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Effects of Temperature and Placement Site on the Dispersal of the Entomopathogenic Nematode, Steinernema carpocapsae in Four Soils【Research report】

溫度與施用深度對蟲生線蟲Steinernema carpocapsae散佈的影響【研究報告】

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Abstract

The effects of temperature and placement site on the movement of the entomopathogenic nematode, Steinernema carpocapsae was conducted in the laboratory. The temperatures tested were -20, 25, and 35℃ at application depths of surface, 5, and 10cm. The soils tested were pure sand, Cecil coarse sandy loam, silty loam and sandy clay loam. At -20℃, lower numbers of nematodes were recovered but the survivors were able to infect Galleria larvae. These nematodes dispersed very little regardless of the placement site. At 25℃, the total number of nematodes recovered at 3 application depths were the highest among the 3 temperatures in the four soil types. Nematodes moved more readily in sand and silty loam than in coarse sandy loam or sandy clay loam. At 35℃, fewer of infective juveniles were recovered from the four soils when compared with those of extracted nematodes at 25℃. When infective juveniles of S. carpocapsae were placed on the soil surface, they displayed little downward movement at -20, 25 and 35 oC in the four types of soil. At 35℃ , no nematodes were recovered from 6cm (or deeper) below the placement site, however, they only tended to move to the next 5cm layer, Higher numbers of nematodes were recovered from sand when placed at a 5cm depth, and higher numbers were recovered from silty loam when placed at a 10cm depth. The present data show that the migration of infective juveniles tends to decrease as the proportion of silt and clay increase in soil.

摘要

在室內進行探討溫度及施用深度對蟲生線蟲Steinernema carpocapsae散佈的影響。測試所選用的溫度為 - 20，25及35℃，施用深度為表土5及10公分。測試選用的土壤為純砂、西索砂質壤土、矽質壤土和粘質壤土。在 - 20℃下所粹取的線蟲數較低但皆能感染蠟蛾幼蟲，不論施用深度為何移動不多。在25℃下各種土壤自三種施用深度所粹取的線蟲數為三種溫度中最高。線蟲在純砂及矽質壤土比在砂質壤土和粘質壤土移動較佳。在35℃下，自四種土壤各層深度下所粹取的線蟲數皆低於25℃的線蟲粹取數。在 - 20，25和35℃下，當致病性幼蟲施於四種土壤的表面時，往下移動的線蟲數很少。若施於5及10公分時，在35℃下，致病性幼蟲並不會在施用地點6公分以下被粹取到，大部份的線蟲傾向於移向下5公分土層。當施於5公分深度時，從純砂中粹取的線蟲數最多。當施於10公分深度時，從砂質壤土中粹取的線蟲數最多。本實驗的數據指出，當土中矽粒及粘粒比率增加時線蟲的移動會減少。

Key words: Steinernema carpocapsae, temperature, application depth, dispersal.
關鍵詞: Steinernema carpocapsae、蟲生線蟲、溫度、施用深度、散佈。

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Effects of Temperature and Placement Site on the Dispersal of the Entomopathogenic Nematode, *Steinernema carpocapsae* in Four Soils

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ABSTRACT

The effects of temperature and placement site on the movement of the entomopathogenic nematode, *Steinernema carpocapsae* was conducted in the laboratory. The temperatures tested were -20, 25, and 35℃ at application depths of surface, 5, and 10cm. The soils tested were pure sand, Cecil coarse sandy loam, silty loam and sandy clay loam. At -20℃, lower numbers of nematodes were recovered but the survivors were able to infect *Galleria* larvae. These nematodes dispersed very little regardless of the placement site. At 25℃, the total number of nematodes recovered at 3 application depths were the highest among the 3 temperatures in the four soil types. Nematodes moved more readily in sand and silty loam than in coarse sandy loam or sandy clay loam. At 35℃, fewer of infective juveniles were recovered from the four soils when compared with those of extracted nematodes at 25℃. When infective juveniles of *S. carpocapsae* were placed on the soil surface, they displayed little downward movement at -20, 25 and 35℃ in the four types of soil. At 35℃ , no nematodes were recovered from 6cm (or deeper) below the placement site, however, they only tended to move to the next 5cm layer. Higher numbers of nematodes were recovered from sand when placed at a 5cm depth, and higher numbers were recovered from silty loam when placed at a 10cm depth. The present data show that the migration of infective juveniles tends to decrease as the proportion of silt and clay increase in soil.

