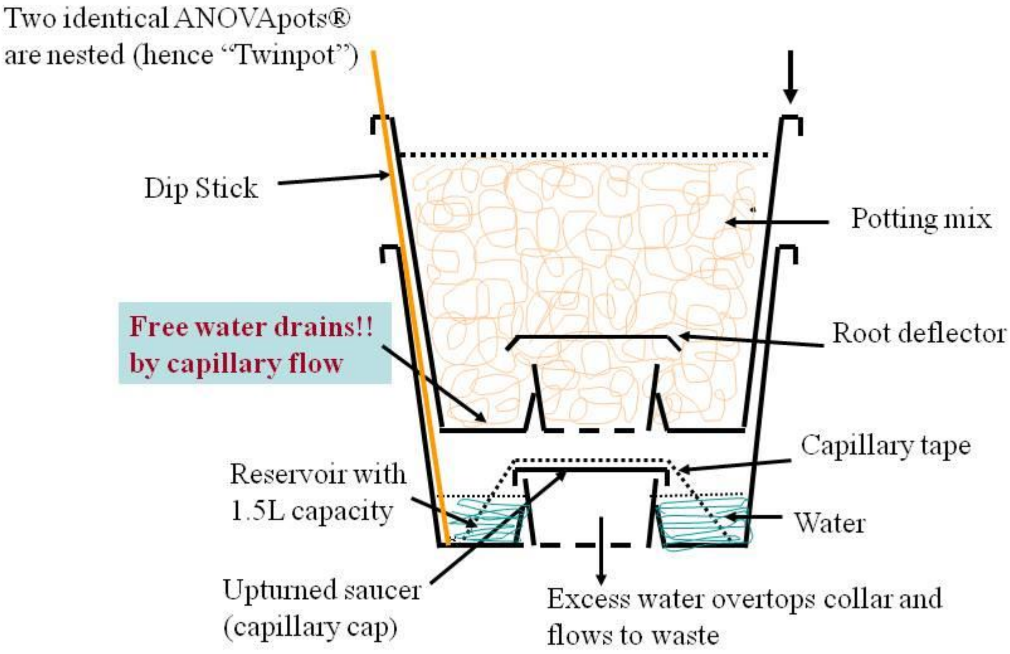


Figure 14. The Twinpot Water Management System (TWMS) using the 18L (320mm) ANOVApot®.

Figure 15. The Twinpot Water Management System (TWMS) with *Murraya sp.* and Dr Wal Scattini at Cedar Glen Nursery. Note clips connecting lower pots to increase stability and maintain the vertical separation of the nested 320mm ANOVApot®s.

The Production Manager, Dr Satnam Singh, inspects *Eucalyptus sp.* and deciduous purple leafed maple (*Acer sp.*).

Compared with the standard system, frequency of irrigation was halved and fewer weeds developed. The quality of plants was excellent.

Figure 16. Twinpot Water Management System under commercial evaluation at Hazelbrook Nursery in the ACT in winter (June 2014).

Water retention study at 3 commercial nurseries

This series of experiment was initiated to show how an extension in collar length in the ANOVApot® impacted on water retention under commercial conditions with a number of species. We were also interested to find out how the use of a pot-in-pot (PIP) configuration of two nested 200mm ANOVApot®s (Twinpot), similar to that described above for the much larger 320mm pots, could increase water retention even further. The bracketed PIP system is a recognized nursery system used to reduce plant ‘blow over’ (Mathers, 2000) but with its two freely draining side-holed pots differing considerably from the Twinpot option indicated here, in terms of water and root control. The PIP system is used in the US where the lower of the two pots is set into the ground for plant stability, but importantly also to minimise the adverse occurrence of root-ball freezing.

Experiments were set up at three commercial nurseries in South-east Queensland using 4.5L side-holed (Slimline) and 4.0L bottom-holed (Europot) pots, two 4.0L (200mm) ANOVApot®s with an 8mm and an 18mm collar, respectively, and two 200mm pot-in-pot (or Twinpot) configurations. Twinpots were set up as described earlier. The lower pot in one of the Twinpots had an18mm collar while in the second, the lower pot had a 40mm collar (a 40mm length of 50mm diameter conduit glued over an existing 8mm collared ANOVApot® (Figure 17; Hunter and Scattini, 2008). With the exception of the conduit attachment, all pots were commercially available and all had a volume of 4L except for the 4.5L Slimline.

Nine plant species were grown in these 6 pot treatments (replicated three times at each nursery) for 2-3 months to point-of-sale. Just before their final irrigation and despatch to retail nurseries, pots were weighed and 1.5L of water poured onto the surface of each pot. Pots were re-weighed after about 1.5 hours.

Partial section of conduit reveals central collar and grid of the ANOVApot®.

Entire conduit section glued in place over the central collar. Dotted line indicates the position of the capillary tape that, when in place (resting on an impervious plastic cover) will transmit drainage water from this pot to an upper one sitting in it (refer to the TWMS configuration).

Figure 17. Attachment of conduit to the central collar of the cut-away 200mm ANOVApot®.

Not unexpectedly, the Twinpot configuration, with its bottom reservoir, retained between 2 and 2.6 times more water than was retained by a single Europot (many holes in base), with most retention occurring in the 40mm conduit version (Table 3). Overall, the two single ANOVApot® versions also retained more water (36-39%) than retained by the Europot. These two versions (4L) even retained slightly more water than the Slimline (not statistically different with some species) despite the latterǿs larger volume of 4.5L and hence higher water holding capacity. The lower water retention of the Europot reflects its superior ability to drain rapidly, as was found in the short-term drainage experiment reported above (p. 9). The small difference in water retention between the ANOVApot®s and the Slimline also reflects what was observed in the 40-day experiment (Table 2).

These positive results for water retention provided the basis of an application for the ANOVApot® to receive the nationally accredited Smart Approved WaterMark, granted to inventions throughout Australia for water saving innovations. The application was approved. Twelve months later, the ANOVApot® was awarded the honour of Water Saving Product of the Year, in a field that included all approved water-saving devices granted accreditation in 2010.

Smart Approved WaterMark

Table 3. Relative variation (%) in water retention among 6 pot types (4-4.5L) or their configurations, after adding 1.5L water to each pot and draining for 1.5hr.

POT[1]	SPECIES[2, 3]									MEAN (%)
	A	B	C	D	E	F	G	H	I	
1[4]	100 *448*	100 *491*	100 *551*	100 *474*	100 *346*	100 *388*	100 *374*	100 *308*	100 *394*	100 *419*
2	119	144	112	127	117	130	117	112	123	123
3	123	138	114	162	131	113	134	156	156	136
4	132	138	115	154	147	111	131	193	149	139
5	192	174	181	214	239	139	187	343	216	204
6	206	235	229	263	370	200	196	431	311	263

[1]**Pots:** 1=4L **Europot**, 2=4.5L **Slimline**, 3=8mm collar 4L **ANOVApot®**, 4=18mm collar 4L **A/pot®**, 5=18mm/18mm collar 4L **A/pot® (Twinpot)**, 6=18mm/40mm collar 4L **A/pot® (Twinpot)**; in 6 the greater of the two collar heights is in the lower pot. [2]**Species:** A=Bamboo Palm, B= Kentia, C= Golden cane, D= Parlour Palm, E=Grevillea, F=Syzygium, G= Lomandra, H=Red Fountain Grass, I=Tiger Grass. [3]**Red column values are significantly ($P<0.05$) greater than measured in the Europot (1).** [4]The actual amount (mL) retained by the Europot (1) appears in italics immediately below the 100% value.

Root control in the Twinpot

An evaluation in Oregon, USA

The effectiveness of the ANOVApot® design in reducing root escape was again demonstrated in a field experiment in Oregon, USA, where the 18L (320mm) Twinpot configuration was compared with the Pot-in-Pot (PIP) system in the control of root escape (Klick et al., 2011). In PIP, one pot sits in another sunk into the ground, with the lower one thus providing stability from wind and some protection from root-ball freezing (Mathers, 2000). Both PIP pots have basal side holes.

Root escape from the top pot increases the time and effort required for later removal of the upper pot; a few roots may also escape the lower pot, effectively anchoring the pot to the underlying pad. This severely disrupts harvesting operations, with the plant often becoming so reliant on the escaped roots for water and nutrients that their removal renders the plant unsaleable.

Not only did the ANOVApot® in the TWMS configuration significantly reduce root escape in three tree species (Table 4; Figure 18), the combination of the two ANOVApot®s pots also ensured that no roots were able to escape at all from the bottom pot.

Table 4. Effectiveness of three types of pots, one fabric lined, in preventing root escape from the top pot (in pot-in-pot configuration) in three tree species after 10months. [1, 2]

Tree species	Pot type	Rating of escaped roots Nil=0, 5=many[6]	Length of longest escaped root (cm)	Dry weight of escaped roots (g/pot)
Salix integra	Side hole (SH) PIP[4]	5	56a	19a
	Twinpot[5] (ANOVApot®)	**3.3**	**57a**	**2c**
	Fabric lined (SH) PIP	1	31b	1c
Arborvitae	Side hole (SH) PIP	4.9a	56a	24a
	Twinpot (ANOVApot®)	**2.0b**	**24b**	**0.2b**
	Fabric lined (SH) PIP	1.8b	29b	0.4b
Chamaecyparis obtusa[3]	Side hole (SH) PIP	4.3a	43a	5a
	Twinpot (ANOVApot®)	**1.1c**	**14c**	**0.1b**
	Fabric lined (SH) PIP	1.9bc	23bc	0.7b

[1]Experiment conducted at Woodburn Nursery and Azaleas Inc., Woodburn, Oregon, USA, 2011. [2]Adapted from Klick et al., 2011. [3]Grafted onto *Thuja occidentalis* root stock. [4] Pot-in-Pot configuration. [5]Two 18L (320mm) **ANOVApots®** in TWMS configuration. [6]Each value is a mean of 3 replicates; values sharing a common letter in a column within a species are not significantly different (Fishers LSD separation procedure, $\alpha = 0.05$).

In Side Holed Pot-in-Pot (PIP) roots escape both top and bottom pot and anchor pot to the ground.

Root escape in PIP (left) compared with almost complete absence in **ANOVApot®** TWMS (no difference in shoot growth).

Figure 18. Comparison of the effectiveness of *Salix integra* root control in TWMS (ANOVApot®, right) with that in Side Holed Pot-in-Pot (Oregon experiment).

