Role of *Pythium* in Sugarcane Stubble Decline: Effects on Plant Growth in Field Soil

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ABSTRACT

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Sugarcane plants grown in sugarcane field soil treated with methyl bromide or metalaxyl showed significant increases in several components of root and shoot growth as compared with plants treated with fosetyl-Al or grown in untreated field soil. Metalaxyl applied at two rates completely controlled root rot caused by *Pythium arrhenomanes* in a pathogenicity test. In field experiments, significant yield increases were obtained in ratoon crops in metalaxyl-treated plots compared with untreated plots of two sugarcane cultivars. Experimental results suggest that *P. arrhenomanes* functions as a cryptic pathogen and causes significant reductions in sugarcane plant growth in field soil. These findings are discussed with respect to a syndrome in sugarcane known as stubble decline.

Additional keywords: cryptic disease, feeder root necrosis.

Pythium root rot was determined to be one of the major factors responsible for the failure of cultivars of *Saccharum officinarum* L. in Louisiana during the 1920s (18,36). Extensive research indicated that *Pythium arrhenomanes* Drechs. was the principal causal agent of sugarcane root rot (36). Low temperatures and high soil moisture were demonstrated to be conducive to disease development (22,44). The severity of Pythium root rot subsequently was reduced by the introduction of more tolerant interspecific hybrid cultivars of *Saccharum* (36).

Sugarcane is vegetatively propagated, and several successive annual cuttings are obtained from one planting. Ratoon or stubble crops develop from buds remaining on the basal portions of plants left in the soil after harvest. In Louisiana, the crop cycle is limited to the plant cane crop and two ratoon or stubble crops by a complex syndrome known as stubble decline. Factors thought to be associated with stubble decline include low winter temperatures and freezes, poor soil aeration and drainage, the physiological maturity of cane plants at the time of harvest, the condition of the stubble root system (affected by cultural practices and Pythium root rot), a stalk rot caused by *Glomerella tucumanensis* (17,19,36), single and combined effects of ratoon stunting disease caused by *Clavibacter xyli* subsp. *xyli* (16), and sugarcane mosaic virus (29,30,41).

A second phase of research concerning Pythium root rot of sugarcane centered around descriptions and field surveys of soil microorganisms antagonistic to *P. arrhenomanes* (9,13,27,31), and biological control of root rot was demonstrated in plants grown in

sterile soil amended with antagonistic microorganisms and inocula of *Pythium* (27). Results from these studies suggested that antagonistic soil microorganisms limit the severity of root rot in sugarcane soils, and, initially, severe root rot could not be obtained in greenhouse experiments employing nonsterile field soils (27). However, in later tests, plants grown in nonsterile soil exposed to flooding periods of up to 72 hr developed severe root rot (44). In India, field resistance and susceptibility shown by two different cultivars were demonstrated to be associated with differences in the composition of the rhizosphere microorganism population associated with each cultivar in the field (39).

The development of resistant cultivars, the apparent antagonism of numerous microorganisms to *P. arrhenomanes*, and improvements in surface drainage are all factors believed to have reduced the importance of Pythium root rot. As a result, it currently is considered to be a disease capable of causing injury to plants mainly during cold, wet winters (33).

The occurrence of excess soil moisture during the winter was correlated with low sugarcane stubble crop yields in Louisiana (5), and subsurface drainage during the winter has been demonstrated to contribute to significant increases in stubble crop yields (6,7). This information suggests that *Pythium* spp. might play a more significant role in stubble decline than currently is recognized. In addition, Pythium root rot has been demonstrated to be a factor in a serious disease complex of sugarcane in Australia known as poor root syndrome (14,20). Finally, *Pythium* spp. recently have been implicated in yield decline or replant diseases of numerous crops (10,11,12,23,24,35,37,38,40,43), including wheat (10,11,12) and corn (43), in which obvious symptoms are not apparent.

All of the evidence presented above prompted a reinvestigation of the effects of *Pythium* spp. on the growth of sugarcane in Louisiana. Results from pathogenicity tests indicated that *Pythium* spp., particularly *P. arrhenomanes*, can significantly reduce the growth of current Louisiana sugarcane cultivars (26). The severity of root rot symptoms that developed in pathogenicity tests under disease-conducive conditions probably would result in stand failures in the field. Inasmuch as this does not occur, experiments were conducted to determine the effects of *Pythium* spp. on the growth of sugarcane plants in field soil, and the results are presented here. A portion of these results was presented previously (25).

