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Response of Lotus (*Nelumbo nucifera* Gaertn.) to Planting Time and Disbudding

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Abstract*. Lotus (*Nelumbo*) is a highly valued plant with a long history for vegetable, ornamental, and medicinal use. Little information is available on the effects of planting time on performance of lotus, especially when grown in containers. The objectives of this study were to find a suitable planting time and to determine best management practices that are of importance for container lotus production. Effects of planting time and disbudding on plant growth indices in southeast Alabama were evaluated in a container production system for the ornamental lotus, *N. nucifera* 'Embolene'. Results indicated that plant growth indices were little influenced by different planting dates in March, but were much influenced by planting dates with a difference over a month between February and May. Plants potted and placed outdoors in March and April performed best, and lotus planted in the greenhouse in February and planted outdoors in February and May performed worst. Flower number was not largely influenced by the planting time, but flowering characteristics, especially the flowering peaks, were different among treatments. Planting lotus outdoors between March and May produced the largest return. Influence of planting time on plant growth indices of lotus appeared to be explained by effects of growth-season climate conditions after planting. Disbudding had no impact on plant height but significantly increased underground fresh weight and the number of propagules. Therefore, disbudding should be considered a best management practice to maximize the yield of rhizomes or propagules. Positive linear, quadratic, or cubic relationships were detected among emerging leaf number, underground fresh biomass, and propagule number. Based on the regression models, the yield of lotus rhizomes or propagules can be predicted by the number of emerging leaves. This research provided a guide for nurseries, researchers, and collectors to select the best time to plant lotus outdoors.

Lotus (*Nelumbo nucifera* Gaertn.), also called Asian lotus, is an aquatic herbaceous perennial plant. *N. nucifera* has an extremely long history in cultivation as a vegetable, medicinal, and ornamental plant in Eastern countries (Wang and Zhang, 2004). Lotus rhizome is one of the major vegetables in Asia. Recently, lotus has become a potential crop in Australia (Nguyen, 2001), New Zealand (Follett and Douglas, 2003), and the United States (Tian et al., 2006). Lotus is usually planted in a tilled pond or rice field for vegetable production or planted in containers, small ponds, and lakes for ornamental uses. Planting time is often between late spring and early summer (Sou and Fujishige, 1995) with plant growth ending in the fall under natural conditions. Growth and yield of lotus may be influenced by diverse factors such as genotype (Zhou et al., 2004), media (Li and Qian, 1994; Meyer, 1930; Wang and Zhang, 2004), water depth (Nguyen, 2001; Snow, 2000; Wang and Zhang, 2004), light (Li et al., 2000; Snow, 2000), temperature (Meyer, 1930), planting time and propagation methods (Katori et al., 2002; Wang and Zhang, 2004), planting techniques (Min et al., 2006; Sang et al., 1994; Shen et al., 2001; Wen, 1987), fertilization (Hicks, 2005; Li and Qian, 1994; Orimoto and Takai, 2007; Song et al., 2006; Sou and Fujishige, 1995; Zhang et al., 1994), and other environmental factors (Hicks, 2005; Nguyen, 2001).

Cultivar selection and cultivation techniques are dependent on the environmental setting of the lotus plant. Lotus can be propagated by seeds, rhizome divisions with viable growing points, and tissue culture. Effects of propagation methods and planting techniques on yield of lotus have been much reported (Katori et al., 2002; Min et al., 2006; Sang et al., 1994; Shen et al., 2001; Wang and Zhang, 2004; Wen, 1987). Propagation by division of running stems (nonenlarged rhizomes or straps) during the growing season cannot only save stock rhizomes and reduce cost, but also increase efficiency and prolong flowering period of plants and may replace plants that do not survive early in the year (Wang and Zhang, 2004). Days to flowering are significantly shorter in the strap propagation method than in the enlarged rhizome propagation method where flowering time is delayed (Katori et al., 2002). Plants generated through the rhizome strap method also produce larger flowers.