Automated water control

Two ways of automating water control in the Twinpot have been developed. The first is based on sensor strips that respond to both water level and salt concentration of the solution in the lower pot (Figure19; Hunter et al., 2009). The electronic signals generated are transmitted via radio to activate a solenoid switch that controls water flow into the pot. The system can be set up to actuate at any selected depth in the reservoir and even after the reservoir has been dry for some time. The time elapsed between irrigations also automatically controls how much water is added, the longer the interval the greater the amount.

All cycles can be recorded. It is envisaged that the sensor system would be installed in a single pot in a defined area of similarly treated pots in a commercial nursery (e.g., in 1% of pots), and used to control the automatic irrigation of the rest of the block. TWMS, with the prototype water level controller, significantly increased growth in *Syzygium australis* by 45%, 91 days after transplanting (Figure 20). With overhead drip irrigation and an automated TWMS it should be possible to greatly reduce all irrigation waste and nutrient loss resulting from leaching.

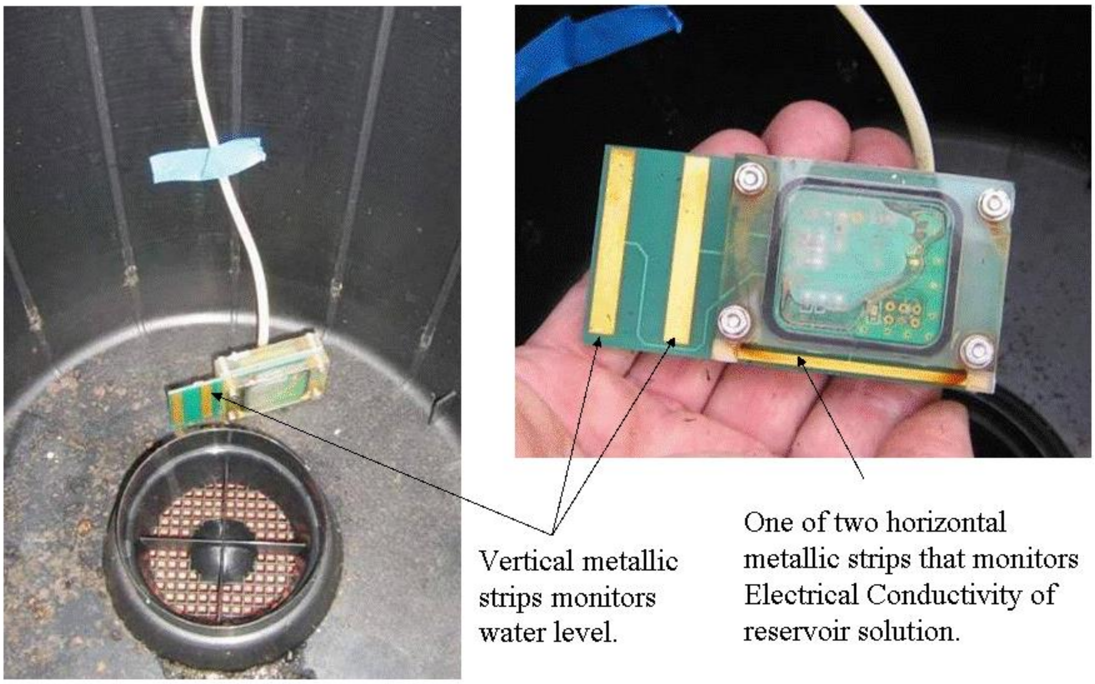


Figure 19. Water Level and Electrical Conductivity Sensor (prototype) in the reservoir of the lower pot in the Twinpot Water Management System.

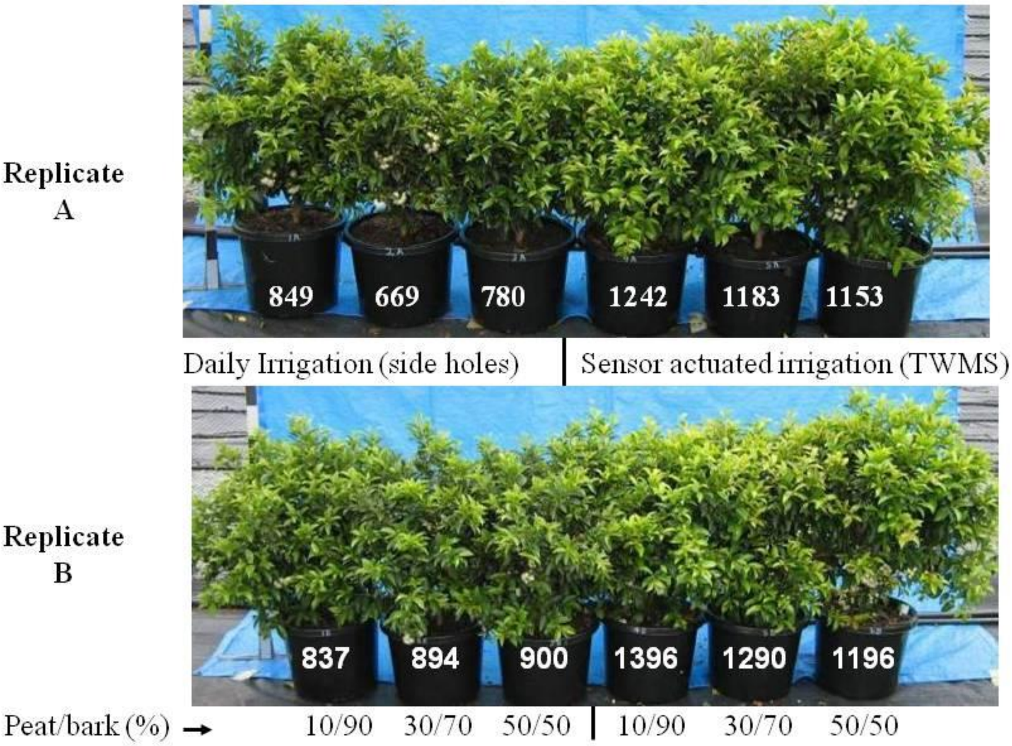


Figure 20. Effect of irrigation system and peat/ bark composition of potting mix on growth of *Syzygium australis*, cv. Aussie Boomer, 91 days after transplanting . Fresh shoot weights (g/plant) are shown on each pot.

The second automated system includes a simple float valve that rests on the floor of the lower pot. The valve (Figure 21) is connected through a medical infusion set to a low pressure irrigation line (or a reservoir, one or two metres above the pot) and maintains a constant water table in each (lower) pot. The infusion set includes a length of polyethylene tubing (OD 4mm), a tap to control water flow, and a sight glass in which solution flow as drops can be observed. A 200µm filter prevents particles blocking the outlet tip of the valve. Retaining the filter but replacing the transparent tubing with black tubing is recommended to prevent algal development for longer term use. Protecting the reservoir from light is also recommended.

A water level sensor placed in the reservoir itself (rather than the pot) could be set to activate an irrigation solenoid to refill the reservoir with a predetermined amount of water once that amount had been consumed. As well, the same amount of water could be added to an adjacent cohort of plants of the same species and size (e.g., 99) that the sensor-controlled plant represents. Examples of the growth of various TWMS-managed plants are presented in Figure 22 and Appendix 1, App. Figures 1-10.

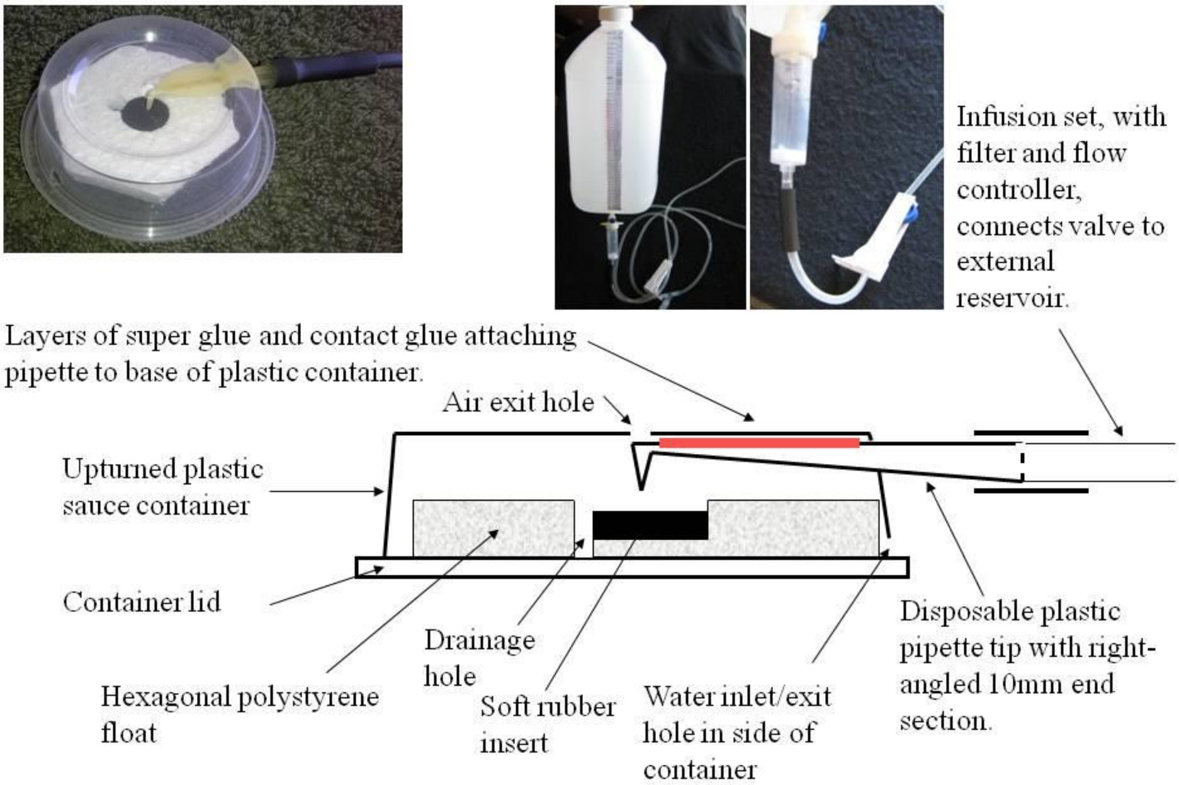
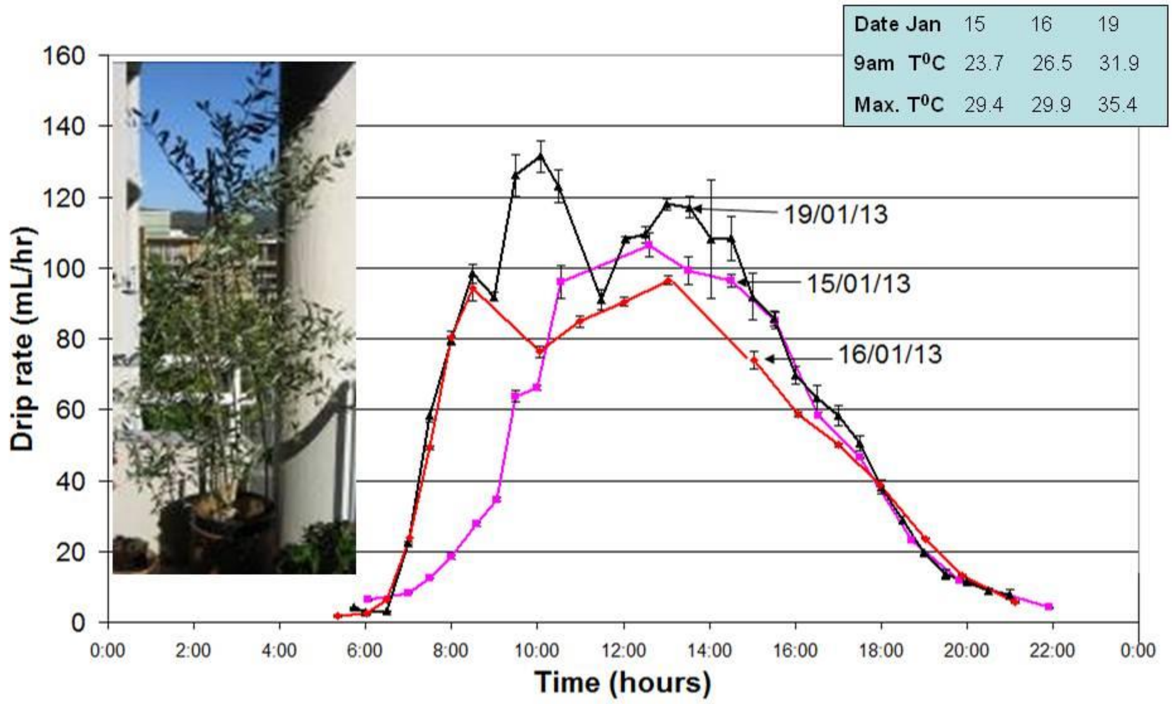


