CHANGES IN SOIL ENZYMATIC ACTIVITY AND CONTROL OF *MELOIDOGYNE INCOGNITA* USING FOUR ORGANIC AMENDMENTS[†]

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ABSTRACT

Chavarría-Carvajal, J. A., and R. Rodríguez-Kábana. 1998. Changes in soil enzymatic activity and control of *Meloidogyne incognita* using four organic amendments. Nematropica 28:7-18.

Four organic amendments (velvetbean, kudzu, pine bark, and urea-N) were evaluated in separate experiments for the management of the root-knot nematode (*Meloidogyne incognita*). The amendments were applied to nematode-infested soil at rates of 0 to 5%, placed in pots, maintained moist in a greenhouse (25-30°C) for 2 weeks, and planted with 'Davis' soybean (*Glycine max*). The experiments were continued for eight more weeks and harvested ten weeks after treatment. Pre-plant soil samples and post-harvest soil and root samples were analyzed, and the number of *M. incognita* juveniles and nonparasitic nematodes associated with the soil and root tissues were determined. Soil samples were taken at 0, 2, and 10 weeks after amendment application for determination of soil enzyme activities. At the end of the experiments, data on plant growth were recorded, and the incidence of root galling was determined using the number of galls per gram root and a gall index scale. Most organic amendments were effective in reducing root galling and root-knot nematodes and increasing populations of non-parasitic nematodes. Catalase and esterase were sharply increased by most rates of velvetbean, kudzu, and pine bark. Application of velvetbean, kudzu, and urea to soil stimulated urease activity in proportion to the amendment rates. Results suggest that complex modes of action operating in amended soils are responsible for suppression of *M. incognita.*

Key words: Biological control, *Glycine max, Meloidogyne incognita, Mucuna deeringiana,* organic amendments, pine bark, *Pueraria lobata,* soil enzymes.

RESUMEN

Chavarría-Carvajal, J. A. y R. Rodríguez-Kábana. 1998. Cambios en la actividad enzimática del suelo y control de *Meloidogyne incognita* utilizando cuatro enmiendas orgánicas. Nematropica 28:7-18.

Cuatro enmiendas orgánicas (mucuna, kudzu, corteza de pino, y urea-N) fueron evaluadas en diferentes experimentos para el manejo de *Meloidogyne incognita.* Las enmiendas fueron aplicadas al suelo a dosis de 0 a 5%, puestas en tiestos y mantenidas humedas en un invernadero (25-30°C) por 2 semanas y el suelo enmendado fue sembrado con soya (*Glycine max*) cv. 'Davis'. Los experimentos se continuaron por ocho semanas mas efectuándose la cosecha a las diez semanas del inicio del experimento. Muestras de suelo y raíz fueron tomadas antes de la siembra y a la cosecha, y el número de nematodos noduladores y nematodos no parasiticos fueron determinados. Además, se tomaron muestras de suelo a las 0, 2, y 10 semanas después del tratamiento para determinar la actividad enzimática del suelo. Al final del experimento, el crecimiento de la planta fue estimado, y la incidencia del nematodo nodulador fue determinada de acuerdo con el número de nódulos/g de raíz, y el índice de nodulación. La mayoría de las enmiendas orgánicas fueron efectivas en reducir la nodulación

[†]Portion of a Ph. D. thesis submitted by the first author to Auburn University.

de la raíz, e incrementaron las poblaciones de nematodos no parásitos. Las actividades de la catalasa y de la esterasa fueron incrementadas en relación a las dosis de mucuna, kudzu, y la corteza de pino. La aplicación al suelo de mucuna, kudzu, y urea estimularon la actividad de ureasa, en proporción a la dosis usada. Los resultados indican que la supresión de *M. incognita* en los suelos enmendados se debe a mecanismos complejos fundamentados en las actividades microbianas de los suelos.

