Container Medium and Nitrogen Form Affect Production of Amur Maackia (*Maackia amurensis* Rupr. & Maxim.)

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Abstract. Amur maackia (*Maackia amurensis* Rupr. & Maxim.) has potential as a more widely grown nursery crop, but little information is available on effects of media and nutrition on growth of containerized plants. We compared growth of seedlings in five media and determined growth responses to two fertility regimes. After 35 days, total dry mass of plants grown in 1 perlite : 1 vermiculite (by volume) or in 5 sphagnum peat : 3 perlite : 2 soil was 3.2 times the dry mass of plants grown in three soilless media that contained composted bark; and after 70 days, growth was greater in the medium with soil than in 1 perlite : 1 vermiculite. Plants grown in solution culture with N at 0.75 mM had 1.8 times the dry mass of those provided N at 3.75 mM. Form of N in solution did not affect dry mass, but N content of leaves of plants grown with $\geq 50\%$ NH_4^+ was 1.3 times as great as that of plants provided only NO_3^- . Plants in containers attained maximal dry mass when fertilized with solutions containing N at 10.8 mM from NO_3^- , NH_4^+ , and urea or N at 7.5 mM with equal amounts of NO_3^- and NH_4^+ . None of the soilless media used consistently evoked growth similar to growth of plants in the soil-based medium.

Amur maackia has potential for increased use as a tree of medium size in urban landscapes and the cold climates of the upper Midwest and Great Plains of North America (Ranney and Powell, 1992). However, commercial production and availability of Amur maackia are limited, and there is little information on producing this species in containers. Protocols to accelerate plant development are particularly important for Amur maackia because of its slow rate of growth. Trees in Minnesota were only 4–6 m tall and 4–5 m wide after 32 years (McNamara et al., 1994), and accrual of mass among seedlings was lower than for other legumes such as thornless honey locust (*Gleditsia triacanthos* L. var. *inermis* Willd.), Japanese pagoda tree (*Sophora japonica* L.) (Graves, 1991), and black locust (*Robinia pseudoacacia* L.) (Aiello and Graves, 1996). The ultimate size of Amur maackia is ideal for many urban sites and small landscapes, or under utility lines, yet the slow growth rate may impede adoption of this species by commercial growers. Although efforts to select genotypes that grow rapidly are in progress (Pai and Graves, 1995b), we also need to determine the extent to which cultural practices can increase growth.

Amur maackia is sensitive to the properties of its root medium. Seedlings cultured in aerated Hoagland solution #1 with N at 7.5 mM as

NO_3^- (Hoagland and Arnon, 1950) accumulated excessive P and became chlorotic and necrotic, while seedlings grown in 5 sphagnum peat : 3 perlite : 2 soil (by volume) and irrigated with the same nutrient solution grew well and showed no foliar damage (Aiello and Graves, 1996). Unexplained poor growth has also been reported for seedlings grown both in the field and in a soilless medium in containers (B. Swanson, personal communication). Most nurseries that produce trees in containers use soilless media, often with a large component of composted bark (Judd, 1983; Wright and Niemiera, 1987). Amur maackia grew well in 5 sphagnum peat : 4 composted bark : 1 perlite (by volume) (Graves et al., 1995; Pai and Graves, 1995a), but direct comparisons of the effects on growth of various media have not been made.

Forms and rates of fertilizers affect growth of woody species produced in containers (Sartain and Ingram, 1984; Wright and Niemiera, 1985), and the form of N used can be particularly important (Cruz et al., 1993; Troelstra et al., 1985). Amur maackia associates with rhizobia that fix dinitrogen (Batzli et al., 1992), yet supplemental applied N is needed for maximal growth even if plants are nodulated (Pai and Graves, 1995a). Effects of form of N on growth vary among woody species (Hummel et al., 1990; Ingram and Joiner, 1982; Raker and Dirr, 1979).

The objectives of our research were to compare several media and fertilizer rates and to determine how ion concentration and form of N affect dry mass and foliar N content of Amur maackia seedlings.