Figure 21. Small float valve (77mm x 25mm) suitable for 320mm Twinpot and Pot-in-Bucket systems for the five sizes of ANOVApot®s.

Figure 22. Growth of coffee (*Coffea arabica*) in the Twinpot Water Management System.

Drip rates (mL/hr) have been monitored to reveal diurnal water loss in olive (Figure 23) and show how this varies during the day and from day to day. Such information could be used to investigate species and varietal responses in water loss to changing light conditions, temperature and humidity as well as aspects of plant nutrition and salinity. This knowledge could be useful in breeding more water efficient genotypes.

Current water flow measuring equipment (Burgess et al., 2000) that measures the rate that heat pulses travel along vascular bundles is very expensive and cannot be used with thin stemmed species. These automated systems irrigate plants in direct response to plant water use rather than on the basis of potting mix moisture status, or pot plant weight (Lieth and Oki, 2008). Both these latter systems cannot match the TWMS in cost effectiveness, sensitivity or relative simplicity of water management.



Balcony grown plant received direct sun, 6.00-8.30 am, otherwise partial to complete shade. Each value is the mean of three observations of drip rate supplying a constant water table in the lower 18L (320mm) pot of the TWMS configuration. Vertical bars show standard deviation. Weather details are from Brisbane (station 040913, Lat. 27.48, Long. 153.08).

Figure 23. Daily water uptake by olive (*Olea europea*) on three days, January 2013.

Financial Benefits of TWMS for Commercial Nurseries (Robinson and Wilson, 2012)

The profitability of the TWMS based on the 320mm ANOVApot® (18L) was compared with a single un-bracketed stand-alone 320mm Slimline pot (17L) (US) and the Pot-in-Pot above-ground, bracketed 320mm Slimline pot (17L) (PIP). An interactive template was developed that could be customized according to an individual nursery's operational variables. We have assumed that the automated irrigation is commercially available but note that it is currently only in prototype form.

In developing this example, we accepted, on the basis of growth responses reported earlier, that the TWMS generated positive responses in growth rate compared with the other two systems, with less water loss and hence less fertilizer leaching losses. Trials conducted with the new system have shown that this growth increase can be expected to average 30%, effectively reducing stock turnover from 6 months to 4.6 months. The TWMS system will therefore produce 2.6 ñcropsò to saleable size per year compared with two crops for the other two systems.

An Excel Template (ANOVAProfit) was developed to estimate the profitability of installing a TWMS in a wholesale nursery that is currently using either a US system of stand-alone pots or a pot-in-pot (PIP) system (Appendix 3). The template assesses the changed profitability of wholesale nurseries that are able to market their plants once they have achieved a targeted size. Faster growth therefore generated more rapid turnover and hence cash flow.

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 PIP 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.

Template description

Data are displayed on three sheets. The following key variables can be varied to suit the conditions existing in individual nurseries:

Summary sheet

1. Size of nursery (Total no. of pots)
2. Value of sales/plant ($)
3. Months for plants to reach saleable size (No.)
4. Throw-outs with each system (%)

The Summary sheet also shows the estimated changes in profitability in moving to a TWMS.

Materials & services sheet

1. Cost of transplants/plant ($)
2. Capital cost of control system & sensors ($)
3. Annual computer maintenance ($)
4. Annual water savings/pot (nursery size) from using TWMS pots (litres)
5. Water cost per 1000 litres ($)
6. Pumping costs per 1000 litres ($)
7. Cost of Slimline pot for US and PIP systems ($)
8. Cost of TWMS pot ($)
9. Cost of potting mix/litre ($)
10. Cost of fertiliser/kilogram ($)

Labour sheet

1. Labourer cost/hour ($)
2. Management cost/hour ($)
3. No. of blow-over events/year (applies to US pots only)
4. Percentage blown over each event (%)

Results

Table 5 shows the estimated increase in annual profits for a 10,000 pot nursery after changing to a TWMS from either an un-bracketed single pot system (US) or a two pot (PIP) system, both based on the 320mm Slimline pot. As shown, these figures are based on a reduction in the TWMS from 6 to 4.6 months in the number of months for plants to reach saleable size. It also predicts that with the adoption of TWMS the proportion of discarded plants falls from 8% to 5%.

Table 5. Estimated profitability of installing 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 PIP**
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
TWMS	**cf. US**	**cf. PIP**
Change in annual gross sales	$159,565	$159,565
Plus annual materials & services savings (Appendix 3)	$1,720	$1,720
Plus annual labour savings (Appendix 3)	$5,462	$3,031
Sub total	**$166,747**	**$164,317**
Less extra materials & services annually (Appendix 3)	$97,547	$90,347
Less extra labour annually (Appendix 3)	$20,821	$19,988
Change in annual profit (10,000 pots)	$48,379	$53,981
Change in profit/pot (Nursery size)	**$4.84**	**$5.40**

These estimates show that the annual profits of a 10,000 unit nursery should increase by around $50,000. The increased profit in TWMS in changing from an existing PIP is slightly higher than for the US because the cost of a single pot system (US) is less than that of a two pot (PIP) system.

Appendix 3 shows more specific details of the calculations behind these estimates.

Sensitivity analysis

The increased profits are very sensitive to changes in some of the key factors, particularly the increase in plant growth and the reduction in the percentage of discarded plants. Table 6 shows the estimated increase in annual profit per pot for a 10,000 pot nursery in changing from a PIP system to a TWMS under varying responses in plant growth (and hence time to market) and increasing the proportion of discarded plants.

Table 6. Estimated increase in annual profit per pot ($) under varying plant growth and discard scenarios in changing to a TWMS from a PIP 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

Under the most favourable scenario (4.6 months for plants to reach saleable size and a decrease in discards from 8% to 5%), the annual profit per pot is $5.40 (Table 6). If there were no improvements in either of these factors, the nursery would incur an annual loss of $3.11 per pot by installing a TWMS.

The break-even situation for the nursery would be where the plant growing time was reduced from 6 months to 5.5 months and the percentage of discards was reduced from 8% to 6%. That is, there would be no change in profits.

Key results

1. Installation of the TWMS has the potential to increase the profitability of commercial nurseries significantly. This could be of the order of $5 per pot.

2. Improvements in profitability are highly dependent on achieving improvements in technical efficiency. Faster growth should lead to earlier sales of plants and more rapid turn around in production capacity.

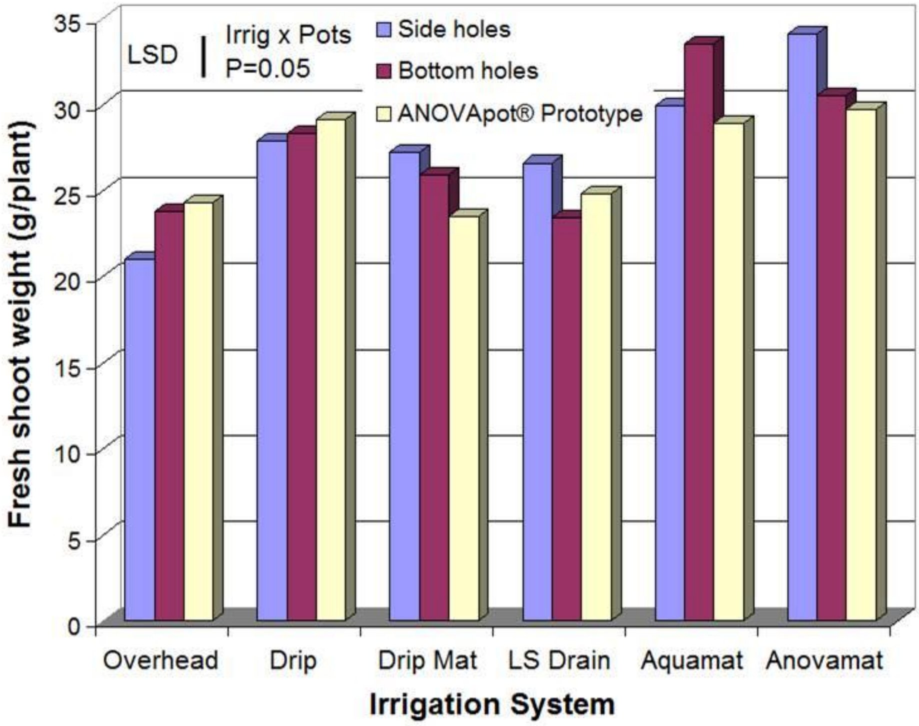
Because of the nature of the technology, nursery operators who are interested in installing TWMS should do it on a small trial basis to find out for themselves whether they are able to achieve the improvements necessary for it to be profitable in their situation.

