行政院國家科學委員會補助專題研究計畫成果報告

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計畫主持人：葉德銘
共同主持人：

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中　華　民　國　89　年　9　月　25　日

行政院國家科學委員會專題研究計畫成果報告
國科會專題研究計畫成果報告撰寫格式說明
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一、中文摘要

為減少傳統灌溉造成 20%-60%的溢流和淋溶對環境造成污染, 本研究探討不同養液濃度於潮汐灌溉系統下對綠巨人白鶴芋生長之影響, 並比較潮汐灌溉與傳統澆灌對其生產之效益。潮汐灌溉宜在 1/2 至 1/4 Johnson 氏營養液下得到品質較佳的綠巨人白鶴芋。介質 EC 值隨營養液濃度增加而增加, 到栽培後期全量營養液處理者介質的上層 EC 高達 7.19mS/cm，然而在使用 1/4 Johnson 氏營養液用量下，其中上層介質之 EC 值仍能維持在 0.79mS/cm 在右，不會影響根部之生長, 顯示低肥量適合綠巨人白鶴芋潮汐灌溉之生產方式。潮汐灌溉生產的綠巨人白鶴芋在維持相同灌溉類頻率的情況下, 植株之生長量與傳統澆灌生長之植株並無顯著差異, 能夠減少下位黃葉和皺摺葉之發生。減少用水量達 33%及提高水份利用效率達 40%，能減少氮素之使用量達 33%，椰粉之充氣孔隙度和保水力較加拿大水苔泥炭為低，然而椰纖以 33-60%與珍珠石、蛇木屑混合後, 其物理性質皆符合理想之範圍內。椰粉和泥炭苔的 pH 值皆在理想範圍 (~pH5.8)，然而椰纖的 EC 較高 (2.16mS/cm), 以飽和萃取法(SME)分析其元素含量，Na 含量為泥炭苔之 6 倍，K 含量為泥炭苔之 3 倍，然而椰纖含 P、Mg、Ca 等元素較少。若介質以椰粉取代，氮素用量在 4-8mM 處理下，潮汐灌溉處理在地上部乾重及葉面積皆相等於泥炭苔以 4-8mM 氮素澆灌處理者。葉片中氮含量隨施用氮素增加而增加，但施用量增加至 16mM 時。葉片 K、Ca 和 Mg 元素含量隨著葉片中 N 元素含量增加而遞減, 壞疽葉片數亦同時有增加之趨勢。在低氮素使用下，潮汐灌溉可以部分解決椰粉保肥力不足之問題, 在使用椰粉取代泥炭苔之同時, 配合潮汐灌溉系統可獲得更佳之效益。

關鍵詞：潮汐灌溉、與椰纖、白鶴芋

Abstract

In order to reduce the irrigation run-off and contamination of the underground water, effects of different nutrient levels were investigated in *Spathiphyllum* “Sensation” grown in an ebb and flow system, and comparison on the growth with hand-watering was also determined. Environmental and economical concerns had generated interest in the development of substitutes to peat, under the conditions of this study, coir-based media was also used in the experiments to compare the growth responses of *Spathiphyllum* “Sensation” under the ebb and flow system.

Plants grew equally well from a range of 1/4 to full-strength of Johnson’s solution in the ebb and flow system, indicating the possible luxury consumption of plants was grown in the full-strength treatment, moreover, full-strength treatment produced more necrotic leaves and reduced the root growth. However, the chlorophyll content was lower in the 1/4-strength treatment and leaves showed chlorotic spots symptoms. In the full strength treatment, a high EC of 7.19mS/cm was measured in the upper portion of the medium measured at the end of the experiment, whereas for the 1/4 strength treatment, EC at the root zone was maintained at 0.79mS/cm, which was considered to be save for the plant growth. These results indicated that a range of 1/4 to half strength of Johnson’s solution was optimum for the growth of *Spathiphyllum* “Sensation” in the ebb and flow system.

From September, 1997 to April, 1998,

there were no difference in the plant growth between irrigation methods at the same irrigation frequency, however plants grown in the ebb and flow system had the fewest number of chlorotic and puckered leaf. From May, 1998 to January, 1999, plants growth in the ebb and flow system was better than that of the hand watering treatment. In additions, the ebb and flow system could save water and nitrogen use by 33% and increased the water use efficiency by 40%.

Coirdust had a lower air-filled porosity and water holding capacity than Canadian sphagnum peat. Growing mix containing 33-60% of coirdust with perlite and treefern exhibited desirable physical properties, the pH of coirdust was desirable but EC was higher than that of peat. Na and K were tested to be 6 and 3 times higher than peat respectively, however, the P, Mg, Ca content of coirdust was less than optimum range.

No difference was observed in plant growth among various medium mixture containing either 33-50% of coirdust or 33% of peat. However, the coirdust content higher than 50% could reduce plant growth. In another experiment with medium composed of 50% of perlite and various proportions of coirdust and peat, results indicated that coirdust content up to 25% gave lower root dry weight. All these suggested that the chemical properties would affect the root growth of *Spathiphyllum* "Sensation".

Maximum growth was observed in 8mM-N applied in the ebb and flow system by using peat-mix as the media, while plants grown in coirdust were equally well with the ebb and flow by 4-8mM-N treatment. As a medium in the ebb and flow system, it appeared that coirdust could be a good substitute for peat. For either peat or coirdust-based medium, the optimum nitrogen requirement for *Spathiphyllum* "Sensation" in the ebb and flow system was 8mM. Plant dry weight decreased and necrotic symptoms occurred when nitrogen concentration exceeded 16mM in all treatments, and root dry weight decreased sharply especially in the ebb and flow treatment. Increasing nitrogen concentration paralleled increased the no of necrotic leaves, and root growth foliar N content, while K, Ca and Mg content was decreased. Due to the absence of leaching in the ebb and flow system, it was suggested to reduce the nitrogen application rates in order to maintain good quality of *Spathiphyllum* "Sensation".

Fertigation using once in every 3 days was shown to be optimum for peat and coirdust-mix in the ebb and flow system, while increasing the frequency to once a day was unnecessary. Coconut husk-mix had a poor water retention capacity, but the problem could be solved by increasing the fertigation frequency to once a day, suggesting that coconut husk is suitable for constantly irrigation.

Keywords: Coir, ebb-and-flow,
Spathiphyllum

二、緣由與目的

由於全球水資源不足，且傳統灌溉易造成肥料和農藥的淋溶和溢流，使地下水的污染日漸嚴重(Martens, 1991)**，同時影響人類之健康和安全。先進國家之研究與經驗指出未來從事設施園藝作物生產必須採用自動化肥灌系統重複使用灌溉水、肥料以降低生產成本、減低環境污染。有鑑於此，許多歐美、日本業者已採用無溢流損失的自動化潮汐灌溉系統**(ebb and flow)**生產品質良好之盆花及觀葉植物。在本省環保意識日漸高漲，而施肥、灌溉等日常管理之人工成本又愈來愈昂貴的情況下，建立本省自動化及不會污染環境的潮汐灌溉系統已成為必然之方向(葉，**1998)**。**

另一方面，無土介質的探求，也是園藝事業非常重要的課題，泥炭苔雖然具備理想的理化條件，然而泥炭苔也是再生性困難的天然資源，長期的採用亦總有用盡的一天，因此探求可以和泥炭苔具有相同特性的介質非常重要(Evans **等人，**1996)**。椰纖主要來自斯里蘭卡、馬來西亞、印尼、越南以及海南島等熱帶地區，其中斯里蘭卡每年有** 25 **億個椰子的出產，因此椰纖的來源不構成問題。由於椰纖在處理後之物理性質類似**

