Chapter 6

Key Irrigation Technologies and Substrate Choice for Soilless Potted Flowers in Greenhouses

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Additional information is available at the end of the chapter

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1. Introduction

Total area of flower production in China has reached 834, 000 hm^2 In 2009, with the total sales of ¥719.80 billions; the planting area of potted flower has reached 81 710.6 hm^2, with the sales amount of ¥180.80 billions, the amount of protected cultivation area for flower has reached 81767.5 hm^2, where the area of greenhouse is 21 490.5 hm^2 (The website of state forestry administration, 2009). Facility substrate culture has been one of the production models pushed mainly for urban modern agriculture, so it is very significant in practice for the application of soilless culture technology to find an economic, high-yield and efficient culture substrate suitable for the locality. According to statistics, the typical irrigation quota of facility flower is 3 150~3 900 m^3/hm^2 (Beijing Water Science and Technology Institute, 2007) with high quality and clean water resource, but problems such as undefined water consumption amount, low utilization efficiency of irrigation water, lack of irrigation program, wasting of good water and fertilizer resource, unscientific application of water and fertilizer that may impact economic quality of flower are existing.

It is inevitably demand to uncover water consumption of plant for research about natural hydrological cycle, exploration of plant ecological functions and guidance of plant precision irrigation, and assurance of high yield and quality of commercialcrop, thereby this area is always the hot spot of research in various disciplines such as hydrology, meteorology, irrigation and water conservancy, ecotope and so on. At present, there are many findings in water consumption of typical crops (GuoShenghu et al., 2010; ShenXiaojun et al., 2007; Zheng Baoguo et al., 2010; Zhao Ying et al., 2011), fruit trees (Zhao Jinghua et al., 2010; Liu Hongguang et al., 2010; Abrisqueta J M, 2008) and landscape plants (GuHongzhong et al., 2006; Philips N et al., 1996; Sun Huizhen et al., 2004), the research efforts for facility flower water-saving irrigation is still weak, where the research achievement for water consumption concerned soilless culture facility flower is rarely seen, which falls behind rapid development of flower industry seriously.

Research about the irrigation technology for soilless culture flower still lags behind for the walking tube-well irrigation wasting manpower and water-fertilizer resource and then ruining the environment, while the drip irrigation system cannot fit for changing of the density of potted flowers, which hard to manage. But the ebb-and-flow system can recycle water and fertilizer resource as a new irrigation technology. In 1990s, researchers started systematic study on influence to plant growth irrigated by ebb-and-flow technology from fertilizer and substrate (Poole R T et al., 1992; Erin James et al., 2001), comparison of water utilization between various irrigation technologies in a greenhouse (Catherine A. Neal et al., 1992) algae control in an ebb and flow irrigation system (Chase R et al., 1993), some get the patents (Robert W et al.,1994). At the beginning of the 21st century, Chinese researchers started to introduce the ebb-and-flow technology (Ren Jianhua et al., 2004; Yang Tieshun et al., 2009), which settled in Ningxia (GaoYuting et al., 2010), in 2011, a special planting bed was developed (Zhang Xiaowen et al., 2011), in addition to the ebb-and-flow culture test for potted *Hydrangea macrophylla*(Zhang Li et al., 2011), and get many patents of irrigating equipment quickly.

But the ebb-and-flow technology has not been used massively yet for the limitation of its large initial investment, high requirements for the operation and management personnel's technical level and the production facilities after it is introduced to China (Ma Fusheng et al., 2012).The drip arrow technology is used in production of potted plant cultivated with solid substrate as soon as its appearance (Meng Qingguo et al., 2005), the research achievements concentrate mainly on water-fertilizer coupling effect of vegetable, comparison and selection of proper substrate and determination of the lower limit of irrigation (Pang Yun et al., 2006; Yue bin et al., 1998; Wang Ronglian et al., 2009; ZhongGangqiong et al., 2005). Peat soil becomes the main substrate for soilless substrate potted flower, because which can provide available mosisture, fertilizer, air and temperature supplying enviroment. Based on the research results, though various irrigation low limits are key for water utilization efficiency, growth and quality of potted flower (De Boodt M et al., 1983; Zhang Tiejun et al., 2010; Wang Yajun et al., 2003; Zhang Jianhua et al., 2009; Zhang Ning et al., 2011; R. KastenDumroese et al., 2011), there is seldom reports about research results of influence to water utilization efficiency, growth and quality of soilless substrate potted flower from various dripper flows. Scientific basis for selection and matching the drip irrigation emitters of soilless substrate potted flower are lack.

At present, there have been reports concerned influences to growth and development, yield and quality from soilless culture substrate by scholars both here and abroad (De Boodt M et al., 1983; Zhou Yanli et al., 2005; Zhang Tiejun et al., 2010; Wang Yanjun et al., 2003; Zhang Jianhua et al., 2009; Zhang Ning et al., 2011; R. KastenDumroes et al., 2011; David W R. Water et al., 2006; Kang Hongmei et al., 2006; Zhao Jiuzhou et al., 2001; Li Jing et al., 2000; Chen Zhende et al., 1998; Tian Jilin et al., 2003). But the researches are only concentrated on raw material and suitability of substrate based on the indexes of plant growing, yield and quality; in addition to testing evaluation of the indexes such as pore structure, volume-weight and so on for substrate moisture physical property.

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Based on the status quo of weak research efforts for high level facility flower water consumption and research lag on new irrigation technology, we take the typical potted foliage flower "Anthurium" as the object of study, the water consumption law and utilization efficiency during the overall process of the facility systematically were studied, in order to provide scientific basis for design of the irrigation system and precision irrigation control of facility potted anthurium. We take drip irrigation as a comparison to study influence of various nutrient solution depths to substrate moisture content, irrigation water utilization, plant growth and water consumption in order to provide scientific basis for the new technology of facility anthurium ebb-and-flow irrigation. For the sake of a proper dripper flow, we choose peat soil (PINDSTURP) that is popular in the market as the culture substrate, study the law of influence to water utilization, growth and quality of soilless potted flower from various dripper flows systematically, in order to provide basis for selection of facility substrate potted flower drippers. At the same time, proceeding from hydrodynamic parameter testing and evaluation of substrate, 8 typical substrates of facility soilless culture were chosen to discuss the water binding capacity, storativity and water availability of them, in order to provide enough theoretical basis for substrate comparison and selection.

2. Experimental site and methods

2.1. Site and experiment description

- Beijing Jidinglida Technology & Trade Co., Ltd.

We start test and research about influence to water utilization and growth of facility drip irritation soilless culture anthurium under various irrigation low limits, facility soilless potted anthurium ebb-and-flow technology, facility potted anthurium proper dripper flow selection at the intelligent multi-span greenhouse of Beijing Jidinglida Technology & Trade Co., Ltd. (39°20′, east longitude 114°20′, elevation 12m).The material of the greenhouse is double hollow polycarbonate sheet with the span of 8m, and the standard width of a room is 4m. There are the temperature and humidity sensors in the rooms, which drive the wetted pads and the fans automatically. The wetted pads and fans are fitted on the south and north walls in the room, in addition to the small fans to accelerate air circulation inside. When the wetted pads and fans are operated, at the same time the door and the skylight are closed, air circulation can be improved and suitable environment is guaranteed. The greenhouse is heated by the heating radiators to keep the temperature between 20°C~30°C. There are external sun louver and internal sunshading to avoid flower leaf burns.

- Central Station for Irrigation Experiment of Beijing

The soilless culture substrate moisture characteristic parameter test and research are performed at the soil physics laboratory of Central Station for Irrigation Experiment of Beijing, Yongledian Town, Tongzhou, Beijing (39°20′, East longitude 114°20′, Elevation 12m).

2.2. Experimental methods

- Water consumption

Weigh the flowerpot everyday with a balance that has a precision of 0.01g. When irrigating, monitor seepage loss collected by the water collector pot by port; weight the pot before and after irrigation, and determine stage water consumption by the water quantity balance method. Weigh the flower sample every other 5~7 days during the test, check the results to guarantee accuracy. Count the water consumption by the water consumption of single pot, and determine the stage water consumption with the water quantity balance method, refer to formula (1).

$$ET_i = W_1 - W_2 + I - D \tag{1}$$

Where, ET_i is the water consumption at period I; W_1 is the flowerpot weight at the beginning of the period, g. Pot^{-1}; W_2 is the flowerpot weight at the end of the period, g. Pot^{-1}; I is the flowerpot irrigation during the period, g. Pot^{-1}; and D is the flowerport water leakage during the period, g. Pot^{-1}.

- Crown diameter and Plant height

Measure the crown diameter of the sample in the directions of east-west and north-south with a ruler, and take the mean values in both directions as the representative values of the sample crown diameter. Take the pot edge as the datum, measure the distance from the pot edge to the peak of the sample as the representative value of the plant height. Take the distance between the spathe to the root of the petiole as the length, and the distance of the widest as the width.

- Substrate moisture physical property

Measure the dry volume mass and the substrate water holding capacity of the cultural medium with the conventional methods (Jiang Shengde et al., 2006).

- Substrate moisture content

The dry substrate mass is determined by the dry unit weight filling before testing, the empty pot mass is determined by weighing before testing, and the overall mass of the flower and the pot is the average mass of the 5 sample pots. Take 3 plants from the same treatment in protecting line, which are same as the sample plant weighted, weigh their net mass and take the mean value as the representative value of plant mass, the testing period is about 5 days. Take the testing day as the middle, and 2 days both before and after it to use the mass value of the same plant, and calculate the moisture content of the substrate day by day. Subtract the plant mass, the dry substrate mass and the pot mass from the overall mass of the testing flower and the pot to get the water mass in the substrate. Divide the mass with water by the unit weight of water, and then by the substrate volume to get the moisture content of substrate.

- Substrate porosity

The saturated gravity drainage method is used to determine the porosity (Jiang Shengde et al., 2006), which including determination of total porosity, the water holding porosity, the aeration porosity and the gas water ratio. Weigh a vessel with a known volume (V) and weigh its mass (W_1), fill the testing substrate according to the design unit weight and weigh its mass (W_2). Soak the vessel with substrate for 24 hours and weigh its mass (W_3), encase the upper port of the vessel by wet gauze with a known mass (W_4) to avoid seepage of fine particle. There shall be no water seepage when inversing the vessel, and weigh its mass (W_5). The formula for the porosity of the substrate is:

$$\varphi = \left[W_3 - W_1 - \left(W_2 - W_1\right)\right] / V \times 100\% \tag{2}$$

$$\varphi_t = \left[W_3 + W_4 - W_5\right] / V \times 100\% \tag{3}$$

$$\varphi_c = \left[W_5 - W_2 - W_4\right] / V \times 100\% \tag{4}$$

$$d = {}^{\varphi_c}\!/_{\varphi_t} \tag{5}$$

Where φ = Total porosity, %; φ_t = Aeration porosity, %; φ_c = Water holding porosity, %; d = Gas water ratio; the units of W_1~W_5 are g; and the unit of V is cm^3.

- Substrate permeability coefficient

It is determined with the constant head method (Tian Jilin, 2003). Fill the cutting ring as required by the test, soak it for 24h before take off. Connect an empty cutting ring on it, seal the connecting place to avoid leakage. Add filter paper at the bottom of the connecting cutting ring. Add water into the empty cutting ring till the water level 1mm lower than the edge of the cutting ring. Time when the funnel starting dripping, record the seepages at 1, 3, 5, 7, 10, 15, 20min..., at the same time, add water into the empty cutting ring to the initial level and record the water temperature. End the test when the seepage becomes stable. Repeat each treatment for 3 times and average them. Hereinafter is the formula for the permeability coefficient:

The permeability coefficient at t°C

$$K_t = vL / \left(h + L\right) \tag{6}$$

Where v — Permeability speed, mm min^{-1}; h — Height of water layer, cm; L — Height of substrate, cm

The permeability coefficient at 10°C

$$K_{10} = K_t / \left(0.7 + 0.03t\right) \tag{7}$$

- Substrate moisture characteristic curve

Determine the moisture contents of substrate under 0, 0.01, 0.03, 0.05, 0.1, 0.3, 0.5, 1 and1.5Mpa respectively with the 1500F1membrane pressure gauge and dray the moisture characteristic curve.

