Nonchemical, Cultural Management Strategies to Suppress Phytophthora Root Rot in Northern Highbush Blueberry

John R. Yeo
Department of Crop and Soil Science, 3017 Agricultural & Life Sciences Building, Oregon State University, Corvallis, OR 97331

Jerry E. Weiland
U.S. Department of Agriculture, Agricultural Research Service, Horticultural Crops Research Unit, 3420 NW Orchard Avenue, Corvallis, OR 97330

Dan M. Sullivan
Department of Crop and Soil Science, 3017 Agricultural & Life Sciences Building, Oregon State University, Corvallis, OR 97331

David R. Bryla
U.S. Department of Agriculture, Agricultural Research Service, Horticultural Crops Research Unit, 3420 NW Orchard Avenue, Corvallis, OR 97330

Abstract

Phytophthora cinnamomi Rands causes root rot of northern highbush blueberry (Vaccinium corymbosum L.), which decreases plant growth, yield, and profitability for growers. Fungicides are available to suppress the disease, but are prone to development of resistance in target pathogens and cannot be used in certified organic production systems. Alternative, nonchemical, cultural management strategies were evaluated to reduce phytophthora root rot in a field infested with P. cinnamomi. The field was planted with ‘Draper’ blueberry, which is highly susceptible to the pathogen. The soil was either amended with gypsum or not before planting, and the plants were irrigated using narrow (adjacent to plant crown) or widely spaced (20 cm on either side of the plant crown) drip lines and mulched with Douglas fir sawdust or black, woven geotextile fabric (weed mat). A fungicide control treatment was also included in the study and consisted of applying two conventional fungicides, mefenoxam and fosetyl-Al, to plants irrigated with narrow drip lines and mulched with sawdust. Initially, root infection by P. cinnamomi was lower with the combination of gypsum, wide drip lines, and sawdust mulch than with any other treatment, except the fungicide control. Soil under weed mat accumulated more heat units than under sawdust and resulted in faster hyphal growth by the pathogen. However, plant growth was similar in both mulch types. The effects of drip line placement and gypsum, on the other hand, were interactive, and plants grown with a combination of wide drip lines and gypsum produced the greatest amount of biomass among the cultural treatments. Narrow drip lines negated the disease-suppressive effects of gypsum by moving zoosporic-inhibiting Ca2+ away from the plant root zone, and also resulted in wetter soil near the crown of the plants, which likely promoted zoospore discharge and root infection. However, wide drip lines resulted in N deficiency symptoms during the first year after planting and, therefore, resulted in less plant growth than the fungicide control. Thus, if N management is properly handled, this study suggests that concerted use of gypsum and wide drip lines can help suppress phytophthora root rot in northern highbush blueberry and increase production in field soils where the pathogen is present.

Phytophthora cinnamomi Rands is a soil-borne pathogen that causes root rot in >900 plant species worldwide, including northern highbush blueberry (Zentmyer, 1980). Currently, there are two groups of fungicides (phenylamides and phosphonates) registered for root rot control in blueberry, including mefenoxam and fosetyl-Al (Brannen et al., 2009). Unfortunately, the risk of developing fungicide resistance is very high in Phytophthora species, especially to mefenoxam (Hu et al., 2010). In addition, organic blueberry production is increasing rapidly, but neither
To enhance uniform disease pressure, additional *P. cinnamomi* inoculum was incorporated into the soil in May 2012 after the beds were shaped. Inoculum was produced in fungal spawn bags with filter patches (*Fungi Perfecti, Sheldon, WA*). Twenty-seven bags were filled with 3 L of medium-grade vermiculite and 1.5 L of V-8 juice broth consisting of 10% V-8 juice (Campbell Soup Co., Camden, NJ) by volume and amended with 2 g L⁻¹ CaCO₃. The bags were autoclaved for 55 min. After cooling, a 100-mm-diameter petri plate filled with potato dextrose agar (PDA) and fully colonized with a 10-d-old isolate of *P. cinnamomi* was sliced into 100 pieces and added to each bag. The isolate was obtained in 2010 from a ‘Draper’ blueberry plant infected naturally in a field located in Corvallis, OR (Vargas et al., 2015) and was successfully used in previous experiments to cause root rot (Yeo et al., 2016). Each bag was incubated in the dark at 20°C and shaken at 2-week intervals. After 4 weeks, inoculum from all of the bags was homogenized in a cement mixer, and 1.56 kg of the resulting mixture was spread out in a 30-cm-wide band and incorporated 15 cm deep into each planting bed using a front-line rototiller (Sears and Roebuck, Hoffman Estates, IL). The final density of the inoculum was 2.7 cfu per cm² of soil.

