Relationship of Soil Cations to the Distribution of *Phymatotrichum omnivorum*

J. P. Mueller, R. B. Hine, D. A. Pennington, and S. J. Ingle

First and second authors—Department of Plant Pathology; third author—Department of Soils, Water, and Engineering, University of Arizona, Tucson 85721; and fourth author—U.S. Department of Agriculture, Fruit Protection and Production Laboratory, Weslaco, TX 78596, respectively.

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ABSTRACT

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The observation that root rot of cotton, caused by *Phymatotrichum omnivorum*, occurs in sharply defined, localized areas in Arizona cotton fields led to the hypothesis that a specific soil chemical factor may limit distribution of the fungus. Comparisons were made of the sodium, potassium, calcium, and magnesium contents of infested and adjacent noninfested soils in 13 fields. At 11 sites, there were no significant differences in the sodium contents of infested and adjacent noninfested areas ($P = 0.01$). Sodium levels were higher in infested areas than in adjacent noninfested areas at two sites. Calcium levels were higher in the noninfested area than in the infested area at one site. Magnesium levels were higher in the noninfested areas at two sites. Contrary to previous reports, the fungus survived in soils with sodium contents as high as 5.1 milliequivalents (meq) per 100 g of soil, as indicated by the occurrence of severe disease in such areas in several successive seasons. Applications of sodium chloride at rates ranging from 1,800 to 4,000 kg/ha (equivalent to increasing exchangeable sodium by 1.4–3.1 meq per 100 g of soil) did not reduce disease severity or increase yield significantly in 10 field trials in several locations in Arizona. Also, there was no reduction in disease severity when cotton was planted into infested soil that had been treated with sodium chloride the previous year.

Additional key words: *Gossypium hirsutum*, *G. barbadense*, Phymatotrichum root rot, sodium chloride, soil chemistry.

Phymatotrichum root rot, caused by *Phymatotrichum omnivorum* (Shear) Duggar, is unusual among soilborne diseases because it often occurs in a localized pattern, and is seldom, if ever, spread by tillage or irrigation. In many fields it appears annually in essentially the same areas. The disease is most common in the alkaline, low organic matter soils of the southwestern United States and northern Mexico. In Arizona, it occurs almost exclusively in the floodplains of the major rivers and their tributaries (5). The occurrence of the disease in these well-defined areas led to the suggestion that its distribution might be influenced by some local soil condition (6). If a soil factor responsible for localizing the fungus could be identified, it might be possible to manipulate this factor to control the disease.

Many methods have been tested to control root rot (12), including application of sodium chloride. This treatment was first reported in 1889 (10), and was studied in more detail in the 1930s (13). In 1974, Lyda and Kissel (9) reported that certain soils infested with *Phymatotrichum* contained only 10–25% as much exchangeable sodium as noninfested soils from the same fields. Laboratory experiments (8) indicated that sodium influenced the ability of the fungus to produce sclerotia and to survive in the absence of host plants. Lyda (7) stated that high soil sodium was a likely factor limiting the distribution of *P. omnivorum*. The objective of this work was to determine whether a relationship exists between soil cation content and the occurrence of Phymatotrichum root rot in Arizona. Since cation analysis of alkaline, calcareous soils is complicated by the presence of calcium and magnesium carbonates, several extraction methods were compared to find a procedure that would minimize the error introduced by solubilization of the carbonates. Field trials were conducted to determine whether soil amendments with sodium chloride would reduce disease severity.

MATERIALS AND METHODS

Location and sampling of infested areas. Cotton fields infested with *Phymatotrichum* were located by using aerial infrared photographs taken on 21 September 1978, 6 October 1979, and 22 September 1980, when plant death due to Phymatotrichum root rot was maximal. The photographs were taken with a modified K-37 camera (focal length, 30.5 cm) with Kodak Aerochrome Infrared Film 2443 (ESTAR base) and Kodak Wratten 15 and CC 70B filters from elevations of 3,050 m (air speed, 300 km/hr) and 1,525 m (air speed, 185 km/hr).

Soil cores were taken in 13 infested areas and 10–30 m into the adjacent noninfested areas. That these areas were indeed noninfested was inferred by observing aerial photographs taken at the peak of disease development in several consecutive years. The photographs showed healthy plants in these areas and severely

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diseased plants in the nearby areas from which the infested soil samples were taken. Ground surveys were also made for three consecutive years. The samples were obtained with a hydraulic soil-coring machine (Bull Soil Sampler, 1904 South 21st Street, Chickasha, OK 73018) mounted in the bed of a truck. The 90 × 2.5-cm cores were divided into 30-cm increments. For each of three depth zones (0–30, 30–60, and 60–90 cm), increments from three cores were combined to form a composite sample. Two sets of such composites were obtained from infested areas and two from the immediately adjacent noninfested areas. Each composite sample was mixed thoroughly, passed through a 2-mm-mesh sieve, and oven dried at 60 C for 5 days. Duplicate subsamples were analyzed for cation content.