Plant Growth

The Redlands experiment (90 days)

A very large experiment was conducted over 90 days at Redlands Research Station to examine the performance of three species, in four types of pots, under 6 irrigation systems, in two potting media, at two fertility levels, with two replicates of each (Hunter et al., 2005). The species included marigold (*Tagetes* sp.) fig (*Ficus* sp.) and duranta (*Duranta* sp.). Two of the pots were industry standards (Slimline with 8 side holes, Europot with 28 basal holes); one of the others was the prototype of the ANOVApot®; while the fourth had no regular holes but included a tape inserted through a slot in its base in contact with the underlying capillary mat. Two of the irrigation systems delivered water from above (overhead spray and drip), while three of the other four were variations of sub-irrigation from capillary mats (LS Drain®, Aquamat®, ANOVAmat) combined with overhead spray irrigation. In the sixth irrigation regime (Drip Mat) the capillary mat was flood irrigated daily and then allowed to drain to waste.

When averaged over all factors other than irrigation, faster growth was recorded in the ANOVApot® prototype than in the Europot or the Slimline under over-head irrigation (spray or drip) (Figure 24). However, growth appeared slower with sub-irrigation alone (Dripmat) or when irrigation included both overhead and sub-irrigation (LS DrainÊ , AquamatÊ or ANOVAmat). Sub-irrigation also led to substantial root escape (data not shown) particularly in the two commercial pots (Slimline, Europot) which may explain the faster growth in these pots than in the ANOVApot®. Because of their spread, escaped roots would have had greater access to water and nutrients external to the pot. It is likely that this short term advantage would have become a liability following removal of these roots for sale.



Side holes = Slimline pot, Bottom holes = Europot, n = 24.

Figure 24. Interactions between pot type and irrigation system on the mean growth of marigold (*Tagetes* sp.), duranta (*Duranta* sp.) and fig (*Ficus* sp.).

Other experiments

In the 40-day experiment reported previously (p. 10) pot type (Slimline side-holed, or two ANOVApot® configurations that varied in collar height, 8 and 40mm respectively) did not significantly affect growth of maize plants, irrigated from above, or from above and below, over a 40-day period in the glasshouse (Table 2). In the water retention study at three commercial nurseries (3 nurseries x 9 species x 6 pot types, p. 14), the significant differences between the 6 pot types in water retention following the once-off simulated hand-applied irrigation of 1.5L (Table 3) were not related to any apparent pot type advantages in growth during the commercial irrigation phase.

The positive results in growth with the ANOVApot® under overhead irrigation regimes also support the very large positive growth responses with automated water control in Twinpots, when compared with daily watering of single Slimline pots (Figure 20). However these positive results must be contrasted with the lack of differences observed in the performance of maize in ANOVApot®s and side-hole pots (Table 2). No apparent differences were also noted in the growth of nine species in the comparison of 6 pot types, including two ANOVApot®s, two Twinpot configurations and two standard industry pots (Water retention study, p. 14).

The claim of increased growth

It is suggested that the claims of faster growth in ANOVApot®s should be qualified in terms of the associated water supply. Thus the growth benefits of the ANOVApot® may not emerge under well managed commercial irrigation regimes that are designed to maximize growth and hence minimize time to point-of-sale. Excessive water use in these regimes may mask any advantage to be derived from an enhanced water store associated with the use of the ANOVApot®.

While anecdotal reports indicate the success of reduced irrigation frequency and hence a saving of water for plants in ANOVApot®s, further definitive studies are required. However, it is probable that current irrigation regimes designed for side-holed or bottom-holed pots could be modified to take advantage of the improved water relations generated in the ANOVApot®. Alternatively, it may be possible to achieve the same outcome with ANOVApot®s in terms of plant growth with less potting mix volume, but the same amount of water, without changing irrigation regimes.

Other irrigation systems incorporating the ANOVApot®

As already outlined, the ANOVApot® has many attributes that place it in a class of its own. However, its unique design also lends itself to considerable value-adding, again in the area of root control and water management.

Pot-in-Bucket (PIB)

The Pot-in-Bucket system is a variant of the TWMS, again with a float valve (Figure 21), but with the lower pot replaced by a bucket, in which the valve is located (Figure 25; Hunter et al., 2012). The bucket was originally used to increase greatly the lower water reservoir for manual water management: it has been retained even after the provision of a constant water supply (via a valve connected to an external reservoir), which has rendered the capacity of the bucket irrelevant. However, the extra volume is useful in studies on the effects that height of the water table below the base of the upper pot may have on plant performance.

The upper ANOVApot® rests on a capillary tape on a cap that covers the valve which maintains a constant water table in the bucket. The capillary tape which dips into the water on both sides of the cap transmits water from the water table in response to plant demand, up through the central basal hole of the ANOVApot® and into the potting mix. The valve is connected to a reservoir via an infusion set as described above.

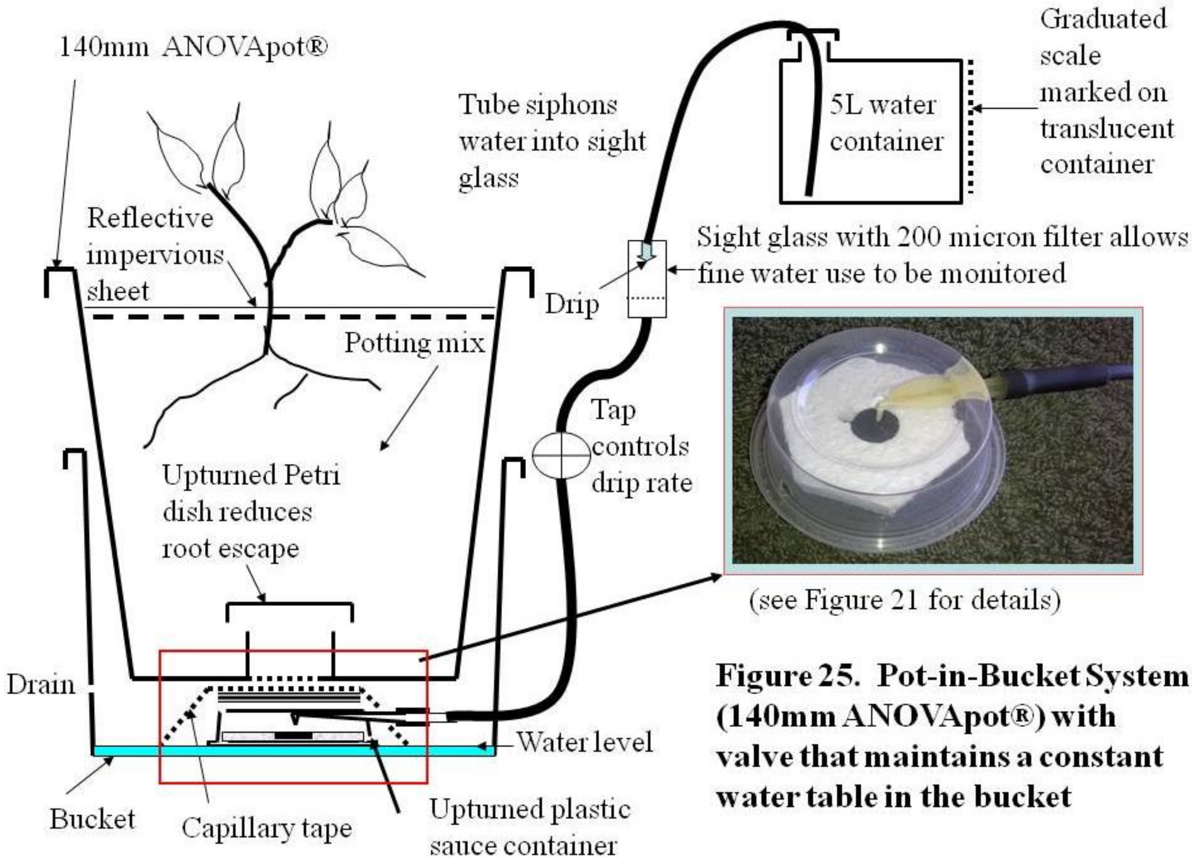


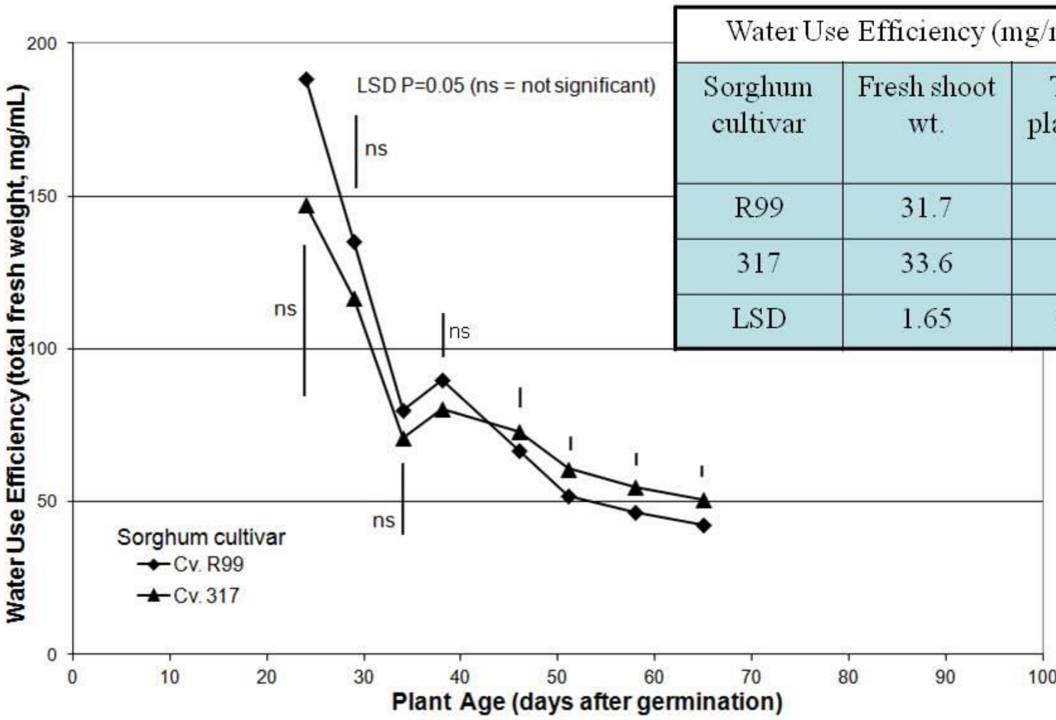
Figure 25. Pot-in-Bucket System (140mm ANOVApot®) with valve that maintains a constant water table in the bucket

Measurement of Water Use Efficiency
The provision of a constant water table means that without a plant the moisture tension in the medium above becomes constant. This should apply also with a plant present provided the rate of transpirational water loss does not exceed the replacement rate through the capillary tape and potting medium. The constancy of pot water tension is likely to apply particularly if measurements are taken at sunrise or thereabouts (plus 1-2 hrs) after a dark period when transpiration would be at a minimum, and before daily water losses escalate. Pot weight measurements support this contention (data not shown).

