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Nitrogen and Substrate Assessment For Pot-in-Pot Production in the Intermountain West¹

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– Abstract –

We investigated optimum nitrogen rates and different growth substrates for short-term finish production of container and bare root shade tree liners in a pot-in-pot production system in the Intermountain West. In one study, nitrogen ranging from 0–27 g N-tree⁻¹ $(0-36 \text{ lbs N}\cdot 1000 \text{ ft}^{-2})$ as urea was applied to quaking aspen (*Populus tremuloides*), 'Autumn Blaze' maple (Acer × freemannii 'Autumn Blaze'), 'Chanticleer' flowering pear (Pyrus calleryana 'Chanticleer'), and 'Canada Red' chokecherry (Prunus virginiana 'Canada Red'). Twenty-six liter liners (#7 container) were transplanted into 57 liter (#15) containers in a retail nursery finishing pot-in-pot system. Trunk diameter growth and shoot-tip elongation measurements were recorded for one growing season. Overall, only pear had a consistent increase in terminal shoot and trunk growth in response to N at 9 g N·tree⁻¹ (12 lbs N·1000 ft⁻²). Maple and chokecherry exhibited modest lateral shoot growth at 4.5 and 18 g N tree⁻¹ (10-24 lbs N 1000 ft⁻²), and aspen growth had no response to N. The second study evaluated the effect of nitrogen rates and substrate type on first-year trunk diameter growth of bare root common chokecherry (Prunus virginiana) and Aristocrat flowering pear (Pyrus calleryana 'Aristocrat'). Large bare-root liners were installed into a finishing pot-in-pot system with three substrate treatments, a proprietary, a commercial mix using several organic matter sources, and a simple composted bark-pumice mix. Five nitrogen rates, 0-9 g N·tree⁻¹, (0-12 lbs N·1000 ft⁻²) were applied to each substrate. Pear again had a modest increase in trunk growth at 2.2 g N per tree, but had no response to the different growth substrates. Chokecherry trunk growth did not increase with nitrogen nor did substrate treatment substantively affect growth. This study indicates that Intermountain West retail nurseries can likely reduce first-year nitrogen applications to container and bare root liner stock during finish production, and use a simpler media to achieve optimum growth at potentially lower cost.

Index words: nitrogen response, inorganic substrate, shade tree, leaching, pumice, establishment.

Species used in the study: quaking aspen (*Populus tremuloides* Michaux); 'Autumn Blaze' maple (*Acer × freemannii* 'Autumn Blaze'); 'Chanticleer' flowering pear (*Pyrus calleryana* D. 'Chanticleer' and 'Aristocrat'); 'Canada Red' chokecherry (*Prunus virginiana* L. 'Canada Red'), and common chokecherry (*P. virginiana* L.).

Significance to Nursery Industry

Pot-in-pot production using larger bare-root and container liners offers retail nurseries in the high desert of the Intermountain West a means to cost-effectively produce finished landscape shade tree stock compared to buying in finished stock. However, nurseries commonly base management practices on historical policies rather than data that can optimize production by reducing costs. The results of this study suggest that first-year nitrogen applications for container-liner stock that comes well fertilized are probably unnecessary, and for healthy bare-root stock, nitrogen fertilization beyond a low level is not cost effective as water is likely to be more of a limiting factor. Similarly, complex growing substrates may not offer sufficient improvement in tree growth over a simpler mix.

Introduction

Since the 1990s, pot-in-pot tree production has become an important technique in the ornamental tree nursery industry (15). Pot-in-pot production offers several advantages over conventional field and container techniques, including year-round harvesting (8), reduction of transplant shock, and greater wind protection (17). The Intermountain West

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(IMW), the high desert region bordered by the Sierra Nevada and Cascade mountain ranges on the west, and the Rockies on the east encompassing USDA hardiness zones 3-6, is experiencing rapid population growth and increased landscaping that has spurred increased demand for nursery stock. Pot-in-pot (PIP) production is increasingly used by nursery growers in the IMW. PIP provides moderated root zone temperatures during summer and winter and reduced irrigation requirements compared to above-ground production (2). PIP production is particularly attractive to retail nurseries in the IMW. Finish production of purchased large liner stock, such as container and bare root, is cheaper than buying in finished, landscape ready, stock. PIP production, however, has several problematic challenges, including potentially limited drainage, root penetration into ambient soil hindering harvest, and high initial cost of installation (8). Similar to conventional container production, PIP tree systems require careful attention to growing substrates and nutrient applications needed for optimum growth (23).