Off-season cultivation methods have been developed to meet the demands of the market. Availability of vegetable rhizomes could be advanced to June by growing edible lotus earlier in the season (Fu et al., 1994). Flowering lotus generally blooms from June to August, but population flowering time can be extended to early October when lotus is propagated by dividing growing plants in July (Deng et al., 1990). It is feasible to prolong flowering time of lotus through the winter when plants are planted in a heated greenhouse (Li et al., 2000). If the technologies of advancing and delaying flowering are incorporated, three cycles of population flowering are possible in 1 year (Wang and Zhang, 2004). Reports indicate that production of lotus cut flowers may be on a year-round schedule (Chomachalow, 2004). However, little information is available on effects of planting time on overall lotus performance in various climatic regions. Productive organs of lotus plants are nutrient sinks. Disbudding of lotus would possibly increase plant yield of lotus rhizomes and other plant growth indices. The major goal of this study was to investigate effects of planting time and disbudding on lotus growth and development in containers.

Materials and Methods

A medium-sized ornamental lotus, *N. nucifera* 'Embolene', was used to evaluate response to planting times and disbudding. Expts. 1 and 2 were conducted in 2005 and 2007, respectively. Expt. 1 evaluated if lotus growth was influenced by disbudding or planting time with a difference less than 1 month in the typical Zone 8A planting season. A 2 × 3 factorial experimental design was used. Cooler-stored (4 °C) lotus propagules (two to three internodes with shoots) were planted outdoors in 0.029-m^3 (29-L) black plastic containers (31 cm bottom and 37 cm top in diameter, 32 cm height) without holes on 1 Mar., 16 Mar., and 31 Mar. 2005. Twenty propagules were planted each time with one propagule per container. Each treatment had 10 replicates. All containers were filled to two-thirds container level (21 cm, 0.018 m^3) with natural sandy loam soil and immediately filled to three-fourths container level with municipal tap water (pH 7.0, electrical conductivity = 0.13 $mS \cdot cm^{-1}$) after planting. Fertilization began when several floating leaves developed. After containers were filled to full container level with water, each plant was fed 8 g of soluble fertilizer 20N–4.4P–16.6K (Pro•Sol 20-10-20; Pro•Sol Inc., Ozark, AL) at 20-d intervals. Fertilizer was applied four times and each treatment received the same amount of fertilizer. During the flowering period, flower buds were discarded as found above water once every 3 d for one half of plants from each planting

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date, whereas the other half was not pruned allowing flower buds and fruits to mature. Plant height and emerging leaf number were measured on 20 Aug. 2005 when plants reached maximum height. Underground parts were harvested on 1 Jan. 2006.

Because only fresh underground weight and propagule number were influenced by planting dates within March in Expt. 1, the second experiment with treatments of more than 1 month's difference of planting time was conducted in 2007. The same type of containers were used but only filled to half container level (16 cm, 0.013 m^3) of the same type of soil in Expt. 1. Cooler-stored propagules of lotus 'Embolene' were planted on 25 Feb., 25 Mar., 25 Apr., and 25 May. There were two treatments for the plants planted on 25 Feb.: greenhouse (heating set point of 23.3 °C and a ventilation set point of 26.7 °C) and outdoors. Plants planted on all other dates were placed outdoors. Each treatment contained six plants (pots). Soluble fertilizer 20N–4.4P–16.6K (Pro•Sol 20-10-20) was applied beginning on 20 Apr. for plants planted on 25 Feb., 10 May for plants planted on 25 Mar., 20 May for plants planted on 25 Apr., and 15 June for plants planted on 25 May based on the equal dose and sequence with 4, 8, 12, 12, 8, and 4 g/pot at a 20-d interval. Blooming time and flower number were recorded once every 1 or 2 d. Data on plant height and emerging leaf number were taken on 20 June, 10 July, 2 Aug., 20 Aug., and 12 Sept. Underground parts were harvested on 23 Nov. 2007. Ambient temperatures and daylength of Auburn City of Alabama in 2007 were provided by Weather Underground (http://www.wunderground.com).