Key words: *Steinernema carpocapsae,* temperature, application depth, dispersal.

Introduction

Entomopathogenic nematodes, *Steinernema carpocapsae* (synonyms *S. feltiae* Filipjev and *Neoaplectana carpocapsae* Weiser) in the family Steinernematidae, have long been recognized as effective insect control agents (Kaya and Gaugler, 1993). This nematode infects over 250 different species of insects from 75 families in 11 orders (Poinar, 1979).

The infective juveniles (IJs) are a non-feeding resistant stage and are ensheathed in the 2nd-stage cuticle. An IJ is formed inside the host cadaver, but represents the only stage in the life cycle

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that occurs outside of the host. The sole purpose of the IJ is to find a new host to begin its parasitic cycle. In natural conditions, infectivity is restricted by ecological and behavioral barriers (Salt, 1970) and has resulted in varying degrees of pest suppression (Benham and Poinar, 1973; Poinar, 1979). The environmental stressors include sensitivity to desiccation (Welch and Briand, 1961; Simons and Poinar, 1973), ultraviolet radiation (Gaugler and Bouch, 1978), and high temperature (Kaya, 1977; Kaya *et al.*, 1982; Molyneux, 1986). Temperatures influence the infection potential, death rates, migratory activity, sex ratio in the insect, and successful application of *S. carpocapsae* (Pye and Burman, 1978; Burman and Pye, 1980; Byers and Poinar, 1982; Kaya *et al.*, 1982). Schmiege (1963) placed IJs of *S. carpocapsae* in water drops at different temperatures and found that an exposure of 1 hr at 35℃ caused high nematode mortality, and IJs that survived the treatment did not resume normal activity. Exposure for 16 h at 37℃ and 1 h at 41℃ resulted in 100% mortality. However, IJs could be held in water at 5℃ for up to several years with only a gradual loss of infectivity. He also noted that, whereas 70% of the IJs were killed when placed in a freezer at -10℃ for 18 h, the survivors were still infective.

Gray and Johnson (1982) reported that the highest survival of *S. carpocapsae* in the soil was at 30℃. While nematode survival declined significantly as the temperature exceeded 35℃, some survival occurred at 35℃ and 40℃. In dosage mortality studies, Dunphy and Webster (1986) found that median lethal dosage (LD_{50}) and median lethal time (LT_{50}) declined in the following order: 15>20>25℃ with both DD-136 and Mexican strain of *S. carpocapsae*.

The behavior of *S. carpocapsae* can vary in different types of soil. When IJs of *S. carpocapsae* are mixed in a small amount of soil, most migrate to the surface of the soil (Poinar, 1979; Kondo and Ishibashi, 1986). This characteristic movement toward the surface seems to be a natural feature of most strains of *S. carpocapsae* (Reed and Carne, 1967). Poinar (1979) indicated that IJs of *S. carpocapsae* behave differently when placed on the surface of different soil types. Moyle and Kaya (1981) placed IJs at 2.5 and 5.0cm below the surface of sand and found little dispersal occurred. When introduced 14cm below the surface of 4 different soil types, the majority of IJs were recovered above the point of placement. Nematodes moved laterally from placement point and infected *Galleria* pupae placed 14cm away. The percentage of IJs able to migrate and infect wax moth pupae placed in the soil decreased as the percentage of clay and silt increased (Georgis and Poinar, 1983).

The purpose of this study was to evaluate the effects of temperature, placement site, and soil texture on the dispersal of infective juveniles of *S. carpocapsae* in 4 different soils.

Materials and Methods

A. Nematode culturing and inoculum preparation

IJs of *S. carpocapsae* (All strain) which were used throughout the experiment, were collected from the larvae of the grape root borer, *Vitacea polistiformis* Harris, in 1974 (All *et al.*, 1980) and continuously cultured in the last-instar larvae of the greater wax moth, *Galleria mellonella* L., using the method described by Dutky *et al.* (1964). Forty-eight hours after infection, cadavers of infected larvae were placed in an emergence system composed of a plastic container ($17.5\times8\times4cm^3$) with a lid, inside of which was a piece of tile ($10\times4cm^2$) wrapped with filter paper (Whatman # 1, dia.=15cm) and submerged in a 0.1% formalin solution. Harvested infective juveniles were

stored in a 0.1% formalin solution at 5℃ after they emerged from the cadavers for 5 to 10 days before use. New nematode inoculum solution was cultured monthly to maintain a fresh, highly infective stock. The *Galleria* colony used in this study was reared on a holisdic diet at 27℃ and has been maintained in our laboratory for at least 6 years.

