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Study of Plant Parasitic Nematode Species and there Impacts on Soybean Crop Health in India

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Abstract

This study looks into how plant-parasitic nematodes affect the health of soybean crops in a particular area in India. A standardized questionnaire was used to gather primary data from farmers in order to evaluate management strategies, crop harm, yield loss, infestation levels, and awareness. According to the findings, the most common nematode species is Meloidogyne incognita (52%), which causes root knots (47%), leaf yellowing (29%), and stunted development (18%). Infestations were most common during the germination (41%) and vegetative (33%) phases, especially in sandy soils (52%). 61% of farmers experienced substantial output losses (>40%) as a result of nematode proliferation caused by continuous monocropping (43%). Despite the use of cultural techniques such crop rotation (53%) and deep plowing (29%), as well as chemical (Fluopyram, 46%) and biological (Paecilomyces lilacinus, 58%) controls, 63% of farmers were still unhappy with yields. In order to increase soybean output and lower financial losses, the study emphasizes the necessity of integrated nematode control techniques, increased farmer knowledge, and institutional assistance.

Keywords: Crop, Farmer, Impact, Plant Parasitic Nematode, Pesticides, Soyabean, etc.

1. Introduction

The majority of plant parasitic nematodes are tiny worms that prey on crops. On several continents throughout the world, they are recognized as a significant biotic barrier to agricultural productivity[1]. Nematodes are roundworms that resemble threads and may be found in both fresh and saline water, as well as soil. Certain nematode species consume plants, fungus, bacteria, protozoa, and other nematodes[2]. They are also capable of parasitizing people, animals, and insects. Plant parasitic nematodes (PPN) are worms that are common in agricultural soils that feed on plant parts[3]. Nematodes may overwinter at any stage of their life cycle, which consists of eggs, juveniles, and adults. The surroundings, the beginning nematode numbers at planting, the toxicity of the nematode species, and the plant's capacity to withstand nematode feeding all interact intricately to cause crop harm[4].

The majority of PPNs use needle-like projections called stylets to pierce and destroy root cells in order to feed. Lesion, lance, needle, sting, stunt, and sting nematodes are among the nematodes that use this kind of feeding[5]. Nematode infection symptoms can mimic both biotic causes like stem & root rots and abiotic stressors like drought & nutritional deficits because they are comparable to those brought on by reduced root development and function[6]. Nematodes typically cause yellowing, stunting, & wilting along with a decrease in production. When SCN is present, visible white-to-pale-yellow female bodies in the roots are indicative of infection. However, surface indications are occasionally evident, and illnesses may remain undiagnosed until populations surpass economic thresholds. Root galling is caused by RKN, however the severity of galling may vary depending on how the plant interacts with the RKN species[7].

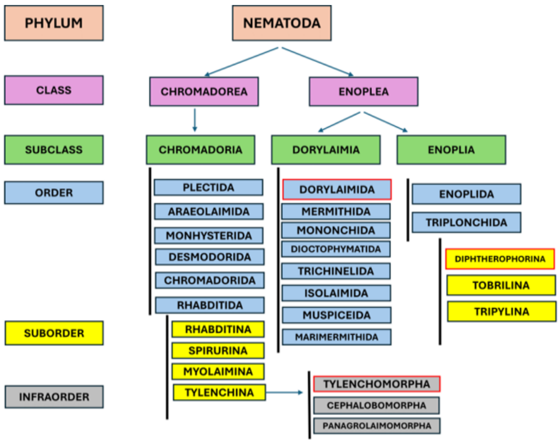

Figure 1 Classification of Plant Parasitic Nematodes [Source: Sujit Das, 2024]

Nematode breeding and growth in population will be supported by a crop once it is planted and its roots begin to expand. Therefore, just before harvest or during harvest, when nematode populations are at their peak, is the ideal period to evaluate nematode

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concentrations in the soils[8]. These findings can be utilized to forecast possible nematode issues in next harvests. It should be mentioned, nevertheless, that if there is a suspicion that nematodes are harming the crop, sampling can be done during the growth season[9]. Due to adverse circumstances for the microbe and a lack of host crops, samples taken in the spring often contain lower levels of nematodes, and occasionally species like the RKN may not be found[10]. Some of the most economically harmful nematodes, such as the soybean cyst nematode (SCN) and root knot nematode (RKN), penetrate roots and create permanent feeding sites where they finish their life cycles without destroying the surrounding cells[11].

A major oilseed crop in the world and a good source of protein is soybeans. Soybeans have gained popularity recently in many regions of the world as a source of protein and oil for human consumption as well as animal feed.[12] They are also a crucial part of better agricultural systems. A promising crop, soybeans will assist agricultural scientists and other stakeholders in achieving the objective of environmentally friendly agriculture and food production for the world's growing population[13]. Therefore, it is useful to investigate issues that might lower soybean agronomic production, such as the threat of nematode parasites on the crop.

Plant nematodes that are parasitic are one of the many obstacles to soybean production. The nematode species, the extent of the nematode population, the host plant's vulnerability, and a number of outside variables, such as temperature, the length of the growing period, the accessibility of nourishment and water to the plant, and the existence of other organisms that contribute to the overall damage inflicted upon the crop, all influence how much damage sustained by plant parasitic nematodes[14]. Examining the link between nematodes and a single plant, the impact on the latter might vary from death in certain cases to no discernible harm in others. Plant parasitic nematodes can inflict a range of lesions on host plant roots during entry or feeding, depending on particular life cycles[15].

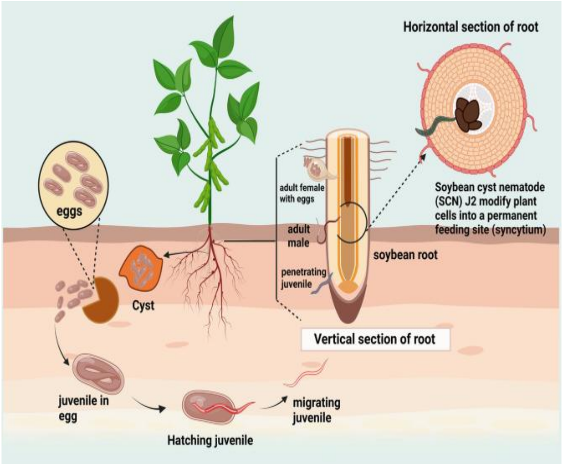

Figure 2 Nematode in Soyabean [Source: Rishil Gupta, 2025]

Indian soybeans are severely impacted by plant parasitic nematodes, which cause stunting, yellowing, poor root growth, decreased nutrient and water absorption, and entrance spots for fungus that cause root rot, all of which result in large output losses. Nematodes are important yield-limiting factors that result in large annual economic losses. They impede the absorption of water and nutrients by forming galls (Root-knot) or causing tissue injury (Lesion/Reniform)[16]. Damage is exacerbated by fungus and bacteria entering wounds caused by nematode feeding. Plant development is impacted by nematodes' interference with nitrogen-fixing bacteria. Especially in lighter soils, infested fields exhibit sporadic areas of stunted, yellow, underdeveloped plants. In India and across the world, nematodes such as root-knot and cyst nematodes reduce nodulation and make plants susceptible, requiring resistant types and appropriate rotation for management.