Data on fresh biomass, number of marketable propagules (two to three expanded internodes with shoots), secondary propagules (two to three nonexpanded internodes with shoots), total propagules (including both marketable and secondary propagules), and the number of expanded internodes (1 cm or greater in diameter) were immediately taken after harvest. The expanded internodes (four samples/treatment) were sent to the Soil Testing Laboratory at Auburn University for nutritional analysis. Major effect factors and interactions between plant time and disbudding were determined by SAS PROC MIXED procedure in Expt. 1. Means of variables were separated by Tukey honestly significant difference or least significant difference procedure (when difference was not determined by Tukey) at the 0.05 significance level using SAS 9.1 (SAS Institute Inc., 2002). To investigate whether one plant index, especially the yield of rhizomes or propagules, could be predicted by another plant index, relationships among plant growth parameters were determined by regression analysis with SAS 9.1 using pooled data from all outdoor treatments in Expt. 2.

Results and Discussion

In Expt. 1, planting time and disbudding were detected as factors in only three of four plant growth indices (Table 1). Plant growth indices of 'Embolene' were affected by different planting dates in March and more influenced by disbudding treatment (Table 1). Planting dates did not influence plant height (PH) and emerging leaf number (ELN) but influenced underground fresh weight (UFW) and total propagule number (TPN) of plants. The UFW and TPN of 'Embolene' in the control group planted on 31 Mar. were significantly increased compared with rhizomes of plants planted on 1 Mar. Disbudding only increased ELN of plants planted on 1 Mar. but increased nearly all UFW and TPN of treated plants (Table 1). Plants grown from rhizomes planted later performed better than those grown from rhizomes planted earlier in March.

In the second experiment, plants responded to environmental conditions in the greenhouse and outdoors differently. Because of higher average temperatures (data not shown), plants in the greenhouse grew faster in the early stage and reached a peak plant height and flowered earlier but had the lowest values in PH and ELN measured on 12 Sept. (Table 2; Figs. 1, 2, and 3). Plants in the greenhouse also entered dormancy and stopped growth earlier based on observation. Initial flowering times, flowering peak, and plant growth were obviously influenced by plant growth environment (greenhouse versus outdoors) and planting time. Days to the first flower were 76, 90, 71, 45, and 60 for plants planted on 25 Feb. in the greenhouse; and on 25 Feb., 25 Mar., 25 Apr., and 25 May outdoors, respectively. This is important scheduling information for projecting optimum shipping times to retail outlets. Days to the largest flower peak were 90, 95, 85, 55, and 85 d, respectively. An obvious decrease in flowering occurred between 30 June and 20 July, except for rhizomes planted on 25 May. No flowers developed after 20 Aug. for plants in the greenhouse and after 20 Sept. for all plants planted outdoors. Plants grown outdoors showed similar growth patterns associated with the ambient temperatures and daylength (Figs. 1 and 4), which were particularly reflected in PH and ELN. Plant growth leveled off after late August as plants gradually entered dormancy. Leaves of plants planted on 25 Feb. died back earliest and plants planted on 25 May died back latest (data not shown). If foliage for scheduled displays is needed, a later planting date is advisable. No visible difference in the time of leaf death was observed between the treatments of plants planted on 25 Mar. and 25

Table 1. Effects of planting time and disbudding on major plant growth indices of lotus 'Embolene' grown in 0.029-m^3 containers in 2005.

Planting time	Disbudding	Ht (cm)	Emerging leaf number	Underground fresh wt (g)	Total propagule number
1 Mar.	No	88.7 a[z]	40.7 b	450.8 d	32.3 b
	Yes	87.1 a	51.1 a	559.4 bc	40.8 a
16 Mar.	No	87.9 a	44.9 ab	506.9 cd	33.4 b
	Yes	92.6 a	50.3 a	648.4 a	40.4 a
31 Mar.	No	87.5 a	47.8 ab	516.3 bc	42.6 a
	Yes	87.1 a	50.9 a	596.3 ab	45.5 a
Significance					
	Planting time	NS	NS	**	**
	Disbudding	NS	**	***	***
	Planting time × disbudding	NS	NS	NS	NS

[z]Means were separated by Tukey honestly significant difference at the 0.05 significant level based on data collected on 20 Aug. 2005 for plant height and emerging leaf number and on 1 Jan. 2006 for underground fresh weight and total propagule number.

