Growth and Survival of Two Western Milkweed Species: Effects of Container Volume and Fertilizer Rate

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ADDITIONAL INDEX WORDS. **narrowleaf milkweed, showy milkweed, controlled-release fertilizer, morphology, restoration planting, stocktype, transplant survival**

SUMMARY. **Diminishing milkweed (*Asclepias* sp.) populations are contributing to the conspicuous decline of the iconic monarch butterfly (*Danaus plexippus*). This research sought to improve milkweed propagation success, a core component of summer habitat restoration projects. Specifically, this research assessed the effects of container volume and fertilizer application rate on growth and first year field survival of two species of milkweed common to western North America, namely showy milkweed (*A. speciosa*) and narrowleaf milkweed (*A. fascicularis*). Generally, larger roots and shoots developed when plants were given the high rate of fertilizer (6.5 g·L^{-1}) and when reared in the largest containers (2600 mL). For narrowleaf milkweed, nearly all plants developed a firm plug (i.e., one in which the root system remained intact when removed from the container) after 22 weeks. Most narrowleaf milkweed plants flowered 15 weeks after sowing when grown in the largest container with either the low (2.7 g·L^{-1}) or high fertilizer rate or the midsized container (444 mL) with a high rate of fertilizer. For showy milkweed, a firm plug developed for nearly all individuals by the end of the growing season only when given the high fertilizer rate. None of the showy milkweed plants developed an inflorescence by 15 weeks. Results of this research improve our understanding of milkweed propagation and will aid in the efforts to restore the monarch butterfly's summer breeding habitat by providing propagation protocols across a range of stocktypes.**

Conspicuous population declines of the iconic monarch butterfly are the result of loss of summer breeding habitat, extreme weather events, and deforestation of overwintering habitat (Brower et al., 2002, 2012; Casner et al., 2014; Flockhart et al., 2015; Hartzler, 2010; Pleasants and Oberhauser, 2012). Two migratory populations of monarch butterfly exist in North America. The eastern population is the larger of the two and migrates over successive generations ≈4000 km from overwintering grounds in the high-elevation oyamel fir (*Abies religiosa*) forests of central Mexico to summer breeding grounds in the United States and southern Canada (Brower, 1995). The relatively smaller western population spans ≈500 km from overwintering sites in coastal California to summer breeding grounds west of the Rocky Mountain Range (Dingle et al., 2005).

Monarch larvae (caterpillars) feed almost exclusively on milkweed, a genus of perennial dicotyledonous plants with more than 130 known species native to North America (Woodson, 1954). Larvae acquire protection from predators as a result of the toxic cardenolide glycosides in the milkweed foliage they consume (Malcolm et al., 1989). Monarch migration is closely tied to the timing of milkweed development across the summer breeding range (Stevens and Frey, 2010). Shrinking populations of milkweed due to a combination of extensive planting of genetically modified herbicide-resistant soybean (*Glycine max*) and corn (*Zea mays*), widespread herbicide use, and land-use change have reduced the suitability of summer breeding grounds (Pleasants and Oberhauser, 2012). Climate change is predicted to further reduce summer breeding habitat suitability (Lemoine, 2015).

Given the need to restore monarch butterfly summer breeding habitat, recent efforts have promoted milkweed propagation (Cutting and Tallamy, 2015; Dumroese et al., 2016; Landis, 2014; Landis and Dumroese, 2015; Luna and Dumroese, 2013). Much of what is known about milkweed biology and propagation is based on work done with common milkweed [*Asclepias syriaca* (reviewed in Bhowmik, 1994)]. Propagation protocols have also been developed to facilitate production of other milkweed species, including the federally threatened mead's milkweed [*Asclepias meadii* (Baskin and Baskin, 2002)]. Our research focuses on two milkweed species, showy milkweed and narrowleaf milkweed, common to western North America, essential to the western monarch population, and in high demand for habitat restoration efforts.

Showy milkweed is a species distributed across western North America from British Columbia to Manitoba and south to Texas and is found in well-drained soil in open habitats from 0 to 1900 m elevation [U.S. Department of Agriculture (USDA), 2017a].