Materials and Methods

Plant materials, experimental design, and data analysis. Seeds of Amur maackia from a

tree at the U.S. National Arboretum, Washington, D.C., were scarified in 18 M H_2SO_4 for 1 h, soaked in tap water 1 h, and sown 1 cm deep in plastic flats filled with coarse perlite. Seeds were irrigated daily with tap water (Expt. 1) or with 25% Hoagland solution #1 (Expts. 2 and 3). Solution pH was 5.8 to 6.0 and contained N at 3.75 mM as NO_3^- and iron (Fe) as 25 μmol Fe-EDDHA. Seedlings and subsequent experimental plants were held on benches in a greenhouse glazed with glass, 1.2 m below 400-W high-pressure sodium lamps that provided 15-h photoperiods. Photosynthetically active radiation (PAR), air temperature, and relative humidity (RH) adjacent to plants all were measured by using a LI-COR 1600 steady-state porometer (LI-COR, Lincoln, Nebr.). Randomized complete-block designs were used. Plants were assigned to blocks based on their mass the day treatments began.

Data were analyzed by using the Statistical Analysis System (SAS; SAS Institute, Cary, N.C.). Each experiment was conducted twice. Treatment means from the individual runs were used as replicates in analyses of variance performed by using the General Linear Model (GLM). Treatment means were separated with Fisher's LSD ($P \leq 0.05$). Regression analysis was performed on data from Expt. 3 by using the regression procedure of SAS.

Expt. 1. Effects of media and fertility on seedling mass. Seeds were sown on 6 July 1994 and 6 Jan. 1995 for the two runs of the experiment. Two weeks after seeds were sown, treatments began when seedlings were transferred to potting media. During both runs, 10 round plastic containers (15.2 cm in diameter, 15.2 cm tall, 1.9-L volume) were filled with each of five media (Table 1). Five containers of each medium were assigned randomly to each of two fertilization rates. Plants in these treatments were irrigated to container capacity twice weekly with 250 mL of tap water with N at 5.4 or 10.8 mM from Peters Excel All-purpose 21N–2.2P–16.6K fertilizer (Scotts, Marietta, Ga.). Nitrogen in this fertilizer was 32% NO_3^- , 58% NH_4^+ , and 10% urea.

Each container was considered an experimental unit. Pots were arranged in five blocks, each with one replication of the 10 fertilizer-medium treatment combinations. Treatments were applied for 35 d. Shoots and roots were then dried at 67 °C for 48 h after media were washed from the roots. A saturated media extract method was used to determine pH and electrical conductivity (EC) of media in each container (Warncke, 1988). Similar volumes from beneath the upper 3 cm in each container were combined for determination of physical properties of each medium. The combined portions were sampled three times to measure percent air-filled pore space at container capacity, bulk density, and water-holding capacity at container capacity (Table 1). Loose-packed cores with a height and inside diameter of 7.5 cm and a volume of 345 mL were used as described by Byrne and Carty (1989) and Evans et al. (1996).

Expt. 2. Effects of N concentration and form on growth in solution culture. Seeds were sown on 29 Sept. and on 21 Dec. 1995 for the

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Table 1. Composition and characteristics of five media used during Expt. 1. Physical properties data are means from three samples. Electrical conductivity and pH values are means of data combined from two replicate experiments, each of which contained 10 replications per medium treatment.

Composition of media by volume	Air-filled pore space at container capacity [v/v (%)]	Bulk density (g·cm ⁻³)	Water-holding capacity at container capacity [mass/mass (%)]	pH
1 Coarse vermiculite : 1 coarse perlite	20	0.12	470	6.1
5 Sphagnum peat : 3 perlite : 2 soil ²	13	0.17	384	6.5
5 Sphagnum peat : 4 composted pine bark : 1 perlite ³	10	0.10	700	6.8
4 Composted hardwood/softwood bark : 1 coir ⁴	17	0.14	462	7.4
4 Composted hardwood/softwood bark : 1 sphagnum peat	23	0.12	463	6.8
<i>P</i> > <i>F</i>	0.0281	0.0003	0.0001	0.0001
LSD ⁵	8	0.02	49	0.3

²Field soil (fine loam) from Story Co., Iowa, was used. Calcium carbonate (Mississippi Limestone Co., Alton, Ill.) was added to this medium, and the medium was pasteurized by heating to 75 °C for 2 h.

³Purchased as Fisons Special Blend 1 medium, Fisons Horticulture, Vancouver, B.C.

⁴Obtained from Soriano Fiber Co., San Pablo City, Luzon, Philippines.

