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Effects of Nitrogen Concentration on Growth and Nutrient Uptake of *Anthurium andraeanum* Lind. Cultivated in Coir under Different Seasonal Conditions

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***Abstract*. Coir is used around the world as a cultivation medium for plants; its commercial popularity is the result of its availability, low cost, and environmentally friendly characteristics. It is used as a medium in the hydroponic cultivation of *Anthurium* (*Anthurium andraeanum* Lind.) in Taiwan and is a new source for cut flower production around the world. Little is known about the nutrient requirements of *Anthurium* cultivated in coir under fluctuating climatic conditions. The objective of this study was to evaluate the influences of various nitrogen (N) concentrations on the growth and nutrient uptake of *Anthurium* cultivated in coir under different seasonal conditions. Four levels of N concentration in nutrient solution were used: 79 mg·L^{-1} (NS79 treatment), 105 mg·L^{-1} (NS105 treatment), 158 mg·L^{-1} (NS158 treatment), and 210 mg·L^{-1} (NS210 treatment) with NS105 serving as the control. The effects of N concentration and seasonal fluctuations on *Anthurium* were measured in dry weight, leaf growth, flower growth, and nutrient uptake at different growth stages during the 2-year study period. The results show that the dry weight, leaf area, and flower number were higher in plants receiving NS105 and NS158 treatments than those receiving NS79 and NS210 treatments. However, the NS158-treated plants produced better quality cut flowers than the NS105-treated plants in the first year of cultivation as indicated by their wider, circular spathe. Retarded growth of NS79-treated *Anthurium* was the product of insufficient N supply and reduced carbon (C) assimilation. The excess supply of N in the NS210 treatment resulted in small potassium (K) and magnesium (Mg) uptakes, which in turn resulted in poor growth in the second year of cultivation. However, the nutrient supplies in the NS158 and NS210 treatments yielded better *Anthurium* growth during the initial stage than the NS79- or NS105-treated groups. Regardless of plant growth, flower yield, and nutrient uptake, there were significant interactions between N treatments and seasonal fluctuations in subtropical conditions during year-round cultivation. We concluded that the limiting factor in *Anthurium* growth and yield during the spring and summer is the N supply, whereas climate conditions are the limiting factor during the fall and winter.**

Anthurium (*Anthurium andraeanum* Lind.) is one of the important cut flowers in the global tropical cut flower market (Pizano, 2005). Recently it has become a popular cut flower in Taiwan, and its cultivation acreage and yield have increased steadily (Chang et al., 2010; Peng, 2003). Nutrient supply is one of the key factors affecting the growth and yield of *Anthurium* cut flowers (Chang et al., 2010; Dufour and Guérin, 2005; Higaki et al., 1992; van Herk et al., 1998). The optimal nutrient supply depends on a number of factors including medium composition, species, growing stage, and climate (Cardarelli et al., 2010; Gómez-López et al., 2006; Mengel and Kirkby, 2001). Higaki and Poole (1978) and Higaki et al. (1992) studied fertilization effects on *A. andraeanum* Lind. 'Ozaki' with different media in Hawaii and found that the optimal nutrient supply for *Anthurium* depended on the medium. The nutrient solution formulae recommended by Dufour and Guérin (2005) and van Herk et al. (1998) for the cultivation of *Anthurium* were different. Dufour and Guérin (2005) and Higaki et al. (1992) also found that the effects of various nutrient solutions on *Anthurium* flower yield were different, although the observed difference in flower yield was less than one flower per year (Higaki et al., 1992) or two flowers per year (Dufour and Guérin, 2005).

Development and growth of *Anthurium* were significantly affected by seasonal fluctuations (Klapwijk and van der Spek, 1988; van Herk et al., 1998) and the nutrient requirements were dependent on climatic conditions (Fallovo et al., 2009; Mirdehghan and Rahemi, 2007; Rouphael et al., 2008). However, the interaction between fertilization management and seasonal fluctuations on growth, flower yield, and nutrient uptake of *Anthurium* during year-round cultivation is not clear.

Coir is an important substrate for economical horticultural cultivation and is used around the world as a result of its availability, low cost, and environmentally friendly characteristics (Handreck, 1993; Merrow, 1994; Noguera et al., 2000). Coir is used as a medium in the hydroponic cultivation of *Anthurium* in Taiwan (Chang et al., 2010) and is a new source for cut flower production around the world. However, no information is available concerning the nutrient requirements of *Anthurium* cultivated in coir under seasonal fluctuations. The objective of this study was to determine the influences of various N concentrations on the growth and nutrient uptake of *Anthurium* cultivated in coir under subtropical seasonal fluctuations.

