Title: Investigating the effects of gypsum soil amendments on Phytophthora root rot in southern highbush blueberry (*Vaccinium corymbosum* interspecific hybrids).

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Public Abstract

Gypsum ($CaSO_4$) soil amendments have been associated with improvements in soil drainage and can serve as a source of soluble calcium without increasing soil pH. In blueberry plantings, amending the soil without increasing the pH is of particular importance, as blueberries thrive in low pH conditions of pH 4.5-5.5. Prior evidence indicates that high soluble calcium in the soil can disrupt the infection process of important soilborne pathogens such as *Phytophthora cinnamoni*, cause of root rot in blueberry plantings. In particular, the use of gypsum soil amendments in Phytophthora-infested plantings of northern highbush blueberry (V. *corymbosum*) in the Pacific Northwest resulted in increased plant biomass and decrease production of pathogen reproductive structures under specific field conditions and irrigation methods. Since blueberry production conditions, practices, and pathogen pressures in the southeastern U.S. typically differ substantially from those encountered elsewhere in the U.S., we investigated the use of gypsum on blueberry in Georgia. Specifically, greenhouse and field trials with southern highbush blueberry (*Vaccinium corymbosum* interspecific hybrids) were carried out over a period of two years to investigate the impact of gypsum soil amendments on Phytophthora root rot. Results from these trials did not indicate a significant impact of gypsum soil amendments on either Phytophthora root rot or on plant growth parameters.

Introduction

Phytophthora root rot can cause significant damage to the root system of plants and dramatically reduce vigor. In blueberry, Phytophthora root rot is caused by *Phytophthora cinnamomi*, a soilborne oomycete pathogen. Chlamydospores are the prevalent overwintering source of inoculum, and these persist in soil, bark, and on infected plant roots (Milholland and Oudemans, 2017). Though rabbiteye blueberries (*V. virgatum*) can be infected, southern highbush (SHB) blueberry cultivars are particularly susceptible to root rot and Phytophthora is frequently detected in SHB blueberry plantings in the southeastern U.S. Wet conditions promote the growth

and spread of *P. cinnamomi*. Zoospores are produced by sporangia, which are mobile under wet conditions. It is zoospores that infect actively growing roots where they cause damage and reduce nutrient and water uptake by the plant, eventually killing the infected plant. The ability for water to freely drain from the soil is essential for controlling the pathogen. If the site has poor drainage, blueberry should not be planted unless drainage issues can be rectified during establishment. Commonly, growers will plant blueberry in contiguous rows across high and low spots in a field. Water collects in the low spots where plant vigor is reduced and production is lost. Growers attempt to manage production losses through the use of fungicides like phenylamides (mefenoxam) and phosphonates.

Prior evidence indicates that high Ca^{2+} levels in the soil can disrupt the infection process of *Phytophthora* sp. by inhibiting the motility of zoospores. Accordingly, gypsum ($CaSO_4$) soil amendments can decrease the incidence of Phytopthora root rot (Messenger-Routh et al. 1996; Messenger et al. 2000a). Gypsum soil amendments can improve soil drainage in some cases, and compared to other sources of soluble Ca^{2+} such as lime, gypsum provides more soluble Ca^{2+} without increasing soil pH (Messenger et al. 2000a; Shainberg et al. 1989). Since blueberry thrives in an acidic soil medium of pH 4.5 – 5.5, this is of significant importance. Work with *P. cinnamomi* in both avocado and northern highbush blueberry (NHB; *V. corymbosum*) has shown that gypsum use reduced sporangial production by the pathogen and increased plant biomass (Messenger et al. 2000a,b; Yeo et al. 2017). Recent work with NHB in Oregon indicated that irrigation method (widely spaced driplines) can impact the effectiveness of the use of gypsum in this manner (Yeo et al. 2017). In the southeastern U.S., SHB are grown in conditions that differ significantly from NHB in the Pacific Northwest. Not only are soil types and weather conditions different, but growing practices in the southeastern U.S. often include the widespread use of pine bark mulch and frequent use of single dripline irrigation. To determine if gypsum soil amendments are capable of providing southeastern U.S. grown SHB blueberries with the same benefits as those observed in NHB plants in the Pacific Northwest, we examined the impact of gypsum in both an established blueberry planting and in greenhouse experiments. Specifically, our objectives were to determine the effects of gypsum soil amendments on soil properties (including soil moisture, pH, and nutrient composition), blueberry growth parameters (plant height, dry weight and nutrient composition), and Phytophthora root rot (root infection and pathogen abundance).