⁵Mean separation within columns by LSD for dependent variables at *P* > *F* of 0.05 or less.

two runs. Treatments began 19 d later by transferring seedlings to round plastic containers (8.8 cm in diameter, 8.8 cm high, 0.5-L volume) filled with 5% or 25% aerated nutrient solution that contained N at 0.75 and 3.75 mM, respectively. Three formulations of solution at both concentrations were based on Hoagland and Arnon (1950) and contained N as either all NO₃⁻, equal parts NO₃⁻ and NH₄⁺, or all NH₄⁺. All solutions contained MES buffer [2-(4-morpholino)-ethane sulfonic acid] at 1 mM and Fe-EDDHA at 5 or 25 µM for 5% and 25% solution, respectively. Individual seedlings were considered experimental units and were arranged in 10 blocks, each with one replication of the factorial of two concentration and three N-form treatments. Culture solutions were replaced weekly. Solution pH for all plants was measured by using a Fisher Portable Digital pH Meter model 107 (Fisher Scientific, Pittsburgh) 2, 5, and 7 d after solutions were replaced. PAR, air temperature, and RH, measured 16 times at midday at six positions on the greenhouse benches throughout both runs, ranged from 90 to 1100 µmol·m⁻²·s⁻¹, 19 to 27 °C, and 10% to 50%, respectively. Means were 386 µmol·m⁻²·s⁻¹, 21.8 °C, and 24%, respectively.

Treatments were terminated after 35 d. Roots and the basal 3–5 cm of stems were rinsed three times in distilled water. Laminae, all other shoot tissues, and roots were weighed separately after they had been dried at 67 °C for 48 h. The root system was defined as all tissue beneath the cotyledon scars. Three plants from each N-form treatment in 5% solution were chosen randomly for analysis of laminal N content. Dried laminae were ground in a Wiley Mill (40 mesh; Thomas Scientific Co., Philadelphia). Samples underwent micro-Kjeldahl digestion before flow injection analysis with a Lachat Quickchem AE ion analyzer (Zellweger Analytics, Milwaukee).

Expt. 3. Effects of N form on growth in container media. Seeds were sown on 29 Sept. 1995 and 26 Jan. 1996 for the two runs. Individual seedlings were transferred to media in round plastic containers (15.2 cm in diameter, 15.2 cm tall, 1.9-L volume) when fresh mass of seedlings ranged from 0.30 to 0.45 g. Two media were used, 5 sphagnum peat : 3 perlite : 2 soil (fine loam) (by volume) and 1 vermiculite : 1 coarse perlite (by volume). Each con-

tainer was considered an experimental unit. During both runs, eight containers with both media were assigned randomly to each of six fertilizer treatments. Pots were arranged in eight blocks on greenhouse benches; each block contained one replication of the 12 fertilizer-medium treatment combinations. PAR, air temperature, and RH at midday, measured at five positions on the greenhouse benches on 34 occasions over the two runs of the experiment, ranged from 64 to 1670 µmol·m⁻²·s⁻¹, 18 to 34 °C, and 10% to 53%, respectively. Mean values were 463 µmol·m⁻²·s⁻¹, 22.4 °C, and 26%, respectively.

Four of the six fertilizer treatments were applied in solution. Pots assigned to these treatments were irrigated to container capacity at 3- or 4-d intervals with 250 mL of solution. The solutions were 1) distilled water plus N at 10.8 mM from Peters Excel All-purpose 21N–2.2P–16.6K fertilizer, 2) nutrient solution with

N at 7.5 mM as NO₃⁻, 3) nutrient solution with N at 7.5 mM as NO₃⁻ (50%) and NH₄⁺ (50%), and 4) nutrient solution with N at 7.5 mM as NH₄⁺. The latter three solutions were half-strength based on Hoagland and Arnon (1950) and contained P at 0.5 mM and K at 3 mM. A controlled-release fertilizer at two rates was used for the two remaining fertilizer treatments. Sierra 17N–2.6P–8.3K, a plastic resin-coated, inorganic, slow-release fertilizer, was applied as an unincorporated topdressing at 3 and 6 g per pot. Nitrogen in this fertilizer was 79% NO₃⁻ and 21% NH₄⁺. Containers with Sierra were irrigated to container capacity with 250 mL of tap water when plants provided with fertilizer solution were irrigated. All treatments were terminated after 70 d. Shoots and roots were dried at 67 °C for 48 h after media were removed from roots. A saturated media extract method was used to determine pH of media used in each container (Warncke, 1988).

Fig. 1. Dry mass of 35-d-old Amur maackia seedlings grown in: 1) 1 coarse vermiculite : 1 coarse perlite (by volume) (■); 2) 5 sphagnum peat : 3 perlite : 2 soil (by volume) (□); 3) 5 sphagnum peat : 4 composted pine bark : 1 perlite (by volume) (▨); 4) 4 composted bark : 1 coir (by volume) (▩); or 5) 4 composted bark : 1 sphagnum peat (by volume) (▤). Values are means from two replicate experiments, each of which had 10 single-plant replications per medium treatment.