- Substrate horizontal diffusivity

Determine it with the horizontal soil columnInfiltration method (Lei Zhidong, 1988). Put the substrate (Or soil) with the air drying unit weight as required by the test into the organic glass tube with the diameter of 5cm and the length of 50cm, ignore the gravity, water it with the Markov bottle. Refer to Fig. 1 for the test unit. Record the variation of water level in the bottle and the time when the wetting front passes every 1cm. At the end of the test, take soil (Or substrate) from the wetting front quickly, weigh it and dry it by heating, so get the moisture content distribution of the soil (Or substrate) column. With the testing time t and the moisture content distribution of the soil (Or substrate) column at that time, λ corresponding to various θ can be calculated with the formula $\lambda = xt^{-1/2}$, so the formula for the horizontal diffusivity is:

$$D\left(\theta\right) = -\frac{1}{2}\frac{\Delta\lambda}{\Delta\theta}\sum_{\theta_0}^{\theta}\lambda\Delta\theta \tag{8}$$

Where $D(\theta)$ — Horizontal diffusivity, $cm^2\ min^{-1}$; θ_0 — Initial moisture content, $cm^3\ cm^{-3}$; θ — Moisture content, $cm^3\ cm^{-3}$; λ —Boltzmann transformation parameter, $\lambda = xt^{-1/2}$; x — The moving distance of the wetting front at t, cm; t— Time, min

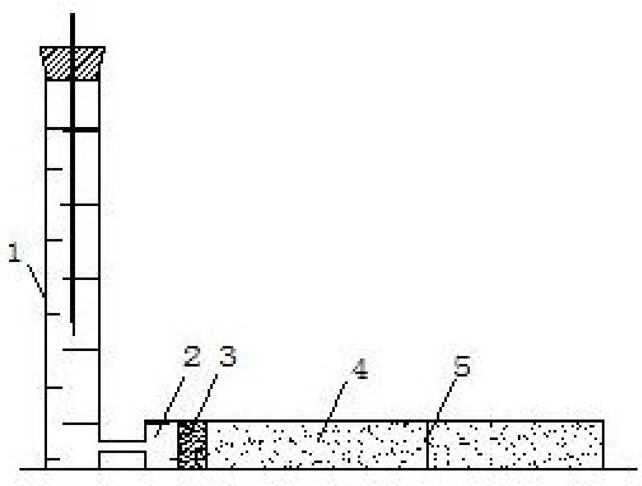


Figure 1. Experimental equipment of measuring soil water diffusivity

1. Markov bottle 2.Water chamber 3. Filter layer 4. Horizontal soil column 5. Wetting front

- Evaluation method

The matrix method is used for substrate comprehensive evaluation. A matrix method refers to form a matrix with all development activities and all environmental factors impacted, establish direct causality, in order to show the impact of the activity on the environmental factor (Duan Zhaolin, 2003). In this paper, the values in the order of merit of 8 substrates under influence from the total porosity, gas water ratio, permeability coefficient, water availability and transmissibility are formed, the better, the larger. Finally, perform comprehensive evaluation to various substrates according to the synthesis score.

3. Impact of various low irrigation threshold on water utilization and growth of facility drip soilless culture anthurium

3.1. Experimental plant and design

The anthurium is chosen as the testing object, its variety is "Flame", which belongs to *Araceae* and *Anthurium*. The culture substrate is mixture of PINDSTURP peat soil imported from Denmark and perlite from China in a volume ratio of 10:1, its dry volume mass is 0.16 g/cm^3, and the volume water holding rate (θ_{FC}) is 0.4315. The tested anthurium is cultivated in a pot, the top diameter of the pot is 16cm, the bottom diameter is 10cm, the height is 12.8cm, the volume is about 1.4L, and the substrate is filled about 2cm to the pot top. Refer to Table 1 for testing treatment.

Testing stage	Lower limit of irrigation/(%)				
	T1	T2	T3	T4	T5
Whole growing period	90	80	70	60	50

Note: The lower limit of irrigation is counted in percentage of the substrate water holding capacity.

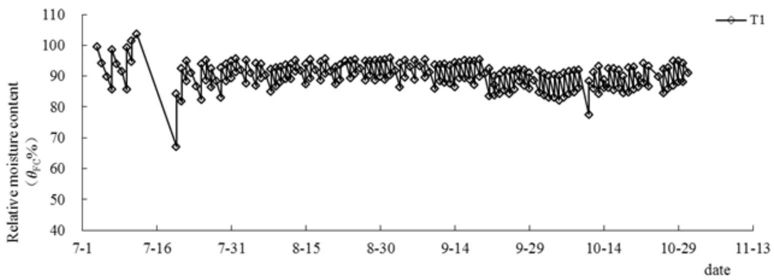
Table 1. Experimentle treatments

In this paper, all treatment irrigation quota are controlled by the substrate water holding capacity as the upper limit. The test starts from July 4, 2009 when transplanting to November 5, 2009, takes 124d. The placing density of tested plantlet is 15 pot/m^{2}in the seeding stage, and 10 pot/m^2 in the later stage. The plantlet is 18cm in height with uniform growth when transplanting. Use the pressure compensating dripper with water yield of 3.85 L/h (The working pressure range is 0.05~3 MPa), with the flat perforated pipe configured 4 outlets. Connect the drip arrow with uniform 1m long capillary tube, insert shallowly in the pot substrate from the side direction about 1cm within the center area of the root system. Determine the irrigation quota with the substrate water holding rate as the upper limit according to the relative lower control limit. Place the pot on the bracket, and put the PVC collector under the bracket to collect water leakage. Repeat 5 times per treatment. There are the protection lines at both sides of the monitored sample plant. The self-prime stabilized pressure pump with the pressure tank is used; the hydraulicproportioning fertilization pump made by USA is used for fertilization with water.All test plots are distributed randomly, the treatment measures such as farming, fertilizing, and pest control are same.

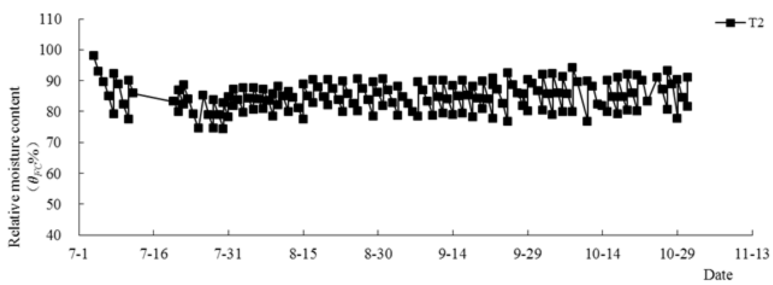
3.2. Results and discussion

3.2.1. Impact of various low irrigation threshold on Moisture content of substrate with drip irrigation

Refer to Fig. 2 for influence to moisture content of substrate from various low irrigation threshold. At the beginning of the test, adjust the basic moisture contents of all treatment substrates to the water holding capacity of the substrate. There is no irrigation for all treatments from July 4 to 7, so the moisture contents of substrate of various treatments have no large difference as shown on Fig. 1. From July 7 to 12, T1, T2 and T3 reach the lower irrigation limit and start to irrigate, the moisture contents of the 3 treatment substrates go down in turn from T1 to T3, but all of them are higher than T4 and T5 that do not irrigate and have not very large difference in moisture contents. After July 20, the overall performance of the moisture contents of substrate are 82%~96%θ_{FC} of T1, 75%~94%θ_{FC} of T2, 64%~88%θ_{FC} of T3, 56%~80%θ_{FC} of T4 and 44%~76%θ_{FC} of T5, which goes down from T1 to T5 along with decreasing of the low irrigation threshold. It identifies with the research result of influence to the soil moisture content from the lower irrigation limit (Karam K. et al, 2011).



a. T1 (The lower irrigation limit is 90% of the water holding rate of substrate)



b. T2 (The lower irrigation limit is 80% of the water holding rate of substrate)

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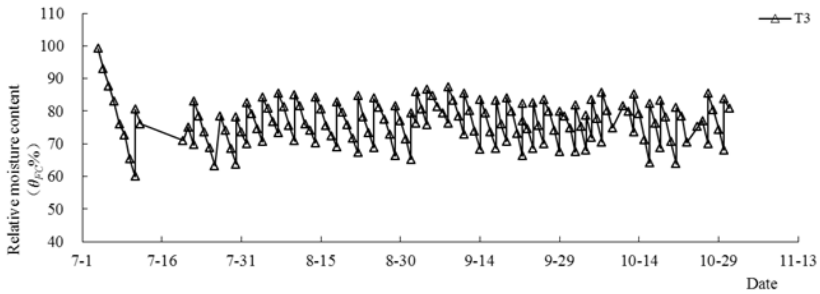
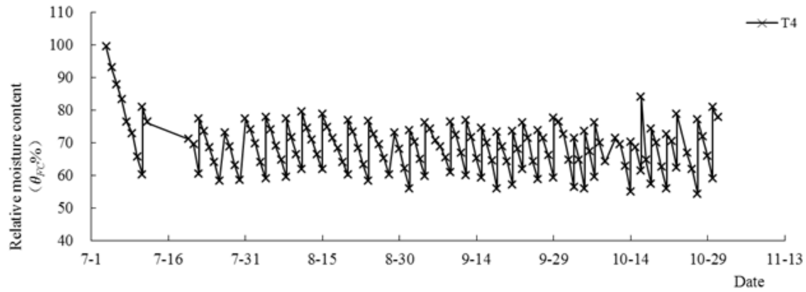
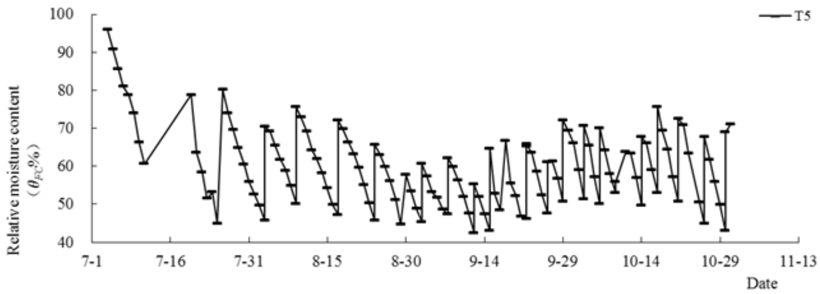


c. T3 (The lower irrigation limit is 70% of the water holding rate of substrate)



d. T4 (The lower irrigation limit is 60% of the water holding rate of substrate)



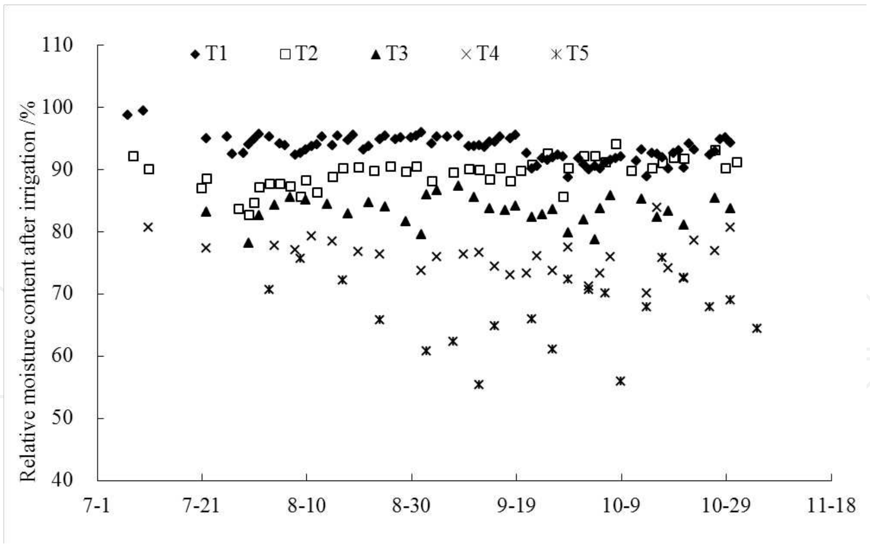
e. T5 (The lower irrigation limit is 50% of the water holding rate of substrate)

Note: The relative moisture contentis counted in percentage of the substrate water holding capacity.