Palaras clave: control biológico, corteza de pino, enmiendas orgánicas, enzimas del suelo, *Glycine max, Meloidogyne incognita, Mucuna deeringiana.*

INTRODUCTION

Soil amendments have been explored as a method for suppressing plant-parasitic nematodes. It has been shown that the efficacy of organic amendments against nematodes depends on the chemical and physical properties of the amendment (Rodríguez-Kábana, 1986). Nematicidal compounds are released from decomposing organic matter, or synthesized by microorganisms involved in the decay process. Microbial by-products include organic acids, hydrogen sulfide, phenols and tannins, and nitrogenous compounds (Mian and Rodríguez-Kábana, 1982b). The use of nitrogenous organic matter as soil amendment is a successful strategy for the management of *Meloidogyne* spp. and other plant-parasitic nematodes in vegetables and other root-knot susceptible crops (Mian and Rodríguez-Kábana, 1982a; Rodríguez-Kábana *et al.*, 1990). Amendments to soil with crotalaria [*Crotalaria spectabilis* (L.)], kudzu [*Pueraria lobata* (Willd) Ohwi] and ramie [*Boehmeria nivea* (Hook et. Arnott)] effectively reduced root galling by *M. arenaria* (Neal) Chitwood on squash (*Cucurbita pepo*) (Mian and Rodríguez-Kábana 1982b). Also, control of root-knot nematodes (*Meloidogyne* spp.) can be achieved when urea is applied at rates above 300 kg N/ha (Rodríguez-Kábana *et al.* 1989). Anhydrous ammonia applied at rates of 62 mg N/kg soil or higher was effective in reducing soil populations of *Tylenchorhynchus claytoni* Steiner and *Helicotylenchus dihystera* (Cobb) Sher on soybean (Rodríguez-Kábana and Pope, 1981).

Velvetbean (*Mucuna deeringiana* (Borr) Merr.), and kudzu are two tropical legumes available in the southern United States that have been used in crop rotation, to prevent soil erosion and for the production of hay and green pasture (Allen and Allen, 1981). Due to the high nitrogen content of their shoots and foliage, velvetbean and kudzu could be used to control plant-parasitic nematodes. However, the current literature lacks information on the use of either legume as an organic amendment for the management of phytonematodes, and on how these materials affect soil enzymatic activities and other variables indicative of the decomposition of amendments in soil.

Another material readily available in large quantities in the southern United States as a by-product of the forestry industry is pine bark. Significant control of *M. arenaria* and *H. glycines* Ichinohe on soybean have been reported (Kokalis-Burelle *et al.*, 1994) after application to soil of pine bark.

Activities of several soil enzymes have been used as indices of microbial activity in ecological studies (Chavarría-Carvajal, 1997; Kokalis-Burelle and Rodríguez-Kábana, 1994; Rodríguez-Kábana *et al.*, 1983). Catalase (H_2O_2: H_2O_2 oxidoreductase, EC.1.11.1.6) is a widely occurring enzyme associated with tissues of animals, higher plants and aerobic microorganisms

(Rodríguez-Kábana and Truelove, 1982). Its presence in soil is correlated with microbial activity and fertility. Esterase can be used as a general measure of total microbial activity in soil (Schünurer and Rosswall, 1982). Urease (urea amidohydrolase, EC 3.5.1.5) catalyzes the hydrolysis of urea to CO_2 and NH_3 and it is widely distributed in nature, occurring in microorganisms, plants and animals (Kuprevich and Shcherbakova, 1971). Urease activity is correlated with the overall number of microbes in soil (Skujins, 1971).

The objective of this study was to determine the effects of selected organic amendments incorporated into soil on: a) plant-parasitic and nonparasitic nematode populations in soil and those associated with the roots; b) soil enzymatic activities; and c) plant growth.

