Management Strategies and Control Activities for Nematode Infestation in Soybean Production

Abstract

Soybean is an important oilseed crop in India, but its productivity is hampered by plant-parasitic nematodes, which cause large production losses and poor crop quality. The current study was done in Washim District to examine farmers' nematode management techniques and control activities in soybean growing. A total of 210 farmers were chosen, and data were gathered via a structured questionnaire, field observations, and secondary sources such journals, publications, and internet databases. The data was analyzed using descriptive statistical methods. The results found that 43% of farmers were very aware of nematode-related diseases, and 52% recognized Meloidogyne incognita as the most frequent worm species affecting soybeans. The studies also revealed that 64% of farmers were neutral and 29% were dissatisfied with current worm management approaches, indicating that existing strategies had little effectiveness. Overall, the study concludes that nematode infestation is a major constraint in soybean production, and there is a strong need for integrated nematode management approaches that combine cultural, biological, and chemical methods, as well as improved farmer awareness and institutional support to ensure sustainable soybean productivity.

Keywords: Nematode, Infestation, Soybean, Management Strategies, Control Activities, Production, Impacts, Effectiveness

1. Introduction

The soybean is one of the most significant legume crops grown worldwide, and it is especially important in India. Soybean is one of the most commercially important crops farmed worldwide for food, feed, and industrial use. This crop is a valuable agricultural product and source of revenue because it is one of the world's greatest sources of animal protein feed and the second largest source of vegetable oil. To fulfil the demands of the tremendously rising population, enhancing soybean yield (SY) is one of the key goals of breeding programs worldwide(Malekar, 2025). Understanding soybean in-season growth and production is critical for government, corporate, and farmer decision-making, as it has a direct impact on crop health and harvest management, crop insurance, food security, supply regulation, the financial market, and strategic planning regarding social, environmental, and economic policies. Various stressors, particularly the soybean cyst nematode, can drastically limit soybean productivity, causing yield losses of up to 90%(Gorny, 2025).

Nematodes are microscopic roundworms that do not have segments. They are a complex group of creatures with a variety of eating patterns, including both "free-living" helpful nematodes and plant parasitic nematodes. Soilborne plant-parasitic nematodes survive and breed by feeding on plant tissues. Their feeding can cause root injury, compromise root function and resulting in yield loss(Arjoune et al., 2022). Plant-parasitic nematodes, which are minute and often just 0.01 to 0.04 in. (300 to 1000 μm) long, can cause noticeable damage to soybean crops through disease symptoms. Their impact can also be quantified when yields do not meet expectations. In addition to direct harm, feeding wounds on soybean roots provide a pathway for secondary illnesses produced by fungus or bacteria. Most plant-parasitic nematodes have a life cycle of three to four weeks, therefore multiple generations of worms can occur in a growing season(Yadav, 2017).

Figure 1 Nematode at Soybean roots

Plant-parasitic nematodes are typically more problematic and have a bigger influence on yield in coarse, sandy soils, but they can occur in any soil type and growing region. Sandy, coarse soils have bigger soil pores, which facilitates nematode migration(Jjagwe et al., 2024). Nematodes that harm soybeans live on or inside root tissues, then travel through water films between soil particles to find a host plant. Because they are so small, nematodes move very slowly through the soil, often only 5 feet per year. However, they may be disseminated over greater distances through phenomena that move the soil they inhabit, such as flooding and wind, or movement of planting or tillage equipment from field to field(Shinde et al., 2018).