Figure 2. The influence to moisture content of substrate from various low irrigation threshold

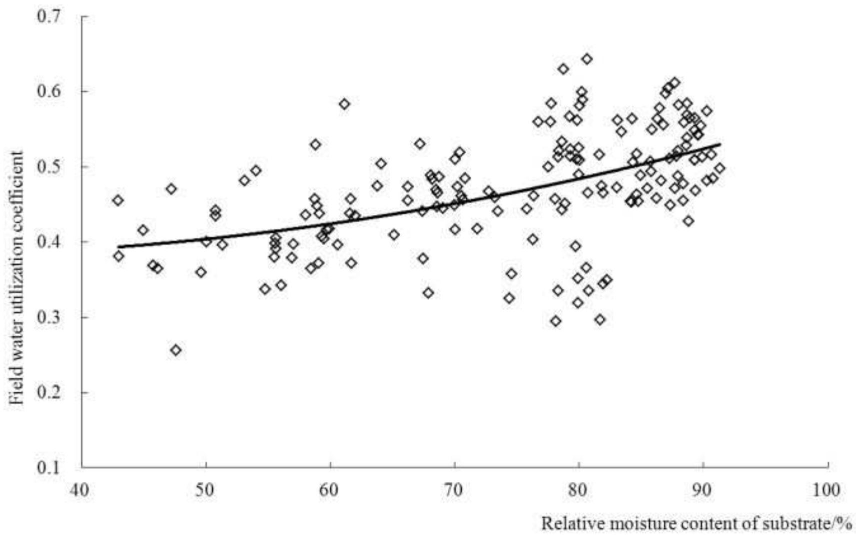
Refer to Fig. 3 for the influence to the substrate moister content from various low irrigation threshold after irrigation, while the influence to the field water utilization coefficient is shown in Fig. 4.

As shown in Fig. 3, the substrate moisture contents after irrigation go down along with decreasing of the low irrigation threshold. During the test, the mean values of T1, T2, T3, T4 and T5 after irrigation are 93.32%θ_{FC}, 89.31%θ_{FC}, 83.31%θ_{FC}, 76.02%θ_{FC} and 66.95%θ_{FC} respectively, all of them are lower than the level of substrate water holding capacity measured with conventional methods. It is caused by the substrate drip irrigation local water supply and the physical property of organic medium changing along with the substrate moisture content. Based on the measured results during the test, the average water leakage losses of all irrigations



Note: The relative moisture content is counted in percentage of the substrate water holding rate.

Figure 3. The influence to the substrate moister content from various low irrigation threshold after irrigation



Note: The relative moisture content is counted in percentage of the substrate water holding rate.

Figure 4. Influence to the field water utilization coefficient from various low irrigation threshold after irrigation

for T1, T2, T3, T4 and T5 are 22.30, 49.05, 78.02, 107.74 and 138.62g/pot respectively, the irrigation leakage losses increase along with decreasing of the low irrigation threshold.

The field water utilization coefficient is the ratio between the available water irrigated into field (For dry farmland, it refers to the irrigation water stored in the planned moisture layer) and water discharge from the last stage of the fixed ditch (Field ditch) (Guo Yuanyu et al., 2006). In this paper, it refers to the ratio between the water stored and absorbed by the substrate in the port and the total water irrigated in the port. The total water irrigated in the port can be measured, and the water stored by the substrate is the difference between the total water and leaked water. Refer to Fig. 4,under the test conditions, the total field water utilization coefficient goes down along with the substrate moisture content before irrigation. During the test, the average field water utilization coefficients of T1, T2, T3, T4 and T5 are 0.519, 0.471, 0.439, 0.419 and 0.402. While the irrigation water utilization coefficient specified in *Technical code for microirrigation engineering* (GB/T 50485-2009) shall not be less than 0.9, so the field water utilization coefficient in the tested substrate is even less than it.

In conclusion, the lower irrigation limit is the key factor for the substrate moisture and field irrigation water utilization coefficient (Both of them go down along with the lower irrigation limit) under the conditions that may affect water supply of drip irrigation. Based on their research about influence to substrate physicochemical properties from various water supply modes, Qi Haiying et al. (Qi Haiying et al., 2009) find that various water supply modes can affect the substrate pore structure, substrate volume, salinity, and acid and alkali environmentdramatically. So the change feature of the substrate moisture content and the field irrigation water utilization coefficient maybe the influence result to the tested culture substrate volume and pore structure from local water supply of the drip arrow, while the water absorption, storage and dissipation mechanism of soilless culture substrate needs more intensive study.

3.2.2. Influence to anthurium irrigation water amount from various low irrigation threshold treatments under drip irrigation conditions

Refer to Table 2 for influence to anthurium irrigation water capacity from various low irrigation threshold under drip irrigation conditions.

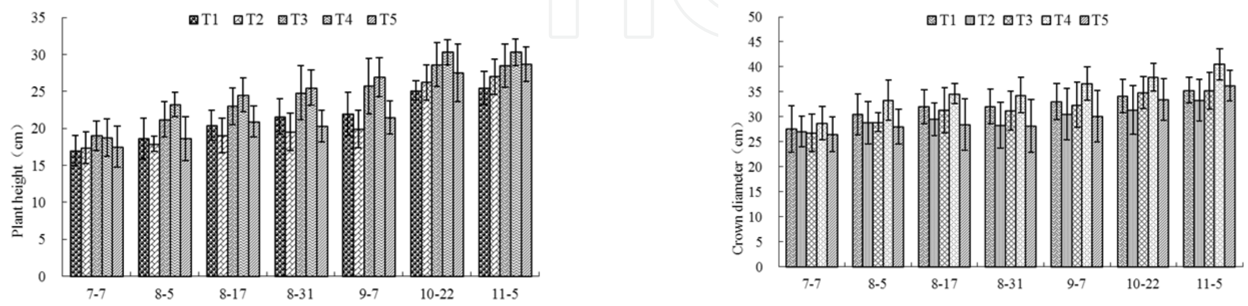
Treatment	Irrigation quota/ ($g \cdot pot^{-1}$)	Irrigation period/d	Irrigation quota/ ($g \cdot pot^{-1}$)
T1	46.36	All are 1~2 d during the test.	4865.4
T2	92.72	All are 2~3 d during the test.	5124.1
T3	139.08	3~4 d before 60 d after planting, and 2~3 d from 60 to 120d.	5953.9
T4	185.44	4~5 d before 60 d after planting, and 2~3 d from 60 to 120d.	6725.6
T5	231.80	5~7 d before 60 d after planting, and 3~5 d from 60 to 120d.	6344.0

Table 2. Effect of different low irrigation threshold to irrigation resume of Anthurium

As shown in Table 2, the irrigation period expands along with the decreasing of the lower irrigation limit, which is basically same as the conclusion of the routine soil water-saving irrigation test (Yang Wenbin, 2003; Tian Yi et al., 2006); but the irrigation quota of each treatment goes up along with decreasing of the lower irrigation limit. To compare with T1, the quota of T2, T3, T4 and T5 increases 5.3%, 22.7%, 38.2% and 29.3% respectively, which is on the contrary of the routine soil water-saving irrigation test (Sun Huayin et al., 2008). The field water utilization coefficient of the tested substrate goes down along with decreasing of the lower irrigation limit, it is the reason that causes the substrate culture irrigation quota increases along with decreasing of the lower irrigation limit.

3.2.3. Influence to anthurium growth status from various low irrigation threshold under drip conditions

Refer to Fig. 5a and Fig. 5b for influences to the plant height and crown diameter of the anthurium from various low irrigation threshold under drip conditions.



a Plant height

b Crown diameter

Figure 5. Effect of different low irrigation threshold to plant height and crown diameter

As Fig. 5a shown, T3 and T4 appear obvious growth vigor. By the end of the test, the plant heights of T1, T2, T3, T4 and T5 are 25.4, 27.0, 28.5, 30.3 and 28.7 cm respectively. Based on the significance testing results, the height of T4 is 19.3% higher than T1 obviously; the differences between other treatments and T1 are not obvious.

As Fig. 5b shown, as with the plant height, the crown diameter of T4 appears obvious growth vigor. By the end of the test, the anthurium crowns of T1, T2, T3, T4 and T5 are 35.3, 33.3, 35.2, 40.5 and 36.2 cm respectively. Based on the significance testing results (p=0.05), the crown diameter of T4 is 14.7% higher than T1 obviously, but the differences between other treatments and T1 are not obvious.

Treatment	Parameter			
	Qty. of spathe	Length of spathe/cm	Width of spathe/cm	Height of inflorescence/cm
T1	2.7±0.8	10.7±1.2	7.5±1.5	3.5±0.4
T2	2.4±0.5	10.4±2.3	7.3±1.5	3.4±1.0
T3	2.5±0.5	10.9±1.5	7.4±1.5	3.7±0.7
T4	2.6±0.4	10.9±1.9	7.8±1.3	4.3±0.7
T5	2.7±0.5	9.8±1.3	7.1±1.0	3.6±1.1

Table 3. Effect of different low irrigation threshold to spathes

Under drip irrigation conditions, refer to Table 3 for influence to the ornamental part - the spathe of the anthurium from various low irrigation threshold. The flower quantity of the 5

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treatments are all 3, there is no large difference among treatments. The lengths of the spathe of T1~T4 are all about 10.5cm, the widths are all about 7.5cm, and there is no large difference among treatments (p=0.05). The lowest lower irrigation limit – T5 has the smallest length and width of the spathe, it has negative influence to ornamental quality of the anthurium.

3.2.4. Influence to anthurium water consumption from various low irrigation threshold under drip irrigation conditions

Refer to Table 4 for influence to the anthurium water consumption from various low irrigation threshold under drip irrigation conditions.

Treatment	Anthurium water consumption of each treatment/(g·pot^{-1})				
	07-04~07-31	August	September	10-01~11-04	Total water consumption during experiment
T1	572.2	655.5	729.2	1028.9	2985.8
T2	554.4	559.5	599.1	849.3	2562.3
T3	554.4	632.2	696.0	922.4	2805.1
T4	578.8	661.8	699.3	918.4	2858.3
T5	557.3	534.2	538.6	891.7	2521.7

Table 4. Effect of different low irrigation threshold to water consumption amount of Anthurium

Based on Table 4, the water consumption of the tested anthurium during test is between 2 521~2 985 g/pot. To compare with T1, the total anthurium consumption of T2, T3, T4 and T5 are all reduced, in the degree of 14.2%, 6.1%, 4.3% and 15.5% respectively, viz. decreasing of the low irrigation threshold reduce the water consumption of the tested anthurium. Li Xia (Li Xia et al., 2010) carry out research about the transpirations of potted tomato with various substrate moisture contents, they also find that decreasing of the substrate moisture content reduces the transpiration of substrate potted tomato. Difference of water consumption between various treatments is caused by both the plant transpiration and substrate evaporation. Based on the plant heights (Fig. 5 (a)), growth of T1 and T2 is relatively weak; since the substrate moisture content of T1 is always at a higher level because of frequent irrigation, the main reason of large total water consumption is strong substrate evaporation; while the moisture content of T2 is lower than T1 obviously, the main reason of reduced water consumption may be weak substrate evaporation; on account of good growth of T3 and T4, their higher water consumption may be caused by strong transpiration; and the substrate moisture content of T5 is the lowest with weaker growth, substrate evaporation and plant transpiration, which may be the main reason to cause its lower water consumption. So water consumption mechanism of potted substrate needs intensive study.

