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Plant Parasitic Nematodes: An emerging threat in banana cultivation

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Introduction

Banana is one of the most important fruit crops grown in tropical and subtropical regions, serving as a major source of food, nutrition, and income for millions of farmers. However, its productivity is seriously constrained by plant-parasitic nematodes, which are among the most destructive and underestimated pests of banana. These microscopic, soil-borne organisms primarily attack the root system, impairing the plant's ability to absorb water and nutrients efficiently. As a result, affected plants exhibit poor vigor, reduced growth, and a significant decline in yield and fruit quality. Nematode infestation in banana leads to extensive root damage such as lesions, rotting, and gall formation, depending on the nematode species involved. This root deterioration weakens anchorage, making plants highly susceptible to lodging or toppling, especially during windy conditions or at the bunch-bearing stage. Poor root health also results in reduced bunch size, fewer hands, and smaller fingers, directly affecting market value. Under severe infestation, yield losses may range from 20 to 60%, and in unmanaged fields, losses can be even higher over successive crop cycles.

Several economically important nematode species are associated with banana. *Radopholus similis*, the burrowing nematode, is considered the most destructive as it causes extensive tunneling and necrosis of roots and corm tissues. *Meloidogyne* spp. induce characteristic root galls that interfere with normal root function. *Pratylenchus coffeae* causes lesions that predispose roots to secondary infections by fungi and bacteria, while *Helicotylenchus* spp., though less aggressive individually, contribute to overall root degeneration when present in mixed populations. The simultaneous occurrence of multiple nematode species often aggravates damage and accelerates plant decline. One of the major challenges in managing nematodes in banana is their hidden mode of attack. Since nematodes live in the soil and within roots, early symptoms are often overlooked or confused with nutrient deficiencies or water stress. By the time above-ground symptoms become visible, substantial root damage has already occurred. Moreover, nematodes spread easily through infested soil, irrigation water, tools, and infected planting material, making them a persistent problem in banana-growing regions. Therefore, nematodes play a critical role in limiting banana productivity and sustainability, highlighting the need for effective and integrated nematode management strategies.

Symptoms

Nematode infestation in banana manifests through a range of above-ground and below-ground symptoms, with the latter being more reliable for diagnosis. Above-ground symptoms are generally non-specific and often resemble nutrient deficiency or moisture stress, making early identification difficult. Infected plants exhibit stunted growth, general chlorosis or yellowing of leaves, reduced leaf size, and poor overall vigor. The leaves may appear narrow, erect, and pale, with premature drying of older leaves. Flowering is often delayed, and bunch development is poor, resulting in fewer hands, smaller fingers, and reduced bunch weight. As nematode damage progresses, the root system becomes severely compromised, leading to weak anchorage of the plant. Consequently, heavily infested plants frequently show toppling or lodging, especially during periods of high

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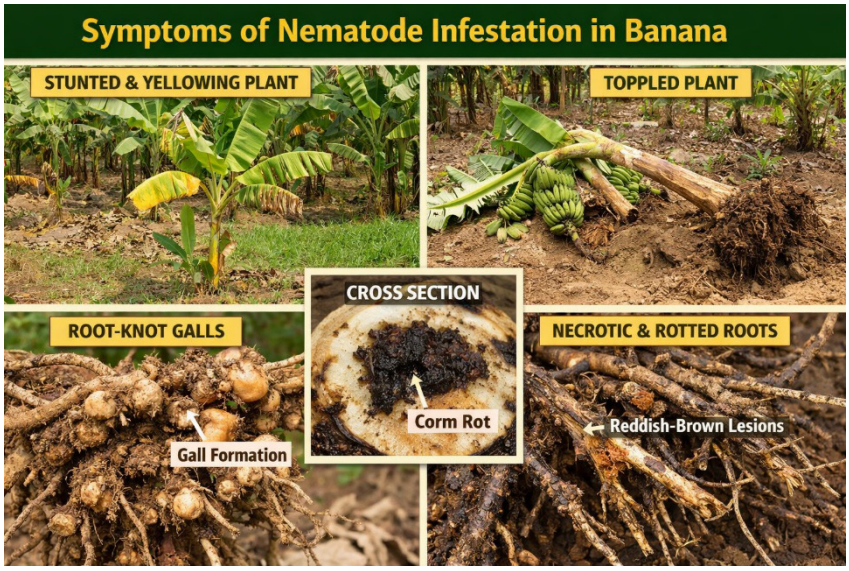
wind or at the fruit-bearing stage when the plant is under maximum load. This symptom is particularly prominent in infestations caused by the burrowing nematode (*Radopholus similis*) and results in significant yield loss.



Below-ground symptoms are more characteristic and diagnostic of nematode attack. Infected roots show lesions, necrosis, rotting, and a marked reduction in feeder roots. The root system becomes sparse, brittle, and darkened, losing its normal white and healthy appearance. Root-knot nematodes (*Meloidogyne* spp.) induce distinct galls or swellings on the roots due to the formation of giant cells, which disrupt normal root function. In contrast, burrowing nematodes produce elongated reddish-brown to black lesions that enlarge and coalesce over time, leading to extensive root and corm decay. The damaged root tissues provide easy entry points for secondary pathogens such as fungi and bacteria, resulting in complex disease interactions and accelerated plant decline. Such combined infections further aggravate root rot, reduce plant longevity, and severely limit ratoon crop performance. Overall, nematode infestation significantly weakens the banana plant, adversely affecting growth, yield, and sustainability of banana cultivation.

