

## Application of alkaline-stabilised biosolids for *Meloidogyne incognita* suppression in microplots

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**Summary** – N-Viro Soil (NVS) is an alkaline-stabilised biosolid that has been shown to suppress *Meloidogyne incognita*. In separate microplot studies, NVS was applied either alone at different rates (0, 25, 50, 75, 100 dry t ha<sup>-1</sup>), or in combination with *M. incognita*-resistant and *M. incognita*-susceptible cultivars, to different *M. incognita* initial densities (0, 37 500, 75 000 eggs/microplot). NVS suppressed *M. incognita*. During year 1, increasing rates of NVS resulted in higher soil solution pH and greater *M. incognita* J2 and egg suppression. Soil solution pH remained higher in NVS-amended plots compared to the unamended control in years 2 and 3. NVS was more effective in reducing moderate than in reducing high initial nematode populations, with 94-100% reduction in egg and juvenile populations compared to 75-79%, respectively. In all experiments, a reduction in nematode populations by NVS, alone or in combination with a resistant cultivar, did not occur consistently in years 2 or 3. Unfortunately, the application rate of NVS required to achieve this reduction in nematode populations is probably not agronomically realistic. Additional research may allow the rate of NVS required to suppress plant-parasitic nematodes to be reduced.

**Keywords** – ammonia, biosolid, *Glycine max*, N-Viro Soil, pH, soybean.

The N-Viro process mixes dewatered municipal biosolids with alkaline admixtures (*i.e.*, cement kiln dust, fly ash or quicklime) to yield a pathogen-free, solid material with many beneficial agronomic properties (Logan & Burnham, 1995). The agricultural value-added benefits of N-Viro Soil (NVS) include improved soil fertility, addition of organic matter and suppression of plant-parasitic nematodes (Welacky & Topp, 2001; Zasada & Tenuta, 2004; Zasada, 2005).

N-Viro Soil has been shown to suppress plant-parasitic nematodes in a range of studies (Alptekin, 2001; Welacky & Topp, 2001; Zasada & Tenuta, 2004; Meyer *et al.*, 2005; Zasada, 2005). In laboratory tests (Zasada & Tenuta, 2004), the lethal concentration of NVS that killed 90% (LC<sub>90</sub>) of second-stage juvenile (J2) populations was 1.4% dry weight amendment/dry weight sand for *Meloidogyne incognita* and *Heterodera glycines*. The LC<sub>90</sub> values for eggs were 2.6 and >3.0% for *M. incognita* and *H. glycines*, respectively. Nematode mortality caused by NVS was positively correlated with sand suspension pH levels and, to a lesser extent, with ammonia accumula-

tion following amendment (Zasada & Tenuta, 2004; Zasada, 2005). Glasshouse and field experiments have also demonstrated some suppression of *H. glycines* (Alptekin, 2001; Welacky & Topp, 2001) and *M. incognita* (Meyer *et al.*, 2005).

We have previously reported on the ability of NVS to suppress *M. incognita* and *H. glycines* and the mechanisms involved (Zasada & Tenuta, 2004), the factors that may influence the efficacy of NVS (Zasada, 2005), and NVS in combination with a biological control agent for *M. incognita* suppression on melon (Meyer *et al.*, 2005). The research reported here is a step towards the practical field application of NVS for plant-parasitic nematode management. The objectives of this research were to: *i*) evaluate different application rates of NVS for *M. incognita* management in a loamy sand; *ii*) evaluate the potential for combining *M. incognita*-resistant soybean (*Glycine max*) cultivars with NVS; *iii*) determine the influence of initial *M. incognita* populations on NVS suppressiveness; and *iv*) monitor the impact of NVS on soil solution pH.

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## Materials and methods

*Meloidogyne incognita* race 1, originally isolated from a field near Salisbury, MD, USA, and cultured on glass-house-grown pepper (*Capsicum annuum*) 'PA-136' was used. Eggs were extracted with 0.5% sodium hypochlorite solutions from the roots of 3-month-old pepper plants and used immediately.