Materials and Methods

Plant materials and growing conditions. The experiment was conducted at the Floriculture Research Center of the Taiwan Agriculture Research Institute (lat. 23°37′ N, long. 120°35′ E) in central Taiwan from 6 Oct. 2006 to 8 Oct. 2008. Plants were cultivated in a shadehouse covered with two pieces of shade curtain: a curtain with 70% shading efficiency was placed on top of a curtain with 50% shading efficiency. The shadehouse was also covered with a rain screen consisting of a transparent plastic membrane that was placed on top of the shade curtains. The monthly average air temperature and photosynthetically active radiation (*PAR*) during the experimental period are shown in Figure 1.

Young plantlets of *A. andraeanum* Lind. 'Tropical', 20–30 cm in length and with an average leaf number of 4.1, were used in this study. Before transplanting, 24 randomly selected uniform plantlets were measured for

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number of leaves, petiole and blade length, blade width, and mineral element composition. The N, C, phosphorus (P), K, calcium (Ca), and Mg concentrations in the plantlets were 17.3, 413, 7.1, 24.9, 8.2, and 3.6 g·kg^{-1}, respectively. The plantlets were transplanted to W-shaped gutters measuring 120 cm × 60 cm × 26 cm (length, width, and height) filled with coir (the outer husk of coconut) measuring 31.2 mm × 21.9 mm × 7.7 mm (average length, width, and height) on 3 Oct. 2006. Eight plantlets were planted in each gutter filled with ≈86 L coir and irrigated by an automated trickle irrigation system. Twelve months after planting (MAP), another 45 L of coir was applied to the gutter. The plants were irrigated three times per week (Monday, Wednesday, and Friday) and each plant received 420 mL of nutrient solution per irrigation. Approximately 5% to 10% of nutrient solution dripped away in each irrigation. The coir composition is shown in Table 1. During the experimental period, newly grown mature flowers were harvested when the spadix color changeover reached 75% of the length; however, senescent leaves were not pruned.

Experimental design. Treatments consisted of four levels of N concentration in nutrient solution (79 mg·L^{-1}, NS79; 105 mg·L^{-1}, NS105; 158 mg·L^{-1}, NS158; and 210 mg·L^{-1}, NS210). van Herk et al. (1998) recommended 105 mg·L^{-1} for *Anthurium* cultivation; this served as the control in this study. All treatments contained the same concentrations of P, K, Ca, Mg, sulfur, iron (Fe), copper (Cu), zinc (Zn), molybdenum (Mo), and boron as the recommendation of van Herk et al. (1998). Nitrogen, P, K, Ca, and Mg were applied as NH_4NO_3, $Ca(NO_3)_2$, KNO_3, KH_2PO_4, K_2SO_4 and $MgSO_4$. Boron, Zn, Cu, Mo, and Fe were applied as $Na_2B_4O_7$, $ZnSO_4$, $CuSO_4$, Na_2MoO_4, and EDTA-Fe. Tap water was used to prepare the nutrient solution. Nutrient compositions of tap water and the treatments are shown in Table 2. Citric acid was used to regulate pH of nutrient solution. Twenty-four plantlets were planted in each treatment. There were three gutters in each treatment. All treatments were arranged in a randomized complete block design with three replications (W-shaped gutters).

Measurement of growth and cut flower quality. Blade length, blade width, and petiole length of all newly emerged leaves were measured every 45 d (Dufour and Guérin, 2005). The length of the peduncle and spathe and the width of the spathe of newly matured flowers were also measured every 45 d. The leaf area was estimated from the equation: leaf area = 0.92 × blade length × blade width

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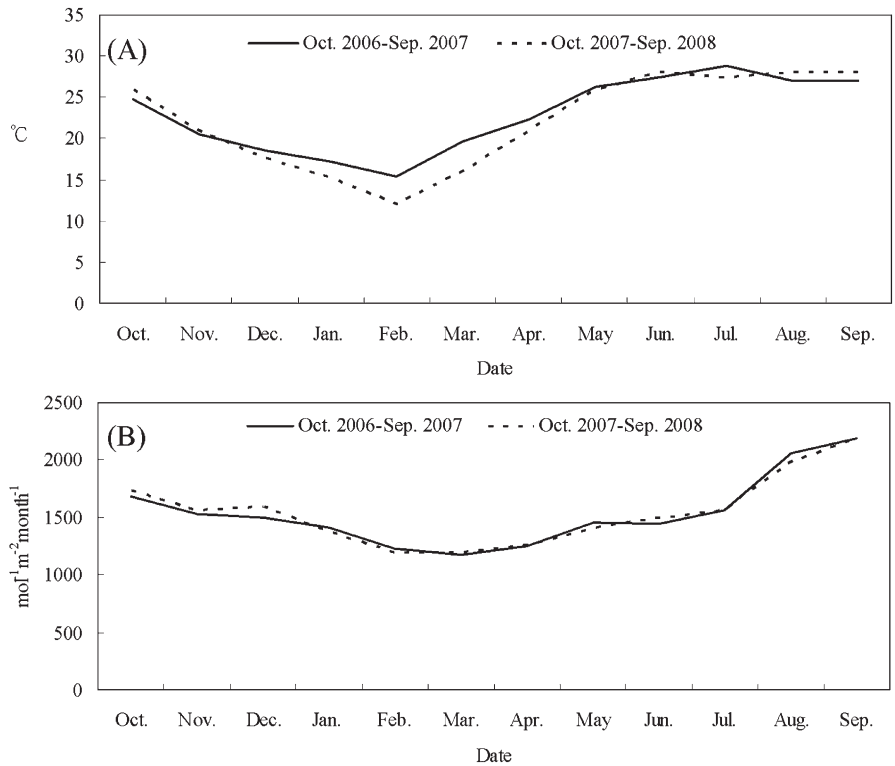

