Preliminary and Regional Reports

A High Incidence of *Pythium* and *Phytophthora* Diseases Related to Record-breaking Rainfall in South Florida

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SUMMARY. **Florida's ornamental plant industry flourishes due to environmental conditions that allow for a 12-month growing season. Florida leads the nation in production of tropical foliage, and Miami-Dade County ranks number one in nursery and landscape production with sales reaching $2 billion annually. The well-advertised El Niño pattern made its presence felt this past winter in south Florida with the wettest conditions since record keeping began in 1932. As a result, ornamental nursery growers contended with a higher incidence of root rots, crown rots, and foliar blight diseases, confirmed by samples submitted to the University of Florida's Extension Plant Diagnostic Clinic in Homestead, FL. The present study focused on environmental conditions occurring over the past 4 years and included rainfall, solar radiation, and temperature variables and examined their influence on the incidence of diseases affecting ornamental plants. Results indicated *Pythium* and *Phytophthora* species as the primary plant pathogens responsible for these diseases. The drastic increase of diagnostic samples identified as *Pythium* and *Phytophthora* can be attributed to the unusually wet weather experienced. These two oomycetes are well known for causing disease under wet conditions and growers should closely monitor weather forecasts and practice preventative disease management accordingly.**

According to Baker and Linderman (1979), the more difficult a crop is to grow, the higher its value, the greater is the investment risk involved, and the fewer the growers who will successfully produce it. Ornamental plants showing any indication of disease are not acceptable, since they are grown primarily for aesthetics and high market quality standards. The environmental conditions that typically favor nursery production can also affect the quality and health of plant products. For instance, warm temperatures and high relative humidity are both conducive for proper plant growth and development of tropical foliage, but these conditions are also favorable for many disease-causing organisms.

Ordinary weather in south Florida is divided by two seasons: the 5-month rainy season from June to October, when 70% of the year's rain falls, and the 7-month dry season from November to May, also known as winter season [South Florida Water and Management District (SFWMD), 2013].

This past dry season (2015–16) was greatly influenced by El Niño, which is the warm phase of the El Niño/Southern Oscillation. El Niño winters typically bring increased episodes of cloudy, wet, and stormy weather to south Florida. Unfortunately, these environmental conditions are highly favorable for disease. Two predominant waterborne pathogens reported during the unusual wet "dry" season were *Pythium* and *Phytophthora*. Both are water molds meaning that both are ecologically favored by free water in soil and on foliage (Erwin and Ribeiro, 1996). Several other important waterborne diseases of ornamentals can be listed, but this initial research report focused on the genera *Pythium* and *Phytophthora* to underline the importance of variability and unpredictable weather conditions in high intense production areas of ornamental crops in Florida.

This study addresses the incidence of *Pythium* and *Phytophthora* affecting ornamental crops and the relationship with environmental conditions such as rainfall, solar radiation, relative humidity, and temperature occurring over the past four dry seasons.

Materials and methods

DATA COLLECTION. All plant disease diagnostic data were obtained from the University of Florida's Extension Plant Diagnostic Clinic located at the Tropical Research and Education Center (TREC) in Homestead, FL. The diagnostic data used for the present study comes from plant disease samples that were submitted during the dry season occurring from 1 Oct. to 1 Mar. over a 4-year period (2012–16). Environmental data were collected

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1	ppm	mg·L^{-1}	1
10.7639	W/ft^2	W·m^{-2}	0.0929
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

over the same period. Environmental data included average rainfall in inches taken at 2 m height, average solar radiation in watts per square meter taken at 2 m height, average temperature in Fahrenheit taken at 60 cm height, and average dew point value in Fahrenheit taken at 2 m height using the weather station located at the TREC (lat. 25°30′40.809″N, long. 80°30′3.983″W) and obtained from the Florida Automated Weather Network (FAWN) website (Lusher et al., 2008). Overall values for each environmental condition were calculated as a mean accumulation based on daily recordings from the selected dates.