**Treatments and experimental design.**

Nine treatments (eight cultural treatments and one fungicide control treatment) were applied to the center six beds in the planting on May 2012. The outer two beds in the planting served as nontreated borders. The treatments were arranged in a split-plot design with six replicate blocks (beds). Two mulch types (weed mat and sawdust) were randomly assigned as main plot treatments, and a combination of two drip line spacings (narrow and wide) and two gypsum levels (applied or not) were randomly assigned as subplot treatments (4.6-m long each), for a total of eight cultural treatments (two mulch types × two drip line spacings × two gypsum levels). A fungicide treatment (below) was also included in the study and was randomly assigned as a subplot within each of the sawdust main plots.

Gypsum (CaSO₄·2H₂O) was applied at a rate equivalent to 2.24 t ha⁻¹. The gypsum was spread out in a 0.3-m-wide band on the beds and was incorporated 15-cm deep with a narrow front-line rototiller (Sears and Roebuck, Hoffman Estates, IL). Mulch and drip lines were added to the beds after planting. A line of drip tubing (Toro Micro-Irrigation, El Cajon, CA) was installed on each side of the bed and secured either next to (narrow spacing) or 20 cm (wide spacing) from the plant crown using wire staples. The tubing had 1 L h⁻¹ in-line, pressure-compensating drip emitters spaced every 30 cm. Douglas fir sawdust mulch was applied ≥ 8 cm deep on the beds using a side-discharge mulch spreader. Black weed mat (Berry Hill Drip Irrigation, Buffalo Junction, VA) was placed on each side of the beds and secured in place with wire staples; two strips were used and overlapped in the center of the bed. Slits were cut and folded under to create 15-cm-square openings in the weed mat for each plant.

The fungicide control treatment had no gypsum and was irrigated with narrow drip lines. The plots were treated with mefenoxam (Ridomil Gold SL; Syngenta Crop Protection, Greensboro, NC) and fosetyl-Al (Aliette WDG; Bayer CropScience, Research Triangle Park, NC). Mefenoxam was sprayed on the surface of the beds (45-cm-wide band) shortly after planting in May 2012 and again in May 2013 at a rate of 0.18 mL m⁻². Fosetyl-Al was sprayed on the fully expanded leaves of the plants in late May each year at a rate of 3.4 kg ha⁻¹ (0.62 g/plant).

The treatment plots were planted with ‘Draper’ northern highbush blueberry on 15 May 2012. ‘Draper’ was selected based on its susceptibility to *P. cinnamomi* (Yeo et al., 2016). The plants were obtained from a commercial nursery (Fall Creek Farm and Nursery, Lowell, OR) as 3-L container stock and spaced 0.76-m apart in the beds. Soil P was low at the site; therefore, triple superphosphate (0N–45P–0K) was mixed into each planting hole at a rate of 45 kg ha⁻¹ P before planting. Each treatment plot consisted of six contiguous plants, and each bed of treatments had two border plants on each end. The outer beds on either side of the planting were planted on the same date with ‘Toro’ and ‘Reka’ northern highbush blueberry.