Fig. 1. The monthly average meteorological data obtained from the Floriculture Research Center of Taiwan Agriculture Research Institute during the whole experimental period, (**A**) air temperature and (**B**) photosynthetically active radiation.

Table 1. Some selected properties of coir determined before application.

pH	EC[z]	Density (g·cm^{-3})		Concn (g·kg^{-1})			
(1:5)[y]	(1:5)[y]	Real	Bulk	Nitrogen	Phosphorus	Potassium	Calcium
5.72	0.31	0.465	0.08	6.62	0.63	6.21	0.21

Concn (mg·kg^{-1})					
Magnesium	Sulfur	Iron	Manganese	Copper	Zinc
513	—[x]	1287	24	9	27

[z]Electrical conductivity, dS·m^{-1}.
[y]Weight of material measured:deionized water ratio.
[x]No determination.

Table 2. Some selected nutrient composition of irrigation water and four treatments of various levels of nitrogen concentration before application.

Treatment[z]	pH	EC[y] (dS·m^{-1})	Concn (mg·L^{-1}) Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
TW	6.8	0.31	5.2	0.8	1.6	24.0	8.1
NS79	6.0	1.20	79.0	31.0	176.0	60.0	24.0
NS105	6.0	1.33	105.0	31.0	176.0	60.0	24.0
NS158	6.0	1.45	158.0	31.0	176.0	60.0	24.0
NS210	6.0	1.64	210.0	31.0	176.0	60.0	24.0

	Concn (mg·L^{-1}) Sulfur	Iron	Manganese	Copper	Zinc	Molybdenum	Boron
TW	—[x]	<DL[w]	<DL	<DL	0.07	—	—
NS79	48.0	0.80	<DL	0.03	0.20	0.05	0.22
NS105	48.0	0.80	<DL	0.03	0.20	0.05	0.22
NS158	48.0	0.80	<DL	0.03	0.20	0.05	0.22
NS210	48.0	0.80	<DL	0.03	0.20	0.05	0.22

[z]TW = tap water. The nitrogen concentrations in the nutrient solution were 79, 105, 158, and 210 mg·L^{-1} for NS79, NS105, NS158, and NS210, respectively.
[y]Electrical conductivity.
[x]No determination.
[w]Below detection limit.

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(Dufour and Guérin, 2003). The average length of the new petiole growth (cm per petiole) = the total length of the newly grown petiole (cm per plant) ÷ the total increase in leaf number (leaves per plant). The average length of the new growth of spathe length, spathe width, or peduncle length (cm) = the total length of the newly grown spathe length, spathe width, or peduncle length (cm per plant per year) ÷ the total increase in the number of flowers (flowers per plant). The ratio of length/width ratios of new growth spathe = the average length of the new growth of spathe length ÷ the average length of the new growth of spathe width.

The vase life and color of the spathe of the first and second large flowers (spathe width larger than 10 cm at 6 and 8 months after planting) of three plants for each treatment were measured (Paull, 1982). The color of the spathe was measured with a chroma meter (Nippon Denshoku NF333, Japan) and the results were expressed as *L*, *a*, and *b* related to visual perception (McGuire, 1992).

Sampling and chemical analysis. The nutrient compositions of coir and plantlets used were determined before planting. After 6 (28 Mar. 2007), 12 (27 Sept. 2007), 18 (28 Mar. 2008), and 24 (27 Sept. 2008) months of planting, three whole plants (including root, stem, leaf, and flower) in which the spadix color changeover had reached 75% of the length were sampled from each treatment group. The plant material was dried at 70 °C to constant weight. After weighing, the plant samples were ground to pass a 0.2-mm sieve. The C and N were measured with an elemental analyzer (Thermo FlashEA 1112, The Netherlands). Plant samples were digested by using concentrated sulfuric acid (Yoshida, 1972) and the digests analyzed for P [using the Murphy and Riley (1962) method], K, Ca, Mg, Fe, Mn, Cu, and Zn (using atomic absorption spectrophotometry).