或優於泥炭苔(Fonteno, 1996)，已有愈來愈多學者注意到椰纖取代泥炭苔的可能性(Evans 和 Stamps，1996； Prasad, 1997； Stamps 和 Evans，1997；1999)，然而一些報告卻指出椰纖中的化學成分較不利植株之生長(Evans 等人，1996)，或指出椰纖之保肥力較泥炭苔為低(Evans 等人，1996； Prasad, 1997)，因此以椰纖完全取代泥炭苔之可能性仍有待探討. 減少淋溶可有效改善介質對養分之保持力, 潮汐灌溉在減少淋溶量的情況下, 應可部分解決椰纖類介質保肥力不足的問題。

綠巨人白鶴芋(*Spathiphyllum* " Sensation")曾在濱江花市佔有前三名的總銷售量, 全省於 86 年共出售 29 萬盆, 總金額達 2688 萬元(葉和林，1998)，目前也是台灣最具有外銷潛力的觀葉植物之一. 本研究以潮汐灌溉方式觀察綠巨人白鶴芋的生長情形及適應性, 並比較椰纖類介質和傳統泥炭苔為主的介質於潮汐灌溉系統下對綠巨人白鶴芋生長與品質之影響, 以提供業者未來之參考。

三. 結果與討論

秋冬季以潮汐灌溉處理的植株其生長量與傳統手澆處理並無顯著差異，潮汐灌溉可減少約 27%淋溶量所造成之水資源浪費，在獲得相同生長量之前提下，潮汐灌溉仍具有節省水資源之優點。此結果與聖誕紅、天竺葵等盆栽植物在利用潮汐灌溉時能維持其生長量和品質的結果相同(Dole 等人，1994；Morvant 等人，1997)。本研究指出，潮汐灌溉使用 1/2 Johnson 氏營養液用量下綠巨人白鶴芋可獲得生長量相當與品質較佳的效果，且減少淋溶量和節省水資源。

在品質方面，潮汐灌溉可減低下位黃葉和皺縮葉的發生，則可能與環境因子或氮素之吸收與移動有關. N 是合成葉綠素不可或缺的元素，因此葉片黃化是一種缺 N 的症狀(Joiner, 1981)，由於 N 在植物體內為移動性相當高的元素，當植株在缺 N 的情況下，老葉的蛋白質會分解成氨基酸，然後移動至生長比較旺盛的葉片中利用，因此葉片黃化通常發生在下位(Joiner, 1981)。本研究在 1998 年 5 月 30 日取樣的結果顯示葉片 N 含量以潮汐灌溉比手澆處理為高，顯示綠巨人白鶴芋以潮汐灌溉其營養狀態比以手澆處理為優。由於潮汐灌溉處理不具淋溶效果，養分較易保留在介質中(Yelanich 和 Biernbaum，1993)，因而可以提供植株有效利用 N 肥而增加綠巨人白鶴芋葉片的品質。至於皺縮葉片發生的問題，林(1998)指出當環境處於高溫、強光時，葉片可能因分化過快而使葉片伸展不平衡所致。在本研究中，平均遮光環境為 70%，平均溫度也在 35℃以下，推論潮汐灌溉可降低皺縮葉片乃與灌溉方式有關，因而需要後續試驗作進一步的探討。

觀察八個月生長期間綠巨人白鶴芋其葉片成分的變化，可知在秋末(1997 年 10 月 31 日)和初夏(1998 年 5 月 30 日)葉片的元素含量較高，可能因環境溫度較高，適合綠巨人白鶴芋生長有關(林，1998)，而於 1998 年 4 月 4 日取樣的植株其葉片 N、K、Ca 元素含量明顯較低，顯示冬季生長之綠巨人白鶴芋植株會減少吸收上述元素。綠巨人白鶴芋對 K 與 Ca、Mg 的吸收似有拮抗作用，當 N、K 含量提高後，Ca、Mg 含量則顯著下降, pH 在較低的情況下也會減少 Ca、Mg 的有效性(Marschner, 1995)。

介質分析顯示潮汐灌溉 EC 較高, 上、中、下三層的 EC 平均值為 1.23mS/cm，遠高於手澆處理的 0.46mS/cm，潮汐灌溉處理下之介質 EC 符合 Warncke 和 Krauskopf (1983) 建議在 0.75-1.25mS/cm 的範圍，這主要是由於潮汐灌溉不會造成養分流失之原因. 潮汐灌溉處理其上層介質的 EC 為手澆的 4.4 倍，而中、下層介質的 EC 分別為手澆處理的 1.75 和 1.3 倍, 顯示潮汐灌溉與手澆處理以相同的灌溉頻率及營養液濃度下, 潮汐灌溉可以保留較多的養分, 因而也能減少下位黃葉之產生。然而介質 EC 比較集中於上層，以潮汐灌溉處理的上層介質其 EC 分別為中、下層的 3.5 和 4.4 倍，手澆處理者其上層介質的 EC 也分別是中、下層的 1.4 和 1.3 倍，此與大部分前人的結果相同(郭，1994；何，1996 郭，1997；Argo 和 Biernbaum，1995；Morvant 等人，1997)，上層介質 EC 比中、下層為高主要受蒸發作用所致(Argo 和 Biernbaum，1994)，潮汐灌

溉由於是以底部方式吸取養液，因此介質表層沒有經大量的水分淋溶，以致上層介質的 EC 和中、下層距離較手澆處理為大(Argo 和 Biernbaum，1994)。同時潮汐灌溉處理的盆栽也因受蒸發量帶動鹽類到上層介質，而使根圈的 EC 維持較穩定的狀態(Argo 和 Biernbaum，1994)，在栽培中不會因為鹽類累積而影響生長。

潮汐灌溉與傳統手澆的比較試中，潮汐灌溉處理者有介質提早酸化的情形發生，此結果與聖誕紅、蔓綠絨、天竺葵等盆栽作物以潮汐灌溉處理的結果相同(郭，1994；郭，1997；Morvant 等人，1997)。Molitor (1990) 認為 pH 下降是由於潮汐灌溉少有淋溶作用，因而呈現 H^+離子累積的情形；介質酸化也有可能是由於硝化作用所引起的。而 Heiskanen (1995)認為由於潮汐灌溉以底部吸水，下層介質含水量會比傳統灌溉高，因而加速介質的礦質化和釋放有機酸，是導致下層介質酸化的原因。

於 1998 年 5 月 10 日至 1999 年 1 月 25 日的栽培期間內，以潮汐灌溉處理的植株其生長量比傳統手澆處理為優，當中又以直徑 24cm 盆最為顯著，此結果與天竺葵(郭，1994)、蔓綠絨(郭，1997)、西瓜皮椒草、白玉萬年青、斑葉鵝掌藤、電信蘭、人參榕(葉，1998)相同，可能春夏季平均溫度較高，或光度較強，綠巨人白鶴芋在水、養分需求殷切之時，使用潮汐灌溉較有利植株之生長。試驗期間測得之光合作用、氣孔導度與蒸散作用皆以潮汐灌溉處理為優，可能因為潮汐灌溉處理的植株其水分生理狀況比手澆為優之故(Kramer 和 Boyer，1995)。從葉片分析來觀察，潮汐灌溉處理者雖具較少之 N、K，此可能乃生長稀釋所致，所有元素除 Ca 以外皆在適當範圍(Mills 和 Jones,Jr.，1991)。

