Evaluation of Deep-Chiseled Anhydrous Ammonia as a Control for Phymatotrichum Root Rot of Cotton

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ABSTRACT

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A 5-yr study was conducted to evaluate an anhydrous ammonia (NH_3) fumigation for controlling Phymatotrichum root rot of cotton. NH_3 (112 kg/ha) was chiseled 40 cm deep into the soil with a Big Ox chisel plow. NH_3 distribution studies showed the retention zone to be about 25 cm wide. NH_3 fumigation was compared with deep chiseling without NH_3 and conventional tillage as a means of controlling root rot. Despite the known toxicity of NH_3 to *Phymatotrichum omnivorum*, the NH_3 treatment was no more effective in controlling Phymatotrichum root rot than deep chiseling alone. The highest amount of disease and lowest yields occurred in the conventional tillage plots.

Anhydrous ammonia (NH_3) has long been recognized as a fungicidal compound. Rush and Lyda (14) evaluated the toxicity of NH_3 to *Phymatotrichum omnivorum* and found that 84 μg NH_3/ml air and a 1-hr exposure reduced sclerotial germination to zero. However, when sclerotia were mixed with Houston black clay, a 24-hr exposure and 224 μg NH_3/g soil was required to reduce sclerotial germination to 21%. Eno and Blue (3) and Eno et al (4) studied the effects of NH_3 on nematodes, fungi, and bacteria. Immediately after treatment, populations of these organisms declined within the ammonia retention zone but remained unchanged outside this zone. Within 10 days, the number of bacteria in the treated soil had increased 10-fold, but fungal populations were depressed. Birchfield et al (1) used NH_3 alone and in combination with potassium azide to control selected fungi and nematodes pathogenic to soybean. They injected the gas into the center of an 18.9-L container filled with soil. Determination of microbial populations was made at selected distances from the injection point. A concentration gradient was produced that was directly related to the biocidal gradient. Within 5 cm of the injection point, NH_3 alone was very effective in reducing the number of microorganisms; however, the number of organisms increased at a distance greater than 10 cm from the injection point. Leach and Davey (9,10) found that NH_3 could be used effectively to control *Sclerotium rolfsii*. They applied NH_3 (300 μg/ml) to irrigation water and increased sugar beet yields from 11 to 20 kg/ha above those of the untreated plots. This increase was attributed to a reduction in disease severity. Smiley et al (15,16) used NH_3 in an attempt to control Fusarium root rot of wheat. The ammonia was applied 7–10 cm deep with a chisel. Although good control was obtained within the ammonia retention zone, overall disease control failed, with more disease occurring in the NH_3-treated plots than in controls.

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Use of NH_3 fumigations to control soilborne pathogens has had limited success, primarily because of a relatively uniform distribution of the pathogens, uneven distribution of NH_3, and high rates of nitrification. However, because of certain biological characteristics of *P. omnivorum*, we felt that control of Phymatotrichum root rot with NH_3 fumigation was feasible. *Phymatotrichum* sclerotia are not evenly distributed throughout the soil but are formed in isolated clumps within a field (usually at a depth of 30–60 cm [11]), making localized treatment possible. In addition, *P. omnivorum* is restricted to calcareous, clay soils in Texas. Nitrification is not a serious problem in these soils when the NH_3 is placed lower than 15 cm. Because of these facts plus the known toxicity of NH_3 to *P. omnivorum*, a field study was conducted to evaluate NH_3 fumigation as a method of controlling Phymatotrichum root rot of cotton.

MATERIALS AND METHODS

Field tests were conducted from 1977 through 1982 at the Blackland Research Center in Temple, TX. A cotton field with a history of severe Phymatotrichum root rot was used. The soil type was Houston black clay (Udic Pellustert [fine montmorillonitic thermic]), pH 7.8–8.2. NH_3 ammonia (82% N) stored as a pressurized liquid in a nurse tank was applied at the rate of 112 kg/ha.

Deep placement of NH_3 was accomplished with a Big Ox chisel plow with parabolic-shaped shanks spaced 50 cm apart. An application tube welded to the back of each shank was connected to a gas regulator attached to the nurse tank. The desired depth of application was about 46 cm but varied from 36 to 46 cm, depending on soil conditions.