As in above-ground container production, substrates in pot-in-pot systems typically need to be supplemented with N fertilizers, typically in slow release form, to ensure an optimum growth response (19, 21). However, information is lacking on appropriate N fertilization applications in an IMW PIP system for first-year establishment of container and bare root liners that come well fertilized from wholesale nurseries. The loss of money from over fertilization and the consequent nitrogen leaching and denitrification may be a concern if conventional fertilization and irrigation practices are followed (20), particularly in the IMW where shade tree transpiration and water demand can be lower than more humid climates (12). Consequently, knowledge of N fertilization

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rates appropriate for first year production of large shade tree liners in the IMW is critical for efficient production.

As in conventional container production, management of growing substrate is a critical concern and large expense for PIP production (8, 17). Substrates for container/pot-in-pot production are comprised predominately of organic components, such as bark, coconut coir, peat, and composted plant and animal wastes for low weight and drainage, often mixed with inorganic components such as sand, processed clay, or pumice stone also for drainage. Organic substrate sources are more limited in the IMW compared to high rainfall regions due to fewer vegetation sources, so nurseries use complex mixtures of organic ingredients that may include animal and green composts of variable salt content. In addition, sand or field soil is often locally incorporated to improve drainage but also adding significant weight that increases shipping costs. Pumice is a local, low bulk density alternative to field soil and sand that can improve drainage and reduce weight. Whether or not the addition of these organic and inorganic ingredients such as pumice enhance growth for PIP production in the IMW is not known

The objectives of this research were twofold: 1) to determine optimal tree growth as a function of N levels for container liner trees during one-year finish production; 2) determine optimum N rates for bare-root liners during first year establishment in a two-year production cycle and assess impact on growth of substrates varying in organic ingredient diversity and pumice content.

Materials and Methods

Two studies were performed to optimize PIP tree production systems for the IMW. Study I evaluated the effect of different levels of N on the growth of four tree species planted as container-grown liners during finish production in a PIP system. Study II investigated N dose response for bare root trees during a two-year production cycle when planted in three different growing media commonly used in Utah.

Study I. This study was conducted in a commercial retail tree nursery (J&J Nursery) — 41.1°N 111.9'W, USDA hardiness zone 6b, elevation 1326 m (4346 ft) — that included a PIP finish production system located in a suburb approximately 30 km north of Salt Lake City. Four tree species commonly used in the Intermountain West were chosen: quaking aspen (Populus tremuloides), 'Autumn Blaze' maple (Acer × freemannii 'Autumn Blaze'), 'Chanticleer' flowering pear (Pyrus calleryana 'Chanticleer'), and 'Canada Red' chokecherry (Prunus virginiana 'Canada Red'). Trees were obtained from an Oregon liner nursery fall 2003 in 27 liter (#7) containers. The trees (along with the associated liner production growth medium) were transplanted into 57 liter (#15) containers for finish production, and filled with the production nursery's proprietary growing medium (described in Study II below). To prevent potential wind damage during establishment, a steel stake was inserted through the container into the soil near the trunk to which the trees were secured with stretchable tree tape and foam spacers to reduce damage to the trunks. Treatments, including a non-fertilized control, a control with iron, and N fertilization, were:

1) Control group: no additional of nutrients.

2) Control plus Fe: at 5 g FeSO₄·tree⁻¹ (3 lbs·1000 ft⁻²)

3) Proprietary tree fertilizer: at 9 g N (as 23-7-10 blend) tree⁻¹ (24 lbs 1000 ft⁻²)

- 4) Low N rate: 0.9 g N (2 g urea) $tree^{-1}$ (1 lb N·1000 ft⁻²)
- 5) Medium-low N rate: 4.5 g N (10 g urea) tree⁻¹ (6 lbs N·1000 ft⁻²)
- 6) Medium N rate: 9 g N (20 g urea) tree⁻¹ (12 lbs N·1000 ft⁻²)
- 7) Medium-high N rate: 18 g N (40 g urea) tree⁻¹ (24 lbs N·1000 ft⁻²)
- 8) High N rate: 27 g N (60 g urea) tree⁻¹ (36 lbs N·1000 ft⁻²)