MATERIALS AND METHODS

Soil for the experiments was a Norfolk sandy loam (fine loamy, siliceous thermic, Typic Paleudults, pH 6.1, <1.0% organic matter), from a soybean *Glycine max* (L.) Merr. field naturally infested with *Meloidogyne incognita* (Kofoid and White) Chitwood and non-parasitic species of nematodes. Soil was screened and mixed (1:1 by volume) with builders' sand. This mixture, which will be called soil, had pH = 6.8, organic matter <1.0%, nitrogen 0.05%, with P = 19.4 ppm, K = 30.8 ppm, Mg = 95.3 ppm, and Ca = 482.7 ppm. Four different greenhouse experiments were done. The experimental design for each experiment was a randomized complete block, with eight replications per treatment. Each experiment tested the effect of just one amendment compared to an untreated control. In the first two experiments, green foliage and stems of velvetbean and kudzu were collected near blooming time, dried (25°C) and ground into a powder (particle size = 250 µm). In the third experiment, commercially available dry pine bark nuggets from slash pine (*Pinus elliottii*) Engelm and loblolly pine (*Pinus taeda*) L. were ground (250 µm), and used as amendments at 0, 10, 20, 30, 40 and 50 g/kg soil. In the fourth experiment, urea (34% N) was applied to soil at concentrations of 0, 0.15; 0.30; 0.45; 0.60; 0.75 and 0.90 g N/kg soil. In each experiment the soil was apportioned in 1.0-kg quantities, placed into 4-L capacity polyethylene bags, thoroughly mixed with each amendment, and transferred to 1-L, 10-cm-diameter PVC pots. Pots and soil were placed in a greenhouse (25-30°C) and kept moist (60% field capacity) for two weeks before planting. In every experiment, each pot was planted with five soybean cv. Davis seeds. Ten days after planting, the percent germination was recorded and the plants were allowed to grow for eight weeks when they were removed from the soil and the fresh weighs of shoots and roots were determined. Other plant variables recorded were the number of galls caused by *M. incognita* per gram of root, and a gall index value based on a scale of 0 to 10 (0 = no galls and 10 = maximal galling) (Zeck, 1971). Pre-plant and final population densities of plant-parasitic and nonparasitic nematodes were determined from soil and roots using the "salad bowl" incubation method (Rodríguez-Kábana and Pope, 1981).

Catalase was determined from soil using the method described by Rodríguez-Kábana and Truelove (1982) and was expressed as meq H_2O_2 decomposed per hr/g soil. Esterase activity was determined using fluorescein diacetate (1 mg/ml dissolved in acetone) as a substrate and the optical absorbance of released fluorescein in the supernatant was determined at 490 nm using a spectrophotometer. Esterase activity was expressed as mg fluorescein released per hr/g soil. Urease activity was determined only in experiments with velvetbean, kudzu and nitrogen. Urease activity was measured using a microdiffusion dish procedure (Rodríguez-Kábana and King, 1980) and was expressed as μg NH_4^+ per hr/g soil.

The data were analyzed using standard procedures for two-way analysis of variance (ANOVA) (Steel and Torrie, 1980). Means were compared using Least Significant Differences (LSD) when F values were significant ($P \leq 0.05$).

RESULTS

Effect of organic amendments on nematodes: Velvetbean and kudzu increased pre-plant populations of non plant-parasitic nematodes (Rhabditida and Dorylaimida), but neither amendment was effective in reducing population densities of *M. incognita* in soil two weeks after application (Table 1). Pine bark applied to soil between 10 and 50 g/kg soil was very effective in reducing pre-plant soil populations of *M. incognita.* Pine bark also stimulated populations of non-parasitic nematodes when applied between 20 and 50 g/kg soil. Pre-plant populations of *M. incognita* were significantly reduced by urea-N (Table 2). Unlike the other amendments, urea-N reduced the number of free-living nematodes when applied at rates of 0.15 g/kg and from 0.45 to 0.90 g/kg.

At the end of the experiment, kudzu effectively reduced root populations of *M. incognita* (Table 1), and when this amendment was applied at 30-50 g/kg, it increased populations of nonparasitic nematodes. Velvetbean applied between 30 and 50 g/kg significantly increased populations of nonparasitic nematodes in soil and roots, but was not effective in reducing *M. incognita.* Pine bark added to soil at 30-50 g/kg controlled *M. incognita* 10 weeks after treatment; at rates of 40-50 g/kg it stimulated soil populations of nonparasitic nematodes. Applications of urea-N between 0.30 and 0.90 g/kg reduced *M. incognita* populations in roots and soil 10 weeks after application; however, soil populations of nonparasitic nematodes were significantly increased by most urea rates (Table 2). Overall, organic amendments reduced the number of galls/gram of root and the gall index values (Fig. 1, A-D).