Pathogen identification. Many diseased samples initially suspected for *Phytophthora* were tested using commercially available immunostrips (ImmunoStrip®; Agdia, Elkhart, IN). Due to the potential of a cross reaction with some *Pythium* species, all samples were processed in the following manner. Plant tissue showing any indication of rot or appearing water soaked and discolored, including roots, stems, petioles, and leaves, were washed in autoclaved distilled water for 2 min. Then the tissues were sectioned into 10 pieces about 1 cm in size, blotted dry on clean paper towels, and plated on a selective medium for isolating *Pythium* and *Phytophthora*. The select medium contained 10 $mg \cdot L^{-1}$ pimaricin, 25 $mg \cdot L^{-1}$ ampicillin, 50 $mg \cdot L^{-1}$ rifampicin, and 100 $mg \cdot L^{-1}$ pentachloronitrobenzene (Kannwischer and Mitchell, 1978). Cultures were stored at 25 °C in the dark for a minimum of 5 d. Identification to genus was accomplished by observing morphological characteristics of asexual and sexual structures using light microscopy (Laborlux; Leitz, Wetzlar, Germany) for either *Phytophthora* (Erwin and Ribeiro, 1996; Stamps et al., 1990) or *Pythium* (Dick, 1990; van der Plaats-Niterink, 1981).

Statistical analysis. The incidence of diagnostic samples testing positive for *Pythium* and *Phytophthora*, and the average of different environmental parameters (rain, temperature, solar radiation, dew point, and relative humidity) were analyzed. Comparisons using analysis of variance (ANOVA) and Pearson correlations were calculated with SAS software (version 9.4; SAS Institute, Cary, NC).

Results and discussion

The existence of a plant disease caused by a biotic agent requires the interaction of three components called the disease triangle: a susceptible host, a virulent pathogen, and an environment favorable for disease development (Agrios, 2005). Changes in weather are considered stress factors affecting the incidence of many crop diseases (Schoeneweiss, 1975). Heavy rainfall and severe weather conditions are known to provide a window of opportunity for diseases caused by oomycetes such as *Pythium* and *Phytophthora* (Bostock et al., 2014). Unusual conditions related to El Niño phase were observed in south Florida during the corresponding 2015–16 wet "dry" season where data from the study period (1 Oct. to 1 Mar.) showed an average rainfall of 0.157 inch compared with previous dry season values ranging from 0.046 to 0.097 inch (Table 1). For instance, daily data for Dec. 2015, showed two consecutive highest rainfall peaks up to 3.71 and 3.08 inches corresponding to the third and fourth day of the month, respectively (FAWN). SFWMD documented its wettest January since record keeping began in 1932, characterized by at least twice the normal rainfall amount, with some areas receiving up to six times more above normal values (Miami-South Florida National Weather Service, 2016). Corresponding January rainfall values from 2013 to 2015 were 0.005, 0.096, and 0.009 inches and as much as twice during the presence of El Niño in 2016 (0.212 inch) (FAWN).

Plant disease data analyses from the TREC Extension Plant Diagnostic Clinic indicated an unusually high incidence (12.5%) of diseases caused by *Pythium* and *Phytophthora* affecting ornamental crops during the 2015–16 wet "dry" season (63 out of 503 samples) in comparison with the three previous years combined showing a lower average of 3.3% [from a range of 16–17 out of 420–556 samples (Table 2)]. The majority of ornamental disease samples originated from containerized commercial nurseries within Miami-Dade County, which is Florida's top ornamental plant production area within the state (Hodges et al., 2015).

The plant disease data indicate a 4.2% increase in the incidence of *Pythium* (21 samples/wet "dry" season) and 8.3% for *Phytophthora* (42 samples/wet "dry" season) during 2015–16 when compared with the three previous years combined (2012–15), which was an average of 2.3% for *Pythium* (12 samples/dry season) and 1.0% for *Phytophthora* (6 samples/dry season) (Table 2).

The ANOVA showed the number of positive samples during the unusual wet "dry" season 2015–16 was statistically higher than the three previous dry seasons combined [P = 0.07 (Table 3)]. This can be attributed to the high amount of rainfall compared

Table 1. Average values for rainfall, solar radiation, temperature, dew point, and relative humidity over the dry season (1 Oct. to 1 Mar.) covering a 4-year period from 2012 to 2016 collected from Florida Automated Weather Network (FAWN) for Homestead, FL.