MATERIALS AND METHODS

Pesticide treatment of sugarcane plants and field soil. Three experiments were conducted with a silt loam soil collected from sugarcane fields at the LSU St. Gabriel Branch Experiment Station. Soil was sieved through a 1-cm-mesh screen and mixed with sterile sand to a final soil:sand ratio of 2:1 (v/v). Inorganic nutrients were provided by the addition of a 4-mon slow-release fertilizer (Osmocote, Sierra Chemicals, San Jose, CA). Two experiments were conducted in 19-L plastic pots, and a third experiment was conducted in 58.6-L rubber tubs.

Pesticides used as experimental treatments included a broad spectrum fumigant, methyl bromide/2% chloropicrin (MC-2 Dowfume, Dow Chemical Co., Midland, MI), and two pesticides specific for pythiaceous fungi, metalaxyl (Ridomil, Ciba Geigy, Greensboro, NC) and fosetyl-Al (Aliette, Rhone-Poulenc Inc., Monmouth, NJ). Controls consisted of plants grown in untreated field soil. Methyl bromide-chloropicrin was applied in all three experiments at a rate of 40 ml per 58.6 L of soil in sealed cans. Cans were kept sealed for 1 wk, then the fumigant was allowed to disperse from the can for 1 wk and for an additional 2 wk in pots before planting. Metalaxyl was applied at a rate of 0.075 ml of a.i. (0.3 ml of 25% a.i. liquid) per 19 L of soil in one experiment, and at a similar rate of 0.25 ml of a.i. (1.0 ml of 25% a.i. liquid) per 58.6 L of soil in the third experiment. Fosetyl-Al was applied at a rate of 0.56 g of a.i. (0.7 g of 80% a.i. crystalline solid) per 19 L of soil in one experiment, and at a rate of 1.0 g of a.i. per 58.6 L of soil in 500 ml of deionized water. Fosetyl-Al was drenched over the plant top and root system at planting. Repeat treatments of metalaxyl and fosetyl-Al were applied at the same rates at 30-day intervals.

Plants of sugarcane cultivar CP 70-321 were obtained from single-bud cuttings as described previously (26). Three-wk-old plants were transplanted (one plant per pot), and each treatment was replicated five times.

In the experiment conducted in 58.6-L tubs, shoots were removed from plants after 115 days, and the plants were allowed to ratoon. The stubble regrowth was harvested 98 days after topping. Each time the shoots were removed, the number of shoots per plant was recorded, and the shoots of each plant were individually bagged, dried, and weighed. To determine the treatment effects on root system development, two soil cores, 7.5 cm in diameter (810 cc each), were removed from each tub 109–114 days after planting. All root segments contained in the two cores from individual tubs were washed from the soil and collected on a 0.3-mm-mesh sieve. Lateral roots were removed from the primary roots, blotted dry, and weighed. Determinations were made of the total number, total length, and fresh weight of the primary root segments. This sampling and data collection process then was repeated just before harvesting stubble regrowth. In experiments conducted in 19-L pots, growth data were collected from entire root systems of individual plants washed free of soil.

At each sampling, 50 1-cm primary and lateral root segments from each plant were randomly selected, dipped in 70% ethanol, blotted dry with a paper towel, and pressed into pimaricin-vancomycin-pentachloronitrobenzene (PVP) medium (34). A quantitative estimate of root infection by *Pythium* spp. then was determined for each plant by counting the number of colonies developing from primary and lateral root sections after incubation for 24 and 48 hr.

Pathogenicity test with metalaxyl treatments. Two isolates of *P. arrhenomanes* (147 and 10-1) and single isolates of *P. irregulare* Buisman (6-2) and *P. dissotocum* Drechs. (7-1), previously isolated and tested for pathogenicity (26), were included in an experiment in which plants of cultivar CP 70-321 were transplanted into soil infested with a single isolate and then treated with metalaxyl or left untreated. Inoculum of each isolate was produced, and a 1:1 sterile soil:sand mix was infested as described previously (26). Three-wk-old plants were transplanted into 15-cm-diameter clay pots. Treatments consisted of plants growing in either untreated infested soil, infested soil drenched at the time of planting with 7.5 μl of a.i. metalaxyl (0.03 ml of 25% a.i. liquid) dissolved in 300 ml of water, or infested soil drenched with 37.5 μl of a.i. metalaxyl (0.15 ml of liquid formulation) dissolved in 300 ml of water. Plants treated with metalaxyl were retreated at the same rates after 54 days. Controls consisted of plants grown in unamended sterile soil:sand mix, and plants grown in sterile soil mix treated with high and low rates of metalaxyl. There were five replicates for each treatment.