Statistics. Statistical analysis was performed by one-way analysis of variance followed by Duncan's multiple range test at the 95% level of probability to determine any significant difference between treatments using the SAS software package (SAS Enterprise Guide 4, Cary, NC).

Results

Effects on plant growth, flower yield, and flower quality

The effects of N on plant growth and flower yield were different at different stages of growth (Table 3). Six MAP, the increase in dry weight of the NS79 plants was significantly smaller than that in the other treatment groups; no difference in the increase in dry weight was measured in the NS105-, NS158-, and NS210-treated groups (Table 3). Twelve and 24 MAP, the increase in dry weight of the NS210 plants was the smallest (Table 3). There was no difference in the increase in dry weight in the NS79-, NS105-, and NS158-treated groups.

Six MAP, the increase in leaf area in the NS158 and NS210 groups was significantly greater than in the NS79 and NS105 groups (Table 3). However, after 12 and 24 MAP, the increase in NS105 and NS158 leaf area was significantly greater than in NS79 and NS210 (Table 3). There was no difference in the increase in dry weight and leaf area of the plants among all treatments at 18 MAP (Table 3).

There was no difference in the increase in flower number of the plants among all treatments at 6 MAP (Table 3). Twelve MAP, the increase in flower number of plants receiving the NS79 treatment was significantly smaller than the other treatments. Eighteen MAP, the increase in flower number of plants receiving the NS210 treatment was smaller than NS158 treatment. Twenty-four MAP, the increase in flower number of plants receiving the NS105 treatment was significantly greater than that receiving NS79 and NS210 treatments (Table 3). In the first year's cultivation, the new growth of spathe width for NS158 plants exhibited the largest of all groups; however, NS210 plants exhibited the smallest of all groups in the second year (Fig. 2A). The length/width ratio of new spathe growth in NS158 plants was the smallest of all groups over the entire experimental period (Fig. 2B).

There were no significant difference in the vase life and color of the spathe of the first and second large flowers among treatments (data no shown).

During the 2-year growth period, the total increased dry weight, leaf area, and flower number of NS105- and NS158-treated groups were significantly greater than those of NS79- and NS210-treated groups (Table 3).

Table 3. Effects of nitrogen concentrations on the increase in dry weight, leaf area, and flower number of *Anthurium* at different growing stages.

Treatment[z]	Plantlets (Oct. 2006)	6 Oct.–7 Apr. (0–6 MAP[y])	7 Apr.–7 Oct. (6–12 MAP)	7 Oct.–8 Apr. (12–18 MAP)	8 Apr.–8 Oct. (18–24 MAP)	6–8 Oct. (0–24 MAP)
		Dry weight increased (g per plant)				
NS79	3.5	22.8 b[x]	14.6 a	7.0 a	19.2 a	63.6 b
NS105	3.5	32.7 a	13.6 a	8.0 a	22.3 a	76.6 a
NS158	3.5	33.7 a	15.1 a	7.8 a	21.4 a	78.0 a
NS210	3.5	34.7 a	9.6 b	6.7 a	14.6 b	65.6 b
Mean		31 A[w]	13.2 C	7.4 D	19.4 B	
		Leaf area increased (cm^2 per plant)				
NS79	323	1035 b	1722 b	1031 a	2473 b	6261 b
NS105	323	1018 b	2137 a	1043 a	3077 a	7275 a
NS158	323	1298 a	2221 a	1038 a	3012 a	7569 a
NS210	323	1240 a	1960 b	1004 a	2333 b	6537 b
Mean		1148 C	2010 B	1029 D	2724 A	
		Flower number increased (flowers per plant)				
NS79	0	2.7 a	3.7 b	2.2 ab	3.3 b	11.9 b
NS105	0	2.7 a	4.2 a	2.2 ab	4.0 a	13.1 a
NS158	0	2.8 a	4.4 a	2.4 a	3.7 ab	13.3 a
NS210	0	2.7 a	4.0 ab	1.9 b	3.6 b	12.2 b
Mean		2.7 C	4.1 A	2.2 D	3.7 B	

[z]The nitrogen concentrations in the nutrient solution were 79, 105, 158, and 210 $mg \cdot L^{-1}$ for NS79, NS105, NS158, and NS210, respectively.
[y]MAP = months after planting.
[x]Means in the same columns followed by the same small letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).
[w]Means in the same rows followed by the same capital letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

Effects on nutrient uptake

Nitrogen, phosphorus, and carbon/nitrogen ratio. At all growth stages, the NS210 treatment was found to yield the highest plant N concentration followed by NS158 and NS105 and the lowest was NS79 (Table 4). The amount of N uptake in NS79 plants was the smallest of all treatments except for the growth stage from Oct. 2007 to Apr. 2008 (12–18 MAP). N uptake did not differ between treatments between Oct. 2007 and Apr. 2008 (Table 5).