Materials and Methods

Field experimental locations. Field experimentation was conducted at the University of Georgia (UGA) Alapaha Blueberry Research Farm in Alapaha, Georgia and at a commercial blueberry farm in Ware County, Georgia. Both locations have a high water table and remain flooded for long periods of time after heavy rains. Phytophthora root rot was previously reported as a persistent problem in both sites.

Isolation of *Phytophthora cinnamomi*, inoculum preparation, and inoculum quantification. Prior to the initiation of field experiments, the presence of *P. cinnamomi* in the field was confirmed through isolation and molecular identification. *Phytophthora cinnamomi* was isolated from the soil on selective PAR(PH)-V8 media prepared according to the protocol of Jeffers (2006). The identity of obtained isolates was confirmed by PCR and sequencing of the ITS1 and ITS2 regions. Primers ITS4 (5'-TCCTCCGCTTATTGATATGC-3') and ITS6 (5'-GAAGGTGAAGTCGTAACAAGG-3') were used for amplification of a 941 bp product (EPPO

2004). A GoTaq® (Promega®, Fitchburg, WI) PCR kit was used, with reagents as follows: 10 µL 2x GoTaq® Green Master Mix, 2 µL each of forward and reverse primers (10 µM), 1 µL DNA (1-3 ng/µL) and 5 µL dH_2O. PCR conditions were as follows: 94°C for 3 min, 34 cycles of 94°C for 30 sec, 55°C for 30 sec, and 72°C for 1 min, and a final extension at 72°C for 10 min. Resulting amplicons were sequenced in both directions by Sanger sequencing at Eurofins Genomics (Louisville, KY). Obtained sequences were compared to known *P. cinnamomi* sequences available on the GenBank database (www.ncbi.nlm.nih.gov) to verify isolate identity. Following isolate identity confirmation, *P. cinnamomi* isolates were stored in sterile water cultures according to the protocol of Boesewinkel (1976) for use as inoculum in field and greenhouse experiments.

Experimental inoculum was prepared from a *P.cinnamomi* isolate originally cultured from the UGA Alapaha Blueberry Research Farm. A mixture of 150 mL V8 juice, 3g $CaCO_3$, 22.6 g agar, 1350 mL DI water, and 3 liter medium grade vermiculite was added to each sterilizable airflow spawn bag (Fungi Perfecti®, Olympia, WA). Bags were autoclaved for 55 min and cooled to room temperature. Stocks of *P. cinnamomi* were cultured on Potato Dextrose Agar (PDA) media for 10 days at room temperature, then sliced and incorporated into each spawn bag mixture. Inoculum bags were then sealed, placed in the dark, and incubated at 22˚C for four weeks. Every two weeks, inoculum bags were shaken to ensure content mixing. Uninoculated spawn bags were also prepared to serve as an uninoculated control treatment mixture for use in greenhouse experiments.

Prior to inoculum application, *P. cinnamomi* samples were taken from inoculum bags to quantify the population of *P. cinnamomi*. A sample of inoculum mix was suspended in 50 mL sterile DI water in a 50 mL conical. A dilution series of this suspension was plated on PAR(PH)-V8C selective media to allow for determination of CFU concentration. Plates were incubated in the dark at 22˚C for 10 days, and resulting colonies were counted to calculate CFUs in the original suspension and inoculum mixture.

Commercial blueberry farm field experiment design and treatments. The commercial field experiment was conducted in a 5-year old block of SHB cultivar ‘Farthing’ in 2018. A randomized complete block design was used with three blocks per treatment. Gypsum was applied to the soil of the respective treatment plots at 2240 kg/ha (1 ton/A) on 30 Mar 2018. This field experiment consisted of two treatments (gypsum and no gypsum), and standard management practices and pest spray programs were applied to all blocks throughout the year. Leaf nutrient compositions and soil parameters were assessed on 1 Jun 2018. Percentage root infection assessments were conducted on 7 Aug 2018 and 3 Oct 2018. Plants were not assessed in 2019, as the entire block was removed by the grower.