Samples were obtained from 13 fields in the Marana, Safford, and Coolidge areas of southern Arizona. Subsamples from 10 fields were analyzed for available sodium, potassium, calcium, and magnesium content. Soils from the other three fields were analyzed only for available sodium. Samples from infested and noninfested areas in five of the fields were also analyzed for water-soluble sodium, potassium, calcium, and magnesium.

Determination of cation content of soil samples. The solvent used for extracting the exchangeable cations from a soil can also dissolve carbonates and phosphates, which are only sparingly soluble in the soil solution and are not actually part of the exchangeable cation pool. To identify a cation extraction method that minimizes this source of error, four methods were compared in two separate randomized complete block experiments. In one experiment, clay loam soil samples (3) with a cation exchange capacity (CEC) of 16 meq per 100 g of soil were used. In a second experiment, very fine sandy loam soil samples (4) with CEC values of approximately 13 meq per 100 g soil were tested. The specific rinsing sequences and extracting times for the methods are listed in Table 1. In two of the methods, the soil was first rinsed with isopropanol, a procedure recommended by some soil analysts for the removal of water-soluble cations. The general extraction procedure is described below. The CEC values for the soils were determined as described by Bower et al (1), using ammonium saturation.

TABLE 1. Comparison of methods for determination of soil cation content

	Extraction methods compared			
Extraction method	1	2	3	4
Number of 5-min 99% isopropanol treatments used	0	0	3	3
Time (min) of each 1N ammonium acetate extraction	15	30	15	30
Total cations extracted[a]				
Soil series 1[b]	104	123	135[c]	119
Soil series 2[b]	120	160[c]	186[c]	156[c]

[a] Expressed as percent of an independently determined estimate of the cation exchange capacity, a measure of the number of cation exchange sites present in a soil sample.

[b] Mean values for four soils. Series 1 consisted of samples of four clay loam soils and series 2 consisted of samples of four very fine sandy loam soils.

[c] Significantly greater than the cation exchange capacity ($P = 0.05$).

TABLE 2. Comparison of the ammonium acetate-extractable cation content of soil samples from *Phymatotrichum*-infested areas and the adjacent noninfested areas

	Numbers of locations with:			
		Cation content higher in:		
Cation[a]	No difference	Infested area	Noninfested area	Locations tested (no.)
Na	11	2[b]	0[b]	13
K	10	0	0	10
Ca	9	0	1	10
Mg	8	0	2	10
Total	10	0	0	10
ESP	10	2	1	13

[a] The measure of cation content in these comparisons was milliequivalents per 100 g of soil, except ESP (exchangeable sodium percentage = (extractable sodium)/(total extractable cations) × 100).

[b] Significant differences in at least one of three soil depth zones (0–30, 30–60, 60–90 cm), F test, and $P = 0.01$.

For determination of the exchangeable cation content of a soil sample, the cations held on the exchange complexes in the soil are displaced by ammonium ions, which are present in excess in the extracting solvent (ammonium acetate). For extraction of each soil subsample (1,11), 25 ml of 1 N ammonium acetate (pH 7.0) and 5.0 g of soil were placed in a 50-ml centrifuge tube, which was then stoppered, shaken horizontally on a slide action shaker for 30 min, and centrifuged at 10,000 rpm for 15 min. The supernatant was decanted into a 100-ml volumetric flask, the extraction procedure was repeated, and the combined extracts brought to volume with ammonium acetate. Aliquots (20 ml) of the final preparation were stored at 10 C. One milliliter of an ionization buffer (26,600 mg of cesium chloride per liter) was added to each aliquot (2) and the extracts were analyzed for sodium, potassium, calcium, and magnesium by flame atomic absorption spectrometry.

For the determination of water-soluble cations, 10.0 g of soil and 10.0 ml of distilled water were placed in a 50-ml centrifuge tube. The tube was stoppered and shaken horizontally on a slide-action shaker for 15 min, centrifuged at 10,000 rpm for 15 min, and 5 ml of supernatant was removed and brought to 100 ml volume with distilled water. The extract was stored and analyzed for cation content as described above.

