Fusarium Foot Rot of Wheat and Peas as Influenced by Soil Applications of Anhydrous Ammonia and Ammonia-Potassium Azide Solutions

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ABSTRACT

Populations of *Fusarium roseum* f. sp. *cerealis* 'Culmorum', F. *solani* f. sp. *pisi*, and saprophytic fusaria were reduced within the NH_3 retention zone in situ in the field following injection of the soil with liquid anhydrous NH_3 using a portable, hand-operated dispenser. However, little or no reduction in numbers of *Fusarium* propagules could be detected in the tillage layer when anhydrous NH_3 was applied to soil with a field applicator using different methods of placement at rates up to 224 kg N/hectare at each of three widely separated geographical locations during two different seasons. Chlamydospore germinability was markedly reduced by exposure to 400 or 600 μg NH_3-N/g of dry soil for 5 or 1 min, respectively. However, banding the NH_3 within the wheat row at comparable concentrations failed to control Fusarium root and foot rot of winter wheat. Potassium azide dissolved in NH_3 increased slightly the effectiveness of kill within the NH_3 retention zone in the laboratory, but was ineffective in the field. Failure of NH_3 to reduce the *Fusarium* population in the field was attributed primarily to insufficient distribution of NH_3 throughout the tillage layer. Nearly all treatments where N was applied caused increased incidence of Fusarium foot rot of wheat.

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In previous laboratory trials (15), populations of *Fusarium roseum* (Lk. ex Fr.) emend. Snyd. & Hans. f. sp. *cerealis* (Cke.) Snyd. & Hans. 'Culmorum', *F. solani* (Mart.) Appel & Wr. f. sp. *pisi* (F. R. Jones) Synd. & Hans., and total fusaria (including saprophytes) were eliminated, or nearly so, within the NH_3 retention zones of both Ritzville (RSL) and Palouse (PSL) silt loams after injection of the soils with liquid anhydrous NH_3. *Fusarium* populations outside the retention zone remained unchanged whereas, in the zone (up to 5 cm from the point of injection) there was no recovery at 225 days after injection.

The question remains: Can application of anhydrous NH_3 at practical rates effectively control plant parasitic fusaria in the field? In the Northwest, anhydrous NH_3 is the principal N source for wheat, and is usually applied during the summer or early fall prior to planting. Application depth is generally 13 to 15 cm (tillage depth) at shank spacings of 40 to 50 cm. Propagules of *Fusarium* are uniformly distributed in the tillage layer (8), and propagule kill is limited to the NH_3 retention zone (15). Thus, the mode of application must be modified to adequately expose all infested soil to the NH_3. Alternatively, it may be sufficient to treat only that soil of the region destined to contain plant parts commonly infected by *Fusarium* rather than to treat the tillage layer at large. In the Northwest, Culmorum enters winter wheat plants (*Triticum aestivum* L.) primarily through the crowns 2 to 3 cm below the soil surface (4). Eliminating the fungus in the soil zone destined to contain the wheat crown could provide economic reductions in disease, as *Fusarium* propagules are essentially immobile in soils (3). Soil between wheat rows could remain untreated.

The fungicidal effects of anhydrous NH_3 might be enhanced further by dissolving potassium azide (KN_3) in liquid anhydrous NH_3 (1), or by environmental conditions that favor an accumulation of nitrite (NO_2^-) (13, 15, 19). In addition to direct biocidal effects of KN_3 (12), the NH_3 + KN_3 formulation delays nitrification of NH_3 (11), and therefore may prolong the duration of initially higher NH_3 concentrations in the soil.

It would be desirable to derive fungicidal as well as fertility benefits from applications of anhydrous NH_3, or anhydrous NH_3 formulated with another chemical. The fungicidal effects of NH_3 in soil are well documented (15), but little is known of its practical usefulness in disease control. This paper reports the results of field evaluations of NH_3, and of KN_3 formulated with liquid NH_3, as a fungicide against *Fusarium* in four eastern Washington soils.

