Nitrogen Requirement and Nitrogen Form Preference by *Radermachera hainanensis* and *R. sinica* Plug Seedlings

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Abstract

Radermachera hainanensis Merr. and *R. sinica* Hemsl. are popular foliage plants raised from seeds. Nitrogen fertilizer can significantly influence medium pH and EC, plug seedling growth, and photosynthesis. Plug seedlings of both species, each with one pair of leaves, were subjected weekly to nutrient solutions with nitrogen (N) concentrations ranging from 0 to 32 mM. Nitrogen-deficient plants exhibited the lowest leaf area, SPAD-502 value, and shoot dry weight but the highest root-to-shoot ratio. Leaf area, SPAD-502 value, and root and shoot dry weights increased with increasing N concentration up to 12-16 mM, and gradually decreased thereafter. Well-grown plants with 12-16 mM N exhibited peak maximal fluorescence (Fm), photochemical quenching (qP) and the lowest minimal fluorescence (Fo) and non-photochemical quenching (qN). Seedlings received nutrient solutions with varying proportions of NH_4-N: NO_3-N (0:100, 25:75, 50:50, 75:25, and 100:0, in percentages) at 16 mM N. Both species exhibited reduced leaf area, SPAD-502 value, and plant dry weights when supplied with only NO_3-N or NH_4-N. Maximum growth was achieved at a 50% NH_4-N: 50% NO_3-N ratio.

Species used in this study: Golden jasmine tree, *Radermachera hainanensis* Merr.; China Doll, *Radermachera sinica* Hemsl.

Chemicals used in this study: ammonium nitrate; sodium dihydrogen phosphate; potassium sulphate; potassium nitrate; magnesium sulfate heptahydrate; calcium sulfate dihydrate; calcium nitrate tetrahydrate; ammonium sulfate; boric acid anhydrous; potassium chloride; ferrous sulfate heptahydrate; disodium ethylenediaminetetraacetic acid dihydrate; copper sulfate pentahydrate; zinc sulfate heptahydrate; molybdic acid; manganese sulfate monohydrate; nickel sulfate hexahydrate; sodium hydroxide.

Index words: ammonium toxicity, chlorophyll fluorescence, foliage plants, nitrogen concentration, photosynthesis.

Significance to the Horticulture Industry

Excessive fertilizer application not only increases production costs but also contributes to water pollution. Nitrogen significantly influences photosynthesis and the growth rate of plants. The proper nitrogen concentration requirements and the nitrate to ammonium ratio have yet to be determined for *Radermachera* species, which are widely used as ornamental foliage plants or in outdoor landscapes in tropical or subtropical regions. These woody plant species have a longer production cycle, and proper nitrogen fertilizer management for seedling trays can accelerate production. In this research, two species of *Radermachera* were treated with nine nutrient solution nitrogen concentrations and five nitrate to ammonium ratios to determine the proper nitrogen requirements for *Radermachera*. The information acquired from this study should contribute to a better understanding of nitrogen effects on photosynthesis and to accelerate growth, achieving uniform young *Radermachera* seedlings.

Introduction

Radermachera sinica, commonly known as the China Doll, and *Radermachera hainanensis* are native to Southeast Asia. Both species are valued for their attractive, delicate, pinnately compound leaves and are often cultivated as ornamental foliage plants or outdoor landscape plants in tropical or subtropical regions. China Doll was introduced to Europe, America, and New Zealand in the 1980s and 1990s (Griffith 2006, Thomas et al. 1995). *Radermachera hainanensis* has recently been among the top ten ranked potted plants in Taiwan. *Radermachera* plants are primarily propagated from seeds. The use of plug production offers several advantages, such as uniform production and the reduction of transplanting shock. Mineral nutrient management during plug production can impact seedling growth and quality (Styer and Koranski 1997). Growers are eager to explore nutritional management methods to accelerate growth and achieve uniform young *Radermachera* seedlings.

The nutritional requirements of container-grown *R. sinica* have been previously studied. Chase and Poole (1989) demonstrated that plant height and quality were not affected within a wide range of soluble salts, with leachate electrical conductivity (EC) ranging from 0.3 to 4.4 $dS{\cdot}m^{-1}$. Thomas et al. (1995) also found that *R. sinica* is an adaptable species that can thrive with low nitrogen (N) levels. However, a strong growth response is observed when additional N is provided, while phosphorus (P) and potassium (K) levels have little influence on growth. In cases of nitrogen deficiency or excess, photosynthesis may be reduced, actual photosystem II (PSII) photochemical efficiency decreases, the maximum photochemical quantum yield (Fv/Fm) decreases, and reactive oxygen species are generated, causing damage to the photosystem in cassava (Cruz et al. 2003). Currently, information regarding effects of nitrogen concentration on the growth and PSII efficiency of *Radermachera* plug seedlings is lacking.