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L^{-1}	0.1
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
16.3871	inch^3	cm^3	0.0610
1	mmho/cm	mS·cm^{-1}	1
28.3495	oz	g	0.0353
1	ppm	mg·kg^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Narrowleaf milkweed has a much smaller range, covering California, Idaho, Nevada, Oregon, Washington, Utah, and Baja California and is found in dry, barren areas from 50 to 2200 m elevation (USDA, 2017b). Published protocols for the two species use a variety of seed cleaning techniques, either with or without a stratification treatment, and employ an assortment of containers and media, either with or without fertilizer amendments (Bartow, 2006; Leigh et al., 2006; Skinner, 2008; Tilley, 2016). In one protocol for narrowleaf milkweed, seeds were sown directly into flats (1.5 inches deep) containing soilless media, which were then stored in an outdoor coldframe from autumn though the following spring (Leigh et al., 2006). Transplantable seedlings developed within ≈8 weeks of germination and were transferred to a variety of larger pots containing the same soilless media, where they developed into seedlings with fibrous root systems (10–20 cm in length) by the end of the 8-month growing season. In one protocol for showy milkweed, seeds were sown into 10-inch^3 containers filled with soilless media amended with fertilizer (Bartow, 2006). Under controlled greenhouse conditions, seeds germinated within 1 week (80% germination). Developing plants were hand-watered as needed and received 20N–8.8P–16.6K water-soluble fertilizer (JR Peters, Allentown, PA) twice during the 5-month growing period. Skinner (2008) sowed showy milkweed seeds directly into 10-inch^3 containers filled with soilless media and noted germination was complete within 2 weeks. Plants were watered deeply every 2 d and fertilized (formulation unspecified) weekly for ≈3 months. Tilley (2016) provided a third protocol for showy milkweed, directly sowing untreated seeds into 10-inch^3 containers filled with soilless media without fertilizer in a controlled greenhouse environment, providing 20 min of daily irrigation from overhead sprinklers for the first 30 d. Plants were then fertilized [15N–13.1P–12.5K (Miracle Grow All Purpose Plant Food; Scotts, Marysville, OH)] weekly and watered 40–60 min every 2 d for ≈4 months. Although protocols vary, one commonality is the use of small volume (i.e., 10 inch^3) containers. Information on the production of milkweed by directly sowing seeds into larger volume containers is lacking.

In restoration plantings, particularly where competition is a factor and environmental stress limits establishment success, larger seedlings may be superior because of the competitive advantage conferred by greater heights and increased root growth potential associated with larger root systems (Grossnickle, 2012). Evidence suggests that not only do larger volume containers yield larger nursery seedlings, but these larger seedlings also have higher survival rates and continue to realize greater growth rates in the field after planting (Pinto et al., 2015; Sutherland and Day, 1988). Similar to increased container volume, identifying optimal species-specific fertilizer application rates will aid in the propagation of superior seedlings in the nursery (Cardoso et al., 2007; Clark and Zheng, 2015), which may confer these same advantages on outplanting. However, a concern in the production of container milkweed plants from seeds is the formation of a firm root plug; i.e., one in which the root system remains intact when removed from the container (Landis, 2014). Because milkweed plants develop rhizomes without many fibrous roots, transplanting or outplanting seedlings can be challenging if root systems are poorly developed. Thus, the objectives of this research are 1) to develop propagation techniques that yield firm plugs for two species of milkweed common to western North America through the manipulation of container volume and fertilizer application rate, and 2) to assess first year field survival of these seedlings.

Table 1. Containers used to propagate showy milkweed and narrowleaf milkweed.

Container	Diam (inches)^z	Depth (inches)^z	Vol (mL)^z
Ray Leach Cone-tainer™ 10-inch^3 (163.9 mL) Super Cells (SC10 Super)^y	1.5	8.25	164
Large Deepot Cells (D27L)^y	2.7	7.0	444
Blow Molded 1 gal Nursery Containers (#1NC)^x	6.5	7.5	2.600

^{z}1 cm = 0.3937 inch, 1 mL = 0.0338 fl oz.
^{y}Cells arranged in a solid tray (Stuewe & Sons, Tangent, OR).
^{x}Free-standing containers (McConkey & Co., Sumner, WA).

Table 2. Analysis of saturated media extracts from growing media containing low [2.7 g·L^{-1} (0.27%)] and high [6.5 g·L^{-1} (0.65%)] rates of 18N–2.2P–10K controlled-release fertilizer rates.

	Low rate	High rate
pH	6.0	5.9
EC (mmho·cm^{-1})^z	3.01	3.83
Total nitrogen (%)	1.158	1.349
Nitrate (ppm)^z	241	278
Phosphorus (ppm)	21.1	25.0
Potassium (ppm)	167	182
Calcium (ppm)	345	456
Magnesium (ppm)	252	309
Sodium (ppm)	49	49

^{z}1 mmho·cm^{-1} = 1 mS·cm^{-1}, 1 ppm = 1 mg·kg^{-1}.