	Dry season			
Avg/dry season[z]	2012–13	2013–14	2014–15	2015–16
Rainfall (inches)	0.046	0.097	0.047	0.157
Solar radiation ($W \cdot m^{-2}$)	155.9	141.6	156.3	144.2
Temperature (°F)	70.5	72.3	69.8	72.6
Dew point (°F)	64.6	67.1	63.7	67.2
Relative humidity (%)	83.0	84.9	82.6	84.2

[z]1 inch = 25.4 mm, 1 $W \cdot m^{-2}$ = 0.0929 W/ft^2, (°F–32) ÷ 1.8 = °C.

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Table 2. Number of samples and percentages in brackets submitted at the University of Florida/IFAS Tropical Research and Education Center (TREC) Extension Plant Diagnostic Clinic located at Homestead, FL, over the dry season (1 Oct. to 1 Mar.) covering a 4-year period from 2012 to 2016.

	Dry season			
	2012–13	2013–14	2014–15	2015–16
Sample description	Samples/dry season [no. (%)]			
Pythium[z]	13 (2.5)	10 (2.4)	11 (2)	21 (4.2)
Phytophthora[y]	4 (0.6)	6 (1.4)	6 (1.1)	42 (8.3)
Phytophthora foliar blight[x]	1 (0.1)	1 (0.2)	1 (0.2)	7 (1.4)
Phytophthora stem and root rot[w]	3 (0.5)	5 (1.2)	5 (0.9)	35 (6.9)
Oomycetes[v]	17 (3.1)	16 (3.8)	17 (3.1)	63 (12.5)
Other diagnosed samples[u]	501 (96.9)	404 (96.2)	539 (96.9)	440 (87.5)
Total samples	518	420	556	503

[z]Samples for *Pythium* basal stem and root rot.
[y]Samples for *Phytophthora*; foliar blight, and stem and root rot.
[x]Samples for *Phytophthora* foliar blight.
[w]Samples for *Phytophthora* stem and root rot.
[v]Combination of samples of *Pythium* and *Phytophthora*.
[u]Samples submitted and diagnosed for other pathogens except *Pythium* and *Phytophthora* and/or abiotic disorders.

Table 3. Analysis of variance for years and *Pythium* and *Phytophthora* samples submitted over the dry season (1 Oct. to 1 Mar.) 2012–16.

Source	df	SS[z]	MS[z]	*F*	*P*
Model	1	431435563	431435563	4.5	0.07[y]
Error	6	568764447	94794074		
Corrected total	7	1000200010			
Root MSE[z]	9736.2	R^2	0.43		
Dependent mean	20137015	Adjusted R^2	0.33		
CV[z]	0.04				

[z]SS = sum of squares; MS = mean square; MSE = mean square error; CV = coefficient of variation.
[y]Significant at $P \leq 0.10$.

with previous years (Fig. 1), because there was a positive correlation with the incidence of *Pythium* and *Phytophthora* samples and the amount of rainfall [*P* = 0.01 (Table 4)].

In the present study, diseases caused by *Phytophthora* were more common than *Pythium* in ornamental nursery crops, which is of great relevance due to the potential of *Phytophthora* as an important pathogen in a wide range of ornamental crops (Erwin and Ribeiro, 1996; Patel et al., 2016).

Phytophthora has been previously reported as one of the most common and damaging pathogens associated with ornamental plant production in Florida (Patel et al., 2016).

There has been an increase of 6.9% of positive samples for *Phytophthora* stem and root rot during the wet "dry" season compared with an average of 0.8% over 3 years combined 2012–15 (Fig. 1; Table 2). Excessive irrigation and rainfall are often the most important factors that increase the severity and spread of *Phytophthora* diseases (Erwin and Ribeiro, 1996). Ornamental nurseries in south Florida generally use overhead systems instead of drip irrigation for water supplement, which adds to the spread of oomycetes in nearby crops. Excessive amounts of rainfall lead to localized flooding affecting both field grown and containerized ornamental crops. Flooded soil conditions often lead to the development of root rot by increasing the activity of soil fungi and oomycetes as well as susceptibility of the host (Kozlowski, 1997).