NS, *, **, *** = nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on PROC MIXED of the SAS procedure.

Table 2. Effect of planting time on major plant growth indices[z] of lotus 'Embolene' grown in 0.029-m^3 containers in 2007.

Planting time[y]	Ht (cm)	Emerging leaf no.	Flower no.*	Underground fresh wt (g)	Fresh wt of propagules (g)	Marketable propagule no.	Secondary propagule no.*	Total propagule no.	Expanded internode no.	Maximum rhizome diam (mm)
25 Feb.*	63.2 c[x]	38.8 c	11.7 ab	294.8 d	199.6 d	20.8 b	19.6 ab	40.4 c	17.6 b	1.7 b
25 Feb.	92.3 b	73.2 ab	14.7 ab	715.7 c	514.8 c	26.7 ab	22.5 ab	49.2 bc	27.8 a	2.6 a
25 Mar.	100.7 ab	90.5 a	15.8 a	1,133.8 a	762.0 ab	33.8 a	27.3 a	61.0 a	31.3 a	2.8 a
25 Apr.	102.3 a	75.8 ab	15.0 a	1,119.3 ab	802.0 a	32.7 a	24.5 ab	57.2 ab	34.0 a	2.9 a
25 May	98.7 ab	43.3 c	10.3 b	755.17 c	595.5 c	23.7 b	17.7 b	41.3 c	30.2 a	2.6 a

[z]Data on plant height and emerging leaf number were taken on 12 Sept. when all plants reached the highest. Flower number was added based on record once every 1 or 2 d. Underground parts were harvested on 23 Nov. 2007 and data were immediately taken after harvest.

[y]Plants potted on 25 Feb.* were placed in the greenhouse; plants potted on 25 Feb., 25 Mar., 25 Apr., or 25 May were placed outdoors.

[x]Means were separated by Tukey honestly significant difference (HSD) at 0.05 significant level, but for flower number and secondary propagule number, least significant difference ($\alpha = 0.05$) was used when mean difference could not be detected by HSD. Means within a column not followed by same letter are significantly different ($P \leq 0.05$).

Apr. All leaves on plants died in October for outdoor-grown plants.

Plant growth indices were largely influenced by treatments in the greenhouse or outdoors as well as planting time. Plants planted in the greenhouse had the lowest values in most growth indices, whereas plants planted outdoors on 25 Mar. and 25 Apr. had the highest values in all evaluated plant growth indices (Table 2). Significant differences were observed in PH, ELN, UFW, marketable propagule number (MPN), TPN, expanded internode number (EIN), and the average maximum rhizome diameter (MRD) between the plants planted in the greenhouse and outside, although TPN and the number of secondary propagules were similar. Outdoor lotus plants planted on 25 Mar. and 25 Apr. performed best, and no significant differences in observed growth parameters were detected between these two treatments. Performance of plants was similar in plants planted on 25 Feb. and 25 May.

Regression analysis of major plant indices showed a positive linear, quadratic, or cubic relationship between ELN and UFW, PH and UFW, ELN and TPN, UFW and TPN, UFW and MPN, UFW and EIN, and between UFW and MRD. Little or nonsignificant relationship occurred between ELN and PH and between ELN and flower number (Table 3). No correlation was determined between flower number and other plant growth indices.

