Response of Lotus (*Nelumbo sp.*) to Container Soil Volume[1]

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Abstract

The effect of soil volume on containerized lotus (*Nelumbo*) production has been underreported. American lotus (*Nelumbo lutea* Willd.) and three cultivars ('Embolene', '98 Seed' and 'Karizma') of Asian lotus (*N. nucifera* Gaertn.) were investigated for growth response to container soil volume in this study. Electrical conductivity, pH, plant growth indices, and plant nutritional content were influenced by container soil volume. Differences in some plant growth indices were significant between treatments with ¼ and higher (½ and ¾) container height soil (CHS) in 21 or 29 liter (#5 or #7) containers. However, plant growth indices were generally not different between treatments with ½ and ¾ CHS. Lotus planted in containers with ¼ CHS usually produced the greatest plant height and underground fresh weight, while the largest number of propagules often occurred in containers with ½ or ¾ CHS. The highest number of emerging leaves was observed in plants with ¼ or ½ CHS treatments, with no significant difference in emerging leaf number between lotus grown in containers with ½ and ¾ CHS. Flower number generally decreased as soil level increased. The ¼ and ½ CHS were more efficient than ¾ CHS for lotus production in containers.

Index words: *Nelumbo nucifera*, *Nelumbo lutea*, pH, electrical conductivity, fertilization, plant growth index.

Species used in this study: Asian lotus (*Nelumbo nicifera* Gaertn.), American lotus (*Nelumbo lutea* Willd.).

Significance to the Nursery Industry

Container ornamental lotus has a long history in Asian countries and has been recently becoming a nursery crop in the United States. Soil volume is an important consideration for container production of lotus. Generally, soil volume in a container ¼ to ¾ height was suitable for container lotus production depending on cultivar. Inadequate soil in containers did not anchor plants well, while too much soil inhibited plant growth and increased labor cost. Soil volume influenced plant growth not only through nutrient availability, but also indirectly by influencing water level, electrical conductivity (EC), and pH of water. EC was remarkably affected by soil volume to water relationship when the same rate of fertilizer was applied. Therefore, fertilization of lotus should be dependent on soil or water volume in containers for optimal growth of plants.

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Introduction

Lotus (*Nelumbo*) is an aquatic perennial plant of great economic importance especially in Asian countries. Lotus rhizomes from *N. nucifera* Gaertn. are one of the major vegetables in China, Japan and Korea. In 2005, production of lotus in China was estimated at 300,000 ha (741,000 A) resulting in approximately 6.75 million tons of lotus rhizomes per year based on an average yield of 22.5 ton·ha^{-1} (55.6 ton·A^{-1}) (8). As an ornamental, flowering-lotus has been cultivated in pools and containers for at least 1,600 to 2,500 years (18). Although lotus has a long history in container cultivation, only seeds and rhizomes are sold as propagules for retail purposes. Containerized plants have rarely been marketed in the horticultural industry (4).

Studies on propagation and production of lotus in ponds or rice fields have been well documented (14, 16). Higher temperatures at 20–30C (68–86F) are found to greatly accelerate plant growth, while below 15C (59F), growth of *N. lutea* is very limited (10). Optimal temperatures for lotus growth are 22–32C (72–90F) (20). Shallow water is conducive for lotus growth (2) because temperatures in a water-soil system increase quicker in shallow water than in deeper water. The soil volume is usually not a controllable factor in field production and lotus is free to grow to its maximum depth. In container production, lotus performance can be affected by container size, soil level and water level. Soil medium not

only anchors the plants but also provides nutrition for plant growth. Inadequate soil in containers may not stabilize lotus plants well and may not provide enough space for extension of rhizomes and roots during development. In contrast, too much soil may not benefit plant growth while adding to difficulty of shipping and handling as well as extra labor costs. Therefore, the optimal soil volume must be considered before planting lotus based on container size and plant cultivar to obtain maximum profit. Soil with 2/3 and 3/5 container height volume for planting bowl lotus was reported by Li and Qian (7) and Wang and Zhang (19), respectively. However, information about the effects of soil volume on growth of lotus in containers is largely unavailable (18). The major objectives of this study were to investigate how soil volume in containers influences growth indices and nutrient uptake of lotus. The genotypic effect on response of lotus to soil volume was also examined. Results will provide useful guidelines for container production of lotus in nurseries.