Research farm field experiment design and treatments. The blueberry research farm field experiment was established in a randomized complete block design with three blocks per treatment. Two SHB cultivars (‘Emerald’ and ‘Farthing’) were planted contiguously into each row in February 2018. Individual plots consisted of 6 plants in a treatment with two guard plants between plots. Plant spacing was 3 ft (in-row) by 12 ft (between-rows) in beds 4 ft wide by 1.5 ft in height. Pine bark was incorporated into the soil at 10 tons/A with 3 inches of pine bark mulch on top. The field experiment at Alapaha consisted of four treatments: (1) gypsum soil amendment plus fungicide applications, (2) gypsum without fungicide applications, (3) fungicide applications without gypsum soil amendment and (4) an untreated control (no gypsum and no fungicide applications). Gypsum was incorporated into the soil of the respective treatments at planting at

2240 kg/ha (1 ton/A). Once leaves were fully expanded, foliar applications of a phosphonate fungicide (K-Phite® 7LP, Plant Food Systems, Zellwood, Florida) were applied to the fungicide treatment plots. K-Phite (Mono and di-potassium salts of phosphorous acid) was initially applied at 5 qts/A on 27 Jun 2018 using a backpack sprayer until runoff (equivalent to 20 gallons of water per acre). Since phytotoxicity was observed at this concentration, until subsequent applications were made at 2 qts/A. Subsequent applications in 2018 occurred monthly in July, August, and September. In 2019, K-Phite was applied in April, May, August, and September. Otherwise, standard management practices and pest spray programs were applied to all blocks throughout 2018 and 2019. *Phytophthora cinnamomi* inoculum was applied to all plots on 7 Mar 2019 at a rate of 35 g inoculum mix/plant (2.8×10^5 CFU/plant) to increase prevalence of *P. cinnamomi* in the soil. Soil properties, plant growth parameters, and Phytophthora root rot incidence was assessed periodically until 13 Nov 2019, when plants were removed for final assessment. Percent root infection was assessed in June 2018, September 2018, October 2018, April 2019, October 2019, and November 2019. Plant growth was assessed from 9 May 2018 to 31 Oct 2018 and again at the conclusion of the experiment in November 2019.

Greenhouse experiment design and treatments. Greenhouse experiments were carried out on two SHB culitvars, 'Emerald' and 'Farthing'. For each experiment, plants derived from tissue culture were obtained from Lochloosa Lake Farms Nursery (Hawthorne, FL). Each experiment utilized a 2 x 2 x 2 factorial design consisting of two cultivars ('Emerald' and 'Farthing'), two gypsum regimes (unamended soil and soil amended with gypsum), and two inoculation regimes (uninoculated and *P. cinnamomi* inoculated). Each experiment consisted of 48 potted SHB plants, and six replicate plants were given each treatment. Soil composition in all pots was three-parts pine bark to one-part sand, similar to standard blueberry production soil in southern Georgia. For the pots receiving the gypsum soil amendment, gypsum was incorporated into the soil prior to transplanting at a rate of 2240 kg/ha (13.7 g/pot). Approximately one month after transplanting, *P. cinnamomi* inoculum was applied at a rate of 154.2 g/pot (equivalent to 111 CFU/cm^3 soil), spread around the base of each plant, and incorporated into approximately the first 2 cm of soil. This was considered to be Day 0 for the experiment. For the first experiment, inoculations took place on 12 Apr 2019 (Day 0). To ensure adequate inoculum delivery a second inoculation took place on 10 Jun 2019 (Day 79). A second experiment was initiated in October 2019. Plant growth was assessed visually and maximum branch length measurements were recorded weekly starting 30 days post-inoculation (30 dpi). Soil properties (pH, EC, and water retention) were assessed three times during the experiment at 28, 81, and 132 dpi. At 140 dpi, root and shoot dry weight and percent root infection assessments were conducted.