**Irrigation and nitrogen management.** The field was initially irrigated daily with hand-set overhead sprinklers to establish the annual

| Table 1. Effect of fungicide treatment on shoot and root dry weight and percent root infection of ‘Draper’ blueberry grown for 2 years (2012–13) in a field infested with *Phytophthora cinnamomi* in Corvallis, OR. |
| --- | --- | --- | --- |
| Fungicide | Shoot dry wt (g/plant) | Root dry wt (g/plant) | Root infection by *P. cinnamomi* (%)¹ |
| | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 |
| Yes* | 175 | 332 | 72 | 130 | 15 | 4 |
| No | 111 | 94 | 34 | 31 | 22 | 10 |
| Significance | *** | *** | *** | *** | NS | NS |

¹Nonsignificant or significant at *P* ≤ 0.01 and 0.001, respectively.

²The plants were harvested destructively in December of each year. All plants were mulched with sawdust, irrigated with two drip lines located near the plant crown on each side of the bed, and in soil without gypsum amendment.

³Percent of 20 (2012) or 10 (2013) root pieces infected by *P. cinnamomi*.

⁴The fungicide applications consisted of mefenoxam (0.18 mL m⁻², soil spray) and fosetyl-Al (3.4 kg ha⁻¹, foliar spray) in May 2012 and 2013.
ryegrass between the raised beds. Once the grass was established, overhead irrigation was discontinued, and drip irrigation was scheduled four times per week during the growing season using an automated irrigation controller. Irrigation was adjusted weekly based on plant size and reference evapotranspiration obtained from the Corvallis AgriMet agricultural weather station (http://www.usbr.gov/pn/agrimet/), as described previously by Bryla et al. (2011). The weed mat plots were irrigated with 20% more water than the sawdust plots during the first year after planting to compensate for greater plant water use with weed mat. Water use is initially greater with weed mat because of warmer soil and canopy temperatures (Larco, 2010). However, once the plants grow and shade the beds, extra water is no longer needed with weed mat.

Nitrogen fertilizers were applied by fertigation using a fertilizer injector (Dosatron International, Clearwater, FL) installed in the irrigation manifold. In 2012, the plants were fertigated with liquid ammonium sulfate (9N–0P–0K). That year, fertigation was initiated on 30 May and included four applications of 28 kg·ha⁻¹ N every 2 weeks. The first two applications were injected at 2% by volume, but this concentration resulted in N deficiency (yellowing leaves) in the plants irrigated with wide drip lines because the roots in those plots were located too far from this relatively immobile N source. Therefore, the next two applications were reduced to 0.5% by volume, to slow the injection rate and potentially move more N and water through the soil during each fertigation event. The following year, the plants were fertigated with liquid urea (20N–0P–0K). Urea is much more mobile during fertigation than NH₄-N but readily converts to NH₄ within a few days after application (Haynes, 1990). The fertilizer was injected 10 times between 17 Apr. and 17 July at a rate of 18 kg·ha⁻¹ N per application (1% by volume). There were no visual symptoms of N deficiency in the plants in 2013.

Measurements. Soil samples were collected for nutrient analysis using a 2-cm-diameter core sampler. The sampler was inserted 15-cm deep at six random locations near the center of the bed in each treatment plot in June 2012 and July 2013. Each set of samples was pooled, air-dried, ground, homogenized, and analyzed for soil pH [1 soil: 1 water (v/v)] and Mehlich III extractable cations at a commercial laboratory (Brookside Laboratories, New Bremen, OH). Leaves were also collected for nutrient analysis in early August each year. Four recently matured leaves were sampled from the center four plants in each plot, pooled, oven-dried at 70 °C, ground, and analyzed for N using a combustion analyzer (Model CNS-2000; LECO Corp., St. Joseph, MI) and for P, K, Ca, Mg, and S using an inductively coupled plasma optical emission spectrometer (Optima 3000DV; PerkinElmer, Wellesley, MA) after microwave digestion in 70% (v/v) nitric acid (Gavlak et al., 2005).