The measurement of transpirational water loss from the plant and the increases in plant biomass weight from differences in pot weights now allows the calculation of water use efficiency (WUE), being defined here as the amount of total fresh biomass accumulated over a specific period divided by the transpirational water loss over the same period (e.g., Figure 26). These periods may be as short as twenty-four hours.

WUEs based on total fresh wet and dry weights are highly significantly related ($P < 0.0001$; Hunter et al., unpublished). Not only can fresh-weight WUE be determined up until anthesis (before substantial drying of leaves and leaf loss), doing so non-destructively, with access to almost immediate results, allows the cross-breeding of unique plants in the current growing cycle, on the basis of their now known WUEs. The collection of WUE data is currently being automated.

The drip rate can be automatically monitored (Lerner and Tikva,1999) allowing the generation of water loss data, while increases in pot weights, and therefore total plant biomass, can be readily measured with load cells (Hammer, personal communication). Such automation will allow the direct examination of water loss responses and the calculation of non-invasive WUEs, with a frequency determined by the precision of the load cells.



Water Use Efficiency (mg/mL)		
Sorghum cultivar	Fresh shoot wt.	Total plant dry wt.
R99	31.7	8.1
317	33.6	9.1
LSD	1.65	0.45

Table shows a comparison of WUE based on harvested fresh and dry weights at 65 days.

Figure 26. Changes over time (65 days) in Water Use Efficiency (non-destructive, whole plant fresh weight basis) of two sorghum (*Sorghum bicolor*) cultivars under the PIB system.

Split Root System

The PIB concept with valve can be easily modified into a side-by-side two pot system, each with its independent water table in two lower buckets, but with the two top ANOVApot®s joined together (Figure 27).

A 4cm square section down from the top rim is removed in each pot and this gap in the pot wall of each pot aligned, with the aligned perimeters of each square being fastened with óslide-onô clips and then held in position with duct tape.

The side-by-side double pot is then filled with a medium to about 1cm of the rim and the seed (or prepared transplant) of the candidate plant species placed immediately above the join of the two pots. Following plant establishment and root development down both sides of the spilt, the medium can be removed from around the surface structural roots to the depth of the square (4cm) and replaced with material such as coarse sand, which is unable to transmit water from one side of the split to the other, but keeps the roots covered.

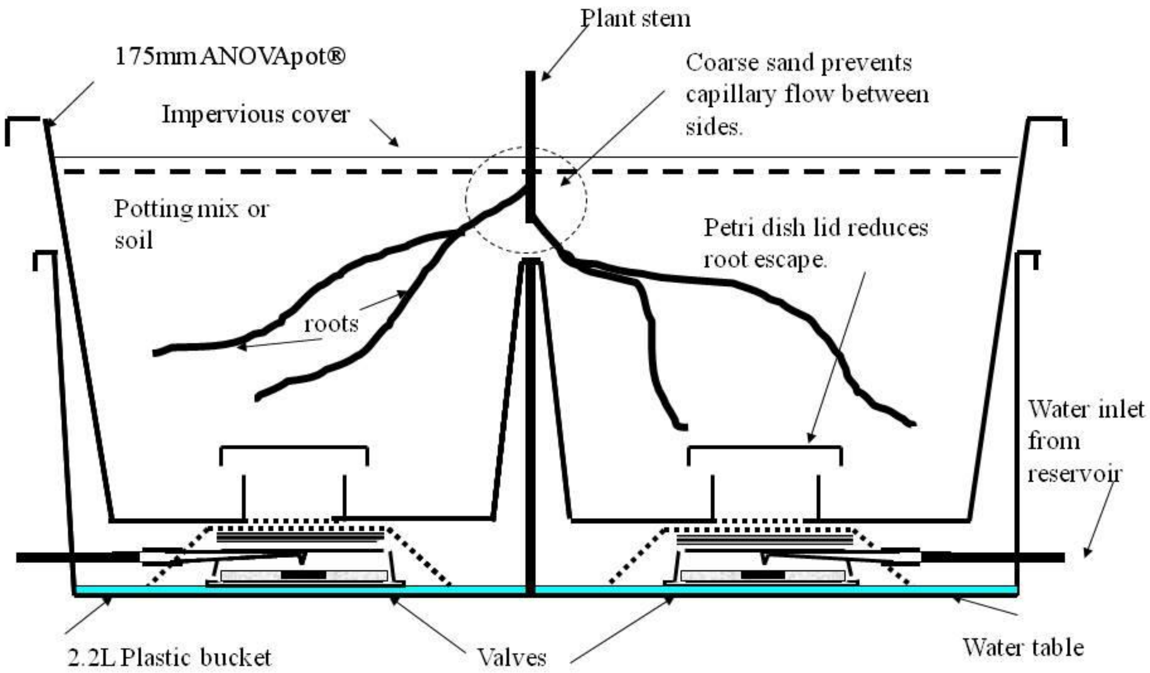


Figure 27. Split Root System. Schematic of two adjacent Pot-in-Bucket units fastened together in an arrangement that allows the development of a split rooted plant, with each side supplied with its own constant water table (see Figure 25 for PIB detail).

Different treatments may be applied to each side of the split; e.g., as different potting media, or different overhead treatments, or in solution via the valve within each bucket. Water would be automatically supplied from a calibrated reservoir, one for each pot through its own valve, in response to water loss from each root ball. This loss, and how quickly differences emerge, would provide insights into how one root ball is functioning in terms of water loss in relation to the other, which would be under a different environmental challenge. Such challenges could include different soil types, different biota, and different salinity/toxicity levels, as some examples.

Pot-in-Trough (PIT)

The PIT is a variant of the PIB (Figure 25), with a trough (680 x 305 x 250mm) substituting for the bucket (Figure 28). This size of trough can accommodate 3 x 200mm ANOVApot®s, all supported by the false floor that rests about 40mm above the base of the trough.

A constant water table is maintained in this lower space (Figure 28) with the valve (Figure 21) connected to a 15-25L reservoir as described earlier. A length of capillary tape (50mm x 750mm) is laid along the surface of the false floor and wrapped around the ends of the false floor, with each end dipping into the constant water table below. The pots, filled with potting mix with good capillary rise attributes, draw water up by capillarity via the capillary tape on which they rest. One valve can supply two additional troughs, each being connected to the first trough (with one valve) via capillary tape (e.g., Figure 29). Very high water demand in the adjoining troughs may exceed the capacity of one trough to supply additional troughs, although some respite to this demand occurs during the night when transpiration is at a minimum.

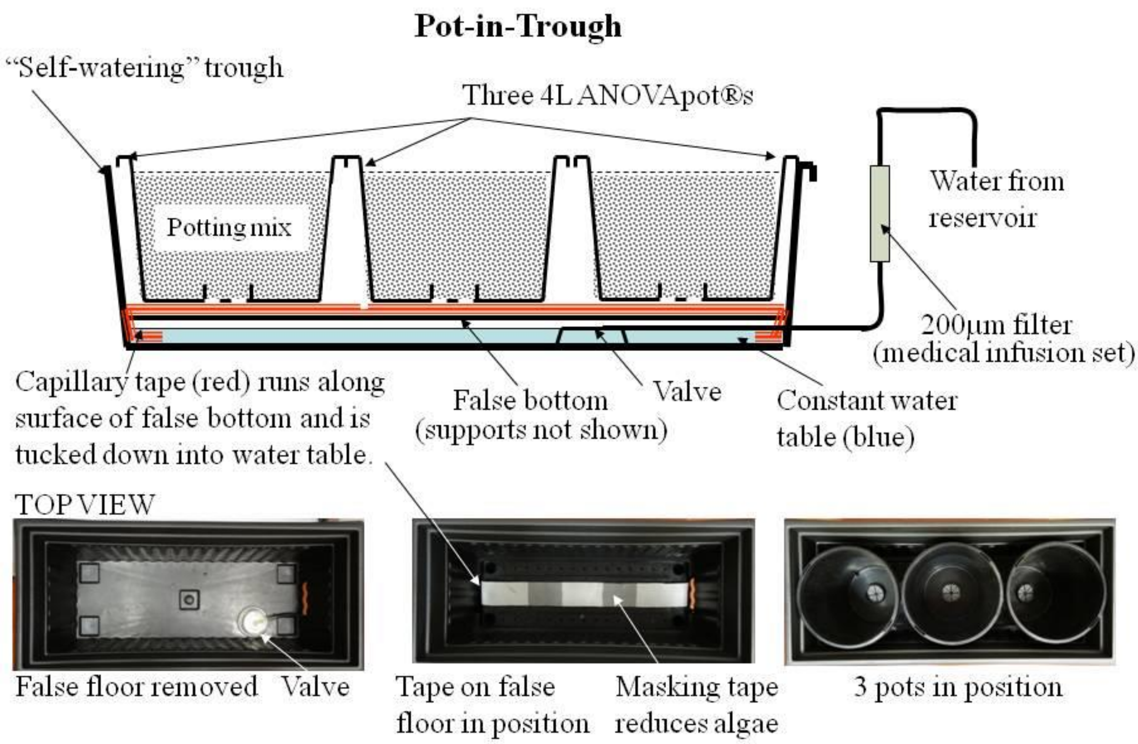


Figure 28 Conversion of a self-watering trough (68 x 30.5 x 25cm) into a bottom-watered 3 ANOVApot® system (Pot-in-Trough); with a constant water table maintained underneath the false floor by a valve connected to a remote water reservoir.