Plants primarily absorb and utilize two forms of nitrogen: nitrate (NO_3^-) and ammonium (NH_4^+). Foliage plants have shown varying growth responses to nitrogen form. For example, the best growth and quality of peacock plant

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(*Calathea makoyana* E. Morr. & Boom) were achieved with NH_4-N or urea-N and poorest with NO_3-N (Conover and Poole 1982). Growth and grade of 'Silver Queen' aglaonema (*Aglaonema commutatum* Schott) and heartleaf philodendron [*Philodendron scandens* subsp. *oxycardium* (Schott) G.S. Bunting] improved when they received N sources containing 25% to 100% NH_4-N or 100% urea-N compared to 100% NO_3-N (Conover and Poole 1986). Dumb cane (*Dieffenbachia maculata* Sweet) 'Camille' grew equally well regardless of N form (Conover and Poole 1986), whereas dumb cane [*D. seguine* (Jacq.) Schott] 'Tropical Snow' showed a preference for NH_4-N (Jiménez and Lao 2005). The nitrogen form can impact rhizosphere pH, plant growth, and photosynthesis (Guo et al. 2007). While there is ample research on nitrogen preferences for various foliage plants, there is currently no report on the nitrogen preference for *Radermachera* species.

Nitrogen fertilizer has the most significant influence on the growth and quality of potted *Radermachera* (Thomas et al. 1995) and many plug seedlings of bedding plants (van Iersel et al. 1999). Therefore, the objectives of this study were to evaluate the effects of N concentration and the NO_3-N to NH_4-N ratio on medium pH and EC, growth and photosynthetic parameters of the plug seedlings in the two *Radermachera* species.

Materials and Methods

Plants. Seeds of *Radermachera hainanensis* and *R. sinica* were sown into 72-celled plug trays (4.5 × 4.5 × 3 cm or 1.8 × 1.8 × 1.2 in) containing 3 peat moss (pH balanced peat moss, Klasmann-Deilmann GmbH, Geeste, Germany): 1 perlite (No.2, Nanhai Vermiculite Industrial Co., New Taipei City, Taiwan): 1 vermiculite (No.2, Nanhai Vermiculite Industrial Co., New Taipei City, Taiwan). Plug trays were placed in a chamber at 24 C (75 F) under 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$ *PPF* (photosynthetic photon flux) (7.4 ft-c) conditions. When seedlings reached one pair of leaves, they were transferred into a phytotron at 30/25 C (86/77 F) and 260 $\mu mol \cdot m^{-2} \cdot s^{-1}$ *PPF* (24.2 ft-c) at plant height to receive N treatments.

Expt. 1. Effects of nutrient solution nitrogen concentration. Seedlings were supplied with nutrient solution formulated as per Johnson et al. (1957). The concentration of NH_4NO_3 was altered to prepare nutrient solutions with 0, 4, 8, 12, 16, 20, 24, 28, and 32 mM N. The nutrient solutions also contained 2 mM NaH_2PO_4, 3 mM K_2SO_4, 1 mM $MgSO_4 \cdot 7H_2O$, and 4 mM $CaSO_4 \cdot 2H_2O$, along with micronutrients specified by Johnson et al. (1957). The corresponding EC of each solution, measured with a conductivity meter (Model SC-170, Suntex Instruments Co., Taiwan) was 1.7, 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.2, and 3.4 $dS \cdot m^{-1}$, respectively. The pH of the nutrient solution was adjusted to 6.5 using 1 N NaOH before each application. Each plant received 50 mL (1.7 oz) of nutrient solution once a week. The treatments were replicated three times, with nine plants per treatment. Measurements were taken on three randomly sampled plants per treatment, with three replicates.

Changes in medium EC and pH during the experiment were monitored using the press extraction method (Scoggins 1999). Leachate was collected from plug cells, and the EC and pH of the leachate were measured using a conductivity meter and a pH/oxidation-reduction potential meter (SP-2300, Suntex Instruments Co.).