After 86 days, the roots of all plants were washed free of soil, and total shoot number, shoot dry weight, primary root number, and root system dry weight were determined. In addition, subjective ratings for lateral root symptoms and root system discoloration were assigned for each plant. Ratings were made on a scale of 1–4, in which 1 = normal appearance and 4 = no lateral roots or severe discoloration. Twelve 1-cm-long root segments were collected from each plant and plated on PVP medium to reisolate *Pythium*.

Metalaxyl field experiments. Two sugarcane cultivars, CP 70-321 and CP 70-330, were planted during November 1984. Stalks of each cultivar were planted in five-row plots 4.3 m in length, with a 0.6 m unplanted gap between plots, at a rate of six 2-m stalks per plot row. Metalaxyl was applied at a rate of 280 g of a.i./ha (1 ml of 25% a.i. liquid dissolved in 2.8 L water/plot row) in a drench over the seed cane before covering and during spring 1985, 1986, and 1987 at a rate of 605 g of a.i./ha (14 g of 5% granular formulation per plot row) incorporated into the sides of rows with fertilizer (112.1 kg/ha of ammonium nitrate and 67.3 kg/ha of potash). The control consisted of fertilized, untreated plots. Each treatment was replicated six times, and plots were arranged in a completely randomized design. The field experiment was repeated twice.

Stalk counts were determined for each plot during August of each of three successive crop years. Stalk weight and sucrose content were determined for each plot from a randomly selected 15-stalk sample collected during November 1985 and 1986 and

October 1987. All five rows of each plot were treated with metalaxyl; however, data were collected from the center three rows of each plot and used to estimate tons of cane and kg of sucrose per hectare for both cultivars.

RESULTS

Effects of pesticide treatments on growth of sugarcane plants in field soil. Results from three experiments were similar. Data from the experiment conducted in 58.6-L pots are presented.

Plants grown in soil fumigated with methyl bromide showed large increases in growth as compared with control plants (Table 1 and Fig. 1). The only growth parameter that did not increase significantly was the average weight per centimeter of primary root in the final root sampling. Plants treated with metalaxyl showed increases in growth as compared with control plants for all parameters except for mean shoot number in the initial growth phase (Table 1). Significant increases were recorded in the initial growth phase in dry shoot weight, primary root weight, primary root number, and average weight per centimeter of primary root. In the stubble regrowth, significant increases occurred in shoot dry weight, primary root number, and lateral root weight (Table 1 and Fig. 1). Plants treated with fosetyl-Al showed significant increases in primary root number and lateral root weight as compared with control plants in the first sampling (Table 1).

Primary root infections by *Pythium* spp. from the first sampling were 1, 19, 46, and 24% for plants treated or grown in soil treated with methyl bromide, metalaxyl, fosetyl-Al, or untreated, respectively (LSD = 14.3, $P = 0.05$). The infection level for plants grown in fumigated soil was significantly less than that for control plants in both samplings, and the level of infection was significantly higher in plants treated with fosetyl-Al in the first sampling.

Lateral root infection levels were 2, 6, 30, and 13% in the first sampling (LSD = 15.4, $P = 0.05$), and 13, 3, 10, and 15% in the final sampling (LSD = 7.4, $P = 0.05$) for plants from the methyl bromide, metalaxyl, fosetyl-Al treatments, and control, respectively. The lateral root infection level was significantly lower for metalaxyl-treated plants in the final sampling, and the infection level in the fosetyl-Al treatment was significantly higher than the control in the first sampling.

Pathogenicity test with metalaxyl treatments. In the control treatment receiving no application of metalaxyl, two isolates of *P. arrhenomanes* caused severe symptoms, and each significantly reduced shoot dry weight, primary root number, and root dry weight of inoculated plants compared with plants grown in unamended sterile soil (Table 2). Single isolates of *P. dissotocum* and *P. irregulare* caused significant reductions in shoot dry weight (Table 2).