Two experiments were conducted at the Lower Eastern Shore Research and Education Center (LESREC), Salisbury, MD, in 56 cm diam. polystyrene microplots on a Norfolk A loamy sand (85% sand, 10% silt, 5% clay) with a pH of 6.0. For both experiments, the top 15 cm of soil (37 l) was removed from each plot prior to the incorporation of the amendment and/or inoculation of *M. incognita* eggs. The first experiment evaluated the effect of increasing rates of NVS on *M. incognita* survival and soil solution pH. The experimental design was completely randomised with five replications. N-Viro Soil (N-Viro International, Toledo, OH, USA) was incorporated at rates of 0, 25, 50, 75 and 100 dry t ha<sup>-1</sup> and 75 000 *M. incognita* eggs were inoculated into each microplot in 10 ml water. All treatments were thoroughly mixed into the soil that had been removed from the plot and the mixture was returned to the microplot. Approximately 1 h after treatment, soil samples were collected to measure soil solution pH. Five days after treatment, 20 *M. incognita*-susceptible soybean cv. Hutchinson seeds were planted per microplot and thinned to eight plants per microplot approximately 4 weeks after planting. An additional set of untreated plots inoculated with *M. incognita* were planted with the *M. incognita*-resistant soybean 'Delsoy 5710'. Soybeans were fertilised based upon tests of soil nutrient levels and irrigated as needed throughout the experiment. Also at this time, a second set of soil samples was taken to measure soil solution pH. At soybean harvest, yield, eggs/g fresh root, J2/100 ml soil and soil solution pH were determined. During year 2 of this experiment the same experimental design was maintained and the same *M. incognita*-resistant and *M. incognita*-susceptible cultivars were used. Soil solution pH was determined prior to planting and at the end of the experiment. Soybean yield, eggs/g fresh root and J2/100 ml soil were determined at harvest.

The second experiment evaluated the ability of NVS in combination with resistant and susceptible soybean cultivars to suppress three initial population densities of *M. incognita*. The experiment was a factorial randomised complete block design with five blocks. N-Viro Soil (0

or 75 dry t ha<sup>-1</sup>) was incorporated into microplots to which 0 (low), 37 500 (medium) or 75 000 (high) *M. incognita* eggs/microplot were added. The amendment and eggs were thoroughly mixed with the soil. Soil solution pH was determined 1 h after incorporation, at planting and at harvest in five replicates of amended and unamended plots. Five days after treatment, 20 seeds of either susceptible (Hutchinson) or resistant (Delsoy 5710) soybean cultivars were planted and thinned to eight plants per microplot approximately 4 weeks after planting. Soybeans were fertilised based upon soil tests and irrigated as needed throughout the experiments. Soybean yield, eggs/g fresh root and J2/100 ml soil were determined at harvest. During year 2 the same experimental design was maintained and the same cultivars were used. Soil solution pH was determined prior to planting and at the end of the experiment. Soybean yield, eggs/g fresh root and J2/100 ml soil were determined at harvest time.

During year 3 of both experiments, cucumber (*Cucumis sativa*) cv. Sweet Slice was planted in all of the microplots as an indicator plant for *M. incognita* reproduction. Plants were removed from microplots 6 weeks after planting and eggs extracted and expressed as eggs/g fresh root. Soil samples were collected before planting to determine soil pH.

During soil sampling, six cores of 2.5 cm diam. and 15 cm depth were taken from each microplot to form composite soil samples. Cores were collected randomly from the plot and the holes closed. Soil samples were placed in a cooler for transportation to the laboratory. In the laboratory, *M. incognita* J2 were extracted from 100 ml of soil spread thinly on a tissue supported by mesh using the Baermann funnel method. Nematodes were collected after 48 h. Nematodes in the sample were counted on an inverted microscope and J2/100 ml wet soil calculated.