The first year of this study, the NH_3 treatment was applied in the spring, but in subsequent years, applications were made as soon after harvest as possible. Conventional tillage and deep chiseling without NH_3 served as checks. Plots measured 12.2×61 m, with six replicates of each treatment. Thirty meters of the center two rows in each plot were marked off for disease evaluation. Initial stand counts were taken and disease counts were made at 2-wk intervals.

NH_3 distribution after field fumigation. Soil cores were taken from treated and untreated areas in the field 24 hr after chiseling. In the treated areas, cores were taken in the chisel trace and 13 and 25 cm from the trace. Cores (5×91 cm) taken with a hydraulic soil sampler were cut into 7.6-cm segments, placed in plastic bags, and analyzed for NH_4 within a week of the NH_3 application, using the modified Conway microdiffusion test (13).

Table 1. Effects of NH_3 and deep chiseling on root rot incidence

Treatment	Percent cotton root rot[y]						
	1977	1978	1980	1981	1982	5-Yr average	Lint[z] (kg/ha)
Deep chisel + NH_3	1 a	12	34 a	42 a	11 a	20.0 a	458 a
Deep chisel	11 b	19	27 a	28 a	6 a	18.5 a	541 a
Conventional	8 b	32	71 b	73 b	33 b	43.4 b	299 b

[y] Means followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

[z] Average yield from 1980 to 1982.

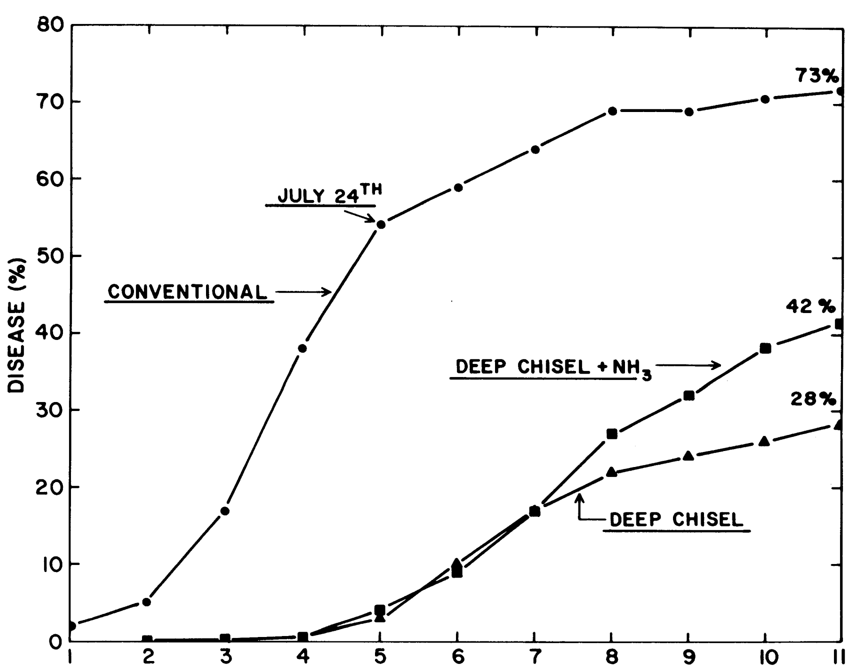

Fig. 1. Development of Phymatotrichum root rot during the 1981 growing season.

RESULTS

In preliminary tests, rates of 224 and 448 kg NH_3/ha with and without nitrapyrin (N-Serve) (2%) or sodium azide (2%) were evaluated. Neither higher rates of NH_3 nor addition of nitrification inhibitors improved disease control over the 112-kg NH_3/ha treatment. For this reason, the lower rate was used in all subsequent tests. Results from the NH_3 fumigation studies are shown in Table 1. Despite the reported toxicity of NH_3 to the strands and sclerotia of *P. omnivorum* (14), the fumigation procedure neither reduced disease incidence nor increased yield over deep chiseling alone. However, both deep chiseling and deep chiseling plus NH_3 reduced disease incidence, delayed disease onset, and increased yield compared with conventional tillage. Deep chiseling has previously been suggested as a method for controlling Phymatotrichum root rot (17), but results have been erratic. In this study, however, deep chiseling provided the best results among the three treatments.

Deep chiseling with or without NH_3 greatly delayed the onset of disease. Figure 1 shows the development of Phymatotrichum root rot during the 1981 growing season. Five weeks after disease initiation, an average of 54% of the plants were dead in the conventional tillage plots, whereas fewer than 5% had died in either of the other two treatments. Once disease began to appear, however, the rate of disease increase was equivalent to that in the conventional tillage plots. The same general trends were observed each year of this study.