MATERIALS AND METHODS.—*Pullman.*—The experiment was located on PSL containing an estimated 4,500 Culmorum and 2,800 *F. solani* f. sp. *pisi* propagules/g of soil. Liquid anhydrous NH_3 was injected 8 cm deep into fallow soil with a portable, hand-operated applicator which closely duplicated

the laboratory applicator used in previous studies (10, 14, 15). A series of injections at 730 mg N/injection were made in September 1967. The NH_3 was retained in a nearly spherical zone, 10 to 15 cm in diam, at each injection point.

Three retention zones were sampled at each of 1, 7, 14, 28, 49, and 104 days after injection. A short trench approximately 2 ft deep was excavated near one side of each NH_3 retention zone to be sampled. A piece of sheet metal was then pressed vertically through the injection point, and the freed soil removed. The exposed face through the center of the retention zone was then sampled with the wire rings of radii described earlier (15). Samples were analyzed for $NH_4^+ + NH_3$, pH, and populations of Culmorum, *F. solani* f. sp. *pisi*, and total fusaria.

Harrington and Ritzville.—In August 1968, anhydrous NH_3 was injected into fallow, Culmorum-infested (500-800 propagules/g soil) RSL at neighboring locations (20 miles apart), using a specially designed tractor-mounted field applicator (16) at intended rates of 0, 56, 112, and 224 kg N/hectare. Applications were made in dry soil at a depth of 10-13 cm: (i) using 76-cm sweeps having NH_3 outlets along the base and spaced 10 cm apart; or (ii) in bands using shanks spaced 40 cm apart. Broadcast applications of NH_4NO_3 were included as controls. A randomized block design with three replications of plots 2.4 X 18.3 m was used. Winter wheat was seeded in moist soil at a 15-cm depth in 40-cm rows with a deep furrow drill 2 weeks following NH_3 application. In the banded treatment, attempts were made to seed the wheat in the application row; with sweep treatments, wheat was seeded perpendicular to the direction of NH_3 application.

In late August 1969, anhydrous NH_3 and a solution of $NH_3 + KN_3$ (6% w/w) were injected into fallow RSL (estimated Culmorum population, 2,400 propagules/g soil) near Harrington, with the field applicator (16) coupled in tandem with a deep furrow drill such that wheat was seeded simultaneously with the treatments. The $NH_3 + KN_3$ solution was formulated by dissolving a predetermined weight of KN_3 with an appropriate volume of liquid NH_3 under pressure in a 38-liter mixing tank as described by Papendick et al. (11). The solution was metered directly from the mixing tank, through the applicator, and through 15-cm sweeps, each with six base outlets 3 cm apart. The sweeps were mounted such that the chemicals were placed in the wheat row (i) in the dust mulch 4-5 cm above the seed; or (ii) in moist soil 1-2 cm above the seed. Applications of anhydrous NH_3, $NH_3 + KN_3$, and broadcast NH_4NO_3 at rates of 0, 112, and 224 kg N/hectare in plots 2.4 X 18.3 m were replicated 3 times in a randomized block design.

Samples of the surface 10 cm of soil were taken from within the wheat rows at 1 and 8 months after seeding in August 1968, and 1 and 5 months after seeding in August 1969. Five samples were taken from each replicate of each treatment, combined, mixed, and dilution-plate counted for Culmorum population (8).

Observations on incidence of Fusarium foot rot of wheat as affected by rate of NH_3 were made both years at Harrington. In the 1968-69 crop year, ca. 100 plants (30-35/replicate) were removed at random from each plot shortly before maturity and examined for brown discoloration (foot rot) of the stem bases and presence or absence of empty heads (whiteheads) caused by the foot rot (4). In the 1969-70 crop year, ca. 100 young plants (30-35/replicate) were removed from each treatment in April and washed, and the crowns then surface-sterilized and placed on potato-dextrose agar to determine the percentage infected by Culmorum. An additional 30-50 plants were examined for foot rot just prior to maturity in June.