Materials and Methods

Three cultivars of lotus (*Nelumbo nucifera*) ['Embolene' (medium size with pink flowers), '98 Seed' (unnamed hybrid, large size with red flowers) and 'Karizma' (medium size with white-yellow flowers), and American lotus *N. lutea*] were investigated. The first experiment was conducted in 2004. Lotus rhizome-propagules of 'Embolene' and '98 Seed' were divided from stock plants with young leaves, and planted in 29 liter (#7) black plastic containers [bottom 31 cm (12.2 in) and top 37 cm (14.6 in) diameter, 32 cm (12.6 in) height] without draining holes on May 17, 2004. Each pot was planted with one propagule, usually with two internodes. Due to limitation of plant material this year, only two treatments were used. Containers were filled to ½ [16 cm (6.3 in), 13 liters] and ¾ container height (CH) [24 cm (9.4 in), 20 liters], respectively, with natural sandy loam soil. After planting, all pots were filled with tap water (pH 7.0, EC = 0.13 $mS \cdot cm^{-1}$). Containers were placed under full sunlight with 25 cm (9.8 in) spacing.

Fertilizer was applied three times once every twenty days beginning on June 9, 2004, when plants had at least several floating leaves and possibly one or two standing leaves. The last fertilizer application was applied on July 21, 2004. Soluble fertilizer Pro•Sol 20–10–20 (20N–4.4P–16.6K) (Pro•Sol Inc., Ozark, AL 36360, USA) was added as 4 g (1 $tsp) \cdot pot^{-1}$ each time. Water solution samples were taken one hour before fertilization and 24 hr after fertilization, respectively, in the late afternoon from the same pots to monitor the nutrient status. Before taking samples, pots were irrigated by hand near the top of containers for all treatments. On August 23, young fully expanded leaves were sampled for nutrient analysis.

The second experiment was started on April 1, 2007. *N. lutea* (medium-large size, ordered from Perry's Water Gardens in North Carolina, USA) was planted in 29 liter (#7) containers filled with ¼ [8 cm (3.1 in), 6 liters], ½ [16 cm (6.3 in), 13 liters], and ¾ CH [24 cm (9.4 in), 21 liters] of sandy loam soil, respectively. *N. nucifera* 'Karizma' (medium size) was planted in 21 liter (#5) white plastic containers [bottom 26.5 cm (10.4 in) and top 28.5 cm (11.2 in) diameter, 36 cm (14.2 in) height] with ¼ [9 cm (3.5 in), 5 liters], ½ [18 cm (7.1 in), 10 liters], and ¾ CH [27 cm (10.6 in), 15 liters] of the same type of soil. Fertilizer (Pro•Sol 20–10–20) was diluted to a 10% (w/v) solution with tap water and applied on a 20-day interval schedule: 4 g (May 10), 6 g (May 30), 8 g (June 20), 10 g (July 10), and 4 g (July 30) per pot. pH and EC were measured with Hanna instruments HI 9811 PH/EC/TDS meter on the 1st and 20th day following fertilization. Data on plant height and emerging leaf number were taken on August 20 when plants reached the maximum size and began dormancy. Flower number was recorded once every 4 days until no flowers developed. Plant rhizomes were harvested on November 10, 2007. Expanded rhizomes of *N. lutea*, which is more a rhizome type (often called vegetable lotus) of *N. nucifera*, were harvested on November 20 and used for nutrient analysis.