Root rot caused by *P. arrhenomanes* was controlled by both metalaxyl treatments. Typical root rot symptoms were not observed, and shoot dry weight, primary root number, and root dry weight for plants inoculated with each isolate and then treated with metalaxyl at each of two rates were not significantly different from uninoculated metalaxyl-treated or untreated control plants

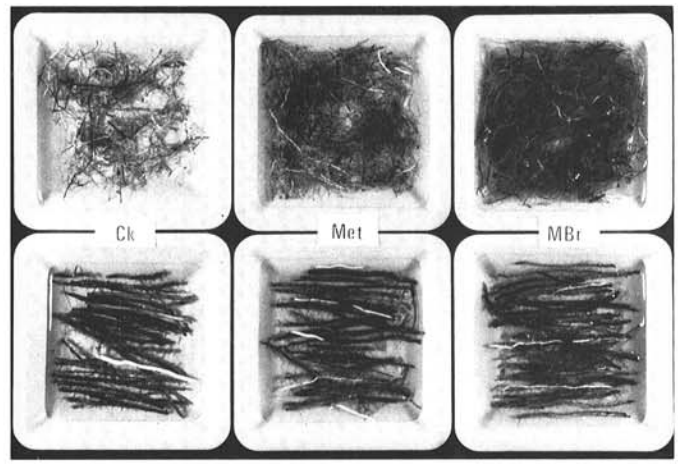

Fig.1. Primary (bottom row) and lateral (top row) roots obtained from two 810-cc soil cores removed from a tub in which a sugarcane plant was growing in either untreated field soil (Ck), field soil treated with metalaxyl (Met), or field soil fumigated with methyl bromide-chloropicrin (MBr).

TABLE 1. Effects of pesticide treatments of sugarcane field soil or plants on initial growth (A) and regrowth (B) of sugarcane cultivar CP 70-321 in the greenhouse

	Plant growth parameter[a]											
	Shoot wt. (g)		Shoot number		Primary root wt. (g)		Primary root no.		Wt./cm root (g)		Lateral root wt. (g)	
Pesticide	A	B	A	B	A	B	A	B	A	B	A	B
Methyl bromide	412.8	645.2	17.6	12.0	7.04	7.35	36.8	83.8	0.028	0.014	6.34	5.25
Metalaxyl	168.6	421.4	6.6	8.8	4.21	3.40	23.8	47.2	0.028	0.012	2.30	3.65
Fosetyl-Al	106.6	367.7	8.0	7.0	3.41	3.15	27.4	39.0	0.019	0.013	2.35	3.21
Control[b]	115.2	327.6	7.6	6.7	2.41	2.35	21.4	34.3	0.017	0.011	1.36	2.71
LSD[c]	39.7	106.7	3.6	2.9	1.63	1.58	5.8	7.0	0.009	0.004	0.56	0.91

[a] Initial plant growth (A) measured after 110 days just before topping. Regrowth (B) measured 98 days after topping. Values represent means of five plants per treatment.
[b] Controls consisted of five plants grown in untreated sugarcane field soil.
[c] Least significant difference ($P = 0.05$).

TABLE 2. Effects of two rates of application of metalaxyl on growth of sugarcane cultivar CP 70-321 inoculated with single isolates of three *Pythium* spp.

	Shoot no.				Shoot dry wt. (g)				Root no.				Root dry wt. (g)			
Pythium spp. (Isolate)	High[a]	Low[b]	UT[c]	LSD[d]	High	Low	UT	LSD	High	Low	UT	LSD	High	Low	UT	LSD
P. arrhenomanes (147)	3.2	3.0	1.8	1.90	15.2	11.9	5.6	2.92	36.5	33.3	23.0	7.94	2.8	2.1	0.8	0.69
P. arrhenomanes (10-1)	3.0	3.3	1.2	1.00	11.5	11.9	5.7	1.52	36.2	35.3	19.5	6.65	2.5	2.9	0.9	0.45
P. dissotocum (7-1)	1.7	2.0	2.2	1.57	11.2	10.2	10.0	2.91	35.8	32.2	34.8	6.32	2.6	2.1	2.3	1.01
P. irregulare (6-2)	2.0	2.4	2.0	1.83	9.4	8.9	9.7	3.53	29.6	29.2	36.8	12.16	1.4	1.4	1.7	0.82
Sterile soil	1.7	4.0	2.7	2.09	9.9	11.5	12.7	2.82	29.3	36.8	41.2	8.77	2.4	2.6	2.6	1.25
LSD[d]	1.2	2.0	1.7	···	2.7	3.2	2.7	···	6.7	8.0	8.9	···	1.0	1.1	1.0	···

[a] Five plants were drenched with 7.5 μl a.i. metalaxyl per plant at the time of planting and again 54 days after planting.
[b] Five plants were drenched with 1.5 μl a.i. metalaxyl per plant at the time of planting and again 54 days after planting.
[c] Untreated sterile soil control (UT) data were included in the statistical analysis for all treatments for each plant growth parameter.
[d] Least significant difference ($P = 0.05$).