Assessment of soil properties. For greenhouse and field experiments, soil properties were assessed to determine the impact of gypsum soil amendments. For the commercial field experiment, assessed properties included soil pH, organic matter, and mineral nutrient composition. For the greenhouse experiment, in addition to these properties, soil water retention was also assessed. For the commercial field experiment, a composite soil sample was taken from each plot under the drip line. Each sample was taken at 0 to 15 cm depth with the surface 2.5 cm removed. Soil nutrients were extracted using a Mehlich I procedure and pH was measured using a 0.01M calcium chloride solution in a 1:1 soil to $CaCl_2$ mixture and reported as an adjusted pH value of + 0.6 units (Kissel and Sonon, 2008). Samples were collected from the commercial blueberry field site on 1 Jun 2018. For the greenhouse experiment, soil water retention was

assessed by measuring the amount of flow through each pot within 2.5 minutes after 1L DI water was applied to the soil. A 50 mL sample of this flow-through water was collected and then assessed for pH and EC (mS/cm and ppm).

Assessment of plant growth and leaf nutrient composition. For the greenhouse and field experiments, plant growth parameters and leaf nutrient compositions were assessed. For the commercial field site, leaf nutrient composition and fruit quality were assessed, while leaf nutrient composition, root and shoot dry weights, and plant height were assessed at the research farm field site. For the greenhouse experiments, root and shoot dry weight and plant height were assessed.

For leaf nutrient composition evaluations, leaf samples were rinsed with distilled water and dried to a constant weight at 80°C prior to sending the samples to an analytical laboratory. The samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), boron (B), zinc (Zn), manganese (Mn), and iron (Fe) (Waters Agricultural Laboratories, Inc., Camilla, GA), where the dried leaves were ground to pass through a 20-mesh screen. The samples were reduced to ash in a muffle furnace, acid digested, and measured by an inductive coupled plasma spectrophotometer (ICP) coupled to a Digiblock 3000 (SCP Science, Baie D'Urfé, Quebec, Canada). Nitrogen was determined through combustion of plant tissue using a LECO FP-428 N analyzer (LECO, ST. Joseph, MI, U.S.). Plant nutrient composition was also assessed in a similar manner as described above for the research farm field site, except that roots and shoots from one plant per plot were dried prior to nutrient evaluation.

To assess plant growth, plant heights and root and shoot dry weights were determined. Plant height was measured for each plant at the blueberry research farm site at the conclusions of the experiment in November 2019. For each greenhouse experiment, plant height was assessed weekly. For root and shoot dry weights, the soil line served as the demarcation between root and shoot elements. Roots were washed with tap water to remove excess sand and pine bark prior to drying. Roots and shoots from assessed plants were placed into brown paper bags and dried at 68°C for 24 hours prior to weighing. For the blueberry research farm field experiment, root and shoot dry weights were determined from four plants per plot at the conclusion of the experiment in November 2019. For the greenhouse experiments, root and shoot dry weights from each plant were measured at the conclusion of each experiment.

Assessment of root infection and Phytophthora incidence. Root rot in the field and greenhouse experiments was assessed as described in Yeo et al. 2017. Briefly, root samples were collected with a soil probe inserted approximately 15 cm deep, diagonally into the root zone. After manual separation of roots from collected soil, roots were initially rinsed with DI water to remove sand and pine bark. Root samples were surface sterilized with 70% ethanol for 1 min and sterile DI water rinse for 10 sec. Root samples were trimmed to approximately 0.5 cm pieces and plated onto PAR(PH)-V8 selective medium. Plating consisted of completely embedding 5 root pieces each onto 6 plates, for a total of 30 pieces per sample. Plates were incubated at room temperature (22˚C), in the dark, for up to 14 days. Root rot incidence was determined by calculating the percentage of root pieces (out of 30) per sample from which *P. cinnamomi* growth was observed.

For the blueberry research farm field experiment, root samples were collected on 27 Jun 2018, 17 Sept 2018, 18 Oct 2018, 5 Apr 2019, 3 Oct 2019, and 13 Nov 2019. Composite samples were collected from the six central plants in each plot. For the commercial blueberry site, root samples were collected on 7 Aug 2018 and 30 Oct 2018. Composite samples were collected from

the ten central plants in each plot. For the greenhouse experiments, each plant was sampled after 140 days post inoculation.