Figure 3 Soyabean Crop Affected by Root-knot Nematodes [Source: Michael Emerson, 2021]

New periods of growth are usually weaker overall and have slightly smaller leaves than plants in good health. Infected plants usually wilt quicker than uninfected ones during droughts or low water levels. Since nematodes are rarely spread uniformly throughout the soil, the damage is typically distributed unevenly. Root symptoms caused by nematodes might vary greatly. Certain nematodes, such root-knot and some foliar kinds, cause aberrant development in the tissues they feed on. Others may stop root growth or destroy cells as they travel through the roots, leaving behind areas of dead tissue. Damage may manifest as galls, stunted development, or rotting roots, according on the nematode type. Infected roots may seem darker than healthy ones. Nematode damage to roots makes them more susceptible to infections caused by bacteria and fungi, which can cause diseases like wilt and root rot. Moreover, certain viruses can be transmitted by worms[17].

Crop rotation, nematicides, and resistant crop cultivars are all part of a combined strategy to managing soybean nematodes. However, shifting from a monoculture to rotating crops and/or switching from conventional to alternative soil as well as cultivation methods can cause an ecosystem disturbance that takes time for the ecosystem—including nematodes along with other soil microorganisms—to adapt to a new, stable equilibrium. The development of non-chemical, ecologically friendly technologies has far surpassed the use of chemical nematodes. Sanitation, handling of soil, and beneficial biological agents are some of these tactics. When it comes to controlling plant-parasitic nematode infestations, biological methods show great potential. Sometimes referred to as "biopesticides," biological control agents (BCAs) are organisms or their byproducts that combat pests.

Biopesticides are generally defined as compounds designed to protect plants that are derived from natural materials or living creatures as a result of species co-evolution rather than being chemically produced. To better safeguard the environment and biocenosis, it is recommended to use them to handle bio-aggression and control pests. Biological agents, such as bacteria, fungus, actinomycetes, and other microorganisms, can eliminate plant-parasitic nematodes. These agents are specific to their host. Nematodes may be greatly controlled by the most prevalent bacteria and fungus in the soil environment[18].

Global food security depends on agricultural output, yet it is frequently threatened by a variety of biological and environmental causes. Parasitic nematodes are one of the major, often disregarded problems. These tiny, soil-dwelling worms have the potential to seriously damage crops, leading to lower yields, worse-quality output, and higher production costs. Despite their small size, they may inflict significant harm to entire agricultural systems as well as individual plants[19].

2. Literature Review

Nematode infections sometimes go unnoticed because they are underground, which results in a persistent loss in output, according to research from India as well as other soybean-growing nations. The literature that is now available also highlights how soil type, environmental factors, and ongoing monocropping increase nematode populations. Therefore, creating focused and long-lasting management plans requires a knowledge of the variety, prevalence, and crop-level effects of plant-parasitic nematodes unique to Indian soybean systems. In order to provide the scientific foundation for assessing nematode species distribution and their impact on soybean health in India, this study summarizes previous studies.

Hemlata Pant, et.al. [2025] at 2024, a study was carried out at twelve locations around Uttar Pradesh. In January, March, May, July, and September, sixty soil samples were taken. The most common species were Tylenchulus & Helicotylenchus, followed by Meloidogyne, Heterodera, Rotylenchus, and Pratylenchus. The areas of Naini, Arail, Shringverpur, Jhusi, Balua Ghat, Daraganj, Jamunipur, Phaphamau, Mankameshwar, Chhatnag, Macpherson Lake area, and Sangam Ghat area had the highest concentrations of Meloidogyne sp., Heterodera sp., Rotylenchus, and Pratylenchus sp. in the samples taken in January, September, March, July, and May, respectively. Samples taken in January and September revealed the lowest concentration of Tylenchulus & Helicotylenchus sp. in the Naini, Arail, and Jhusi regions.

S.S. Bhople, et.al. [2025] showed the prevalence of Helicoverpa armigera, the chickpea pod borer. During the 32nd SMW, the Helicoverpa armigera larval population was 0.80 larvae/mrl. Over the next several weeks, the incidence grew, and the 35th SMW population reported the highest population (4.60 larvae/mrl). The infection grew quickly, and the next week saw the greatest percentage of afflicted plants during the 39th SMW. Rainfall, morning and night relative humidity (r = -102, r = -0.223, and r = 0.011), respectively, showed a weak negative correlation with Helicoverpa armigera as well as Spodoptera litura, while maximum temperature (r = 0.005) and the lowest temperature (r = 0.301) showed a non-significant positive correlation. Girdle beetles did not significantly correlate with meteorological characteristics such as rainfall (r = -0.466), morning relative humidity (r = 0.149), or evening relative humidity (r = -0.465), but they did correlate with maximum temperature (r = 0.594*). Significant and positive correlations were seen with minimum temperature (r = -0.636*), stem fly correlation with rainfall (r = -0.163), morning relative humidity (r = 0.078), and evening relative humidity (r = 0.192), but not with maximum temperature (r = -0.040).

Sujit Das, et.al. [2024] assessing how parasitic nematodes affect agricultural productivity. Certain nematodes, such root-knot, cyst, lesion, and foliar nematodes, have unique characteristics that allow them to enter plant cells and absorb nutrients, causing stunted growth, decreased yields, and in severe cases, plant death. Their importance is often underestimated since the harm they cause is usually obscured by other obstacles to advancement. Effective nematode management requires a comprehensive approach that prioritizes population control above eradication. This chapter highlights the significant agricultural dangers these nematodes pose and the importance of coordinated management techniques to reduce their impact on crop yield and ensure global food security.

Rahul Meena, et.al. [2024In the Jaipur area of Rajasthan, research was done to determine the spread of plant parasitic nematodes in mungbean crops. According to the current study, the only significant economically significant plant parasitic nematode genus that affects mungbean in Jaipur districts beyond the economic threshold level is the root-knot nematode (Meloidogyne javanica). This might be because the nematode is polyphagous, the local environment is favourable, or there is light sandy soil, which is ideal for the development and spread of root-knot nematodes, Meloidogyne spp.

Alexandra C. Kessler, et.al. [2023] found nine nematode genera from Mid-Atlantic soybean fields, with SCN continuing to be a serious pest of concern. Lesion nematodes and RKN were also commonly seen, and surveys in corn, which is a frequent rotational partner with soybeans in the area and a host to both taxa, should be expanded. 54% of the samples in this research had SCN, 18% had RKN, and 13% had both SCN and RKN. Understanding the impact of nematodes on soybeans may be improved by evaluating economic damage thresholds that take into consideration the coinfection of many worm taxa. It is advised to employ management techniques that target several nematode genera, and molecular species-level identification may be helpful in further classifying the geographic distribution and incidence of lesion nematodes. The survey's findings confirm the need for more studies to look into better methods for controlling soy-bean nematodes in the Mid-Atlantic area.

Bhushan Dengale, et.al. [2022] Females were separated from galls after root samples of pome plants afflicted with nematodes were collected and cleaned. The nematode species is determined to be M. javanica based on the perineal pattern. Vidhara leaves were collected, dried in an oven set at 70°C for three days, and then ground into a powder. Five grams of powder were mixed with distilled water, filtered, and centrifuged before the clear aqueous solution was collected for analysis. According to the bioefficacy research, 46.65%, 58.3%, 69.33%, 83.45%, and 90% of juveniles (J2s) died after being exposed to 10%, 20%, 30%, 40%, and 50% concentrations of Vidhara leaf extract at room temperature for 48 hours. The ideal method for controlling nematodes would be to use locally grown plants because they are inexpensive, non-contaminating, and environmentally benign. Thus, a promising botanical for controlling root-knot nematodes in pomegranates is an aqueous leaf extract of the Vidhara plant.

