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EFFECT OF SOIL CATIONS ON THE DISTRIBUTION OF
PHYMATOTRICHUM OMNIVORUM (SHEAR) DUGGAR

The University of Arizona

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EFFECT OF SOIL CATIONS
ON THE DISTRIBUTION OF
PHYMATOTRICHUM OMNIVORUM
(SHEAR) DUGGAR

by

James Paul Mueller

A Dissertation Submitted to the Faculty of the
DEPARTMENT OF PLANT PATHOLOGY
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY
In the Graduate College
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1981

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read
the dissertation prepared by James Paul Mueller

entitled The Effect of Soil Cations on the Distribution of Phymatotrichum
omnivorum (Shear) Duggar

and recommend that it be accepted as fulfilling the dissertation requirement
for the Degree of Doctor of Philosophy in Plant Pathology.

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Final approval and acceptance of this dissertation is contingent upon the
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I hereby certify that I have read this dissertation prepared under my
direction and recommend that it be accepted as fulfilling the dissertation
requirement.

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to Diane

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ABSTRACT

The occurrence of the cotton root rot fungus, Phymatotrichum omnivorum (Shear) Duggar, in sharply defined, localized areas in certain fields led to the suggestion that there may be a specific soil chemical factor which limits the spread of the fungus. The available sodium, potassium, calcium, and magnesium contents of infested and adjacent noninfested soils in 13 fields were determined and compared. At seven sites, there were no significant differences in cation contents of infested and adjacent noninfested areas ($p = 0.05$). Available sodium levels were higher in infested areas at three sites, and higher in noninfested areas at three sites. Potassium and calcium levels were higher in the infested area at one site, and higher in the noninfested areas at two sites. Magnesium levels were higher in the noninfested areas at three sites. Contrary to previous reports, the fungus was found to cause severe disease in soils with available sodium contents as high as 4.2 milliequivalents per 100 g soil. Applications of sodium chloride at rates ranging from 1800 to 4000 kg/ha did not reduce disease severity or increase yield significantly in ten field trials.

INTRODUCTION

The cotton root rot fungus, Phymatotrichum omnivorum (Shear) Duggar, is unusual among soil-borne pathogens in that it often has a peculiar localized distribution pattern, and is not spread by cultivation and irrigation. In some cases it appears year after year in essentially the same areas. Where spread does occur, it is generally uniform in all directions. This was first indicated by farmers and early researchers (14,15,16,19), and is clearly demonstrated in the aerial photographs used in this study. The occurrence of the fungus in these well-defined areas led to the suggestion that its distribution might be influenced by some local soil condition (10). If a soil factor responsible for localizing the fungus could be identified, it may be possible to manipulate this factor and thereby control the disease.

A variety of treatments and cultivation methods have been tested in attempts to control root rot (20). One method is application of sodium chloride, a treatment first reported in 1889 (16), and studied in more detail in the 1930's (21,22,23). In 1974, Lyda and Kissel (12) reported four to ten times less exchangeable sodium in infested soils

than in noninfested soils from the same fields. Laboratory experiments (11) suggested that sodium may influence the ability of the fungus to produce sclerotia and may affect its ability to survive in the absence of host plants. Lyda has stated that soil sodium is the "intrinsic factor" limiting distribution of Phymatotrichum omnivorum (10).

Many available soil cations are adsorbed on the surface or within the crystal framework of soil minerals (clays) and on organic colloidal particles such as humus. These are known as exchangeable cations. The exchange of one cation for another on soil colloids is one of the most common and important of soil reactions. Plants and microorganisms force exchangeable cations into solution by displacing them with other cations, particularly hydrogen. The displaced cations can then be assimilated by living organisms, transported in soil water, or reabsorbed (3).

Varying amounts of the soil cations are also present in the soil solution surrounding these particles. Under normal conditions, the concentrations of cations on and near the exchange sites is constantly changing. To get an estimate of the amount of a specific cation potentially available for interaction with the biosphere, both the soluble and exchangeable forms must be measured.

To determine whether there is a relationship between

soil cation content and the occurrence of Phymatotrichum, soils from 13 infested and adjacent noninfested areas were sampled. Levels of four cations (sodium, potassium, calcium, and magnesium) were determined and compared. Field trials were conducted to determine whether soil amendments of sodium chloride would reduce disease severity.