B. Soil preparation and physical characteristics analysis

Four different soils were used in this study: sand, Cecil coarse sandy loam, sandy clay loam, and silty loam. A sample of soil was collected from the upper 15cm of the A horizon at the Midville and UGA Plant Science Farm sites in Georgia, U.S.A. Textures of these soils were determined by the Soil Testing and Plant Analysis Laboratory of the USDA in Athens, Georgia, U.S.A. The characteristics of these 4 soils were: (1) pure sand; (2) Cecil coarse sandy loam (85% sand, 5% silt and 10% clay); (3) silt loam (95% sand, 2% silt, and 3% clay); and (4) sandy clay loam (68% sand, and 32% clay).

Coarse sandy loam and sandy clay loam were obtained from the University of Georgia Plant Science Farm near Watkinsville, Georgia, and the silty loam was obtained from the Southeastern Branch Experiment Station near Midville, Georgia.

Soil was sieved through a 1-cm screen to remove pebbles and plant debris, fumigated with methyl bromide, and stored in a garbage can. In these studies, the soils were processed through a sieve series into a 2-mm particle size and oven-dried for 48 h at 105℃ before testing.

C. Apparatus and soil preparation

Vertical dispersal of *S. carpocapsae* was determined using six 5-cm sections of polyvinyl chloride (PVC) pipes (5.5cm i.d.) joined together with adhesive tape. Four different oven dried soils were packed according to their bulk density to a density of 1.5 g/cm^3 for sand and silt loam; and 1.05 g/cm^3 for sandy clay loam; 1.40 g/cm^3 for sandy loam (Table 1). The moisture content of each column was adjusted with distilled water to 10% (W/W) for sand, sandy loam and silty loam and 20% for sandy clay loam. Parafilm^R was used to seal the bottom and top of each column to maintain the moisture.

Table 1. The bulk density and porosity of four soils used in experiments with *Steinernema carpocapsae*

Soil type	Bulk density (g / cm^3)	Total Porosity[1]
Sand	1.5228	0.4242
Coarse sandy loam	1.3489	0.4910
Sandy clay loam	1.0768	0.5937
Silty loam	1.4493	0.4531

[1] Porosity(f) = $1-\rho b / \rho s$; ρb=bulk density; ρs =average particle density=2.65g / cm^3.

D. Effects of temperatures and placement site on vertical dispersal of S. carpocapsae

Approximately 15,000 *S. carpocapsae* juveniles in 1 ml of 0.1% formalin solution were placed on the surface of the soil columns, or pipetted to the soil at depths of 5cm and 10cm. The top of each column was capped first with a sheet of parafilm and then covered with piece of aluminum foil to reduce drying. Columns with nematodes were set in an incubator under different temperatures of -20, 25, and 35℃. After 7 days, the columns were separated into 6 sections and soil cores were weighed and placed in a Baerman funnel to extract IJs.

Numbers of IJs recovered from each section were recorded after 48 h. To verify pathogenicity, nematodes recovered

from each section were bioassayed with 25 newly molted 5th instar *Galleria* larvae. There were 4 replicates per treatment. The soil was then dried at 105℃ for 48 h. Bulk density was determined to estimate the degree of compactness.

Twenty grams of each soil types was placed on the petri dish (dia. 9cm). A drop of nematode solution was pipetted onto the surface to observe infective juveniles movement and behavior.

Results

After the infective juveniles are applied on the surface of soil, they crawl on the soil surface or nictate by taking a waving, standing straight, and then forming a loop after small waving which precedes leaping as Knodo and Ishibashi (1986) have described. The juveniles use riding, swarming, or bridging when they travel to neighboring soil particles if the distance between the 2 particles is longer than their body length.

Low temperature effect

When nematodes were placed on the surface, no nematodes were recovered below 5cm after 7 days at 20℃ in all 4 soil types (Table 2a). Soil texture affected the vertical dispersal of nematodes, as shown by higher numbers recovered from sand and silty loam than in sandy loam or sandy clay loam. When nematodes were placed at a 5cm depth, the number of nematodes recovered from both the sandy loam and silty loam were significantly greater than in the sand or sandy clay loam soil. When nematodes were placed at a depth of 10cm, the number of infective juveniles recovered from the sand was greater than in the other 3 soils (Table 2b).