以潮汐灌溉處理，地上部與地下部生長皆明顯優於手澆處理者，但以潮汐灌溉處理其 R/S 仍低於以手澆處理者，顯示潮汐灌溉較有利地上部之生長。當聖誕紅盆花以底部灌溉處理 54 天後，R/S 也較澆灌處理為低，特別是當介質 EC 較高的時候(Argo 和 Biernbaum，1995)。然而 Leskovar 和 Heineman(1994)則指出以潮汐灌溉處理番椒穴盤苗會得到較多的側根(lateral root)，因而增加了 R/S。將盆栽介質分成三等分來觀察，以直徑 15cm 盆處理，潮汐灌溉處理的上層介質 EC 分別為中、下層之 3.88 和 7.09 倍；而手澆處理則為 1.96 和 2.08；如以直徑 24cm 盆處理，潮汐灌溉處理的上層介質 EC 為中、下層之 4.94 和 6.41 倍；而手澆處理則為 2.74 和 2.93，此結果與秋冬季比較潮汐灌溉與手澆處理下之介質的 EC 特性相同。將介質上、中、下三層的 EC 平均計算，潮汐灌溉比手澆為高，但結果顯示 EC 較集中在上層介質部分，而根群分佈較多的中、下層則 EC 低於理想範圍(Warncke and Krauskopf, 1983)，此現象在直徑 24cm 盆處理上效果更為明顯。潮汐灌溉把大量鹽類帶到表層，而中、下層反而出現 EC 不足之現象，與 Argo 和 Biernbaum(1994)指出鐵炮百合以底部灌溉處理易造成根圈介質鹽類低於適合濃度的結果相同。進一步推測介質表面積可直接影響蒸發量的多寡，直徑 24cm 盆的表面積較大，因而鹽類被蒸發流帶動至表層的情形會比直徑 15cm 盆較為顯著。

從根的分佈來看，下層介質的根乾重以潮汐灌溉處理者較多， Heiskanen(1995) 認為由於潮汐灌溉由於底部吸水，下層介質較易飽和，因此有利根部往下生長，在本研究也觀察到潮汐灌溉有提早出現盤根的現象，與番椒穴盤苗以潮汐灌溉處理較易使根往盆外生長(Leskovar，1998)和蔓綠絨較易發生盤根(郭，1997)等現象相同。直徑 24cm 盆處理者其 pH 最為穩定，與較大容積其緩衝能力較佳有關(Schaller, 1987)。潮汐灌溉處理其下層介質 pH 最低，但手澆者以上層 pH 最低，觀察結果顯示亦是根群分佈最多的部分，其 EC 和 pH 皆較為低，估計與根部旺盛生長使鹽類濃度下降和因吸收陽離子而釋於出 H^+離子增加有關(Mengel 和 Kirkby，1982)。推論潮汐灌溉方式首先影響介質中鹽類和水分分佈，進而影響根群分佈和 pH 值。

潮汐灌溉除了可以減少水資源的流失，也能維持或提高綠巨人白鶴芋之生長，並提高水分利用效率，與前人結果相同(Dole 等人，1994)，Fare 等人(1994)指出每次澆灌植物約會造成 68% NO_3^-N 之流失，使用潮汐灌溉生產綠巨人白鶴芋，不

僅可以減少淋溶對環境造成污染，同時也具備節省水資源和肥料之優點。在本研究中，不曾發生介質通氣性不足或嚴重的病害傳播，在短暫栽培期內和使用低營養液濃度下也不會造成太嚴重之鹽類累積，因此綠巨人白鶴芋應適合以潮汐灌溉之生產模式。

本研究使用之加拿大泥炭苔的充氣孔隙度在 10.98%，總孔隙度在 93.37%，符合理想之範圍 (王，1994；de Boodt 和 Verdonck，1972)，而其總孔隙度和總體密度等物理性狀也與其他地區出產之泥炭苔大致相同 (Fonteno,1996)。從斯里蘭卡進口之椰粉其充氣孔隙度與泥炭苔並無顯著差異，此結果與 Ho(1995)指出椰纖比泥炭苔充氣孔隙度低的結果不同；椰粉的保水力和總孔隙度稍低於泥炭苔，分別只有 71.80 和 81.10%，此與 Evans 等人(1996)指出椰纖的保水力在 73-80%稍低，也比 Fonteno(1996) 指出椰纖的總孔隙度在 92-94%為低；椰粉的總體密度較泥炭苔為高，此結果也與 Evans 等人(1996)指出椰纖的總體密度範圍在 0.04-0.08g/cm^3 有所不同。關於椰粉的一些物理性方面的結果與前人有所差異，Evans 等人(1996)認為椰纖的物理性會因來源地不同而有所變動，加上來源地對椰纖的處理方法不同，其粒徑分布差異會較大，因此也影響了介質的總體密度、保水力、總孔隙度和充氣孔隙度(Evans 等人，1996)。

椰粉、椰塊、泥炭苔和保綠人造土在添加珍珠石和蛇木屑後，氣相會增加而液相則減少，此結果與泥炭苔在混合粗砂、粒徑較大的珍珠石或保麗龍後可使容氣量(air space)增加和保水力減少的結果相同(Prasad, 1979)，但無論泥炭苔、椰粉和保綠人造土以任何比例與珍珠石和蛇木屑混合，其充氣孔隙度皆在理想之範圍(王，1994)，其保水力除椰粉以 60%比例處理外，其他各組也是種植觀葉植物之理想範圍內 (Joiner, 1981)。椰塊由於粒徑較大，介質中不論以多少比例增加，其充氣孔隙度則只在 63-68%之間，已不符合王(1994)所建議之理想範圍內，然而其保水力仍可以接受(Joiner, 1981)。總孔隙度增加可助根部之生長 (Fonteno 等人，1981)，因此總孔隙度應在 85%以上(de Boodt 和 Verdonck，1972)，然而增加泥炭苔、椰粉和保綠人造土在介質的比例會降低總孔隙度，在泥炭苔和椰粉的用量達 50%時，其總孔隙度已低於理想範圍。總體密度在不同介質比例下都仍低於 0.15g/cm^3 的理想範圍(Joiner 等人，1981)，但椰粉不論以任何比例混合其總體密度仍高於其他各組介質，乃因椰粉本身總體密度較高所致。

泥炭苔、椰粉與珍珠石以五種不同比例的介質在總孔隙度和充氣孔隙度並沒有差別，而保水力相差也只在 3%之內，由於椰粉的總體密度較重，因而與其他介質混合後其總體密度也較高，但相差仍不大，顯示椰粉和泥炭苔的物理性相差不大，此與 Ho(1995)指出介質中保持 40%的珍珠石，其餘的 60%不論如何變動泥炭苔和椰粉的比例皆不會影響其保水力與充氣孔隙度的結果相同。

泥炭苔在 EC、pH 和營養元素含量皆在 Warncke 和 Krauskopf(1983)建議的範圍內，這可能與泥炭苔在出土後，經過人工調節有關(Lucas 等人，1975)。四種介質的 pH 除了椰塊皆在 5.5-6.5 的理想範圍內。以飽和萃取法測得椰粉的 EC 明顯較高，雖然在 Warncke 和 Krauskopf(1983)建議的範圍內，但當介質 EC＞1 時應用於穴盤苗則可能會影響較敏感的作物生長(Koranski, 1993)。

椰粉中 K、Na、B 含量比泥炭苔為高，此結果與 Handreck(1993)的結果相同。介質中 Na 為泥炭苔含量的 6 倍，而 K 則為泥炭苔的 3 倍，B 為泥炭苔含量的 13 倍，其中 Na 和 K 已超出 Warncke 和 Krauskopf(1983)建議的範圍，椰粉中 P、Ca、Mg、Zn 含量比泥炭苔為少，亦低於 Warncke 和 Krauskopf(1983)建議的範圍內。由於 K、Ca、Mg 在根的吸收過程中會互相競爭，因此常會因介質中上述元素的不平衡而產生拮抗作用，而介質中含有過量的 Na 也會影響 K、Ca、Mg 的吸收，因此 Warncke 和 Krauskopf(1983)建議介質中不能含有超過 10%的 Na，然而 Handreck(1993) 認為 Na 過量可以用淋溶的方法來解決。椰塊相對於椰粉含有較少 Na 和 B，但其含量仍高於泥炭苔；椰塊的 Ca、Mg 與 P 元素也低於 Warncke 和 Krauskopf(1983)的建議範