Cation analysis of the alkaline, calcareous soils of arid and semi-arid regions is complicated by the presence of calcium and magnesium carbonates. Solutions used for extracting the "available" (soluble and exchangeable) cations (18) may dissolve significant amounts of the carbonates (2), which are not normally available to most of the soil microflora. To find a method which minimizes the error introduced by solubilization of the carbonates, four extraction methods were compared. This source of error was reduced further by expressing cation levels as milliequivalents of each cation rather than as a percentage of the total extracted (which is common in soil chemistry literature).

In certain soil systems it is important to differentiate the cations adsorbed on the soil colloids and those present in the soil solution. The water soluble cation content of 55 soil samples was measured to determine whether water soluble cations constitute a significant proportion of the available cations.

A COMPARISON OF THE CATION CONTENT OF PHYMATOTRICHUM -
INFESTED AND NONINFESTED AREAS IN ARIZONA

Materials and Methods

Location and Sampling of Infested Areas

Series of aerial infra-red photographs of cotton fields were taken on September 21, 1978, October 6, 1979, and September 22, 1980, when Phymatotrichum root rot was at a maximum level. The photographs were taken with a modified K-37 camera (30.5 cm focal length) with Kodak Aerochrome Infrared Film 2443 (ESTAR base) and a Kodak Wratten filter Number 12, from elevations of 3050 m (air speed 300 km/h) and 1525 m (air speed 185 km/h). Each 20 x 30 cm high resolution image can be greatly enlarged with little loss of detail. The photographs were used to locate the infested areas at any time of year. Without them it was only possible to sample accurately when a diseased crop was present.

Soil cores were taken in infested areas and in adjacent noninfested areas with a hydraulic soil coring machine mounted in the bed of a truck. The 90 x 2.5 cm cores were divided into 30 cm increments. Each sample consisted of a

composite of three core increments from a given depth. 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. Subsamples were used for cation analysis. Series of samples were obtained from 13 fields in the Marana, Coolidge, and Safford, Arizona areas. Samples from ten of the fields were analyzed for available sodium, potassium, calcium, and magnesium content. The other three sample series were analyzed only for available sodium. Samples from five of the fields were also analyzed for water soluble sodium, potassium, calcium, and magnesium.

Determination of Cation Content of Soils

The preliminary experiments for determining the best ammonium acetate extraction (NH_4OAc) method are reported in the next section. For NH_4OAc extraction of the sample, 25 ml of 1 N NH_4OAc (pH 7.0) was added to the tube, which was then stoppered, shaken for 30 min, and centrifuged at 10000 rpm for 15 min. The supernatant was decanted into a 100 ml volumetric flask and the extraction procedure was repeated, and the extract brought to volume with NH_4OAc . Aliquots (20 ml) of the extracting solution were stored at 10 C in 22 ml plastic vials. After addition to each vial of 1 ml of

26,600 ppm cesium chloride (an ionization buffer, final concentration 100 ppm)(5), the extract was analyzed for sodium, potassium, calcium, and magnesium by flame atomic absorption spectrometry.

For determination of water soluble cations, 10.0 g of soil and 10.0 ml distilled water were placed in a 50 ml plastic centrifuge tube. The tube was stoppered and shaken horizontally on a slide action shaker at moderate speed for 15 min, centrifuged at 10000 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. The water soluble cation content of 55 soils was determined. To test the reproducibility of the extraction technique, a randomized complete block experiment with three replications per soil was performed with 32 of the soils (8).

The ppm values for the cations in the extracts were converted to milliequivalents per 100 g soil (meq). Cation values for replicate samples from infested areas were compared to values for samples from the adjacent noninfested areas with a one - way analysis of variance (F test) at the 95% and 99% confidence levels.

Results

In all 55 soils tested, the water soluble cations made up a small (in most cases negligible) portion of the available cations. In the replicated experiment with 32 soils, total water soluble cations ranged from 0.1% to 0.8% of the amount extracted by NH_4OAc (mean = 0.3%). Percentage values for the individual cations were also very low (Table 1). This indicates that it would not be necessary to perform water extractions on all of the soil samples in the survey. No appreciable error is introduced by including the water soluble components as part of the exchangeable cation pool.