Materials and methods

Seeds were collected in Autumn 2014 from wild populations of showy milkweed in Rogue Valley, OR (lat. 42°44′N, long. 122°93′W″) and narrowleaf milkweed in Applegate Valley, OR (lat. 42°32′N, long. 123°29′W″). Seeds were soaked for 2 d in aerated water before stratification at 3 ± 1 °C for 4 weeks. For each species, the experiment followed a completely randomized design consisting of three container volumes [small (164 mL), medium (444 mL), and large (2600 mL) (Table 1)] and two fertilizer rates, with each treatment comprising five, 15-plant replicates (for a total of 450 plants per species). The small container was included as it is a conventional container used by many restoration growers, whereas the large container is the typical "1-gal" pot commonly used in both restoration and ornamental nurseries; the medium container offers an intermediate option for propagation. Seeds (one to four per cell) were sown at a depth of ≈0.5 cm directly into sterile containers filled

Table 3. Effects of 18N–2.2P–10K controlled-release fertilizer rate (low = 2.7 $g \cdot L^{-1}$ and high = 6.5 $g \cdot L^{-1}$)[z] and container volume (small = 164 mL, medium = 444 mL, and large = 2600 mL)[z] on growth of showy milkweed. Means (SE) are presented and significant differences (at α = 0.05) within each column are indicated using uppercase letters for each main effect in the absence of an interaction. Significant differences among interacting treatments for height, root collar diameter, and plug form are shown in Figs. 1A, 2A, and 3, respectively.

		Ht (cm)[z]	Root collar diam (mm)[z]	Root vol (cm^3)[z]	Root dry wt (g)[z]	Shoot dry wt (g)	Plug form[y]
		Mean (SE)					
Fertilizer (F)	Low	12.0 (0.2)	2.9 (0.1)	28.6 (4.2) B	6.2 (0.9) B	2.4 (0.2) B	0.41 (0.04)
	High	13.8 (0.2)	3.2 (0.1)	41.4 (4.2) A	8.9 (0.9) A	3.3 (0.2) A	0.99 (0.04)
Container (C)	Small	10.4 (0.3)	2.3 (0.1)	9.1 (4.9) B	1.7 (1.1) B	0.4 (0.3) B	0.54 (0.05)
	Medium	14.5 (0.3)	3.1 (0.1)	22.5 (4.9) B	4.6 (1.1) B	1.3 (0.3) B	0.76 (0.05)
	Large	13.8 (0.3)	3.7 (0.1)	73.4 (4.9) A	16.3 (1.1) A	6.7 (0.3) A	0.80 (0.05)
Source of variation	df (num./den.)[x]	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)
F	1/20	32.28 (<0.0001)	19.18 (0.0003)	6.30 (0.0208)	5.19 (0.0338)	4.62 (0.0440)	108.76 (<0.0001)
C	2/20	71.36 (<0.0001)	111.86 (<0.0001)	58.15 (<0.0001)	59.45 (<0.0001)	95.49 (<0.0001)	8.65 (0.0020)
F × C	2/20	17.17 (<0.0001)	5.74 (0.0107)	0.74 (0.4880)	0.82 (0.4537)	0.85 (0.4431)	10.65 (0.0007)

[z] 1 $g \cdot L^{-1}$ = 0.1%, 1 mL = 0.0338 fl oz, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch, 1 cm^3 = 0.0610 $inch^3$, 1 g = 0.0353 oz.
[y] Plug form refers to the proportion of plugs in which the root system remained intact when removed from the container.
[x] num. = numerator; den. = denominator.