Three root systems were removed from each microplot to determine eggs/g fresh root. Root weights were determined and the roots were cut into small pieces. Root pieces were placed in a blender with 200 ml of 0.5% sodium hypochlorite solution and blended for 2 min at high speed. The resulting slurry was poured over nested 60- and 500-mesh sieves. The eggs were retained on the 500-mesh sieve, where they were washed with water to remove the sodium hypochlorite before saving in aqueous suspension under refrigeration until they were counted. Two, 1 ml aliquots were counted to determine the numbers of eggs/g fresh root.

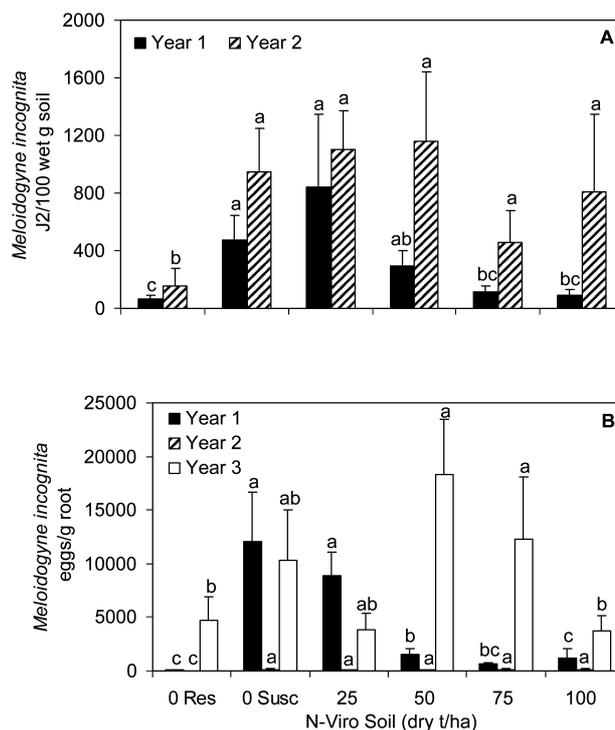
For pH determination, composite soil samples of six cores (2.5 cm diam., 15 cm depth) were taken from each microplot, homogenised and a 25 g subsample taken. Ten g of soil was placed in a 100 ml Erlenmeyer flask, and 50 ml deionised water added. The mixture was agitated using a reciprocal shaker at 2000 rpm for 15 min, allowed to settle for 15 min and the pH of the solution was then determined. Soil moisture content was determined on approximately 10 g of the subsample by weight loss after heating at 100°C for 24 h.

Differences in response variables among treatments were analysed using PROC MIXED (SAS 9.1, Cary, NC, USA). *Meloidogyne incognita* J2 data were log-transformed prior to analysis to meet the assumptions of the model; egg data were analysed using weighted variance groupings. A repeated statement was included in the analysis to identify difference in soil solution pH within a treatment over time in the rate experiment. Means were compared using Tukey's adjustment for multiple comparisons ( $P > 0.05$ ). All errors are presented as the mean  $\pm$  1 standard error.

## Results

### EFFECT OF INCREASING RATES OF N-VIRO SOIL ON *MELOIDOGYNE INCOGNITA* POPULATION DENSITIES, SOIL SOLUTION pH AND SOYBEAN YIELD

In year 1, only the two highest rates of NVS, 75 and 100 t ha<sup>-1</sup>, reduced J2 populations compared to the susceptible cultivar control (Fig. 1A). These rates of NVS reduced J2 populations to levels similar to those found in the resistant cultivar control. There was no difference between the two lower NVS rates, 25 and 50 t ha<sup>-1</sup>, and the susceptible variety control; 25 t ha<sup>-1</sup> resulted in a non-significant increase in J2 populations. During year 2 (Fig. 1A), suppression of soil J2 populations by any rate of NVS was lost. Only the resistant cultivar control had fewer J2 than the susceptible cultivar control. Similar trends were observed for number of eggs/g of fresh root (Fig. 1B). During year 1 the three highest rates of NVS decreased the number of eggs compared to the susceptible cultivar control; 75 and 100 t ha<sup>-1</sup> were not different from the resistant cultivar control. In year 2, egg numbers were lower in all treatments than they were in year 1. The resistant cultivar control had fewer eggs than the susceptible cultivar control and NVS treatments. In year 3, the lowest (25 t ha<sup>-1</sup>) and highest (100 t ha<sup>-1</sup>) rates of NVS had the fewest eggs/g cucumber root of those plots