The randomized complete block experiment testing the water extraction technique demonstrated that the method is highly reproducible. There were no significant differences among replications for any of the cation determinations, even at very high confidence levels ($p = 0.003$ to 0.008).

The results of the survey of infested fields are summarized in Tables 2, 3, and 4. The instances in which there were significant differences in the available cation contents of adjacent infested and noninfested areas are discussed here. The soils in four of the fields are in the Agua very fine sandy loam soil series, and consist of very

fine sandy loams and silt loams to a depth of about 70 cm with fine sand or gravelly sand beneath, to a depth of approximately 180 cm. The pH values for these soils range from 7.9 to 8.4, and the electrical conductivity values (EC) range from 0 to 2 millimhos per cm (mmho/cm) (7). In one of these fields, the available sodium content of the noninfested soil was significantly higher ($p = 0.05$) than that of the infested soil. In another field, available calcium, magnesium and total available cations were significantly higher in the noninfested areas.

Four fields had soils in the Vinton - Anthony series, with sandy loams and loamy fine sands to a depth of approximately 150 cm. The pH and EC values for these soils range from 7.4 to 8.4 and 0 to 2 mmho/cm, respectively (7). The noninfested area in one of these fields had significantly higher available sodium ($p = 0.05$). In one field, the potassium content was higher in the noninfested area.

In a field of Grabe silty clay loam (pH 7.4 to 8.4, EC 2 to 4 mmho/cm), the available sodium content of the infested soil was higher than that of the noninfested soil. In a field of Grabe clay loam (pH 7.4 to 8.4, EC approx. 2 mmho/cm), available sodium and calcium levels were higher in the infested area. The noninfested soil in one field of Guest clay (pH 7.9 to 8.4, EC 0 to 4) had significantly

higher levels of all four cations. The available sodium and potassium contents were significantly higher in the infested area in a field of Vecont clay loam (pH 7.9 to 8.4, EC approx. 1), while the magnesium content of the noninfested soil was significantly higher.

When the data were analyzed at a higher confidence level ($p = 0.01$), none of the locations had significantly higher sodium levels in the noninfested soils. At two locations, available sodium was significantly higher in the infested than in the noninfested soils ($p = 0.01$).

Water soluble cation contents of soils from infested and adjacent noninfested areas in five fields were compared. At one site, levels of all four cations were significantly higher in the noninfested area ($p = 0.05$). At one other site, the soluble potassium content was higher in the infested area ($p = 0.05$). There were no significant differences at the other locations.

Table 1. Comparison of the cation contents of ammonium acetate extracts and water extracts of 32 soils.

cation	ammonium acetate extract	water extract	percent
Na	2.2 ¹	.064 ¹	2.9 ²
K	1.1	.0036	.33
Ca	28.	.023	.082
Mg	.052	.0058	1.1
Total	31.	.096	.31

1. milliequivalents/100 g soil, mean of 32 soils.

2. (water extract/ammonium acetate extract) x 100.

Table 2. Comparison of cation content of Phymatotrichum infested soils with adjacent noninfested soils ($p = 0.05$).

parameter	number of sites with		
	no difference	parameter higher in infested area	parameter higher in noninfested area
meq Na	7	3 ¹	3
meq K	7	1	2
meq Ca	7	1	2
meq Mg	7	0	3
meq total	8	0	2

1. significant difference in at least one of three depth zones (F test, $p = 0.05$).

Table 3. Comparison of cation content of Phymatotrichum infested soils with adjacent noninfested soils (p = 0.01).

parameter	number of sites with		
	no difference	parameter higher in infested area	parameter higher in noninfested area
meq Na	11	2 ¹	0
meq K	10	0	0
meq Ca	9	0	1
meq Mg	8	0	2
meq total	10	0	0

1. significant difference in at least one of three depth zones (F test, p = 0.01).

Table 4. Average values of available soil cations which differ significantly between Phymatotrichum infested and adjacent noninfested soils ($p=0.05$).

field #	cation	depth zone	average value	
			noninfested	infested
2	Na	1	0.35 ²	0.22 ²
2	Na	2	0.32	0.25
3	K	1	1.3	0.88
3	K	2	0.63	0.45
4	Ca	1	29.	28.
4	Mg	1	2.5	2.0
4	Total	1	33.	32.
5	Na	1	0.65	0.89
6	Na	3	0.70	0.51
8	Na	3	3.5	4.2
8	Ca	1	34.	37.
8	Total	1	41.	44.
9	Na	1	5.4	3.8
9	Na	3	3.9	2.5
9	K	1	2.5	1.6

1. zone 1 = 0 to 30 cm, zone 2 = 30 to 60 cm, zone 3 = 60 to 90 cm.