Soil and water pH in the Intermountain West are high enough (pH 7–8) compared to higher rainfall regions that Fe can sometimes be deficient for non-native imported tree species, thus the need for the second control (Treatment 2). Treatment 3 was the proprietary fertilizer blend the cooperating nursery uses for finish production, including a Fe supplement, so did not receive the additional Fe. Otherwise treatments 4–8 all received the same 50 mg·kg⁻¹ (5 g FeSO₄·pot⁻¹) per tree as Treatment 2 and N in increasing dosage as listed as a controlled release, polymer-coated urea (42–0–0; Osmocote, Scotts Inc.).

Each tree species was considered a separate experiment block, with each of the eight treatments replicated 10 times per species, and each species block consisting of four rows with 20 trees per row. The 80 trees within a species block were randomly assigned to fertilizer treatments, and fertilizer treatments were arranged in a completely randomized design within the four rows. The fertilizer was evenly distributed around the inside diameter of each container as a top dress application April 1, 2004, at early budbreak.

Throughout the rest of the growing season the trees received uniform irrigation delivered by a micro-irrigation system using drip tubes connected to spray-stake emitters at a rate of 0.71 liters per minute. Trees were irrigated for 20 minutes every other day, consistent with current practices of the production nursery. Rainfall for April–August study period was 147 mm (5.8 in), nearly all falling April–June.

Initial trunk diameter measurements were taken at the time of fertilization. Two diameters were taken with a digital caliper at a height 150 mm (6 in) above the soil line, one north-south and the other east-west. An average was then calculated and recorded. Subsequent trunk diameter measurements were taken once a month for three months, the last occurring early July. Three shoot-tip elongation measurements were also taken in early July, the primary leader and two randomly selected lateral branches. Trunk diameter growth and shoot-tip elongation were both analyzed for significance using one-way analysis of variance within a species, PROC MIXED in SAS (ver. 9.1 SAS, Inc., Cary, NC), $\alpha = 0.05$, to compare among treatments. When there was a difference among treatments, means were compared with a least significant difference test (LSD), also at $\alpha = 0.05$.

Prior to treatment initiation, substrate samples were collected from the liner trees, as well as the nursery's own proprietary substrate mix that was added to fill out the study containers. Samples were submitted to Utah State University Analytical Laboratories (USUAL) for analysis, where the saturated media extract (SME) method was used to determine soluble nutrient availability, pH, and salinity as measured by electrical conductivity (21). In July 2004, leachate and substrate samples were randomly collected from the bottom of all containers for containers treated with the highest N rate (60 g urea-tree⁻¹, 36 lbs N·1000 ft⁻²) and analyzed by the

USUAL using a saturated paste extract to check for possible nitrate (NO_3^{-}) leaching (22).

Study II. We then investigated the effect of three locally common substrates on bare root 'Aristocrat' flowering pear (Pyrus calleryana 'Aristocrat'), and common chokecherry (Prunus virginiana), in conjunction with N dose response treatments. Bare root liners, 32 mm caliper, 1.83 m (1.25 in, 6 ft), were obtained from a bare-root liner nursery in Oregon (J.F. Schmidt, Inc., Boring, OR) early March 2005. Upon arrival, trees roots were covered with sawdust and kept moist and cool until planted. After root pruning the trees were planted into 57 liter (#15) containers where three substrates were randomly assigned. Trees were then placed in a pot-in-pot production field located at the Utah Botanical Center in Kaysville, UT, approximately eight km (five miles) from the cooperating production nursery in Study 1, and staked as previously described in Study I. The three common substrates evaluated were:

Proprietary: proprietary substrate of the retail nursery from the first study, consisting of 10% sand, 10% sphagnum peat moss, 14% 8 mm (5/16 in) pumice, and 66% bark fines, plus micronutrients (bulk density 520 g-liter⁻¹).

Commercial: commercial medium from a local company that contained 7% composted animal waste incorporated with 60% composted forest humus, 5% sphagnum peat moss, 15% 8 mm (5/16 in) coarse pumice, and 13% sandy loam soil (bulk density 540 g·liter⁻¹).

Simple: lighter substrate similar to proprietary mix containing 60% composted bark fines, but substituting 30% 3.1 mm (1/8 in) pumice for sand and with 10% 8 mm (5/16 in) pumice (bulk density 580 g·liter⁻¹).