At 55 d after treatments began, two recently fully expanded leaves from each plant were sampled to measure chlorophyll fluorescence parameters using a portable chlorophyll fluorometer Mini-Pam (Heinz Walz GmbH, Effeltrich, Germany). Minimal fluorescence (Fo) was determined after 30 min dark adaptation, while maximal fluorescence (Fm) was measured after a saturation pulse (ca. 18,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ or 1,672 ft-c) at 25 C (77 F). The fluorescence ratio Fv/Fm, with Fv = Fm - Fo being the variable fluorescence, was then calculated. Photochemical quenching (qP) and non-photochemical quenching (qN) were also measured.

At 60 d after treatments were initiated, the relative chlorophyll content of the most recently fully expanded leaf was also measured in situ with a chlorophyll meter (SPAD-502, Minolta Camera Co., Tokyo, Japan). Leaf area of the most recently fully expanded leaf was calculated using ImageJ (National Institute of Health, Bethesda, MA). Plants were divided into above-ground (shoot) and below-ground (roots) parts, oven-dried at 70 C (158 F) until constant, and dry weights were recorded. The root-to-shoot ratio was calculated as root dry weight divided by shoot dry weight. This experiment was arranged in a completely randomized design, and regression analysis was used to describe the relationships between nutrient solution N concentration and growth and PSII parameters.

Expt. 2. Effects of nutrient solution nitrogen form and ratio. Nutrient solutions with various nitrate to ammonium ratio including 0:100, 25:75, 50:50, 75:25, and 100:0 (in percentages) ratios. Nutrient solutions supplied with, in mM, 16 N, 1 P, 8 K, 6 Ca, and 1 Mg. $Ca(NO_3)_2 \cdot 4H_2O$, $(NH_4)_2SO_4$, KNO_3, NaH_2PO_4, K_2SO_4, $MgSO_4 \cdot 7H_2O$ and $CaSO_4 \cdot 2H_2O$ were nutrient sources. The actual EC values of these solutions were measured using a conductivity meter (Model SC-170, Suntex Instruments Co.), as 2.26, 2.57, 2.66, 3.02, and 3.42 $dS \cdot m^{-1}$ for 0:100, 25:75, 50:50, 75:25 and 100:0 (nitrate: ammonium), respectively. Treatments were replicated three times, with nine plants per treatment. Three plants per treatment were randomly sampled for measurements, with three replicates.

Medium EC and pH were monitored as described above. Leaf area and relative chlorophyll content of the most recently fully expanded leaf was determined and chlorophyll fluorescence parameters were also measured as previously described. Photosynthetic parameters were assessed using a portable photosynthesis system (LI-6400, LI-COR, Lincoln, NE, USA). Air was pumped through the desiccant (Drierites, W.A. Hammond Drierite Co., Xenia, OH, USA) and soda lime [a mixture of sodium hydroxide (NaOH) and calcium hydroxide ($Ca(OH)_2$)] (LI-COR) to eliminate excess water vapor and CO_2. Light intensity within the leaf chamber was set at 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ *PPF* (74.3 ft-c) and a reference CO_2 concentration of 400 $\mu mol \cdot mol^{-1}$ was provided. The air flow rate was set at 600 $\mu mol \cdot s^{-1}$, and the measurement area was set at 3 cm^2 (0.465 in^2). Temperature