3.2.5. Proper lower irrigation limit for soilless culture anthurium under drip irrigation conditions in a multi-span greenhouse

The characteristics of the flower industry are high input cost and seeking high returns, so the irrigation technology and the irrigation system are crucial to affect flower quality and benefit. Since the economic value of flower depends on quality, the high priority consideration when making the irrigation system shall be high quality of flower. At the same time, multiple benefits such as water saving, fertilizer saving, energy saving and manpower reducing shall be considered synthetically.

In this paper, the lower irrigation limit is key to water consumption and quality of the anthurium. To compare with T1, the flower count and the spathe of T4 that has the lower irrigation limit 60% of the substrate water holding capacity are not affected, but its water consumption has 4.3% reduction, the plant height has 19.3% increasing obviously, the crown diameter has 14.7% increasing obviously, which improves ornamental quality of the anthurium. While to compare T1 with others, though the water consumption goes down to varying degrees, there is no ornamental quality improvement, even negative effect to T5. So under the drip irrigation conditions in this paper, the proper lower irrigation limit of the anthurium shall be 60% of the substrate water holding capacity, here the substrate moisture content is between 60%~80% of the substrate water holding capacity; the irrigation period within 60d of transplanting is 4~5d, for 60~124d it is 2~3d, and the irrigation quota during the test is 185.44g/pot.

Though T4 has better irrigation effect in this paper, its field water utilization coefficient is only about 0.42, with serious leakage loss of good water and fertilizer resource from drip irrigation that become crucial environmental pollution source. It is urgently needed for intensive study on soilless culture substrate water absorption and storage mechanism, research and development of substrate culture drip irrigation technical mode, development of substrate with stable physicochemical property, reinforcement of circulation utilization of good water and fertilizer resource. Improve the utilization efficiency of water and fertilizer, meanwhile guaranteeing flower quality; support the flower industry, meanwhile achieve water-saving irrigation, good product quality and environmental protection and so on.

3.3. Conclusions

(1) The low irrigation threshold is the key controlling factor for the substrate moisture content and the irrigation water use efficiency. Both the substrate moisture content and the field water utilization coefficient go down along with the low irrigation threshold, while the irrigation leakage loss increases along with decreasing of the lower irrigation limit. Under the testing conditions in this paper, the field water utilization coefficient is only about 0.40~0.52, the irrigation period was prolonged along with the low irrigation threshold, but the irrigation quota increases on the contrary. To compare with the treatment that has the prolong as much as 90% of the substrate water holding rate, the irrigation quotas of treatments that have the low irrigation threshold as much as 80%, 70%, 60% and 50% of the substrate water holding rate increase 5.3%, 22.7%, 38.2% and 29.3% respectively.

(2) Under the testing conditions, the difference of the anthurium flower count between various treatments is not large, all of them are 3. When the lower irrigation limit is 60% of the substrate water holding capacity, the spathe size of the anthurium is not affected. But the plant height and the crown diameter increase 19.3% and 14.7% (p=0.05) obviously, in addition to improving ornamental quality. For the other treatments, except for the treatment with the lower irrigation limit as much as 50% of the substrate water holding rate that has reduced anthurium spathe, the others have no obvious difference from the treatment with the lower irrigation limit as much as 90% of the substrate water holding rate.

(3) During the test, the anthurium water consumption is about 2 522~2 986 g/pot, and the water consumption goes down along with decreasing of the lower irrigation limit. To compare with the treatment with the lower irrigation limit as much as 90% of the substrate holding capacity, the water consumptions of the treatments with the lower irrigation limit as much as 80%, 70%, 60% and 50% of the substrate water holding rate reduce 14.2%, 6.1%, 4.3% and 15.5% respectively. In order to achieve the anthurium optimal ornamental quality under the test conditions, determine that the proper lower irrigation limit of the anthurium shall be 60% of the substrate water holding capacity. When the substrate moisture content is between 60%~80% of the substrate water holding capacity, the irrigation period within 60d of transplant is 4~5d, and it is 2~3d after 60d~124d, the irrigation quota is 185.44g/pot.

4. Ebb-and-flow irrigation technology for soilless potted anthurium

4.1. Experimental plant and design

The test starts planting on July 4, 2009 and ends on November 5, takes totally 124d. The pot density to October 14 is 15 pot/m^2, and 10 pot/m^2 after that day. The planted seedlings have uniform growth, about 18cm high. The tested object is potted anthurium, its variety is "Flame", which belongs to *Araceae* and *Anthurium*. The culture substrate is mixture of PINDSTURP peat soil imported from Denmark and perlite from China in a volume ratio of 10:1, its dry volume mass is 0.16 g/cm^3, and the volume water holding rate (θ_{FC}) is 0.4315. For the tested pot, its top diameter is 16cm, its bottom diameter is 10cm, its height is 12.8cm, and its volume is about 1.4L. There are five treatments in the test, from T1 to T4 are ebb-and-flow irrigation, their nutrient solution depths are 1/2, 1/3, 1/4 and 1/5 of the pot height (*H*). T5 is drip irrigation treatment, as shown in Table 5.

Growth stage	Add English version				
	T1	T2	T3	T4	T5
Whole growth period	Nutrient solution depth of $\frac{1}{2}H$	Nutrient solution depth of $\frac{1}{3}H$	Nutrient solution depth of $\frac{1}{4}H$	Nutrient solution depth of $\frac{1}{5}H$	Drip irrigation

Note: *H* is the pot height, here the pot height is 12.8cm.

Table 5. Experimental treatments

The water channel bonding with transparent acrylic sheet is used as the culture vessel of ebb-and-flow irrigation. The tested pots are placed according to the production density. Control the liquid volume according to the set nutrient solution depth for each treatment, after 30min soak, discharge residual water. For drip irrigation treatment, use the pressure compensating dripper with water yield of 3.85 L/h (The working pressure range is 0.05~3 MPa), with the flat perforated pipe configured 4 outlets. Connect the drip arrow with uniform 1m long capillary tube, insert shallowly in the substrate within the center area of the flower root system. Place the pot on the bracket, and put the PVC collector under the bracket to collect water leakage;the lower irrigation limit of each treatment are unified as 80% of the substrate water holding rate (θ_{FC}),but the irrigation quota of drip irrigation takes the upper irrigation limit as 100%θFC. Repeat 5 times per treatment. There are the protective plants around the sample. The self-prime stabilized pressure pump with the pressure tank is used; the hydraulicproportioning fertilization pump made by USA is used for drip irrigation. But for ebb-and-flow irrigation, dissolve fertilizer in water directly for fertilization with water. Determine the times of drip irrigation and fertilization as required by production, the fertilization times of ebb-and-flow is same as drip irrigation. Distribute the 5 test areas randomly, management, protection, pest control, and fertilizer solution concentrations are same.

Test treatment	Irrigation system
T1	The irrigation period for the whole growth period is 5~7 d, with an average of 5.6d. Irrigate nutrient solution till 1/2 of the pot height is reached.
T2	The irrigation period for the whole growth period is 4~6 d, with an average of 4.9d. Irrigate nutrient solution till 1/3 of the pot height is reached.
T3	The irrigation period for the whole growth period is 3~5 d, with an average of 3.7d. Irrigate nutrient solution till 1/4 of the pot height is reached.
T4	The irrigation period for the whole growth period is 3~5 d, with an average of 3.7d. Irrigate nutrient solution till 1/5 of the pot height is reached.
T5	The irrigation period for the whole growth period is 2~3 d, with an average of 2.6d. And the irrigation quota is $92.72 g\cdot pot^{-1}$.

Table 6. Irrigation system for all treatments

4.2. Results and discussion

4.2.1. Dynamics of substrate moisture content

Refer to Fig. 6 for substrate moisture content after irrigation of each treatment. For all treatments, the substrate moisture content after irrigation appears slight fluctuation. The ranges of substrate moisture content after irrigation for T1, T2, T3, T4 and T5 are 106.5%~118.2%θ_{FC}, 96.7%~110.0%θ_{FC}, 90.2%~103.4%θ_{FC}, 89.4%~105.0%θ_{FC} and 82.7%~93.1%θ_{FC} respectively. The mean values of substrate moisture contents after irrigation are 112.8%θ_{FC}, 105.8%θ_{FC}, 95.9%θ_{FC}, 96.8%θ_{FC} and 89.1%θ_{FC} respectively. Based on those, the average relative substrate moisture content after ebb-and-flow irrigation is 6.8~23.7%θ_{FC} higher than that of drip irrigation. The moisture contents of T1 and T2 are higher than the other 3 treatments obviously. T1 is the highest, while T5 with drip irrigation treatment is the lowest; the moisture contents of T3 and T4 with ebb-and-flow irrigation are not very different. When the nutrient solution depth does not exceed 1/4 of the pot height, the influence from the nutrient solution depth to the relative substrate moisture rate after irrigation is not large; but when it exceeds 1/4 of the pot height, the influence increases obviously along with increasing of the nutrient solution depth.

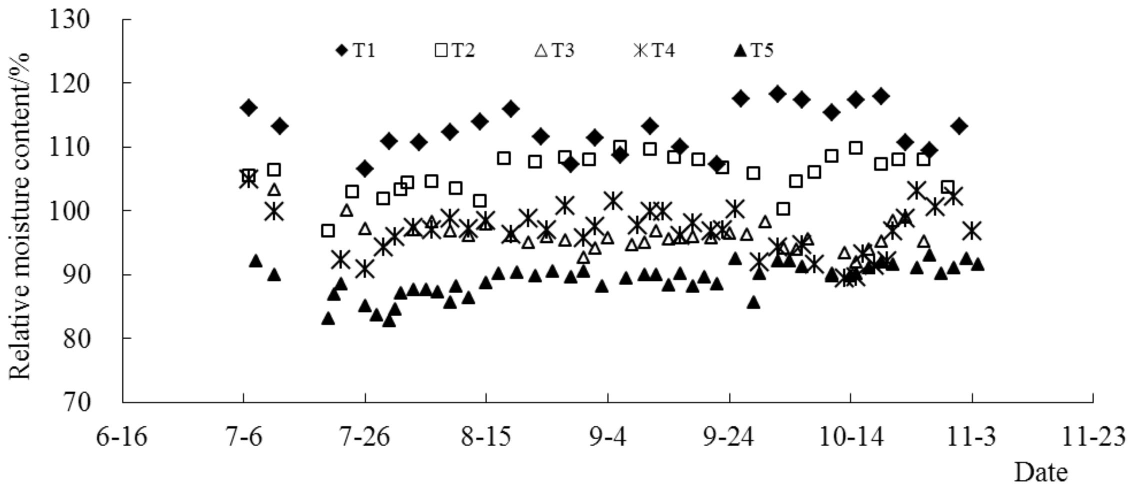

Figure 6. Moisture content after irrigation for all treatments

Refer to Table 7 for the substrate moisture contents analysis during the test. The average relative substrate moisture contents of T1, T2, T3, T4 and T5 are 98.5%θ_{FC}, 95.4%θ_{FC}, 90.4%θ_{FC}, 90.7%θ_{FC} and 84.7%θ_{FC} respectively. The ebb-and-flow is 5.7%~13.8%θ_{FC} higher than drip irrigation. Both of them have the phenomenon that the moisture content exceeds the substrate water holding rate. The moisture content of drip treatment T5 is lower than its substrate water holding rate. So 1/4 of the pot height is the critical value at which nutrient solution may affect the substrate moisture content. When the nutrient solution depth does not exceed 1/4 of the pot height, there is no large influence to the substrate moisture content, but when it exceed 1/4 of the pot height, the proportion of number of days when the moisture content exceeds 100%θ_{FC} increases along with increasing of the nutrient solution depth, while the number of days when it is between 80%~100%θ_{FC} is relatively decreasing.