Effect of organic amendments on soil enzymes: Catalase activity at the 2-week sampling increased in response to soil treatment with velvetbean (Table 3); however, at the other 2 sampling dates the activity in amended soils decreased but was still higher than in the non-amended control soil. A similar response was observed after kudzu was added to soil. Kudzu at rates between 20 and 50 g/kg soil significantly increased soil catalase activity. Initially pine bark had no effect on catalase activity; however after two weeks, pine bark at rates of 20 to 50 g/kg soil significantly enhanced catalase activity. Applications of urea-N (0.15 to 0.90 g/kg soil) diminished catalase activity in the first two samplings (Table 4); however, at the end of the experiment at rates between 0.30 and 0.75 g/kg, resulted in increased catalase activity.

Soils treated with velvetbean (30-50 g/kg) or kudzu (20-50 g/kg), increased the rate of esterase activity (Table 3). When the soil was amended with pine bark, FDA hydrolysis was reduced or remained unchanged compared with the control. Overall, urea-N reduced esterase activity initially (Table 4). But, fluorescein hydrolysis recovered 2 weeks later, when this amendment was added at 0.45 and 0.60 g/kg soil. At the end of the experiment increases in esterase were associated with urea-N rates of 0.60-0.75 g/kg.

Table 1. Effects of velvetbean, kudzu, and pine bark on pre-plant and final population densities of non-parasitic nematodes (N-P)[z] and *M. incognita* (R-K) from soil and roots.

	Pre-plant soil populations (nematodes/100 cm^3 soil)						Final soil populations (nematodes/100 cm^3 soil)						Final root populations (nematodes/g root)					
	Velvetbean		Kudzu		Pine Bark		Velvetbean		Kudzu		Pine Bark		Velvetbean		Kudzu		Pine Bark	
Rate g/kg soil	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K	N-P	R-K
0	228	32	459	40	692	115	320	35	205	50	698	115	7	35	15	33	200	128
10	1691	37	2173	35	794	33	420	22	265	10	594	33	43	19	13	3	107	112
20	1457	15	4410	45	1096	81	950	5	308	30	1105	82	59	16	28	1	158	78
30	2443	7	7498	16	1380	0	1580	5	790	10	1375	0	169	7	81	4	209	40
40	3132	23	9516	15	1659	60	2995	0	457	25	1644	60	193	8	40	2	191	31
50	1543	6	10919	23	1585	11	2915	15	615	5	1600	11	319	12	83	1	159	12
LSD	1783	44	2781	34	684	44	1018	40	328	27	684	44	152	95	47	23	161	68

[z]Non-parasitic nematodes include Rhabditida and Dorylaimida.

Table 2. Effects of urea-N on pre-plant and final population densities of non-parasitic nematodes (N-P)' and *M. incognita* (R-K) from soil and roots.

Rate g/kg soil	Pre-plant soil populations (nematodes/100 cm^3 soil)		Final soil populations (nematodes/100 cm^3 soil)		Final root populations (nematodes/g root)	
	N-P	R-K	N-P	R-K	N-P	R-K
0	67	30	501	58	15	9
0.15	18	8	1230	34	13	3
0.30	54	2	1000	4	9	2
0.45	18	0	1380	1	3	0
0.60	6	0	912	2	1	0
0.75	0	0	1950	2	4	0
0.90	0	0	2089	0	1	0
LSD	32	15	984	41	11	10

'Non-parasitic nematodes include Rhabditida and Dorylaimida.