Dayton.—Two soils infested with *F. solani* f. sp. *pisi* were selected; a Patit Creek silt loam (PCSL) with an estimated 1,000 propagules/g, and an Athena silt loam (ASL) with an estimated 440 propagules/g of soil. Anhydrous NH_3 was injected at a 10-cm depth into fallow soil with the field applicator, using the 76-cm sweeps as described for the Harrington and Ritzville sites. Applications at intended rates of 112 and 224 kg N/hectare were made in September 1968. Equivalent rates of surface-applied NH_4NO_3 were included as controls. Treatments were arranged in a randomized block design using four replications of plots 2.4 X 18.3 m on PCSL and two replications of plots 2.4 X 91.4 m on ASL.

Soil samples were taken from both sides at 0 and 2 weeks after application, and from the PCSL again at 23 weeks after application. The sampling procedure and subsequent analyses were identical to those described for the Harrington and Ritzville sites.

Ammonium N (Pullman site only) was determined from equilibrium extracts of soil in 2 N KCl (1:10 ratio) by steam distillation, using a semimicro Kjeldahl procedure (2). The extract was also used for pH measurements. The *Fusarium* population was estimated using three 1-g samples from each composite field sample, diluted 1:200. Three petri dishes were prepared for each of the three diluted samples, making a total of nine petri dishes/composite field sample.

The Pullman and Dayton sites are in the higher rainfall (52 and 49 cm annually, respectively) wheat-pea region, and Ritzville and Harrington are in the low rainfall (25 and 33 cm, respectively) wheat-fallow area.

NH_3 concentration and exposure time needed to affect Culmorum chlamydospore germinability.—A laboratory study was conducted to provide information on NH_3 rates and exposure time needed to kill chlamydospores of Culmorum. Air-dry RSL, infested with an estimated 7.5×10^5 Culmorum chlamydospores/g of soil, was wetted to ca. −2 bars water potential and stored at 25 C for 1 week. Half the soil was then air-dried at room temperature, and 25-g lots of dry soil and moist soil were placed in stoppered Erlenmeyer flasks. Ammonia was metered into the flasks at rates of 0, 200, 400, 600, or 1,000 μg

NH_3-N/g of dry soil, using a gaseous anhydrous NH_3 dispenser (9). Each flask was vigorously shaken while introducing the NH_3, and intermittently during incubation to ensure uniform mixture of NH_3 in the soil. At 1, 5, or 30 min, or at 3, 10, or 24 hr of incubation in darkness at 25 C, the soils were washed three consecutive times with a solution of 0.025 M glucose plus 0.025 M ammonium sulfate, decanted, and finally incubated at 20 C for 24 hr to allow chlamydospore germination. Percentage germination was determined by microscopic observation using soil smears (7). A total of 100 spores for each of three replicate samples/treatment was counted.

Injection of soil with NH_3 + KN_3 solutions.—RSL infested with chlamydospores of Culmorum was wetted to ca. −2 bars water potential and packed into each of six 3.8-liter (1-gal) cans that were previously split in half longitudinally, taped back together, and lined with polyethylene bags (15). Two cans each were then injected, respectively, with NH_3 alone, 730 mg N/can; 4.46% KN_3 (w/w) dissolved in NH_3 (equivalent to 10 μg KN_3/g of dry soil); and 8.92% KN_3 in NH_3 (20 μg KN_3/g). The point of injection was in the center of the can approximately 8.8 cm (3.5 inches) below the soil surface. Injection of the cans was done by J. F. Parr, Baton Rouge, La., using a previously described method (1) and injector (14). The cans were sampled for populations of Culmorum ca. 1 month after injection. The method of obtaining soil from within the NH_3 retention zone was as described earlier (15). Soil from the top, bottom, and edges of the cans was also sampled and tested for survival of Culmorum. Each sample consisted of 1 g diluted 1:1,000 and seeded in three petri dishes of the petone-PCNB agar medium (8).