The substrate moisture content is the main factor of influence for the substrate water, air and temperature environment. Because organic substrate is different from soil, absorption, research on storage and migration of water in substrate is not intensive yet. Qi Haiying (Qi Haiying et al., 2009) find that the substrate pore structure and volume are obviously affected by various water supply modes. Furthermore, pore structure transformation may cause change of water holding capacity. It may be drip arrow local water supply affecting the tested culture substrate volume and pore structure that cause the relative substrate moisture content is lower than the substrate water holding rate after drip irrigation (Ma Fusheng et al., 2012). It is necessary to study further for the law of the pore structure change for soilless culture substrate and its influence to the substrate water absorption, storage and dissipation under various water supply conditions.

Moisture content	Item	Treatment				
		T1	T2	T3	T4	T5
>100%θ_{FC}	Number of days/d	54	43	7	6	0
	Percentage in total test days/%	43.5	34.6	5.6	4.7	0
80%~100%θ_{FC}	Number of days/d	70	81	117	118	124
	Percentage in total test days/%	56.5	65.4	94.4	95.3	100
Average substrate moisture content during the test/(%θ_{FC})		98.5	95.4	90.4	90.7	84.7

Table 7. Level of substrate moisture content for all treatments

4.2.2. Irrigaiton timing and irrigation water use efficiency

In this paper, the irrigation periods of all treatments during the test are 5~7 d (Average 5.6 d) for T1, 4~6 d (Average 4.9 d) for T2, 3~5 d (Average 3.7 d) for T3 and T4, and 2~3 d (Average 2.6 d) for T5 respectively. Based on those, when all the low irrigation threshold are 80% of the substrate water holding rate, the irrigation period of the ebb-and-flow irrigation is longer than drip irrigation. The average irrigation periods of T1, T2, T3 and T4 are 3d, 2.3d and 1d longer than T5, the treatment of drip irrigation, which is in conformity with the law of substrate moisture content change. So 1/4 of the pot height is the critical value of the nutrient solution depth at which the ebb-and-flow irrigation period may be affected. When the nutrient solution depth does not exceed 1/4 of the pot height, there is no large difference among irrigation periods, but when it exceed 1/4 of the pot height, the irrigation period is prolonged along with increasing of the nutrient solution depth. Viz. under the conditions of controlling the same low irrigation threshold, ebb-and-flow irrigation may prolong the irrigation period and reduce manpower. Catherline A. Neal (Catherline A. Neal et al, 1993) find the irrigation period of ebb-and-flow irrigation is longer than drip irrigation, the same result as this paper.

As the main production form of facility flower, substrate potting mainly adopt walking tube-well irrigation, drip irrigation and other traditional water supply technology. The drip irrigation field water utilization coefficient of tested substrate in this paper is only 0.4~0.5 (Ma Fusheng et al., 2012), which is even lower than the limit of 0.9 specified in *Technical code for microirrigation engineering* (GB/T 50485-2009), there is serious clean and good water and fertilizer leakage loss. This may be affected by the dripper flow. According to Li Mingsi and others' (Li Mingsi et al., 2006) study, there is obvious influence to the soil wetting pattern. But the impact of law from the dripper flow on the organic culture substrate wetting pattern with finite volume needs to be study further. With the help of the ebb-and-flow irrigation technology, equipment such as residual water recycling, water treatment and recycling can be used

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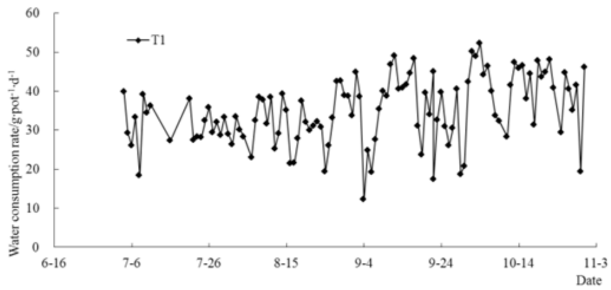
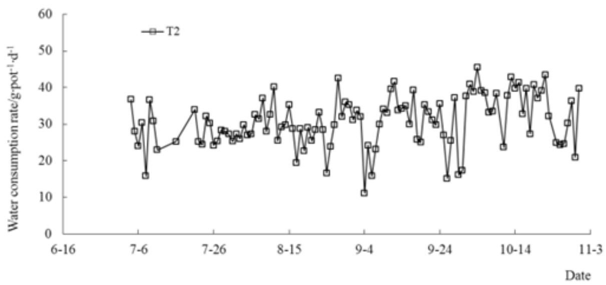
to achieve circulation utilization of water and fertilizer resources, so the water and fertilizer utilization efficiency can be more than 90% (Zhang Xiaowen et al., 2011). To compare with drip irrigation, ebb-and-flow irrigation may improve water and fertilizer utilization efficiency, and reduce their leakage loss significantly.

4.2.3. Water consumption of anthurium

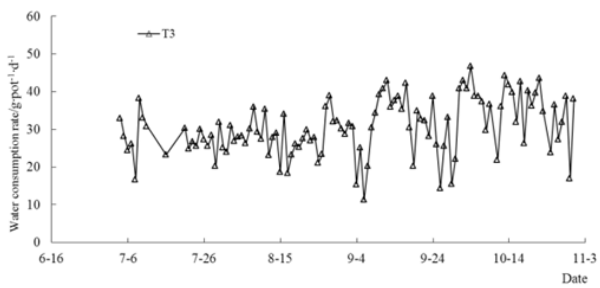
Refer to Fig. 7 for changing process of water consumption rate of anthurium in the 5 treatments. The water consumption rate of the tested anthurium increases gradually with fluctuation along with extension of growth and development. During the test, the Max. water consumption rates of T1, T2, T3, T4 and T4 are 52.3, 47.8, 46.8, 45.2 and 33.6 g/ (pot d) respectively, while the Min. water consumption rates are 12.3, 11.2, 11.3, 9.0 and 7.0 g pot^{-1} d^{-1} respectively, and the averages are 35.1, 31.7, 30.6, 29.8 and 21.1 g pot^{-1} d^{-1}. All the water consumption rates of ebb-and-flow irrigation treatment of anthurium are higher than drip irrigation.



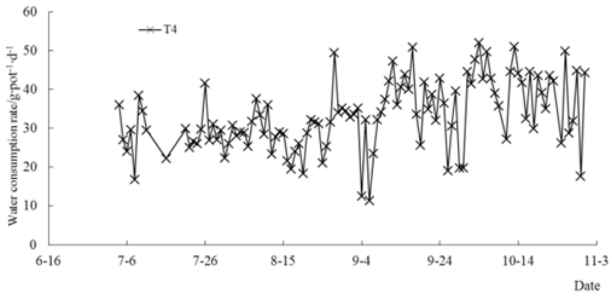
a. T1(Ebb-and-flow irrigation, the nutrient solution depth is 1/2 of the pot height)



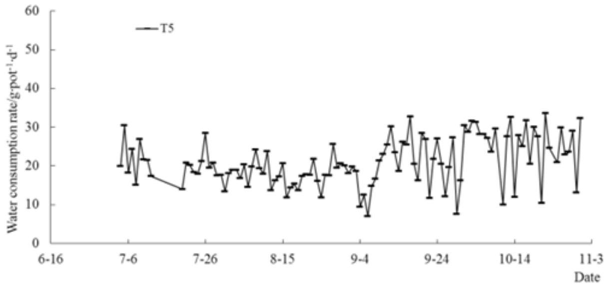
b. T2 (Ebb-and-flow irrigation, the nutrient solution depth is 1/3 of the pot height)



c. T3 (Ebb-and-flow irrigation, the nutrient solution depth is 1/4 of the pot height)



d. T4 (Ebb-and-flow irrigation, the nutrient solution depth is 1/5 of the pot height)



e. T5 (Drip irrigation)

Note: Count by pot.

Figure 7. Daily water consumption for all treatments during experiment

Refer to Table 8 for the monthly average water consumption rate and water consumption during the test. From July to October, the water consumption rate and water consumption of each treatment increase along with plant growth. The irrigation modes affect water consumption of anthurium obviously. The average water consumption rate, monthly water consumption and total water consumption of ebb-and-flow irrigation are higher than drip irrigation obviously during the test, the total water consumptions of T1, T2, T3 and T4 increase 69.3%, 53.2%, 47.5% and 44.2% than T5, so the variation trend of increasing along with increasing of the nutrient solution depth generally.If the nutrient solution utilization efficiency in ebb-and-flow irrigation is 0.9, and in drip irrigation is 0.5, nutrient solution used in ebb-and-flow irrigation during the test is 4 106.6~4 820 g pot^{-1} d^{-1}, 6%~20% lower than drip irrigation (5 124.6 g pot^{-1} d^{-1}), it is reduced distinctly.

Item	Treatment	Time				
		07-04-07-31	08-01-08-31	09-01-09-30	10-01-11-04	Total
Average water consumption rate /(g·pot^{-1}·d^{-1})	T1	30.8	32.0	34.2	41.7	-
	T2	27.6	29.6	30.5	37.8	-
	T3	26.7	28.3	29.9	36.0	-
	T4	27.1	28.5	26.7	35.8	-
	T5	18.1	18.0	20.0	25.7	-

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Item	Treatment	Time				
		07-04-07-31	08-01-08-31	09-01-09-30	10-01-11-04	Total
Water consumption/ ($g \cdot pot^{-1}$)	T1	861.8	991.4	1026.3	1458.2	4337.6
	T2	771.8	918.9	914.1	1321.8	3926.7
	T3	747.4	876.6	896.8	1259.5	3780.2
	T4	758.6	884.9	801.0	1251.4	3695.9
	T5	505.6	559.5	599.1	898.0	2562.3

Table 8. Daily and total water consumption amount of Anthurium for all treatments from 07-04 to 11-04

4.2.4. Growth and quality of anthurium

The plant height and the crown diameter are the key indexes concerned ornamental quality of the anthurium, refer to Fig. 8 for the plant height and the crown diameter of the anthurium in each treatment. By the end of the test, the plant heights of T1, T2, T3, T4 and T5 are 33.6, 34.7, 35.3, 38.4 and 27.0 cm respectively, the crown diameters are 41.9, 42.6, 40.6, 43.9 and 33.3 cm respectively. The plant heights and the crown diameters from ebb-and-flow treatment are better than drip irrigation treatment obviously (p=0.05). The plant height of T4 in ebb-and-flow treatment is 14.3% higher than T1 (p=0.05), but the plant heights among other treatments and the crown diameters of all treatments have no obvious difference.