NH_3 distribution. Each year, an attempt was made to place the NH_3 at least 45 cm deep; however, as indicated by the values in Table 2, 38 cm was the maximum depth reached by the chisel during the 1980 treatment. The NH_3 moved outward and upward from the injection point forming a V-shaped area 22 cm high and 25 cm wide. The depth of retention was about 19–34 cm below the soil surface in the chisel trace and 12.7 cm from the trace, it was 19–27 cm deep. There was no downward movement of NH_3 from the point of injection. No NH_4 above those concentrations found in the check soils was detected farther than 12.7 cm from the chisel trace.

DISCUSSION

NH_3 is very fungitoxic but has been ineffective in controlling diseases caused by soilborne pathogens. The usual reasons cited for this failure are widespread distribution of the pathogen and minimal movement of NH_3 through

Table 2. Distribution of NH_4^+ in field soil after NH_3 chiseling treatment in 1980

Sample depth (cm)[a]	Horizontal distance from chisel (cm)			
	Check	0	12.7	25.4
3.8	24.2[b]	26.2	18.1	20.5
11.4	24.8	26.9	19.3	21.2
19.0	22.9	147.3	142.0	20.8
26.6	22.3	315.0	151.0	20.8
34.2	21.2	213.0	18.9	14.3
41.8	18.6	29.4	15.5	15.2

[a] Value represents midpoint of each 7.6-cm segment.
[b] Each value represents the mean of nine samples. NH_3 distribution was determined by measuring μg NH_4^+/g of soil at various levels and distances from the injection point.

the soil. The first of these problems does not apply to *Phymatotrichum* and we felt the latter could be overcome by the lifting action of the Big Ox chisel plus the high pressure at which the gas entered the soil. Although the NH_3 retention zone in this study measured 25 cm wide compared with the usual 5–10 cm reported by others (1,7,16), only one-half of the soil was exposed to the gas. Spacing the chisels closer than 50 cm apart would increase the area treated but would also increase the energy required to pull the plow because of the high clay content of the soil.

The clay fraction of Houston black clay (about 60%) is composed of a 2:1 expanding lattice mineral, montmorillonite (8). This mineral has a high cation exchange capacity, shrinks and swells, and has a high percentage of exposed surface area. When exposed to NH_3, clay minerals instantaneously adsorb large amounts of the gas. There are two types of adsorption involved, physical sorption and chemsorption. The NH_3 that is "loosely held" is termed physically sorbed ammonia. Physical adsorption is considered to be achieved through H-bonding, of which there are three forms (5): 1) bonding of the NH_3 hydrogens to the O of the clay lattice surface, 2) bonding of the NH_3 hydrogens to the hydroxyl ions on the octagonal surface, and 3) bonding of the NH_3-N to the hydroxyl ions. Of these three, the N . . . HO bond is the strongest.

Chemsorbed NH_3 is characterized by a chemical change of NH_3 to NH_4. It is more tightly held than physically sorbed NH_3 (12). There are four proposed mechanisms for chemsorption (2,5,6). The first is a reaction between NH_3 and the lattice hydroxyls found on the exterior planar surface and also among the broken edges of clay minerals. Because all clays contain these weak acid hydroxyl groups, this type of adsorption should be expected to some degree.

The second and third proposed mechanisms for chemsorption deal with soil water in different states, a reaction between NH_3 and free water or a reaction with the tightly held water of hydration.

The fourth mechanism for chemsorption is formation of amine-type complexes with cations on the clay mineral surface. This reaction is based on the similarities between NH_3 and H_2O. Both molecules are polar but NH_3 has only one unshared electron pair. Al and Zn amine complexes can be formed and are stable in aqueous media. Any substance that will hydrate can also ammoniate with stability of the complex, depending on the cation (18).

The reactions described help explain why soil fumigation with NH_3 to control soilborne pathogens is usually unsuccessful. These reactions occur to some degree in all soils containing a clay fraction. The same reactions occur in high organic soils. NH_3 fumigation would perhaps be more effective in sandy soils, but the problems of volatilization, leaching, and nitrification would also be more pronounced. We believe NH_3 fumigations to control soilborne plant pathogens or other crop pests will be ineffective because of the extreme reactivity of NH_3 with soil components and its rapid conversion to the nontoxic NH_4^+ form.

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