When nematodes were placed on the surface, mortality of *Galleria* in sand and silty loam was higher than in sandy loam or sandy clay loam (Table 2b). The nematodes that were placed at a 5-cm depth, and extracted in the 6-10cm layer, produced higher mortality to *Galleria* larvae as compared with the other layers in all 4 soil types. If soil type is considered, the *Galleria* mortality of the 6-10cm layer was greater in sandy loam as compared with the other 3 soils. When nematodes were placed at a 10cm depth, *Galleria* mortality in the 11-15cm layer was significantly greater than the mortality in the other 5 layers, and the pathogenicity was higher in the sand as compared with the other 3 soils.

Intermediate temperature effect

The nematodes were more active at 25℃ than they were at -20℃, as shown by the greater number of nematodes recovered from each layer at the higher temperature (Table 3). Overall, the highest number of nematodes recovered from all layers was from the sand as compared with the silty loam, sandy loam, and sandy clay loam soils no matter the placement site. No *S. carpocapsae* individuals were recovered below 15cm from the surface in the 4 soils, regardless of the placement site. When applied to the surface, 100% of the nematodes were found on the surface layer. Placement at a depth of 5cm resulted in movement of most nematodes to the surface layer in the sand and silty loam soils, and to the 6-10cm layer in the sandy loam and sandy clay loam soils. A small number of nematodes were recovered from the 11-15cm layer in the sand and silty loam soils, while none were found in this layer in the sandy loam and sandy clay loam soils (Table 3a).

Greater numbers of nematodes were found in the 6-10cm layer of the sandy loam and sandy clay loam soils than the other 2 soils at the same layer. Soil texture affected the vertical dispersal of *S. carpocapsae* at 25℃, as shown by the fact that significantly higher numbers of

Table 2a. Vertical migration of *S. carpocapsae* juveniles 7 days after placement on the surface and at depths of 5 cm and 10 cm in four soils at -20℃.

Layers (cm)	Mean no. nematodes recovered			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	245.8aA	21.5aB	165.5aA	29.0aB[1]
6−10	0.0b	0.0b	0.0b	0.0b
11−15	0.0b	0.0b	0.0b	0.0b
Total	245.8	21.5	165.5	29
			5−cm application	
0−5	00bB	70.3bA	0.0bB	0.0bB
6−10	46.5aB	289.0aA	116.5aA	17.5aB
11−15	0.0b	0.0c	0.0b	0.0b
Total	46.5	359.3	116.5	17.5
			10−cm application	
0−5	0.0b	0.0b	0.0b	0.0b
6−10	29.5bA	10.5bB	0.0bB	0.0bB
11−15	136.3aA	33.8aB	28.0aB	38.0aB
15−20	0.0b	0.0b	0.0b	0.0b
Total	165.8	44.3	28.0	38.0

[1] Duncan's multiple range test ($P<0.05$); means within a column of a given application followed by the same lower-case letter are not significantly different; means within a row followed by the same capital letter are not significantly different (SAS Institute, 1985).

Table 2b. Pathogenicity of infective juveniles of *S. carpocapsae* to *Galleria* larvae 7 days after placement on the surface and at depths of 5 cm and 10cm in four soils at−20℃.

Layers (cm)	Mortality(%)			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	100a	18a	100a	25a[1]
6−10	0b	0b	0b	0b
11−15	0b	0b	0b	0b
			5−cm application	
0−5	0b	60b	0b	0b
6−10	28a	100a	95a	18a
11−15	0b	0b	0b	0b
			10−cm application	
0−5	0b	0b	0b	0b
6−10	3b	5b	0b	0b
11−15	98a	23a	23a	33a
16−20	0b	0b	0b	0b

[1] Duncan's multiple range test ($P<0.05$) ; means within a column of a given application followed by the same lower-case letter are not significantly different, means within a row followed by the same capital letter are not significantly different (SAS Institute, 1985).

infective juveniles were recovered from the surface layer in the sand, silty loam as compared with the sandy loam and clay loam soils.