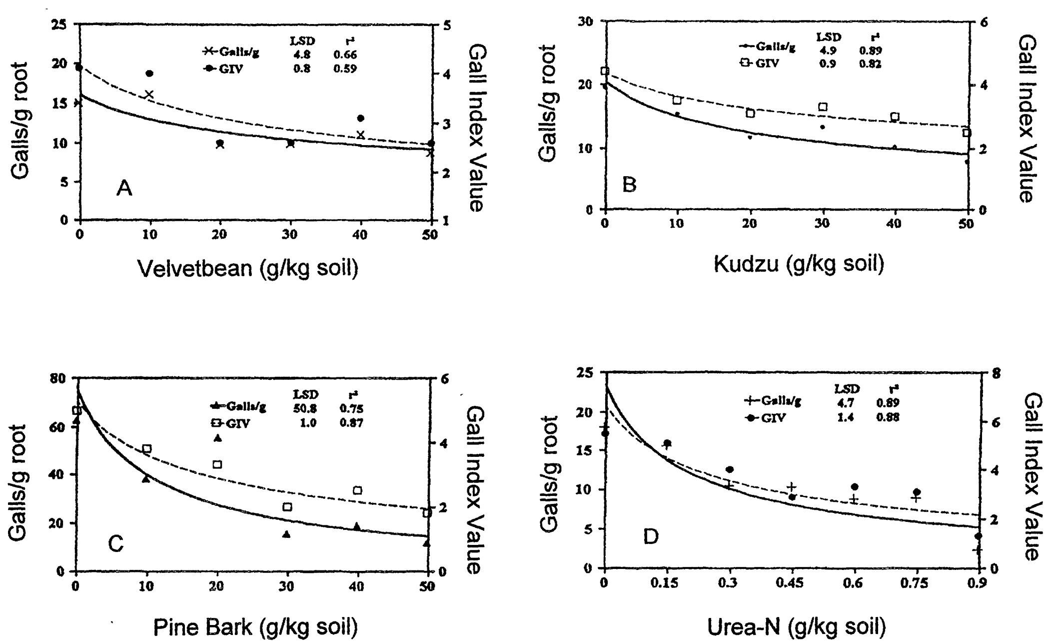

Fig. 1. Effects of velvetbean (A), kudzu (B), pine bark (C), and urea-N (D) on gall formation on soybean caused by *M. incognita* 10 weeks after treatment. Disease assessed by both the number of galls/g root and the gall index value (GIV) (Zeck, 1971).

Table 3. Effects of velvetbean, kudzu, and pine bark on catalase[y] (CA) and esterase[z] (ES) activities in soil.

	0 Weeks						2 Weeks						10 Weeks					
	Velvetbean		Kudzu		Pine Bark		Velvetbean		Kudzu		Pine Bark		Velvetbean		Kudzu		Pine Bark	
Rate g/kg soil	CA	ES	CA	ES	CA	ES	CA	ES	CA	ES	CA	ES	CA	ES	CA	ES	CA	ES
0	2.71	2.65	2.90	2.64	2.93	8.88	2.79	2.62	2.59	2.62	2.66	8.68	2.65	2.66	2.65	2.65	2.68	9.12
10	6.33	3.55	4.47	2.96	2.85	9.00	5.32	2.99	3.76	3.04	2.75	8.70	3.67	2.76	3.35	2.72	2.78	8.57
20	10.69	4.74	6.17	3.15	2.92	8.87	7.10	3.44	5.72	3.38	2.86	8.53	4.37	2.81	4.17	2.80	3.18	9.04
30	25.17	7.69	6.47	3.83	2.86	8.80	8.77	4.17	5.86	3.90	2.89	8.46	5.03	3.03	5.48	3.11	3.03	8.92
40	43.12	8.23	10.65	5.43	2.80	8.59	10.78	5.15	9.53	5.55	2.95	8.44	6.47	3.36	5.36	2.95	3.71	9.28
50	47.57	13.37	14.43	4.66	2.86	8.42	14.53	6.10	9.98	5.82	2.95	8.31	8.97	3.24	8.18	3.41	3.44	8.51
LSD	6.25	3.25	3.22	0.47	0.11	0.22	1.26	0.86	1.21	0.49	0.12	0.33	0.61	0.11	0.62	0.23	0.18	0.44

[y]meq H_2O_2 decomposed per hr/g soil.
[z]µg fluorescein released per hr/g soil.

Table 4. Effects of urea-N on catalase[y] (CA) and esterase[z] (ES) activities in soil.