**Fig. 1.** A: *Meloidogyne incognita* juveniles; B: Eggs – after incorporation of N-Viro Soil at different rates over time. Unamended resistant (res) and susceptible (susc) cultivar controls were included. Bars with the same letter are not significantly different according to Tukey's HSD test ( $P < 0.001$ ).

amended with NVS. These two rates were not different from plots planted with resistant or susceptible soybeans during the previous 2 years.

Amendment of soil with NVS at any rate during year 1 increased soil solution pH compared to the unamended control (Table 1). The application of 25 and 50 t ha<sup>-1</sup> resulted in similar soil solution pH levels upon incorporation. Significantly higher soil solution pH levels were achieved with 75 and 100 t ha<sup>-1</sup> of NVS. At planting, soil solution pH remained elevated in the NVS-amended plots, but had dropped ( $P < 0.01$ ) compared to pH at incorporation; soil solution pHs were still higher in the 75 and 100 t ha<sup>-1</sup> treatments compared to the other treatments. Soil solution pHs at harvest during year 1 had not changed significantly from pHs at planting time at any NVS rate. During year 2 of this experiment, soil solution pH values at planting were still higher in the NVS-amended plots compared to the unamended control. Soil solution pH increased in all treatments by year 2 harvest, in some cases to levels comparable to those observed immediately after incorporation (Table 1). At the beginning of year 3 of

**Table 1.** Soil solution pH (1:5 soil:water slurry) over time in microplots amended with different rates of N-Viro Soil<sup>a</sup>.

N-Viro Soil (dry t ha <sup>-1</sup> )	Year 1			Year 2	
	Incorporation <sup>b</sup>	Planting	Harvest	Planting	Harvest
0	6.1 ± 0.8 aB	5.6 ± 0.3 aB	5.9 ± 0.3 aB	6.3 ± 0.1 aB	7.6 ± 0.3 aA
25	8.1 ± 0.3 bA	7.1 ± 0.5 bC	7.5 ± 0.4 bBC	7.5 ± 0.2 bB	7.8 ± 0.2 aAB
50	8.1 ± 0.3 bA	7.0 ± 0.6 bB	7.8 ± 0.3 bA	7.8 ± 0.0 bA	8.0 ± 0.5 aA
75	8.8 ± 0.6 cA	7.6 ± 0.4 cC	8.0 ± 0.2 bBC	8.1 ± 0.2 cbB	8.6 ± 0.2 bA
100	9.2 ± 0.3 cA	7.9 ± 0.2 cD	8.0 ± 0.3 bCD	8.4 ± 0.2 cBC	8.7 ± 0.1 bB

<sup>a</sup> N-Viro Soil was provided by N-Viro International (Toledo, OH, USA) and was initially pH 10.1 (1:5 soil:water slurry).

<sup>b</sup> N-Viro Soil was incorporated to a depth of approximately 30 cm, 5 days prior to soybean planting.

<sup>c</sup> Values are the average of five replications ± standard error. Values followed by the same lower case letter are not significantly different within a sampling time. Values followed by the same upper case letter are not significantly different between sampling dates according to Tukey's HSD test ( $P < 0.05$ ).

this experiment, soil solution pHs for all NVS rates and the controls were similar to at harvest pH values in year 2 (unpubl.).