Results and Discussion

Impacts of gypsum soil amendments at a commercial blueberry farm. Soil and leaf nutrient assessments were carried out at the commercial blueberry farm site in Ware County on 1 Jun 2018. No significant differences among the soil parameters assessed were noted between any of the treatments (**Table 1**), and only a small difference in Mg was noted in the leaf analysis (**Table 2**). Fruit harvested from this site on 1 Jun 2018 also did not indicate substantial differences between treatments (**Table 3**), but differences in fruit weight, % acid, firmness, and diameter were noted (**Table 3**). At this site, percent root infection with *P. cinnamomi* was assessed twice during the growing season (7 Aug 2018, and 3 Oct 2018). Low overall disease incidence was noted (**Table 4**). Due to the removal of this planting by the grower, no results are available for this site from 2019. Taken together, these results suggest that gypsum soil amendments did not have a notable impact on root rot incidence or plant and soil nutrients.

Table 1. Soil analysis results from Ware County site taken 1 Jun 2018 (n=3).

	P (lb/A)	K (lb/A)	Mg (lb/A)	Ca (lb/A)	Mn (lb/A)	Zn (lb/A)	pH	OM (%)
Untreated	31.25 a	94.47 a	163.53 a	863.7 a	5.46 a	3.52 a	4.17 a	6.69 a
Gypsum	32.73 a	77.25 a	119.63 a	1064.8 a	4.72 a	3.66 a	4.14 a	6.48 a

Different letters represent significant differences between means at $P < 0.05$ according to Fisher's least significant difference test.

Table 2. Leaf tissue nutrient analysis results from Ware County site taken 1 Jun 2018 (n=3).

	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	S (%)	B (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
Untreated	1.89 a	0.08 a	0.51 a	0.32 b	0.87 a	0.19 a	61.4 a	18.6 a	180.7 a	50.0 a
Gypsum	2.05 a	0.12 a	0.50 a	0.35 a	0.93 a	0.22 a	76.4 a	19.6 a	231.0 a	77.7 a

Different letters represent significant differences between means at $P < 0.05$ according to Fisher's least significant difference test.

Table 3. Fruit harvested from Ware County site on 1 Jun 2018 (n=100).

	100 fruit count weight (g)	Individual Fruit Weight (g)	Soluble Solids (Brix)	% Acid	pH	Firmness (g/mm)	Diameter (mm)
Untreated	197.6 b	1.98 b	10.6 a	0.47 b	3.85 a	155.7 a	16.6 b
Gypsum	216.2 a	2.16 a	10.7 a	0.54 a	3.66 a	151.8 b	17.2 a

Different letters represent significant differences between means at $P < 0.05$ according to Fisher's least significant difference test.

Table 4. Root infection at commercial field site.

	Root infection by *P. cinnamomi* (%)	
	7 Aug 2018	3 Oct 2018
Gypsum	0.0	1.1
No Gypsum	4.0	1.1

Impacts of gypsum soil amendments at the blueberry research farm. Percent root infection with *P. cinnamomi* assessed three times during the 2018 growing season indicated relatively low overall disease incidence. No significant differences in root rot incidence between gypsum treated and untreated plots were noted in 2018; however, there was a significant fungicide

x cultivar interaction, and fungicide and cultivar both had a significant effect on root rot incidence (**Table 5**). In 2019, no significant differences in root rot incidence were noted between gypsum treated and untreated plots or between fungicide treated and untreated plots (**Table 6**); however, cultivar had a significant effect on root rot incidence with relatively higher root rot incidence in 'Farthing' versus 'Emerald'. Plant growth was assessed from 9 May to 31 October 2018 at the blueberry research field experiment site and relatively poor growth was noted during the course of the 2018 season (data not shown). In 2019, differences in plant growth between cultivars were noted, with 'Emerald' being numerically taller and larger than 'Farthing' at the conclusion of the experiment; however, gypsum and fungicide treatment did not have a significant effect on plant growth (**Table 7**). Taken together, these results suggest that gypsum soil amendments did not have a notable effect on root rot incidence and plant growth in this field experiment.

Table 5. Root infection in 2018 at the blueberry research farm site by *P. cinnamomi* for (a) fungicide x cultivar, (b) cultivar, and (c) fungicide.