When the nematodes were placed at a depth of 10cm at 25℃, higher numbers were recovered from the 11-15cm layer as compared with other layers, regardless of soil type. A tendency for upward nematode migration was noted, and the relative abundance of recovered nematodes was in the order: 11-15cm>6-10cm>0-5cm>all other depths. Higher numbers of infective juveniles migrated upwards in the sand and silty loam soils than in the sandy loam and sandy clay loam soils (Table 3a).

At 25℃, when *S. carpocapsae* individuals were placed at a depth of 5cm, the *Galleria* mortality that was produced by Baermann extracts of nematodes from the surface layer in the sandy loam was lowest as compared with the other 3 soils (Table 3b). When the nematodes were placed at a depth of 10cm, the *Galleria* mortality that was produced by the Baermann extracts of nematodes from the surface layer in the sandy loam and sandy clay loam was significantly different than sand and silty loam soils. Insect mortality that was produced by Baermann extracts of nematodes from the 6-10cm layer of the sandy loam soil was significantly lower than in the other 3 soils. The pathogenicity of Baermann extracts of *S. carpocapsae* from the 11-15cm depth was 100% in all 4 soils (Table 3b).

High temperature effect

At 35℃, no infective juveniles were recovered below 10cm when applied to the surface or at a depth of 5cm. No nematodes were found below 15cm when applied at a depth of 10cm (Table 4a). Most of the nematodes applied on the surface remained there at 35℃. When infective juveniles were applied at a depth of 5cm, the majority were recovered from the 6-10 cm layer, and those applied at a 10cm depth were found in the underlying layer at 11-15cm. This suggests that at high temperature such as 35℃, *S. carpocapsae* individuals do not disperse greatly when introduced to a particular location in a soil column.

In considering the effect of soil texture on nematode dispersal at 35℃, the number of *S. carpocapsae* recovered was the highest in sand when placed on the surface at a depth of 5cm (Table 4a). The *Galleria* mortality in the infectivity bioassay corresponded to the number of nematodes recovered from each layer (Table 4b). The mortality that was produced by Baermann extracts of nematodes in sandy clay loam was lower than in the other 3 soils when the nematodes were applied to the surface. *Galleria* mortality that was produced by Baermann extracts of nematode from 0-5cm was highest in sand when nematodes were applied at a depth of 5cm. When nematodes were applied 10cm deep in the silty loam soil at 35℃, the *Galleria* mortality that was produced by Baermann extracts in the 2 upper layers was significantly higher than in the other soils. Analysis of variance of the data indicated that soil texture had a significant effect on the vertical dispersal at 3 temperatures in this study (Table 5).

Discussion

Nematode mobility is known to be affected by soil type (Georgis and Poinar, 1983; Kaya, 1990; Kaya and Gaugler, 1993) and moisture (Silvermann *et al.*, 1982; Kondo and Ishibashi, 1985). Elsherif (cited in Poinar, 1979), demonstrated that the DD-136 strain of *S. carpocapsae* had a tendency to disperse upwards when placed 15cm below the surface of a coarse sandy loam, while the Agriotos strain dispersed both upwards and downwards in about equal numbers. However, both strains of nematodes stayed near the point of placement. Reed and Carne

Table 3a. Vertical migration of *S. carpocapsae* juveniles 7 days after placement on the surface and at depths of 5 cm and 10 cm in four soils at 25℃.

Layer (cm)	Mean no. nematodes recovered			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	99950aA	11042.5aA	9000.aA	9749.0aA[1]
6−10	6.3b	0.0b	0.0b	0.0b
11−15	0.0b	0.0b	0.0b	0.0b
Total	10001.3	11042.5	9000.0	9749.0
			5 cm application	
0−5	3209.5aA	14.8bC	677.5aB	1923bC
6−10	504.8bA	416.8aB	327.8bB	802.3aA
11−15	0.8cB	0.0bB	32.5cA	0.0cB
16−20	0.0c	0.0b	0.0c	0.0c
Total	3715.0	431.5	1037.8	994.5
			10 cm application	
0−5	231.3cA	20.3bcB	107.8cA	18.5bB
6−10	577.5bA	32.5bC	404.5bA	117.5bB
11−15	1906.8aA	132.8aC	2415.8aA	886.8aB
16−20	0.0c	0.0b	0.0b	0.0b
Total	2715.5	185.5	2928.0	1022.8

[1] Duncan's multiple range test ($P<0.05$); means within a column for a given application followed by the same lower−case letter are not significantly different ; means within a row followed by the same capital letter are not significantly different (SAS Institute, 1985).