Randomly imposed upon the substrate treatments were the following five N treatment rates as polymer-coated urea (42–0–0; Osmocote, Scotts Inc.):

- 1) Control: no N added
- 2) Low N rate: 0.9 g N (2 g urea) tree⁻¹ (1 lb N·1000 ft⁻²)
- 3) Medium N rate: 2.2 g N (5 g urea) tree⁻¹ (3 lbs N·1000 ft⁻²)
- 4) Medium-high N rate: 4.5 g N (10 g urea) tree⁻¹ (6 lbs N·1000 ft⁻²)
- 5) High N rate: 9 g N (20 g urea) tree⁻¹ (12 lbs N·1000 ft^{-2})

Each substrate \times nitrogen rate treatment combination was replicated five times, where again tree species was considered a separate experiment block. Each species block consisted of three rows of 25 trees each, 75 total. Trees were randomly assigned to the treatment combinations, and each treatment combination was randomly assigned to positions within the tree rows. All trees received a one-time blanket application of P in the form of Triple Super Phosphate (0-45-0)at the recommended rate of 4 g·tree⁻¹ (2.3 lbs P_2O_c ·1000 ft⁻²), and a one time blanket application of K in the form of potassium chloride (0-0-60) at the recommended rate of 6 g·tree⁻¹ (4.6 lbs K₂O·1000 ft⁻²). Fertilizers were applied as a top-dress application around the inside diameter of each container. To ensure that micronutrients were not limiting, a recommended rate of Baicor's Phyto-Plus liquid Micro Mix (Logan, UT) was applied at 30 ml (1 oz) per tree each month for four months starting on May 12, 2005. Trees received uniform watering delivered by a micro-irrigation system with spray-stake emitters at a rate of 1.9 liters per minute. Each irrigation cycle ran for 15 minutes, and each tree received one irrigation cycle every third day throughout the growing season. April-September study period precipitation was 271 mm (10.7 in), again nearly all falling April-June.

Initial trunk diameter measurements were taken at the time of fertilization in mid April 2005. Two readings were taken with a digital caliper at 15 cm above the soil line, one measurement again north-south and the other east-west. An average was then taken and recorded. Subsequent trunk caliper readings were taken once a month for 5 months, with the last reading being taken in mid September 2005. Data from the trunk diameter growth in Study II was analyzed with a two-way analysis of variance again using PROC MIXED (ver 9.1 SAS, Inc., Cary, NC), at $\alpha = 0.05$. Means were compared with a least significant difference test (LSD).

Samples of the three substrate mixes were collected. Moisture content at saturation, as well as at field capacity, were analyzed by the USUAL. A chemical analysis was also performed on the substrate mixes using a saturated extract (SME) (21), useful in determining specific soluble nutrient concentrations and pH in artificial growth media (21). At the end of the growing season of Study II, random leaf tissue samples were collected from each treatment level of each tree species. The leaf tissue samples were then analyzed for nutrient element content. This process involves a wet acid (HN0₃)/peroxide digestion of dried plant tissue. Nutrient concentrations were measured by USUAL via Inductively Coupled Plasma (ICP) — Emission Spectrometry on sample digests.

Results and Discussion

Study I. Chemical analysis of the original liner production substrate and the proprietary substrate suggested that both were suitable for tree production. The original liner production medium was slightly acidic (pH 5.2), with excessive P (182 ppm) and K (350 ppm), higher than the recommended levels of 6–9 ppm P and 150–200 mg·kg⁻¹ K (3), evidently

 Table 1.
 Chemical analysis of three different substrates used in the production of finish pot-in-pot production of Pyrus calleryana 'Aristocrat' and Prunus virginiana as bare root trees in suburban Salt Lake City, Utah.

	рН	ECe (dS·m)	Nitrate	Phosphorus	Potassium — (mg·L) —	Calcium	Magnesium
Proprietary ^z Commercial ^y	7.1	1.62	0.2	7.9	114	108 44	30 21
Simple ^x	7.5	2.63	0.0	13.7	220	84	33

²66% bark fines, 10% peat, 10% sand, 14% 8 mm pumice.

^y60% humus, 5% peat, 15% 8 mm pumice, 13% sand.

x60% bark fines, 30% 3.1 mm pumice, 10% 8 mm pumice.