The inoculum that initiates disease for both *Pythium* and *Phytophthora*, which causes foliar as well as root diseases, increases from very low often undetectable levels to high levels within a few days. Long periods of leaf wetness brought on by overhead irrigation and heavy rains provide favorable conditions for foliar disease outbreaks (Erwin and Ribeiro, 1996). Rain and wind blown rain are also very important for the dissemination of these pathogens as the sporangia can be splashed or blown in water to nearby plants. Sporangia release short-lived, one-celled, flagellated zoospores that can swim through thin films of water on leaf surfaces or in water-filled soil pores and can accumulate in puddles and ponds (Fry and Grünwald, 2010).

Rainfall and the presence of temperatures between 15 and 20 °C were reported to be optimal for hyphal growth, sporulation, and infection for *Phytophthora* species (Eyre and Garbelotto, 2015; Fry et al., 2015; Yakabe et al., 2009). However, in this study, an average of 22.6 °C was present during the wet "dry" season compared with a range of 20.9 to 22.4 °C for the other dry seasons analyzed. Similar results were found at containers mixes from ornamental crop nurseries in North Carolina where *Phytophthora* was more frequently detected at 20 and 25 °C than at 15 °C (Ferguson and Jeffers, 1999). This supports the fact that temperature has no major role in the incidence of these two oomycetes in this initial south Florida report.

Table 5 shows the host range of plant samples diagnosed positive for *Pythium* or *Phytophthora* during the 4-year period. For *Pythium* diseases the number of host remained at 11 susceptible host plants during the 4-year period with a new host range for the wet "dry" season such as wild date palm (*Phoenix sylvestris*) and syngonium (*Syngonium podophyllum*) (Table 5). For *Phytophthora*, there were twice as many host plants during wet "dry" season 2015–16 (Table 5) and this was statistically greater when compared with the other years [*P* = 0.07 (Table 3)]. A survey to query the ranking of plant-pathogenic oomycete taxa based on scientific and economic importance showed *Phytophthora* was in 6 out the top 10 species, more commonly studied among oomycetes (Kamoun et al., 2015). Common diseases of ornamentals crops caused by *Phytophthora* in south Florida include stem and foliar blight of english ivy (*Hedera helix*); root, stem, and foliar blight of pothos (*Epipremnum aureum*) and peperomia (*Peperomia* sp.); root, crown, and foliar blight of spathiphyllum (*Spathiphyllum* sp.); stem rot of dieffenbachia (*Dieffenbachia* sp.); and foliar blight and root rot of anthurium (*Anthurium* spp.) and mandevilla (*Mandevilla* sp.) (TREC Plant Diagnostic Clinic,