圍。保綠人造土的 EC 最低，介質中元素含量也相當低，此與黃(1995)之結果相同，顯見保綠人造土本身不具肥效，施肥量宜增加。

種植前泥炭苔、椰粉、椰塊與保綠人造土以不同比例與珍珠石和蛇木屑混合之介質其 EC 和 pH 皆在理想範圍之內 (Warncke 和 Krauskopf，1983)。試驗結束時，泥炭苔以 33%處理者，其 EC 分布在中、下層與椰粉以 33%處理者甚為一致，但於上層 EC 較椰粉 33%為低，顯示椰粉有較早出現鹽類累積的情形。各組介質中以椰粉處理的 EC 最高，上層介質 EC 以椰粉 33%和 50%處理最高，中層以椰粉 50%和 60%處理為最高，而下層則以 60%最高，顯示隨著椰粉用量的增加，鹽類比較趨向停留在介質之下層。

觀察不同介質處理下盆栽一天的蒸發散量，顯示椰粉以 33%與 50%處理的蒸發散量並無重大差異，但比 60%處理者為高，此結果符合前人指出蒸發量可把鹽類帶到介質的表面(Argo 和 Biernbaum，1995)，而另一方面也顯示隨著椰粉用量增加而減少其蒸發量。椰塊的 EC 較低，則可能乃椰塊保肥力較差所致。保綠人造土的中、下層介質其 EC 較泥炭苔為低，顯示其保肥力較差，然而其上層介質的 EC 與中、下層介質 EC 的差距卻比泥炭苔為大，也可能因為受其介質性質和蒸發作用共同影響所致。

介質 pH 則是隨著椰粉用量增加而下降，顯示椰纖的緩衝能力(buffer capacity)較差；其他盆栽有機介質如金針菇堆肥、蔗渣堆肥和稻草堆肥的 pH 也會隨著栽培時間增加而 pH 有下降的情形(曾，1997)，其中 pH 的變化和介質的陽離子交換能力(cation exchange capacity, CEC)有很大的相關性(Helling, 1964)；椰粉的 CEC 較泥炭苔為低(Evans, 1996)，因此推論椰纖的緩衝能力(buffer capacity)也較泥炭苔為差，pH 也較泥炭苔變化為大。

椰粉以 33%和 50%處理與泥炭苔以 33%處理之植株在生長量和品質沒有顯著差異，顯示椰粉可以取代泥炭苔之使用，此結果與香龍血樹(Stamps 和 Evans，1999)、繁星花(Merrow,1994)、火鶴花和國王椰子(Merrow, 1995)相同。當椰粉在介質中比例增加至 60%時，其地上部、地下部乾重和葉面積皆不如泥炭苔以 33%比例用量者。當椰粉於混合介質的用量超過 25%時，也會影響介質中、下層根部的生長

泥炭苔、椰粉與珍珠石以五種不同比例在潮汐灌溉下處理的結果也顯示，椰粉比例在 10-25%用量植株之葉片乾重、葉片數和葉面積皆與 50%泥炭苔處理者無甚差異，顯示以 10-25%的椰粉可部分取代泥炭苔的應用。然而當椰粉增加用量至 50%，即完全取代泥炭苔處理時，植株之生長量和葉片品質則已較 50%泥炭苔處理為差，其中壞疽葉片數出現較多，顯示椰粉用量最適合的使用量不宜超過 50%。

本研究結果與前人指出椰纖用量增加使保水力提高的同時，植株的生長量也會隨著增加(Merrow, 1994；Stamps 和 Evans，1997；Evans 和 Stamps，1996)的結果不同。本研究中，椰粉處理未能增加綠巨人白鶴芋之生長量，此亦與不少前人研究指出使用椰粉取代泥炭苔之同時，可以增加仙丹花(Merrow, 1994)、黛粉葉(Stamps 和 Evans，1997)、白鶴芋(Stamps 和 Evans，1999)和萬壽菊、矮牽牛(Evans 和 Stamps，1996)、非洲鳳仙等(Braggs 等人，1993)花壇植物等生長量的結果不同。

椰塊不論以任何比例處理植株之地上部乾重和葉面積皆較泥炭苔處理者為差，應與介質保水力不足有關，由於增加椰塊的比例對於介質物理性的改變並不如泥炭苔、椰粉和保綠人造土等明顯，因此在植株之生長量也不會因改變椰塊的含量而有所變化。

在品質方面，各組介質處理，對黃葉數、黃斑葉片數和皺縮葉片數和葉綠素含量並無差異，相對於林(1998)指出以椰粉處理的綠巨人白鶴芋因介質保肥力不足而使植株之葉綠素含量和葉色皆比泥炭苔處理為差的結果，顯示以潮汐灌溉處理，已可提升椰纖類介質的應用潛力。由於影響葉色和葉綠素含量主要因子為氮素(Poole 和 Conover，1977；Poole 和 Conover，1981)，潮汐灌溉由於重複應用營養液，且不會因灌溉造成之淋溶將氮肥沖離介質，因而可以保留較多的養分於介質中(Biernbaum, 1992)，本研究也顯示潮汐灌溉可減少因椰纖保肥力不足的問題而能提升植株之品質。

椰粉以 50-60%處理者出現較多的壞疽

葉片數，則可能與介質中之化學性有關。觀察各組介質處理下葉片之元素含量可知：隨著椰粉用量的增加，葉片中 K 元素有增加之趨勢，而 Ca、Mg 則有下降之情形。於椰粉 60%處理下其葉片 Ca、Mg 含量是各組處理的最低，Ca 含量已接近於適當範圍(0.8-2%)的低標，已出現葉片壞疽之症狀，葉和林(1999)亦指出葉片缺 Ca 較易發生壞疽葉片數。Mg 含量也低於標準範圍(0.2-1%)，已有類似缺 Mg 的情形出現。壞疽葉片與葉片缺 Ca 有關，可能因椰粉中 K 含量高，而又缺乏淋溶的情形下植株有增加吸收的情形而導致陽離子之間的拮抗作用。在葉片中 K 含量高時，粗肋草(Poole 和 Conover，1977)、蔓綠絨(Poole 和 Conover，1986)、黛粉葉、竹芋(Poole 和 Conover，1981)和電信蘭(葉，1998)等觀葉植物葉片的 Ca、Mg 含量皆有減少的情形發生。另一方面，由於椰粉的用量增加時，介質中 Na 含量也會增加，而椰粉中的 Na 含量，亦可能會影響 Ca、Mg 的吸收(Warncke and Krauskopf, 1983)，Grieve 和 Maas(1988)指出介質中高比例的 Na/Ca 會影響 Ca 元素往地上部的運輸，而生長中的葉片也將會有缺 Ca 的情形發生。本研究椰粉以 60%處理者出現較多的壞疽葉片數可能是因為介質中含 K、Na 過多所引起的缺 Ca 症狀。相對於黛粉葉(Stamps 和 Evans，1997)、繁星花、仙丹花(Merrow, 1994)等以椰粉為主的介質處理下沒有出現此症狀而言，乃由於在每次澆灌的過程中，Na 和 K 等元素已被持續地溶出而不構成對植株生長之影響(Handreck, 1993)；因此椰粉應用於潮汐灌溉系統下雖可保留較多的養分，但同時也因椰粉中 Na 和 K 的累積而對植物生長構成影響，因此椰粉以潮汐灌溉方式種植綠巨人白鶴芋需先浸泡以溶出椰纖中過量之 Na 和 K。