Both experiments were conducted outside the Paterson Greenhouse Complex at Auburn University, AL, using a completely randomized design with six replications. Containers were placed under full sun on weed fabric with 25 cm of spacing between pots. The temperatures were 16–27C (61–81F) in spring and 20–38C (68–100F) in summer. Plant growth data collected included plant height, number of emerging leaves, flowers, propagules (normally containing 2 or 3 internodes), expanded internodes, and fresh weight of underground parts (rhizomes and roots). Plant height was measured from the bottom of containers to the top of plant. The number of expanded internodes was calculated based on the number of swollen internodes with a diameter larger than 1.5 cm (0.6 in). All samples of water (for 2004 experiment only) and plant tissues were analyzed by Soil Testing Laboratory at Auburn University. Water pH was determined at 25C (77F) using a Fisher Accumet Model 50 pH meter. Nutrient contents of water were determined simultaneously by Inductively Coupled Plasma (ICP) Atomic Emission Spectrometry using a Varian Vista-MPX Axial Spectrometer (9). Plant samples were dried in a forced air oven at 60C (140F) for 72 hr prior to determination of moisture content and dry mass. Mineral nutrient contents of plant tissue were analyzed by Inductively Coupled Plasma Emission Spectroscopy using a Varian Vista-MPX Axial Spectrometer (5, 12, 13). Total nitrogen was analyzed with an Elementar Vario Macro CNS Analyzer (3). Nitrate-nitrogen was analyzed colorimetrically with a Thermo Spectronic Genesis 20 Spetrophotometer (1). Mean differences were examined by t-test for the first experiment and by Tukey's test (HSD) with ANOVA procedure for the second experiment using SAS 9.1 (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414 USA).

Results and Discussion

After the addition of water to all containers, soil volumes decreased 2–6 cm (0.8–2.4 in) in height depending on the initial soil volume and container type. In the first experiment, the pH slightly increased from 7.0 to 7.3 three weeks after planting. The pH decreased after fertilization and increased as nutrients were absorbed by plants (data not shown). EC increased sharply after fertilization and was higher in the ¾ CHS treatment than in the ½ CHS treatment for both cultivars (Fig. 1). EC decreased as plants grew and nutrients were absorbed. After the first or second fertilizer applications, absorption rates of N, P, and K were 99 to 99.6%, 93 to 96.4%, and 80.1 to 96.2%, respectively (Table 1), which indicated that N was completely utilized by plants and more P and K were absorbed in the second than the first fertilizer application. Our results suggested that 4 $g \cdot pot^{-1}$ of Pro•Sol 20–10–20 every 20 days might not be enough to meet the maximum growth potential of lotus, which was confirmed

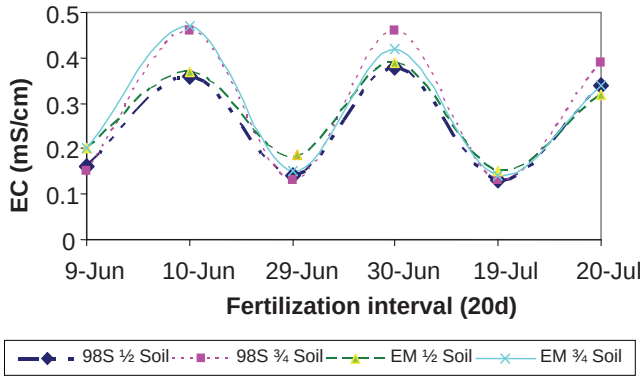

Fig. 1. Influence of soil volume on water electrical conductivity in 29 liter (#7) containers during fertilization of lotus (2004). Plants were supplied with 4 g of Pro•Sol 20–10–20 on June 9, June 29, and July 19 at a 20-d interval. EC was measured before each fertilizer application, 12 hrs and 20 days following fertilization, respectively. 98S – '98 Seed' lotus, EM – 'Embolene'; Soil – soil volume based on container height.