Life cycle

Banana nematodes are predominantly soil-borne and complete their entire life cycle in close association with the banana root system. Most economically important species are endoparasitic or semi-endoparasitic in nature, spending a major part of their life within the root tissues. The life cycle begins with the egg stage. Eggs are laid either singly or in masses, depending on the species, and may be deposited in the soil, within root tissues, or in a gelatinous matrix on the root surface, as commonly observed in root-knot nematodes. After hatching, the second-stage juvenile (J2) emerges as the infective stage. These juveniles actively move through the soil water films and penetrate young, tender banana roots, usually near the root tips or zones of elongation. Once inside the root, the juveniles migrate intercellularly and establish permanent feeding sites within the cortical or vascular tissues. In the case of *Meloidogyne* spp., the juveniles induce the formation of specialized multinucleate giant cells by altering normal plant cell metabolism, which results in characteristic gall formation on the roots. Following successful establishment, the nematodes undergo successive molts and continue their development while feeding on host tissues. As development progresses, distinct sexual dimorphism becomes evident. Adult females are generally sedentary, swollen, and remain embedded within the root tissues, whereas

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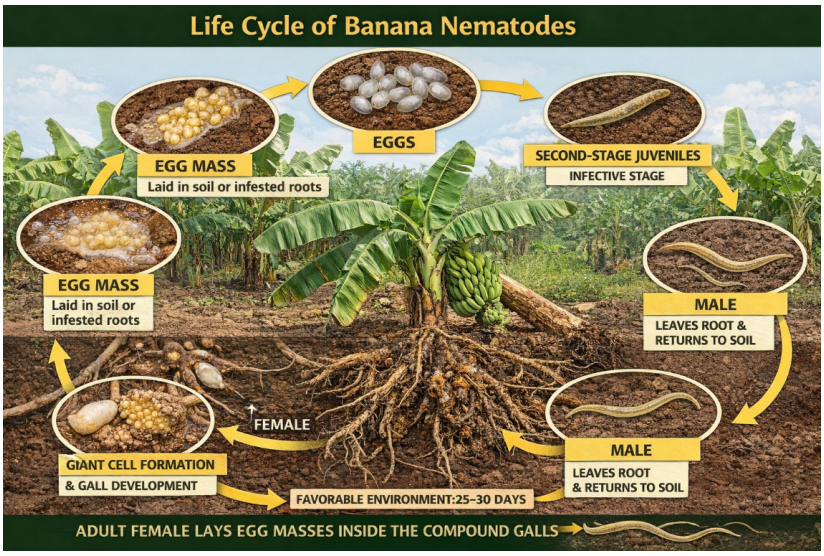
adult males regain a vermiform shape, exit the roots, and live freely in the soil, playing a role in reproduction. Species such as *Radopholus similis* remain migratory endoparasites and cause extensive tissue destruction as they move and feed within the roots. Under favorable environmental conditions such as warm temperatures and adequate soil moisture, the entire life cycle is completed within approximately 25–30 days. This rapid life cycle allows several overlapping generations to occur within a single banana growing season, leading to rapid population build-up and severe root damage if effective management practices are not adopted.



Management

Effective management of nematodes in banana requires a well-planned **integrated nematode management (INM)** strategy, as no single method provides complete or long-term control. Since nematodes are soil-borne and persistent, combining preventive, cultural, biological, and chemical approaches is essential for sustainable management.

1. **Use of healthy planting material (preventive management):** The first and most critical step is the use of nematode-free planting material. Tissue-cultured plantlets produced under sterile conditions are highly recommended because they are free from nematodes and other soil-borne pathogens. When suckers are used, they should be carefully selected from healthy mother plants, pared to remove infected tissues, and treated with hot water (about 50–55°C for 15–25 minutes) or appropriate biocontrol/ chemical dips before planting. This greatly reduces the initial nematode load in the field.

2. **Cultural practices**: Cultural methods help lower nematode populations and improve plant tolerance. Deep summer ploughing exposes nematodes to desiccation and sunlight, reducing their survival. Crop rotation with non-host or poor-host crops such as marigold, sunhemp, or certain cereals can effectively suppress nematode populations. Field sanitation, including removal and destruction of infected roots and crop residues, prevents carryover of nematodes to the next crop. Proper drainage and irrigation management also reduce nematode multiplication, as waterlogged or stressed plants are more vulnerable.

3. **Organic amendments**: Application of organic matter such as farmyard manure (FYM), compost, neem cake, pongamia cake, poultry manure, or vermicompost improves soil structure and stimulates beneficial microflora. Many organic amendments release toxic compounds during decomposition that

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are harmful to nematodes. Neem-based products, in particular, have nematicidal properties and can significantly reduce nematode populations while enhancing soil fertility.

4. **Biological control**: Biological management is an eco-friendly and sustainable option. Several antagonistic fungi and bacteria parasitize nematode eggs or suppress their populations. Notable examples include *Paecilomyces lilacinus* and *Pochonia chlamydosporia* (egg-parasitic fungi), *Trichoderma* spp. (general biocontrol agents), and *Bacillus* and *Pseudomonas* spp. These organisms can be applied through enriched compost, nursery treatments, or soil application around the root zone. Regular use helps build a suppressive soil environment.

5. **Chemical control**: Nematicides may be used where infestations are severe and economically damaging. Granular or liquid nematicides can reduce nematode populations quickly, but they should be applied judiciously and in accordance with local recommendations. Overreliance on chemicals is discouraged due to high cost, environmental risks, and potential harm to beneficial soil organisms. Chemicals are most effective when used as a supportive measure within an integrated program.

6. **Integrated approach**: The most successful and sustainable nematode management in banana comes from integrating these methods. For example, planting tissue-culture plants, applying organic amendments and biocontrol agents, practicing crop rotation, and using chemicals only when necessary can collectively keep nematode populations below damaging levels. Such an approach not only manages nematodes effectively but also improves soil health, plant vigor, and long-term productivity of banana plantations.