The NS79 treatment yielded the greatest C/N ratio followed by the NS105 and NS158 treatments, and the NS210 treatment was the smallest in all stages of growth (Table 3). The amount of C uptake by NS79 plants was the smallest except for the growth stage from Oct. 2007 to Apr. 2008 (12–18 MAP) and Apr. 2008 to Oct. 2008 (18–24 MAP) (Table 5). At all growth stages, C uptake by plants receiving NS105 or NS158 was greater than in the other treatments (Table 5).

Six MAP, the P concentration in NS105-treated plants was significantly lower than that in the other treatments; however, P concentrations did not differ at the other growing stages (Table 4). From Oct. 2006 to Apr. 2007 (0–6 MAP) and Apr. 2007 to Oct. 2007 (6–12 MAP), P uptake by NS79-treated plants was significantly smaller than P uptake in the other treatments. However, from Oct. 2007 to Apr. 2008 (12–18 MAP), the NS158 and NS210 plants showed the smaller P uptake (Table 5) and the smallest P uptake was found in NS210-treated plants during Apr. 2008 to Oct. 2008 (18–24 MAP).

Potassium, calcium, and magnesium. At all growing stages, the K concentration in NS79-treated plants was the highest, whereas the lowest was observed in NS210-treated plants. However, K concentration did not differ between NS105- and NS158-treated plants (Table 6). Among all treatments, plants treated with NS210 showed the smallest amount of

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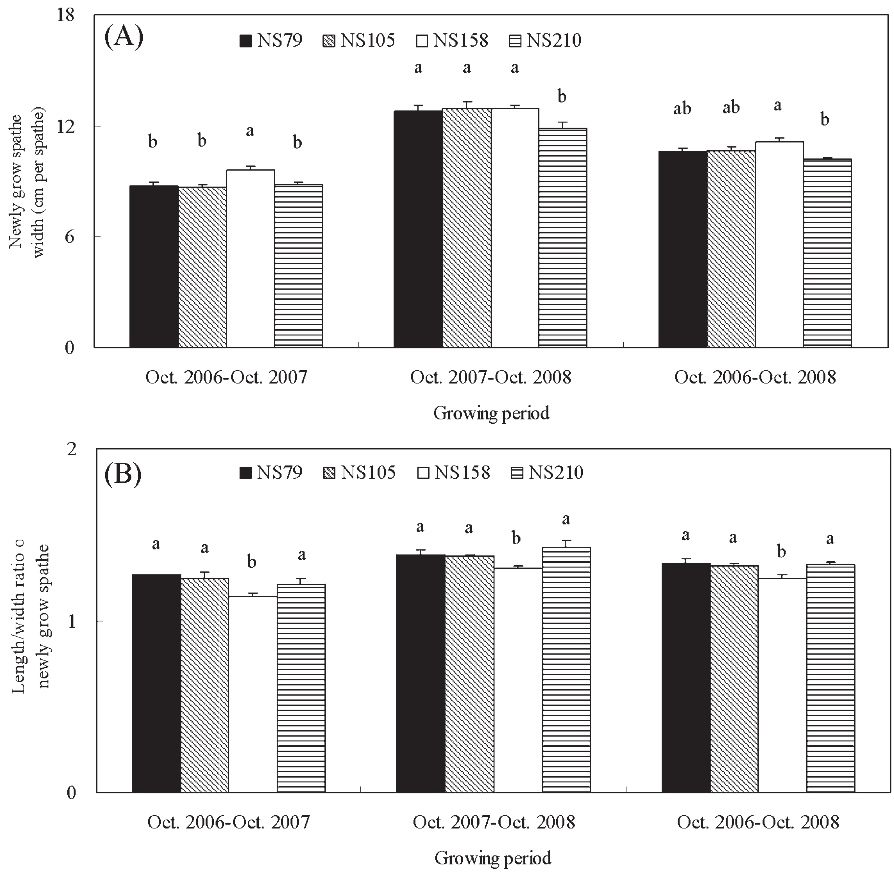

Fig. 2. Effects of nitrogen (N) concentration in nutrient solution on (**A**) new growth of spathe width and (**B**) length/width radio of new growth spathe on *Anthurium* during the first year, second year, and whole period of cultivation. Error bar denotes SDs of mean (n = 3). Means in the same part followed by the same letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$.

Table 4. Effects of nitrogen (N) concentrations on the levels of N and phosphorus (P) and carbon (C)/N in plant of *Anthurium* at the different growing stages.

