Root-Knot Nematode:

The soil pest costing agriculture billions

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Root-Knot Nematodes (RKN), belonging to the genus *Meloidogyne*, are among the most damaging plant pests in the world. These microscopic worms - barely 0.3–1 mm long and invisible to the naked eye - live in the soil and attack the roots of a remarkably wide range of plants, both cultivated and wild. Their ability to thrive across diverse soil types and climates has made them a persistent challenge for farmers globally.

Infestation triggers the formation of distinctive swellings on plant roots, known as galls. These galls are not merely cosmetic - they disrupt the root's ability to take up water and nutrients, weakening the plant and leaving it vulnerable to stress and further infection by other soil-dwelling pathogens.

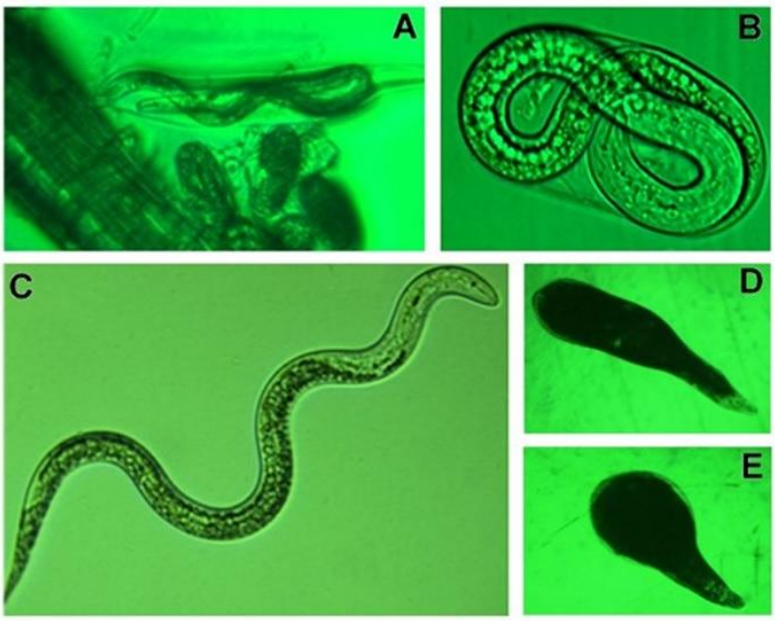
A fast and stealthy life cycle

What makes RKN particularly difficult to control is their life cycle. Once inside the root, *Meloidogyne* nematodes complete their entire development - feeding, growing, and reproducing - entirely within plant tissue. By the time symptoms appear, an infestation is often already well established. Beyond reducing plant growth and crop yields, RKN also affect the quality and marketability of produce.

The nematode's life cycle from egg to reproducing adult can be completed in as little as 3–6 weeks, depending on species and conditions. Temperature is the critical factor: populations grow fastest between 25 and 30°C, meaning warm summers and heated greenhouses can trigger rapid build-up. *Meloidogyne* populations can multiply very quickly under these conditions, raising the risk of severe crop damage.

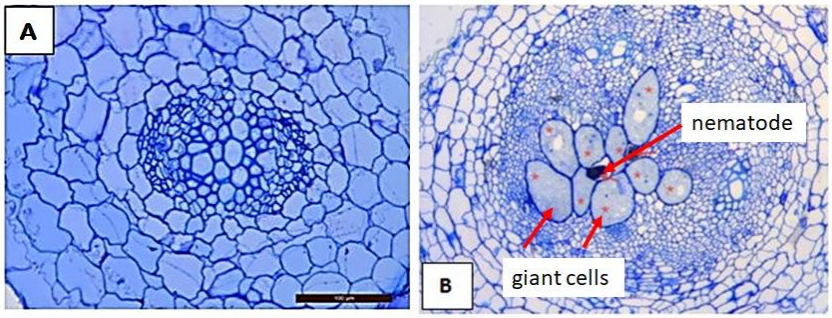
Each adult female produces hundreds, sometimes thousands, of eggs, held together in a protective gelatinous mass on or within the root. The eggs develop through two juvenile stages (J1 and J2). It is the J2 stage that is mobile in the soil and capable of actively seeking out new host roots to infect.

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The different stages of the Root Knot Nematode life-cycle

Once a J2 juvenile enters a root, it navigates through the tissue towards the plant's vascular system. There, it uses a needle-like mouthpart called a stylet to inject proteins that essentially hijack the plant's own cells. The targeted cells are reprogrammed to become enlarged "giant cells": nutrient-rich feeding stations that the nematode exploits throughout its development.



A cross section of a tomato root under the microscope, showing the giant cells created by the nematode compared to a healthy root.

