Association of Sugarcane Rust Severity with Soil Factors in Florida

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ABSTRACT

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Sugarcane production in Florida has been affected by sugarcane rust, caused by *Puccinia melanocephala*, since the first recorded outbreak of the disease in 1979. During 1988 and 1989, seven first-year production fields exhibiting high variability in rust severity were selected for study. Each field site was spatially sampled for soil variability and assessed for rust infection levels. Although rust severities are negatively correlated with soil pH at each and across all locations, rust severity is site- and cultivar-specific. Soil pH is an important criteria, but it is not the sole determinant affecting rust severity in sugarcane. High levels of soil phosphorus were also associated with high rust severity at all locations. At two locations, high levels of soil magnesium and potassium were associated with lower rust severity. These associations, although not conclusive of a causal relationship, provide a basis for identifying soil conditions promoting high rust intensity as well as for directing sugarcane rust research in the future.

Sugarcane (*Saccharum* spp.), a perennial grass, is Florida's most important field crop, with a crop value in excess of $500 million in 1988. Sugarcane production in Florida has been affected by sugarcane rust, caused by *Puccinia melanocephala* H. Syd. and P. Syd., since the first recorded outbreak of the disease in 1979 (8,13,14). On susceptible cultivars, rust has been estimated to be responsible for tonnage reductions of up to 40% (16). Observations during the past 10 yr indicate that rust has increased in severity on several commercially popular cultivars when compared to other commercial cultivars. There also appears to be a geographical influence, with rust being consistently more severe in specific regions of the Florida sugarcane industry. Explanations for these observations could be the appearance of new and possibly more virulent races of *P. melanocephala* (5,7,15) and the influence of edaphic factors (2). Although there has been no direct evidence that soil nutrient conditions affect rust severity on sugarcane, evidence of edaphic conditions affecting the rust/host interaction on other crops is abundant (6,10,18, 21,23). Cultivar resistance is the only viable rust control measure in sugarcane at the present time (14); therefore, information leading to development of additional rust management strategies is important.

Anderson and Dean (2) showed a relationship between plant nutrition and sugarcane rust infection; however, the relationship of rust severity to soil characteristics was not discussed. Approximately 80% of Florida's sugarcane production is located on the organic soils of the Everglades Agricultural Area (EAA) situated in the vicinity of Lake Okeechobee. In the EAA, several field observations have led to a hypothesis that soil conditions and rust severity are related. One observation has been referred to as the "rock road effect," where rust severity appears to be lower

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on field edges adjacent to rock (calcium carbonate) road spoils high in pH. This border effect is not apparent on field edges where rock spoils are absent. Another observation is the apparent increased susceptibility of the first-year crop over succeeding crops (3). These observations may offer valuable clues pertaining to the influence of soil nutrient conditions on rust infection; however, they have not been systematically investigated to identify the factors or mechanisms involved.

The influence of soil fertilization on diseases caused by biotic pathogens of cereals and other crops was reviewed by Anderson and Dean (2). This review indicated that numerous soil conditions have been shown to influence host/pathogen interactions but that these relationships have been poorly quantified. Sugarcane rust investigators have reported observations that both soil moisture stress (9,17) and high water table (11) contribute to high rust incidence. However, aside from these observations, literature regarding the association between *P. melanocephala* and soil conditions is lacking. The objective of this study was to quantify possible relationships between sugarcane rust severity and soil nutrient characteristics found in the Florida sugarcane industry.

MATERIALS AND METHODS

In May 1988, six commercial field locations of plant sugarcane (first-year crop) exhibiting high variability in rust severity within fields and between locations were selected for disease assessments and soil sampling. An additional field location was selected in March 1989. Six sites were located on EAA organic soils (Table 1). One site (site 6) was located on a fine sand soil west of the EAA. Observations with respect to sugarcane rust were made during the latter stages of the respective rust epidemics. Disease gradients, which were present during the initial stages because of nonuniform levels of primary inoculum, were no longer evident because of gradient flattening, which occurs with secondary disease spread.