(Table 2).

When growth parameters were compared across treatments (high and low rates of metalaxyl application and untreated) for each *Pythium* isolate, shoot dry weight, primary root number, and root weight of plants treated with both rates of metalaxyl were all significantly higher than for untreated plants inoculated with isolates of *P. arrhenomanes* (Table 2). The number of shoots for plants inoculated with the two isolates and then treated with metalaxyl was higher than the number for untreated, inoculated plants; however, the difference was only significant for plants inoculated with isolate 10-1 and treated with the low rate of metalaxyl.

Growth parameters of uninoculated plants grown in sterile soil and treated with the high rate of metalaxyl were all lower than those for untreated plants (Table 2). The differences were significant for shoot dry weight and primary root number; however, no visible symptoms of phytotoxicity were observed.

Lateral root symptom ratings were 2.9, 2.9, 1.0, and 1.9 for untreated plants inoculated with *P. arrhenomanes* (147 and 10-1), *P. dissotocum*, or *P. irregulare*, respectively, and 1.0 for untreated sterile soil control plants. Discoloration ratings were 2.9, 2.7, 1.0, 1.9, and 1.0 for the same plant groups, respectively. The only metalaxyl treatment in which root rot severity ratings exceeded 1.0 was the one in which plants were inoculated with *P. arrhenomanes*, isolate 147, then treated with the low rate of metalaxyl. The ratings for lateral root symptoms and root system discoloration were 1.5 and 1.3, respectively.

Pythium was reisolated from 61, 74, 42, and 90% of the 72 root pieces collected from plants inoculated with *P. arrhenomanes* (147 and 10-1), *P. dissotocum*, and *P. irregulare*, respectively. Reisolation frequencies of *Pythium* decreased for plants treated with the low rate of metalaxyl to 5, 3, 5, and 5%, respectively, and for plants treated with the high rate of metalaxyl to 0, 3, 0, and 0%, respectively. *Pythium* was not isolated from roots collected from control plants.

Metalaxyl field experiments. Stalk weights and stalk counts were both higher in metalaxyl-treated plots compared with untreated plots in first and second stubble crops of cultivars CP 70-321 and CP 70-330 (Table 3). Plot stalk numbers were 15% and 22% higher in metalaxyl-treated plots in first stubble and 32% and 27% higher in second stubble for CP 70-321 and CP 70-330, respectively. These differences resulted in estimated tons of cane and kg of sucrose per hectare being higher in metalaxyl-treated plots of both cultivars (Table 3). Sucrose/ha increases of 31% and 53% were obtained in first stubble and 30% and 33% in second stubble for CP 70-321 and CP 70-330, respectively. Increases were not significant in tons of cane per hectare (27%) for CP 70-321 in first stubble or tons of cane (29%) and sucrose per hectare (33%) for CP 70-330 in second stubble because of plot variability. Significant yield increases have resulted from metalaxyl treatment in one of two subsequent field experiments.

TABLE 3. Comparison of yields from metalaxyl-treated and untreated plots of two sugarcane cultivars (A) CP 70-321 and (B) CP 70-330 over a 3-yr crop cycle

Crop cycle year[a]	Metalaxyl[b] (+/−)	Plot stalk number[c]	Mean stalk weight (kg)	Tons of cane/ha	Sucrose (kg/ha)
(A) CP 70-321					
Plant cane	+	156	1.14	78.0	8,309
	−	169	1.18	84.9	9,048
First stubble	+	207	1.32	110.4	11,706
	−	180	1.18*	87.1	8,963*
Second stubble	+	194	0.95	75.0	8,705
	−	159*	0.91	59.6*	6,679*
(B) CP 70-330					
Plant cane	+	133	1.41	80.9	8,149
	−	134	1.41	81.5	8,216
First stubble	+	179	1.50	110.2	11,192
	−	135	1.36	75.6*	7,339*
Second stubble	+	159	1.13	73.0	8,148
	−	125*	1.10	56.7	6,145

[a] Data are shown for each of the 3 yr of the crop cycle. Within each year, yield data of each type followed by an asterisk are significantly different ($P = 0.05$) as determined by a t-test.

[b] Metalaxyl was drenched over the seed cane in furrow at planting at a rate of 0.8 kg a.i./ha. Metalaxyl then was incorporated into plot rows with fertilizer during the spring each year at a rate of 0.6 kg a.i./ha.

[c] Individual plots were 0.0023 ha.