Treatment[z]	Apr. 2007 (6 MAP[y])	Oct. 2007 (12 MAP)	Apr. 2008 (18 MAP)	Oct. 2008 (24 MAP)
		N ($g \cdot kg^{-1}$)		
NS79	13.1 d[x]	12.5 d	12.5 d	12.2 d
NS105	16.1 c	16.2 c	15.5 c	15.3 c
NS158	19.7 b	20.3 b	19.6 b	18.2 b
NS210	22.4 a	24.1 a	23.0 a	23.6 a
Mean	17.8 B[w]	18.3 A	17.7 B	17.3 C
		C/N		
NS79	31.6 a	31.2 a	32.0 a	31.2 a
NS105	27.7 b	27.8 b	28.8 b	27.2 b
NS158	21.5 c	21.2 c	22.0 c	23.5 c
NS210	18.7 d	18.9 d	19.1 d	19.0 d
Mean	24.9 AB	24.8 B	25.5 A	25.2 A
		P ($g \cdot kg^{-1}$)		
NS79	4.4 a	4.5 a	4.4 a	4.2 a
NS105	3.6 b	4.7 a	4.5 a	4.4 a
NS158	4.1 a	4.8 a	4.5 a	4.4 a
NS210	4.0 a	5.2 a	4.9 a	4.5 a
Mean	4.0 B	4.8 A	4.6 A	4.4 AB

[z]The N concentrations in the nutrient solution were 79, 105, 158, and 210 $mg \cdot L^{-1}$ for NS79, NS105, NS158, and NS210, respectively.
[y]MAP = months after planting.
[x]Means in the same columns followed by the same small letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).
[w]Means in the same rows followed by the same capital letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

K uptake, except in the period from Oct. 2006 to Apr. 2007 (0–6 MAP). During this period, the NS79-treated plants showed the smallest amount of K uptake (Table 7).

Plants treated with NS79 were noted to have the lowest Ca concentration throughout the study except for 18 MAP (Table 6). Six MAP, the Ca absorption in NS79-treated plants was significantly lower than that in the other treatments; however, Ca absorption by NS210-treated plants was significantly smaller than Ca absorption in the other treatments at 24 MAP (Table 7). No difference in Ca uptake was observed from Oct. 2007 to Apr. 2008 (12–18 MAP) among all treatments (Table 7).

Throughout the study, NS210-treated plants showed the lowest Mg concentration, whereas NS79-treated plants had the highest concentration (Table 6). Throughout the study, no consistent pattern of Mg absorption was identified in any of the treatments. No difference in Mg uptake was observed from Oct. 2007 to Apr. 2008 (12–18 MAP). Approximately 50% of the Mg in plants was absorbed during the first growth stage (0–6 MAP) (Table 7) as compared with the total amount of Mg absorbed after 24 months' growth.

Seasonal effects on plant growth, flower yield, and nutrient uptake

The net increase in dry weight of plants in the cool season (Oct. 2006–Apr. 2007) (0–6 MAP) of the first year was greater than that in the warm and hot seasons (Apr. 2007–Oct. 2007) (6–12 MAP). However, the opposite was true in the second year (Table 3). In contrast, the increase in leaf area and flower number of plants growing in the cool season (0–6 MAP) of the first year were smaller than those in the warm and hot seasons (6–12 MAP). The same results were observed in the second year of cultivation (Table 3).

Regardless of the seasonal fluctuations, there was a tendency for C, N, P, K, Ca, and Mg concentrations to decrease with increasing cultivation time (Tables 4 and 5). At the end of cultivation (24 MAP), the N, K, Ca, and Mg concentrations were lower than at any other point during growth. Regardless of dry matter yield, flower yield, nutrient concentration, and nutrient uptake, significant interactions were noted between the N treatments and the growing stages (Tables 3–7). The net uptake of C, N, P, K, Ca, and Mg was greatest in the first growth stage (0–6 MAP) and smallest in the third stage (12–18 MAP).

Discussion

The nitrogen requirement of Anthurium *cultivated in coir.* The amount of N applied in the NS79 treatment was insufficient for growth and flower yield of *Anthurium* cultivated in coir. This result was similar to that reported by Dufour and Guérin (2005) who reported an N concentration of 63 $mg \cdot L^{-1}$ in mixed substrate (pouzzolane and wood chips). However, other studies have suggested that

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Table 5. Effects of nitrogen (N) concentrations on uptake of carbon (C), N, and phosphorus (P) of *Anthurium* at the different growing stages.

Treatment[z]	6 Oct.–7 Apr. (0–6 MAP[y])	7 Apr.–7 Oct. (6–12 MAP)	7 Oct.–8 Apr. (12–18 MAP)	8 Apr.–8 Oct. (18–24 MAP)
		N (mg per plant)		
NS79	283 c[x]	169 c	87 a	207 b
NS105	528 b	221 b	89 a	329 a
NS158	674 ab	329 a	116 a	305 a
NS210	797 a	296 a	104 a	335 a
Mean	571 A[w]	254 C	98 D	294 B
		C (mg per plant)		
NS79	9,400 b	5,200 b	2,700 ab	5,900 b
NS105	14,800 a	6,200 ab	3,400 a	7,500 a
NS158	14,400 a	6,700 a	3,400 a	8,900 a
NS210	14,600 a	5,700 ab	2,300 b	5,300 b
Mean	13,300 A	5,950 C	2,950 D	6,900 B
		P (mg per plant)		
NS79	81 b	79 b	27 a	71 b
NS105	107 a	103 a	26 a	92 a
NS158	128 a	99 a	20 b	88 a
NS210	129 a	96 a	19 b	45 c
Mean	111 A	94 B	23 D	74 C