by fertilization experiments (17, 18). The nutrient absorption rate also increased after the second fertilizer application because plants grew faster during this period than in the period following the first application due to increased temperature, light intensity, and day length. No differences were observed in macronutrients (N, P, K, Ca, and Mg) of young leaf tissue between the ½ and ¾ CHS treatments for both 'Embolene' and '98 Seed' (Table 2). However, micronutrients in leaf tissue were generally higher in the ¾ CHS than in the ½ CHS treatment, possibly because increased soil volume offered increased availability of minor nutrients. The higher ($P < 0.05$) contents of B and Mn in plants with ¾ CHS than in plants with ½ CHS for both selections indicated that the absorption of macronutrients B and Mn was significantly increased by soil volume in containers. '98 Seed' lotus grown in containers with higher soil volume [¾ CH, 18 cm (7.1 in)] showed a decrease in flower number (Table 3). Other plant growth indices were not significantly affected by soil volume. However, both 'Embolene' and '98 Seed' lotus grown in containers with ¾ CHS generally produced more propagules and expanded internodes.

In the second experiment, 40 days after planting, pH increased slightly from 7.0 to 7.4–7.7 (½ to ¾ CHS treatments) for *N. lutea* in 29 liter (#7) containers but remarkably increased from 7.0 to 9.0–9.2 for 'Karizma' in 21 liter (#5) containers. A rapid increase of pH in containers with 'Karizma' was possibly caused by alkalization of water and medium due to proliferation of some alkaliphilic species of algae (6, 15) such as string algae, which was found to associated with high pH between 8 and 10 in our later experiments. pH decreased after fertilization and increased as nutrients were absorbed during the period of the first 3 fertilizer applications. pH values generally were in a range of 6.0 to 7.0 with some exceptions occurred in the earlier application period for

Table 1. Influence of soil volume on concentration (ppm) and nutrient absorption rate (%) of N, P, K based on water samples in 29 liter (#7) containers for the first two fertilizer applications with 4 g of Pro•Sol 20–10–20 at a 20 d interval (2004).

Lotus cultivar	Time period and AR[z]	Soil volume[y]:	N (%)		P (%)		K (%)	
			½	¾	½	¾	½	¾
Embolene	6/10/2004		21.1	40.7	4.3	6.4	29.2	42.7
	6/29/2004		0.2	0.3	0.3	0.3	5.8	6.3
	AR		99.1	99.3	93.0	95.3	80.1	85.2
	6/30/2004		27.6	40.6	8.3	9.7	34.6	49.8
	7/19/2004		0.1	0.1	0.5	0.5	5.1	5.9
	AR		99.6	99.8	94.0	94.8	85.3	88.2
98 Seed	6/10/2004		29.0	43.8	4.8	7.6	24.0	44.3
	6/29/2004		0.3	0.2	0.3	0.3	1.7	5.3
	AR		99.0	99.5	93.8	96.1	92.9	88.0
	6/30/2004		27.6	40.6	8.3	9.7	34.6	49.8
	7/19/2004		0.1	0.1	0.3	0.3	0.8	1.9
	AR		99.6	99.8	96.4	96.9	97.7	96.2

[z]AR = nutrient absorption rate (%).

[y]Soil volume (½, ¾ container height) was based on 29 liter containers (32 cm height).

Table 2. Effect of soil volume in 29 liter (#7) containers on nutrients[z] of young leaves of lotus sampled 70 days after planting (2004).

Cultivar	Soil volume[y]	Macronutrients (%)					Micronutrients (ppm)						
		N	Ca	K	Mg	P	Fe	Al	B	Zn	Cu	Na	Mn
Embolene	½	1.87	1.30	1.15	0.38	0.17	39.2	26.2	17.7	10.5	8.7	257.0	1580.2
	¾	1.92	1.18	1.25	0.36	0.19	50.2	33.7	35.2*	14.1	8.5	312.4	1992.6*
98 Seed	½	1.50	1.41	0.75	0.39	0.13	30.5	24.7	15.7	17.3	5.9	233.3	1545.8
	¾	1.49	1.33	0.71	0.39	0.13	34.5	27.8	25.6*	13.8	6.5	222.8	2014.1*

[z]*Significant ($P \leq 0.05$, t-test) comparing soil treatments within column for the same cultivar.