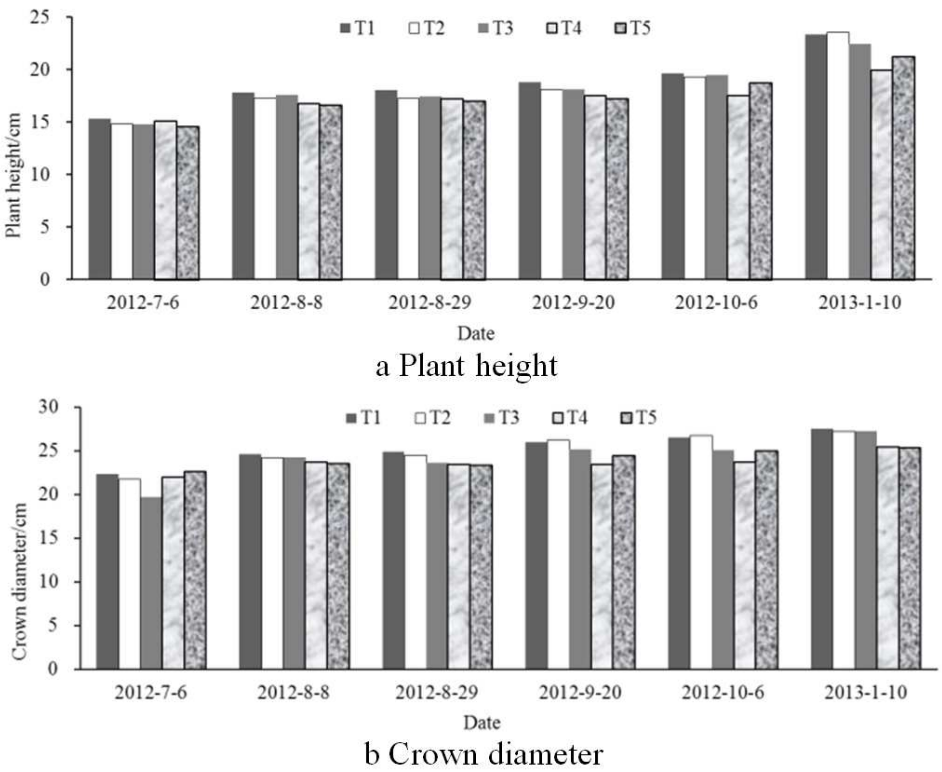


Figure 8. Plant height and crown diameter for all treatments

Refer to Table 9 for the spathe of each treatment. The spathe is the main ornamental part of the anthurium. By the end of the test, the quantity difference of the spathe in each treatment is not large, all are about 3. Compared with T5 of drip irrigation, the length of the spathe with ebb-and-flow irrigation increases 0.8~1.5 cm, the width of it increases 0.5~1.8 cm, except for the inflorescence height of T4 with ebb-and-flow irrigation treatment is about 1cm higher than T5, the inflorescence heights of other treatments have no large difference from T5. There is no obvious difference among treatments (p=0.05).

Treatment	Parameters			
	Qty. of spathe/pc	Length of spathe/cm	Width of spathe/cm	Height of inflorescence/cm
T1	3.0	11.2	7.8	3.7
T2	2.6	11.5	8.1	3.6
T3	2.4	11.9	8.2	3.7
T4	3.4	12.9	9.1	4.4
T5	2.4	10.4	7.3	3.4

Table 9. Spathes of all treatments

In conclusion, when the low irrigation threshold are controlled to 80% of the substrate water holding rate, growth of the anthurium is affected obviously from irrigation modes. Anthurium growth of ebb-and-flow treatment is better than that from drip irrigation treatment. The anthurium plant height and spathe size of T4 with the nutrient solution depth being 1/5 of the pot height appear uniform superiority.Catherine A. Neal (Catherine A. Neal et al. 1992) find plant growth is affected by irrigation modes, while ebb-and-flow irrigation is a technology that may improve irrigation water utilization efficiency and get potential optimal growth. Interaction between water and fertilizer is an important factor for plant growth. John M. Dole (John M. Dole et al, 1994) find the Poinsettias with ebb-and-flow irrigation has the best water utilization efficiency, plant height, stem diameter, leaf width and total amount of dry matter, in addition, its growth is affected by the nutrient concentration of the nutrient solution. Daniel I. Leskovar (Daniel I. Leskovar et al, 1998) find the irrigation mode, water regime and fertilizer application are key for growth of the plant root system and sprouting, but their interaction mechanism needs intensive study. Ma Fusheng (Ma Fusheng et al., 2011) find the lower irrigation limit affect anthurium growth even under drip irrigation conditions. Influence to anthurium growth from various irrigation modes in this paper may be caused by water and fertilizer coupling mechanism of each treatment, the influence mechanism from soilless culture water and fertilizer utilization to plant growth needs intensive study.

4.2.5. Suitable irrigation system for anthurium

According to experimental results, the quantity, length and width of the spathe, in addition to the inflorescence height of T4 with the nutrient solution depth as much as 1/5 of the pot height are the best. In addition, its water consumption is 15% less than T1. So it is the suitable nutrient solution control depth with ebb-and-flow irrigation, here the nutrient solution depth is 2.56cm, identify with the result of 25mm for most flower nutrient solution depth recommended by Yang Tieshun (Yang Tieshun et al., 2009). So in the testing conditions of this paper, in order to get optimal anthurium quality, the 1/5 pot height shall be taken as the ebb-and-flow irrigation nutrient solution depth, viz. 2.56cm, the irrigation period is affected by water, fertilizer, air and temperature environment of flower, it is 3~5d.

4.3. Conclusions

(1) The irrigation technologies are key factor to the substrate moisture content, the irrigation period and the water consumption law. The substrate moisture content after ebb-and-flow irrigation is between 96%~113%θ_{FC}, increase 7%~23%θ_{FC} than 89.1%θ_{FC} of drip irrigation; the average substrate moisture content during the ebb-and-flow test is 90.4%~98.5%θ_{FC}, increase 5.7%~13.8%θ_{FC} than 84.7%θ_{FC} of drip irrigation treatment. The anthurium water consumption with ebb-and-flow irrigation is 3 696~4 338 g pot^{-1} d^{-1}, increase 44.2%~69.3% than 2 562.3 g pot^{-1} d^{-1} of drip irrigation; the irrigation water utilization increases from 0.4~0.5 of drip irrigation to 0.9, the irrigation nutrient solution reduces from 5124.6g/pot to 4106.6~4820.0g/pot; the irrigation period of ebb-and-flow irrigation is 3~7 d, extending 1~3 d than drip irrigation in average, which improve the labor productivity.

(2) The irrigation modes have significant influence to quality of the anthurium. The plant height of the anthurium in ebb-and-flow irrigation treatment is 33.4~38.6 cm, 6.6~11.4 cm higher than 27.0 cm in drip irrigation, the crown diameter is 40.6~43.9 cm, 7.3~10.6 cm higher than 33.3 cm in drip irrigation; the length and width of the spathe are 11.2~12.9~cm and 7.8~9.1 cm, 0.8~1.5 cm and 0.5~1.8 cm higher than 10.4cm (Length) and 7.3cm (Width) in drip irrigation respectively, the inflorescence height of the spathe is 3.6~4.4 cm, 0.2~1.0 cm higher than 3.4cm in drip irrigation treatment.

(3) The 1/4 pot height is the critical value of the nutrient solution depth that affects the substrate moisture content, the anthurium water consumption and the irrigation period of ebb-and-flow irrigation. When the nutrient solution depth is not more than the 1/4 pot height, there are no large differences among the substrate moisture content, the anthurium water consumption and the irrigation period; but when it is more than the 1/4 pot height, the substrate moisture content, the anthurium water consumption and the irrigation period soar along with increasing of the nutrient solution depth.

(4) When the ebb-and-flow irrigation nutrient solution depth reaches the 1/5 pot height, the ornamental value of the anthurium is optimal, furthermore, the water consumption reduces 15% than that of T1 at which the nutrient solution depth is the 1/2 pot height. The total irrigation water consumption reduces 20% than drip irrigation. Here the nutrient solution depth is 2.56cm, the irrigation period is between 3~5d, the average value is 3.7d. So 2.56cm can be the better nutrient solution depth under the testing conditions.

5. Experimental research on suitable dripper discharge for potted anthurium with soilless culture

5.1. Experimental plant and design

The anthurium is chosen as the testing object; its variety is "Alabama", which belongs to *Araceae* and *Anthurium*. The culture substrate is PINDSTURP peat soil imported from Denmark, with the dry volume mass of 0.16g/cm^3, and the water holding rate (θ_{FC}) of 0.4315 (V/V). The tested anthurium is cultivated in plastic pot with 16cm of top diameter and 12.8cm of height, the volume is about 1.4L, and the substrate is filled to the pot evenly. Refer to Table 10 for testing treatment.

Testing stage	Dripper flow/(L/h)				
T1	T2	T3	T4	T5	
Whole growing period	0.55	0.95	1.1	2.2	3.8

Table 10. Experimentle treatments

Note: T1 adopts the plain end water separator configured 4 outlets with the flow of 2.2L/h, T2 adopts the plain end water separator configured 4 outlets with the flow of 3.8L/h, T3 adopts the plain end water separator configured 2 outlets with the flow of 2.2L/h, T4 adopts the 2.2L/h dripper, and T5 adopts the 3.8L/h dripper, the capillary tube after the distributive pipe connects the drip arrow.

In this paper, all treatment irrigation quota are controlled by the substrate water holding capacity as the upper irrigation limit, and 60% of the substrate water holding capacity as the lower irrigation limit. The test starts on June 6, 2012 and ends on January 12, 2013, takes 221d totally. The placing density of tested anthurium plantlet is 27 pot/m^2; and 23 pot/m^2 from August 9, 2012 to the end of the test. The plantlet is 16cm in height with uniform growth when transplanting. For all treatments, connect the drip arrow with uniform 1m long capillary tube, insert shallowly in the pot substrate from the side direction about 1cm within the center area of the root system. Place the pot on the bracket. Repeat 7 times per treatment. There are the protection lines at both sides of the monitored sample plant. The self-prime stabilized pressure pump with the pressure tank is used for driving; the hydraulicproportioning fertilization pump made by USA is used for fertilization with water.All test plots are distributed randomly, the treatment measures such as farming, fertilizing, and pest control are same.

5.2. Results and discussion

5.2.1. Influence to water consumption of soilless potted anthurium from emitters with various dripper flows

The water consumption rate of tested anthurium was analyzed in this paper. Table 11 shows the water consumption rate of each treatment is between 8~24g pot^{-1} d^{-1} in June and July, and between9~32 g pot^{-1} d^{-1} in August and September, reaching the peak of water consumption 12~36g pot^{-1} d^{-1} in October, and falling back to 8~24g pot^{-1} d^{-1} in November and December. The change process from June to December is rise-fall. Refer to Table 11 for the average monthly water consumption rate and the water consumption per treatment.

Item	Treatment	Month							
		6	7	8	9	10	11	12	Total
Average water consumption rate/ g·pot^{-1}·d^{-1}	T1	16.6	17.3	20.5	20.0	22.6	17.3	17.1	——
	T2	16.0	16.9	19.4	19.0	21.9	16.8	17.3	——
	T3	16.0	17.0	19.7	18.9	22.7	17.0	17.3	——
	T4	15.9	15.7	17.7	17.4	21.5	16.4	16.7	——
	T5	15.8	16.1	18.9	17.7	21.0	16.6	16.7	——
Water consumption/ g·pot^{-1}	T1	414	479	637	599	679	485	529	3823
	T2	400	466	609	571	657	471	536	3709
	T3	400	472	612	567	680	476	535	3743
	T4	397	437	548	522	643	459	517	3523
	T5	396	448	585	530	629	464	517	3569

Table 11. Daily and total water consumption amount of all treatments

According to Table 11, the water consumptions of each treatment in the whole growth period are 3823g pot^{-1} of T1, 3709g pot^{-1} of T2, 3743g pot^{-1} of T3, 3523g pot^{-1} of T4 and 3569g pot^{-1} of T5, the variation trend goes down along with increasing of the dripper flow. The water consumption of T1 with the Min. dripper flow is the highest, which is about 8% more than T5 (The Max. dripper flow) and T4 (The second largest dripper flow). This may be that the dripper with a small flow can establish a higher substrate moisture content, thereby creates more favorable transpiration environment. The water consumptions of T2 and T3 (Their dripper flows are not different greatly) are also close. Though the dripper flow of T4 is far lower than T5, there is no large difference between their water consumption. So increasing the anthurium water consumption by reducing the dripper flow has obvious effect only in a certain range and certain gradient. Wang Xiukang (Wang Xiukang et al., 2010) find the influence to corn root system from the dripper flow. When 1L h^{-1}~2.5L h^{-1}is chosen as the dripper flow, the dripper flow of 2L h^{-1}has obvious influence to spatial distribution of corn root system.