Table 3b. Pathogenicity of the infective juveniels of *S. carpocapsae* to *Galleria* larvae 7 days after placement on the surface and at depths of 5cm and 10 cm in four soils at 25℃.

Layer (cm)	Mortality(%)			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	100aA	100aA	100aA	100aA[1]
6−10	0b	0b	0b	0b
11−15	0b	0b	0b	0b
			5−cm application	
0−5	100aA	13bB	100aA	100aA
6−10	100aA	100aA	100aA	100aA
11−15	0b	0b	0b	0b
			10−cm application	
0−5	100aA	18cC	65bB	18bC
6−10	100aA	30bB	95aA	98aA
11−15	100aA	100aA	100aA	100aA
16−20	0b	0c	0c	0b

[1] Duncan's multiple range test ($P<0.05$); mean within a column for a given application followed by the same lower-case letter are not significantly different, means within a row followed by the same capital letter are not significantly different (SAS Institute, 1985).

Table 4a. Vertical migration of *S. carpocapsae* juveniles 7 days after placement on the surface and at depths of 5 cm and 10 cm in four soils at 35℃.

Layers (cm)	Mean no. nematodes recovered			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	1415.8aA	1333.3aA	164.5aB	61.0aB[1]
6−10	0.0b	1.7b	22.5b	0.0b
11−15	0.0b	0.0b	0.0b	0.0b
Total	1415.8	1335.0	189.0	61.0
			5-cm application	
0−5	84.3bA	21.5bAB	3.8bB	37.3bAB
6−10	288.3aA	260.0aA	188.8bB	106.aB
11−15	0.0b	0.0b	0.0b	0.0B
Total	372.5	281.5	192.5	143.5
			10-cm application	
0−5	0.3cB	0.8cB	69.3cA	7.0bB
6−10	51.0bB	31.0bB	198.5bA	12.8abB
11−15	307.8aC	901.3aB	1232.0aA	28.0aD
16−20	0.0c	0.0b	0.0b	0.0b
Total	359.0	933.1	1499.8	47.8

[1] Duncan's multiple range test ($P<0.05$) ; mean within a column or row followed by the same letter are not significantly different; means within a row followed by the same capitalized letter are not significantly different (SAS Institute, 1985) .

Table 4b. Pathogenicity of *S. carpocapsae* juveniles to *Galleria* larvae 7 days after placement on the surface and at depths of 5 am and 10 cm in four soils at 35℃.

Layers (cm)	Mortality(%)			
	Sand	Sandy loam	Silty loam	Sandy clay loam
			Surface application	
0−5	100aA	100aA	100aA	630aB[1]
6−10	0bB	3bB	25bA	0bB
11−15	0b	0b	0c	0b
			5-cm application	
0−5	65bA	20bB	3bC	35bB
6−10	100aA	100aA	100aA	98aA
11−15	0b	0b	0b	0c
			10-cm application	
0−5	0cB	0cB	60bA	5bB
6−10	45bB	28bB	95aA	8bC
11−15	100aA	100aA	100aA	23aB
16−20	0c	0c	0b	0b

[1] Duncan's multiple range test ($P<0.05$); mean within a column or row followed by the same letter are not significantly different ; means within a row followed by the same capitalized letter are not significantly different (SAS Institute, 1985).

Table 5. Analysis of variance of the data showing which factors had a significant effect on number of *S. carpocapsae* recovered in the four soils at 3 temperatures

Source	df	Mean square	F values
	−20℃		
Model	14	0.9249	11.96**
Soils (S)	3	1.5749	20.37**
Displacement (Disp)	2	0.1499	1.94
S x Disp	6	0.8874	11.48**
	25℃		
Model	14	1.2509	20.24**
Soils (S)	3	1.0959	17.73**
Displacement (Disp)	2	4.7620	77.03**
S x Disp	6	0.4099	6.63**
	35℃		
Model	14	1.2974	13.87**
Soils (S)	3	2.9841	31.89**
Displacement (Disp)	2	0.0782	0.84**
S x Disp	6	1.0001	10.69**

**Designate a significant effect at P=0.01.

(1967) indicated that gliding movement, in general, is the only movement possible in a packed substrate and appeared to result in randomly directed movement, which eventually takes the nematodes to the soil surface. Reed and Carne (1967) reported that most DD-136 juveniles dispersed toward the soil surface. Schroeder and Beavers (1987) concluded that the Mexican strain remained in the top 15cm when applied to the surface of a Lakeland sandy loam. Georgis and Poinar (1983) indicated that nematodes tended to disperse upwards from the point of application in 4 soil types. The percentage of infective juveniles able to migrate and infect *Galleria* pupae placed in the soil decreased as the percentage of clay and silt increased. Movement was least in clay soil and limited in silty loam.