Results

Expt. 1. Effects of media and fertility on seedling mass. The effects of fertilizer rate and the interaction of fertilizer rate $\times$ growth medium were nonsignificant (data not shown). Root, shoot, and total dry-mass accumulation of plants grown in peat : perlite : soil or vermiculite : perlite were approximately three times as great as that of plants in the media containing composted bark (Fig. 1). The average pH for the perlite : vermiculite and the soil-based media (6.3, $SE = 0.3$) was 0.7 lower than the average pH of the three media with bark (7.0, $SE = 0.2$) (Table 1). EC did not vary among the five media and averaged 0.57 $dS \cdot m^{-1}$. However, air-filled pore space, bulk density, and water-holding capacity did vary among the media (Table 1).

Expt. 2. Effects of N concentration and form on growth in solution culture. Plant dry mass was similar regardless of the form of N supplied and averaged 393 mg. Plants grown in 5% solution had 1.8 times the total dry mass of those grown in 25% solution (504 and 279 mg, respectively; $LSD = 110$ mg). Leaf, shoot, and root dry mass were 254, 120, and 130 mg, respectively, for plants grown in the 5% solution and 170, 57, and 52 mg, respectively, for plants grown in the 25% solution. Laminar N content was higher in plants supplied 50% (3.21% of dry mass) or 100% (3.29%) NH_4^+ than in plants provided N only as NO_3^- (2.60%) ($LSD = 0.49$). The pH of nutrient solutions for plants supplied N only as NO_3^- increased between solution replacements, whereas pH decreased for solutions containing 50% or 100% of N as NH_4^+ (Fig. 2).

Expt. 3. Effects of N form on growth in container media. There were no medium $\times$ fertilizer interactions for dry mass. Plants grown in the soil-based medium had 1.5 times the total dry mass of those grown in the 1 perlite : 1 vermiculite. Root and shoot dry mass were 1.0 and 2.36 g, respectively, for plants grown in the soil-based medium and 0.77 and 1.41 g, respectively, for plants grown in 1 perlite : 1 vermiculite. Seedlings attained the greatest dry mass when fertilized with Excel All-purpose fertilizer with N at 10.8 mM, or with nutrient solutions that contained NH_4^+ and in which total N was 7.5 mM (Fig. 3). On average, plants receiving $\geq 50\%$ of their N as NH_4^+ in solution had nearly twice the dry mass of plants receiving N as only NO_3^- or topdressed with Sierra. The influence of growth medium on pH of the medium varied with fertilizer ($P = 0.03$), and pH among treatment combinations ranged from 4.4 to 7.2. Mean total dry mass over all medium $\times$ fertilizer treatment combinations decreased with increasing medium pH [total dry mass = $8.2 - 1.0$ (pH), $r^2 = 0.59$].

Discussion

Based on results of Expts. 1 (Fig. 1) and 3 (Fig. 3), in which 5 sphagnum peat : 3 perlite : 2 soil optimized dry mass, we cannot recommend any of the soilless media we used for production of Amur maackia seedlings. Dif-

Fig. 2. Change with time of pH of 5% Hoagland solution in which Amur maackia seedlings were grown with three ratios of NO_3^- and NH_4^+ . Solutions were changed at weekly intervals starting at day 0. Except for the 1st week, solution pH was measured 2, 5, and 7 d after solutions were replaced.

Fig. 3. Effects of six fertilizer regimes on dry mass of Amur maackia seedlings, averaged over two media treatments. Values are means from two replicate experiments, each of which contained eight single-plant replications (grown in 1.9-L containers) per medium-fertility treatment combination. Fertility treatments were: 1) N at 10.8 mM in solution from Peters Excel All-purpose 21N-2.2P-16.6K fertilizer that contained N as NO_3^- (32%), NH_4^+ (58%), and urea (10%) (■); 2) N at 7.5 mM in solution as NO_3^- (50%) and NH_4^+ (50%) (□); 3 and 4) N at 7.5 mM in solution as NH_4^+ (100%) (▨) or as NO_3^- (100%) (▩); 5 and 6) Sierra 17.0N-2.6P-8.3K controlled-release fertilizer that contained N as NO_3^- (79%) and NH_4^+ (21%) at 3 (▧) or 6 g per container (▨).

