

Dissemination of Phytoparasitic Nematodes ¹

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INTRODUCTION: An understanding of all aspects of nematode biology and epidemiology, which includes dispersal mechanisms, is a cornerstone for developing effective strategies to manage phytoparasitic nematodes. This circular discusses the means by which nematodes are disseminated, and the importance of sanitation and certification programs in preventing their dispersal.

DISSEMINATION THROUGH THE ACTIVE MOVEMENT OF NEMATODES: Nematodes migrate limited distances by their own active movement. Foliar nematodes may move as much as 1.5 cm per minute and at least 15 cm up a chrysanthemum stem overnight (Wallace 1959). Vertical and horizontal movement of 50 cm in 3 days and 75 cm in 9 days, respectively, has been observed for juveniles of root knot nematode, *Meloidogyne javanica*, in soil (Prot and Netscher 1979). In columns containing field soils, *Meloidogyne chitwoodi* moved vertically upwards 45 cm in 4 days and 60 cm in 10 days. *Meloidogyne hapla* migrated upward 25 cm in 6 days (O'Bannon and Inserra 1988). *Meloidogyne arenaria* migrated vertically 120 cm to host roots in sandy soils in Florida in one month (Dickson and Hewlett, personal communication). *Trichodorus* species have been observed to move 250 cm downward in soil in 100 days (Rossner 1972). Although these distances are short, active movement can be important if it enables nematodes to be disseminated by other agents such as wind, water, vehicles and animals.

DISPERSAL IN SOIL WITH THE AID OF PEOPLE: The activities of people contribute greatly to the dissemination of nematodes over great distances. Modern air transport allows nematodes to hitchhike on travellers' shoes or other items and move to the other side of the world in less than 24 hours. In 1993, Florida nurseries imported 380 million cuttings and bare-rooted plants originating from 50 different countries. "Bare-rooted" plants are often contaminated by soil particles which may contain nematodes. Roots can host endoparasitic nematodes that are not removed by washing treatments. Nematodes that in the morning are in a field in Central America may find themselves in a nursery in the United States in the afternoon. A few months later the plants may be exported, and the nematodes may end up in another part of the world.

Humans, including scientists, have many times inadvertently moved nematodes in soil to new areas where crop tests were conducted. In the late 1800s and early 1900s commercial inoculants containing the nitrogen fixing bacterium, *Bradyrhizobium japonicum*, were not available. Since this bacterium is essential for good soybean production, raw soil containing the bacterium was imported and distributed in fields where soybeans were first grown (Fairchild 1948). Soil from these fields were then used to distribute this beneficial bacterium to new locations. This practice was not limited to soybean, but also was used for other legumes, and research institutions recommended the quantity of soil per acre needed to ensure nodulation (Hopkin 1904). It is possible that the soybean cyst nematode, and other nematode pests of legumes were introduced into the U.S. and disseminated in this manner.

It is also known that the soybean cyst nematode and other nematodes are spread by soil peds, i.e., soil aggregates which contaminate soybean seed at harvest. These peds are not removed in the seed cleaning process because the peds and seed are similar in size and weight.

Nematodes may be moved on agricultural equipment from farm to farm, sometimes hundreds of miles apart. In Florida, there is evidence that a large commercial company introduced the soybean cyst nematode into several areas in central Florida on equipment that was also used in infested fields in the northwestern part of the state (R. Dunn, personal communication). The corn cyst nematode, *Heterodera zaeae*, was first found in the U.S. in Maryland in the Aberdeen Proving Ground area, where the U.S. military brought in shiploads of raw soil from all over the world in order to predict how military equipment would function in different soil types (L. Krusberg, personal communication).

DISSEMINATION BY ANIMALS: In surveying the Great Plains of central United States, Thorne (1961) noted that the nematode species composition was remarkably similar in various regions. He hypothesized that the millions of American bison that had roamed the Great Plains for thousands of years had uniformly distributed nematodes and other soil

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organisms. These buffalo wallow in mud to protect themselves from swarms of flies and can easily carry 5 to 25 kilos of soil on their hides to new areas where nematodes are distributed.