Rust severity ratings were made during May 1988 at growth stage 4 (4). Growth stage 4 is the stage characterized by stem elongation, which occurs in Florida as early as from mid-April through August. Rust severity was rated on sugarcane plants spatially located on sample grids at specific x and y coordinates within each field, with two exceptions.

After grid sampling at site 1, low rust severity was visually observed along the $x = 12.1$ m transect coordinates into the field. Other areas within the sample grid were uniform in rust intensity. Therefore, 10 rust severity ratings each on plants along the $x = 12.1$ m and $x = 24.2$ m transects were made and selected for interpretation for balanced data comparisons and inspection at this site.

At site 5, two adjacent fields were sampled, neither of which exhibited within-field rust variability. Both fields at site 5 were planted to the same cultivar on the same date. However, sugarcane-press filter mud (2–3 Mg ha^{-1}) was applied 1 yr previous to the plant-cane crop in only one of these fields. Higher rust levels were observed in the field with applied filter mud. Ratings at site 5 were

Table 1. Cultivar, soil type, and simple statistics[a] for soil pH and sugarcane rust severity at seven selected Florida sugarcane field locations

Site	Observations (no.)	Soil type	Cultivar	Soil pH				Rust severity[b]			
				Min	Max	Mean	SD	Min	Max	Mean	SD
1	20	Muck	CP78-1247	6.3	7.9	7.0	0.3	8.2	59.0	28.9	11.8
2	49	Muck	CP78-1247	5.2	8.2	6.9	1.1	1.6	63.0	30.0	20.3
3	16	Muck	CP78-1247	5.8	8.1	7.0	0.9	2.3	46.9	16.9	12.7
4	49	Muck	CP65-357	4.8	5.9	5.3	0.2	0.5	58.8	14.3	14.2
5	20	Muck	CP72-1210	7.1	8.0	7.5	0.3	0.4	11.4	4.7	4.0
6	49	Sand	CP72-1210	4.5	7.6	5.2	0.7	3.0	42.8	18.2	8.3
7	63	Muck	CP78-1247	5.3	8.0	6.8	1.1	1.8	53.8	13.9	11.4

[a] Minimum (min), maximum (max), mean, and standard deviation (SD).
[b] Percent of rust severity on the distal third of the topmost fully expanded leaf.

Table 2. Mean rust severity, soil characteristics, and correlation statistics (r) from seven sugarcane field sites

Site	Rust severity (%)	pH	Soil test levels[a] (mg L^{-1} soil)					P_w:P_a
			P_w	P_a	K	Ca	Mg	
1	28.9	7.0	6	21	38	5,723	580	0.22
		−0.19[b]	...	...	...	...	...	...
		+[c]	ns	ns	ns	ns	ns	ns
2	29.9	6.9	5	31	73	11,480	207	0.16
		−0.91	0.55	−0.75	−0.42	−0.82	−0.88	0.82
		**	*	**	*	**	**	**
3	16.9	7.0	7	53	128	4,889	314	0.11
		−0.84	0.85	...	0.68	−0.81	0.83	0.86
		**	**	ns	**	**	**	**
4	14.2	5.3	68	239	321	4,658	264	0.03
		−0.75	0.81	0.72	0.58	−0.37	−0.37	...
		**	**	**	**	**	**	ns
5	4.7	7.5	29	1,098	293	11,460	642	0.62
		−0.69	0.63	0.84	0.83	0.69	0.73	0.61
		**	**	**	**	**	**	**
6	18.2	5.2	6	11	18	346	14	0.46
		−0.66	0.53	−0.36	...	−0.55	−0.31	0.61
		**	*	*	ns	**	*	**
7	13.9	6.8	9	54	142	---	---	0.16
		−0.80	0.82	−0.48	0.23			0.84
		**	**	**	+			**

[a] P_w = water-extractable phosphorus, P_a = acetic acid-extractable phosphorus.
[b] Simple correlation statistic (r) between rust severity and indicated soil parameter.
[c] **, *, and + indicate significant at $P < 0.01$, $P < 0.05$, and $P < 0.10$, respectively; ns indicates nonsignificant.

taken at 10 coordinates along double transect lines within each of the two fields, with these transects being parallel to each other. At the remaining sites, the number and spacing of each sample coordinate or sampling grid size varied to best suit the observed field variability (Table 1).

