

A Comprehensive Review of Phytoparasitic Nematode Diversity in Western Uttar Pradesh

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ABSTRACT

Phytoparasitic nematodes pose a persistent and significant threat to crop production in the South Western Semi-Arid Agro-climatic Zone of Uttar Pradesh, India. Key genera like *Meloidogyne*, *Pratylenchus*, *Helicotylenchus*, and *Tylenchorhynchus* are commonly linked to major regional crops, leading to serious declines in root health, nutrient absorption, and overall yield—issues that are worsened by moisture stress and continuous cropping practices. This review brings together recent insights on nematode diversity, distribution, pathogenicity, and the specific damage they cause to crops in the area. It also looks at current management strategies, highlighting integrated approaches that include resistant plant varieties, crop rotation, organic amendments, biological control methods, and targeted chemical applications. There are still significant gaps in species-level diagnostics, long-term monitoring, and field-based economic threshold studies. To reduce losses caused by nematodes and boost the resilience of semi-arid agricultural systems, it's crucial to enhance farmer awareness, improve diagnostic capabilities, and validate sustainable management practices tailored to local conditions.

Keywords- Phytoparasitic Nematodes; South Western Semi-Arid Zone; Uttar Pradesh; Root-Knot Nematodes; Integrated Nematode Management; Crop Surveys.

I. INTRODUCTION

Phytoparasitic nematodes are among the most economically important soil pests impacting agriculture worldwide, especially in tropical and subtropical regions. These tiny roundworms invade plant roots, stems, leaves, and seeds, causing significant yield losses, weakening crops, and making them more susceptible to other infections. In India's semi-arid areas, particularly the South Western Semi-Arid Agro-Climatic Zone of Uttar Pradesh, the soil conditions—like temperature and moisture—along with specific cropping practices, create a perfect environment for various plant-parasitic nematode (PPN) species to thrive. As farming intensifies, with more monocropping and changing climate patterns, the number and variety of PPNs have surged over the past decade, posing a serious risk to both crop yields and the health of soil ecosystems (Jones *et al.*, 2020). Globally, there are more than 4,100 species of

plant-parasitic nematodes, and among them, root-knot nematodes (*Meloidogyne spp.*), cyst nematodes (*Heterodera and Globodera spp.*), reniform nematodes (*Rotylenchulus reniformis*), and lesion nematodes (*Pratylenchus spp.*) are the most destructive. Recent studies indicate that the damage caused by nematodes leads to crop losses exceeding USD 157 billion each year, with root-knot nematodes alone contributing to nearly 27% of the total global yield reductions (Nicol *et al.*, 2019). In India, the economic impact of these nematodes is estimated to be over ₹200 billion annually, particularly affecting vegetable, pulse, oilseed, and cereal crops. The semi-arid zones, characterized by low rainfall, sandy-loam soils, and intensive irrigation, create the perfect conditions for these pests to survive, reproduce, and spread (Kumar and Hussain, 2021). The South Western Semi-Arid Agro-Climatic Zone of Uttar Pradesh includes districts like Agra, Mathura, Aligarh, Etah, and Hathras, where farming mainly revolves

around crops such as potatoes, tomatoes, brinjals, okra, wheat, pearl millet, mustard, and a variety of legumes. Research from this area shows a significant presence of nematodes like *Meloidogyne incognita*, *M. javanica*, *Pratylenchus thornei*, *Hoplolaimus spp.*, and *Helicotylenchus spp.*

The distribution of these nematodes is heavily influenced by factors like cropping intensity and soil type (Singh *et al.*, 2019). Root-knot nematodes, in particular, wreak havoc on solanaceous and cucurbitaceous crops, leading to root galling, stunted growth, nutrient deficiencies, and substantial yield losses that can reach 30–60% during severe infestations (Khan *et al.*, 2022). Likewise, lesion nematodes damage root systems, hinder water and nutrient absorption, and make plants more vulnerable to fungal pathogens like *Fusarium* and *Rhizoctonia*. Environmental factors in semi-arid zones—like high soil temperatures ranging from 25 to 35°C, frequent droughts, and a heavy reliance on groundwater for irrigation—play a crucial role in the survival and growth of nematode populations. Warmer temperatures speed up their life cycles, while irrigation helps them move through the soil (Sharma and Jain, 2021). Climate change adds another layer of complexity, as rising temperatures and erratic rainfall create favorable conditions for new nematode species to emerge and for existing populations to expand. Recent modeling studies suggest that by 2050, we can expect to see a greater spread of *Meloidogyne spp.* and *Pratylenchus spp.* in India's semi-arid regions (Gaur *et al.*, 2022).