N-Viro Soil at 25 t ha<sup>-1</sup> had the highest soybean yield in year 1 199 (± 20) g/plot, and this was similar to yields in the resistant cultivar control, 169 (± 11) g/plot, and 50 t ha<sup>-1</sup> of NVS, 152 (± 16) g/plot. The highest rate of NVS had the lowest yield, 90 (± 13) g/plot, which was similar to that of the susceptible cultivar control and of 75 t ha<sup>-1</sup> of NVS but not the other treatments. Detection of treatment effects during year 1 may have been masked because yield loss occurred in some microplots due to deer grazing. In year 2 there was no difference in soybean yield between any of the treatments ( $P = 0.05$ ), with soybean yields ranging from 353 to 462 g/plot.

#### ABILITY OF N-VIRO SOIL IN COMBINATION WITH RESISTANT AND SUSCEPTIBLE SOYBEAN CULTIVARS TO SUPPRESS THREE INITIAL POPULATION DENSITIES OF *MELOIDOGYNE INCOGNITA*

At the lowest initial *M. incognita* density (*i.e.*, no eggs added to microplots) no J2 or eggs were found during year 1 (Table 2). In year 2, some nematodes were found in these microplots but there was no difference in their population densities due to cultivar or NVS amendment. At the intermediate initial density (37 500 eggs/microplot), NVS in combination with a resistant cultivar increased egg suppression above that by a resistant cultivar alone during year 1, but not for J2. In year 2, NVS in combination with a resistant cultivar did not increase egg or J2 suppression above that by a resistant cultivar. This was not the case when a susceptible variety was combined with 75 t NVS ha<sup>-1</sup>; NVS resulted in a 96 and 93% reduction in J2 and

egg populations in year 1, respectively. In year 2, this suppression was maintained for egg populations with 94% reduction, but was lost for J2 at the intermediate initial density. During year 1 at the highest initial nematode density (75 000 eggs/microplot), NVS combined with resistant or susceptible cultivars reduced J2 populations >79%, and egg populations >81% over unamended plots. This reduction was sustained in year 2 in plots containing the susceptible cultivar and NVS, with reductions of 79 and 80% for J2 and eggs, respectively. There was no difference in numbers of J2 or eggs in the resistant cultivar plots with or without NVS-amendment in year 2, with very few nematodes found. At all initial *M. incognita* densities the use of a resistant cultivar reduced the number of J2 in soil and eggs/g fresh root ( $P \leq 0.001$ ) compared to the susceptible cultivar during both years (Table 2).

In year 3, when cucumber was planted as an *M. incognita*-indicator plant, there was still no difference in numbers of eggs between plots at the lowest initial density. At the intermediate initial density there was also no difference in 6-week egg populations between the plots. At the highest initial density, there were fewer eggs in those plots where a resistant soybean cultivar had been grown, regardless of NVS amendment but this was not different from the susceptible soybean cultivar plus NVS treatment. When cucumber was planted into plots that had grown susceptible soybean the previous 2 years, the decrease in *M. incognita* egg production continued regardless of NVS amendment; but, the decrease was greater in plots amended with NVS.

Similar to the rate experiment, soil solution pH in the 75 t NVS ha<sup>-1</sup>-amended plots was higher than the control at all sampling dates during year 1. Soil solution pH levels

**Table 2.** *Meloidogyne incognita* juveniles and eggs in microplots that received three initial egg densities (0, 37 500 and 75 000 eggs/microplot) prior to the application of N-Viro soil at two rates (0 and 75 dry t ha<sup>-1</sup>) during the first year and were planted with resistant and susceptible soybean cultivars during both years<sup>a</sup>.