Rate g N/kg soil	0 Weeks CA	0 Weeks ES	2 Weeks CA	2 Weeks ES	10 Weeks CA	10 Weeks ES
0	2.35	14.33	2.85	18.94	3.24	17.42
0.15	2.34	13.13	2.76	16.47	3.09	16.15
0.30	2.16	13.97	2.68	15.91	3.43	17.85
0.45	2.11	13.00	2.65	20.63	3.52	17.83
0.60	2.14	13.41	2.69	21.16	3.42	24.96
0.75	2.03	13.80	2.67	17.08	3.68	22.62
0.90	2.11	13.84	2.56	16.65	3.34	18.28
LSD	0.07	0.47	0.08	1.51	0.17	1.86

[y]meq H_2O_2 decomposed per hr/g soil.
[z]µg fluorescein released per hr/g soil.

Overall, both velvetbean and kudzu increased urease activity in proportion to the rates applied, with the major increases occurring two weeks after treatment (Table 5). A similar response was observed when urea-N was added to soil at 0.30-0.90 g N/kg (Table 6).

Effect of organic amendments on soybean growth: Velvetbean amendment significantly improved germination of soybean (Table 7). Also, shoot and root weights were superior when the amendment was applied at rates of 10, and 30-50 g/kg. Germination was improved by kudzu at rates

Table 5. Effect of velvetbean, and kudzu on urease activity in soil.[z]

Rate g/kg soil	0 Weeks Velvetbean	0 Weeks Kudzu	2 Weeks Velvetbean	2 Weeks Kudzu	10 Weeks Velvetbean	10 Weeks Kudzu
0	41.33	40.80	41.31	43.60	41.00	41.93
10	50.27	62.80	58.18	75.61	45.19	51.80
20	55.56	71.81	105.70	104.30	58.49	78.70
30	79.85	112.10	143.50	119.22	78.12	100.83
40	73.29	113.20	156.70	178.10	78.93	77.12
50	81.46	143.11	193.50	181.70	127.80	130.10
LSD	3.59	18.10	38.63	12.11	10.76	6.72

[z]µg NH_4^+-N per hr/g soil.

Table 6. Effects of urea-N on urease activity in soil.[z]

Rate g N/ kg soil	0 Weeks	2 Weeks	10 Weeks
0	40.68	42.42	40.52
0.15	42.28	43.24	40.56
0.30	43.40	55.59	40.70
0.45	49.48	80.92	42.17
0.60	57.01	96.79	53.40
0.75	74.80	175.80	82.82
0.90	71.76	195.80	122.30
LSD	2.68	15.40	11.76

[z]µg NH_4^+-N per hr/g soil.

of 20-50 g/kg; shoot weight was increased when this amendment was added between 10-20 g/kg and at 50 g/kg. All kudzu rates, but one (30 g/kg) resulted in increased root weights. Pine bark applied at 20-50 g/kg improved germination (Table 7), but increased neither shoot nor root weights at harvest. The use of urea-N as soil amendment at 0.15, 0.30 and 0.60 g/kg, improved germination (Table 8). Most urea rates did not affect root weights. Urea-N applied at 0.30-0.90 g/kg, reduced shoot weights. Urea-N at 0.90 g/kg soil decreased the weights of shoots and roots.

DISCUSSION

Results indicate that velvetbean, kudzu, pine bark and urea-N are effective in reducing root-knot caused by *M. incognita* and increasing populations of nonparasitic nematodes. Nonparasitic nematodes feed on different components of the soil microbiota and may also compete with *M. incognita* for ecological niches both in the soil and roots (Stirling, 1991).

Pine bark was effective in reducing *M. incognita* populations. In this study, the suppression of plant parasitic nematodes by pine bark, could be through the release of toxic compounds or by the development of an antagonistic microflora. Despite a general agreement that bacteria and fungi are important in the decomposition of organic matter, the decomposition of cellulose and lignin in soil after the application of woody materials, is accomplished mainly by fungi. Pine bark stimulates fungal populations antagonistic to plant-parasitic nematodes (Kokalis-Burelle and Rodríguez-Kábana, 1994). Also, pine bark is a material rich in phenolic compounds that may be directly toxic to phytonematodes during its decomposition (Kokalis-Burelle *et al.*, 1994).