In Western Uttar Pradesh, the intensification of farming practices has unintentionally led to a rise in nematode populations. Factors like the continuous planting of susceptible crops, excessive use of chemical fertilizers, limited crop rotation, and minimal organic amendments have all contributed to deteriorating soil health and increased pest pressure. Additionally, the widespread use of tube-well irrigation and farm machinery has facilitated the spread of nematodes through contaminated soil and seedlings (Yadav and Babu, 2020). Despite the growing economic impact, nematode issues often go undiagnosed due to a lack of awareness, insufficient diagnostic facilities, and a reliance on observing symptoms rather than conducting thorough scientific analyses of soil nematodes. Recent developments in nematology have really enhanced our diagnostic capabilities and management strategies. With the help of molecular techniques like PCR-based identification, DNA barcoding, and qPCR quantification, we can now identify nematode species more effectively, allowing for quick detection of their populations in soil and plant tissues (Subbotin and Bert, 2020). These tools have been integrated into agricultural research, helping us document species diversity, phylogenetic relationships, and nematode distribution patterns with greater accuracy in India, including its semi-arid regions. Moreover, remote sensing and

geospatial modeling have contributed to the creation of spatial nematode risk maps, which facilitate targeted management interventions (Kumari *et al.*, 2023). The management of phytoparasitic nematodes in semi-arid agro-ecosystems is increasingly leaning on integrated nematode management (INM). This strategy combines various cultural practices, resistant cultivars, biological agents, and eco-friendly inputs. Effective cultural methods for nematode suppression in dry areas include crop rotation with non-host crops, organic mulching, applying farmyard manure, and soil solarization (Nair *et al.*, 2020). Biological control methods using nematophagous fungi like *Paecilomyces lilacinus* and *Trichoderma harzianum*, along with beneficial bacteria such as *Pseudomonas fluorescens* and *Bacillus subtilis*, have shown promising results against *Meloidogyne* and *Pratylenchus* species (Siddiqi *et al.*, 2023). Additionally, botanicals like neem cake, mustard oil cake, and marigold intercropping are widely recommended for their nematicidal effects. Chemical nematicides are effective, but they come with environmental concerns and are facing more regulations. Thankfully, safer options like bionematicides and botanical solutions are stepping in as sustainable alternatives, especially in semi-arid farming systems where soil organic matter tends to be low. Exciting innovations like biofumigation with cruciferous crops, the creation of nematode-resistant plant varieties, and formulations based on microbial consortia are starting to gain traction as long-term solutions.

II. REGIONAL SETTING AND CROPPING SYSTEMS

The South Western Semi-Arid Agro-Climatic Zone in Uttar Pradesh stands out as one of the most ecologically unique agricultural areas in North India. This region includes districts such as Agra, Mathura, Aligarh, Hathras, and Etah, which are characterized by sweltering summers, inconsistent rainfall, and mainly alluvial to sandy-loam soils. The average annual rainfall here is between 450 and 650 mm, with most of it falling during the monsoon months. The agricultural dynamics of this zone are influenced by high evapotranspiration rates, limited natural drainage, a dependence on groundwater, and a decline in soil organic matter (Kumar and Hussain, 2021). The semi-arid climate, with its long dry spells and high soil temperatures (between 25 and 38°C), creates a perfect environment for various soil-borne pests, including phytoparasitic nematodes. Agriculture in this area is incredibly diverse, featuring a mix of both food and cash crops. During the rabi season, you'll find wheat, pearl millet, mustard, chickpeas, and lentils taking center stage. Meanwhile, kharif crops like pearl millet, sorghum, cluster beans, and groundnuts are also popular choices among farmers. The region's economy benefits significantly from perennial horticultural crops such as citrus fruits, guava,

pomegranate, and aonla (Yadav and Babu, 2020). Vegetable farming plays a crucial role in the overall cropping system, with crops like potatoes, tomatoes, brinjal, okra, cucurbits, cabbage, and cauliflower being grown intensively under irrigation. While the rise of high-value vegetable crops has boosted year-round farming, it has also led to challenges like soil fatigue, nutrient imbalances, and increased nematode infestations. In this area, the patterns of cropping are largely dictated by the availability of tube-well irrigation. The common sequences include wheat followed by potatoes and pearl millet followed by mustard, while many spots are dedicated to continuous vegetable farming. This kind of ongoing monoculture, along with minimal crop rotation and low organic matter input, leads to soil degradation and increases the risk of plant-parasitic nematodes like *Meloidogyne incognita*, *Pratylenchus thornei*, and *Hoplolaimus* spp. (Singh *et al.*, 2019). The sandy-loam soils, which have a moderate level of porosity, facilitate the easy movement and rapid multiplication of nematodes, particularly in irrigated vegetable fields. Recent research highlights that semi-arid areas with heavy vegetable farming and regular irrigation cycles often have higher nematode populations compared to less intensively farmed lands (Sharma and Jain, 2021). This means that grasping how local climate conditions and farming practices interact is crucial for creating effective nematode management strategies that are specifically designed for this type of agro-ecological zone.