[y]Soil volume (½, ¾ container height) based on 29 liter containers (32 cm height).

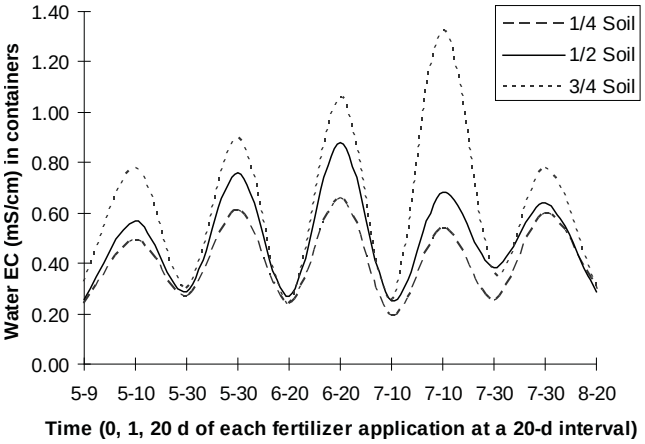

Fig. 2. Influence of soil volume on EC in water during fertilization of *Nelumbo lutea* grown in 29 liter (#7) containers (2007). Fertilizer Pro•Sol 20–10–20 was applied for five applications with a sequence of 4, 6, 8, 10, and 4 g·pot^{-1} from May 10 to July 30 at a 20-d interval. EC was measured on May 9 before first application, on the 1st day and the 20th day following each fertilizer application. Soil – soil volume based on container height.

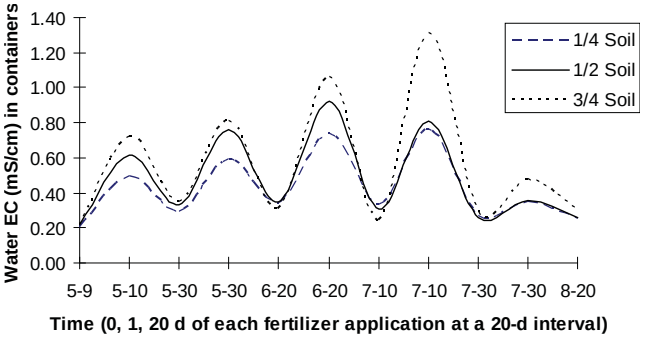

Fig. 3. Influence of soil volume on water EC during fertilization of lotus 'Karizma' grown in 21 liter (#5) containers (2007). Fertilizer Pro•Sol 20–10–20 was applied for five applications with a sequence of 4, 6, 8, 10, and 4 g·pot^{-1} from May 10 to July 30 at a 20-d interval. EC was measured on May 9 before first application, on the 1st day and the 20th day following each fertilizer application. Soil – soil volume based on container height.

'Karizma'. EC increased sharply after fertilizer was applied then dropped as nutrients were absorbed by plants (Figs. 2, 3). EC was highest in containers with ¾ CHS because of lower water volume and higher concentration of nutrients. EC was lowest in containers with the ½ CHS because of more water providing greater dilution.