DISCUSSION

The large increases in initial growth and regrowth exhibited by sugarcane plants grown in fumigated soil strongly suggest that soil microorganisms cause significant reductions in initial and ratoon growth in field soil in Louisiana. Increases in sugarcane growth in fumigated soil have been reported in Hawaii (32), Louisiana (42), and Australia (15). Soil fumigation was used in Louisiana to attempt to reduce the effects of nematodes and ratoon stunting disease, then thought to be a soilborne virus disease. However, the elimination of root rotting organisms was speculated to be partially responsible for the observed yield increases. A reduction in root rot severity was considered to be an important factor affecting the plant response in the Hawaiian and Australian studies.

Metalaxyl provides a tool that can be used to determine the effects of pythiaceous fungi on plant growth. The significant increases in root development and shoot growth in the metalaxyl-treated as compared with untreated plants in greenhouse field-soil experiments indicate that *Pythium* can cause significant reductions in the growth of sugarcane in field-soil without causing aboveground symptoms often associated with root rots, such as wilting or collapse and death of plants.

Growth was significantly less in metalaxyl-treated plants than in plants grown in fumigated soil. This suggests that sugarcane growth is affected by a complex of microorganisms in field soil. Nematodes have been demonstrated to cause reductions in sugarcane growth singly (1,4,28) and in combination with *Pythium* (2,3,8). An interaction between *Pythium* spp. and nematodes affecting sugarcane stubble crop yields in Louisiana needs further investigation.

The results of the pathogenicity test with metalaxyl treatments demonstrated that metalaxyl can control symptoms caused by *P. arrhenomanes* in sugarcane. The high rate of application caused some significant reductions in plant growth; however, there were no visible symptoms of phytotoxicity. A lower metalaxyl concentration controlled the disease, and growth reductions were not evident in uninoculated, metalaxyl-treated control plants. A comparable rate used in field soil experiments gave significant increases in plant initial growth and regrowth. These results suggest that metalaxyl might have some potential for controlling this disorder and increasing sugarcane initial growth and stubble regrowth in the field, and confirmed the role of *Pythium* spp. as a factor in stubble decline.

The application of fosetyl-Al did not result in significant increases in plant growth. These results could be explained by research that demonstrated lower in vitro sensitivity to fosetyl-Al and phosphorous acid by *Pythium* spp. as compared with *Phytophthora* spp. (21).

Visible symptoms of disease were not observed in untreated plots of two sugarcane cultivars in the metalaxyl field experiment; however, significant stubble crop yield increases were obtained from metalaxyl-treated plots. The second stubble tonnage yields in metalaxyl-treated plots of cultivars CP 70-321 and CP 70-330 were 4% and 11% less, respectively, than plant cane yields for the same plots, and an economic third stubble crop would likely be obtained. In comparison, the second stubble yields of untreated plots were 42% and 44% less, respectively, than plant cane yields, and fallowing and replanting at the normal time would be necessary. These results suggest that *Pythium* spp. can cause reductions in sugarcane growth sufficient to significantly reduce stubble crop yields in the field.

In Louisiana, sugarcane stubble regrowth is affected by a complex of factors including pathogens, other soil microorganisms, weed competition, and environmental and cultural factors. The

role of *Pythium* in stubble decline has been considered to be minor in typical years. However, the results of pathogenicity tests (26) and the growth of plants in field soil treated with metalaxyl strongly suggest that cryptic disease caused by *Pythium* spp., particularly *P. arrhenomanes*, plays a significant role in sugarcane stubble decline. The ecology of *P. arrhenomanes* and other *Pythium* spp. during the growing season and 4-yr crop cycle and fallow period needs further investigation.

Various terms, including feeder root necrosis, rootlet infection, and subclinical and cryptic disease, have been used to describe or explain disorders caused by soilborne fungi without obvious aboveground symptoms that result in significant yield losses (23,24,40). The causal agents of such disorders have been termed "minor pathogens" (37). Root symptoms caused by *P. arrhenomanes* may at times be limited to feeder root necrosis, but under disease-conducive conditions, extensive rotting of primary root tips can occur (26). *P. arrhenomanes* fits the characteristics proposed by Salt (37) to define "minor pathogens." However, the widespread distribution of this pathogen and its demonstrated potential to reduce yields make the term "minor pathogen" an incongruous one. Considered altogether, the effects of *P. arrhenomanes* on plant growth represent a syndrome that we feel is best described as cryptic disease.