Initial <i>M. incognita</i> eggs/microplot	J2/100 ml soil				Eggs/g fresh root			
	Resistant		Susceptible		Resistant		Susceptible	
	N-Viro Soil (dry t ha <sup>-1</sup> )							
	0	75	0	75	0	75	0	75
<b>Year 1</b>								
0	1 ± 1 a <sup>b</sup>	0 a	0 a	0 a	0 A	0 A	0 A	0 A
37 500	10 ± 6 a	0 a	53 ± 27 b	3 ± 2 a	93 ± 58 B	0 A	5988 ± 2548 C	409 ± 194 B
75 000	90 ± 38 b	7 ± 7 a	1625 ± 558 c	337 ± 236 b	317 ± 107 B	18 ± 128 A	95 374 ± 17 848 D	17 921 ± 6408 C
<b>Year 2</b>								
0	0 a	19 ± 17 a	5 ± 5 a	0 a	2 ± 1 A	6 ± 4 A	2 ± 1 A	2 ± 2 A
37 500	17 ± 17 a	10 ± 10 a	180 ± 110 b	225 ± 175 b	2 ± 1 A	1 ± 0 A	95 ± 47 B	6 ± 2 A
75 000	0 a	0 a	1262 ± 378 c	260 ± 147 b	2 ± 1 A	6 ± 3 A	464 ± 108 C	91 ± 35 B
<b>Year 3</b>								
0					0 A	2 ± 2 A	7 ± 4 A	1 ± 2 A
37 500					1 ± 1 A	0 ± 1 A	21 ± 8 A	95 ± 83 A
75 000					6 ± 5 A	10 ± 7 A	583 ± 187 B	66 ± 22 A

<sup>a</sup> Values shown are the average of five replications ± standard error. N-Viro Soil was provided by N-Viro International (Toledo, OH, USA).

<sup>b</sup> Replicate data were log transformed prior to PROC MIXED analysis. Values followed by the same letter within a row are not significantly different according to Tukey's HSD test ( $P < 0.001$ ).

at incorporation, planting and harvest were 6.0, 5.6 and 5.8 in the controls (0 t NVS ha<sup>-1</sup>) and 8.5, 7.6 and 8.0 in the 75 t NVS ha<sup>-1</sup> plots. In year 2 soil solution pH levels remained higher in the NVS-amended plots compared to the controls with pH levels of 7.7 and 8.3 at planting and harvest compared to 6.3 and 7.4 in the controls for the same dates. Soil pH levels in year 3 were similar to those recorded at the end of year 2.

During both years, the only factor which had an influence on soybean yield was cultivar ( $P < 0.009$ ), with the effects of all other factors non-significant ( $P = 0.05$ ). Yields were higher in those plots planted with a *M. incognita*-resistant soybean cultivar.

## Discussion

N-Viro Soil applied to soil at 75 and 100 dry t ha<sup>-1</sup> suppressed *M. incognita* populations. In laboratory studies, it was demonstrated that *M. incognita* egg hatch was suppressed with a NVS rate equivalent to 75 dry t ha<sup>-1</sup> in a sandy soil (Zasada & Tenuta, 2004). We did not observe nematode suppression at 25 dry t ha<sup>-1</sup>

of NVS. N-Viro Soil did suppress *H. glycines* in other studies at application rates of 2 and 20 dry t ha<sup>-1</sup> (Welacky & Topp, 2001) and 10 and 55 t ha<sup>-1</sup> (Alptekin, 2001). The rates used in this experiment were higher than those which would be recommended if NVS was used solely as a liming agent, ca 5 dry t ha<sup>-1</sup>. The rates tested in this experiment were chosen based upon previous laboratory experiments (Zasada & Tenuta, 2004; Zasada, 2005). The higher rates that were necessary to achieve suppression in this study are not realistic from an agronomic perspective because of the sharp increase in soil pH. High soil pH levels can compromise the availability of phosphorus and micronutrients and disrupt soil physical properties. It is essential to reduce the rate of NVS needed to achieve nematode suppression by combining it with other nematode management strategies if its use is to be adopted.

We combined NVS with resistant soybean cultivars. During the first year, we observed additional nematode suppression at high initial populations, when NVS was applied and a resistant cultivar planted, over that with a resistant cultivar alone. It is unlikely that reduced rates of NVS in combination with resistant cultivars would

reduce the rotation length necessary in nematode-infested soils to less than that required when a resistant cultivar or non-host crop is grown. This is especially relevant in the management of *H. glycines*, which would be expected to respond to NVS amendments in a similar manner to that of *M. incognita* (Zasada & Tenuta, 2004).