RESULTS.—*The NH_3 retention zone, and the influence of NH_3 or NH_3 + KN_3 applications on Fusarium populations in the field.—Pullman.*—The NH_4^+-N concentrations presented in Table 1 and concentration changes in the retention zone during the study period compare reasonably with those found after injection of NH_3 into PSL in the laboratory (15). Moreover, though the NH_3 was introduced by a point-source mode, the resulting NH_4^+-N concentration distributions closely resemble those reported for typical field applications where placement is by a line source (6, 11). Initially, most of the NH_3-N was retained within a radial distance of 5 cm. Some outward movement of NH_4^+-N occurred at later dates. Both the pH and NH_4^+ levels are generally lower than those for the previous laboratory injections.

Populations of Culmorum, *F. solani* f. sp. *pisi*, and total fusaria declined with time within the NH_3 retention zones (Table 1). The pattern was again similar to that detected earlier in the laboratory (15). Population reductions were detectable in the centermost region of the zones within the 1st week following injection of NH_3. The decline was less rapid at increasing distances from the site of injection, but by 104 days, even the outermost region (4- to 5-cm zone) contained a low or undetectable *Fusarium* population.

Harrington and Ritzville.—During the 1968 postinjection period, the population of Culmorum was not significantly decreased by applying up to 224 kg N/hectare as NH_3, whether placed in bands above the seed row or uniformly throughout the 15-cm tillage layer. In fact, the Culmorum population

TABLE 1. Concentration of NH_4^+ + NH_3, pH, and populations of fusaria in the NH_3 retention zone following injection of liquid anhydrous NH_3 into Palouse silt loam near Pullman, Wash.

Days after injection	NH_4^+ + NH_3, μg N/g of soil			NO_3^-, μg N/g of soil			pH		
	0-2[a]	2-4	4-5	0-2	2-4	4-5	0-2	2-4	4-5
1	1,823[b]	1,129	86	0	0	0	8.3[c]	7.5	5.7
7	1,633	1,003	614	0	0	0	7.1	6.6	5.9
14	1,189	1,118	660	1	2	2			
28	1,116	829	521	24	27	24	6.9	6.5	5.7
49	559	604	450	82	95	90	6.2	6.6	6.2
77	249	128	63				5.8	5.3	5.2

	Culmorum				*F. solani* f. sp. *pisi*				Total *Fusarium*			
	0-2	2-4	4-5	Control	0-2	2-4	4-5	Control	0-2	2-4	4-5	Control
1	0.94[d]	2.55	4.05	4.51	0.55	1.38	1.61	1.94	7.00	14.33	16.88	27.16
7	0.42	1.08	3.75	4.83	0.00	0.83	2.17	3.00	1.75	4.83	14.50	24.66
28	0.11	3.16	2.44	4.76	0.59	1.71	1.80	2.85	3.45	14.70	12.97	24.29
49	0.00	0.13	0.66	4.62	0.07	0.13	0.20	2.71	0.83	1.35	3.47	25.03
104	0.06	0.00	0.00	4.91	0.12	0.09	0.38	2.91	0.63	0.09	0.76	25.70

[a] Radial distance in cm from the NH_3 injection site. The control was nonammoniated soil taken near the sampling site.

[b] The NH_4^+ + NH_3 and NO_3^- concentrations are expressed as averages of three replications of actual concentrations minus the nonammoniated control.

[c] The pH was determined from equilibrium extracts of soil in 2 N KCl (1:10 ratio).