5.2.2. Influence to irrigation period of soilless potted anthurium from emitters with various dripper flows

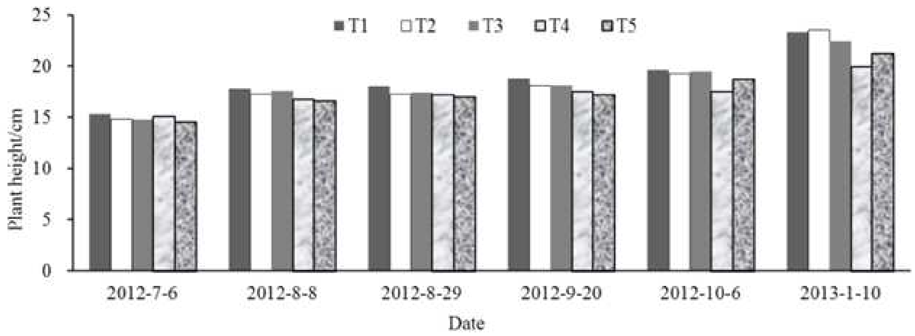
Refer to Table 12 for influence of soilless potted anthurium irrigation period (*T*) from emitters with various dripper flows. The irrigation period goes up along with decreasing of the dripper flow, so the manpower cost can be saved.

Treatment	T1	T2	T3	T4	T5
T (d)	8.3	8.1	8.1	7.6	6.3

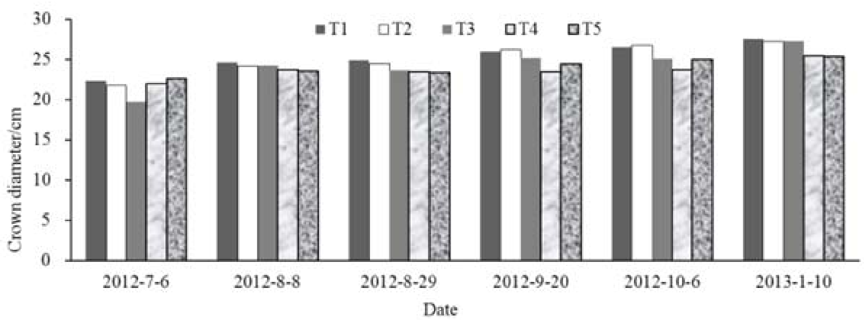
Table 12. Effect of different dripper discharge to water use efficiency and irrigation cycle of Anthurium

5.2.3. Influence to anthurium growth and quality from emitters with various dripper flows

There is no obvious difference on the tested anthurium spathe by the end of the test. Analyze the monitoring information of July 6, August 8, August 29, September 20, October 6 and December 31. Refer to Fig. 9 (a) for influence to tested anthurium plant height from various dripper flows, and to the crown diameter refer to Fig. 9 (b).



a Plant height



b Crown diameter

Figure 9. Effect of different low irrigation threshold to plant height and crown diameter

Based on Fig. 9, there is no large difference on the anthurium plant height and the crown diameter under the treatment conditions of T1, T2 and T3 (With lower dripper flows), all of them have obvious growth vigor. The plant heights and the crown diameters of T4 and T5 are lower than the first 3 treatments. By the end of the test, the plant heights of each treatment are

23.3cm of T1, 23.5cm of T2, 22.4cm of T3, 19.9cm of T4 and 21.2cm of T5; the crown diameters are 27.5cm of T1, 27.2cm of T2, 27.3cm of T3, 25.4cm of T4 and 25.3cm of T5.

5.2.4. Selection of drip irrigation emitters suitable for tested soilless potted anthurium

Based on comprehensive analysis on influence to the tested anthurium substrate moisture content, anthurium water consumption, field water utilization coefficient, irrigation period and anthurium quality from various dripper flows, to compare with T5, the anthurium water consumption of T1~T3 increases 5%~8%, and the irrigation period prolongs 1~2d, in addition to better ornamental effect on the anthurium plant height and crown diameter, especially the comprehensive advantage of T1. So within the range of the tested dripper flow, the dripper flow of 0.55L h^{-1} is recommended for tested soilless potted anthurium, with the irrigation period of 8.3d. Because of the limited research conditions in this paper, the suitability to tested anthurium irrigation if the dripper flow continues to reduce needs further investigation.

The low irrigation threshold in this paper is 60%θ_{FC}. Ma Fusheng (Ma Fusheng et al., 2012) and others find there is obvious law of influence to the field water utilization coefficient of soilless potted anthurium under the same dripper flow in various low irrigation threshold, the higher lower irrigation limit, the larger field water utilization coefficient. Selection and supporting technology of dripper flow under various low irrigation threshold needs further study. Good water and fertilizer resource leakage loss in drip irrigation is serious, and becomes major environmental pollution source, so it is urgent to research the water absorption and storage mechanism of soilless culture substrate, develop the substrate culture drip irrigation technical mode, develop the substrate materials with stable physicochemical properties, improve cyclic utilization of good water and fertilizer resource, improve the utilization efficiency of water and fertilizer resource meanwhile guarantee flower quality, in order to support the flower industry for the achievement of water-saving irrigation, good product quality, industrial environment protection and so on.

5.3. Conclusions

(1) The water consumption rate of the tested anthurium increases from 8~24g pot^{-1} d^{-1} in June to 12~36g pot^{-1} d^{-1} in October, and then fall back to 8~24g pot^{-1} d^{-1} in December; the water consumption of the whole growth period per treatment is 3569g pot^{-1}~3823g pot^{-1}, with the change trend of decreasing along with the increasing of the dripper flow.

(2) Under the 3 low-flow drippers with the flows of 0.55L h^{-1}, 0.95L h^{-1} and 1.1L h^{-1}, the plant height and the crown diameter of the anthurium have no large difference, but all of them are higher than the two treatments of 2.2L h^{-1} and 3.85L h^{-1}, which affects the spathe largely. So a dripper with the small flow is conductive to good quality.

(3) The small dripper flow may prolong the irrigation period for about 2d, and get better ornamental quality. To compare and select the tested drippers based on the economic benefit and water utilization efficiency, the small-flow dripper is suitable for the soilless substrate potted flower.

6. Research on moisture characteristic parameters for soilless culture substrate

6.1. Test design

Perform the single factor test with typical soilless culture substrates, and use sandy soil and sandy loam soil for the contrast test. There are 10 treatments, domestic peat (T1), vermiculite (T2), perlite (T3), peat imported from Germany (T4), domestic peat and vermiculite in 2:1 of mass ratio (T5), domestic peat and perlite in 2:1 of mass ratio (T6), domestic peat, vermiculite and perlite in 1:1:1 of mass ratio (T7), domestic peat, vermiculite and perlite in 3:1:1 of mass ratio (T8), sandy soil (CK1), sandy loam soil (CK2). Because perlite and peat imported from Germany have large particle, so the air-dried volumetric specific gravities when filling are 0.12 g/cm^3 and 0.15 g/cm^3 respectively, sandy soil and sandy loam soil are 1.4g/cm^3, the other treatments are 0.25 g/cm^3. Determine the moisture characteristic parameters such as the porosity, the permeability coefficient, the water characteristic curve, the diffusivity and so on for each treatment. Repeat 3 times per treatment.

6.2. Results and analysis

6.2.1. Porosity

During practical production of seedling raised with substrate, the total porosity is normally 70%~90%, the water-air ratio is normally 2.0~4.0, which may meet demands of crop to moisture and oxygen (Li Douzheng, 2006). But a single substrate is hard to meet all those requirements at the same time. Refer to Table 13, the water holding porosity of vermiculite (T2) is large, viz. vermiculite has good water holding capacity, but poor aeration porosity, so its water-air ratio is unreasonable. The perlite (T3) has large aeration porosity, viz. perlite has good air permeability, but poor water holding capacity. So in the mixtures of T5, T6, T7 and T8, vermiculite is used to improve its water holding capacity, and perlite is used to improve the air permeability.

	T1	T2	T3	T4	T5	T6	T7	T8	CK1	CK2
Total porosity/%	80.11	81.10	82.41	81.82	78.09	82.45	78.42	84.73	50.74	40.55
Aeration porosity/%	18.38	14.91	37.10	18.01	19.51	21.90	20.70	21.90	2.84	1.94
Water holding porosity/%	61.73	66.19	45.31	63.81	58.58	60.55	57.72	62.83	47.90	38.61
Water-air ratio	3.35	4.44	1.22	3.54	3.00	2.77	2.79	2.87	16.87	19.90

Table 13. Comparison of the different height containers

Refer to table 13, the porosity of the substrate is higher than sandy soil (CK1) and sandy loam soil (CK2) obviously, this is due to the particle of sandy soil and sandy loam soil is small, and the unit weight is considerably higher than that of the substrate. Thereby the porosity of sandy soil and sandy loam soil is small. To compare with sandy soil and sandy loam soil, moisture in substrate is easier to be used by plant, to compare the above mentioned 4 mixed substrate, T8 has the Max. porosity of 84.7%, the water-air ratio of 2.9, so it has large total porosity and good air permeability, and a reasonable water-air ratio.

6.2.2. Analysis of permeability coefficient

The permeability coefficient is an important index to affect plant growth, a permeability coefficient suitable for plant growth depends on the soil type. Normally sandy loam soil, loam and clay are suitable for corn growth. The permeability coefficients of the 3 kinds of soil are 6×10^{-2}, 6×10^{-3} and 6×10^{-4}mm min^{-1}(Du Yanling et al., 1992). Currently, there is seldom research on the permeability coefficient of a substrate. If the permeability coefficient is too high, the substrate is difficult to hold water to cause leakage after irrigation and waste water resource, if the permeability coefficient is too low, the air permeability of the substrate is bad, which may affect breath and growth of the root system (Shi Lianhui et al., 2008).

Refer to Fig. 10, except for T3 and CK1, the standard deviations of all treatments are all 0.2%~10% without large fluctuation. It means this determination method for the permeability coefficient can represent the permeability coefficient of a substrate. The permeability coefficient of sandy loam soil is 5×10^{-2} mm/min, which can meet requirement for corn growth. After comparing the permeability coefficients of CK2 and the substrate, the permeability coefficient of the substrate is higher than CK2 obviously for the aeration porosity of the substrate is larger, and water infiltration rate is faster than sandy loam soil after irrigation. So it may reach the corn water demand quickly, and little and frequent irrigation is appropriate. By comparing the permeability coefficients of substrates, the permeability coefficient of T2 is the largest, 2.20 mm min^{-1}, while T6 is the smallest. In addition, the permeability coefficient of a single substrate is higher than the composite substrate obviously, for there are more small particles in the composite substrate to blocking the pores in the substrate to slow down the permeation. So if a single substrate is used for culture and seedling, the irrigation frequency shall be adjusted reasonably.

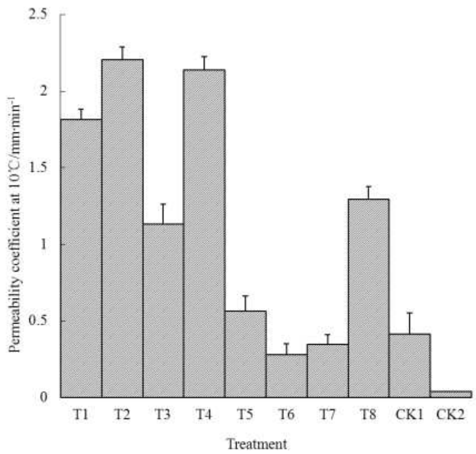


Figure 10. Comparison of permeability coefficient

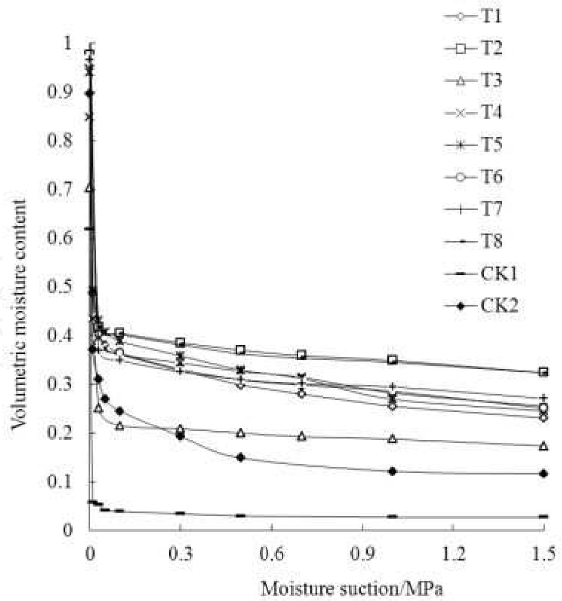


Figure 11. Comparison of moisture retention curves

In the drip irrigation engineering design, the dripper spacing is an important index to affect irrigation evenness, while the permeability coefficient is an important index to affect the dripper spacing (Yao Zhenxian et al., 2012). The dripper spacing suitable for the substrate shall be determined according to the dripper flow in order to improve the water utilization efficiency of the drip irrigation system.