Rust was visually assessed on the adaxial surface of five randomly selected top-visible dewlap leaves per plant per coordinate. Severity ratings were made on a 30-cm-long leaf section measured basipetally from the point on the leaf's distal third where the leaf width was 1 cm. Ratings were made on a percentage basis with the use of a pictorial scale after Purdy and Dean (12), indicating the extent of leaf area visibly affected by rust. Plant response was also recorded (12). Five 2.5-cm soil cores were collectively sampled to a 15-cm depth around each rated plant and were bulked. Soils were sieved to pass through a 60-mesh screen and air-dried at 30 C for 3 days before soil analyses. Soils were analyzed for soil pH, water-extractable phosphorus (P_w), acetic acid-extractable phosphorus (P_a), potassium, calcium, and magnesium (1,22). Calcium and Mg data were not obtained for site 7.

Relationships between rust ratings and various soil characteristics were analyzed by using simple and multiple regression procedures (19). Auto-correlated soil parameters were eliminated from regression models. Only statistically significant ($P < 0.1$) linear, quadratic, or simple 1:1 interaction term regressions and variables were included in final regression models describing rust severity as a function of soil parameters. Models and data were graphically plotted with the use of SAS/GRAPH procedures (20).

RESULTS

Simple statistics (data range, mean, and standard deviation) for soil pH and rust severity at each site are presented in Table 1. Ranges in soil pH exceeded one full pH unit at all sites with the exception of site 5. Ranges in soil pH varied from 0.9 pH units at site 5 to 3.0 pH units at site 2. Ranges in rust severity were likewise broad, ranging from 11% at site 5 to 61% at site 2. Rust severity was negatively correlated with soil pH across all sites (Table 2). Based upon best-fit criteria in examining first- and second-order regressions models, the relationship between rust severity and soil pH was best described by linear models at sites 2, 3, 5, and 6, and by quadratic models at sites 1, 4, and 7 (Table 3, Fig. 1). Site 5 was not included in Fig. 1 because the pH and rust severity ranges were not highly variable (± 0.3 pH units and ± 4.0% SD, respectively, Table 1).

Soil pH was not the sole factor associated with influencing rust severity (Table 2). With the exception of site 1,

Table 3. Rust severity models as a function of soil pH or soil nutrients[a]

Site	Rust regression models[b]	R^2
1	Rust = 1,590 − 426 pH + 29 pH^2	0.623
	Rust = 52.3 − 277.3 P_w:P_a + 850.6 $(P_w:P_a)^2$	0.654
2	Rust = 148.4 − 17.2 pH	0.837
	Rust = 19.8 + 199.1 P_w:P_a − 176.8 $(P_w:P_a)^2$ − 0.291 K + 0.0010 K^2	0.818
3	Rust = 101.9 − 12.2 pH	0.704
	Rust = −77.2 − 42.1 P_w + 3.2 P_a − 0.031 P_a^2 + 1,102 P_w:P_a + 0.428 ($P_w \times P_a$)	0.907
4	Rust = 1,704 − 596.2 pH + 52.3 pH^2	0.620
	Rust = − 7.7 + 0.324 P_w	0.648
5	Rust = 66.6 − 8.20 pH	0.479
	Rust = 0.72 + 0.012 P_a − 0.00000362 P_a^2	0.901
6	Rust = 58.2 − 7.71 pH	0.437
	Rust = 13.1 + 2.21 P_w − 0.546 Mg	0.438
7	Rust = 317.5 − 83.9 pH + 5.63 pH^2	0.702
	Rust = 3.57 + 64.2 P_w:P_a	0.710

[a] All parameters significant at $P < 0.10$ or lower. At site 3, $P_w \times P_a$ is the interaction parameter between P_w (water-extractable P) and P_a (acetic acid-extractable P).
[b] At each site, the first model is the "best-fit" model considering soil pH alone. Because of the high autocorrelation between pH and other soil parameters, the second model is the "best-fit" model considering two parameters other than pH.