Results in this study indicated that variable scheduled planting times of lotus in USDA Hardiness Zone 8A affected plant growth. Differences of growth indices were most likely attributed to factors such as temperature and daylength (Figs. 1, 2, and 4), which was in agreement with previous reports by Li et al. (2000), Zhang (2003), and Masuda et al. (2006). In the earlier growth stages (before June), plants grew slowly and fewer leaves developed because of lower temperatures. Plant growth rate increased with temperatures peaking from June to Aug. and gradually decreased after August as plants entered dormancy (Fig. 4). Masuda et al. (2007) reported that high temperature and long daylength accelerated vegetable growth and short daylength rather than low temperature was the main environmental factor responsible for induction of dormancy in lotus plants. In our studies, emerging leaves began to die in early September and were totally desiccated by mid-October. A similar situation was reported by Peng et al. (2004) in field production of vegetable lotus. Lotus performed better in an environment with flexible temperatures. Continuous high temperatures (32 to 40 °C) above the optimal range (22 to 32 °C) and small differences of day–night temperature in the greenhouse inhibited plant growth and advanced plant maturation and senescence. Underground fresh weight in the greenhouse treatment was only 25% to 39% of that in the outdoor treatments, which suggested that a possible increase of nighttime respiration at higher temperatures inhibited enlargement of rhizomes, whereas flexible day–night temperatures were more beneficial for accumulation of carbohydrates. Expansion of lotus rhizomes is important for quality liner sales. Therefore, the greenhouse system with somewhat constant day–night temperatures was not optimal for production of lotus as propagules or vegetables.

Scheduling planting time for a specific climatic zone is especially critical for a nursery to maximize yields, coordinate optimum shipping schedules, and increase profits of crops. This study indicated that March and April are the best seasons to begin planting lotus for container production in Auburn area

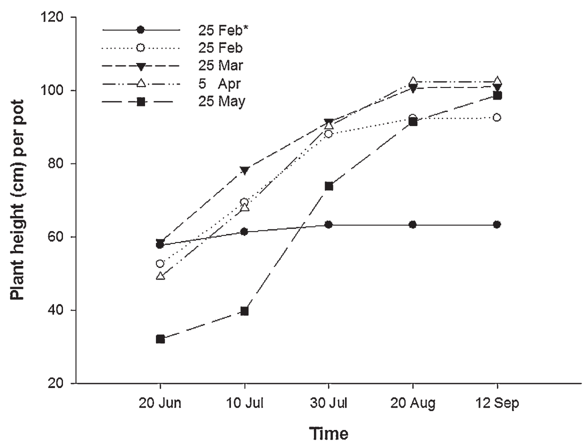

Fig. 1. Effect of planting time on plant height of lotus 'Embolene' in 0.029-m^3 containers in 2007. Plants were planted on 25 Feb.* (greenhouse), 25 Feb., 25 Mar., 25 Apr., and 25 May outdoors, respectively.

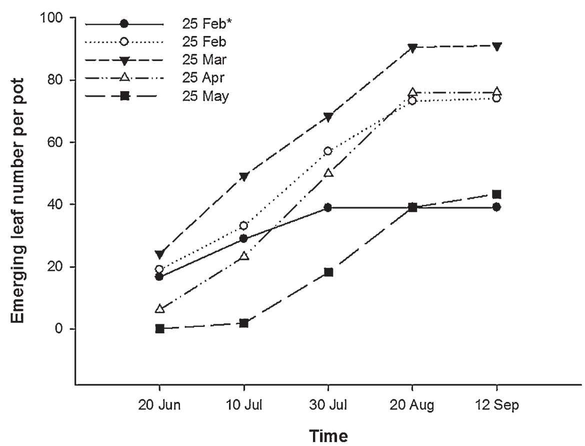

Fig. 2. Effect of planting time on emerging leaf number of lotus 'Embolene' grown in 0.029-m^3 containers in 2007. Plants were planted on 25 Feb.* (in greenhouse), 25 Feb., 25 Mar., 25 Apr., and 25 May outdoors, respectively.

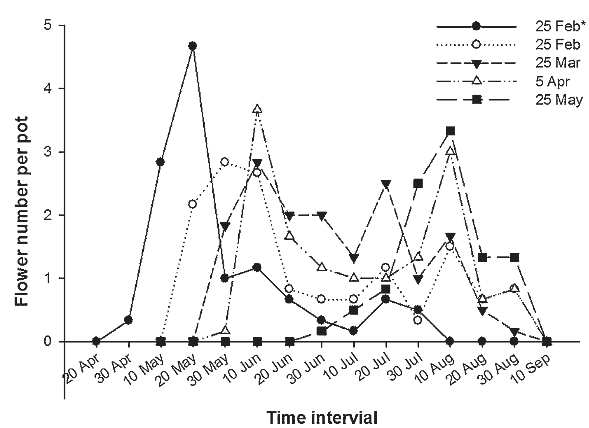

Fig. 3. Effect of planting time on flowering of lotus 'Embolene' grown in 0.029-m^3 containers in 2007. Plants were planted on 25 Feb.* (greenhouse), 25 Feb., 25 Mar., 25 Apr., and 25 May outdoors, respectively. Calculation of flower number was based on a 10-d interval such as 20 Apr. for 20 to 29 Apr., 30 Apr. for 30 Apr. to 9 May, and so on.