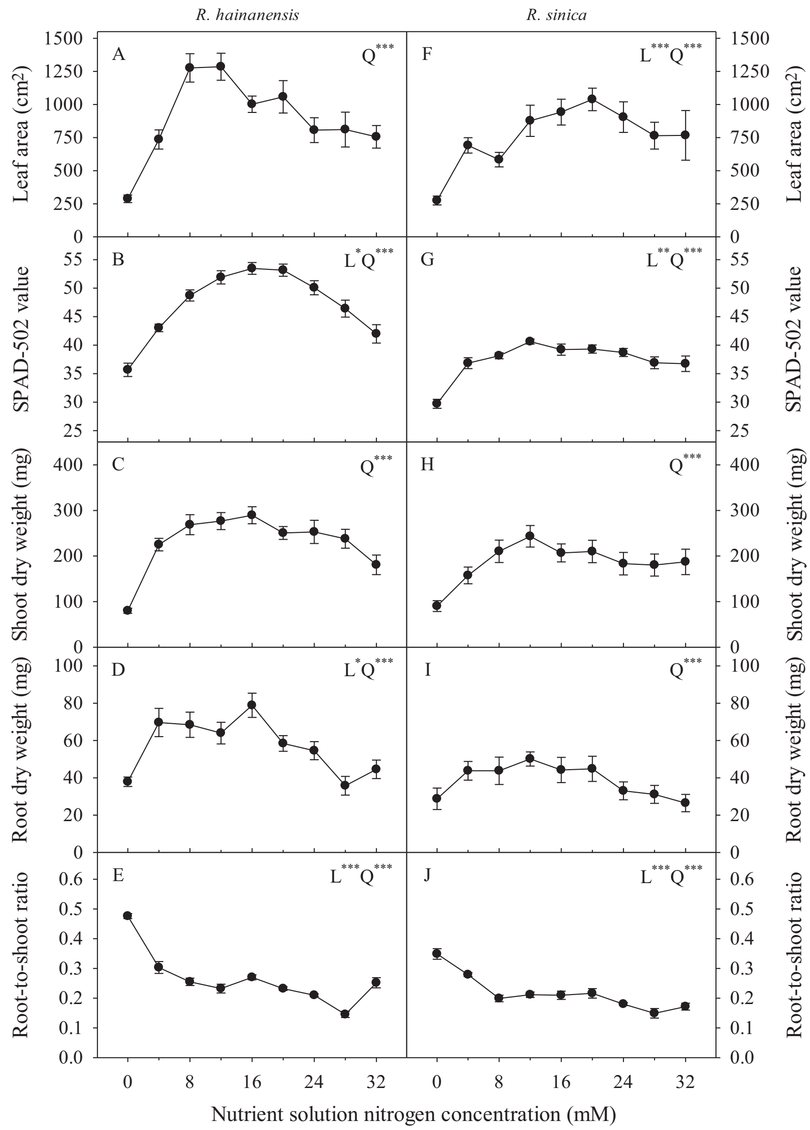

Fig. 1. Effects of nutrient solution nitrogen concentration on leaf area, SPAD-502 value, shoot and root dry weights, and root-to-shoot ratio in *Radermachera hainanensis* (A-E) and *R. sinica* (F-J) plug seedlings. Bars represent standard error of the means and are not visible if smaller than the symbol.

at the leaf surface was maintained at an average of 25.3 C (77.5 F). This allowed for the measurement of the net CO_2 assimilation rate (Pn), stomatal conductance (g_s), transpiration rate (E), and intercellular CO_2 concentration (C_i) of the most recently fully expanded leaves. The plants were divided into shoot and roots, dried, and dry weights were determined as previously described. The experiment was arranged in a completely randomized design. Regression analysis was performed with SigmaPlot 10.0 (Systat Software Inc., Palo Alto, CA, USA) using the percentage NH_4-N as the independent variable.

Results and Discussion

Expt. 1. Effects of nutrient solution nitrogen concentration. Both species under N deficiency exhibited smaller leaf areas (Fig. 1A and F) and lighter green leaves as indicated by the lowest SPAD-502 value (Fig. 1B and G). This suggests that nitrogen deficiency inhibits cell expansion and chlorophyll synthesis (Yanagida et al. 2011). Shoot and root dry weights were significantly reduced, while the root-to-shoot ratio increased, in response to the N-deficient treatment (Fig. 1C-E, H-J). Similar examples for preferential partitioning of photosynthetic carbon to the roots and an increase in root-to-shoot ratio are well-documented for other species under N deficiency (Chen et al. 2018, Hermans et al. 2006, Yeh et al. 2000).

Leaf area, SPAD-502 value, shoot and root dry weights increased as nutrient solution N concentration increased and plateaued at 12-16 mM N treatments and then declined gradually thereafter (Fig. 1A-D, F-I). These results are consistent with Thomas et al. (1995), demonstrating that N nutrition has a strong growth-promoting effect. More pronounced declines in leaf area, SPAD-502, and root dry weight were observed in *R. hainanensis* receiving 20 mM or higher N treatments (Fig. 1A, B, D). Excessive N accumulation in the rhizosphere may cause leaf necrosis from excess salt levels and limit root water uptake, and result in