Soil water content was measured in each plot on 12 July and 7 Aug. 2013 using the Trase I time domain reflectometry system (Soilmoisture Equipment Corp., Santa Barbara, CA). The system was equipped with a 15-cm waveguide. The waveguide was inserted vertically into the soil at three locations in each treatment plot. Each measurement was taken between plants in the center of the bed within 1–2 h after an irrigation event.

Hyphal growth of *P. cinnamomi* was measured in a subset of the sawdust and weed mat plots in Corvallis, OR. Roots were sampled from soil cores (●, ○) or from destructively harvested plants (■, □). An asterisk above the symbols on a given sampling date indicates the means are significantly different at *P* ≤ 0.05.

| Treatment          | Shoot dry wt (g/plant) | Root dry wt (g/plant) |
|--------------------|------------------------|-----------------------|
|                    | 2012    | 2013    | 2012    | 2013    |
| Mulch              |         |         |         |         |
| Sawdust            | 96      | 106     | 43      | 36      |
| Weed mat           | 86      | 85      | 45      | 41      |
| Significance       | NS      | NS      | NS      | NS      |
| Drip lines (D)     |         |         |         |         |
| Narrow             | 121     | 87      | 39      | 26      |
| Wide               | 61      | 105     | 49      | 51      |
| Significance       | ***     | NS      | *       | ***     |
| Gypsum (G)         |         |         |         |         |
| No                 | 84      | 78 b    | 70 b    | 43      |
| Yes                | 98      | 96 b    | 139 a   | 46      |
| Significance       | NS      | D × G** | NS      | NS      |

| Treatment          | Shoot dry wt (g/plant) | Root dry wt (g/plant) |
|--------------------|------------------------|-----------------------|
|                    | 2012    | 2013    | 2012    | 2013    |
| Sawdust            | 96      | 106     | 43      | 36      |
| Weed mat           | 86      | 85      | 45      | 41      |
| Significance       | NS      | NS      | NS      | NS      |
| Drip lines (D)     |         |         |         |         |
| Narrow             | 121     | 87      | 39      | 26      |
| Wide               | 61      | 105     | 49      | 51      |
| Significance       | ***     | NS      | *       | ***     |
| Gypsum (G)         |         |         |         |         |
| No                 | 84      | 78 b    | 70 b    | 43      |
| Yes                | 98      | 96 b    | 139 a   | 46      |
| Significance       | NS      | D × G** | NS      | NS      |

*NS, **NS, ***NS nonsignificant or significant at *P* ≤ 0.05, 0.01, and 0.001, respectively.

*The plants were harvested destructively in December of each year.

*Means followed by the same letter are not significantly different (*P* = 0.05).
Table 3. Soil heat units and hyphal growth of *Phytophthora cinnamomi* grown in situ on potato dextrose agar in sealed petri plates buried 5-cm deep under sawdust and weed mat for 7–10 d in a field of ‘Draper’ blueberry in Corvallis, OR.

|       | Soil heat units (°C) |         | P. cinnamomi hyphal growth (cm²) |
|-------|---------------------|---------|----------------------------------|
|       | 9–16                | 11–19   | 9–16                              | 11–19                           |
| Mulch | Aug. 2012           | Apr. 2013 | July 2013                        | July 2013                       |
| Sawdust | 97                  | 52      | 114                               | 29.8                            |
| Weed mat | 112                | 64      | 118                               | 37.1                            |
| Significance | ***               | ***    | ***                               | ***                            |

*Significant at *P* ≤ 0.05, 0.01, and 0.001, respectively.