Phytoparasitic nematodes are known to be disseminated after they pass through the digestive tract of endotherms, such as humans, sheep, cattle, swine, rabbits, guinea pigs, white rats, mice, moles, and armadillos, as well as chickens and other species of birds. In 1919, in the course of a hookworm survey of U.S. Army personnel stationed in Texas, Kofoed and White (1919) reported a strange nematode in 429 of 140,000 fecal samples. They described this new nematode as *Oxyuris incognita* and erroneously thought it was a parasite of humans. It is now known that this nematode was root knot nematode, *Meloidogyne incognita*, and that soldiers likely ingested it when they ate raw vegetables. Such occurrences are not uncommon. In one study in Sao Paulo, Brazil, *Meloidogyne* species were found in 17% of the human feces examined (Sanches 1952). Birds are perhaps the most important animals that disseminate nematodes over great distances. The central part of the U.S. is a major flyway for migrating birds, especially ducks and geese which may disseminate nematodes as they feed in grain fields en route. Some examples where birds have been implicated in the spread of nematodes are: *Anguina tritici* by finches (Marcinowski 1909); *Heterodera glycines* by blackbirds (Epps 1971); and *Globodera rostochiensis* by many species of birds (Brodie 1976; Inagaki 1973).

Insects and other invertebrates also have a role in disseminating nematodes. The role of beetles as nematode vectors in the red ring disease of coconuts and the pine wilt disease is well known. In studies on banana in Bahia, Brazil, Zem and Lordello (1983) recovered the following nematodes from two species of weevils feeding on the rhizomes: *Helicotylenchus* spp., *Meloidogyne* sp., and *Rotylenchulus reniformis* from *Cosmopolites sordidus* and *Bursaphelenchus cocophilus* from *Metamasius hemipterus*. Field slugs, *Derocerus reticulatum*, have been shown to ingest and disseminate adults, juveniles, and eggs of the stem nematode, *Ditylenchus dipsaci* (Cook *et al.* 1989). Nematodes are also disseminated in fields by earthworms (Wallace 1978).

DISPERSAL BY WATER: Under natural conditions nematodes may move from infected plants to non-infected susceptible hosts by splashing of water droplets. The runoff and flooding which occurs during periods of heavy rainfall is undoubtedly a major factor in nematode dissemination. This means of dispersal may be especially important in areas with a monsoon climate, .

Nematodes are readily disseminated when field runoff water used in irrigation is reused in other fields. Faulkner and Bolander (1966, 1970) reported that this was the primary means by which *Ditylenchus dipsaci*, *Meloidogyne hapla*, and species of *Hemicycliophora*, *Heterodera*, *Paratylenchus*, *Pratylenchus*, *Tylenchorhynchus*, and *Xiphinema* were distributed throughout about 500,000 ha. of the Columbia Basin in the state of Washington. It was estimated that as many as 16 billion phytoparasitic nematodes per day passed a given point along the irrigation canals where they sampled. In Spain, *Meloidogyne* juveniles were found in 45% of the samples from irrigation water from the Grenada Plain. *Helicotylenchus*, *Paratylenchus*, *Pratylenchus*, *Tylenchorhynchus* were all present in 60% or more of samples (Tobar and Palacios 1974). In Nigeria, *Heterodera sacchari* cysts were carried in the water for at least 8 km. Cysts with viable eggs were found both in surface water and bottom mud (Odihirin 1976).

Florida turf and pine nurseries have been contaminated with the awl nematode, *Dolichodorus* sp. when plants were irrigated with water from nearby lakes and ponds (Esser 1979). In ornamental nurseries where containerized plants are hung above other plants, nematodes may be dispersed in the water dripping from these plants on to the plants on the benches or surface below.

DISPERSAL BY WIND: Phytoparasitic nematodes are dispersed by the wind, and this may be especially important in areas with a dry season, or in regions with low rainfall. Cysts of *Heterodera* and *Globodera* provide protection from desiccation. Petherbridge and Jones (1944) reported that cysts of *Heterodera schachtii* were dispersed by wind. Chitwood (1951) reported that *Globodera rostochiensis* was windborne. In Australia, spread of *Heterodera avenae* is thought to have been primarily due to wind dispersal (Meagher 1977). When many nematode species are subjected to drying, they remain viable for months, and in some cases for years, in a coiled anhydrobiotic state. For this reason, juveniles of many phytoparasitic nematodes are able to survive when they are windborne in dust and debris. Species of *Criconemoides*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus*, and *Tylenchorhynchus* were recovered from dust traps placed two meters above the ground in Texas (Orr and Newton 1971). In India, dust trapped during a windstorm at 5 m above the ground and 5 km away from the nearest agricultural area contained viable species of *Meloidogyne*, *Pratylenchus*, *Rotylenchulus*, and *Tylenchorhynchus* (Guar 1988).