2. milliequivalents of cation per 100 g soil.

Table 4. -- Continued.

9	K	¹ 2	² 1.7	² 1.1
9	K	3	1.6	0.5
9	Ca	1	43.	30.
9	Ca	2	37.	29.
9	Ca	3	34.	13.
9	Mg	3	0.55	0.4
9	Total	1	52.	36.
9	Total	2	45.	34.
9	Total	3	40.	17.
10	Na	1	0.66	1.1
10	Na	2	1.0	1.7
10	Na	3	1.1	1.8
10	K	2	0.37	0.4
10	Mg	3	0.48	0.1

1. zone 1 = 0 to 30 cm, zone 2 = 30 to 60 cm,
zone 3 = 60 to 90 cm.

2. milliequivalents of cation per 100 g soil.

COMPARISON OF METHODS FOR DETERMINATION
OF SOIL CATION CONTENT

Several methods for obtaining estimates of available soil cations have been used in soil chemical studies. These methods are of two general types: "leaching" methods, which involve passing an extractant solution through a soil sample held in a filter apparatus (1,4), and "shaking" methods, which involve agitation of the soil and the extracting solution, followed by removal of particulates by centrifugation or filtration (18,25). With soils of low permeability, the leaching method is time-consuming and inconvenient. More rapid and efficient soil processing is possible by shaking samples in centrifuge tubes with successive portions of the extracting solution. In the experiments reported here, four modifications of the basic shaking-centrifugation technique (18) for ammonium acetate extraction were compared to find a method which minimizes the error introduced by solubilization of the carbonates and phosphates. The sum of all cations extracted by a given method was compared to an independently determined estimate of cation exchange capacity (CEC), a measure of the number of exchange sites present in a soil sample.

Materials and Methods

Ammonium Acetate-Extractable Cations

Four extraction methods were compared. The specific rinsing sequences and extracting times for the methods are listed in Table 6. In two of the methods, the soil was first rinsed with alcohol, a procedure recommended by some soil analysts for the removal of water-soluble cations (13). To process a sample, 5.00 g of oven-dried (60 C, 5 days), sieved (2 mm mesh) soil was placed in a 50 ml plastic centrifuge tube. For methods requiring alcohol rinses, 25 ml of 99% isopropyl alcohol was added and the tube was stoppered and shaken horizontally on a slide action shaker at moderate speed for the specified amount of time. After rinsing the stopper and the sides of the tube into the tube with isopropyl alcohol, the tube was centrifuged at 10,000 rpm for 10 min. The supernatant was discarded and the rinsing procedure was repeated two more times.

For ammonium acetate extraction of the sample, 25 ml of 1 N ammonium acetate (pH 7.0) was added to the tube, which was then stoppered and shaken for the specified amount of time by the method described above. The supernatant was decanted into a 100 ml volumetric flask and the extraction procedure was repeated. Aliquots (20 ml) of the extracting

solution were stored at 10 C in 22 ml plastic vials. After addition to each vial of 1 ml of 26,600 ppm cesium chloride (an ionization buffer, final concentration 100 ppm)(5), the extract was analyzed for sodium, potassium, calcium, and magnesium by flame atomic absorption spectrometry.

Cation Exchange Capacity by Sodium Saturation

A 5.00 g sample of oven-dried, sieved soil and 25 ml of 1 N sodium acetate (pH 8.2) were placed in a 50 ml plastic centrifuge tube, which was then stoppered and shaken for 5 min horizontally on a slide action shaker set at medium speed. The stopper and sides of the tube were then rinsed into the tube with the sodium acetate solution. The tube was centrifuged at 10,000 rpm for 10 min. The supernatant was discarded. The pellet was resuspended in sodium acetate and processed as described above. The entire process was repeated a total of four times. The sample was then washed in an identical manner with three successive 33 ml portions of 99% isopropyl alcohol to remove the excess sodium acetate. The sample was then extracted with three 25 ml portions of 1 N ammonium acetate (pH 7.0). The supernatants were decanted into a 100 ml volumetric flask and brought to volume with ammonium acetate solution. The sodium content

of the extract was determined by flame atomic absorption spectrometry.