with media composed of Canadian peatmoss, coarse perlite, dolomitic limestone, a long-lasting wetting agent, and a proprietary blend of silicon known as RESiLIENCE® (Sunshine Professional Mix #4 Natural & Organic; SunGro® Horticulture, Agawam, MA). Containers were amended with controlled-release fertilizer at one of two label-recommended rates per liter of the growing medium: 2.7 $g \cdot L^{-1}$ (low) or 6.5 $g \cdot L^{-1}$ (high) of 18N–2.2P–10K (Osmocote® N–P–K blended with micronutrients, Everris Nursery Mix; Everiss NA, Dublin, OH). The fertilizer stated a nutrient release period of 5–6 months. To ensure homogenization, the fertilizer was thoroughly mixed into media on clean tarps before filling containers. Plants were carefully thinned to a single plant per cell 23 d after sowing, once several true leaves had developed. Plants were grown at the Oxbow Native Plant Nursery in Carnation, WA (lat. 47°69′N, long. 121°98′W″) in a retractable-roof greenhouse (Cravo Equipment, Brantford, ON, Canada) without supplemental temperature, light, or relative humidity controls. Containers were periodically rearranged on greenhouse benches throughout the study to minimize the impact of potential confounding variables such as light, humidity, and temperature. Irrigation frequency was determined by gravimetric water content (GWC) as per the "manager technique" (Dumroese et al., 2015) according to plant growth phase (Landis et al., 1998) such that plants were irrigated when the container GWC declined to 75% to 80% of the container weight at field capacity during the establishment phase (weeks 1 through 3) and 60% to 65% GWC during the growth and hardening phases (weeks 4–22).

During the establishment phase, algae began to colonize media surfaces, particularly of the large containers that remained wet for longer durations relative to small containers. Algal growth attracted shoreflies (Ephydridae) and fungus gnats (Mycetophilidae), which produce larvae that feed on plant roots. To address this issue associated with direct sowing into large containers, beneficial insects were used as an organic method of pest control. Considerable detail is provided about the pest control approach used, given the

Table 4. Effects of 18N–2.2P–10K controlled-release fertilizer rate (low = 2.7 g·L^{-1} and high = 6.5 g·L^{-1})[z] and container volume (small = 164 mL, medium = 444 mL, and large = 2600 mL)[z] on growth of narrowleaf milkweed. Means (SE) are presented and significant differences (at α = 0.05) within each column are indicated using uppercase letters for each main effect in the absence of an interaction. Significant differences among interacting treatments for height, root collar diameter, and inflorescence development are shown in Figs. 1B, 2B, and 4, respectively.

		Ht (cm)[z]	Root collar diam (mm)[z]	Inflorescence	Root vol (cm^3)[z]	Root dry wt (g)[z]	Shoot dry wt (g)	Plug form[y]
		Mean (SE)						
Fertilizer (F)	Low	21.0 (0.9)	3.3 (0.1)	0.42 (0.05)	33.9 (3.2) B	8.5 (0.8)	6.0 (0.8) B	0.97 (0.02)
	High	22.5 (0.9)	3.5 (0.1)	0.59 (0.05)	41.4 (3.2) A	9.5 (0.8)	8.0 (0.8) A	1.00 (0.02)
Container (C)	Small	15.0 (1.0)	2.6 (0.1)	0.02 (0.05)	10.3 (3.7) C	2.4 (0.9) C	0.7 (0.9) B	0.96 (0.02)
	Medium	25.4 (1.0)	3.7 (0.1)	0.61 (0.05)	24.0 (3.7) B	5.9 (0.9) B	3.3 (0.9) B	1.00 (0.02)
	Large	24.9 (1.0)	4.0 (0.1)	0.89 (0.05)	78.6 (3.7) A	18.8 (0.9) A	17.0 (0.9) A	1.00 (0.02)
Source of variation	df (num./den.)[x]	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)	F ratio (*P* value)
F	1/20	3.64 (0.0708)	3.07 (0.0950)	11.24 (0.0032)	4.48 (0.0469)	1.39 (0.2515)	4.48 (0.0470)	1.0 (0.3293)
C	2/20	74.75 (<0.0001)	51.16 (<0.0001)	104.10 (<0.0001)	139.43 (<0.0001)	153.70 (<0.0001)	118.25 (<0.0001)	1.0 (0.3855)
F × C	2/20	11.68 (0.0004)	7.34 (0.0041)	10.51 (0.0008)	0.35 (0.7106)	1.29 (0.2969)	0.63 (0.5443)	1.0 (0.3855)

[z] 1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch, 1 cm^3 = 0.0610 inch^3, 1 g = 0.0353 oz.
[y] Plug form refers to the proportion of plugs in which the root system remained intact when removed from the container.
[x] num. = numerator; den. = denominator.

known toxicity of neonicotinoids commonly found in insecticides to monarch larvae and foraging pollinators, including monarch butterflies (Krischik et al., 2007; Pecenka and Lundgren, 2015). Predatory nematodes (*Steinernema feltiae*) were applied as a soil drench to all containers three times, with a 1-week interval between the first and second applications and a 2-week interval between the second and third applications. During the final application, a second nematode species (*Steinernema carpocapsae*) was also applied. Predatory mites (*Stratiolaelaps scimitus*) were applied as a follow-up treatment to ensure control. To reduce algal growth on media surfaces, each container was top dressed with washed gravel (Cadman Rock and Sand, Redmond, WA) at a depth of ≈0.5 cm. A predatory mite (*Neoseiulus cucumeris*) and a generalist predatory beetle (*Atheta coriaria*) were applied to all containers to combat western flower thrips (*Frankliniella occidentalis*), which appeared on milkweed leaves in July 2015, ≈6 weeks after germination.