Values for cation contents of replicate samples from infested areas were compared to values for samples from the adjacent noninfested areas with a one-way analysis of variance.

Field tests of sodium chloride application. Ten plots were established in several Phymatotrichum-infested fields in Arizona in 1978, 1979, and 1980. Granulated rock salt (98% NaCl) was broadcast at rates ranging from 1,800 to 4,000 kg/ha. The sodium chloride was disked in and the beds were shaped. This was followed within 2–4 wk by irrigation, bed mulching, and planting with common cultivars of Upland cotton (*Gossypium hirsutum*) or Pima cotton (*G. barbadense*). Treated strips, eight to 16 rows wide, were alternated with untreated strips of equal width. All plots were replicated at least four times.

Cotton plant stand was recorded after emergence. Disease severity was evaluated with aerial infrared photographs, ground observations, and yield data. The middle four rows of each plot were machine-harvested and weighed with a field-scale (Weighmaster model MD-400-C, General Electrodynamics Corporation, Garland, TX 75040).

RESULTS

Ground observations and aerial infrared photographs revealed no reduction in disease severity in any of the sodium chloride-treated field plots. There were no significant differences between seed cotton yield or percent lint in the treated plots and the controls. No effects were noted in later seasons.

Four cation extraction methods were compared to find a method that minimizes solubilization of carbonates and phosphates. The results are reported in Table 1. The sum of all cations extracted by a given method was compared to an independently determined estimate of the CEC. With clay loam soils, extraction method 3 (Table 1) yielded total extractable cations significantly larger than the CEC. Calcium was the component that was present in greater quantities in the method 3 extracts. For the sandy loam soil samples, only method 1 yielded total cation values which were not significantly different from the CEC. The other three methods extracted quantities of total cations significantly greater than the CEC. This can be accounted for by their extraction of greater amounts of calcium, since method 1 did not differ from the other methods in its recovery of any of the other cations (Table 1). Method 1 was used for the determination of cation contents of all soils in this study.

Determinations were made of the water-soluble cation content of soil subsamples from infested and noninfested areas in five of the 13 fields included in this study. In all 55 samples, the water-soluble cations made up a small (in most cases negligible) portion of the available cations. In another experiment with 32 samples from infested and noninfested areas in three fields, total water-soluble cations ranged from 0.15 to 0.8% of the amount extracted by ammonium acetate (mean = 0.3%). Percentage values for the individual cations were also very low. Therefore, no appreciable error is introduced by including the water-soluble components as part of the exchangeable cation pool.

The results of the cation analysis of infested and adjacent noninfested soils are summarized in Tables 2, 3, and 4. The most important finding is that none of the noninfested areas had significantly more sodium than the adjacent infested areas ($P = 0.01$). At two locations, the mean sodium content was significantly higher in the infested areas than in adjacent noninfested areas in at least one of the three soil depth zones sampled.

The percentage of the total cation exchange sites which are occupied by sodium, exchangeable sodium percentage (ESP) is a parameter commonly used in soil chemistry to evaluate the influence of sodium on the soil system. In at least one of the three soil-depth zones sampled, the mean ESP values in the infested areas of two fields were significantly higher than those of the noninfested areas for the two fields, while the reverse was true for one other field ($P = 0.01$). Mean ESP values in infested and adjacent noninfested areas of the other 10 fields sampled did not differ significantly.

DISCUSSION

Soil sodium content does not appear to be a factor limiting the distribution of *P. omnivorum* because there were instances in which the sodium levels in the infested areas were significantly higher than in the noninfested areas. At some locations, levels of other soil cations differed significantly between infested and noninfested areas. There were no differences in cation contents of infested and adjacent noninfested soils in most comparisons. Contrary to other reports (7), severe disease occurred even in soils with available sodium contents as high as 5.1 meq per 100 g of soil and ESP values as high as 12.2. Phymatotrichum root rot is widespread in the Gila River Valley in southeastern Arizona, where high soil sodium is a major production problem.

High cation contents may be a characteristic of certain soils that *Phymatotrichum* does not colonize effectively, but it does not follow from this that the higher cation levels are directly responsible for limiting the distribution and spread of the fungus. In some cases, high cation levels might be correlated with absence of the fungus, but this correlation would not imply a cause-effect relationship. Rather than being directly detrimental to the fungus, the higher cation contents could be a manifestation of some other feature of the soil system.