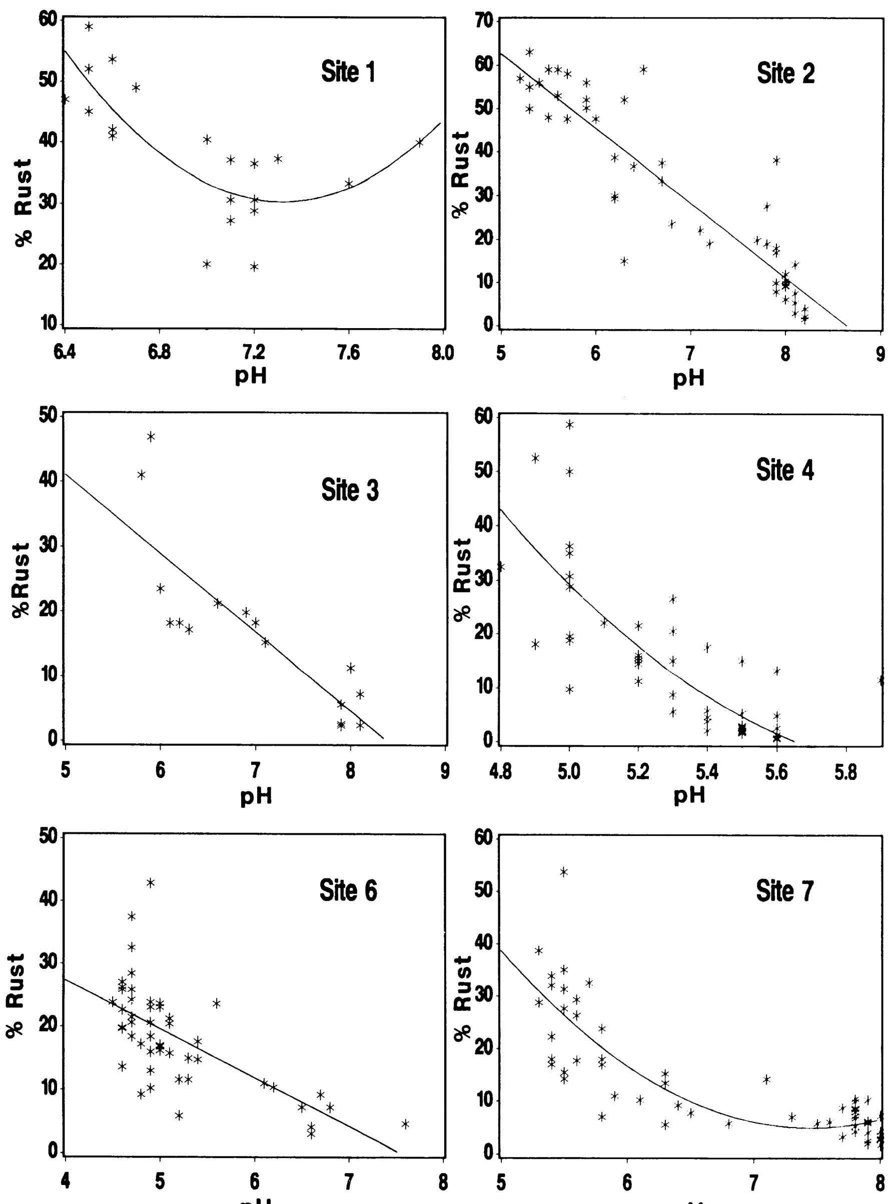

Fig. 1. Relationship between sugarcane rust severity and soil pH at six field sites. The models and statistics are presented in Table 3.

rust was singly and significantly correlated (r, $P < 0.1$) with more than one soil nutrient parameter at each site. Associations of rust with K, Ca, and Mg, although significant at some locations, were highly variable and site dependent.