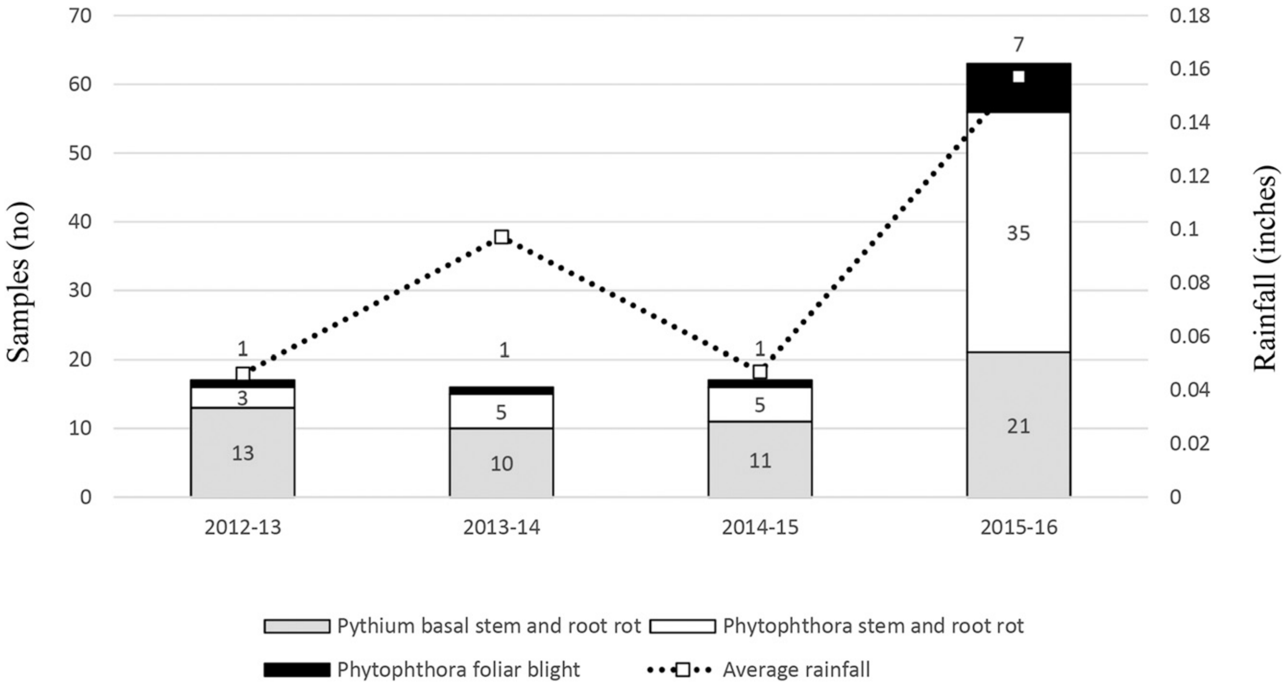

Fig. 1. Comparison between amount of average rainfall per dry season (1 Oct. to 1 Mar.) covering a 4-year period from 2012 to 2016 vs. the number of samples identified positives for *Pythium* and *Phytophthora* for ornamental plants in south Florida. Black bars represent samples diagnosed as *Phytophthora* foliar blight, white bars are for *Phytophthora* stem and root rot, and gray bars are for *Pythium* basal stem and root rot. Black dash line represents average rainfall; 1 inch = 25.4 mm.

Table 4. Analysis of variance for rainfall and *Pythium* and *Phytophthora* samples submitted over the dry season (1 Oct. to 1 Mar.) 2012–16.

Source	df	SS[z]	MS[z]	F	P
Model	1	0.0104	0.0104	10.03	0.01[y]
Error	6	0.0062	0.0010		
Corrected total	7	0.0166			
Root MSE[z]	0.0322	R^2	0.6258		
Dependent mean	0.0868	Adjusted R^2	0.5634		
CV[z]	37.0867				

[z]SS = sum of squares; MS = mean square; MSE = mean square error; CV = coefficient of variation.
[y]Significant at $P \leq 0.10$.

2010). Mandevilla is one of the common ornamental plants produced in south Florida and remains highly susceptible to *Phytophthora*. In fact, a recent publication focusing on *Phytophthora* species affecting ornamentals in Florida indicated mandevilla is susceptible to both *Phytophthora palmivora* and *Phytophthora nicotianae* (Patel et al., 2016).

In addition to the hosts listed in Table 5, new diseases reported in south Florida include a foliar blight of the zz plant (*Zamioculcas zamiifolia*) and 'Petra' croton (*Codiaeum variegatum*) caused by *P. nicotianae*, and a root and basal rot of echeveria (*Echeveria* sp.) caused by *Pythium myriotylum* (Sanahuja et al., 2016a, 2016b; Suarez et al., 2016). These new and newly emerging diseases are affecting popular plants for use in the interior scape and house plant industry, which remain economically important.

A recent study by Weiland et al. (2015) showed the impact of unintentionally introducing oomycetes by transporting nursery stock and provides direct evidence that new species and isolates of *Pythium* were moved among forest nurseries of the Pacific northwestern United States. Based on this initial report, we strongly believe that there are opportunities for further studies on the variability of *Pythium* and *Phytophthora* communities among nurseries in the southeastern United States and the differences among diversity based on years of sampling.

Results from this preliminary study have important implications for the ornamental industry. The latest industry report indicates losses as great as 70% during this unusual wet "dry" season (Greenhouse Grower, 2015). This study provides an initial insight into the role of one or more environmental conditions in combination with susceptible hosts and virulent pathogens.