本研究顯示 10-50%的椰粉用量可以部分取代泥炭苔獲得生長和品質相當的綠巨人白鶴芋，顯示椰粉作為栽培介質已可以節省進口泥炭苔的成本，還可以減少對天然資源的依賴，保持介質來源的穩定性和永續性，以潮汐灌溉的生產方式可以部分解決因保肥力不足的問題，但椰粉中含有的若干不利植物生長的化學成分及其解決方法則尚待進一步的研究。

潮汐灌溉以泥炭苔處理，氮素在 8mM 用量下，可獲得最佳之植株生長量植株生長量。當氮素濃度增加至 16-32mM 時，則不論灌溉方式如何已不利植株之生長，其中以潮汐灌溉處理較為嚴重，此結果與 Kent 和 Reed(1996)指出以 8mM 氮素以潮汐灌溉系統下可獲得生長最佳的白鶴芋的結果相同。高氮素（16-32mM）對於地下部之影響更為明顯。Kent 和 Reed(1996)也指出氮素超過 10mM 即影響根部生長。於無氮素和低氮素濃度下(4mM)處理的植株具較高之 R/S，其中以潮汐灌溉者其 R/S 較手澆者低，顯示潮汐灌溉於適當的營養液用量下比較有利地上部之生長，而無氮素處理者則獲得最高之 R/S，顯示在缺氮的情況下，植物傾向地下部的生長，以利獲取更多的養分(Marschner, 1995)，另外高氮素濃度處理也會使天竺葵(Ganmore-Neumann，1992)、天門冬屬植物(Waters 等人，1990)、聖誕紅(Argo 和 Biernbaum，1995)等植物 R/S 的降低。

以氮素 16mM 椰粉澆灌處理，如不計算葉片品質，可獲得植株地上部最佳之生長量，此結果與林(1998)相同，比泥炭苔以手澆處理者在氮素用量於 8mM 獲得最佳生長量時需多加 8 mM 的氮素，此與 Prasad(1997)認為椰纖保肥力不足較易流失氮素，因而每星期要多補充氮素的結果相同。

然而當椰粉以潮汐灌溉處理時，只需用 4mM 的氮素其生長量便相當於泥炭苔以 8mM 氮素澆灌處理者，顯示以潮汐灌溉已能減少因介質 CEC 不足使 N 造成淋溶的情形(Prasad, 1997)。潮汐灌溉可以提高椰纖對養分之保持，已能部分解決椰纖保肥力不足之問題。椰粉以潮汐灌溉處理者，氮素在 4mM 氮素用量時已獲得最佳生長量，較澆灌處理者需以 16mM 用量下始獲得最佳之地上部生長量可節省約 1/4 的氮素。因此推論使用椰纖取代泥炭苔之同時，配合潮汐灌溉系統可獲得更佳之效益。

潮汐灌溉處理者由於不具淋溶效果，當氮素用量超過 8mM 時，植株有明顯有減少分化葉片和葉片生長的情形，但椰粉以手澆處理者其地上部生長和葉片分化皆也不受高濃度氮素之影響，顯然介質的鹽類累積尚未達到影響地上部生長的程度，此結果與

同樣以手澆處理的泥炭苔處理的植株不同，推測由於椰粉保肥力不及泥炭苔(Evans 等人，1996)，當澆灌使用 16-32mM 時，因維持 33%之淋澆量，介質 EC 已能維持平衡，因而尚不足以對地上部構成影響，符合前人建議高濃度肥料使用下須維持 30-40%的淋溶量的結論(Ku 和 Hershey，1991；Yelanich 和 Biernbaum，1993)。

氮素濃度的增加顯然不能提高在椰塊處理下植株的生長，觀察其介質 EC 也會隨著氮素濃度增加而增加，此可能又因椰塊的保水力較差，在維持相同的灌溉頻率下，水分取得較差，因而導致生長緩慢。

另一方面，增加氮素濃度不論任何介質處理下植株之壞疽葉片數也隨著增加，此結果與前人所指出高肥料濃度處理易引起綠巨人白鶴芋葉片(葉和林，1998)與聖誕紅苞片(Woltz 和 Harbaugh，1986；Bierman, 1990)發生壞疽症狀的結論相同。而且因本研究的氮源是以 50%的 NH_4^+處理，也可能會影響葉片品質。依據葉片分析，隨著 N 元素在葉片中增加，其他元素如 P、K、Ca 和 Mg 皆有下降之情形，此符合前人指出氮源含有 NH_4^+會影響其他陽離子如 K、Ca、Mg 等吸收的結論(Marschner, 1995)，雖然 P、K、Ca 和 Mg 仍符合在 Mills 和 Jones,Jr.(1991)指出各種元素在白鶴芋適當生長範圍內，但 Ca、Mg 等元素已接近低標，Bierman 等人(1990)指出 NH_4^+:NO_3^-以 1：2 或 2：1 的處理下，聖誕紅比以 100% NO_3^-處理較易發生葉緣壞疽的缺 Ca 症狀，而每週以 500mg/L 的 Ca 以葉面施肥的方式可改善葉緣壞疽的情形。

當增加氮濃度的同時，會降低植株之蒸散量，尤其以潮汐灌溉處理最為嚴重，似已有水分逆境的發生，此結果與 Schuch 等人(1995)指出聖誕紅於高氮素栽培下會導致氣孔關閉的情形相同也影響水分的吸收。

潮汐灌溉系統下，泥炭苔和椰粉以肥灌頻率維持在每天 1 次至每天 3 次其地上部生長量和地下部生長量皆無顯著差異，顯示每 3 天肥灌一次的頻率已足夠綠巨人白鶴芋生長之需求，然而以椰塊處理則在增加肥灌頻率至每天 1 次其生長量才能比泥炭苔和椰粉為優，當肥灌頻率只要稍微下降至每 3 天一次即影響其生長，在葉面積、根乾重方面皆不如泥炭苔和椰粉處理者，究其原因應與介質之保水力有關。在本研究中只要增加肥灌頻率即可有效提高其生長量，符合 Bilderback 等人(1982)指出花生殼介質的充氣孔隙度高達 72.9%，但在提高肥灌頻率下杜鵑花的生長量反而比充氣孔隙度在 43.8%的泥炭苔與花生殼混合介質處理下為優的結果。另一方面由於通氣性較佳，椰塊以每天肥灌一次的處理更可獲得最佳的地下部生長，也適合自動化潮汐灌溉之生產方式。

在乾旱之狀況下，綠巨人白鶴芋之葉面積、地上部乾重、地下部乾重有下降之趨勢，而 R/S 則有增加之情形，此結果與草莓(Serrano 等人，1992)、蠶豆(Karamaonos 等人，1982)、彌猴桃(Chartzoulakis 等人，1993)等結果相同。葉面積之減少乃是面對水分逆境最先受到影響的部分(Hsiao, 1973)，這主要原因乃由於膨壓是維持細胞之伸長的主要因素。在缺水的環境下，當葉片失去膨壓的同時，水分逆境也會降低 H^+離子從細胞轉移至細胞壁外，使細胞壁不易酸化，繼而使細胞壁的伸展性降低(wall extensibility)(Taiz 和 Zeiger, 1991)，因而使細胞生長速度下降，導致葉面積減少，同時因減少與陽光的接觸面，可以減少蒸散作用，也是一種耐旱機制之表現(Serrano 等人，1992)。在水分最充足的時候，於泥炭苔和椰粉處理下，葉片分化反而降低，顯示在水分充足的情況下，綠巨人白鶴芋較傾向葉片的擴張

隨著肥灌頻率的降低，R/S 於各組介質處理皆有上升之情形，其中以椰塊的處理較為明顯，顯示綠巨人白鶴芋可依據水分狀態而調節其地上部與地下部的生長比例，為對乾旱抗逆境的一種機制(Marschner, 1995；Kramer 和 Boyer，1995)，觀察根群分布顯示較乾旱之環境下，根群分布反而較高肥灌頻率為均勻，顯示綠巨人白鶴芋於介質濕潤時更有利盆栽下層的根部生長。