Table 4. Effects of mulch type, dip line placement, and gypsum amendment on soil water content in a field of ‘Draper’ blueberry infested by *Phytophthora cinnamomi* in Corvallis, OR.

| Treatment | July 2013 | Aug. 2013 |
|-----------|-----------|-----------|
| Mulch     |           |           |
| Sawdust   | 31.5      | 19.1      |
| Weed mat  | 29.5      | 17.6      |
| Significance | NS       | NS        |
| Drip lines (D) |       |           |
| Narrow    | 36.4      | 22.9      |
| Wide      | 24.5      | 13.8      |
| Significance | ***      | ***       |
| Gypsum (G) |           |           |
| No        | 31.2      | 18.8      |
| Yes       | 29.8      | 17.9      |
| Significance | NS       | NS        |

*NS.* **Significant at *P* ≤ 0.001, respectively.

*Calculated at a baseline of 9 °C (Zentmyer et al., 1976). *Grown in situ on potato dextrose agar in sealed petri plates."
Table 5. Effects of mulch type, drip line placement, and gypsum amendment on soil pH and extractable cations in a field of ‘Draper’ blueberry infested by Phytophthora cinnamomi in Corvallis, OR.a

| Treatment | Soil pH | Soil Ca (meq/100 g) | Soil K (meq/100 g) | Soil Mg (meq/100 g) |
|-----------|---------|---------------------|--------------------|---------------------|
|           | 2012    | 2013                | 2012              | 2013                |
| Mulch (M) |         |                     |                    |                     |
| Sawdust   | 4.6     | 5.1                 | 15.9               | 12.2                |
| Weed mat  | 4.7     | 5.3                 | 16.6               | 12.2                |
| Significance | NS   | NS                  | NS                 | NS                  |
| Drip lines (D) |         |                     |                    |                     |
| Narrow    | 4.1 b   | 4.1 b               | 4.9                | 14.8                |
| Wide      | 5.1 a   | 5.2 a               | 5.5                | 17.7                |
| Significance | M x D*  | NS                  | NS                 | NS                  |
| Gypsum (G) |         |                     |                    |                     |
| No        | 4.1 c   | 5.3 a               | 5.4                | 9.8                 |
| Yes       | 4.1 c   | 5.0 b               | 5.1                | 22.6                |
| Significance | D x G*** | NS                  | NS                 | NS                  |
| Recommended range | 4.5–5.5 | N/A                | >0.38              | N/A                |

N/A = not available.
ns, *, ***, ***Nonsignificant or significant at P ≤ 0.05, 0.01, and 0.001, respectively.
aMeasurements were taken at a soil depth of 0–15 cm.
bMeans followed by the same letter are not significantly different (P ≤ 0.05).
cFrom Hart et al. (2006).

during the summer (Fig. 1A; Table 3), when soil temperatures would reach the optimal hyphal growth temperature more often and for longer periods under weed mat than under sawdust. During the rest of the year, soil temperatures are usually less than the optimal temperature for hyphal growth and frequently drop below the minimum growth threshold of 5–6 °C. Our data show that root infection incidence was similar under sawdust and weed mat during the cooler months (Fig. 1A).

The plants also had more root infection at times with narrow drip lines than with wide drip lines (Fig. 1B), but less infection with gypsum, particularly during the latter months of the season each year (Fig. 1C). Soil water content was greater with the narrow drip lines (Table 4) and, regardless of mulch type or gypsum application, likely increased the activity of the pathogen (de Silva et al., 1999). Similar results were found in a previous study on ‘Duke’ blueberry at this site (Bryla, 2006). Calcium ions from the gypsum, in contrast to increased water content, likely inhibited the pathogen (Byrt et al., 1982; von Broembsen and Deacon, 1997). Soil pH and extractable cations, Soil pH and extractable cations were largely unaffected by mulch type each year, but each was often greater near plants with wide drip lines than those with narrow drip lines (Table 3). In general, soil pH decreased after planting, which was likely due to nitrification of NH4-N from the fertilizers (Bryla and Strik, 2015). Only a fraction of the NH4-N applied to a field of blueberry is taken up by the plants; the remainder is converted to NO3-N via nitrification by soil bacteria (Baños et al., 2012). The process results in the release of H+ ions, thereby increasing soil acidity. Presumably, NH4-N was more concentrated near plants with narrow drip lines, thus reducing pH to a greater extent than with wide drip lines.