Jejurkar Gitanjali Baburao, et.al. [2022] According to a survey conducted in 2017–18, the illness incidence across Western Maharashtra's main soybean-growing regions ranged from 10.53 to 37.50%, with an average of 24.07%. District Ahmednagar has the highest illness incidence

(30.12%). The community of Kopargaon Tahsil has the greatest illness incidence (37.50%). A pathogenicity test and visual characteristics were used to identify the root rot pathogen. R. bataticola is characterized by branching that generally occurs at right angles to parent hyphae, while branching at sharp angles has also been noted. Sclerotia might be circular or oblong in form. Using the sick soil method and blotter paper methodology, thirty-four soybean varieties were tested by synthetic inoculations of R. bataticola culture. It was discovered that while some types exhibit a somewhat resistant reaction to the isolates, several kinds have very vulnerable reactivity.

Gufran Ahmad, et.al. [2021] Talk about the latest developments in our knowledge of nematodes and nematophagous microorganisms, focusing on the molecular processes that allow worms to get infected with nematophagous bacteria and how nematodes are protected against harmful infections. The classification of novel genes and biosynthetic metabolites (PKSs, NRPSs, and P450s) can be aided by the availability of genomic and metabolomic data from many species. Lastly, the author discussed a number of important topics for further study and advancement, such as potential methods for using our current knowledge in the creation of effective biocontrol tactics.

Bansa Singh, et.al. [2021] investigated the management of major nematode constraints on pulse crops. Pseudomonas fluorescens and Trichoderma viride have the ability to combat Heterodera cajani in mungbean, pigeonpea, and urdbean. When applied at a rate of 2.5 kg/ha, both bio-agents considerably reduced the nematode population while increasing crop output. M. javanica infestation of cowpea was considerably decreased by using Trichoderma viride and Gliocladium virens as a seed treatment at a rate of 10g/kg seed. Another highly promising biocontrol organism is the bacterial parasite Pasteuria penetrans, which spores adhere to second-stage infectious juveniles, causing them to swarm. The nematode's reproductive system is destroyed by the infection, and it is unable to lay eggs. Additionally, nematicides have no effect on the effectiveness of bacterial spores, allowing P. penetrans & nematicides to be applied together.

K. Kiran Kumar, et.al. [2021] investigated the use of bacterial and fungi endophytes as microbial control agents for nematodes that parasitize plants. Nematicidal endophyte identification, mass manufacturing, and commercialisation offer significant promise for sustainable PPN control in several systems. Endophytes can be all-encompassing instruments for enhancing overall crop health, yields, and crop care costs since some of these endophytes generate systemic resistance against various stressors or antagonize many groups of pests. There are noncommercial compounds based on bacterial and fungal endophytes, despite the fact that various studies have shown their ability to reduce PPN. Nonetheless, certain strains can be used as biofungicides or biostimulants.

KD Thete, [2019] The physico-chemical characteristics of soil samples from several Sakur area seasonal crop locations were examined. The soil samples were gathered and examined using established techniques to evaluate a number of physical and chemical properties. The following soil factors were examined: pH, temperature, EC, organic carbon, calcium, magnesium, nitrogen, potassium, and phosphorus. The investigation revealed how the agricultural field pattern affected the variance in physic-chemical parameters. A study on the nematode diversity of seasonal crops was conducted as an extension of our research. The variety of nematodes revealed how they interacted with plants and other living things. Meloidogyne incognita, M. javanica, Rotylenchulus sp., Heterodera glycines, and Paratrichodorus sp. are the nematode species that have been identified. Among them, M. incognita and M. javanica are the most prevalent species, occurring in all seasonal crops.

Laxmikant V. Shinde, et.al. [2018] The study examines plant parasitic nematodes that were discovered in soybean fields in the Godavari Basin of Jalna District (M.S.) India between August 2010 and October 2010 and August 2011 and October 2011. Two species from two genera related to soybean fields were observed. Meloidogyne incognita and Rotylenchulus reniformis are the nematode species that have been identified.

Matiyar Rahaman Khan, et.al. [2015] neem-based formulas, fungal formulations of P. lilacinus and Trichoderma spp., and bacterial preparations of Pasteuria penetrans and Pseudomonas fluorescens strain have all proved successful in controlling plant parasitic nematodes. However, because to their uneven effectiveness in various agro-ecological conditions, widespread field-scale deployment of bioagents remains a dream rather than a reality. It is possible to investigate the integration of many options based on their availability to farmers, economic feasibility, and compatibility. For the benefit of producers, the biggest task ahead is creating comprehensive strategies for handling field

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issues, such as nematodes causing disease complexes in conjunction with other pathogens including fungus, bacteria, and viruses.

Table 1 Comparative Table for Previous Research Done

Author / Year	Methodology	Results	Research Gap Identified
Pant et al., 2025	Survey across 12 locations in Uttar Pradesh; 60 soil samples collected seasonally (Jan–Sept).	Dominance of *Meloidogyne*, *Heterodera*, *Rotylenchus*, *Pratylenchus*; seasonal peaks in January; lowest populations of *Tylenchulus* & *Helicotylenchus*.	Lacks correlation between nematode density, environmental factors, and crop loss; species-level molecular identification missing.
Bhople et al., 2025	Seasonal incidence monitoring of pests in Marathwada soybean fields; correlation with weather parameters.	*Helicoverpa* incidence peaked during 35th SMW; mixed correlations with rainfall and humidity.	Focused on insect pests not nematodes; does not link nematode–pest interactions in soybean ecosystems.
Das et al., 2024	Review of nematode damage mechanisms and agricultural impacts.	Highlights major nematode groups causing hidden yield losses; emphasizes integrated management.	No region-specific data; lacks quantitative assessment for Indian soybean fields.
Meena & Chandrawat, 2024	Field survey of mungbean nematodes in Jaipur district.	Root-knot nematode (*Meloidogyne javanica*) identified as predominant; linked to sandy soils.	Results focused on mungbean, not soybean; lacks multi-species analysis or management evaluation.
Kessler & Koehler, 2023	Survey of nematodes in Mid-Atlantic soybean fields (USA).	SCN (54%), RKN (18%), lesion nematodes (13%); recommends species-level molecular identification.	Region-specific; limited applicability to Indian climatic and soil conditions.
Dengale, 2022	Bioassay of *Argyreia nervosa* leaf extract on *M. javanica* juveniles.	Mortality increased with concentration (46–90% at 10–50% extract).	Laboratory conditions only; requires field validation on soybean nematodes.
Jejurkar, 2022	Survey of soybean root rot (2017–18) in Western Maharashtra; morphological identification.	Disease incidence 10.53–37.50%; *Rhizoctonia bataticola* identified; many varieties susceptible.	Focus on fungal pathogens, not nematodes; no interaction studies with plant-parasitic nematodes.
Ahmad et al., 2021	Review of nematophagous microorganisms and molecular mechanisms.	Summarizes potential biocontrol pathways and genomic insights.	Insufficient applied research on biocontrol efficacy under Indian soil conditions.
Singh & Devindrappa, 2021	Field trials with *Pseudomonas fluorescens*, *Trichoderma viride*, *Pasteuria penetrans*.	Biocontrol agents reduced nematode populations and improved yields.	Limited data for soybean; long-term soil impact and consistency not fully studied.
Kiran Kumar & Dara, 2021	Review of bacterial & fungal endophytes for nematode control.	Endophytes show promise for systemic resistance and nematode suppression.	No commercial formulations available; field-level efficacy remains unclear.
Thete, 2019	Soil physico-chemical assessment; nematode diversity evaluation in seasonal crops.	Identified *M. incognita*, *M. javanica*, *Rotylenchulus*, *Heterodera*, *Paratrichodorus*; highest dominance of root-knot nematodes.	Not crop-specific; lacks yield impact correlation for soybean.
Shinde et al., 2018	Field investigation in Jalna soybean fields (2010–11).	Recorded *Meloidogyne incognita* and *Rotylenchulus reniformis* in soybean.	Limited sampling period; absence of population dynamics and environmental linkage.
Khan, 2015	Review of nematode diseases in crops.	Highlights various nematode-induced disease complexes.	Lacks soybean-specific integrated management guidelines.
Khan, 2014	Monograph on root-knot nematodes in India.	Documents species distribution across crops.	Soybean-specific data missing; lack of regional damage estimates.
Tamilarasan & Rajam, 2013	Host-derived RNAi techniques for nematode resistance.	Demonstrated RNAi-mediated resistance in crops.	Not tested in Indian soybean varieties; field applicability uncertain.
Reddy et al., 2013	Interaction study of *M. incognita* and *Rhizoctonia bataticola*; biocontrol applications.	Biocontrol agents suppressed nematode–fungal disease complexes.	Focused on pathogen interactions, not species diversity or field prevalence.
Bharti, 2012	Study of root-knot and reniform nematodes in soybean.	Identified major nematode species affecting soybean.	Needs updated data; environmental influences not assessed.