In further correlation analyses of the data, soil pH was found to be autocorrelated with the other soil parameters. Therefore, in development of "best-fit" models using stepwise multiple regression for selection of significant soil nutrient parameters, soil pH was excluded in those determinations (Table 3). Only at sites 3 and 5 were the rust severity prediction models significantly improved over the use of soil pH as an independent model variable (Table 3). However, increased soil phosphorus levels (P_w, P_a, and the P_w:P_a ratio) were significantly associated with increased severity of rust at all locations. Higher soil K and Mg levels were generally associated with lower rust severities at sites 2 and 6, respectively.

DISCUSSION

Results from this study indicate significant associations between sugarcane rust severity and several soil parameters, including soil pH, P_w, P_a, P_w:P_a, K, Ca, and Mg. Soil pH was the edaphic factor most consistently associated with rust, with severities increasing as pH decreased. Phosphorus was the soil nutrient most consistently correlated with rust severity, with rust levels generally increasing with increasing P_w or the P_w:P_a ratio. The soil P_w:P_a ratio is a P intensity (P_w):capacity (P_a) ratio indicating relative capacity of soil to supply P. A low ratio indicates a relatively low supply of readily available P. The ratio was found to be inversely related to soil pH with the equation as follows: $P_w{:}P_a = 1.67 - 0.35\ \text{pH} + 0.018\ (\text{pH})^2$, where $R^2 = 0.62$ and $P < 0.01$ (Fig. 2). Therefore, it is likely that the associations of rust with soil pH are also P related. This relationship may prove to be increasingly more important in locating specific soils likely to be more susceptible to rust damage.

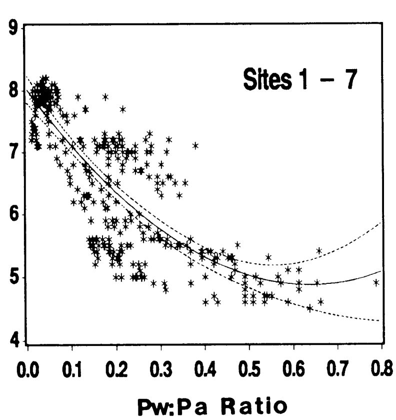

Fig. 2. Relationship between soil pH and the P_w:P_a ratio from data collected from sites 1–6. P_w refers to water-soluble P content, and P_a refers to acetic acid-soluble P content. The 99% confidence interval is indicated by the dotted lines.

Our findings are consistent with recorded observations in the Florida sugarcane industry where rust levels decline in field areas where soil pH is considerably higher (for example, adjacent to lime rock roads and ditch spoil banks). The EAA was aerially surveyed for sugarcane rust intensity during the sugarcane seasons of 1987 and 1988. Geographic locations within the EAA appearing to support higher rust intensities coincide with the more acidic muck soils found in the eastern portion of the EAA, where soil pH typically ranges from 4.0 to 5.5. Associations identified in this investigation may assist in explaining what appear to be geographic influences.

Correlations of rust severity and K, Ca, and Mg levels appeared to be site dependent (Table 2). The inconsistency of these associations makes generalizations difficult, however, soil nutrient conditions above and below those considered optimal have been shown previously to be associated with higher rust levels on other hosts (6,11,18,21,23). This research supports a similar conclusion that either high or low levels of specific soil nutrient conditions are associated with higher rust severity levels on sugarcane.

These results lend support to a hypothesis that soil edaphic factors influence sugarcane rust intensity levels. It should be noted, however, that insufficient data exist to prove a causal relationship between edaphic factors and sugarcane rust. Delineation of causal relationships would be dependent upon experiments conducted under controlled conditions. Numerous attempts at controlled field experiments of this nature have failed thus far because of insufficient disease development.

Control measures for sugarcane rust are currently limited. Fungicidal sprays of sugarcane are not economically feasible because of the large foliar biomass of sugarcane and the long duration of rust epidemics. Cultivar resistance remains the primary management strategy for control of this disease (11). However, recent observations suggest that new rust races are developing (5,7,15), threatening the stability of cultivar resistance. Positive information concerning fertility or edaphic influences on rust could be instrumental in identifying rust risk factors with respect to particular geographic regions or fertility levels. This information could provide additional management strategies for sugarcane rust control.

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