6.2.3. Water characteristic curve

As shown in Fig. 11, at the lower suction stage at which the moisture suction is less than 0.1Mpa, the volumetric moisture contents of 10 treatments reduced sharply along with increasing of suction. The water holding capacity of T8 and T2 is the largest, and CK1 is the smallest. At the stage with the moisture suction is more than 0.1Mpa, the volumetric moisture contents reduce a little along with increasing of suction. Refer to Fig. 4 for the moisture content distribution, within the effective water range, viz. the substrate moisture suction is 0.01-0.1Mpa, the standard deviation of each treatment is 0.8%~3% with small fluctuation, it means the water characteristic curve can represent the water characteristic curve of the substrate.

In recent years, Kang Yuehu and others control the irrigation water suitable for growth and moisture efficient utilization of vegetables such as Chinese cabbage, cowpea and tomato under drip irrigation by controlling the soil matric potential. They guide irrigation of vegetableswithin the lower soil matric potential limit of -0.02~-0.05Mpa (Jiang Shufang et al., 2009; Zhang Chao et al., 2010; Wan Shuqin et al., 2009; Theodore W Sammis et al, 1980; Jia Junshu et al., 2011; Riviere L M et al, 2001). At the same time, take the volumetric moisture content within the ranges of 0.01~0.1Mpa, 0.01~0.05Mpa and 0.05~0.1Mpa of substrate water suction as the basis for division of substrate available water, easy available water and buffer water.

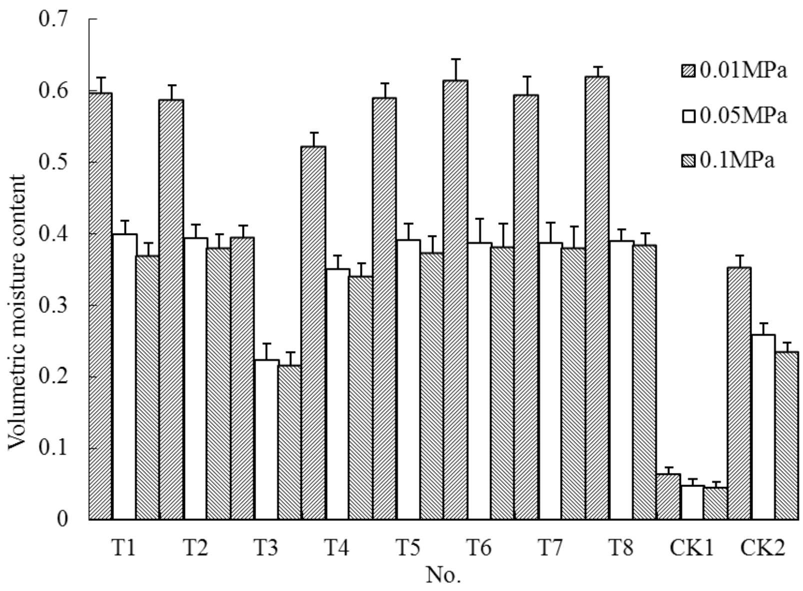


Figure 12. Comparison of water content between 0.01and 0.1 Mpa

The available water, easy available water and buffer capacity are important indexes to judge water available for absorption by plant and guide the irrigation frequency (Shi Lianhui et al., 2008). The available water, easy available water and buffer capacity of 8 substrates may be obtained by the known water characteristic curve as Table 14 shown.

	T1	**T2**	**T3**	**T4**	**T5**
Available water	22.7	20.8	17.9	18.1	21.7
Easy available water	19.6	19.3	17.1	17.1	19.8
Buffer water	3.1	1.5	0.8	1.0	1.9
	T6	T7	T8	CK1	CK2
Available water	23.3	21.3	23.5	2.0	11.7
Easy available water	22.6	20.6	22.9	1.7	9.3
Buffer water	0.7	0.7	0.6	0.3	2.4

Table 14. Available water, easy available water and buffer capacity

As shown in Table 14, the available water capacity of substrate is higher than that of CK1 and CK2 obviously, which means the available water in the substrate is more higher, so crop may absorb more water in the substrate than in sandy soil or sandy loam soil. To compare the 8 substrates, both available water and easy available water in T8 are the highest, secondly is T6, which means the available water content in T8 and T6 is higher, so crop may absorb more available water. Their irrigation frequencies can be reduced than other substrates.

6.2.4. Analysis of horizontal diffusivity

As Fig. 13 shown, when θ<0.3, the diffusivity changes slowly along with increasing of the moisture content, moisture in the substrate is mainly vapor movement [31] (Fan Yanwei, 2008); when θ>0.3, the diffusivity soars along with increasing of the moisture content, a higher substrate moisture content is in favor of substrate diffusive motion; when θ=0.3, refer to Table 3 for the diffusivity of each treatment.

When θ=0.3, the diffusivity of sandy soil is the largest, 654.75 $cm^2\ min^{-1}$, which means the horizontal suction and seepage velocity is quick, moisture spreads horizontally quickly; the second is perlite, 249.15 $cm^2\ min^{-1}$. Because perlite is lighter with smaller unit weight and larger particle size, moisture spreads quickly in perlite; to compare with sandy loam soil, the diffusivity of the substrate is higher, which means the horizontal diffusion velocity in substrate is quick. Thereby when using substrate as breeding and culture substrate, drip irrigation may improve the evenness and be in favor of crop water absorption.

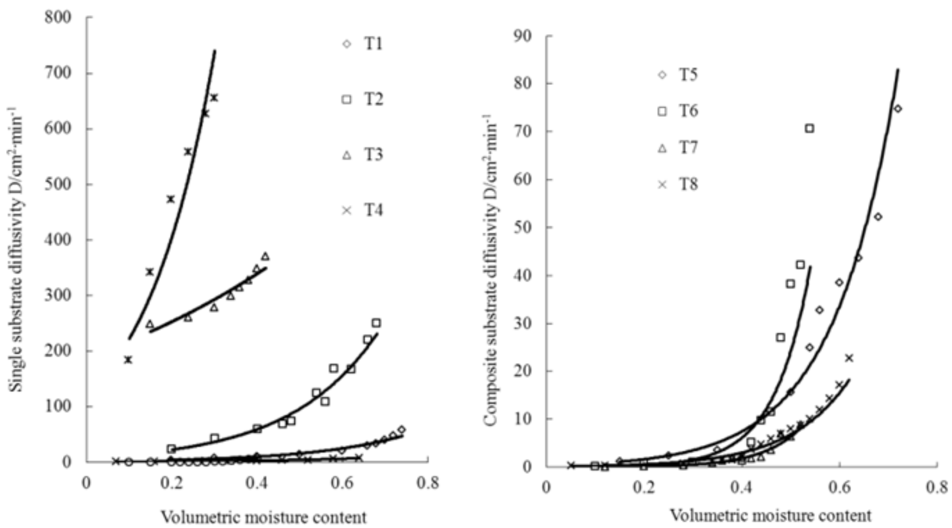


Figure 13. Correlation curve between diffusivity and water content

As Table 15 shown, fit the relation curve of diffusivity D and moisture content θ to get the formula of diffusivity D and moisture content θ.

No.	Fitting relation	Determination coefficient R^2
T1	$D(\theta)=1.6013e^{4.57240\theta}$	0.9771
T2	$D(\theta)=8.5301e^{4.84910\theta}$	0.9732
T3	$D(\theta)=188.64e^{1.46850\theta}$	0.9051
T4	$D(\theta)=0.6172e^{3.82620\theta}$	0.9804
T5	$D(\theta)=0.3662e^{7.53080\theta}$	0.9844

http://dx.doi.org/10.5772/59466

No.	Fitting relation	Determination coefficient R^2
T6	$D(\theta)=0.0256e^{13.694\theta}$	0.9050
T7	$D(\theta)=0.013e^{12.38335\theta}$	0.9823
T8	$D(\theta)=0.1142e^{8.186\theta}$	0.9511
CK1	$D(\theta)=122.04e^{6.00559\theta}$	0.9155
CK2	$D(\theta)=0.0034e^{18.611\theta}$	0.9572

Table 15. Comparison of diffusivity fitted formulas

As shown in Table 15, the relationship between the horizontal diffusivity of substrate and moisture content of substrate are all match with the empirical formula $D(\theta)=ae^{b\theta}$, changed as exponential function. The two have highly significant positive correlation relationship.

6.2.5. Comprehensive analysis

Comprehensive assessment is performed to the 8 tested substrates with the matrix method, the standard is the larger total porosity (70%~90%), the higher score; the water-air ratio close to 3.0 is the best; because the substrate is hard to hold water, easy to leak after irrigation, the lower permeability coefficient, the higher score; for water availability, the larger substrate available water content, the higher score; since the diffusivity may affect water absorption by crop, the larger diffusivity, the higher score. Finally, comprehensive assessment is performed according to the synthesis score to various substrates; refer to Table 16.

Influence factor	T1	T2	T3	T4	T5	T6	T7	T8
Total porosity	3	4	7	5	1	6	2	8
Water-air ratio	4	2	1	3	8	5	6	7
permeability coefficient	3	1	5	2	6	8	7	4
Water availability	6	3	1	2	5	7	4	8
diffusivity	6	7	8	4	5	2	1	3
Synthesis score	22	17	22	16	25	28	20	30

Table 16. Matrix table

Accordingly, the synthesis scores of T6 and T8 are higher than other substrates obviously, which means T6 and T8 are better than others. Viz. the total porosity of T6 and T9 are larger, with good air permeability, reasonable water-air ratio, higher available water content, and in favor of crop absorption. Though the permeability coefficient and diffusivity of T8 are smaller, the irrigation evenness can be controlled by adjusting the irrigation frequency and irrigation amount.

6.3. Conclusions

1. By comparing the porosities of 8 substrates, the substrate formed by Domestic peat, vermiculite and perlite in a mass ratio of 3:1:1 has the largest total porosity, 84.7%; its water-air ratio is 2.9 with good air permeability and reasonable water-air ratio.

2. By comparing the permeability coefficients, the permeability coefficient of single substrate is higher than the composite one. When a single substrate is selected for as the culture and breeding substrate, please pay attention to adjust the irrigation frequency reasonably.

3. By comparing the 8 substrates, the available water and easy available water capacity of the substrate with a mass ratio of 3:1:1 among domestic peat, vermiculite and perlite, and the one with a mass ratio of 2:1 between domestic peat and perlite are the highest, viz. the absorbable water for crop is high.

4. The relationship between the horizontal diffusivity of substrate and the moisture content of substrate are all match with the empirical formula $D(\theta)=ae^{b\theta}$, changed as exponential function. The two have highly significant positive correlation relationship.

5. According to the comprehensive assessment with the matrix method, the substrate mixed with domestic peat and perlite in a mass ratio of 2:1, and the substrate mixed with domestic peat, vermiculite and perlite in a mass ratio of 3:1:1 are the best. The total porosity of the two substrates are larger, with good air permeability, reasonable water-air ratio, higher available water content, and in favor of crop absorption, so they may be promoted and applied in production.

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