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Research Gap

The majority of current research does not connect nematode diversity to real field signs, conditions of the soil, or yield losses; instead, it concentrates on either laboratory detection or extensive surveys. Additionally, under Indian agro-ecological settings, few research have looked at the impact of climate change, new nematode species, and the efficacy of integrated management techniques. Plant-parasitic nematodes receive very little attention in current research on soybean pests in India, which mostly concentrates on bugs or fungal infections. The majority of the research that is now accessible is not region-specific, frequently looks at other crops like mungbean rather than soybean, and lacks quantitative information on nematode species variety, field prevalence, or yield loss. Additionally, there is a lack of defined integrated farming guidelines unique to soybeans, limited data on nematode pathogen interactions, and the effectiveness of biocontrol under Indian soil circumstances. Additionally, original data from important soybean-growing regions is available, particularly with regard to farmer knowledge, field-level detection methods, and nematode control tool uptake. These gaps emphasize the necessity of researching nematode species and how they affect the health of Indian soybean crops.

3. Research Methodology

In order to examine the prevalence of crop parasitic nematode species and their effects on the health of soybean crops in India, the current study uses a field-based empirical study approach. It focuses on a number of agricultural areas in the Risod Taluka of Washim District. A structured questionnaire was used to gather primary data from 200 soybean farmers who were chosen using a straightforward random sample technique to guarantee equitable representation of various localities and farm sizes. Sections on farmers' knowledge of nematode issues, observed crop symptoms, field management techniques, indicators of soil health, and perceived yield losses were all included in the questionnaire. In addition to the survey, soil samples were taken from specific farms for nematode identification and quantification, and field inspections were carried out to record obvious plant health problems. A thorough evaluation of nematode variety, infestation severity, and their direct effects on soybean productivity was made possible by the combination of laboratory analysis, field-level observations, and farmer-reported data. To find trends and connections pertinent to nematode occurrence and crop health conditions in the research region, the gathered data was methodically recorded and examined using statistical analysis, distribution of frequencies, and correlation techniques.

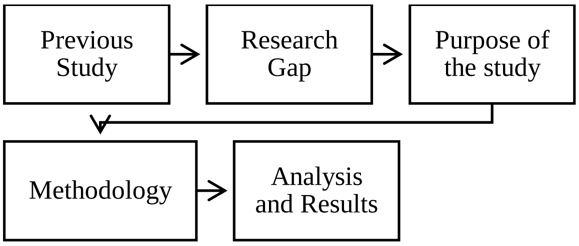
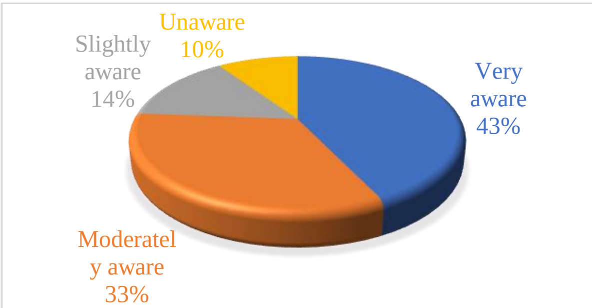


Figure 4 Methodology Flowchart

4. Analysis and Results

the examination of primary data obtained from farmers in the chosen area using a structured questionnaire to evaluate the effects of plant parasitic species of nematodes on the health of soybean crops. The amount of knowledge, perceived degree of nematode infestation, actual crop damage, yield decrease, and efficacy of management techniques were all determined by analysing the farmers' replies. The graphical portrayal of pie charts aids in the clear identification of prevalent trends, such as the percentage of farmers reporting moderate or little effect on soybean output, the percentage of farmers suffering severe nematode infestation, and the degree of satisfaction with current treatment techniques. Overall, the analysis offers a clear summary of farmers' opinions and experiences about nematode-related issues in soybean farming, providing a solid foundation for assessing the scope of the problem and the necessity of efficient management techniques in the chosen area of India.

Nematode-related diseases in soybean crops.



Graph 1 Nematode-related diseases in soybean crops

According to the findings, 33% of farmers have a moderate awareness of nematode-related illnesses in

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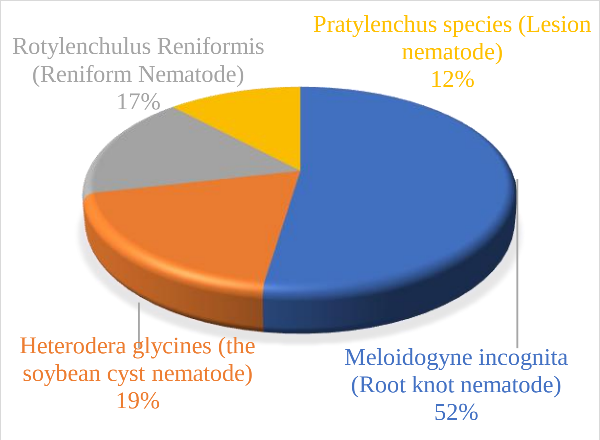
soybeans, compared to 43% who have a high awareness. Although general knowledge is strong, there is still a considerable gap among certain farmers, as seen by the fact that 10% are oblivious and 14% are only marginally aware.

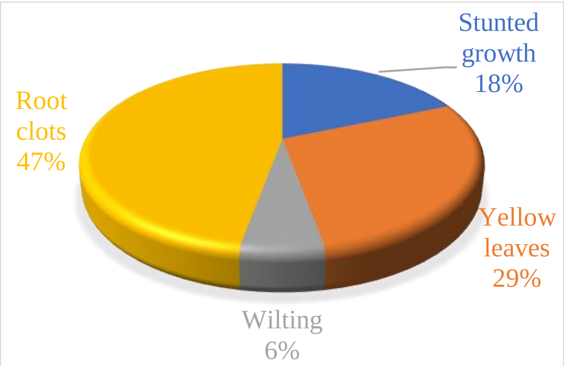
Plant-parasitic nematode is typically linked to soybean damage in India.



Graph 2 Plant-parasitic nematode is typically linked to soybean damage in India.

The root-knot nematode, Meloidogyne incognita, was cited by the majority of farmers (52%) as the primary cause of soybean damage. The predominance of root-knot nematodes in the area is demonstrated by Heterodera glycines (19%), Rotylenchulus reniformis (17%), and Pratylenchus species (12%).

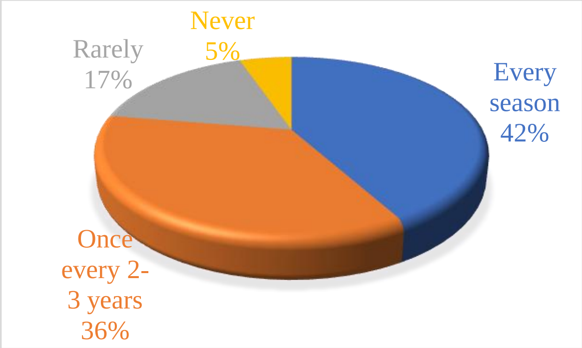
Most prevalent symptoms of nematode-affected soybean plants.