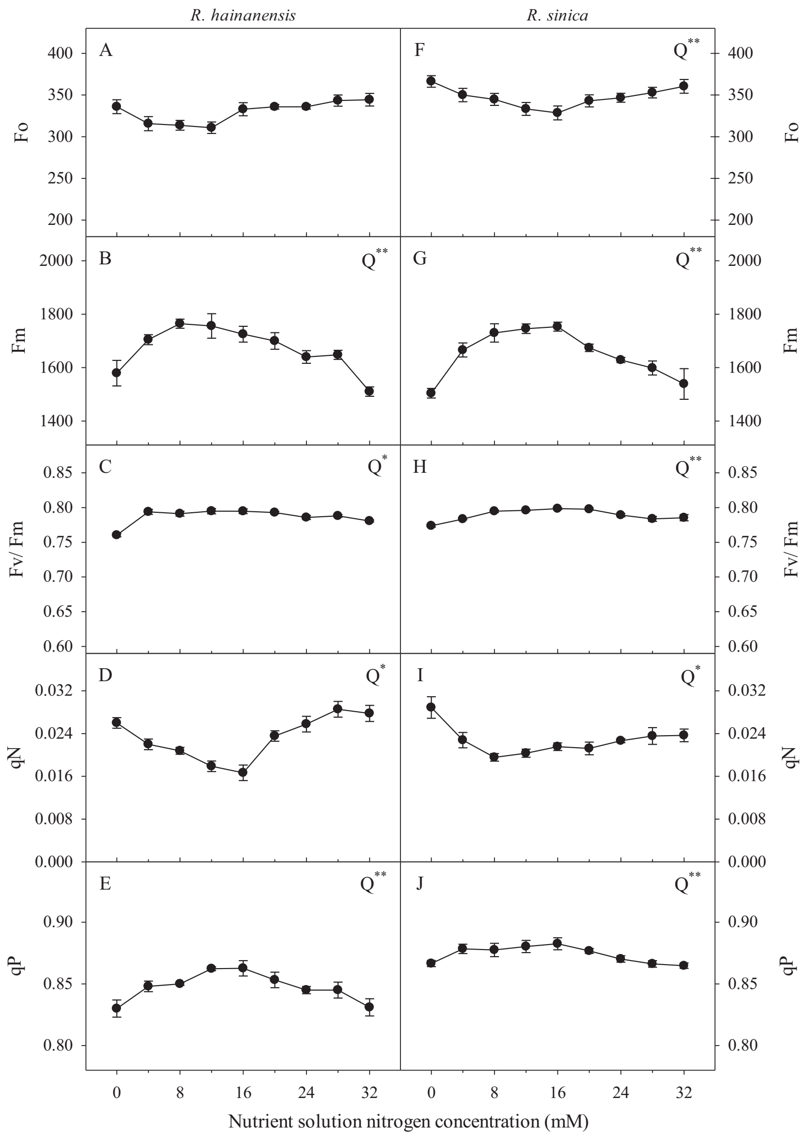

Fig. 2. Effects of nutrient solution nitrogen concentration on minimal fluorescence (Fo), maximal fluorescence (Fm), maximum quantum efficiency of photosystem II (Fv/Fm), non-photochemical quenching (qN), and photochemical quenching (qP) value in *Radermachera hainanensis* (A-E) and *R. sinica* (F-J) plug seedlings. Bars represent standard error of the means and are not visible if smaller than the symbol.

low water turgor for leaf expansion (Mengel and Kirkby 2001). *Radermachera sinica* is reported to have higher water requirements than other foliage plants (Poole and Conover 1992). It was observed that *R. hainanensis*, probably due to its faster growth and larger leaflets, is more susceptible to drought stress compared to *R. sinica*.

Minimal fluorescence (Fo) and qN decreased, while Fm and qP increased, with solution N concentration increasing from 0 to 12-16 mM N (Fig. 2). Nitrogen-deficient *R. hainanensis* exhibited the lowest Fv/Fm (Fig. 2C). Both species treated with 16 mM or higher N concentration exhibited increased Fo and qN and decreased Fm and qP (Fig. 2). Depending on the species/cultivar, plants under different stress conditions can exhibit increases in Fo and/or qN but decreases in Fm and/or qP (Adams III and Demmig-Adams 2004). The growth response to N concentration of *Radermachera* was well correlated with PSII parameters, indicating that N application can alter photosynthesis and growth by regulating PSII. Similar results, where N levels alter PSII, have been reported for other plants (Chen et al. 2018, Cruz et al. 2003, Shangguan et al. 2000, Tantray et al. 2020).