隨著肥灌頻率之降低，各組介質處理除泥炭苔外，其氣孔導度和蒸散作用皆有下降之趨勢，此與 Johnson 等人(1981)指出降低垂榕的肥灌頻率會使其蒸散作用下降的結果相同；其中以保水力較差之椰塊較為明顯，顯示乾旱逆境已促使氣孔的關閉，植株

之蒸散作用和光合作用也隨著下降，Aikin 和 Hanan(1975)指出降低葉片水勢會使玫瑰的光飽和點下降，同時也會降低 $C0_2$ 的吸收。氣孔關閉主要目的在防止蒸散作用，但對於光合作用的抑制，則可能並非單純只因氣孔關閉導致 CO_2 缺乏所引起的(Kramer 和 Boyer，1995)，葉片中之 $CO_2(C_i)$含量於葉片中可能仍相當高(Chartzoulakis 等人，1993)，顯示光合作用之降低是與其他非氣孔性的生化反應有關。

以低肥灌頻率處理者植株葉面積和蒸散作用下降之幅度比光合作用為大，其中以椰塊最為明顯，每 5 天肥灌一次其植株之光合作用是每天 1 次的 0.45 倍，但葉面積卻只有每天 1 次的 0.28 倍，蒸散作用也只有每天 1 次的 0.32 倍。Boyer(1970)指出當葉片水勢降至-4bars 時，葉片之伸展已被抑制下來，然而植株之光合作用要待葉片水勢降至-8bars 才有較明顯之下降，顯示乾旱逆境對葉面積和蒸散作用之影響大於對植株之光合作用，因而綠巨人白鶴芋之水分利用效率(每固定一個μmol 的 CO_2 所需要蒸散的水分)也隨著肥灌頻率之下降而呈上升之趨勢，此結果亦與草莓(Serrano 等人，1992)、桃樹(Harrison 等人，1989)等作物相同。

於 1998 年 9 月 8 日於各處理同步肥灌後，光合作用、蒸散作用和氣孔導度皆有回升，而水分利用效率於不同肥灌頻率處理間則已呈不顯著，顯示植株已能恢復吸收水分。向日葵在含水量降至 40%後恢復供水能回到原來光合作用的水平(Kramer 和 Boyer，1995)，於本研究中椰粉和椰塊處理者於相同光度下，在 5 天後的恢復供水後其植株的光合作用仍低於每天、每 3 天肥灌處理和泥炭苔處理者，一方面顯示 5 天的肥灌頻率已不適合植株之生長，另一方面也顯示椰粉和椰塊的有效水較泥炭苔為低(Ho, 1995)。

隨著肥灌頻率的增加，葉色有增加之趨勢，同時黃葉數也有下降之趨勢。在增加氮素的同時，葉色也有明顯的增加，推測在增加肥灌次數的同時，也能增加植株之葉綠素含量，Kiehl 等人(1992)指出以滴灌處理菊花時，增加肥灌次數也能增加植株之養分吸收而增加生長量，然而當植株在缺水時也可能會加速葉片之老化(Kramer 和 Boyer，1995)。

增加肥灌頻率可減少皺縮葉片之形成，根據林(1998)推測皺縮葉片最易出現在高溫、強光下葉片分化快但環境因子使葉片伸展不正常所致，推測皺葉之形成乃與水分供應是否充足有關。

泥炭苔和椰粉處理以每 3 天肥灌一次可獲得生長量最佳和品質較好之綠巨人白鶴芋，而綜合各處理而言，仍以泥炭苔處理略優，但椰塊以每天肥灌也可以得到生長量最佳、品質相當的結果，顯示不同的介質應用在潮汐灌溉系統下，需因應不同的介質特性而探討正確之肥灌次數。

四. 計畫成果自評

已達成計畫目標。並撰寫 *Nitrogen nutrition of Spathiphyllum 'Sensation' grown in sphagnum peat-based and coir-based media and two irrigation methods* (如附件)投稿於 SCI 期刊 HortScience 並已接受刊登

五. 參考文獻

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附件 (僅附原文與表)

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Nitrogen Nutrition of *Spathiphyllum* 'Sensation' Grown in Sphagnum Peat-based and Coir-based Media and Two Irrigation Methods

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Abstract. Effects of nitrogen application level on growth, stomatal conductance, transpiration, chlorophyll content and tissue content were studied in *Spathiphyllum* Schott 'Sensation' grown in sphagnum peat (SP)- and coir dust (CD)-based media with top-irrigation or subirrigation. Maximum shoot dry weight occurred at 8 mM N in plants grown in SP-based medium under top-irrigation and subirrigation, and in CD-based medium under subirrigation. For plants in CD-based medium under top-irrigation, shoot dry weight peaked at 16 mM N. In SP- or CD-based medium, shoot dry weight was greater in plants treated at 4 and 8 mM N under subirrigation than plants under top-irrigation. Stomatal conductance and transpiration were reduced by nitrogen deficiency (0 N), greatly enhanced by 4 mM N, and thereafter decreased gradually. Chlorophyll content increased with increasing N concentration up to 8 mM. The percentage of maximum total dry weight increased quadratically as leaf N content increased from 1.5% to 3.5 %. Nitrogen at 16 and 32 mM increased number of leaves with marginal necrosis. Reduced growth and more leaves with marginal necrosis were measured in plants grown in SP- or CD-based media with EC >1.25 dS m^{-1} in the middle and bottom layers.

Most foliage plants are grown using sphagnum peat (SP)-based soilless growing media with constant liquid fertilization rates (Poole et al., 1981). Leaching is commonly required to prevent soluble salts from accumulating in SP-based media, while excess nutrients in the leachate result in contamined runoff that enters the ground and surface waters (Dole et al., 1994; Yelanich and Biernbaum, 1993). Recirculatory irrigation systems, such as ebb-and-flow (EF), have been highly publicized as one way to reduce water use and runoff. EF subirrigation is already an accepted technique in European greenhouse production (Molitor, 1990). Reduced optimum fertilizer application rates under subirrigation in SP-based media have been reported for several foliage plants, including *Hedera helix* (Holcomb et al., 1992) and *Spathiphyllum* (Kent and Reed, 1996). However, information on foliage plants grown in coir dust (CD)-based media under subirrigation is presently limited. Before the inherent benefits of EF subirrigation can be exploited, it is necessary to determine the fertilization levels, particularly nitrogen, that result in optimum plant nutrition in growing media containing CD, which has a lower C/N ratio and a faster nitrogen drawdown index than SP (Handreck, 1993a; Merrow, 1994).

Sphagnum peat has desirable properties such as high water-holding capacity and cation exchange capacity (CEC) (Biernbaum, 1992). Environmental and economical concerns have generated interest in seeking alternatives for SP due to the detrimental effects of peat harvesting on wetland ecosystems (Evans et al., 1996; Handreck 1993b). Coir dust is reported to have many physical characteristics that make it equal or superior to SP as a component in growing media (Prasad, 1997). CD has a lower CEC than SP (Evans et al., 1996; Prasad, 1997). Successful production using CD has been reported in tropical foliage plants, including *Diffenbachia* (Stamps and Evans, 1997), *Ravenea rivularis* Jumelle and Perrier, and *Anthurium* 'Lady Jane' (Merrow, 1995), *Dracaena marginata* Bak. and *Spathiphyllum* (Stamps and Evans, 1999).