In the present study, when nematodes were placed on the soil surface, most of the *S. carpocapsae* population displayed little downward movement at all 3 temperatures in the 4 soil types which agrees with the data of previous studies (Moyle and Kaya 1981; Georgis and Poinar, 1983; Schroeder and Beavers, 1987). Nematodes dispersed more readily in lighter soil (sand and silty loam) than heavy soil (sandy loam and sandy clay loam) at 25℃ and 35℃ when applied to a depth of 5cm and 10cm. These results agree with those of Georgis and Poinar (1983).

At 20℃, there were fewer nematodes recovered from each layer, and most of the juveniles remained near the placement site. This was probably caused by the effect of cold on the survival of the infective juveniles. Schmiege(1963) indicated that *S. carpocapsae* is capable of withstanding low temperatures. He placed infective juveniles in-10℃ for 18 h, and approximately 70% were killed. However, the survivors were still capable of infecting insects. In the present study, when *S. carpocapsae* individuals(in water) were placed in-10℃ for 7 days, 99% were killed, but the few survivors still retained pathogenicity to *Galleria* larvae. This indicated that the nematodes could enter cryptobiosis and tolerate freezing.

At the intermediate temperature of 25℃, lower numbers of infective juveniles were recovered when *S. carpocapsae* was placed a depth of 10cm, as compared with 5cm in the sand and sandy loam soil. At a higher temperature of 35℃, lower numbers of infective juveniles were recovered from 5cm deep, as compared with 10cm in the silty loam soil. As the previous study has indicated, when the IJs are placed in the middle of a soil column, significantly more nematodes move upwards than downwards (Georgis and Poinar, 1983).

Porosity affects nematode movement, with less dispersal occurring as the percentages of silt and clay increase in the soil (Wallace, 1963;Georgis and Poinar, 1983). In the present study, compactness occurred in the sand and silty loam soil columns due to gravity. This resulted in an increase in bulk density and a decrease in pore size, thus restricting

nematode movement through pores, and probably increasing mortality in the treated nematode population.

Schmiege (1963) indicated that the activity of infective juveniles (in water drops) began to decrease when the temperature increased from 30 to 32℃. Behavioral observation indicated that the "All strain" is adapted for remaining on the soil surface or the placement site, and not moving more than 15cm below the surface in the absence of hosts. This agrees with observations by Georgis and Poinar (1983) and Schroeder and Beavers (1987).

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溫度與施用深度對蟲生線蟲*Steinernema carpocapsae*散佈的影響

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摘 要

在室內進行探討溫度及施用深度對蟲生線蟲*Steinernema carpocapsae*散佈的影響。測試所選用的溫度為－20，25及35℃，施用深度為表土、5及10公分。測試選用的土壤為純砂、西索砂質壤土、砂質壤土和粘質壤土。在－20℃下所粹取的線蟲數較低但皆能感染蠟蛾幼蟲，不論施用深度為何移動不多。在25℃下各種土壤自三種施用深度所粹取的線蟲數為三種溫度中最高。線蟲在純砂及砂質壤土比在砂質壤土和粘質壤土移動較佳。在35℃下，自四種土壤各層深度下所粹取的線蟲數皆低於25℃的線蟲粹取數。在－20，25，和35℃下，當致病性幼蟲施於四種土壤的表面時，往下移動的線蟲數很少。若施於5及10公分時，在35℃下，致病性幼蟲並不會在施用地點6公分以下被粹取到，大部份的線蟲傾向於移向下5公分土層。當施於5公分深度時，從純砂中粹取的線蟲數最多。當施於10公分深度時，從砂質壤土中粹取的線蟲數最多。本實驗的數據指出，當土中砂粒及粘粒比率增加時線蟲的移動會減少。

關鍵詞：*Steinernema carpocapsae*、蟲生線蟲、溫度、施用深度、散佈。

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