(a)	Root infection by *P. cinnamomi* (%)
No Fungicide+Farthing	7.0 a
No Fungicide+Emerald	0.4 b
Fungicide+Emerald	0.3 b
Fungicide+Farthing	0.3 b

(b)	Root infection by *P. cinnamomi* (%)
Farthing	2.2 a
Emerald	0.3 b

(c)	Root infection by *P. cinnamomi* (%)
No Fungicide	2.4 a
Fungicide	0.3 b

Different letters represent significant differences between means at $P < 0.05$ (LS Means in Proc GLIMMX in SAS)

Table 6. Root infection in 2019 at the blueberry research farm site by *P. cinnamomi*

		Root infection by *P. cinnamomi (%)*		
Treatment	Cultivar	5 Apr 2019	3 Oct 2019	13 Nov 2019
Untreated	Emerald	0.0	2.2	3.3
No Gypsum+Fungicide	Emerald	0.0	0.0	1.1
Gypsum+No Fungicide	Emerald	0.0	0.0	0.0
Gypsum+Fungicide	Emerald	0.0	0.0	0.0
Untreated	Farthing	8.9	1.1	1.1
No Gypsum+Fungicide	Farthing	2.2	2.2	1.1
Gypsum+No Fungicide	Farthing	12.2	0.0	0.0
Gypsum+Fungicide	Farthing	2.2	7.8	1.1

Treatment not significant at $P < 0.05$.

Table 7. Final height and dry weight results from blueberry research farm site.

			Dry Weight (g/plant)			
Treatment	Cultivar	Height (cm)	Shoot	Root	Total	Root:Shoot
Untreated	Emerald	94.7a	285.0a	222.8a	507.8a	0.79bc
No Gypsum+Fungicide	Emerald	82.1ab	154.8ab	122.6b	277.4b	0.84abc

Gypsum+No Fungicide	Emerald	76.8b	153.9ab	119.2b	273.1b	0.79bc
Gypsum+Fungicide	Emerald	75.9b	185.4ab	136.4b	322.8ab	0.76c
Untreated	Farthing	46.2c	55.5b	63.0b	118.5b	1.16a
No Gypsum+Fungicide	Farthing	52.9c	180.4ab	94.1b	274.5b	0.89abc
Gypsum+No Fungicide	Farthing	44.7c	63.4b	67.1b	130.5b	1.12ab
Gypsum+Fungicide	Farthing	53.2c	80.0b	71.8b	151.9b	0.90abc

Different letters represent significant differences between means at P<0.05 according to Tukey's HSD.

Impacts of gypsum soil amendments on potted blueberries in the greenhouse. One greenhouse experiment was carried out and a second greenhouse experiment is currently underway. At the conclusion of the first greenhouse experiment, there was very low incidence of detectable *P. cinnamomi* despite the addition of inoculum twice during the experiment (**Table 8**); in fact, only two of the four treatments that received *P. cinnamomi* had a detectable incidence. During the experiment, assessment of flow-though water did not indicate any notable impact of gypsum on water retention, pH, or EC (mS/cm & ppm) (**Tables 9 & 10**), nor did gypsum soil amendments have an impact on plant growth (**Table 11**). Treatments that were inoculated with *P. cinnamomi* did show numerically reduced heights and sizes, but these reductions were not statistically significant. As a whole, the results from the first greenhouse experiments supported the conclusions from the field experiments that gypsum soil amendments did not have a notable effect on root rot incidence or plant growth.

Table 8. Root infection by *P. cinnamomi* in greenhouse experiment #1.

	Cultivar	Root infection by *P. cinnamomi (%)*
Untreated	Emerald	0.00
Gypsum+No Phytophthora	Emerald	0.00
Gypsum+Phytophthora	Emerald	0.00
No Gypsum+Phytophthora	Emerald	1.11
Untreated	Farthing	0.00
Gypsum+No Phytophthora	Farthing	0.00
Gypsum+Phytophthora	Farthing	3.33
No Gypsum+Phytophthora	Farthing	0.00

Table 9. Soil properties, pH and EC (mS/cm and ppm), results from greenhouse trial 1 at 28, 81, & 132 dpi.