The addition of gypsum increased the concentration of extractable Ca in both the soil and the soil solution each year (Table 5; Fig. 2). In both cases, Ca levels decreased over time and, by the second or third year, were only greater when gypsum was applied in combination with wide drip lines. Apparently, Ca2+ ions, which move primarily by mass flow in the soil (Barber, 1995), were more concentrated beneath the plants with wide drip lines and, over time, leached below the root zone. Most of the roots were located <0.3-m deep in each plot (data not shown), which is typical for blueberry (Bryla and Strik, 2007).

With the exception of plots with narrow drip lines in the first year, gypsum reduced soil pH by 0.3 units (Table 5). Usually, gypsum application has little effect on soil pH in nonsodic soils (Shainberg et al., 1989). However, others have reported a slight decrease in the pH of acidic soils after application of gypsum, which was attributed to the salt effect of the Ca2+ exchanging H+ and Al3+ ions from soil colloids into the soil solution (O’Brien and Sumner, 1988; Takahashi et al., 2006; Toma et al., 1999).

Gypsum also reduced the amount of extractable Mg by nearly 1 meq/100 g soil each year (Table 5). Likely, Mg was replaced by Ca from the gypsum and consequently leached to lower depths in the soil (Toma et al., 1999). Because this commonly happens, Sumner (1993) suggested applying Mg fertilizer following a gypsum application to maintain adequate levels of Mg in the soil.

Foliar nutrients. The concentration of most of the important nutrients in the leaves, including P, K, Mg, S, and, in all but one case, Ca, was within or above the range recommended for northern highbush blueberry; however, leaf N concentration was often below the range, particularly in treatments with wide drip lines (Table 6). As mentioned, the plants were fertigated initially with NH4-N source, which moves very slowly in the soil. Because young blueberry plants have small root systems, much of the N that was applied with wide drip lines in the first year probably never reached the roots before it was converted to NO3-N (Bryla and Strik, 2015). To compensate, the plants would need to be either fertigated with a mobile source of N, such as urea, or fertilized near the crown.
with a granular N product. Liquid urea was indeed more effective in the second year than liquid ammonium sulfate was in the first year, but leaf Ca continued to remain below the recommended range in the treatments with wide drip lines. Vargas (2015) tried spreading small doses of granular urea around the plants before fertigating with wide drip lines; the treatment resulted in greater leaf N than fertigation only, but it did not improve plant growth. More research is needed to develop a suitable method for providing adequate N with wide drip lines during plant establishment.

By the second year, the concentration of Ca in the leaves was slightly below the recommended range in plants grown in plots without gypsum (Table 6). Apparently, soil Ca was insufficient at the site unless gypsum was applied. Low soil pH can sometimes lead to low leaf Ca concentrations in blueberry (Hart et al., 2006). However, the soil pH was always near or within the desired range in each treatment (Table 5). When foliar Ca is low, Hart et al. (2006) recommend applying 1–2 t·ha⁻¹ of lime if the soil pH is <4 and 1–2 t·ha⁻¹ of gypsum if the pH is >5. A slightly greater rate of gypsum (2.24 t·ha⁻¹) was applied in the present study. Adding gypsum increased the concentration of both Ca and S in the leaves, particularly with wide drip lines. Research is underway to identify a method to correct the problem.

Mulch type, drip placement, and gypsum also affected the concentration of other nutrients in the leaves during the first growing season (Table 6). Foliar P, for example, was lower with wide drip lines than with narrow drip lines, but only when the plants were mulched with weed mat. Foliar K, on the other hand, was greater with sawdust mulch, wide drip lines, and gypsum, on average, and the additive combination of each resulted in the highest concentration of foliar K (i.e., 0.66%) among the treatments. Finally, foliar Mg was greater with wide drip lines than with narrow lines under sawdust and was also greater with the combination of wide drip lines and gypsum than with narrow drip lines or no gypsum. Although the cause of the observed treatment effects on foliar P levels is unclear, Vargas (2015) found that K and Mg moved with the wetting front and concentrated near the plants irrigated with wide drip lines.