Fig. 1. Average trunk diameter increase (mm) and terminal and lateral shoot elongation growth (mcm) in 2004 for four shade tree species grown pot-in-pot at six different rates of supplemental nitrogen (N) at a production nursery in suburban Salt Lake City, UT. Letters adjacent to data points indicate significant differences among N treatments at P = 0.05. Arrows at larger symbols indicate proprietary fertilizer rate. Vertical error bars indicate the standard error of each mean of 10 trees.

leading to somewhat high salinity (EC_e) of 1.7 dS·m⁻¹. The proprietary substrate was more neutral (pH 6.8), with lower P and K (50 and 269 ppm, respectively), still above recommended levels, but somewhat lower salinity (0.8 dS·m⁻¹) (Table 1). High levels of P are a concern in that they can cause micronutrient metal deficiencies (11, 14). Salinity and pH values for both substrates were considered acceptable (22). The addition of iron had no impact on any growth measurement, so both controls were combined during analysis.

Variation in trunk diameter growth was generally greater among species than among N treatments (Fig. 1). Quaking aspen had the greatest trunk growth, approximately 10 mm (0.4 in) followed closely by chokecherry then maple. Pear had the lowest trunk growth, 6–7 mm (0.24–0.28 in), but the greatest response to nitrogen, reaching maximum growth at 9 g N·tree⁻¹ (12 lbs N·1000 ft⁻²). None of the other tree species exhibited trunk diameter growth differences among any of the N levels. A significant increase in pear diameter growth of about 1 mm is not necessarily meaningful. Change in grade according to nursery standards is 6 mm (0.25 in) for trees

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(1, 18), so an increase of one mm does not readily translate into added value to the nursery.

The absence of differences in trunk diameter growth in response to the proprietary fertilizer used by the nursery at 18 g N·tree⁻¹ (24 lbs·1000 ft⁻²) indicates lower application rates are adequate and less wasteful. Certainly the P and K in the proprietary fertilizer treatment (7 and 10%), when compared to the other treatments added no value in terms of growth, particularly given the high levels already in the liner and finish production substrate. Eliminating the P and K in the proprietary fertilizer and focusing primarily on an N fertilization regime could reduce potential salinity issues as well as lead to financial savings and reducing possible P leaching (21).

Lateral shoot elongation showed a signification response to N rate in two species, maple at 4.5 g N·tree⁻¹ (6 lbs N·1000 ft⁻²) and chokecherry at 18 g·tree⁻¹ (24 lbs N·1000 ft⁻²), but since there was no corresponding increase in either trunk growth or terminal shoot elongation, the addition of nitrogen had no added value. The only species to show significant increases in terminal shoot elongation was again pear at 18 g N·tree⁻¹ (24 lbs N·1000 ft⁻²), approximately a 25% increase over the control, but terminal shoot elongation was only marginally different from the 9 g N·tree⁻¹ (12 lbs N·1000 ft⁻²).

Analysis of leachate and substrate for nitrate (NO₃⁻) movement below the root zone in July showed no appreciable levels (data not shown). That no NO₃⁻ was detected could have been due to prior leaching beyond the container boundary because of excessive irrigation (4, 5) that can easily occur in container production (13, 20) with highly porous media (10). While irrigation in this study was scheduled to ensure adequate water, it is possible that irrigation practices (5) and rainfall were such that they could have compounded leaching losses with denitrification losses (9). The potential for leaching and denitrification losses would further justify reduced application rates of N for one year finish production of pot-in-pot trees from container-grown liners.

Study II. Similar to Study I, variation in diameter growth between species was greater than the effect of increasing N rates, and the impact of substrate type was minimal with no interactions. While pear diameter growth during first year establishment from a bare root liner was similar to that from the container liner, chokecherry growth was about half of that of the container liner trees in the first study. By contrast, the impact of added N on growth of bare root trees during first year production was minimal. Indeed, chokecherry showed diminished diameter growth at 4.5 g N·tree⁻¹ (6 lbs N·1000 ft⁻²) compared to the no-N control (Fig. 2). Pear showed a modest increase in diameter growth at 2.2 g N·tree⁻¹ (3 lbs N·1000 ft⁻²), but such a negligible amount is unlikely to be meaningful in terms of value-added growth. Because bare root trees loose a substantial portion of their root system during harvest, water is a more limiting factor in establishment than nitrogen if the tree was been well fertilized during liner production (4).