Initial nematode population densities can have a profound impact on the ability of a control measure to reduce nematode damage and the persistence of any effect. Some resistant cultivars are not effective at high nematode densities (Koenning *et al.*, 1993). Initial nematode densities also have an influence on the ability of non-host crops and the length of rotations to reduce nematode damage (Brodie, 1996). In our study, initial nematode densities did not appear to influence the ability of NVS to suppress *M. incognita* during the first year. Suppression of egg populations by NVS was maintained at the highest initial nematode density through year 3.

The duration of nematode suppression varied between and within experiments. In the rate experiment, the suppression observed in year 1 was not sustained in year 2. However, when 75 dry t NVS ha<sup>-1</sup> was combined with a susceptible cultivar in the other experiment, there was a reduction in the number of *M. incognita* J2 and eggs during both years. The population density in the cultivar experiment was higher than in the rate experiment in year 2. The lack of consistent nematode suppression by NVS in year 2 has been observed for other management tactics, such as cover crops (Everts *et al.*, 2006). These results suggest that NVS should be utilised in combination with other nematode management practices or in rotations and incorporated into long-term nematode management programmes.

Calcium dominates the chemical characteristics of NVS (Yamakawa, 1999). NVS is marketed as a substitute for liming agents because of its alkalinity. Amendment of soil with NVS may be more practical to control plant-parasitic nematodes in poorly buffered soils where pH can quickly increase but will eventually drop. The soil on which these experiments were conducted was a good candidate on which to achieve nematode suppression (Tenuta & Lazarovits, 2003). It was a loamy sand, initial pH of 6.0 and low buffering capacity. The addition of NVS at any rate resulted in an immediate significant increase in soil solution pH. At the lower rates, pH at harvest during year 1 had decreased to levels where optimal plant growth would be expected to occur (5.5 to 7.6), but at the higher rates high pH persisted and even resulted in lower yields at the highest NVS rate.

There was greater nematode suppression at the higher NVS rates where soil pH was higher, supporting our proposed pH-mediated mechanism of nematode suppression by NVS. However, in laboratory experiments, pH levels above 10, generated by the addition of Ca(OH)<sub>2</sub> to sand, were necessary to reduce *H. glycines* juvenile survival by 40% (Zasada & Tenuta, 2004). The highest pH measured in our study was 9.2, indicating that pH was probably not solely responsible for the *M. incognita* suppression observed in our study. In initial microplot experiments conducted on the same soil type, amendment with NVS resulted in the production of 6 and 15 mM of ammonia at rates of 50 and 75 dry t ha<sup>-1</sup>, respectively (unpubl.). The production of ammonia was very rapid, and 1 week after incorporation <1 mM ammonia was present. We have reported conflicting results regarding the accumulation of ammonia in soil and the effect on nematode mortality (Zasada & Tenuta, 2004; Meyer *et al.*, 2005) but ammonia is toxic to nematodes (Oka & Pivonia, 2002). The production of ammonia is a dynamic process influenced by temperature, moisture and soil pH (pK<sub>a</sub> = 9.3). At the highest pH measured in this experiment and a soil temperature of 20°C, approximately 30% of the ammonium plus ammonia mixture would exist as free ammonia. Further investigation is needed to determine whether the concentrations of ammonia present in this study were high enough to cause nematode mortality.

N-Viro Soil did suppress *M. incognita* in a field setting. Unfortunately, the rate required to elicit this reduction in nematode populations was probably not agronomically realistic. Additional research needs to concentrate on reducing the rate of NVS necessary to suppress plant-parasitic nematodes. Generally, the quantity of ammonia required for nematode control in alkaline soils is less than that in acid soils (Rodríguez-Kábana *et al.*, 1987). As pH is critical to the generation of ammonia, the pH-raising potential of NVS could be combined with nitrogen sources to facilitate this chemical reaction and reduce the rates of both amendments.

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