The aim of the present work was to determine the effects of nitrogen level on growth and quality for *Spathiphyllum* 'Sensation' grown in SP- and CD- based media under top-irrigation and subirrigation methods. *Spathiphyllum* is one of the most popular tropical foliage plants grown commercially (Stamps and Evans, 1999). Optimal nitrogen fertilization levels for *Spathiphyllum* in SP-based media have been reported for constant liquid fertilizer (Campos and Reed, 1993) and for a subirrigation system (Kent and Reed, 1996), but leaf mineral contents were not measured in these studies. No published reports have been found on the optimal nitrogen fertilization levels for *Spathiphyllum* grown in CD-based media under top-irrigation or subirrigation.

Materials and Methods

The experiment was arranged in a split plot factorial design, with nitrogen level and irrigation method as the two main plots and growing medium as the subplot. There were six replications of each treatment. On 20 Apr. 1998, tissue cultured plants of *Spathiphyllum* 'Sensation' at 6 macroscopic leaf stage were planted in growing medium in 11-cm-diameter × 9-cm-tall (615-mL) pots. Two growing media used commercially in containerized foliage plant production were prepared, with a SP-based mix of 1 sphagnum peat (Fafard No. 1, Conrad Fafard Inc., Agawam, USA): 1 perlite: 1 treefern (by volume), and a CD-based mix of 1 coir dust (Coco peat, Uniceyl Co., Malaysia): 1 perlite: 1 treefern (by volume). Plants in each plot were irrigated independently when the surface of the growing medium began to dry. For the top-irrigation treatments, the amount of irrigation solution applied yielded a 0.33 leaching fraction. For the subirrigation treatments, ten 70 × 40-cm subirrigation trays were manually flooded with irrigation solution to a depth of 3 cm. Trays required 5 to 6 min to fill and 4 to 6 min to drain and were held flooded for a maximum of 25 min at each irrigation, and then irrigation solutions were recycled to the reservoirs. Irrigation solutions were refilled when the level of reservoirs decreased by half.

Irrigation solutions had concentrations of 1.0mM P, 3.0mM K, 2.0mM Ca, and 0.5mM Mg, with 0, 4, 8, 16 or 32 mM N obtained from 0.5mM $MgSO_4$, 1mM $CaCl_2$, 1.5mM K_2SO_4, 0.5mM Ca $(H_2PO_4)_2$, 0.5mM $CaSO_4$ and 0, 2, 4, 8 or 16 mM NH_4NO_3 in tap water. Solution pH was adjusted to 6.0. Samples of individual subirrigation solutions were taken at each irrigation for analysis of electrical conductivity (EC) and pH. EC was measured with a model 44600 conductivity/TDS meter (Hach Co., Loveland, Colo.), and pH was measured using a Hach EC10 pH meter, with a model 50200 electrode (Hach Co., Loveland, Colo.). Plants were grown in a 54% shaded greenhouse, with an average noontime light intensity of 600 μmol $^{-2}\cdot s^{-1}$ and mean daily temperature of 28.8℃.

Physical properties of pre-plant growing media were measured following the methods described by Bragg and Chambers (1988). EC and pH was determined using 1:2 root medium: water (v/v) extracts. Mineral contents in the growing media were determined on saturated media extracts (Warncke and Krauskopf, 1983). Phosphorus, K, Ca, Mg and Na were determined with a simultaneous inductively coupled argon plasma emission spectrometry system (ICAP, Thermo Jarrell Ash Co., USA). There were four replications for these pre-plant measurements.

On 11 Oct. 1998, the growing medium and roots of each plant was divided into top, middle and bottom zones, each about 2-cm, with a sharp knife. Discs were pulverized and samples from each zone were collected for 1:2 extracts, then pH and EC analysis. Shoot and root dry weight, number of leaves with marginal necrosis, and chlorophyll contents were measured. Two 0.65-cm discs from each of the two youngest fully expanded leaves of six plants were used for *N, N*-dimethylformamide (DMF) extraction of chlorophyll (Moran, 1982). Chlorophyll contents were measured using a spectrophotometer (U-2001, Hitachi, Japan) and calculated following the methods described by Inskeep and Bloom (1985). Relative chlorophyll content of the most recently fully expanded leaves was also in situ measured on 11 Oct. 1998 with a SPAD-502 chlorophyll meter (Minolta Camera Co., LTD, Japan). Stomatal conductance and transpiration were measured on the recently developed leaves with a steady-state porometer (LI-1600, LI-COR, Lincoln, NE). Total N concentration of the most recently fully expanded leaves was determined with the Kjeldahl procedure and P, K, Ca, Mg and Na were measured with an ICAP. Data were tested using the analysis of variance procedures of SAS (SAS Institute, Cary, N. C.). Regression analysis was used to describe the relationships between leaf N content and maximum total dry weight, chlorophyll content and SPAD.

Results and Discussion

Properties of pre-plant growing medium. SP- and CD-based media did not differ in air filled porosity (33.6 to 38.9% by volume), water holding capacity (51.4 to 53.7% by volume), total porosity (87.3 to 90.3%, by volume), and bulk density (0.13 to 0.15 g cm^{-3}). Physical properties of growing media measured in the present study were within the recommended ranges for growing foliage plants (Poole et al., 1981).

CD-based medium had higher K and Na contents and EC but had lower P, Ca and Mg contents compared to the SP-based medium (Table 1). High EC values in some sources of CD are caused by high Na, K and Cl contents, because coconut plants are fertilized with KCl and raw coconut husks are soaked in saline water during processing (Evans et al., 1996; Handreck, 1993b). SP- and CD-based media did not differ in pH (5.8 to 5.9), and values were within the optimum range from 5.5 to 6.5, as recommended for most greenhouse crops (Poole et al., 1981; Warncke and Krauskopf, 1983).

Shoot dry weight. For plants grown in SP-based and CD-based medium with subirrigation or top-irrigation, the 0-N treatments significantly reduced shoot dry weight while a small increase in N level to 4 mM sharply enhanced this dry weight (Fig. 1A and B; Table 2).

For plants grown in SP-based medium, shoot dry weight increased up to 8 mM N, after which the dry weight declined gradually (Fig. 1A; Table 2). Leaf number and leaf area exhibited identical responses (data not shown). This was consistent with the optimum N levels at 8 to 10 mM for *Spathiphyllum* 'Petite' in SP-based medium under subirrigation (Kent and Reed, 1996), and represented the lower end of the optimum N level ranges from 7.5 to 30 mM determined for fertigation in top irrigation (Campos and Reed, 1993).

For plants grown in CD-based medium, maximum shoot dry weight occurred also at 8 mM N under subirrigation, beyond which the dry weight decreased. In contrast, the maximum growth was recorded in plants at 16 and 32 mM N under top-irrigation (Fig. 1B; Table 2). Leaf number and leaf area behaved similarly (data not shown). Therefore, subirrigation could sustain adequate *Spathiphyllum* growth at lower N levels, possibly by reducing leaching, and thus could save nitrogen fertilizer. For plants with top-irrigation, both the 8 mM N in SP-based medium and 16 mM N in CD-based medium treatments produced similar shoot dry weights (Fig. 1 A and B; Table 2). The higher N concentration required for maximum growth in CD-based medium with top-irrigation could be explained in two ways. First, CD has a lower CEC than SP and thus more easily leaches nutrients (Evans et al., 1996; Prasad, 1997). Secondly, CD has both a lower C/N ratio and a faster nitrogen drawdown index than SP (Handreck, 1993a; Merrow, 1994). Plants nearly as large as those in SP could be produced in CD, indicating that CD could be used as an acceptable substitute for SP for *Spathiphyllum* production.

Root dry weight and root-shoot ratio. For plants grown by both irrigation methods in SP- or CD-based medium, maximum root dry weight occurred at about 4 mM N, with decreased dry weight above and below this N concentration (Fig. 1 C and D; Table 2). The decreased root and/or shoot growth at higher N levels may indicate the salinity tolerance limits of *Spathiphyllum*.