Plants growing in ANOVApot®s placed inside troughs.

Figure 29. Two connected Pot-in-Troughs in position, with water tables controlled by a valve supplied from translucent containers.

In the ńormalô trough system (NTS) troughs are filled with soil or potting mix, some of which fills the hollow legs that support the false floor. The medium in the legs provides a conduit for water flow by capillarity into the medium above. Approximately 2.5L of water can be stored under the false floor. This system will be quite satisfactory for some time until the hollow legs become filled with roots which change the capillary water flow characteristics, with the likelihood of legs becoming completely blocked. As the legs start to block, the rate of water uptake declines until a critical point is reached when plant demand, which generally becomes greater over time, outstrips supply. This point would be rarely detected and can be followed by severe dehydration both of medium and plant, as well as increasing hydrophobicity (water repellence) of the medium. The natural response of adding copious amounts of water to rectify the visual effects of this development simply leads to water shedding by the hydrophobic medium followed by a flooding event. This can be disastrous for balcony growers where run-off is not tolerated. Total submergence of the trough is required to rehydrate the contents. Unblocking legs will be very disruptive and most likely shock affected plants.

All of the above disadvantages encountered in the NTS are overcome with the PIT system. Few roots escape the ANOVApot® and those that do will not interfere greatly with capillary flow. If necessary, preventing (nearly) all root escape from ANOVApot®s is possible (see Appendix 2). Since water supply to plants in adjoining pots is independent, there is no competition for water, an issue that must often exist in NTS. If for some reason one of the ANOVApot®s dries out, it can be simply removed, repotted or rehydrated in a household 9L bucket and returned. This is not possible in the NTS without disturbing all other plants in the trough.

Pots and the plants they support in the PIT can be extracted for individual spraying purposes, replaced or re-arranged as desired, providing a level of flexibility not possible in the NTS. The reservoir capacity (15-25L) will supply the constant water table for a period of one to two weeks and even longer depending on time of the year, size of the plant and the amount of direct sun. Providing the reservoirs contain some water a constant water table in the trough will be maintained, allowing the provision of very simple instructions for maintenance when owners are away. Finally, the refurbishing of the modular PIT system is very easy, involving about half the quantity of potting mix used in the NTS. The tapes can be washed in bleach and reused without loss of hydrophilic characteristics.

Mosquitoes may breed in the free water under the false floor. This can be avoided by filling the false floor space with sand, its saturated condition being maintained by the same valve after wrapping the valve in fine-weave synthetic fabric (e.g. nylon panty hose) to prevent the entry of sand grains after its burial in the sand layer. This approach with sand is not suitable for the NTS since much of the capacity of the sub-floor space used for water storage would no longer be available. This is irrelevant in the PIT system with the valve included. Using sand free of organic matter would greatly minimise the likelihood of other organisms such as fungus gnats breeding in the sand. Submerging each pot in a bucket of water for half an hour, then leaving it to drain for another half an hour before placing it back into the trough, should get rid of any ant colonies.

ANOVApot® Insert

Many clay and ceramic pots have only one or two holes in their flat base. The idea emerged of glueing a plastic structure internally (essentially a piece of conduit with a screen at one end) over these holes, so that the functions of these pots, in terms of water retention and minimising root escape, were similar to those of the ANOVApot®.

Funds (QSEIF)[1] were raised to manufacture a mould of an ANOVApot® Insert, produce Inserts, and identify a glue suitable for use on plastic, clay and ceramic surfaces under wet conditions. This was all achieved. Inserts were packaged and displayed in a leading retail nursery (Figure 30) but unfortunately, subsequent sales were virtually non-existent. This was due in part to the very high price imposed by the nursery ($10 for a pack of 2) and an apparent lack of customer interest, or perhaps appreciation of its value in pot water management.

Display box-advertising and packaging.

Figure 30. ANOVApot® Insert.

ABC's New Inventors TV Program

In 2005, an application was made for the ANOVApot® to be assessed by the ABCôs New Inventors programôs panel of three. The New Inventors program was broadcast weekly on national television (8.00 to 8.30 pm on a Wednesday) to an audience of about one million. Ten days after application the ANOVApot® was put to air and won both the Panelôs Assessment and the Peopleôs Choice, of the three innovations screened that night. Part of the transcript of the show concerning the ANOVApot® (September 2005) was included in a book that described 50 inventions assessed by the panel over four years (Searle, 2009, p. 74).

[1] Queensland Sustainable Energy and Innovation Fund, Environment Protection Agency, Queensland Government.

Survey of ANOVApot® users

Methodology

A survey was conducted after two years of sales, initially with Plant-it-Rite (PIR) and then with Garden City Plastics (GCP), to assess nursery growersô responses regarding their use of the ANOVApot®. Nursery managers and principals using the ANOVApot® were asked eight questions that included issues of root escape, water saving, growth rate, and characteristics of pot preparation for retail sale. Twenty-one responses were returned, with results collated below.

Reduces root escape?
Roots that escape need to be removed in preparing the pot for sale. This takes time and effort. These roots can attach themselves to material under the pot with the plant becoming dependent on them for an additional supply of water and nutrients. Cutting off these roots can severely shock the plant, while the roots left behind in the mat (or other material) provide sites for infection by disease organisms. Removal of pots and breaking roots disturbs the matting and the levels of the underlying material.

Agree 90% (Greatly 66 Slightly 24 No 10 No comment 0)

Saves Water?
Water takes longer to drain from the **ANOVApot®** than from most other pots. This is particularly evident if the potting mix is allowed to dry out and shrink from the side wall. The longer the water stays in the pot the more thoroughly the potting mix is wetted and less water is lost.

Agree 81% (Greatly 38 Slightly 43 No 14 No comment 5)

Faster Growth?
The better growth in the **ANOVApot®** is probably due to its greater water retention. Thus, the relatively better plant performance in the **ANOVApot®** is most likely in open mixes with low water holding capacity that are watered sub-optimally.

Agree 66% (Greatly 29 Slightly 37 No 29 No comment 5)

Saves time ($) in pot cleaning?
Often when marketing to the retail trade, roots that emerge through the bottom holes of pots have to be removed. The time spent will vary with species, how the plant was grown, how old the plant is and the ótoughnessô of the roots. Roots that do escape through the central hole of the **ANOVApot®** are often the thinner, softer, feeder root type that can be easily removed by a hand held paint scraper. The flat bottom surface of the **ANOVApot®** allows fast and efficient root removal.

Agree 86% (Greatly 53 Slightly 33 No 14 No comment 0)

Easier to extract plants?
The longer a plant stays in a pot the more difficult it is to remove. Much of this resistance to removal is related to root escape which is minimized in the **ANOVApot®.** Landscapers prefer pots without escaped roots because plants are easier to extract. With potting on, the healthy root ball from an **ANOVApot®** is more likely to stay intact than from a pot where roots have escaped.

Agree 95% (Greatly 62 Slightly 33 No 5 No comment 0)

No salt encrustation?
Salt encrustation is unsightly and should be removed in preparing the pot for retail sale. It often occurs under drip irrigation when the drainage water that emerges through the side holes evaporates, leaving behind a layer of calcium phosphate and sulphate salts. This layer enlarges over time with every evaporative cycle. Salt encrustation is not likely to form under overhead irrigation in the **ANOVApot®.**

Agree 72% (Greatly 62 Slightly 10 No 14 No comment 14)

No drainage problems?
Water ponds if the potting mix is very dry. As it wets up, capillary forces drive the water to all parts of the pot including the outlet grid area of the **ANOVApot®**. This capillary flow to the grid area sets up automatically and removes all free water from the bottom of the pot. If the **ANOVApot®** is in contact with an underlying mat that drains well drainage may exceed that of a side hole pot in which a perched water table often occurs. Drainage occurs in the **ANOVApot**® with all sorts of potting mixes with good capillary flow features, including sand based mixes. It is not recommended to place the **ANOVApot®** in direct contact with black plastic film because of the possibility of sealing. Drainage may be seen as too slow under very frequent irrigation cycles.

Agree 86% (Greatly 33 Slightly 52 No 10 No comment 5)

Healthier growth?
Bearing in mind the positive **ANOVApot®** effect on plant water relations as well as its effect in reducing root damage, it is likely that the **ANOVApot®** will also produce healthier plants. Air pruned roots at the base of a holed pot may provide sites for pathogen entry. Such air pruning does not occur in the **ANOVApot®.** Rapid growth in the **ANOVApot®** may produce ósofter plantsô less able to handle moisture stress if it is allowed to develop, such as in transit to the retail outlet or landscape operation.

Agree 71% (Greatly 19 Slightly 52 Do not 29 No comment 0)

Adoption

Sales to the nursery industry

The ANOVApot® range of five pot sizes was manufactured and marketed to the wholesale nursery industry under licence, initially to Plant-It-Right and then to Garden City Plastics (www.gardencityplastics.com). While pot sales so far (July 2014) of 11 million sounds impressive, the number is low in terms of total industry consumption (less than 3%), although it does indicate a sustaining niche market. The 1.5L ANOVApot® accounted for 77% of the total number of ANOVApot®s sold followed by the 4L pot at 15% and the 2.4L ANOVApot® at 6%. The very low numbers sold in the smallest and largest pots partly reflect the delay in their production. By 2012, numbers sold in the 1.2L (125mm), 2.4L (175mm) and 18L (320mm) pots were trending upwards compared with a reverse trend in the 1.5L (140mm) and 4L (200mm) pots. Numbers of 1.5L pots sold annually peaked at 1.4 million in 2008 and then steadily declined to only 700,000 by the end of 2012. There has been considerable variation in year-to-year royalties but little actual overall increase over the 8-year period. Overall, royalties are greatest in the final quarter of the year (Oct-Dec) and generally least in the first quarter. Over the first 8 years, maximum income was generated in 2008 and minimum in 2011, with all years exceeding the agreed minimum performance value, but in some cases by not a large margin.

Use of the ANOVApot® for research

Although the commercial adoption of the ANOVApot® by the nursery industry continues to be somewhat muted, the pot has become the standard across its size range for almost all experimental projects managed by Glasshouse Services at the University of Queensland, St Lucia (Table 7). OôConnell (2007) outlines use of the ANOVApot® in the Universityôs speed breeding program.