Differences in cation content of soils may reflect differences in soil colloid (clay and organic matter) content, since these components bear most of the exchangeable cations. Because of its marked influence on the activity of soil microorganisms, organic matter may directly influence the survival of *Phymatotrichum* (12). However, no significant differences in organic matter content were detected between infested and noninfested soils at four sampling sites, and organic matter content was less than 0.5% in all samples tested.

Numerous field trials have shown that sodium chloride application is not an effective way to control *Phymatotrichum* in the soils commonly encountered in Arizona. Taubenhaus et al (13)

TABLE 3. Mean exchangeable sodium contents at three depths in *Phymatotrichum*-infested soils and adjacent noninfested soils

	Depth, 0–30 cm		Depth, 30–60 cm		Depth, 60–90 cm	
Site	Infested	Noninfested	Infested	Noninfested	Infested	Noninfested
1	0.58[a]	0.62	0.58	0.58	0.49	0.51
2	0.22[b]	0.35	0.25[b]	0.32	0.31	0.35
3	0.59	1.06	0.56	0.70	0.49	0.67
4	0.82	0.72	0.90	0.78	0.88	0.75
5	0.89	0.65	0.87	0.80	1.03	1.19
6	0.56	0.56	0.61	0.65	0.51[b]	0.70
7	3.48	3.64	1.88	2.40	1.71	2.45
8	3.26	3.73	5.10	4.68	4.20[b]	3.53
9	3.81[b]	5.36	4.23	4.79	2.53	3.90
10	1.01[b]	0.66	1.71[b]	1.01	1.76[b]	1.08
11	0.28	0.39	0.43	0.49	0.36	0.30
12	0.60	0.40	0.72	0.69	0.83	0.84
13	0.14	0.07	0.15	0.31	0.26	0.31

[a] Milliequivalents of sodium per 100 g of soil, determined by extraction with 1.0 normal ammonium acetate followed by flame atomic absorption spectrometry.

[b] Significant difference between exchangeable sodium content of infested and noninfested soil at this depth.

TABLE 4. Ranges of exchangeable sodium contents in replicate samples from three depths in *Phymatotrichum*-infested soils and adjacent noninfested soils

	Depth, 0–30 cm		Depth, 30–60 cm		Depth, 60–90 cm	
Site	Infested	Noninfested	Infested	Noninfested	Infested	Noninfested
1	0.57–0.59	0.54–0.69	0.54–0.61	0.48–0.68	0.45–0.52	0.41–0.62
2	0.17–0.28	0.32–0.39	0.23–0.27	0.30–0.36	0.25–0.37	0.29–0.39
3	0.52–0.66	0.80–1.32	0.52–0.59	0.59–0.80	0.49–0.49	0.56–0.77
4	0.69–1.10	0.71–0.72	0.61–1.20	0.75–0.81	0.81–0.95	0.71–0.80
5	0.87–0.90	0.63–0.66	0.77–0.97	0.80–0.80	0.80–1.10	1.08–1.29
6	0.52–0.59	0.49–0.63	0.56–0.66	0.65–0.66	0.49–0.52	0.66–0.73
7	3.20–3.76	3.51–3.76	1.84–1.91	2.19–2.61	1.60–1.88	2.12–2.78
8	3.17–3.34	3.55–3.90	4.98–5.22	4.42–4.94	4.18–4.21	3.48–3.58
9	3.58–4.04	5.36–5.36	3.65–4.80	4.59–4.98	2.23–2.82	3.83–3.97
10	0.87–1.15	0.66–0.66	1.57–1.84	1.01–1.01	1.60–1.91	1.04–1.11
11	0.14–0.42	0.36–0.42	0.33–0.53	0.47–0.51	0.26–0.45	0.16–0.41
12	0.57–0.63	0.31–0.48	0.65–0.78	0.35–1.05	0.40–1.25	0.79–0.88
13	0.11–0.17	0.04–0.10	0.14–0.15	0.19–0.43	0.15–0.37	0.20–0.41

[a] Milliequivalents of sodium per 100 g of soil.

obtained disease control only in artificially inoculated, container-grown plants, and only after three consecutive years of treatments at rates equivalent to 4,500–9,000 kg of sodium chloride per hectare per year in several soil types.

Sodium chloride applications have been tested on a large scale in Texas. Results have been inconsistent, and none appear unequivocal. If application of sodium chloride is found to reduce disease in certain situations, it remains to be determined whether this is due to the effect of the sodium ion, the chloride ion, or to some effect of the ions on the soil system, thereby indirectly affecting the fungus. Any benefits would have to be carefully weighed against the potential detrimental effects of sodium on soil structure and plant vigor.

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