### Conclusions

Based on the results of this study, it appears that gypsum and wide drip lines are effective at suppressing phytophthora root rot in northern highbush blueberry. Together, these practices resulted in the largest plants among the cultural treatments but still did not increase plant growth to levels similar to those obtained with fungicides. However, plant growth was limited during the first year with the treatments, primarily as a result of N deficiency with the wide drip lines. Research is underway to identify a method to correct the problem.

Weed mat increased root infection by *P. cinnamomi* relative to sawdust and resulted in warmer soil conditions and greater hyphal growth. Although plant growth was not adversely affected after 2 years with weed mat, caution is warranted when using weed mat with susceptible cultivars (Ye et al., 2016) and at sites conducive to phytophthora root rot (e.g., heavy soils and poor drainage).

**Literature Cited**

Bañados, M.P., B.C. Strik, D.R. Bryla, and T.L. Righetti. 2012. Response of highbush blueberry to nitrogen fertilizer during field establishment. I: Accumulation and allocation of fertilizer nitrogen and biomass. HortScience 47:638–655.

Barber, S.A. 1995. Soil nutrient bioavailability. 2nd ed. Wiley, New York, NY.

Benson, D.M. 1987. Residual activity of metalaxyl and population dynamics of *Phytophthora cinnamomi* in landscape beds of azalea. Plant Dis. 71:886–891.

Brannen, P.M., P. Harmon, and D.S. NeSmith. 2009. Utility of phosphonate fungicides for management of phytophthora root rot of blueberry. Acta Hortic. 810:331–340.

Bryla, D.R. 2006. Drip irrigation configuration influences growth in highbush blueberries. HortScience 41:1012 (abstr.).

Bryla, D.R. and R.G. Linderman. 2007. Implications of irrigation method and amount of water application on *Phytophthora* and *Pythium* infection and severity of root rot in highbush blueberry. HortScience 42:1463–1467.

Bryla, D.R. and B.C. Strik. 2007. Effects of cultivar and plant spacing on the seasonal water requirements of highbush blueberry. J. Amer. Soc. Hort. Sci. 132:270–277.

Bryla, D.R. and B.C. Strik. 2015. Nutrient requirements, leaf tissue standards, and new options for fertigation of northern highbush blueberry. HortTechnology 25:464–470.

Bryla, D.R., J.L. Gartner, and B.C. Strik. 2011. Evaluation of irrigation methods for highbush blueberry—I. Growth and water requirements of young plants. HortScience 46:95–101.

Byrt, P.N., H.R. Irving, and B.R. Grant. 1982. The effect of cations on zoospores of the fungus *Phytophthora cinnamomi*. J. Gen. Microbiol. 128:1189–1198.

de Silva, A., K. Patterson, C. Rothrock, and R. Mc New. 1999. Phytophthora root rot of blueberry increases with frequency of flooding. HorticScience 34:693–695.

DeVetter, L.W., D. Granatstein, E. Kirby, and M. Brady. 2015. Opportunities and challenges of organic highbush blueberry production in Washington State. HortTechnology 25:796–804.

Downer, A.J., J.A. Menge, and E. Pond. 2001. Association of cellulytic enzyme activities in Eucalyptus mulches with biological control of *Phytophthora cinnamomi* Phytopathology 91:847–855.

Ehret, D.L., B. Frey, T. Forge, T. Helmer, and D.R. Bryla. 2012. Effects of drip irrigation configuration and rate on yield and fruit quality of young highbush blueberry plants. HorticScience 47:414–421.

Erwin, D.C. and O.K. Ribeiro. 1996. *Phytophthora* diseases worldwide. APS Press, St. Paul, MN.