ferences among media in air-filled pore space and EC do not account for growth differences, because air-filled pore space was similar in the medium with soil to that in three soilless media (Table 1), and EC did not vary among media. Bulk density was highest and water-holding capacity was lowest for the medium with soil (Table 1), but we do not know whether other dense media that retain relatively little water will evoke superior growth of Amur maackia. The explanation for superior growth of plants in medium with soil is unclear; more extensive analysis of the physical properties of the media may indicate specific properties that would optimize growth. The medium with soil was pasteurized but not sterilized. Therefore, we cannot rule out a biological influence from mycorrhizal fungi or rhizobial bacteria on seedling growth. Associations between Amur maackia and mycorrhizal fungi have not been documented previously, and we saw no evidence of mycorrhizae or rhizobial symbioses when roots were cleaned for dry-mass determinations.

Effects of N form appear to be related to the pH of media. The two media that optimized growth during Expt. 1 had the lowest pH after treatments, and dry mass decreased as the pH of media after treatments increased from 4.4 to 7.2 during Expt. 3. Uptake of NO_3^- increases external pH because hydroxyl ions are extruded, whereas uptake of NH_4^+ lowers pH due to release of protons (Salsac et al., 1987). Evidence for preferential uptake of NH_4^+ by Amur maackia includes the decrease in medium pH between solution replacements for plants given both NH_4^+ and NO_3^- (Fig. 2) and the high foliar N content of plants given NH_4^+ during Expt. 2. The benefit of N as NH_4^+ was also evident when container media were used during Expt. 3 (Fig. 3). Similarly, Troelstra et al. (1985) found that European alder [*Alnus glutinosa* (L.) Gaertner] had higher dry mass when supplied with both NH_4^+ and NO_3^- instead of only NO_3^- . Mountain laurel (*Kalmia latifolia* L.) (Hummel et al., 1990) and Shumard oak (*Quercus shumardii* Buckl.) (Ingram and Joiner, 1982) grew best when supplied with NH_4^+ and NO_3^- or all NH_4^+ . In contrast, double-flowered viburnum [*Viburnum plicatum* Thunb. *tomentosum* (Thunb.) Rehd.] grew better when supplied with NO_3^- instead of NH_4^+ (Raker and Dirr, 1979). Superior growth resulting from NH_4^+ and a growth medium with low pH may be related to an adaptation to acidic soil in the native habitats of some species (Hummel et al., 1990; Ingram and Joiner, 1982). Amur maackia is distributed in river valleys and as an understory species in broad-leaved forests of Heilongjiang and Jilin Provinces of China, where it occurs with species of *Juglans*, *Tilia*, *Betula*, and *Acer* not restricted to acidic soils (M. Widrechner, personal communication). Amur maackia seems to be tolerant of soils with varying pH (Dirr, 1990), but no studies of growth as affected by pH have been conducted. The relationship we observed between

growth and pH of media after our treatments indicates that effects of container medium pH during production warrant study.

Our results substantiate earlier data on the concentration of nutrients that should be supplied to Amur maackia and are consistent with results of Aiello and Graves (1996). They found poor growth, foliar bronzing, and excessive foliar P among seedlings grown in $\geq 25\%$ Hoagland solution #1 in comparison with those grown in 5% solution. Plants in container media during Expts. 1 and 3 did not show foliar bronzing, probably because the equilibrium concentrations of P in the media were not sufficient to elicit symptoms. During Expt. 3, the mass of plants in container media that received N at 10.8 mM was similar to that of plants given N at 7.5 mM with $\geq 50\%$ as NH_4^+ (Fig. 3). Likewise, Pai and Graves (1995a) reported that growth of Amur maackia was not promoted by N at > 7.5 mM. The low mass of plants provided controlled-release fertilizers during Expt. 3 may have been due to inadequate nutrients caused by topdressing, insufficient application rates, or the frequency of irrigation (Hicklenton and Cairns, 1992; Sharma et al., 1982).

Producers of Amur maackia can influence growth and foliar N content through the selection of a container medium and fertility regime. Under the conditions we used, only the medium that contained pasteurized, fine-loam soil consistently optimized growth, and application of N at 7.5 mM with $\geq 50\%$ as NH_4^+ at each irrigation increased foliar N content during one experiment and plant dry mass during another. Given their potential benefits, additional soilless media should be examined to define at least one that can evoke growth similar to or greater than that of plants cultured in a medium with soil.

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