[z]The N concentrations in the nutrient solution were 79, 105, 158, and 210 $mg\cdot L^{-1}$ for NS79, NS105, NS158, and NS210, respectively.
[y]MAP = months after planting.
[x]Means in the same columns followed by the same small letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).
[w]Means in the same rows followed by the same capital letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

Table 6. Effects of nitrogen (N) concentrations on the levels of potassium (K), calcium (Ca), and magnesium (Mg) in plants of *Anthurium* at the different growing stages.

Treatment[z]	Apr. 2007 (6 MAP[y])	Oct. 2007 (12 MAP)	Apr. 2008 (18 MAP)	Oct. 2008 (24 MAP)
		K ($g\cdot kg^{-1}$)		
NS79	34.1 a[x]	35.9 a	35.5 a	31.4 a
NS105	31.8 b	30.7 b	30.2 b	28.8 b
NS158	32.3 b	30.5 b	29.4 b	27.9 b
NS210	26.1 c	27.0 c	27.7 c	25.9 c
Mean	31.1 A[w]	31.0 A	30.7 AB	28.5 B
		Ca ($g\cdot kg^{-1}$)		
NS79	16.1 c	15.0 b	15.0 b	14.2 b
NS105	19.0 a	16.9 a	16.0 ab	15.0 b
NS158	18.3 ab	18.4 a	17.3 a	16.8 a
NS210	17.7 b	17.8 a	16.5 a	15.1 b
Mean	17.8 A	17.0 B	16.2 C	15.3 D
		Mg ($g\cdot kg^{-1}$)		
NS79	8.0 a	7.0 a	6.8 a	5.7 a
NS105	7.1 b	6.2 b	5.9 b	5.2 a
NS158	7.0 b	6.0 b	5.8 b	5.3 a
NS210	5.7 c	5.5 c	5.3 c	4.8 b
Mean	7.0 A	6.2 B	6.0 B	5.3 C

[z]The N concentrations in the nutrient solution were 79, 105, 158, and 210 $mg\cdot L^{-1}$ for NS79, NS105, NS158, and NS210, respectively.
[y]MAP = months after planting.
[x]Means in the same columns followed by the same small letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).
[w]Means in the same rows followed by the same capital letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

Anthurium flower yield is unaffected by the supplied N concentration (Boertje, 1978; Dufour and Clairon, 1997; Higaki and Poole, 1978). Higaki et al. (1992) cultivated *Anthurium* in a different medium from that of Higaki and Poole (1978) and found that flower yield increased in response to increasing N. The smallest N concentration and N uptake and the highest C/N ratios in the NS79-treated plants were observed among treatments, suggesting that suboptimal N supply and accumulation of carbohydrate retarded plant growth by reducing leaf elongation (Chapin, 1988; Marschner, 1995; Zhao et al., 2005). As a result, the increase in dry weight, leaf area, and flower number of NS79-treated plants were small. The SPAD-502 values in mature leaves of NS79-treated plants were the smallest among the four treatments (data not shown). The leaf is the site of C assimilation, which is necessary for flower development. Therefore, retarded leaf growth will reduce the yield and spathe size of the flower (Dai and Paull, 1990; Dufour and Guérin, 2005).

The high rate of N application (NS210 treatment) also retarded *Anthurium* growth and flower yield. Higaki and Poole (1978) and Higaki et al. (1992) reported similar results: the yield and flower size increased quadratically in response to an increased N supply. The N concentration in the NS210-treated plants was the highest, although the K and Mg concentrations in these plants were the lowest among all treatments. The low K and Mg concentrations can be attributed to the antagonistic effect between N and K or between N and Mg (Marschner, 1995; Poole and Sheehan, 1974). The lower plant K concentration was disadvantageous for flower yield, spathe size, and peduncle length (Chang et al., 2010; Dufour and Guérin, 2005; Higaki et al., 1992). In addition, the small Mg level may reduce leaf number and leaf area in *Anthurium* (Chang et al., 2010).

Plants receiving the NS105 or NS158 treatment produced ≈13 flowers per plant over 2 years' cultivation, which is similar to the results reported by Dufour and Guérin (2005). The supply of nutrients from NS105 or NS158 treatment is sufficient for the growth and flower yield of *Anthurium* cultivated in coir. Taiwanese consumers prefer *Anthurium* flowers with a wide spathe and small length/width ratio (a more circular shape). The NS158-treated plants produced a more marketable cut flower during the first year of cultivation in comparison with the NS105-treated plants. Marschner (1995) reported that the increasing N supply-induced changes in plant morphology were related to changes in the phytohormone balance. Therefore, the NS158-treated plants produced a wider and more circular spathe could be attributed to the N-related phytohormone balance.