III. MAJOR PHYTOPARASITIC NEMATODES OF RELEVANCE TO THE ZONE

In the South Western Semi-Arid Zone of Uttar Pradesh, the agricultural soils are often home to various plant-parasitic nematode genera that significantly contribute to the decline of crops, including vegetables, cereals, and pulses. Below, you'll find a summary of the most crucial taxa affecting the regional cropping systems.

- 1- Root-knot nematodes (*Meloidogyne* spp.) - Polyphagous endoparasites that create those distinctive root galls, which can lead to reduced root function, stunted growth, and yield losses in crops like tomatoes, cucumbers, and pulses. *M. incognita* and *M. javanica* are often seen in intensive vegetable farming, while *M. graminicola* is more common in rice or grassy areas. Warm soil temperatures and irrigated vegetable production really help these nematodes thrive and multiply quickly. (Moens, Perry, and Starr, 2009).
- 2- Lesion nematodes (*Pratylenchus* spp.) - Migratory endoparasites that cause necrotic lesions in the root cortex. This damage weakens the root systems, making plants more vulnerable to secondary pathogens. They play a significant role in crops like

cereals (such as wheat and bajra), pulses (like chickpeas), and tuber crops. Often, they work hand in hand with soil fungi, which can lead to even greater yield losses (Castillo and Vovlas, 2007).

- 3- Reniform nematode (*Rotylenchulus reniformis*) - A type of semi-endoparasite that can significantly reduce the efficiency of roots and the vigor of plants. It used to be more common in subtropical areas, but we're now seeing it more often in irrigated vegetable patches in northern India. This is especially troubling for farmers growing susceptible legumes and high-value vegetables (Robinson *et al.*, 2021).
- 4- Stunt and spiral nematodes (*Tylenchorhynchus*, *Helicotylenchus*) - Ecto/semi-endoparasitic organisms that can cause chronic root damage. This often results in decreased vigor and yield, even if the damage isn't immediately apparent. They thrive in sandy to sandy-loam soils found in semi-arid regions and typically exist in mixed communities, where their cumulative effects can be quite significant (Kaur, Singh, and Brar, 2021).
- 5- Cyst nematodes (*Heterodera* spp.) and other genera (e.g., *Hoplolaimus*, *Xiphinema*) are known to be specific to certain crops and can cause serious damage when they appear. Their current presence in the Southwest zone highlights the need for focused surveys. Although *Hoplolaimus* spp. and dagger nematodes (*Xiphinema* spp.) are not frequently encountered, they can still pose a significant threat, especially in orchards and long-growing crops (Singh, Yadav, and Gautam, 2019).

IV. CROP IMPACTS AND YIELD LOSSES

Phytoparasitic nematodes are a major threat to crop productivity. They mess with root functions, making it tough for plants to absorb water and nutrients, change the way roots grow, and even open the door for secondary infections. All these issues can lead to significant yield losses in vegetables, cereals, and pulses (Moens, Perry, and Starr, 2009). Among them, root-knot nematodes (*Meloidogyne* spp.) are notorious for causing the most noticeable damage in solanaceous and cucurbit crops. In fact, severe infestations can lead to yield reductions of 30–60% in vulnerable vegetable varieties when conditions are just right (Jones *et al.*, 2013). On the other hand, lesion nematodes (*Pratylenchus* spp.) create subtle root damage that's trickier to spot, but they can still significantly impact grain and biomass production in cereals and pulses, especially when they team up with soilborne fungi (Castillo and Vovlas, 2007). In the semi-arid regions of south-western Uttar Pradesh, nematode damage gets worse due to abiotic stress. When roots are already struggling with a lack of moisture, they find it even harder to fend off parasitism. As a result, the same nematode population can lead to a more significant yield loss compared to wetter areas (Vos, Alkemade, and

Helder, 2014). In irrigated, high-intensity vegetable systems, nematode populations can become concentrated, creating localized “hotspots” of severe loss (Singh, Yadav, and Gautam, 2019). Mixed communities of nematodes, like *Meloidogyne*, *Pratylenchus*, and stunt nematodes, often work together in a way that amplifies the overall damage, exceeding what you’d expect from just one species (Moens *et al.*, 2009).

V. MANAGEMENT STRATEGIES

To effectively manage phytoparasitic nematodes in the semi-arid regions of the Southwest, we need to adopt integrated, cost-effective, and locally tailored strategies. These approaches should aim to lower nematode populations while also maintaining soil health and supporting the livelihoods of farmers. Below, you’ll find the key components of these strategies.