					EC					
		pH			mS/cm			ppm		
Treatment	Cultivar	28 dpi	81 dpi	132 dpi	28 dpi	81 dpi	132 dpi	28 dpi	81 dpi	132 dpi
Soil		4.27b	5.58 cd	6.24 b	0.06 d	0.03 c	0.10 a	47.0de	33.8c	80.6a
Soil W/Gypsum		4.07bc	4.88 e	6.02 cd	0.21 cd	0.01 d	0.04 b	156.3cd	17.2d	35.8b
Untreated	Emerald	3.87cd	5.72 bc	6.11 bc	0.47 ab	0.05 ab	0.12 a	341.3ab	45.0ab	89.7a
Gypsum+No Phytophthora	Emerald	3.87cd	5.75 bc	6.22 b	0.53 ab	0.06 ab	0.13 a	378.3ab	47.8ab	102.7a
Gypsum+Phytophthora	Emerald	3.60de	5.82 b	6.10 bcd	0.62 a	0.06 a	0.14 a	448.7a	50.8a	102.7a
No Gypsum+Phytophthora	Emerald	3.80cd	5.47 d	5.95 d	0.37 bc	0.04 bc	0.12 a	270.0bc	40.7bc	88.0a
Untreated	Farthing	4.00bc	5.82 b	6.22 b	0.45 ab	0.05 ab	0.12 a	320.7ab	43.0abc	93.2a
Gypsum+No Phytophthora	Farthing	3.63de	5.85 b	6.17 bc	0.52 ab	0.06 ab	0.13 a	375.3ab	47.7ab	97.2a
Gypsum+Phytophthora	Farthing	3.43e	5.37 d	5.78 e	0.53 ab	0.05 ab	0.13 a	378.0ab	44.8ab	100.3a
No Gypsum+Phytophthora	Farthing	3.83cd	5.78 bc	6.12 bc	0.38 bc	0.06 ab	0.13 a	273.0bc	47.2ab	97.7a

DI Water	6.00a	7.00 a	6.97 a	0.00 d	0.00 c	0.00 c	0.0e	0.0e	1.0c
	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001
Rsq	0.961	0.867	0.797	0.771	0.712	0.670	0.777	0.777	0.070
LSD	0.28	0.22	0.16	0.22	0.01	0.03	153.3	9.3	23.6

Table 10. Soil properties results of flow through from greenhouse trial 1.

		Water flow through (mL)		
Treatment	Cultivar	10 May 2019	3 Jul 2019	22 Aug 2019
Soil		291.7 ab	417.0 abc	422.0 ab
Soil W/ Gypsum		388.3 a	545.0 a	474.0 a
Untreated	Emerald	316.7 ab	433.3 ab	345.0 ab
Gypsum+No Phytophthora	Emerald	316.7 ab	443.3 ab	314.2 ab
Gypsum+Phytophthora	Emerald	275.0 ab	337.5 bc	344.2 ab
No Gypsum+Phytophthora	Emerald	248.3 b	271.7 c	276.7 b
Untreated	Farthing	328.3 ab	460.0 ab	372.0 ab
Gypsum+No Phytophthora	Farthing	328.3 ab	400.8 abc	330.8 ab
Gypsum+Phytophthora	Farthing	271.7 ab	334.2 bc	295.8 b
No Gypsum+Phytophthora	Farthing	256.7 ab	360.0 bc	309.2 ab

Different letters represent significant differences between means at P<0.05 according to Tukey's HSD.

Table 11. Shoot and root dry weight results from greenhouse experiment.

			Dry Weight (g/plant)			
Treatment	Cultivar	[x]AUGPC	Shoot	Root	Total	Root:Shoot
Untreated	Emerald	5251.7 a	64.1 a	22.3 a	86.4 a	0.35 a
Gypsum+No Phytophthora	Emerald	4624.3 a	67.0 a	24.1 a	91.1 a	0.37 a
Gypsum+Phytophthora	Emerald	4071.2 a	46.2 a	14.2 a	60.5 a	0.31 a
No Gypsum+Phytophthora	Emerald	4366.2 a	51.8 a	21.6 a	73.4 a	0.39 a
Untreated	Farthing	5317.3 a	67.2 a	29.8 a	97.0 a	0.43 a
Gypsum+No Phytophthora	Farthing	5976.4 a	61.6 a	27.7 a	89.3 a	0.45 a
Gypsum+Phytophthora	Farthing	5010.7 a	42.1 a	16.7 a	58.8 a	0.39 a
No Gypsum+Phytophthora	Farthing	4948.7 a	54.8 a	20.8 a	75.6 a	0.37 a

[x]Area Under the Growth Progress Curve (AUGPC) calculated based upon measured plant heights measured weekly throughout the course of the greenhouse experiments.
Different letters represent significant differences between means at P<0.05 according to Tukey's HSD.

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