Graph 3 Most prevalent symptoms of nematode-affected soybean plants.

According to the farmers' comments about the most common signs of nematode-affected soybean plants, 47% of them mentioned root knots, and 29% mentioned yellowing of the leaves. Furthermore, just 6% of farmers experienced wilting symptoms, but 18% reported stunted plant development.

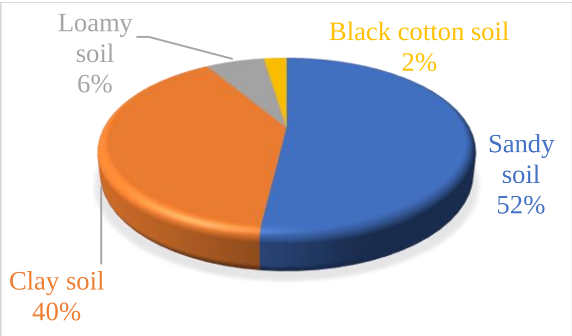
Experience nematode infections on the soybean crop yearly.



Graph 4 Experience nematode infections on the soybean crop yearly.

The findings indicate that soybean nematode infection is a common issue in the research region. Approximately 42% of farmers, or 88 farmers, reported having nematode infections each season, indicating a continuous infestation. An additional 75 farmers, or 36% of the total, reported becoming infected once every two to three years. Only 5% (11 farmers) said they never have worm issues, but over 17% (36 farmers) said that nematode infection happens seldom. Overall, the results unequivocally show that nematode infection is a persistent and pervasive problem impacting soybean harvests.

Soil type in the region is the most easily affected by nematode infestation.



Graph 5 Soil type in the region is the most easily affected by nematode infestation.

According to 109 farmers, or around 52% of the respondents, sandy soil is thought to be the most vulnerable to nematode infection. Following this, 83

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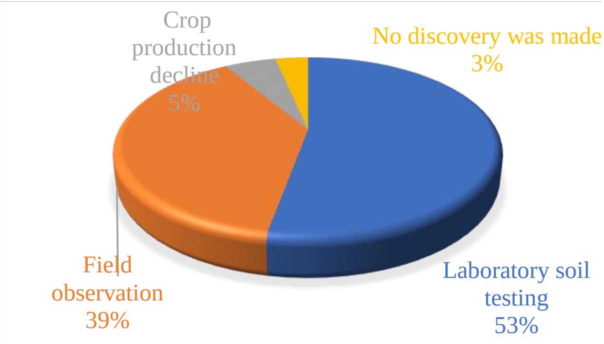
farmers (or almost 40%) reported having clay soil, indicating that nematode issues are equally prevalent in heavier soils. On the other hand, only 13 farmers (about 6%) stated that loamy soil was severely impacted, while only 5 farmers (around 2%) reported black cotton soil. Overall, the results indicate that in the chosen area, nematode infection is more common in sandy and clay soils than in loamy and black cotton soils.

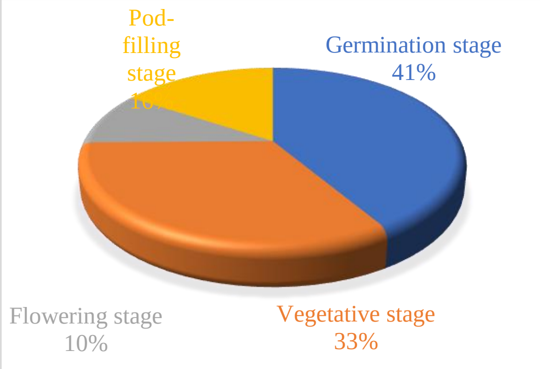
Strategy for identifying nematode infestation.



Graph 6 Strategy for identifying nematode infestation.

According to 111 farmers (or around 53%), laboratory soil analysis is the most popular method for detecting nematode infestation. This follows by field observation, which is utilized by 81 farmers (about 39%), suggesting a dependence on experience and obvious signs. Seven farmers (about 3%) stated that no detection method was utilized, whereas only 11 farmers (almost 5%) recognized nematode infection based on a drop in crop yield. Overall, the findings indicate that despite the widespread use of scientific testing, a sizable percentage of farmers continue to rely on visual evaluation rather than methodical diagnostic techniques.

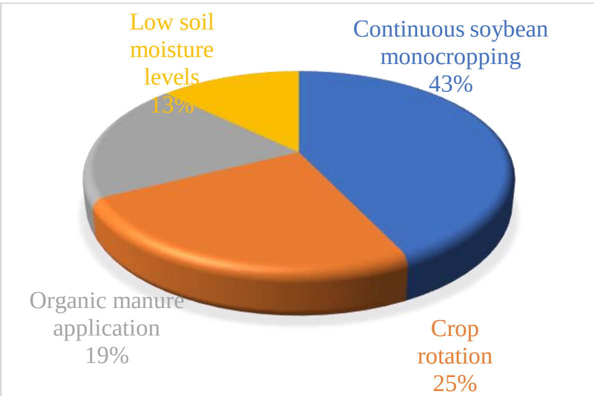
Phase of soybean development do nematodes have the greatest impact.



Graph 7 Phase of soybean development do nematodes have the greatest impact.

According to 87 farmers, or around 41%, the data demonstrate that worms have the most effect during the germination stage, indicating that early crop establishment is extremely susceptible to nematode infection. The vegetative stage, which was recorded by 70 farmers (about 33%), comes next, showing ongoing influence during crop growth. Only 20 farmers (about 10%) reported a major influence during the blooming stage, but about 33 farmers (almost 16%) saw the biggest impact during the pod-filling stage. Overall, the results indicate that nematode infection mostly impacts soybean crops during their early growth phases, resulting in long-term consequences for crop output and health.

Element raises nematode growth in soybean crops.



Graph 8 Element raises nematode growth in soybean crops.

According to 90 farmers (or around 43%), the results show that continued soybean monocropping is the main cause of increasing nematode proliferation. Crop rotation comes next, as stated by 52 farmers (about 25%), indicating that nematode accumulation may still be favored by inadequate or insufficient

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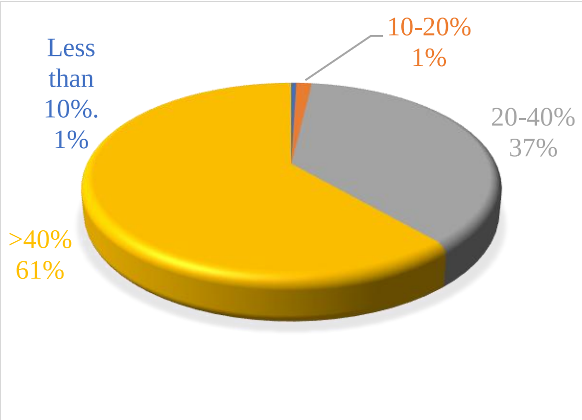
rotation measures. 27 farmers (about 13%) linked nematode proliferation to low soil moisture levels, whereas 41 farmers (around 20%) believed that applying organic manure increased nematode development. Overall, the findings show that the main cause of nematode infection in soybean crops is ongoing monocropping.