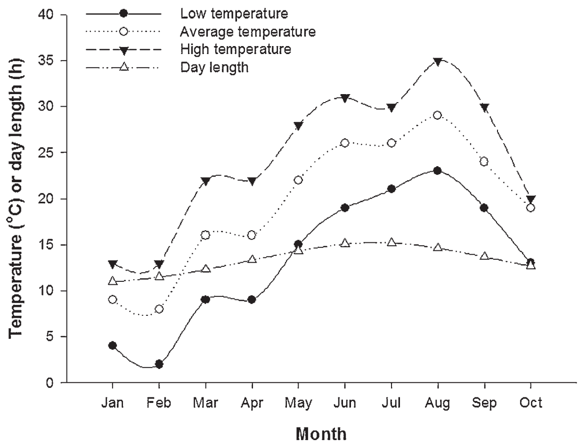

Fig. 4. Monthly mean ambient temperature (low, average, and high) and daylength of the growth season of lotus in 2007 in Auburn (USDA Hardiness Zone 8A), AL.

Table 3. Relationships of major plant growth indices of lotus 'Embolene' grown in 0.029-m^3 containers in 2007.

Plant indices[z]	Model	*P* value	R^2
Emerging leaf no. (x) – height (y, cm)	$y = 81.48 + 0.0021 x^2$	0.0111	0.209
Emerging leaf no. (x) – underground fresh weight (y, g)	$y = -816.9 + 17.72 x$	<0.0001	0.685
Emerging leaf no. (x) – flower no. (y)	$y = 9.68 + 0.059 x$	0.0452	0.136
Emerging leaf no. (x) – total propagule no. (y)	$y = 28.51 + 0.331 x$	<0.0001	0.530
Underground fresh weight (y, g) – height (x, cm)	$y = 475.52 + 0.069 x^2$	<0.0001	0.496
Underground fresh weight (x, g) – total propagule no. (y)	$y = 39.16 + 1.389 \times 10^{-8} x^3$	<0.0001	0.662
Underground fresh weight (x, g) – marketable propagule no. (y)	$y = 19.5 + 1.064 \times 10^{-5} x^2$	<0.0001	0.689
Underground fresh weight (x, g) – expanded internode no. (y)	$y = 13.95 + 0.018 x$	<0.0001	0.569
Underground fresh weight (x, g) – maximum rhizome diameter (y, mm)	$y = 0.76 + 0.0039 x + 1.89 \times 10^{-6} x^2$	<0.0001	0.780

[z]Relationships among major plant growth indices were determined by regression analysis using pooled data of Expt. 2 for outdoor treatments in which plants were potted on 25 Feb., 25 Mar., 25 Apr., or 25 May and placed outdoors.

of Alabama. However, an optimal planting timeframe would be case-dependent considering differences of genotype (early or late season cultivars), local climate, and production system (container or field, greenhouse or field, regular or off-season production). Under natural conditions, it is unnecessary to plant lotus too early as a result of a limitation in temperatures and possible freeze damage in early spring. When soil temperature was below 18 °C and ambient temperature was less than 20 °C, lotus plants almost stopped growth (Li et al., 2000). On the other hand, because of a short life cycle constrained by temperature and photoperiod, lotus should not be planted too late. Disbudding was a useful practice to increase yield of underground weight, propagule number, and leaf number. Large mean differences were evident in plant parameters like ELN, UFW, and TPN or MPN, which were positively correlated with each other. These plant parameters were very effective for evaluation of effect of planting time and disbudding on lotus plants.

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