Test Soils

The methods were compared in two separate experiments. Experiment one used a series of soil samples from the 30 to 60 cm depth in a Phymatotrichum - infested field at the University of Arizona Experiment Station at Safford. These soils are Pima clay loam variants (6,17), and can exchange approximately 16 meq of cations per 100 g soil. Sodium comprises about 12 percent of the exchangeable cations. Experiment two used four Agua very fine sandy loam soil samples (7) obtained from the 30 to 60 cm depth in an infested field near Marana, Arizona. The cation exchange capacities of these soils averaged 13 meq per 100 g soil, and sodium comprised approximately 3 percent of this total.

Experimental Design

The extraction experiments used a randomized complete block design. This minimized variability within blocks by assigning, as experimental units, five subsamples of a soil sample to a single block, and randomly assigning treatments to the experimental units within a block. The

results were analyzed with a one-way analysis of variance (F test) at the 95% confidence level (8).

Results

In NH₄OAc extraction experiment one, method 3 (Table 5) yielded total extractable cations significantly larger than the CEC. Calcium was the component which was present in greater quantities in the method 3 extracts. In experiment two, 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 (Table 5), since method 1 did not differ from the other methods in its recovery of any of the other cations.

The objective of this portion of the research was to devise an extraction method which minimizes the error introduced into available cation measurements by solubilization of the carbonates and phosphates. Several methods were compared to find a method for which the sum of the extracted cations does not differ significantly from an independently determined estimate of the CEC. This approach is valid for the soils used in this study because the water soluble

portion of the NH_4OAc - extractable cations is usually negligible. The cation exchange capacities of the test soils were determined with sodium as the index cation. Therefore, these measurements included no error due to solubilization of calcium and magnesium carbonates and phosphates.

Table 5. Summary of methods for extraction of available soil cations.

	method			
	1	2	3	4
number of 5 min 99% isopropanol treatments	0	0	3	3
time (min) of each 1N ammonium acetate extraction	15	30	15	30
total cations (% of CEC):				
soil series 1 ¹	104 %	123 %	135 % ²	119 %
soil series 2 ¹	120	160 ²	186 ²	156 ²
meq calcium extracted:				
soil series 1 ¹	12 m ³	15 m	17 m	15 m
soil series 2 ¹	15	20	24	20

1. mean values for four soils.

2. significantly greater than the cation exchange capacity ($p = 0.05$).

3. milliequivalents per 100 g soil.

FIELD TESTS OF SODIUM CHLORIDE SOIL
AMENDMENT FOR ROOT ROT CONTROL

Materials and Methods

Ten field plots were established in Phymatotrichum - infested fields. Granulated rock salt (98 % sodium chloride) (NaCl) was broadcast at rates ranging from 1800 to 4000 kg/ha. The sodium chloride was disked in and the beds were shaped. This was followed within two to four weeks by irrigation, bed mulching, and planting with commonly used varieties of upland cotton (Gossypium hirsutum) or long staple (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.

Stand counts were made after emergence. Disease severity was evaluated with aerial infra - red photographs, ground observations, and yield data (the middle four rows of each plot were harvested and weighed).

At one site, where two NaCl rates were being tested, soil samples were obtained for analysis of sodium content. Soil cores (90 cm x 2.5 cm) were taken in the center of the

bed, divided into 30 cm lengths, and composited with the corresponding segments from two other cores. Two sets of such composites were obtained from untreated areas and from areas treated with each rate of NaCl. Also, a series of soil samples were obtained from the tops of the beds, from the sides of the beds, and from the furrows, with a 2.5 cm diameter hand - held soil probe. Each of these samples consisted of a composite of three 30 cm long cores. One such composite was obtained from the treated area, and one each from two of the NaCl - treated areas.

Results

Ground observations and aerial infrared photography revealed no reduction in disease severity in any of the sodium chloride - treated field plots. There were no significant increases in seed cotton yield or percent lint turnout in the treated plots. Also, no effects were noted in later seasons.