For each treatment, the leachate EC value of the medium increased on the day of fertilization and then decreased afterward (Fig. 3A and C). This decrease in leachate EC value was attributed to the absorption of mineral nutrients by seedlings or leaching out of the pot from irrigation, and the leachate EC value increased again only until the next fertilization. The leachate EC increased with increasing nutrient solution N concentration. Throughout the experimental period for both species, the leachate EC values for treatments with 8-16 mM N fell within the recommended range of EC values (0.9-2.5 $dS \cdot m^{-1}$) for plug seedlings (Scoggins 1999). For treatments with N concentrations exceeding 20 mM, the leachate EC values after 28 d exceeded the upper limit of the recommended range by Scoggins (1999).

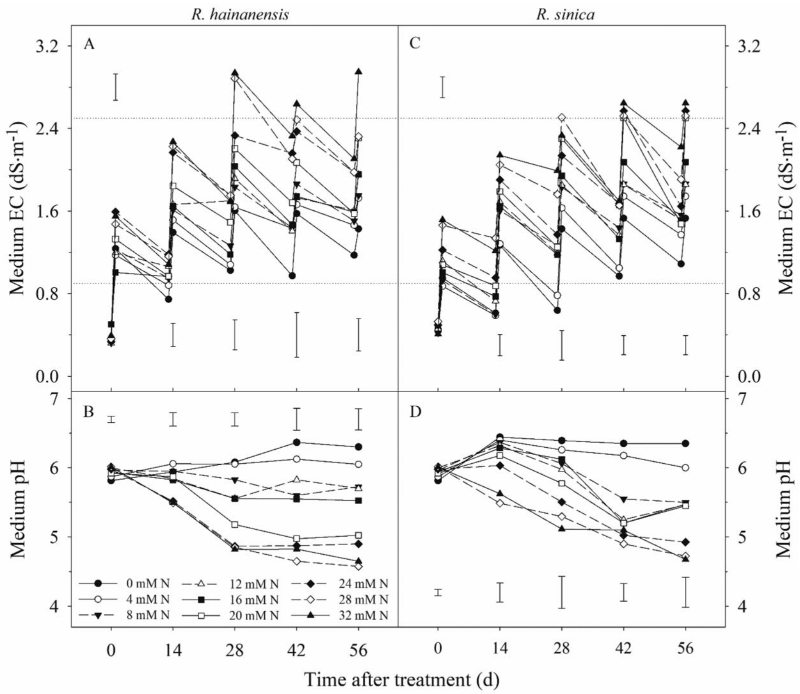

Fig. 3. Changes of electrical conductivity (EC) and pH values in *Radermachera hainanensis* (A, B) and *R. sinica* (C, D) plug medium as affected by various nutrient solution nitrogen concentration during the 56 d of treatments. Vertical bars represent $LSD_{0.05}$ among treatments on the same day (n = 3). Dotted lines indicate proper EC ranges during plug production recommended by Scoggins (1999).

The leachate pH remained constant during the experiment with nitrogen-deficient or 4 mM N treatments (Fig. 3B and D), indicating insufficient nutrition for plant uptake. The leachate pH for well-grown plants under 12-16 mM N treatments ranged from 5.0 to 5.5 (Fig. 3B and D), closely aligning with the medium pH of 4.8 reported for *R. sinica* (Thomas et al. 1995). The leachate pH decreased with increasing nutrient solution N concentration from 8 to 32 mM. This might be attributed to the roots absorbing more cations, leading to the release of H^+ from the roots to maintain ionic balance in the plant (Feng et al. 2020).

Expt. 2. Effects of nutrient solution nitrogen form and ratio. Both species with sole NO_3-N or NH_4-N exhibited reduced leaf area, SPAD-502 value, and plant dry weight compared to 50% NH_4-N: 50% NO_3-N treatment (Table 1). The restriction in leaf expansion may be due to a reduced ability of N absorption in the roots under NO_3-N only treatment (Ruan et al. 2007). High NH_4-N ratios may inhibit shoot growth and leaf expansion, mainly due to reduced osmotic regulation (Raab and Terry 1994, Walch-Liu et al. 2000). Also, high NH_4-N ratios may inhibit K absorption and cause toxicity symptoms for many plant species (Mengel and Kirkby 2001). No foliar symptoms of K deficiency, such as marginal necrosis and irregular spots, occurred, suggesting that the absorption of K was likely not severely reduced by applying sole NH_4-N to *Radermachera* species. However, it was observed that some plants of *R. hainanensis* with 100% NH_4-N expressed downward leaf curling, possibly related to NH_4 toxicity. Maximum growth was obtained with 50% NH_4-N: 50% NO_3-N for both species (Table 1). Foliage plant species show a great diversity of growth response according to N sources. For example, best growth and grade of heartleaf philodendron also occurred with 50% NH_4-N: 50% NO_3-N (Conover and Poole 1986). Growth and grade of Boston fern [*Nephrolepis exaltata* (L.) Schott] was not influenced by N source, whereas peacock plant had best growth and quality with NH_4-N or urea than with NO_3-N (Conover and Poole 1982, 1986).