Soil catalase and esterase activities increased after application of most rates of velvetbean, kudzu, and pine bark. Increases in the activities of these enzymes reflect major increases in the activities of certain groups of microorganisms favored by each organic amendment. Catalase is a good indicator of the general activity of aerobic organisms during the decomposition of organic matter (Rodríguez-Kábana and Truelove, 1982), and esterase is associated with bacterial and fungal activities (Brunius, 1980; Söderström, 1977).

Soil microorganisms obtain carbon, nitrogen, and other nutrients for cell synthesis and respiration from organic materials. The addition to soil of materials with high N content (velvetbean, kudzu and urea-N) increased urease activity, indicating shifts in microbial activity and in the hydrolysis of urea into NH_3 and CO_2. The release of ammonia from these amendments is the result of the hydrolytic enzymatic action by organisms involved in decomposition of nitrogen amendments. Our results confirmed that urea is nematicidal when present in soil at levels exceeding 300 mg N/kg soil (Rodríguez-Kábana and King, 1980). Ammonia may be directly toxic to phytonematodes and may also

Table 7. Effects of velvetbean, kudzu, and pine bark on growth of soybean (*Glycine max*).

Rate g/kg soil	Germination (%)			Shoot Weight (g)			Root Weight (g)		
	Velvetbean	Kudzu	Pine Bark	Velvetbean	Kudzu	Pine Bark	Velvetbean	Kudzu	Pine Bark
0	5.00	2.50	12.50	2.03	2.88	1.28	1.22	2.00	0.68
10	37.50	11.30	12.50	11.94	11.35	1.62	5.00	8.20	0.67
20	50.00	30.00	50.00	7.72	10.15	2.40	3.01	7.25	0.88
30	37.50	58.80	37.50	14.96	5.89	1.71	5.95	5.43	0.56
40	75.00	61.30	42.50	12.16	7.45	1.70	5.63	6.33	0.71
50	60.00	40.00	70.00	11.45	8.05	1.80	5.05	7.56	0.66
LSD	28.74	15.90	24.88	7.60	5.12	1.13	3.42	3.76	0.54

Table 8. Effects of urea-N on plant growth of soybean (*Glycine max*).

Rate g N/kg soil	Germination (%)	Shoot Weight (g)	Root Weight (g)
0	30.00	7.41	7.26
0.15	76.75	5.46	5.60
0.30	70.00	3.52	3.80
0.45	43.25	3.20	4.01
0.60	56.75	4.61	5.71
0.75	26.75	3.70	5.17
0.90	13.25	2.85	3.40
LSD	23.49	2.74	3.47

exert a selective influence for microbial antagonists of nematodes. Reductions in phytonematodes have been associated with the proliferation of fungal parasites of the nematode following application of urea to soil (Rodríguez-Kábana *et al.*, 1989).

The beneficial effects of organic amendments for improving the physical, chemical and biological properties of soil are well recognized (Abawi and Thurston, 1994). In this study, most amendments increased soybean emergence in proportion with the rates added to soil. This was probably the result of the amelioration of soil physical properties and reduction of microorganisms involved in seed decay. Additionally, some amendment rates improved soybean growth suggesting that these materials provide nutrients or may increase their availability in soil. However, the use of urea-N at 0.30-0.90 g/kg was clearly phytotoxic. Most urea rates strongly reduced the activity of catalase indicating a negative impact on populations of soil aerobes. The phytotoxic effects of urea on soybean may be due to accumulation of ammoniacal nitrogen as expected from increased soil urease activity. These results are in agreement with previous work (Rodríguez-Kábana, 1986) where it was shown that the application of nematicidal rates of urea into soil does not permit the use of all available nitrogen by soil microorganisms, a situation leading to restricted microbial activity and phytotoxicity.

The suppression of *M. incognita* by the organic amendments used in this study is probably based on a complex mode of action involving multiple mechanisms. Changes in soil enzyme activities indicate shifts in specific groups of microorganisms after the application of organic amendments. Identification of the microorganisms involved in such activity requires further research to determine the specific interactions between microorganisms and plant-parasitic nematodes.

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