[d] Each *Fusarium* count is the average of 18 replicates in thousands of propagules/g oven-dry soil.

remained at an amazingly stable 500-800 propagules/g at both Harrington and Ritzville regardless of the rate of NH_3 applied. All populations, including controls, dropped to about 300-500 by 8 months, possibly because of a severe winter between the 1- and 8-month sampling times. In 1969, applications of NH_3 and a solution of NH_3 + KN_3 caused some reductions in Culmorum populations 5 months after application, but the results were variable. The greatest reductions were found after application of 224 kg N/hectare of NH_3 and NH_3 + KN_3, where the estimated Culmorum populations were 1,280 and 720 propagules/g of soil, respectively, compared to 2,440 propagules/g for the control soil. Both reductions were significant at the 5% level, but in no case were they considered of practical significance because 100 propagules/g of soil are known to cause reductions in yield (4).

Dayton.—None of the N treatments reduced populations of *F. solani* f. sp. *pisi* on PCSL or ASL from initial values of 1,000 or 440 propagules/g of soil, respectively. Instead, populations of the fungus increased slightly (but not significantly) during the study period in which NH_3 and NH_4NO_3 were applied at 112 and 224 kg N/hectare. Whether the increases reflected affects of N or normal population trends is uncertain.

TABLE 2. Incidence of Fusarium foot rot of wheat shortly before maturity (July) as influenced by injection of liquid anhydrous NH_3 at two shank spacings into Ritzville silt loam near Harrington, Wash. (1969 crop year)

NH_3 shank spacing	Rate of NH_3 application	Whiteheads[a]	*Fusarium*-infected culms
cm	*kg N/hectare*	*%*	*%*
10	0	2.6 abc[b]	6.9 bc
	56	1.0 *c*	4.1 *bc*
	112	0.9 *c*	5.3 bc
	224	3.7 a	12.6 a
40	0	0.6	4.9 bc
	56	3.0 ab	7.3 b
	112	2.6 ab	12.5 a
	224	7.1	18.7

[a] Prematurely ripened tillers caused by early death.
[b] Numbers having a common letter were not significantly different from each other; italicized values are significantly different at the 5% level. All other numbers are significantly different at the 1% level.

Influence of anhydrous NH_3 and NH_3 + KN_3 solutions on incidence of Fusarium foot rot of wheat.—Wheat stands were satisfactory in both 1968 and 1969 with all methods of N placement. At the 1968 Harrington site, the N rate was directly correlated with the percentage of wheat plants with Fusarium root and foot rot (Table 2). A severe winter killed the wheat plants at Ritzville, making disease observations at that location impossible.

In April, after the 1969 fall N application at Harrington, wheat crown infection by Culmorum appeared reduced with the 224-kg N/hectare application rate as compared with the control (Table 3). Infections were fewest for surface-applied NH_4NO_3; however, the treatment differences were not significant. In contrast, the number of infected culms just prior to maturity was higher where N was applied, compared with no N, although again differences were not statistically significant. However, the percentage of whiteheads did increase significantly with 112 kg N/hectare as NH_3 + KN_3, and 224 kg N/hectare as NH_4NO_3. Thus, the NH_3 alone or with KN_3 not only failed to rid the soil of *Fusarium* at the rates applied, but actually increased the amount of disease caused by the prevailing Culmorum population.

Culmorum populations following laboratory injections of soil with NH_3 + KN_3 solutions.—Potassium azide dissolved in NH_3 was only slightly more effective against Culmorum than was NH_3 alone. Kill in the peripheral regions of the retention zone (4 to 5 cm from the point of injection) was more effective with NH_3 + KN_3 than with NH_3 alone, particularly at the 20 μg KN_3/g of

TABLE 3. Incidence of Fusarium root and foot rot of wheat in Ritzville silt loam near Harrington, Wash. (1970 crop year) after injection of NH_3 alone and a solution of NH_3 + KN_3 (6% w/w) in dry soil as a band 2 to 3 cm above the wheat seed, or after uniform surface application of NH_4NO_3