LITERATURE CITED

1. Apt, W. J., and Koike, H. 1962. Influence of the stubby-root nematode on growth of sugarcane in Hawaii. Phytopathology 52:963-964.
2. Apt, W. J., and Koike, H. 1962. Pathogenicity of *Helicotylenchus nannus* and its relation with *Pythium graminicola* on sugarcane in Hawaii. Phytopathology 52:798-802.
3. Apt, W. J., and Koike, H. 1962. Pathogenicity of *Meloidogyne incognita acrita* and its relation with *Pythium graminicola* on sugarcane in Hawaii. Phytopathology 52:1180-1184.
4. Birchfield, W., and Martin, W. J. 1956. Pathogenicity on sugarcane and host plant studies of a species of *Tylenchorhynchus*. Phytopathology 46:277-280.
5. Carter, C. E. 1977. Excess water decreases cane and sugar yields. Proc. Am. Soc. Sugar Cane Technol. 6:44-51.
6. Carter, C. E., and Floyd, J. M. 1975. Inhibition of sugarcane yields by high water table during dormant season. Proc. Am. Soc. Sugar Cane Technol. 4:14-18.
7. Carter, C. E., McDaniel, V., and Halverson, B. 1976. Subsurface drainage slows sugarcane yield decline. (Abstr.) J. Am. Soc. Sugar Cane Technol. 6:133.
8. Chandler, K. J. 1984. Plant parasitic nematodes and other organisms as a contributing factor to poor sugarcane root development in North Queensland. Pages 63-67 in: Proc. Aust. Soc. Sugar Cane Technol. 1984 Conf.
9. Connell, T. D. 1952. A survey of bacteria antagonistic to *Pythium arrhenomanes* in Louisiana sugarcane soils. (Abstr.) Phytopathology 42:464.
10. Cook, R. J., and Haglund, W. A. 1982. Pythium root rot: A barrier to yield of Pacific Northwest wheat. Wash. State Univ. Agric. Res. Cent. Res. Bull. XBO913. 18 pp.
11. Cook, R. J., Sitton, J. W., and Haglund, W. A. 1987. Influence of soil treatments on growth and yield of wheat and implications for control of Pythium root rot. Phytopathology 77:1192-1198.
12. Cook, R. J., Sitton, J. W., and Waldher, J. T. 1980. Evidence for *Pythium* as a pathogen of direct-drilled wheat in the Pacific Northwest. Plant Dis. 64:102-103.
13. Cooper, W. E., and Chilton, S. J. P. 1950. Studies on antibiotic soil organisms. I. Actinomycetes antibiotic to *Pythium arrhenomanes* in sugarcane soils in Louisiana. Phytopathology 40:544-552.
14. Croft, B. J., and Magarey, R. C. 1984. Pathogenic fungi associated with northern poor root syndrome of sugarcane. Pages 55-61 in: Proc. Aust. Soc. Sugar Cane Technol. 1984 Conf.
15. Croft, B. J., Reghenzani, J. R., and Hurney, A. P. 1984. Northern poor root syndrome of sugarcane—Studies on soil transmission and the effects of various fungicidal, nutritional and agronomic treatments. Pages 69-77 in: Proc. Aust. Soc. Sugar Cane Technol. 1984 Conf.
16. Davis, M. J., Gillaspie, A. G., Jr., Vidaver, A. K., and Harris, R. W. 1984. Clavibacter: A new genus containing some phytopathogenic coryneform bacteria, including *Clavibacter xyli* subsp. *xyli* sp. nov., subsp. nov. and *Clavibacter xyli* subsp. *cynodontis* subsp. nov., pathogens that cause ratoon stunting disease of sugarcane and Bermudagrass stunting disease. Int. J. Syst. Bacteriol. 34:107-117.
17. Edgerton, C. W. 1939. Stubble deterioration. Proc. Int. Soc. Sugar Cane Technol. 6:344-341.
18. Edgerton, C. W., Tims, E. C., and Mills, P. J. 1929. Relation of species of *Pythium* to the root-rot disease of sugarcane. Phytopathology 19:549-564.
19. Edgerton, C. W., Tims, E. C., and Mills, P. J. 1934. Stubble deterioration of sugar cane. LA State Univ. Bull. No. 256. 27 pp.
20. Egan, B. T., Hurney, A. P., Ryan, C. C., and Matthews, A. A. 1984. A review of the northern poor root syndrome of sugarcane in North Queensland. Pages 1-9 in: Proc. Aust. Soc. Sugar Cane Technol. 1984 Conf.
21. Fenn, M. E., and Coffey, M. D. 1984. Studies on the in vitro and in vivo antifungal activity of fosetyl-Al and phosphorous acid. Phytopathology 74:606-611.