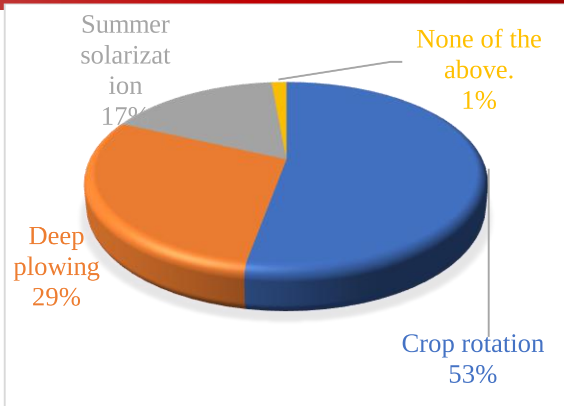
Estimated yield loss owing to nematode attacks



Graph 9 Estimated yield loss owing to nematode attacks

The findings indicate that a significant number of farmers suffer significant output loss as a result of nematode infections. 129 farmers, or almost 61% of the total, reported output losses over 40%, indicating a significant economic effect. 77 farmers (about 37%) who projected output losses in the 20–40% range came next. Only three farmers (about 1%) reported losses of 10–20%, while one farmer (less than 1%) reported losses of less than 10%. Overall, the results unequivocally show that nematode infection significantly lowers soybean crop yields in the studied region.

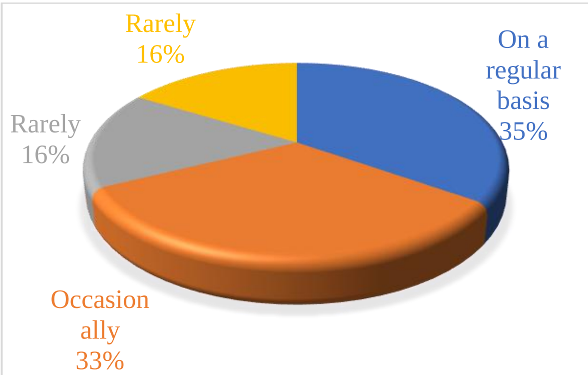
Cultural practices do you use to control nematodes



Graph 10 Cultural practices do you use to control nematodes

According to the replies, crop rotation is the most often employed cultural technique, utilized by 111 farms, or almost 53%. Deep plowing comes next, and 61 farmers (29%) use it. Only 3 farmers (1%) reported using no cultural activities, whereas 35 farmers (17%) utilize summer solarization, demonstrating a good adoption of fundamental control techniques.

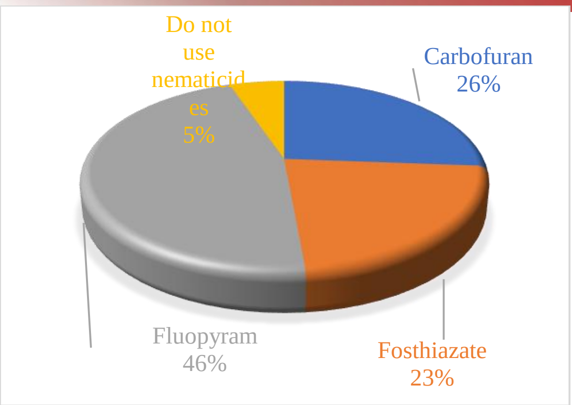
Previously used nematicides on your soybean crops.



Graph 11 Previously used nematicides on your soybean crops.

Nematicides were utilized on a regular basis by about 73 farmers (35%) and infrequently by 69 farmers (33%). Chemical control is prevalent but not always employed by all farms, as seen by the 34 farmers (16%) who used nematicides seldom.

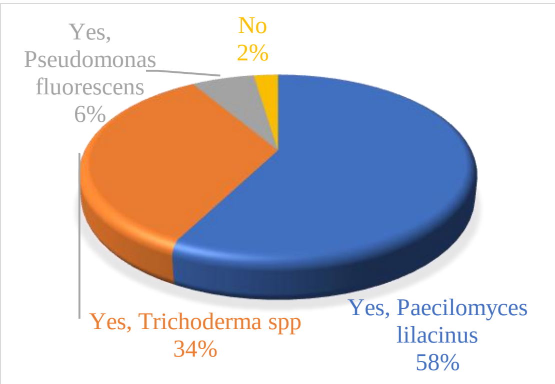
Nematicide recommend for soybean nematode management.



Graph 12 Nematicide recommend for soybean nematode management.

Fluopyram was the nematicide that 97 farmers (46%) advised. Fosthiazate (22%) and carbofuran (26%) came next. There is a significant reliance on chemical remedies, since just 11 farmers (5%) said they do not use nematicides.

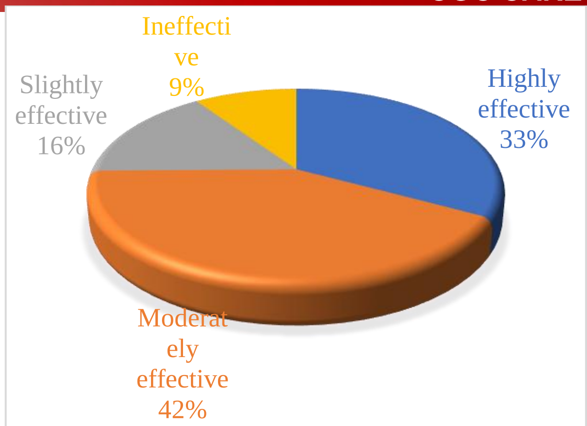
Use biological control strategies for nematode management.



Graph 13 Use biological control strategies for nematode management.

Paecilomyces lilacinus was employed as a biological control agent by the majority of farmers (121; 58%). Thirteen farmers (6%) utilized Pseudomonas fluorescens, whereas 71 farmers (34%) used Trichoderma spp. Just five farmers (2%) did not employ any biological control techniques.

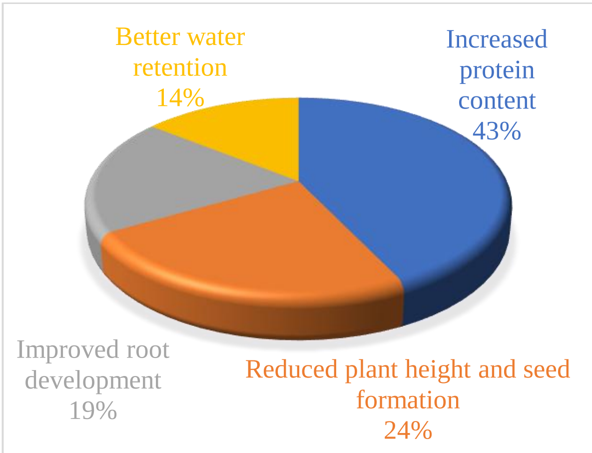
Successful are your existing nematode management strategies.



Graph 14 Successful are your existing nematode management strategies.

Approximately 88 farmers (42%) thought their tactics were fairly effective, and 69 farmers (33%) thought they were very effective. There is room for improvement, though, since 20 farmers (9%) thought they were ineffective and 33 farmers (16%) thought they were just somewhat successful.

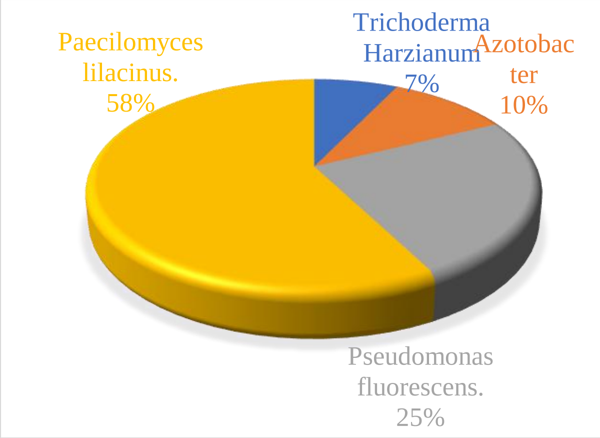
Most prevalent impact caused by nematode infestations on soybean yield.