Height (centimeters) and root collar diameter [RCD (millimeters)] were measured for all plants (n = 900) using a meter stick and digital caliper, respectively, ≈6 weeks after sowing and inflorescence development was assessed 15 weeks after sowing. For both species, five plants from each treatment were randomly selected to assess plug development, root and shoot dry weight (RDW and SDW), and root volume (RV) at the end of the growing season (≈22 weeks after sowing). To assess plug development, plants were lifted from containers to evaluate whether root systems remained intact (i.e., plug form was maintained without the loss of media when removed from containers). Plant RV was measured using a water displacement method (Burdett, 1979). To assess dry weight, plant roots were separated from the shoot at the base of the stem and dried at 70 °C for 72 h before weighing. Analysis of saturated media extracts from the high and low fertilizer rates was conducted by A & L Great Lakes Laboratory (Fort Wayne, IN). One bulked sample for each fertilizer rate was collected at the time of sowing and kept at about –4 °C until shipped for analysis.

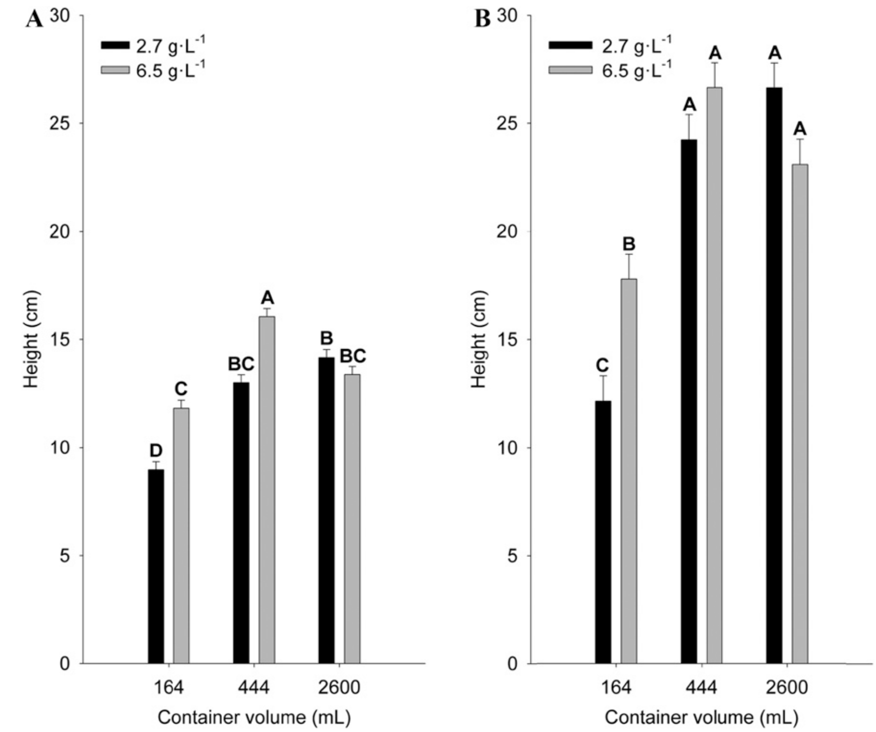

Fig. 1. Mean (±SE) height of (A) showy milkweed and (B) narrowleaf milkweed plants across three container volumes grown with low (2.7 g·L^{-1}) and high (6.5 g·L^{-1}) 18N–2.2P–10K controlled-release fertilizer rates. Significant differences (at α = 0.05) are indicated using uppercase letters; 1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz, 1 cm = 0.3937 inch.