Responses of lotus plants to the soil volume were different for *N. lutea* and 'Karizma' (Table 4). The treatment with lowest soil volume (¼ CHS) resulted in *N. lutea* producing the largest values in plant height [92.6 cm (36.5 in)], standing leaf number (27.4), fresh underground weight (1495.8 g), fresh weight of total propagules (694.6 g), and the maximum diameter of internodes [3.66 cm (1.4 in)]. There were no significant differences in growth indices between ½ and ¾ CHS treatments in *N. lutea*. Although the largest fresh underground biomass was found in the ¼ CHS treatment, the largest number of propagules occurred in the treatment with ½ CHS. Therefore, for the purpose of propagule production, containers filled with ½ CHS would be best. It was interesting to observe that *N. lutea* failed to develop flowers in all treatments. The failure of flowering was possibly due to over fertilization. However, for the plants of *N. lutea* grown in larger containers supplied with lower rate of fertilizer, only one flower developed in four containers. In 2008, a lower rate of fertilizer, 4 g·pot^{-1} of Pro•Sol 20–10–20 at 20-day intervals, was applied to *N. lutea* in 29 liter (#7) containers with ¼, ½, and ¾ CHS, respectively. Only the plants with ¼ CH soil treatment developed flowers. This result suggested flower development of American lotus was also inhibited by higher soil volume in containers. On the other hand, *N. lutea* did not perform well in Wuhan Botanical Gardens of China, which has a climate similar to South Alabama (personal communication). Therefore, American lotus might be more sensitive to environmental conditions. *N. lutea* performs well in ponds and shallow lakes in the wild, but appears unsuitable for container production. Further research is necessary to investigate the reason for failure of flower bud formation of *N. lutea* in containers.

Nutrient analysis of *N. lutea* expanded rhizome tissue revealed the ¼ CHS to have the highest values of Fe and Cu contents but usually the lowest values of the other nutrients (Table 5). Differences between the ¼ CHS treatment and two other treatments (½ and ¾ CHS) were observed in Ca, K and Mg (macronutrients), and in Al, Na and Mn (micronutrients). However, there was no difference in growth parameters between lotus in the ½ and ¾ CHS treatments. Although Fe content in expanded rhizomes of *N. lutea* decreased from 90.8 to 67.8 to 29.7 ppm as soil volume increased from ¼ to ½ to ¾ CH, the mean difference was not statistically significant because of large variation observed among the individual samples. The difference of Fe content between the highest and lowest individual values was extremely high and reached 8.3 fold. This difference was at least partially caused by fertilization-related nutrient stresses with an inhibition of Fe absorption at high EC in containers with high soil volume.

Table 3. Growth response[z] of lotus (*Nelumbo*) to soil volume in 29 liter (#7) containers (2004).

Cultivar	Soil volume[y]	Fresh weight (g)	Propagule no.	Expanded internode no.	Emerging leaf no.	Flower no.
Embolene	½	316.9	28.3	18.0	44.6	12.3
	¾	333.7	31.2	22.3	41.6	12.2
98 Seed	½	693.4	8.6	7.4	20.2	2.0
	¾	656.3	9.0	7.7	23.7	0.5*

[z]*Significant ($P \leq 0.05$, T-test) within column for the same cultivar.

[y]Soil volume (½, ¾ container height) was based on 29 liter containers (32 cm height).

Table 4. Effects of soil volume on growth indices[z] of lotus (*Nelumbo*) in containers (2007).

Cultivar	Soil volume[y]	Plant height (cm)	Standing leaf no.	Flower no.	Underground (g·pot^{-1}, fw[x])	Propagule (g·pot^{-1}, fw)	Propagule no.	Expanded internode no.	Maxim rhizome diameter (cm)
Lutea	¼	92.6a	27.4a	0	1495.8a	694.6a	11.2a	15.4a	3.66a
	½	55.6b	6.4b	0	503.6b	424.0b	13.8a	17.8a	2.92b
	¾	59.8b	5.2b	0	424.6b	370.6b	11.6a	15.2a	2.78b
Karizma	¼	99.8a	59.4b	7.0a	994.8a	480.4a	29.2a	7.4a	2.04a
	½	93.2a	80.4a	5.6ab	851.0ab	512.4a	37.8a	7.5a	2.24a
	¾	85.6a	75.6ab	3.6b	627.8b	367.8a	32.2a	6.8a	2.40a

[z]Means separation by Tukey (HSD) at 0.05 significance level.