Graph 15 Most prevalent impact caused by nematode infestations on soybean yield.

Ninety farmers (43%) indicated higher protein content as the most prevalent consequence. Fifty farmers (24%) reported reduced plant height and seed formation, but fewer farmers reported enhanced root development (19%) and greater water retention (14%).

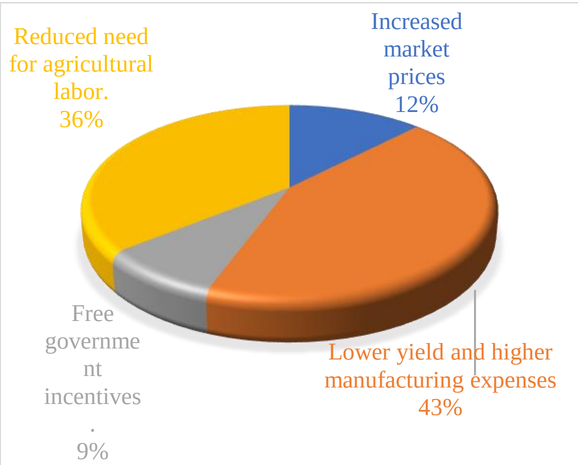
Type of bio-agent is frequently used to deal with plant-parasitic nematodes.



Graph 16 Type of bio-agent is frequently used to deal with plant-parasitic nematodes.

According to 121 farmers (58%), Paecilomyces lilacinus was the most commonly employed bioagent. The predominance of fungal bio-agents was further demonstrated by Pseudomonas fluorescens (25%), Azotobacter (10%), and Trichoderma harzianum (7%).

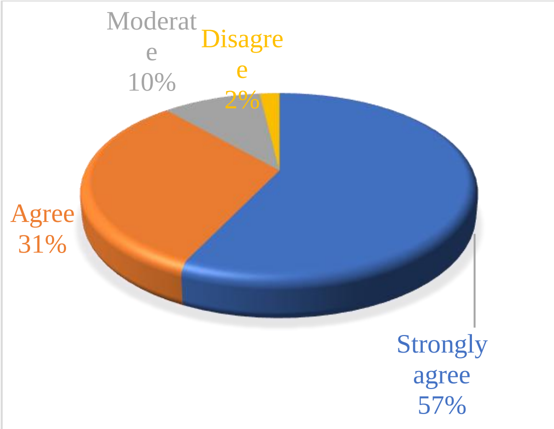
Financial effect of a severe nematode infection on soybean farmers.



Graph 17 Financial effect of a severe nematode infection on soybean farmers.

The primary financial consequence, according to the majority of farmers (91; 43%), was reduced yield and increased production expenses. While fewer farmers mentioned higher market prices (12%) or government incentives (9%), 75 farmers (36%) indicated a decrease in the demand for agricultural labor.

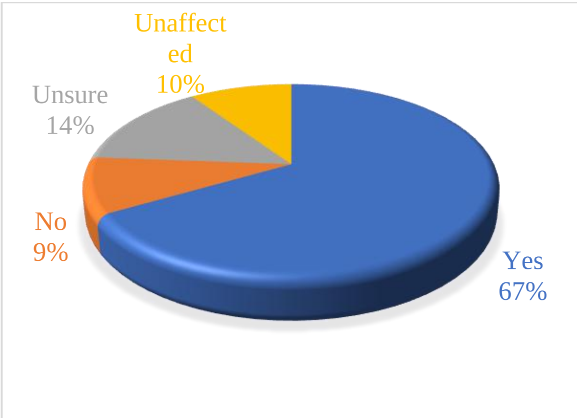
Nematodes provide a significant danger to soybean output in India.



Graph 18 Nematodes provide a significant danger to soybean output in India.

The vast majority of farmers agreed (66; 31%) or strongly agreed (120; 57%) that nematodes are a substantial danger to soybean output. Just 20 farmers (10%) said they were moderately concerned, while 4 farmers (2%) disagreed.

Climate change may be increasing nematode infection in soybean crops.



Graph 19 Climate change may be increasing nematode infection in soybean crops.

The majority of farmers (140; 67%) thought that nematode infection was rising due to climate change. Twenty farmers each (10%) believed that climate change had no effect on nematodes, whereas almost thirty farmers (14%) were unclear.

Farmers are satisfied with the present yields from nematode-affected soybean crops.

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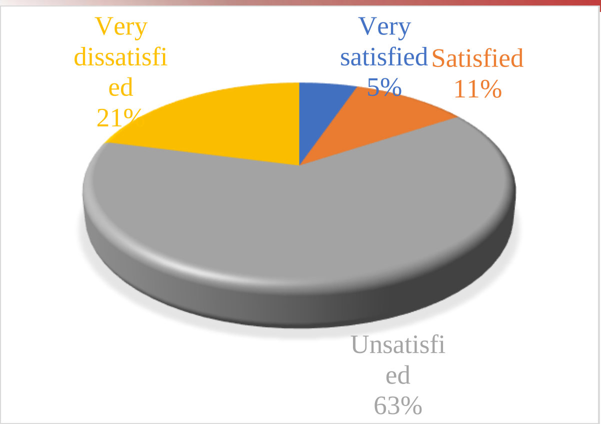
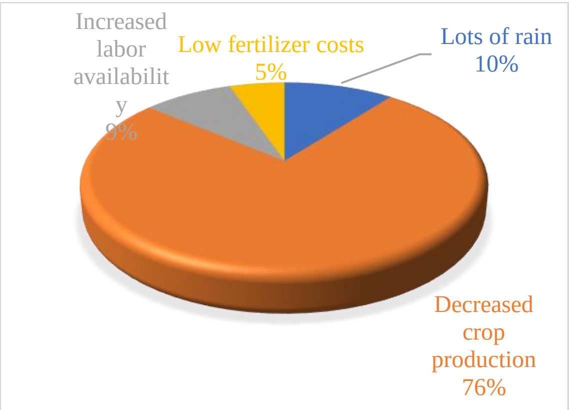


Graph 20 Farmers are satisfied with the present yields from nematode-affected soybean crops.

Many farmers expressed dissatisfaction (133; 63%) or extreme dissatisfaction (44; 21%) with present yields. There was widespread discontent, as just 22 farmers (10%) were satisfied and 11 farmers (5%) were extremely satisfied.

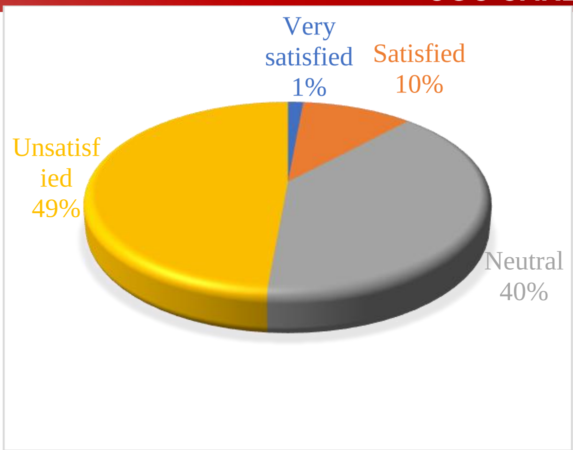
Primary cause for farmer unhappy with nematode infestations.



Graph 21 Primary cause for farmer unhappy with nematode infestations.

Reduced agricultural yield was cited by 159 farmers (76%) as the primary cause of their discontent. Other factors were far less important, including reduced fertilizer costs (5%), increasing labor availability (9%), and excessive rainfall (10%).