As in Study I, no NO_3^- was detected in saturated paste extracts of samples collected in July from the bottom of the pots treated with 9 g N·tree⁻¹ (12 lbs N·1000 ft⁻²) (data not shown). Since increased growth was at the highest application rate was minimal, the absence of NO_3^- suggested that again it may have been leached or denitrified, indicating modest nitrogen application rates for bare root liner stock



Fig. 2. Average trunk diameter increase for two shade tree species planted bare root, then fertilized at five rates of supplemental nitrogen (N) and averaged over three different substrate mixtures in suburban Salt Lake City in 2005. Letters adjacent to data points indicate significant differences among nitrogen treatments at P = 0.05.

as well as container liners during first year establishment is justified (8).

The effect of the three substrates on first-year bare-root growth varied with species and substrate (Fig. 3). Pear diameter growth was unaffected by the substrates during the



Fig. 3. Average diameter increase for two shade tree species planted bare root when grown in three substrates different in components at in suburban Salt Lake City in 2005.

growing season. The absence of differences suggested that the lowest-cost substrate would be warranted. However, chokecherry diameter growth was less for plants grown in the simple substrate compared to the trees grown in the proprietary or the commercial substrates. Observations suggesting micronutrient imbalance (6) and subsequent leaf analysis performed by USUAL revealed that chokecherry leaves grown in the simple substrate had elevated levels of manganese (Mn; 780 mg·kg⁻¹), more than twice the levels of Mn measured in chokecherry leaves growing in the other two substrates. Leaf Mn levels exceeding 500 mg·kg⁻¹ are considered to be phytotoxic (6, 9). Although the Mn levels of pear growing in the simple substrate were also higher than the levels for plants grown in the other substrates, they were evidently not at phytotoxic levels, with pear diameter growth not affected. The difference between the proprietary and the simple substrates was the higher content of fine-textured pumice, suggesting it as the likely source of high Mn levels. The relatively high EC levels measured for the simple substrate could be a result of high Mn levels that were leached out over the season, as anecdotal observation of prior EC measurements of this substrate have shown very low EC levels. Leaching of Mn in the chokecherry grown in simple substrate would be consistent with the pattern of seasonal growth. Diameter growth in the simple substrate was lower the first two measurement dates, but July and August growth was equal to that of chokecherry in the other two substrate treatments. Future studies evaluating the release of Mn from pumice under variable leaching and the effect of Mn on growth of different species are warranted to better understand this phenomenon.

The results of these studies suggest that minimal N fertilization is needed to achieve optimum growth in the IMW for container and bare-root liner trees grown in a PIP finish production system during first year establishment. Performing an initial soil test on the substrate in which the trees are to be grown is critical in determining available nutrients to guide the amount of supplemental fertilization needed.

Large, container-grown wholesale liners often are well fertilized before transplanting for one-year finishing. Our studies suggest finish production of well-fertilizing liners in the IMW does not require more than 4-9 g N·tree⁻¹ (6–12 lbs N·1000 ft⁻²) to achieve optimum production. Addition of the proprietary fertilizer with higher N, as well as P and K, only added cost, not value to the finished plant. By eliminating unnecessary nutrients, adverse growing conditions associated with elevated salinity and other phytotoxic effects may be reduced.

Similar reasoning applies to first-year establishment of bare root trees, during a two-year production cycle, which should also be well fertilized prior to transplanting. With the loss of their root system, water is more likely than N to be the limiting factor during first year production. N fertilization may not be necessary, or at most a minimal 5 g urea per tree, during first year establishment for bare root plants. The second year of production would then require higher rates of N, but as suggested by the first study, 20 g urea per tree (6–12 lbs N·1000 ft⁻²) appears to be sufficient.

Similar analysis can be applied to the different substrates. The additional components in the proprietary and commercial mixes did not improve growth over the pumice mixture for pear, and in essence, chokecherry. Early growth reduction in chokecherry was ostensibly from high Mn levels, not the lack of additional organic ingredients. Indeed, based on the chokecherry recovery later in the season, and other anecdotal observations with this pumice-based substrate, the putative negative effect of higher bioavailable Mn may to be limited to sensitive species, and appears to be mitigated after leaching, although more work is needed.

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