The general trends of changes in photosynthetic parameters and growth in response to N form and ratio were similar for both species (Table 2). Notably, *R. sinica* supplied

Table 1. Effects of nutrient solution nitrogen form and ratio, at 16 mM N, on leaf area of recently fully expanded leaves, SPAD-502 value, shoot and root dry weight in *Radermachera hainanensis* and *R. sinica* plug seedlings.

NH_4^+:NO_3^- (%)	Leaf area (cm^2)	SPAD-502 Value	Dry weight (mg/plant)	
			Shoot	Root
		R. hainanensis		
0:100	10.9	39.4	301.1	84.8
25:75	13.1	47.7	340.9	76.3
50:50	16.1	48.3	351.4	74.7
75:25	13.1	48.4	327.1	80.5
100:0	11.2	45.0	282.7	60.3
Regression	Q***^{z}	Q***	Q**	L*
		R. sinica		
0:100	4.9	29.9	95.0	19.9
25:75	8.6	35.1	127.1	22.6
50:50	11.8	39.4	202.1	41.8
75:25	7.3	38.7	160.0	35.5
100:0	6.8	37.2	152.6	22.6
Regression	Q**	Q***	Q*	Q***

^{z}*, **, *** indicates significant at $P < 0.05$, 0.01, or 0.001, respectively. L, linear; Q, quadratic responses.

Table 2. **Effects of nutrient solution nitrogen form and ratio, at 16 mM N, on net photosynthetic rate (*Pn*), stomatal conductance (g_s), transpiration rate (E), and intercellular CO_2 concentration (C_i) of the recently fully expanded leaves in *Radermachera hainanensis* and *R. sinica* plug seedlings.**

NH_4^+:NO_3^- (%)	*Pn* (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$)	g_s (mol$\cdot m^{-2} \cdot s^{-1}$)	E (mol $H_2O \cdot m^{-2} \cdot s^{-1}$)	C_i (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$)
		R. hainanensis		
0:100	2.6	0.025	0.34	228
25:75	4.6	0.041	0.55	212
50:50	4.4	0.039	0.52	209
75:25	4.2	0.038	0.50	213
100:0	3.8	0.039	0.52	232
Regression	L*Q**[z]	L*Q*	L*Q*	NS
		R. sinica		
0:100	2.2	0.033	0.47	285
25:75	3.2	0.042	0.56	268
50:50	3.4	0.045	0.61	264
75:25	3.4	0.049	0.65	280
100:0	3.7	0.065	0.83	291
Regression	L*	L*	L*	NS

[z]NS, *, ** indicates non-significant or significant at $P < 0.05$ or 0.01, respectively. L, linear; Q, quadratic responses.

with 100% NH_4-N had a higher *Pn*, g_s, and E than those with 100% NO_3-N (Table 2), similar to a report for French bean (*Phaseolus vulgaris* L.) (Guo et al. 2002). This may explain why growth of *R. sinica* was improved with NH_4-N over NO_3-N (Table 1). N form or ratio altered g_s, but not C_i (Table 2), indicating N source affects photosynthesis through regulating stomatal opening and closure for *Radermachera*. However, best growth and photosynthetic performance of *Radermachera* were obtained with both NH_4^+ and NO_3^- sources (Tables 1 and 2). These results agree with Marschner et al. (1986), who reported that a mixture of different N forms increases the efficiency of N use.

Throughout the experimental period, the leachate EC values for treatments with 25% NH_4-N: 75% NO_3-N or 50% NH_4-N: 50% NO_3-N fell within the recommended range of EC values (0.9-2.5 $dS \cdot m^{-1}$) for plug seedlings, as suggested by Scoggins (1999). For treatments with higher NH_4-N ratios, the leachate EC values exceeded the upper limit of the recommended range (Fig. 4A and C; Scoggins 1999). This may explain why reduced growth occurred in plants with 75% NH_4-N: 25% NO_3-N or 100% NH_4-N (Table 1).