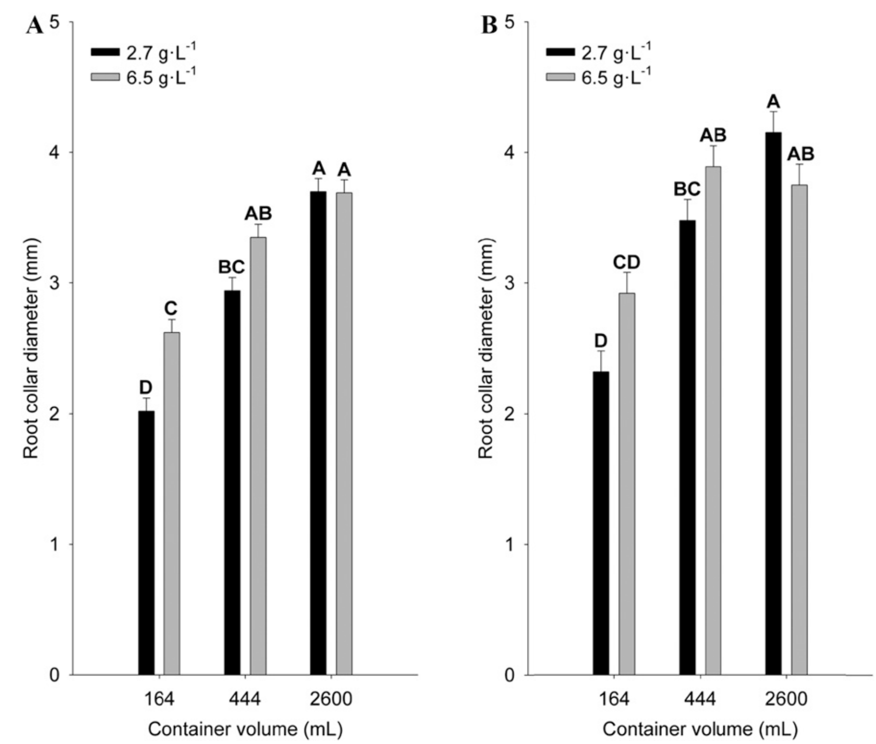

Fig. 2. Mean (±SE) root collar diameter (RCD) of (A) showy milkweed and (B) narrowleaf milkweed plants across three container volumes grown with low (2.7 g·L^{-1}) and high (6.5 g·L^{-1}) 18N–2.2P–10K controlled-release fertilizer rates. Significant differences (at α = 0.05) are indicated using uppercase letters; 1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz, 1 mm = 0.03937 inch.

For both species, five replicates of five randomly selected plants from each treatment (n = 150 plants per species) were planted using a shovel at a field site located at the University of Idaho's Center for Forest Nursery and Seedling Research in Moscow, ID (lat. 46°72′N, long. 116°96′W″) on 3 Nov. 2015. The site was tilled before planting and no supplemental irrigation was supplied. Survival was assessed on 9 Aug. 2016.

Data were analyzed using SAS software (version 9.4; SAS Institute, Cary, NC). For each species, differences among treatments were identified using PROC GLIMMIX, where raw data were averaged within replicate. Type III tests of fixed effects were used to examine interactions and main effects. Differences of least squares means were adjusted for multiple comparisons as necessary.

Results and discussion

Extracts of media treated with both low and high fertilizer rates yielded high pH and electrical conductivity (EC) as well as high levels of nitrate, calcium, and magnesium relative to published values from similar peat-based plugs amended with fertilizer (Scoggins et al., 2001; Table 2). We did not monitor EC throughout the growing season nor did we analyze saturated media extracts at the end of the growing season, thus nutrient levels and EC likely reflect only the initial media and any broken controlled-release fertilizer prills as the fertilizer did not have time to release.

For many plant species, larger propagation stock confers superior survival and growth rates upon outplanting, particularly for restoration projects where site conditions are unfavorable (Grossnickle, 2012; Pinto et al., 2015; Sutherland and Day, 1988). For both milkweed species investigated, plants grown in the large containers and with the label-recommended "high" rate of fertilizer were significantly larger (Tables 3 and 4), as shown for other plant species (Clark and Zheng, 2015; NeSmith and Duval, 1998). For showy milkweed, increasing container volume from small to large resulted in a 698% increase in RV, 859% increase in RDW, and 1240% increase in SDW (Table 3). Similarly, for narrowleaf milkweed plants, relative to small containers, RV increased 133% and 663% and RDW increased 146% and 683% in the medium and large containers, respectively (Table 4). SDW increased 2329% in the large container relative to the small containers (Table 4). Increasing fertilizer rates from 2.7 g·L^{-1} (low) to 6.5 g·L^{-1} (high) resulted in showy milkweed plants with 45%, 44%, and 38% greater RV, RDW, and SDW, respectively. Similarly, for narrowleaf milkweed plants, increasing fertilizer rates resulted in 22% and 33% greater RV and SDW, respectively.