The nitrogen requirement and nutrient uptake of Anthurium *plantlets.* In comparison with the other stages of growth, macronutrient uptake was greatest at the initial stage of cultivation (0–6 MAP); this was probably the result of the warm winter in comparison with the winter (12–18 MAP) of the second cultivation year. In addition, a large amount of nutrient uptake in this stage could also be attributed to rapid growth of the plantlets when they were first transplanted to a larger container, as indicated by the greatest increase of biomass 6 MAP than at any other period in growth. Increased growth of the young plants suggested a greater need for nutrients (Adepetu and Akapa, 1977; Burns, 1992; Mengel and Kirkby, 2001; Vincent et al., 1979). As noted in this study, sufficient N was supplied by NS158 or NS210 for initial plant growth (0–6 MAP).

Growth and nitrogen requirement of Anthurium *in response to climatic fluctuations.* Growth and yield of *Anthurium* were affected by *PAR* and air temperature (Dufour and Guérin, 2003; Poole and McConnell, 1971; Schenk and Brundart, 1981). The ideal air temperature and radiation inside greenhouses for the cultivation of *Anthurium*

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Table 7. Effects of nitrogen (N) concentrations on uptake of potassium (K), calcium (Ca), and magnesium (Mg) of *Anthurium* at the different growing stages.

Treatment[z]	6 Oct.–7 Apr. (0–6 MAP[y])	7 Apr.–7 Oct. (6–12 MAP)	7 Oct.–8 Apr. (12–18 MAP)	8 Apr.–8 Oct. (18–24 MAP)
		K (mg per plant)		
NS79	810 c[x]	537 a	245 a	411 b
NS105	1044 a	366 b	240 a	507 a
NS158	1106 a	379 b	174 b	458 b
NS210	909 b	297 c	181 b	260 c
Mean	967 A[w]	395 C	210 D	408 B
		Ca (mg per plant)		
NS79	393 b	193 b	105 a	222 a
NS105	664 a	150 b	83 a	276 a
NS158	642 a	272 a	80 a	282 a
NS210	622 a	163 b	87 a	140 b
Mean	580 A	194 C	89 D	229 B
		Mg (mg per plant)		
NS79	198 b	76 a	39 a	77 a
NS105	261 a	36 b	32 a	75 a
NS158	248 a	53 b	35 a	83 a
NS210	205 b	46 b	26 a	43 b
Mean	228 A	53 C	33 D	69 B

[z]The N concentrations in the nutrient solution were 79, 105, 158, and 210 $mg \cdot L^{-1}$ for NS79, NS105, NS158, and NS210, respectively.

[y]MAP = months after planting.

[x]Means in the same columns followed by the same small letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

[w]Means in the same rows followed by the same capital letter indicate no significant difference by Duncan's multiple range test at $P \leq 0.05$ (n = 3).

were reported to be 18 to 28 °C and 930 mol/m^2/month (van Herk et al., 1998). In addition, *Anthurium* leaf growth and flower production fluctuate significantly according to the season (Klapwijk and van der Spek, 1988; van Herk et al., 1998). Regardless of nutrient treatment, it was obvious that the climate in the spring and summer (April–October) of this study was beneficial for *Anthurium* growth and flower yield as a result of the higher air temperature and *PAR* than in the fall and winter (October–April). For optimal plant growth, the photosynthetic and N assimilation rates must be in balance (Mengel and Kirkby, 2001). Nutrient requirements positively correlate with growth (Marschner, 1995; Mengel and Kirkby, 2001). In this study, the amount of macronutrient absorbed by the plants in the spring and summer (Apr. 2007–Oct. 2007 and Apr. 2008–Oct. 2008) was significantly greater than that in the fall and winter (Oct. 2007–Apr. 2008). According to the ''law of the minimum'' (Hennessy, 2009; Marschner, 1995), we conclude that the limiting factor in *Anthurium* growth and yield during the spring and summer is the N supply, whereas climate conditions are the limiting factor during the fall and winter (Gallagher, 1987; Goodwin and Ker, 1998; Kaylen and Koroma, 1991; Ker and McGowan, 2000).

Conclusion

Nitrogen concentration of 105 or 158 $mg \cdot L^{-1}$ sufficiently met the nutrient requirement of *Anthurium* cultivated in coir during the growing and flowering stages. The retarded growth of NS79-treated *Anthurium* was the result of insufficient N supply and C assimilation. The small K and Mg uptake of the plants as a result of excessive N supply (NS210 treatment) caused poor growth. Regardless of plant growth, flower yield, and nutrient uptake, this study demonstrated significant interactions between N treatments and seasonal fluctuations in a subtropical region during year-round cultivation of *Anthurium*.

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