Conclusions

To our knowledge, this is the first study focused on *Pythium* and *Phytophthora* and El Niño phase-related weather conditions. There was a positive correlation between incidence of these two economically important plant pathogens and the average daily amount of rainfall for south Florida during the dry season periods ranging from 2012 to 2016. The ornamental industry has exceedingly high standards for plant quality and there is often a zero tolerance for disease symptoms caused by plant pathogens. Ornamental producers and landscape professionals should practice routine scouting for root rot, crown rot, and foliar blight diseases. Diseases caused by *Pythium* and *Phytophthora* are notably fast acting and

Table 5. List of ornamental crops diagnosed for *Pythium* and *Phytophthora* in this study between the dry seasons (1 Oct. to 1 Mar.) covering a 4-year period from 2012 to 2016. Values in brackets correspond to numbers of ornamental crops showing positive for each disease per dry season.

Pathogen	2012–13	2013–14	2014–15	2015–16	
Pythium	Sugar apple (*Annona squamosa*)	Aglaonema (*Aglaonema* sp.) [2]	Poinsettia	Aglaonema	
	Eugenia (*Eugenia* sp.)	Firecracker flower (*Crossandra infundibuliformis*)	Hibiscus	Norfolk island pine (*Araucaria heterophylla*)	
	Poinsettia (*Euphorbia pulcherrima*) [2]	Poinsettia	Mandevilla (*Mandevilla* sp.)	Pigeon plum (*Coccoloba diversifolia*)	
	Gardenia (*Gardenia jasminoides*)	Hoya (*Hoya carnosa*)	Pedilanthus (*Pedilanthus tithymaloides*)	Echeveria (*Echeveria* sp.) [7]	
	Hibiscus (*Hibiscus* sp.)	Holly (*Ilex aquifolium*)	Mondo grass [7]	Poinsettia	
	New guinea impatiens (*Impatiens hawkeri*) [2]	Petunia (*Petunia* sp.)		Privet	
	Ixora (*Ixora coccinea*)	Purpleheart (*Setcreasea pallida*)		Mondo grass [6]	
	Mondo grass (*Ophiopogon japonicus*)	Florida arrowroot		Wild date palm (*Phoenix sylvestris*)	
	Privet (*Ligustrum* sp.)	Mondo grass		Dusty miller (*Senecio cineraria*)	
	Pittosporum (*Pittosporum tobira*)			Syngonium (*Syngonium podophyllum*)	
	Florida arrowroot (*Zamia integrifolia*)				
Phytophthora	Privet	Allamanda (*Allamanda* sp.)	Barbados aloe (*Aloe barbadensis*)	Desert rose (*Adenium obesum*)	Pothos (*Epipremnum aureum*) [2]
	Liriope (*Liriope muscari*)	Dracaena (*Dracaena* sp.)	Liriope	Bromeliad aechmea (*Aechmea fasciata*)	Ficus (*Ficus* sp.) [6]
	Mandevilla (*Mandevilla* sp.)	Bromeliad (*Guzmania* sp.)	Mandevilla [3]	Snapdragon (*Antirrhinum* sp.)	Gardenia
	Madagascar jasmine (*Stephanotis floribunda*)	New guinea impatiens	Pandanus (*Pandanus* sp.)	Yesterday-today-and-tomorrow (*Brunfelsia grandiflora*)	Liriope
		Mandevilla [2]		Boxwood (*Buxus sempervirens*)	Mandevilla [12]
				Chamaedorea (*Chamaedorea* sp.)	Mondo grass
				Clusia (*Clusia* sp.)	Schefflera (*Schefflera* sp.)
				Cordyline (*Cordyline* sp.)	Spathiphyllum (*Spathiphyllum* sp.)
				Dianthus (*Dianthus* sp.)	Windmill palm (*Trachycarpus fortunei*)
				Dieffenbachia (*Dieffenbachia* sp.) [2]	Viola (*Viola* sp.)
				Dracaena [3]	Zz (*Zamioculcas zamiifolia*)

require preventative pesticide applications when weather forecast is for heavy rains. Preventative measures to avoid the establishment and dispersal of these pathogens are crucial for effective disease management.

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