DISPERSAL IN PLANT TISSUE: One of the principal means by which nematodes are disseminated over great distances is in seeds, plant debris, and propagative stock. The seed gall nematode of wheat, *Anguina tritici*, is the earliest scientifically documented example of nematode dispersal in seeds (Needham 1743). Up to 90,000 nematodes have been reported in a large gall. Nematodes have been revived from galls that have been stored under laboratory conditions for 37 years (Thorne 1961). Another nematode which has been distributed throughout the world on seed is *Aphelenchoides besseyi*, the causal agent of the white tip disease of rice. The importance of the dispersal of this nematode on rice seed in Brasil has been recognized for many years (Silveira *et al.* 1990). Well known examples of nematode dissemination

through edible roots, corms and tubers are *Radopholus similis* on banana; *Ditylenchus destructor*, *Nacobbus* and *Meloidogyne* species on potato; *Pratylenchus coffeae*, *Meloidogyne* spp. and *Scutellonema bradys* on yams; *Meloidogyne* spp., *Pratylenchus brachyurus*, *P. coffeae* and *Rotylenchulus reniformis* on sweet potato; and *Hirschmanniella miticausa*, *P. coffeae*, and *Meloidogyne* spp. on the roots of taro (*Colocasia esculenta*) (Jatala and Bridges 1990).

Nematode dispersal in plant debris is especially important for the stem and bulb nematode, *Ditylenchus dipsaci*, which is known to survive for 23 years in dried plant material (Fielding 1951). This means of dispersal is common on crops such as onion, garlic, alfalfa, and lucerne. The stem and bulb nematode of lucerne likely originated in an infested locality in southeast Asia from where it spread on seed and plant debris throughout the world (Thorne 1961). Foliar nematodes, *Aphelenchoides* species, may also be disseminated with plant debris. *Aphelenchoides fragariae*, which infects the leaves of Philippine violet, may survive under favorable conditions for almost a year in dried leaves which then be wind blown from one area to another (P. Lehman and J. Miller, unpublished research).

The primary means by which nematodes have been distributed throughout the world on perennial crops and ornamental plants is on infected root stocks. In one case, root-knot nematodes on propagative stock were the principal cause of an embarrassing international incident. Each year in the spring many thousands of visitors come to the United States capital to enjoy the beauty of flowering cherry trees which were presented to the United States in 1911 by the mayor of Tokyo, Japan. This was the mayor's second attempt to give a collection of his trees as a gift, since U.S. quarantine officials found root-knot nematodes and other pests on the mayor's first gift and ordered that they be destroyed (Thorne 1961).

Examples of nematodes that are frequently distributed on root stocks are: *Hemicriconemoides mangiferae* on mango and lychee; *Heterodera fici* on fig; *Meloidogyne* species on citrus, cocoa, coffee, fig, guava, kiwi, papaya, passionfruit, pistachio, and tea; *Pratylenchus coffeae* on citrus and coffee; *Pratylenchus loosi* on tea; *Pratylenchus vulnus* on fig, peach and olive; *Radopholus* species on citrus and tea; *Rotylenchulus reniformis* on coffee, papaya, and tea; *Tylenchulus semipenetrans* on citrus, olive and persimmon; and *Xiphinema index* on grape (Campos *et al.* 1990; Cohn and Duncan 1990; Duncan and Cohn 1990). Most of the nematode damage to these crops could be prevented with sanitation and certification programs that produce nematode-free seedlings. But unfortunately, too few of these programs have been implemented.

CONCLUSION: Preventing the dispersal of nematodes to new areas is an important management strategy, especially for perennial crops and landscape plants. The old adage, "an ounce of prevention is worth a pound of cure" applies to many of the Florida Department of Agriculture & Consumer Services' sanitation and certification programs. These cost effective programs prevent serious nematode pests from becoming established in citrus groves and ornamental nurseries, reduce crop losses due to nematodes, enable growers to meet the nematode certification requirements of other states and countries to which they export plants, and reduce the use of toxic pesticides in our environment.

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