- 1- **Cultural practices-** Implementing crop rotation with non-host or less favorable species, using biofumigant cover crops like brassicas, scheduling fallows, and practicing sanitation by removing infected roots and volunteer plants, along with soil solarization in irrigated beds, can significantly lower inoculum levels when done on a larger scale (Sikora *et al.*, 2018).
- 2- Additionally, better water management that prevents prolonged saturation or unnecessary irrigation helps to limit nematode movement within the soil profile (Collange *et al.*, 2011).
- 3- **Host resistance and tolerant cultivars-** When available, using nematode-resistant varieties is a cost-effective approach for smallholders. Breeding programs should aim to adapt to local conditions and focus on resistance to the dominant species in the region (Moens, Perry, and Starr, 2009). Plus, integrating tolerant cultivars into crop rotations can help reduce yield risks, even if complete resistance isn’t achieved.
- 4- **Biological control and soil health-** To boost biological suppression, we can conserve natural antagonists by using organic amendments such as compost and farmyard manure, while also scaling back on broad-spectrum soil insecticides. The application of formulated biocontrol agents—like *Pochonia*, *Paecilomyces*, *Trichoderma* species, and beneficial rhizobacteria—along with microbial consortia has shown promising results in field trials. However, it’s worth noting that their effectiveness can vary based on soil type and climate, so local validation is essential. Often, integrating biocontrol with organic inputs leads to more consistent outcomes (Javed, Khan, and Haq, 2023; Kumar *et al.*, 2020).
- 5- **Chemical and bionematicides-** When quick action is necessary, modern selective nematicides and approved bionematicides can be effective options. However, it’s important to use them sparingly and as

part of an Integrated Pest Management (IPM) strategy to prevent environmental damage and the development of resistance. Before making any decisions, conducting thorough cost-benefit and safety assessments at the field level is crucial (Collange *et al.*, 2011).

- 6- **Monitoring, thresholds and extension-** Regularly sampling soil and roots, using straightforward field diagnostics, and applying economic thresholds tailored to specific regions can help us make targeted interventions and cut down on unnecessary treatments. Engaging farmers in participatory trials, showcasing extension demonstrations, and providing decision-support materials—like timing, rotation plans, and application methods—can really speed up the adoption of integrated nematode management (Abd-Elgawad and Askary, 2020).

VI. FUTURE PROSPECTS

Future research and practice should focus on creating integrated solutions that are tailored to specific regions, effectively connecting diagnostics, management, and farmer adoption. To start, we need systematic, multi-year surveys that combine morphology and molecular barcoding (like ITS/COI) to create an updated species inventory, identify hotspots, and spot any emerging or hidden taxa. Next, we should speed up the development and distribution of region-specific resistant or tolerant cultivars for essential crops such as vegetables, chickpeas, and wheat. This can be achieved through participatory trials involving both breeders and farmers to ensure these crops are a good fit for local conditions. Additionally, we need scalable biological tools—like stable bionematicide formulations and microbial consortia—that are validated in large plots across semi-arid soil types and irrigation systems, along with straightforward application methods that smallholders can easily adopt.

Furthermore, combining remote sensing and geospatial risk modeling with affordable field diagnostics will allow for targeted and timely interventions, reducing the need for blanket chemical applications. Lastly, we need innovative extension methods—such as farmer field schools, participatory surveillance, and digital decision-support tools—to turn scientific knowledge into practical applications and build local diagnostic capabilities. Policymakers should encourage practices that promote soil health, like organic amendments and crop rotations, and support demonstration hubs to help overcome adoption barriers. Together, these strategies—modernizing diagnostics, developing resistant cultivars, validating biologicals, precision risk mapping, and farmer-centered extension—provide a clear path to sustainably lessen nematode impacts and boost the resilience of semi-arid farming systems.

VII. CONCLUSIONS AND RECOMMENDATIONS

Phytoparasitic nematodes are a major yet often overlooked challenge in the South Western Semi-Arid Zone of Uttar Pradesh. Here, the combination of a semi-arid climate, intensive vegetable farming, and limited crop rotation really amplifies their effects. The main culprits behind yield losses are root-knot nematodes (*Meloidogyne* spp.), lesion nematodes (*Pratylenchus* spp.), and other related ecto/semi-endoparasites, which work together with drought stress to worsen the situation. To tackle these losses, we should focus on:

- 1- conducting systematic, multi-season surveys that use both morphological and molecular diagnostics to create an updated inventory of species and hotspot maps.
- 2- developing farmer-friendly integrated nematode management (INM) packages that combine locally adapted resistant or tolerant cultivars with crop rotations, organic amendments, and proven biocontrol agents.
- 3- validating and scaling up cost-effective bionematicides and microbial consortia across different soil types.
- 4- enhancing extension services through participatory trials, quick field diagnostics, and decision-support tools to promote adoption.

Additionally, policy support for soil health incentives and demonstration hubs will help speed up the uptake of these practices. By taking these steps, we can improve diagnostics, enable targeted interventions, and boost the resilience of farming systems in semi-arid regions.

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