[y]Soil volume (¼, ½, ¾ container height) was based on 29 liter containers (32 cm height) for *N. lutea*, and 21 liter (36 cm height) containers for 'Karizma'.

[x]fw = fresh weight.

Table 5. Effects of soil volume in 29 liter (#7) containers on nutrient contents in expanded rhizome tissue[z] of *Nelumbo lutea* (2007).

Soil volume[y]	Moisture[x] (%)	Macronutrients (%)					Micronutrients (ppm)						
		N	Ca	K	Mg	P	Fe	Al	B	Zn	Cu	Na	Mn
¼	63.4a[w]	1.93a	0.08b	1.24b	0.13b	0.33a	90.8a	22.2b	5.0a	14.2a	9.2a	205.6b	41.5b
½	68.1a	2.39a	0.11a	1.85a	0.18a	0.43a	67.5a	34.3a	5.7a	17.0a	8.0a	288.6a	78.6a
¾	67.7a	2.50a	0.09ab	1.72ab	0.18a	0.39a	29.7a	36.4a	5.2a	21.9a	9.1a	240.0ab	62.4a
Range	61.6–74.5	1.66–3.54	0.07–0.13	1.07–2.25	0.11–0.21	0.29–0.55	18.1–168.4	17.0–43.9	3.9–7.5	10.9–40.7	4.0–14.7	152.1–341.2	34.9–144.8
H/L[v] ratio	1.21	2.13	1.75	2.10	1.95	1.88	9.29	2.6	1.9	3.7	3.7	2.2	4.1

[z]Expanded rhizomes were sampled on November 10 following harvest.

[y]Soil volume (¼, ½, ¾ container height) was based on 29 liter containers (32 cm height)

[x]Moisture (of expanded rhizomes) was calculated (fresh weight – dry weight) / fresh weight × 100%.

[w]Means separation by Tukey (HSD) at 0.05 significant level within column for the same cultivar.

[v]H/L = the highest value / the lowest value.

After fertilization at higher rates (8–10 g·pot^{-1}) of fertilizer, plants especially in containers with ½ or ¾ CHS showed a slight toxic symptom in young leaves with interveinal yellowing due to Fe deficiency which was often caused by imbalance of nutrient or over-fertilization in container lotus production based on our investigation and other reports (11, 17). Larger interindividual differences among treatments were also seen in Mn, Zn, and Cu contents. Obviously, a large sample size of lotus rhizomes would better evaluate these parameters.

'Karizma' grown in containers with ¼ CHS treatment produced the largest fresh underground weight (994.8 g·pot^{-1}), as well as flower number (7 flowers·pot^{-1}) (Table 4). The highest fresh weight of total propagules, and the largest number of propagules and expanded internodes were found in plants receiving ½ CHS treatment. However, there was no significant difference in all plant parameters of 'Karizma' grown in containers with ¼ and ¾ CHS.

Natural loam soil is a good medium for planting lotus in containers. Results from both experiments suggested that soil volume influenced lotus growth. Although plant height and the underground fresh weight for both *N. lutea* and 'Karizma' were the largest in containers with the lowest soil volume [¼ CH, 8 or 9 cm (3.1 or 3.5 in)], the number of propagules was the lowest. Lotus grown in containers with half CH [16 or 18 cm (6.3 or 7.1 in)] of soil produced the largest number of propagules.

Total availability of nutrients, especially micronutrients, increased with soil volume. Soil volume may influence plant growth through nutrient availability. Plants experienced different nutrient stresses due to an interaction of fertilizer rate and water volume. EC was affected by the soil:water ratio when the same rate of fertilizer was applied. A genotypic effect was shown on response of lotus growth especially flower development to soil volume. Fertilization of lotus should be dependent on water volume in containers for the optimal growth of plants since interactions may exist between factors that include soil or water volume, fertilizer rate, EC, pH, temperature, and plant growth. Future study is necessary to determine the relationships of these factors and the major effects on growth of lotus.

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