The main effects of container volume and fertilizer rate interacted to impact plant height and RCD (Tables 3 and 4) for both milkweed species. Showy milkweed plants were tallest when grown in the medium containers and given the high fertilizer rate (Fig. 1A); they also had the greatest RCD when grown in the medium containers with the high rate of fertilizer or in the large containers regardless of fertilizer rate (Fig. 2A). Narrowleaf milkweed plants were tallest when grown in either the medium or large containers regardless of fertilizer rate (Fig. 1B). RCD was greatest when grown in the medium containers when given the high fertilizer rate or when grown in the large containers regardless of fertilizer rate (Fig. 2B).

Despite concerns over the development of a firm plug, almost all (96% to 100%) narrowleaf milkweed plants developed a firm plug irrespective of fertilizer treatment or container volume 22 weeks after sowing (Table 4). For showy milkweed, the main effects interacted such that nearly all plants developed firm plugs across all container volumes only when treated with the high fertilizer rate (Fig. 3). Specifically, when treated with the high fertilizer rate 100%, 100%, and 96% of showy milkweed plants developed firm plugs in the small, medium, and large containers, respectively, compared with 8%, 52%, and 64% across container volumes when treated with the low fertilizer rate.

Many narrowleaf milkweed plants bloomed during nursery production, a trait that was affected by a significant interaction between container volume and fertilizer rate (Table 4). When grown in the large container, 91% of plants bloomed when given the low fertilizer rate and 88% bloomed when given the high fertilizer rate (Fig. 4). When grown in the medium container, only 36% of plants bloomed when given the low fertilizer rate, whereas 85% bloomed when given the high fertilizer rate (Fig. 4). Almost none of the narrowleaf milkweed plants bloomed when grown in the small

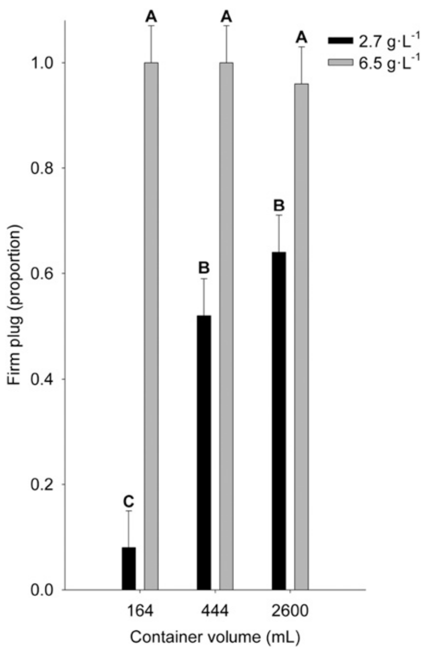

Fig. 3. Mean (±SE) proportion of showy milkweed plants that developed a firm plug across three container volumes grown with low (2.7 g·L^{-1}) and high (6.5 g·L^{-1}) 18N–2.2P–10K controlled-release fertilizer rates. Significant differences (at α = 0.05) are indicated using uppercase letters; 1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz.

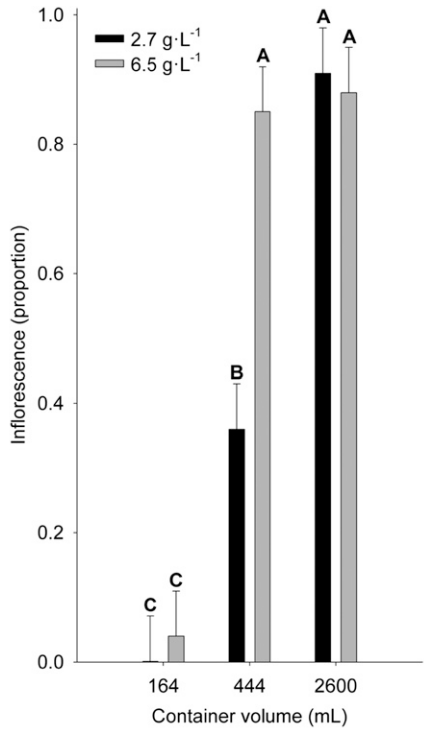

Fig. 4. Mean (±SE) proportion of narrowleaf milkweed plants that developed an inflorescence 15 weeks after sowing across three container volumes grown with low (2.7 g·L^{-1}) and high (6.5 g·L^{-1}) 18N–2.2P–10K controlled-release fertilizer rates. Significant differences (at α = 0.05) are indicated using uppercase letters; 1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz.