Treatment	Rate of NH_3 application	Crowns infected in April	*Fusarium*-infected culms in June	Whiteheads[a] in June	Grain yield
	kg N/hectare	*%*	*%*	*%*	*kg/hectare*
None	0	81	54.0	7.0 bc[b]	3,313
NH_3	112		64.2	5.6 b	4,912
	224	60	60.2	7.4 bc	5,591
NH_3 + KN_3	112		59.1	11.7 a	5,349
	224	55	63.8	6.2 b	3,904
NH_4NO_3	112		56.6	7.0 bc	4,267
	224	48	57.0	9.4 ac	4,825

[a] Prematurely ripened tillers caused by early death. Measurements indicated an average Nugaines wheat kernel weight of 18.4 mg for whiteheads as compared to 38.1 mg for "healthy" wheat heads.
[b] Percentage of whiteheads not having a common letter are significantly different at the 1% level. In addition, the significance between the lowest values (5.6 and 6.2) and 9.4 is at the 5% level. None of the differences in other columns was significant.

TABLE 4. Populations of *Fusarium roseum* f. sp. *cerealis* 'Culmorum' in a Ritzville silt loam in 3.8-liter cans after injection of the soil with NH_3 with and without KN_3

Treatment	Sampling region: Within NH_3 retention zone 0-2[a]	2-4	4-5	Outside retention zone B-1[b]	B-2	T-1	T-2
NH_3	Tr[c]	Tr	15.9	57.8	60.2	39.5	21.8
NH_3 + KN_3 at 10 μg N/g[d]	0	0	10.9	48.2	44.7	32.5	38.3
NH_3 + KN_3 at 20 μg N/g	0	0	1.6	53.6	37.5	41.9	37.9

[a] Centimeters radial distance from the site of injection.

[b] B-1, bottom near one edge of the can; B-2, bottom near the opposite edge of the can; T-1, top or surface soil near one edge of the can; and T-2, top near the opposite edge of the can.

[c] Each number is an average number of colonies per petri dish for 12 plates (two replicates of two 1-g samples, each diluted 1:1,000 and seeded on three petri dishes, 1 ml/petri dish). Less than 100 colonies/petri dish is denoted as a trace (Tr).

[d] Based on oven-dry weight of soil to which it was applied.

soil rate, but in soil above and to the sides of the retention zone (edge of the cans in the surface 1 cm) or beneath the retention zones (bottoms of the cans), no reductions in Culmorum populations were detectable (Table 4). Apparently, the KN_3 remained almost as localized, within the NH_3 retention zone, as did NH_3 alone.

Effect of NH_3 concentration and exposure time on Culmorum chlamydospore germinability.—Percentage "kill" increased as exposure time increased and as NH_3-N concentration increased (Fig. 1). A 1-min exposure was fully adequate when the concentration was 1,000 μg NH_3-N/g of dry soil. Reduction in germinability was slow where 200 μg NH_3-N/g was applied. Even after 24 hr of exposure, the NH_3 concentration required for rapid and effective kill was between 400 and 600 μg N/g of dry soil.

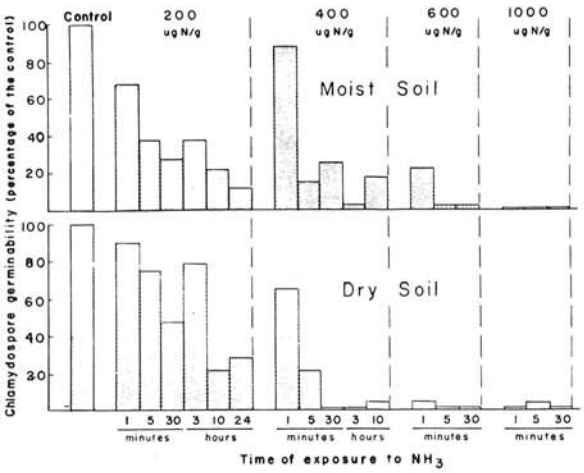

Fig. 1. Percentage germinability of *Fusarium roseum* f. sp. *cerealis* 'Culmorum' chlamydospores after treatment of air-dry and moist (ca. −2 bars water potential) Ritzville silt loam with 0, 200, 400, 600, or 1,000 μg NH_3-N/g of soil, and incubated for 1, 5, or 30 min or 3, 10, or 24 hr.