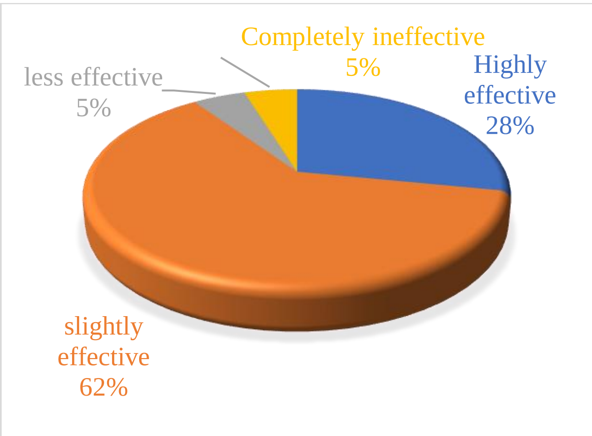
Farmers are satisfied with chemical nematicides as a solution.



Graph 22 Farmers are satisfied with chemical nematicides as a solution.

Regarding chemical nematicides, the majority of farmers were either indifferent (83; 40%) or dissatisfied (102; 49%). There was little trust in chemical remedies, since just 22 farmers (10%) were pleased and 3 farmers (1%) were extremely satisfied.

Different ways that farmers evaluate the effectiveness of biological pesticides.



Graph 23 Different ways that farmers evaluate the effectiveness of biological pesticides.

59 farmers (28%) thought biological pesticides were very successful, whereas 131 farmers (62%) thought they were just somewhat effective. Moderate acceptability was indicated by the small percentage of farmers who thought they were less effective (5%) or totally unsuccessful (5%).

Farmers are believed on government or agricultural improvement support are sufficient.

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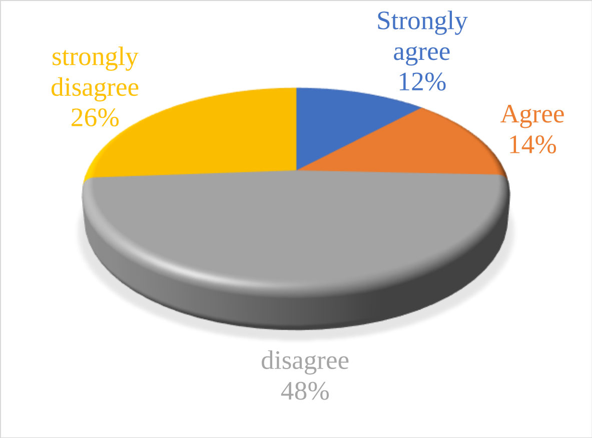
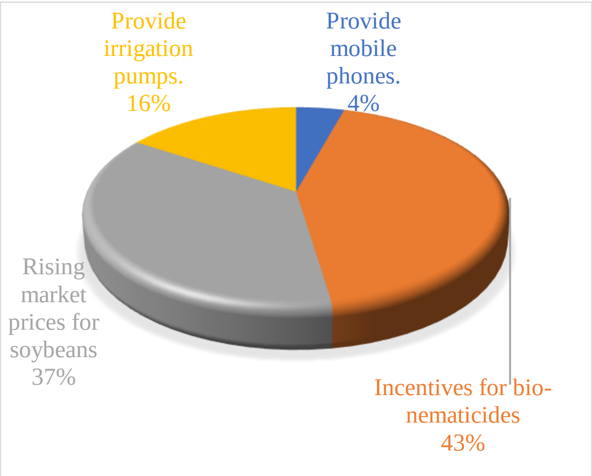


Graph 24 Farmers are believed on government or agricultural improvement support are sufficient.

Most farmers (101; 48%) disagreed and 55 farmers (26%) strongly disagreed that government support is sufficient. Only 25 farmers (12%) strongly agreed and 29 farmers (14%) agreed, indicating dissatisfaction with institutional support.

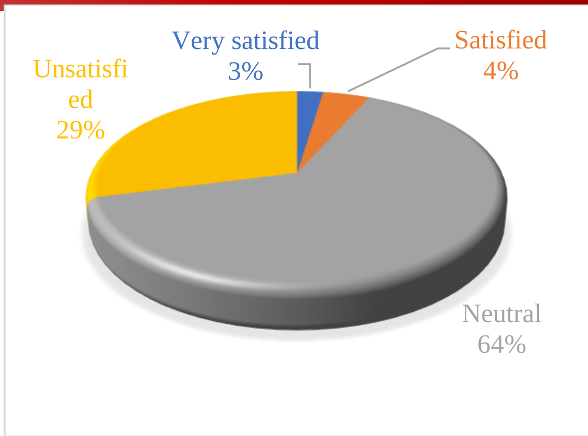
Farmers required further government support.



Graph 25 Farmers required further government support.

The highest demand was for incentives for bio-nematicides, expressed by 91 farmers (43%). This was followed by better soybean prices (37%), irrigation pumps (16%), and mobile phone provision (4%).

Farmers are satisfied with existing nematode control practices for soyabean crops.



Graph 26 Farmers are satisfied with existing nematode control practices for soyabean crops.

Most farmers were neutral (135; 64%) or unsatisfied (61; 29%) with current nematode control practices. Only 9 farmers (4%) were satisfied and 5 farmers (2%) were very satisfied, indicating a need for more effective and farmer-friendly solutions.

5. Discussion

The findings show that the production of soybeans in the chosen area is seriously threatened by plant-parasitic nematodes, particularly root-knot nematodes. Recurrent infestations and significant crop losses (>40% for 61% of respondents) are nevertheless common, despite farmers' high knowledge not entirely translating into effective treatment. The necessity for prompt intervention is highlighted by the vulnerability of early crop stages, especially germination and vegetative development. The kind of soil and ongoing monocropping were shown to be important risk factors, indicating that crop rotation & amending the soil are examples of adaptive agronomic techniques that might reduce infestation. Despite the widespread use of chemical and biological controls, satisfaction levels are still low, suggesting the necessity of integrated management solutions that include cultural, chemical, and biological approaches. Nematode proliferation seems to be accelerated by climate change, making control strategies even more challenging. The need for more easily available, efficient, and locally tailored solutions is highlighted by farmers' discontent with government funding and control methods.

6. Conclusion

Nematode infestation is a chronic, widespread, and economically important problem that affects soybean farming in the chosen region of India, according to the study. According to the poll, Meloidogyne incognita is the most common species (52%), and 43% of farmers are well aware of nematode-related illnesses. The most common symptoms were root knots (47%) and leaf yellowing (29%), with 42% of farmers reporting annual infestations. The primary risk variables were continued monocropping (43%) and sandy soils (52%). 61% of farmers reported yield decreases of more than 40%, indicating significant yield losses. Despite the use of biological agents like Paecilomyces lilacinus (58%), chemical nematicides like Fluopyram (46%), and cultural measures like crop rotation (53%), 63% of farmers are still unhappy with present yields. The issue is made worse by elements including early-stage vulnerability, insufficient government support, and climate change. These results demonstrate the critical need for integrated nematode management techniques that combine biological, chemical, and cultural treatments with increased farmer knowledge and institutional assistance in order to increase soybean yield.

7. Future Scope

Future studies should concentrate on climate-resilient management techniques, and it will be beneficial to examine how shifting weather patterns affect nematode populations. To close the knowledge gap for farmers who are less knowledgeable, more extension services and educational initiatives should be put in place. Proactive management can be promoted by providing incentives for the use of bio-nematicides and expanding the availability of laboratory soil testing. To assist sustainable soybean production, research may also investigate cost-benefit assessments of various management methods and provide digital tools for early nematode infestation identification and monitoring.

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