It is proposed that NO_3^- uptake is mediated by a 2 H^+/1 NO_3^- symport to a plant cell, followed by the release of one H^+ ion from the cell, resulting in increased medium pH (Crawford and Glass 1998). However, the leachate pH from the medium with 100% NO_3-N treatment did not increase substantially and it remained between 5.9 and 6.6 (Fig. 4B and D). In addition, the leachate electrical

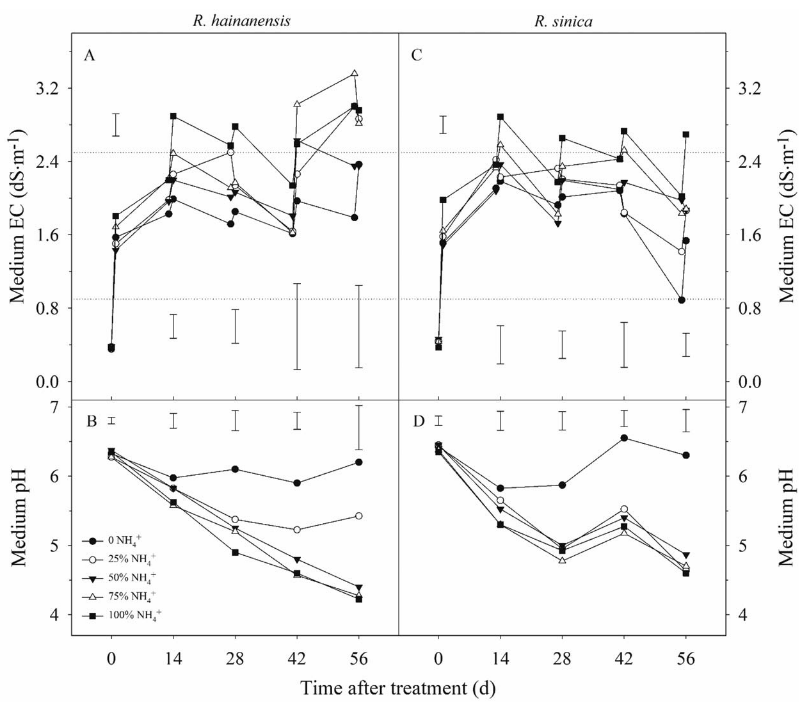

Fig. 4. Changes of electrical conductivity (EC) and pH values in *Radermachera hainanensis* (A, B) and *R. sinica* (C, D) plug medium as affected by nutrient solution nitrogen form and ratio during the 56 d of treatments. Vertical bars represent $LSD_{0.05}$ among treatments on the same day (n = 3). Dotted lines indicate proper EC ranges during plug production recommended by Scoggins (1999).

conductivity (EC) values with sole NO_3-N did not change pronouncedly compared to treatments containing NH_4-N (Fig. 4A and C), implying that *Radermachera* prefers NH_4-N over NO_3-N under suitable medium EC ranges for growth. The leachate pH values decreased with NH_4-N treatments over the experimental period (Fig. 4). This medium acidification might be attributed to the roots absorbing more NH_4^+ and other cations, leading to the release of H^+ from the roots to maintain ionic balance in the plant (Feng et al. 2020, Mengel and Kirkby 2001, Stegani et al. 2019). Similar examples, a decrease in leachate pH with increasing N concentration linked to the absorption of a significant amount of NH_4^+, have been reported in woody plants such as tea plant [*Camellia sinensis* (L.) Kuntze] (Ruan et al. 2007) and mountain azalea [*Rhododendron canescens* (Michx.) Sweet] (Clark et al. 2003).

In conclusion, nutrient solution N concentration significantly affects the growth performance of plug seedlings in *Radermachera hainanensis* and *R. sinica*. Weekly application of a nutrient solution with 12-16 mM N resulted in maximum leaf growth and plant dry weight, along with improved PSII electron transfer efficiency. The EC of medium leachate should be kept below 2.5 $dS{\cdot}m^{-1}$. Both best growth and photosynthetic performance of *Radermachera* seedlings were obtained with 50% NH_4-N: 50% NO_3-N.

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