The general adoption by researchers has been greatly enhanced by the development of the Twinpot and Pot-in-Bucket irrigation systems in which the ANOVApot®ôs root and water control features are important experimental attributes. Another key element of these systems has been the development of the simple float valve (Figure 21) that maintains a constant water table under these pots, which is excellent for critical water management and water use efficiency studies. Not only do the various ANOVApot®-based irrigation systems promote good growth and save water, they also minimise labour costs, particularly at weekends. Importantly, these systems now allow research activity that was rarely attempted previously because of the costs of labour and instrumentation.

Table 7. Use of the ANOVApot® and associated irrigation systems at the University of Queensland, as of March 2014.

No. of Users	41	
No. of Supervisors	20	
No. of Projects and their Pot size	27 x 200mm, 11 x 140mm, 7 x 320mm, 1 x 175mm.	
Type of use	16 single pot, 6 TWMS, 3 PIB alone, 3 TWMS plus valve, 9 PIB plus valve.	
Species	***Horticulture***	Sweet potato, Coconut, Ginger, *Pongamia*, *Senico*, *Brassica*, Turf grass.
	Agriculture	Wheat, Barley, Rice, Sorghum, Sugarcane, Soybean, Peanut, Lucerne, Leucaena, Rhodes grass.
Projects	Salt tolerance, Water flow rate, WUE and disease, Pre-harvest sprouting, Water stress, Temperature, Nitrogen, Metal toxicity, Plant nutrition, Speed breeding, Propagation, Embryo extraction, Tailings management, Nodulation.	
Project Reports	3 Honours, 3 Masters, 15 PhDs, 2 posters, 5 papers (completed or underway).	

PIB = Pot-in-bucket; TWMS = Twinpot Water Management System; WUE = water use efficiency

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*Copies of all unpublished reports are available from the principal author, M. N. Hunter (mhunter@powerup.com.au)

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Appendix 1

Examples of plants under the TWMS

26/01/09

App. Figure 1. Sweet potato (*Ipomea batatas*) growing in 18L 320mm ANOVApot®s under the Twinpot Water Management System.

(root balls upside down)

App. Figure 2. Sweet potato (*Ipomea batatas*) tubers (1.3kg) from one pot under the Twinpot Water Management System.

At transplanting
(24/09/08) into TWMS

App. Figure 3. Tahitian lime (*Citrus aurantifolia*, cv. Sublime) (27/09/09) 12 months after transplanting into Twinpot Water Management System (320mm/18L ANOVApot®s).

At transplanting
(28/10/08) into TWMS

App. Figure 4. Avocado (*Persea americana* cv. Wurtz) (27/09/09), 11 months after transplanting into Twinpot Water Management System (320mm/18L ANOVApot®s).

30/06/2012

Yielded a total of 242 fruit, weighing 2.64kg, harvested over two months 1/6-28/7/2012.

App. Figure 5. Balcony grown cherry tomato (*Lycopersicon esculentum*) under the Twinpot Water Management System.

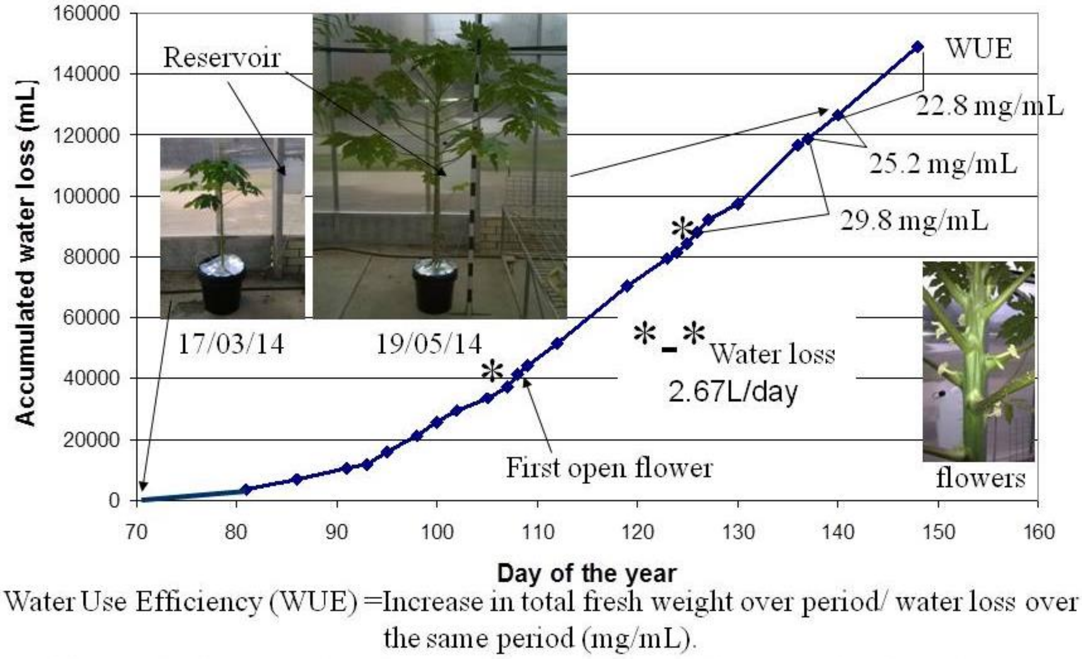
Peter Hunter plus plant.

Upper pot removed from lower pot to reveal escaped roots and capillary cap.

Extracted root ball displays fleshy peripheral roots and much finer central well roots.

App. Figure 6. Banana (*Musa* sp.) growing under the Twinpot Water Management System.

App. Figure 7. Dr Ian deLacy with his 18 month old coconut (*Cocos nucifera*) seedlings under the Twinpot Water Management System (320mm ANOVApot®); a valve is located within each lower pot.



App. Figure 8. Accumulated water loss in bi-sexual *Papaya* (cv. Southern Red) in the TWMS (18L/320mm ANOVApot®) with valve and reservoir; March 17-May 27, 2014. UQ Glasshouse 12.

Chervil

Tarragon

Rosemary

Parsley

40mm central well, 4L ANOVApot®.

App. Figure 9. A range of herb species growing under the Twinpot Water Management System.

Chives

Dipladenia

Olive

Bougainvillea

Begonia

Banksia

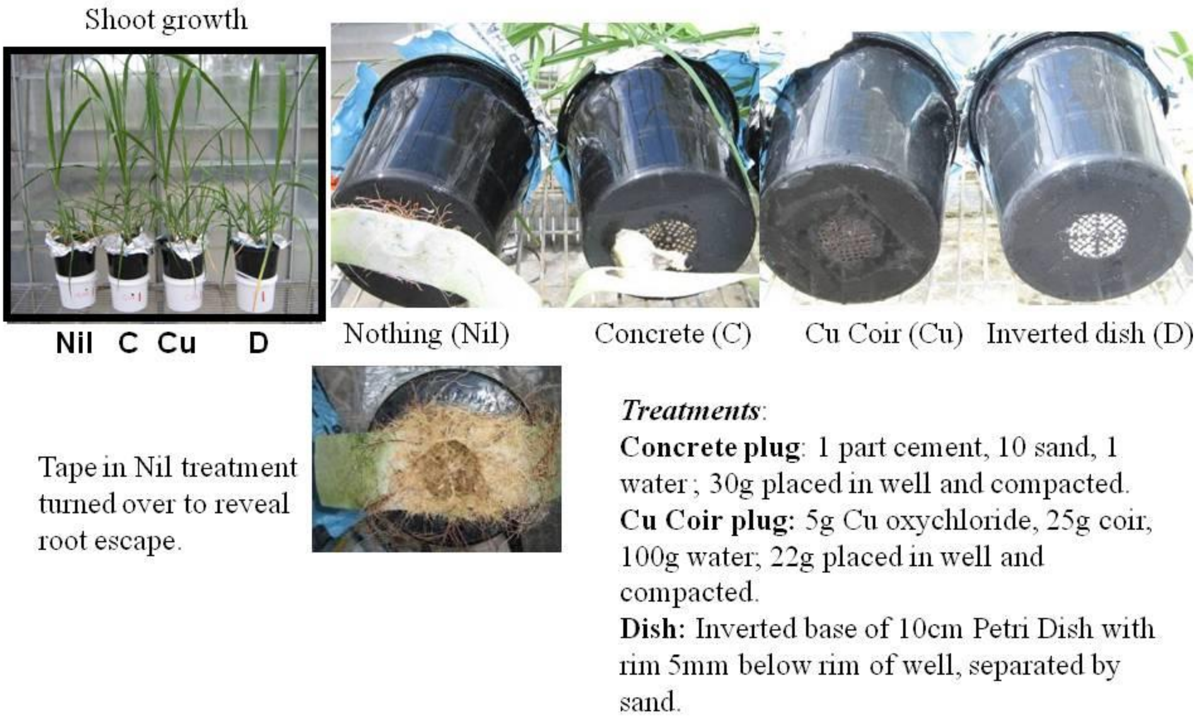
App. Figure 10. Ornamental species under the Twinpot Water Management System, with valves in the Dipladenia and Olive.

Appendix 2

Preventing all root escape

The design of the ANOVApot® does not prevent vertically inclined roots that grow downwards from entering the collar and so escaping through the grid. However, in 200mm pots these roots can be readily deflected sideways by centrally placing the upturned (inverted) base of a Petri dish (100mm diameter) some 33 mm above the top edge of the collar (note detail in Figure 14). The side wall of the dish will also reduce the entry into the collar of some roots growing sideways. Accurate placement can be facilitated with an appropriate template (33 mm tall by 120mm diameter) placed around the collar. The space around the template, including that of the central collar is filled with potting mix to the height of the template, with that in the central collar being tamped down. The upturned base of the Petri dish is then pushed down into the potting mix until its planar surface is level with the top of the template. The template is removed and filling with potting mix continued.

Placing a 90mm square of plastic sheet (preferably biodegradable) horizontally, about 30mm above the floor of the 200mm ANOVApot® during the potting up process would be an acceptable alternative; or similarly, larger pieces of 120mm square for the 320mm ANOVApot®. While these processes are effective, the additional time in their execution would rule this out as routine nursery practice, unless root escape into the local environment could not be tolerated because of subsequent root anchoring.



App. Figure 11. View of pot bases reveals effectiveness of various treatments in preventing escape of sugar cane (*Saccharum officinarum*) roots from the central well of the ANOVApot®.