DISCUSSION.—It seems clear that liquid anhydrous NH_3 may act as a fungicide against Culmorum, *F. solani* f. sp. *pisi*, and probably other fusaria in soil under field conditions. Populations approached, and in some cases reached, zero within the NH_3 retention zone following injection of NH_3 into soil in the field, using a portable, hand-operated dispenser. Although no population decline occurred outside this zone, there was no recovery within the retention zone after 104 days following NH_3 application.

On the other hand, it seems equally clear that the potential usefulness of NH_3 to rid soil of *Fusarium* on a field-scale basis is limited, at least for the methods of NH_3 placement, the rates applied, and the areas included in our study. Reductions in populations of Culmorum or *F. solani* f. sp. *pisi* were not significant either with NH_3 alone, or where KN_3 was formulated with NH_3. Instead, populations remained relatively stable for the duration of the experiments. Higher rates of NH_3 are not feasible for wheat production under dryland conditions, and it is improbable that NH_3 could be placed more accurately near the wheat crown than was done at Harrington (1970 crop year).

In the studies at Dayton, Ritzville, and Harrington (1969 crop year), NH_3 was probably ineffective against the fusaria because inadequate amounts of soil were exposed to NH_3. It can be inferred from calculations that application of 224 kg NH_3-N/hectare to soil in the 15-cm tillage layer and at 10-cm spacings results in an actual treatment (retention zone) of about 20% of the total soil volume. The same rate of N released at 40-cm spacings results in larger but fewer retention zones and treatment of about 15% of the total soil volume in the surface 15 cm of soil. Thus, areas above, below, and between the retention zones would remain infested with fusaria. With movement of soil subsequent to application of NH_3, the treated and

untreated soils undoubtedly are mixed. Soil was disturbed by weed-control and planting operations at all sites during the 1969 crop year.

Assuming that the retention zones occupy no more than 20% of the surface soil volume when 224 kg N/hectare as NH_3 is applied, one could infer that complete treatment of this layer would require 5 times more NH_3, or about 1,200 kg N/hectare. A figure of comparable magnitude is reached if we accept 400-600 μg NH_3-N/g of soil as the threshold for effective control of chlamydospore germination. Uniform application of NH_3 at this rate may be achieved without soil mixing, when soil is treated heterogeneously during the planting operation, as was done at Harrington (1970 crop year). The NH_3 was injected about 10 cm in front of the seed furrow-opener, forming bands spaced at 40-cm centers to conform with the seed row spacing. Yet, even with this method of placement, the chlamydospore population was not reduced sufficiently to control the disease.

Under laboratory conditions (15), more than 80 μg NO_2^--N/g of soil was detected in the NH_3 retention zone during the first few weeks after injection. When KNO_2 was added to soil, 35 μg NO_2^--N/g of soil completely eliminated the *Fusarium* population. Moreover, when NH_3 was injected into soil that had been sterilized by gamma radiation, then infested with Culmorum, NO_2^- did not accumulate and the radial distance of kill out from the site of injection was considerably less than that of nonsterile soil. The ineffective kill of *Fusarium* in our field tests may reflect the fact that NO_2^- did not accumulate. Thus, it appears that although both the pea and wheat foot rot fusaria are destroyed by NH_3 in the retention zone, there is little or no chance for effectively controlling either of these diseases with NH_3 in Pacific Northwest fields. On the contrary, our observations and those of others (5, 17, 18) suggest that such treatments may actually increase the incidence and severity of Fusarium root and foot rot.

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