Having established this feeding site, the nematode becomes permanently fixed in place, losing its ability to move. Females swell into a rounded, sac-like shape as they mature, anchored to the root. Males, where they exist, are slender and may return to the soil, but in many *Meloidogyne* species, females can reproduce without males entirely, relying on a process called parthenogenesis.

This combination (fast life cycle, high egg output, and no need for males) allows RKN populations to grow explosively. Infestations can escalate quickly, particularly in intensive farming and greenhouse settings where warm, stable conditions allow successive generations to develop year-round.

Species to watch

Among the most economically significant species, *Meloidogyne incognita* is generally considered the most widespread and aggressive, particularly in tropical and subtropical regions. *Meloidogyne hapla* is better suited to cooler, temperate climates. More recently, the emerging species *M. enterolobii* has become a growing concern: it is highly aggressive and, crucially, can overcome the resistance traits that have been bred into several crops - including tomato - to defend against other RKN species.

Impact on crops and farmers

Above ground, infected plants show symptoms that are easy to miss or misdiagnose: yellowing leaves, wilting, stunted growth, and in severe cases, premature death. These signs look similar to nutrient deficiency or drought stress, which means that by the time RKN is correctly identified, significant damage has often already occurred. The characteristic root galls are usually only visible when plants are uprooted.



A comparison of healthy tomato plant roots, with RKN-infected ones, showing characteristic galls.

Root-knot nematodes are generalist pests with a very broad appetite. Vegetable crops such as tomato, pepper, eggplant, cucumber, courgette, lettuce, carrot, and potato are all susceptible, as are industrial crops including cotton, tobacco, and sugarcane. Even staple cereals like maize and rice can be affected in some regions, along with legumes including soybean, common bean, and peanut. Perennial crops are not spared either: citrus, grapevine, banana, and coffee all feature on the list, as do many ornamental and nursery plants.

For tomato growers, the numbers are stark: RKN routinely causes yield losses of 24–38%, rising to over 60% in severe outbreaks. In protected cultivation locations, such as greenhouses, warm conditions allow the pest to cycle continuously through the year, and damage tends to be worse still. Globally, the economic cost of RKN is estimated at over 100 billion US dollars per year, placing it among the most significant threats to agricultural productivity and food security. The pest also spreads readily through contaminated nursery plants and propagation material, creating serious biosecurity risks.

Climate change is making the situation worse. Rising average temperatures are allowing RKN to establish in regions that were previously too cold to support them. Under medium-to-high emissions scenarios, climate modelling suggests that conditions suitable for *Meloidogyne* species could expand significantly across temperate regions by the end of this century.

At the same time, the rapid growth of greenhouse and protected agriculture is adding further pressure. These environments provide the warm, stable conditions that RKN thrive in, enabling populations to persist and multiply year-round, even in cooler climates, and providing a foothold from which the pest can spread further.

Managing the threat

Managing RKN is complicated by how many plants they can infect - *Meloidogyne* species can parasitise thousands of plant species, which limits the effectiveness of any single control measure. Effective management requires combining several strategies together.

Agronomic approaches include rotating crops with species that RKN cannot easily infect, though the pest's wide host range limits how much this helps. In warm climates, soil solarisation (covering the ground with plastic sheeting to raise temperatures to lethal levels) can be effective. Improving soil health through organic amendments also helps build natural resilience.

Biological control offers another avenue. A range of naturally occurring organisms are known to suppress RKN populations, including nematode-attacking fungi (such as *Purpureocillium lilacinum*, *Pochonia chlamydosporia*, and *Trichoderma* spp.), beneficial bacteria (including *Pasteuria penetrans*, *Bacillus* spp., and *Pseudomonas* spp.), and plant growth-promoting rhizobacteria (PGPR).

These organisms work in various ways: directly attacking RKN eggs and females, producing compounds toxic to nematodes, competing for space and resources, or triggering the plant's own defences. While biological control alone is unlikely to eliminate an established infestation, it forms a valuable part of an integrated approach, especially when combined with resistant varieties, crop rotation, and sound agronomic practice.

CROPSAFE's approach

This is where CROPSAFE comes in. Within the project, the Institute for Sustainable Plant Protection (IPSP-CNR) is leading work on tomato protection strategies using bio-sourced materials. The approach centres on extracting biologically active compounds from agricultural, forestry, and marine by-products - materials that might otherwise go to waste - and developing them into effective, nature-derived pest control products.

IPSP's role within CROPSAFE is to understand how these compounds affect RKN biologically and to integrate the most promising candidates into practical, sustainable crop protection strategies. The goal is not just to control a pest, but to help

move agriculture towards systems that are safer for people, kinder to the environment, and less dependent on synthetic chemistry.

CROP SAFE

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