Table 6. Sodium content of soil cores from field plots treated with sodium chloride.

		sodium chloride applied (kg/ha)		
		0	2000	4000
		depth ¹ zone		
pre-plant ² samples	1	.68a ³	.98a ³	3.0a ³
	2	.63x	1.5xy	1.8y
	3	.68z	.93z	.92z
post-harvest ⁴ samples	1	.60a	1.0b	1.1b
	2	.58x	1.2y	1.0y
	3	.50a	.58a	.86b

1. zone 1 = 0 to 30 cm, zone 2 = 30 to 60 cm, zone 3 = 60 to 90 cm.
2. means, two composite samples of three cores each.
3. milliequivalents available sodium / 100 g soil. In each row, numbers followed by the same letter are not significantly different ($p = 0.05$).
4. means, four composite samples of three cores each.

Table 7. Sodium content of bed and furrow soils in field plots treated with sodium chloride.

sample ¹	sodium chloride applied (kg/ha)		
	0	2000	4000
hill top	0.68 ²	1.0	0.90
hill side	0.28	0.49	0.48
furrow	0.26	0.48	0.52

1. composite of three 2.5 x 30 cm cores.

2. milliequivalents available sodium / 100 g soil.

DISCUSSION

The results of this work indicate that, in most cases, sodium is not the factor which limits the distribution of Phymatotrichum omnivorum in Arizona. Although there were instances in which the sodium levels in the noninfested areas were significantly higher than in the infested areas, there were also cases for which the reverse was true. At some locations, levels of other soil cations differed significantly between infested and noninfested areas. In most cases there were no differences in cation contents of infested and adjacent noninfested soils. Contrary to other reports (10), the fungus was found to be well established in soils with available sodium contents as high as 4.2 milliequivalents per 100 g (Table 4).

High cation contents may be a characteristic of certain soils which Phymatotrichum does not colonize effectively, but it does not follow from this that the higher cation levels are responsible for limiting the spread of the fungus. Rather than being directly detrimental to the fungus, the higher cation contents could be a manifestation of some other feature of the soil system. High cation levels might

in some cases be correlated with absence of the fungus, but this correlation would not imply a cause - effect relationship.

Differences in cation content of soils may reflect differences in clay or organic matter content, since these components bear most of the cations. Because of its marked influence on the activity of soil microorganisms, organic matter could directly influence the survival of Phymatotrichum (20). Cation content can also be an indicator for many other features of the soil environment.

Numerous field trials have shown that application of sodium chloride is not an effective way to control Phymatotrichum in the types of soils commonly encountered in Arizona. It remains to be seen whether applications of sodium will result in disease control in soils which differ from the types common in Arizona. With several soil types common in Texas, Taubenhans et. al. obtained disease control only in artificially inoculated, container - grown plants, and only after three consecutive years of treatments at rates equivalent to 4000 to 8000 pounds of sodium chloride per acre per year (21,22,23,24).

Several researchers and cotton growers in Texas have been testing sodium chloride applications on a large scale.

Results have not been consistent, and no unequivocal results have been published to date. 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 or the chloride ion, or to some effect of the ions on the soil system, thereby indirectly affecting the fungus. In any case, the benefits obtained by applying sodium would have to be carefully weighed against the detrimental effects of sodium on soil structure and plant vigor.

The soil components active in cation exchange, the soil colloids (both organic and inorganic), are essentially complexes of negatively charged substances and adsorbed cations. In the alkaline, calcareous soils of arid and semi-arid regions, the most common adsorbed cations are calcium, magnesium, sodium, and potassium. The quantities of exchangeable cations in a soil sample can be estimated by replacing them with cations from an extracting solution. Mainly by mass action effects (the extracting cation is present in large excess), the cations in the extracting solution displace the cations on the exchange sites (3).

The ammonium acetate solution used in this study extracts cations which, under natural conditions, were held in the exchangeable form on the soil colloids, and also

those which were present in the soil solution. The extractant can also dissolve the carbonates and phosphates. These forms are only sparingly soluble in the soil solution and do not interact with the soil microorganisms to the extent that the soluble and exchangeable forms do. The presence in the soil extract of calcium and magnesium derived from the carbonates introduces error into measurements of available soil cations (2). This source of error was minimized by selecting the proper combination of extracting method and time.

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