Table 5. Effects of container volume and 18N–2.2P–10K controlled-release fertilizer rate (low = 2.7 g·L^{-1} and high = 6.5 g·L^{-1})^z on irrigation frequency. Means (SE) are presented and significant differences (at α = 0.05) within each column are indicated using uppercase letters.

Container^z	Fertilizer rate	Irrigation events for showy milkweed (no.)^y	Irrigation events for narrowleaf milkweed (no.)^y
		Mean (SE)	
Small (164 mL)	Low	30.0 (0.9) A	32.6 (1.1) B
	High	33.6 (0.9) A	39.4 (1.1) A
Medium (444 mL)	Low	22.2 (0.9) B	23.6 (1.1) C
	High	25.0 (0.9) B	27.4 (1.1) C
Large (2600 mL)	Low	12.4 (0.9) C	15.2 (1.1) D
	High	10.8 (0.9) C	14.2 (1.1) D
Source of variation	df (num./den.)^x	F ratio (*P* value)	F ratio (*P* value)
Fertilizer (F)	1/24	4.61 (0.0421)	13.32 (0.0013)
Container (C)	2/24	247.71 (< 0.0001)	196.70 (<0.0001)
F × C	2/24	4.70 (0.0189)	6.71 (0.0048)

^{z}1 g·L^{-1} = 0.1%, 1 mL = 0.0338 fl oz.
^{y}Number of irrigation events between 27 June 2015 and 18 Sept. 2015.
^{x}num. = numerator; den. = denominator.

container, regardless of fertilizer rate (Fig. 4). Inflorescence development was not observed for showy milkweed plants 15 weeks after sowing (data not shown). Many nursery personnel have indicated that milkweed plants grown from seeds typically do not flower in the first year: Kimberley Bell (Outsidepride.com, Independence, OR), Penny Nyunt (Las Pilitas Nursery, Santa Margarita, CA), Kirk Shillinglaw (Prairie Nursery, Westfield, WI), Deanna Giuliano (Grassroots Ecology Nursery, Los Altos Hills, CA), and Ellen Uhler (Central Coast Wilds Ecological Concerns, Santa Cruz, CA). Our research indicates that manipulation of container volume and fertilizer rate can facilitate flower development for narrowleaf milkweed during nursery production. This may be desirable for restoration projects requiring well-developed propagation stock that will provide an immediate food supply for foraging pollinators upon outplanting (Landis, 2014). Plants that are already blooming with established root systems will also have higher potential to self-seed and proliferate by rhizomes within the first year.

Container choice is a function of target seedling specifications and production logistics (Landis et al., 2010). Not only were firm plugs of the two milkweed species propagated from seeds across a range of container volumes by manipulating fertilizer rate, but outplanting survival rates were high (>90%), regardless of species or treatment. Thus, depending on the desired seedling specifications, these propagation techniques offer a range of viable options. The small containers allow plants to be propagated and planted most economically, whereas the more costly, larger propagation stock may better meet the objectives of a particular restoration project. For both milkweed species, RDW and SDW were strongly positively correlated ($r = 0.77$, $P < 0.0001$ and $r = 0.83$, $P < 0.0001$, for showy milkweed and narrowleaf milkweed, respectively), thus, whether hot-planted or planted once dormant, the benefits of larger seedlings will remain given the strong positive correlation between shoot and root biomass. Finally, from the standpoint of production efficiency, it is worth noting that for both species the large containers required significantly less frequent irrigation relative to medium and small containers (Table 5).

Conclusions

Nursery cultural practices, namely, the use of large containers and the application of high fertilizer rates can produce sizable, firm plugs of showy milkweed and narrowleaf milkweed within a single growing season. Building on the work of Bartow (2006), Leigh et al. (2006), Skinner (2008), and Tilley (2016), these results improve our understanding of propagation of these species from seeds across a range of container volumes. The results aid in the efforts to restore the monarch butterfly's summer breeding habitat by developing propagation protocols that produce plants suitably developed for immediate habitat restoration on outplanting given their large size, high survivorship, and in the case of narrowleaf milkweed, abundant inflorescences.

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