An experiment was carried out with sugar cane, in which concrete and copper impregnated coir plugs were placed in the wells of 200mm ANOVApot®s and compared in their effectiveness in preventing root escape, with that occurring in unamended ANOVApot®s and in ANOVApot®s that included inverted Petri dish bases (as above) (App. Figure 11). All three treatments were effective but the copper coir plug and the dish were much more consistently so than the concrete plug. Of these, the dish is preferred because of its simplicity and avoidance of chemical use. Copper impregnated coir plugs and concrete plugs were also effective with sunflowers (Figure 10) and marigold (Figure 11).

Increasing capillary contact

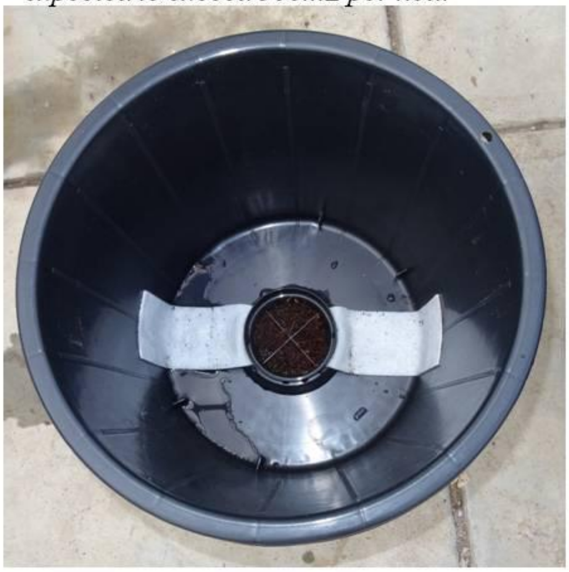
The type of medium used in the ANOVApot® has a great bearing on contact of the medium with the capillary tape below the grid that covers the central hole. It is less of a problem with organic media where the relatively stable organic fraction hangs through or is actually pressed through the hole of the grid when potting up. Surface applied water flows through the grid but the organic material stays in place.

Soil, rather than potting mix, is often studied in pots to develop insights into how to manage that soil in field environments. In the ANOVApot®, when water is surface applied to a soil medium the soil fines are washed through the grid, leaving the more resistant peds on top of the grid rather than through the grid. Lifting of the pots for weighing purposes will disturb the capillary connection with the result that it may become a limiting factor in water uptake.

Increased contact can be achieved by cutting out the grid and replacing it with a patch of capillary tape glued onto the base of the ANOVApot®. All soil fines are now retained on the tape after watering from above, ensuring that connection with the underlying capillary tape is now maximised. Even better uptake may be achieved in the 320mm ANOVApot® by extending the ends of the capillary patch through slots made midway up the collar to stand about 10cm inside the pot itself, being surrounded and supported vertically by the potting medium (App. Figure 12). This will greatly increase the contact area between the capillary mat and the potting medium. While root-ball extraction will be more difficult than without these tapes, root-ball extraction can be facilitated by cutting the tapes at their point of entry into the base of the pot, before root-ball removal.

The minor elements of the grid in between the 4 major cross bars may also be removed and a layer of moistened coir placed in the well before replacing the existing root ball (or filling with potting mix)

Recommended when water demand is expected to exceed 500mL per hour



Tape is passed through slots made half way up the side of the well

App. Figure 12. The upper 320mm (18L) ANOVApot® of the Twinpot Water Management System showing capillary tape configuration that greatly increases contact between the root ball and moist capillary tape.

Make your own float valve

Development of a float valve for the various ANOVApot® watering systems became a necessity because of the excessive cost or incompatibility of existing valves. The cost, design and reliability of the float valve are yet to be finalised with recently published descriptions (Hunter et al., 2012) already being superseded.

The latest version includes a polypropylene sauce container (Sunrise Plastics) with a basal diameter of 59mm, a top diameter (with lid) of 77mm and a height of 25mm (Figure 21). Three 6mm holes are made in the container at positions as indicated in Figure 21 to allow the insertion of a pipette tip and free flow of water and air.

A disposable pipette tip (Greiner or Axygen 200µL Pipette tips, polypropylene) is placed tapered-end down into a 10mm deep, vertical hole drilled into a piece of flat wood. The protruding section is bent forward to meet the surface of the timber. It is extracted from the hole and the bent tip section bent further by hand until it can be bent no further. After holding it in this position momentarily, the bent tip is then released and adjusted to the right-angled hook position. It may be necessary to soak tips in very hot water immediately prior to this operation, if ambient conditions are less than 28^{o}C.

The 6mm hole is made in the wall of the sauce container located 2mm above the base (which becomes the ʻtopô when in the inverted position). Another 6mm hole is made in the centre of the base. The inner container surface between the side hole and the central hole is treated with a primer (Sellys All Plastics and Toy Glue). After priming the surface of the pipette tip (along the strip to be in contact with the surface of the sauce container) and applying a thin bead of glue, it is inserted through the side hole until the right-angled tip is pointing down immediately under this central hole. The pipette should be aligned with the previously primed surface. The pipette tip is pressed down and kept in position with light pressure for about 15 seconds. Solvent-based contact glue is then applied liberally to the pipette where it meets the surface of the sauce container.

A hexagonal float based on a 57mm diameter circle and thickness of 10mm is cut out of polystyrene sheet with the sides preferably inclined at an angle of 10 degrees (not vertical). A 14mm hole is drilled through the centre of the float. A second 6mm hole is drilled alongside so it just intersects with the first hole.

A soft rubber plug (Grippy Rubber; 15mm diameter, 5mm thick) is placed in the 14mm diameter hole in the float with its planar surface 3mm below the top surface of the polystyrene float. The space below the plug on the lower surface of the float is filled with silicone.

The float is contained within the upturned sauce container; it moves vertically in response to the rising level of water as it accumulates on the floor of the container following flow through the pipette tip of the valve, or from drainage water from the upper pot. Because of the angled cut the diameter of one side of the float will be greater than the other. It is important the greater side is always uppermost to help prevent the float from sticking to the wall. This will ensure that any contact between the float and the sauce container is restricted to the points of the hexagon. The smaller of the two float holes allows drainage and reduces the accumulation of water on the upper side of the float, which may otherwise influence the floatǿs buoyancy and hence the consistency of drip intervals.

A 20mm section of black rubber tubing with 5mm ID is placed in hot water and then slipped onto the end of the pipette tip that protrudes through the wall of the sauce container. A 120mm section of black 4mm ID flexible tubing is inserted into the tubing and ultimately connects with the medical infusion set containing a 200µm filter, which ensures that the 400µm tip of the pipette does not become blocked.

Finally, with the hexagonal float in position (so that the 3mm deep rubber surface lies opposite the pipette tip) the lid of the sauce container is attached.

The infusion set is connected to a 5-25L reservoir. It also includes a sight glass (polypropylene) that allows the rate of water movement through the pot to be monitored (as a drip), in response to evaporation and transpiration. This rate may be automatically monitored on a continuous basis to develop diurnal and total transpirational water losses.

The valve is compatible with all sizes of PIB configurations from the 125mm pot through to the 200mm ANOVApot®. It can also be used in the Twinpot configuration with the 320mm ANOVApot®. It is also compatible with all PIT systems.

Appendix 3

Financial benefits of TWMS to nursery growers: detailed calculations

Link to the Excel Template (ANOVAprofit)

Go to: http://www.anovapot.com

App. Table 1. Changes in annual materials & services costs (10,000 pot nursery)

Cost of transplants/plant	$5	
Capital cost of control system & sensors	$5,000	
Annual computer maintenance	$200	
Annual water savings/pot (Nursery size) from using TWMS pots (Litres)	215	
Water cost per 1000 litres	$0.60	
Pumping costs per 1000 litres	$0.20	
Cost of Slimline pot for US and PIP systems	$1.60	
Cost of TWMS pot	$2.20	
Cost of potting mix/litre	$0.10	
Cost of fertiliser/kilogram	$7.60	

Annual materials & services savings	**Annual change $ TWMS cf. US**	**Annual change $ TWMS cf. PIP**
Water saving	$1,290	$1,290
Pumping power	$430	$430
Total	**$1,720**	**$1,720**
Extra materials and services annually		
Transplants	$30,435	$30,435
Upper pots	$25,391	$25,391
Depreciation on lower pots (Life of 5 years)	$4,400	$1,200
Depreciation on Windclips - $2/pot for TWMS & PIP (Life of 10 years)	$4,000	$0
Capillary cap - $1 for TWMS pots (Replaced every 2 crops)	$13,043	$13,043
Dip stick - 10% of TWMS pots, replaced annually, cost 5 cents	$50	$50
Root deflector - 10 cents/pot/crop for TWMS	$2,609	$2,609
Potting mix - TWMS pots hold 15 litres, Slimline hold 12 litres	$15,130	$15,130
Fertiliser - 52.5g/pot TWMS, 60g/pot for Slimline (30% fertiliser saving in TWMS)	$1,289	$1,289
Depreciation on control system (Life 5 years)	$1,000	$1,000
Computer maintenance	$200	$200
Total	**$97,547**	**$90,347**

App. Table 2. Changes in annual labour costs (10,000 pot nursery)

Labourer cost/hour	$25	
Management cost/hour	$40	
No. of blow-over events/year	10	
Percentage blown over each event (%)	50%	

Annual labour savings	**Annual change $ TWMS cf. US**	**Annual change $ TWMS cf. PIP**
Picking up blowovers - 7 seconds/pot/event (Applies to US comparison only)	$2,431	$0
Reduced pot detailing time - 30 seconds/pot for US and BS, 10 seconds/pot for TWMS	$2,355	$2,355
Reduced weed control - 20 seconds/pot for US and BS, 15 seconds/pot for TWMS	$60	$60
Reduced pad maintenance - 20 seconds/pot for US and BS, 15 seconds/pot for TWMS	$60	$60
Reduced irrigation management - 4 seconds/pot for US and BS, nil for TWMS	$556	$556
Total	**$5,462**	**$3,031**
Extra annual labour		
Setup supp.pot arrays - 30 seconds for TWMS and BS pots every 5 years.	$417	$0
Attach windclip brackets - 30 seconds for TWMS and BS pots every 5 years.	$417	$0
Install deflector - 10 seconds/TWMS pot/crop	$1,812	$1,812
Place capillary cap - 10 seconds/TWMS pot/crop	$1,812	$1,812
Clean capillary cap - 5 seconds/TWMS pot/crop	$906	$906
Extra pot handling - 20 seconds/TWMS crop/crop	$3,623	$3,623
Pot filling, setting up, harvest, packing etc - 280 seconds/pot for all systems	$11,836	$11,836
Total	**$20,821**	**$19,988**