The 0 N treatment produced the highest root/shoot ratio; however, increasing N from 8 to 32 mM did not affect root/shoot ratio (Fig. 1 E and F, Table 2). Nitrogen deficiency may have reduced the provision of photosynthates by decreasing leaf number and leaf area, but increased root-shoot partitioning of photoassimilates. Similar examples for nitrogen deficiency increasing root-shoot ratio have been well documented, and this preferential partitioning is dependent on phloem mobility and hence on nitrogen cycling from shoot to root (Marschner et al., 1996).

Fig. 4

Top-irrigation generally increased root dry weight and produced small but significant increases in root-shoot ratio, as compared to subirrigation (Fig. 1 C-F, Table 2). A previous report for subirrigated poinsettias noted that, particularly at high nutrient levels, resulted in lower root-shoot ratio than top-irrigated plants (Argo and Biernbaum, 1995).

Stomatal conductance and transpiration. Regardless of SP- or CD-based medium, stomatal conductance and transpiration showed a trend similar to root growth patterns with respect to nitrogen levels (Fig. 2; Table 2). Stomatal conductance and transpiration were reduced by 0 N, greatly enhanced by only a small increase in N concentration to 4 mM, and decreased gradually with increasing N above 4 mM. *Spathiphyllums* grown with subirrigation had lower stomatal conductance and transpiration than those grown with top-irrigation, particularly at 8 and 16 mM N. Radin and Boyer (1982) also noted that nitrogen level can affect stomatal closure and transpiration that relate well with plant water status.

Fig. 5

Chlorophyll content and number leaves with marginal necrosis. Well-developed dark green leaves of *Spathiphyllum* are considered to be a measure of good plant quality. Chlorophyll content increased with increasing N concentration up to 8 mM, after which chlorophyll content remained almost constant. Plants grown with subirrigation generally had slightly higher but significant chlorophyll content than plants grown with top-irrigation (Fig. 3 A and B, Table 2).

Number of leaves with marginal necrosis increased with increasing N level from 0 to 32 mM (Fig. 3 C and D, Table 2). This suggested a generic salinity effect, which may be due to the increasing EC of the media in increasing N level. High fertilizer levels have been reported to increase numbers of necrotic leaves for *Spathiphyllum* (Chase, 1997).

Leaf mineral content. Leaf N content increased dramatically with increasing N level from 0 to 8 mM, after which leaf N content increased gradually (Fig. 4). Plants treated at 8 and 16 mM N had leaf N content ranging from 3.3% to 5%, as recommended for healthy *Spathiphyllum* (Mills and Jones, 1991). Plants grown with 32 mM N had higher leaf N content than the recommended upper limit.

Leaf P, K, Ca and Mg contents decreased sharply with increasing N level from 0 to 4 mM, decreased gradually from 4 to 8 mM, and thereafter changed little (Fig. 4). Leaf P, K, Ca and Mg contents in all treatments were within the optimum ranges, i.e. P (0.2-1.0%), K (2.3-6.0%), Ca (0.8-2.0%), and Mg (0.2-1.0%) as recommended by Mills and Jones (1991). Tissue analysis revealed no trends in leaf Na content between treatments (data not shown). Number of leaves with marginal necrosis was little affected by the higher Na content in pre-plant CD-based medium used in the present study.

Relationships between leaf N content, chlorophyll content and growth. The percentages of maximum total dry weight for all treatments were calculated and plotted against their leaf N contents and presented in Fig. 5A. Plant growth increased quadratically as leaf N content increased from 1.5% to 3.5%, and plateaued between 3.5% and 4.5%. Growth decreased at leaf content >4.5% N, which is close to the upper limit of 5% N as recommended for *Spathiphyllum* (Mills and Jones, 1991). Regressions of chlorophyll content measured with extraction from leaf disks or with a SPAD chlorophyll meter on leaf N content showed highly significant curved relationships (Fig. 5 B and C). SPAD showed a trend similar to the percentage of maximum growth with respect to leaf N content. This non-destructive in situ chlorophyll meter could aid in monitoring leaf N status of *Spathiphyllum*.

Growing medium EC. No published reports were found on the upper limit of growing medium EC to avoid growth suppression in *Spathiphyllum*. For greenhouse crops in general, an EC range from 0.75 to 1.25 dS m^{-1} is recommended (Warncke and Krauskopf, 1983). EC in the growing media increased with increasing nitrogen levels, and EC was higher in the top layer than in the middle and bottom layers (Fig. 6). A similar trend in salt stratification was reported for plants grown with subirrigation (Kent and Reed, 1996). Salts that accumulate in the top layer are mostly due to the surface evaporation of medium (Argo and Biernbaum, 1995). For top-irrigation treatment, EC in the middle and bottom layers were all below 1.25 dS m^{-1}, while EC in top layers exceeded 1.25 dS m^{-1} at 16 and 32 mM N levels. For subirrigation treatment, EC in the top layers ranged from 3 to 14 dS m^{-1}, while EC in the middle and lower layers exceeded 1.25 dS m^{-1} only at 16 and 32 mM N. Salt accumulation in the top layer is considered to be safe for growing plants under subirrigation, as root systems are concentrated in the middle and bottom layers (Kent and Reed, 1996). Reduced growth and more necrotic leaves were measured in plants grown in SP- or CD-based media with EC > 1.25 dS m^{-1} in the middle and bottom layers (Figs. 1, 3 and 6), indicating 1.25 dS m^{-1} as the upper limit for the optimum growth of *Spathiphyllum*. Similar EC values in middle and bottom layers were measured in both SP- and CD-based medium under subirrigation (Fig. 6).

The growing medium containing CD, as an alternative to SP, was shown to be conducive for *Spathiphyllum* production with maximum shoot dry weights at 8 mM N under subirrigation and 16 mM N under top-irrigation. High N at 16 or 32 mM with subirrigation increased EC particularly in the top layer of CD-based medium that increased number of leaves with marginal necrosis and caused reductions in root dry weight, stomatal conduction and transpiration (Figs. 1-3, 6). The higher EC of the CD-based medium in subirrigation imparted a salinity stress, a part of which may have been manifested as a water stress at the higher N concentrations. It is well documented that stomatal closure is the main cause for transpiration decline as water stress develops (Hsiao, 1973).

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Table 1. Pre-plant mineral nutrient content, EC and pH in the extractants of sphagnum peat (SP) or coir dust (CD)-based growing media.

Growing medium	P	K	Ca	Mg	Na	EC
	(mg L^{-1})					(dS m^{-1})
SP-based	12.6	.4	.9	.1	.4	25
CD-based	4.2	2.6	4	7	4.7	16
Significance[Z]	***	*	*	*	*	*

[Z] *** Significant at *P*=0.001.

Table 2. Analysis of variance for the effects of five nitrogen levels, two irrigation methods and two growing media on growth, stomatal conductance (Cond.), transpiration (Trans.), chlorophyll content and number of necrotic leaves in* Spathiphyllum *'Sensation'.

Contrasts	Dry weight		Root/shoot	Cond.	Trans.	Chlorophyll	Number of
	Shoot	Root				content	necrotic leaves
Nitrogen(N)	***	***	***	***	***	***	***
Irrigation(I)	NS	**	**	NS	*	***	NS
(I)×(N)	**	NS	***	*	NS	NS	NS
Medium(M)	NS	NS	**	NS	NS	*	NS
(I)×(M)	NS	NS	NS	NS	NS	NS	NS
(N)×(M)	***	**	***	NS	NS	NS	NS
(I)×(N)×(M)	**	NS	NS	NS	NS	NS	NS

NS, *, **, *** Non-significant or significant at $P \leqq 0.05$, 0.01, or 0.001, respectively.