22. Flor, H. H. 1930. Relation of environmental factors to growth and pathogenicity of *Pythium* isolated from roots of sugar cane. Phytopathology 20:319-328.
23. Hancock, J. G. 1985. Fungal infection of feeder rootlets of alfalfa. Phytopathology 75:1112-1120.
24. Hendrix, F. F., Jr., and Campbell, W. D. 1983. Some pythiaceous fungi—New roles for old organisms. Pages 123-160 in: Zoosporic Plant Pathogens. A. T. Buczacki, ed. Academic Press, New York. 352 pp.
25. Hoy, J. W., and Schneider, R. W. 1986. Possible role of Pythium root rot in sugarcane stubble decline. (Abstr.) Phytopathology 76:1089.
26. Hoy, J. W., and Schneider, R. W. 1988. Role of *Pythium* in sugarcane stubble decline: Pathogenicity and virulence of *Pythium* species. Phytopathology 78:1688-1692.
27. Johnson, L. F. 1954. Antibiosis in relation to Pythium root rot of sugarcane and corn. Phytopathology 44:69-73.
28. Kahn, S. A. 1959. Pathogenic effects of *Pratylenchus zeae* on sugarcane. (Abstr.) Phytopathology 49:543.
29. Koike, H. 1974. Interaction between diseases of sugarcane: Sugarcane mosaic and ratoon stunting disease. Proc. Int. Soc. Sugar Cane Technol. 15:258-265.
30. Koike, H. 1977. Diseases as a factor influencing sugarcane yields in Louisiana during the last decade. Proc. Am. Soc. Sugar Cane Technol. 6:178-181.
31. Luke, H. H. 1952. Fungi isolated from sugarcane soils of Louisiana and their antagonistic effect on *Pythium arrhenomanes*. (Abstr.) Phytopathology 42:469.
32. Martin, J. P., Wisner, C. A., Koike, H., and Apt, W. J. 1959. Some biological factors associated with yield decline of sugar cane varieties in Hawaii. Proc. Int. Soc. Sugar Cane Technol. 10:77-85.
33. Matherne, R. J., Breaux, R. D., and Millhollon, R. W. 1977. Culture of sugarcane for sugar production in the Mississippi delta. USDA Agric. Handb. No. 417. 42 pp.
34. Mircetich, S. M., and Matheron, M. E. 1976. Phytophthora root and crown rot of cherry trees. Phytopathology 66:549-558.
35. Pillay, M., Schneider, R. W., and Rush, M. C. 1986. Association of *Pythium* spp. with seedling disease and feeder root decline in rice. (Abstr.) Phytopathology 76:1094.
36. Rands, R. D., and Dopp, E. 1938. Pythium root rot of sugarcane. USDA Tech. Bull. No. 666. 96 pp.
37. Salt, G. A. 1979. The increasing interest in "minor pathogens." Pages 289-312 in: Soilborne Plant Pathogens. B. Schippers and W. Gams, eds. Academic Press, New York. 688 pp.
38. Sewell, G. W. F. 1984. Replant diseases: Nature, etiology and importance. Brit. Crop Prot. Conf. Pests Dis. 11 B-1:1175-1182.
39. Srinivasan, K. V. 1968. The role of the rhizosphere microflora in the resistance of sugarcane to Pythium root rot. Proc. Int. Soc. Sugar Cane Technol. 13:1224-1236.
40. Stanghellini, M. E., and Kronland, W. L. 1986. Yield loss in hydroponically grown lettuce attributed to subclinical infection of feeder rootlets by *Pythium dissotocum*. Plant Dis. 70:1053-1056.
41. Steib, R. J., and Chilton, S. J. P. 1967. Interrelationship studies of mosaic and ratoon stunting diseases in sugarcane in Louisiana. Proc. Int. Soc. Sugar Cane Technol. 12:1061-1070.
42. Steib, R. J., Hollis, J. P., and Chilton, S. J. P. 1965. Effects of treating the soil with bromomethane on yield of sugarcane infected with the ratoon stunting disease virus. Proc. Int. Soc. Sugar Cane Technol. 12:1087-1088.
43. Sumner, D. R., Gascho, G. J., Johnson, A. W., and Threadgill, E. D. 1986. Root diseases and yield decline in continuous double-crop corn. (Abstr.) Phytopathology 76:1088-1089.
44. Van der Zwet, T. 1957. The effect of flooding upon the severity of Pythium root rot. M.S. thesis. Louisiana State University, Baton Rouge. 73 pp.