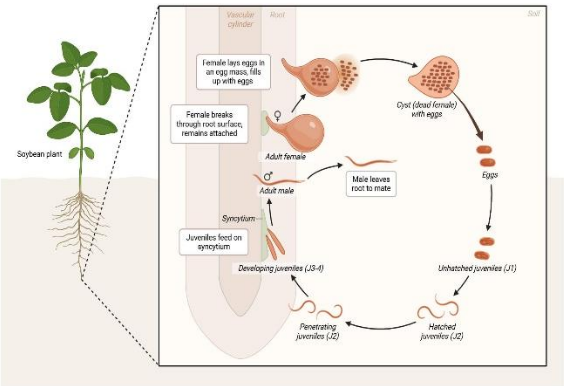


Figure 2 Soybean Nematode Life Cycle

Effects of Nematode Infection on Soyabean Plant Health

Nematodes have a characteristic impact on the roots They infect soybean plants. Some nematode infection symptoms are obvious, while others take a long time to resolve. In some circumstances, the severity of apparent symptoms is proportionate to the drop in yield. Root infesting nematodes reduce harvest quality in crops containing edible tubers, rhizomes, and taproots. Nematode-infected soyabean plants respond similarly to those with distorted or damaged root systems(Lima et al., 2017). Symptoms vary depending on the genus that infest different regions of the soyabean plant. In addition to the creation of root galls and cysts in the roots, the above-ground symptoms of nematode infection include: Stunted shoot growth and subsequent drop in shoot-root ratio, chlorosis in foliage due to nutritional inadequacies, temporary wilting due to water stress induced by root inefficiency in transporting water, and decrease in plant fresh weight(Nisha, 2024).

Management Practices and Control Activities for Nematode Infestation in Soybean

1. Cultural Management Practices

Crop Rotation

Crop rotation is one of the most effective cultural techniques used in India's soybean-growing regions, particularly Maharashtra and Madhya Pradesh. Farmers alternate soybeans with non-host crops such as maize, sorghum, wheat, or cotton to disrupt the life cycle of plant-parasitic nematodes(Nisha, 2024). Continuous soybean cultivation increases nematode buildup in the soil, resulting in significant yield losses. Rotation reduces nematode populations naturally, without the need of chemicals. It also increases soil fertility and microbiological activity(KVVS, 2021). Crop rotation is a viable and cost-effective strategy in Indian rainfed agriculture. It reduces infestation by species such as Meloidogyne incognita and soybean cyst nematode. Farmers that use rotation strategies frequently report enhanced root health and crop vitality(Lima et al., 2017). Agricultural extension programs heavily support this strategy. However, adoption is occasionally hampered due to market preference for soybeans. Overall, it remains a viable and environmentally friendly control technique(Kumar, 2025).

Deep Summer Ploughing

Deep summer ploughing is frequently used in India's soybean belts, particularly in the Vidarbha and Marathwada areas. During the summer, fields are ploughed thoroughly, exposing soil layers to high temperatures. This exposure helps to kill nematode eggs, larvae, and other soil pests(Abd-elgawad, 2025). The hot Indian summer, which frequently exceeds 40°C, increases the efficacy of this approach. It lowers nematode survivability before the sowing season starts. Farmers benefit from better soil aeration and weed control. This approach is inexpensive and does not require chemical input(Sharma, 2014). Indian agricultural universities promote it as part of an integrated nematode management approach. However, its performance is contingent on appropriate timing and soil moisture conditions. Many farmers use it with organic additives to achieve better results. It is a precautionary and environmentally safe technique(Swain, 2025).

Use of Healthy Seeds

In India, using certified and healthy soybean seeds is crucial to avoiding nematode infection. Nematodes might enter new fields through contaminated or untreated seeds. Farmers are guaranteed a high-quality seed supply by agricultural organizations such as seed certifying boards(Abhishek, 2023). Strong root development and consistent germination are encouraged by healthy seeds. In the early phases of growth, strong roots are less susceptible to nematode assault. It is advised in many Indian states to treat seeds with nematicides or bioagents prior to sowing. This aids in preventing early infection in seedlings. In general, farmers who use certified seeds report higher output stability. Farm-saved tainted seeds are discouraged via awareness campaigns. It's a straightforward but successful preventive measure. It is essential to systems of sustainable soybean production(KVVS, 2021).

Field Sanitation

Crop debris, weeds, and contaminated plant leftovers must be removed and destroyed as part of field sanitation. Nematodes live in soil particles and residual roots in Indian soybean fields. These leftovers serve as a source of reinfestation in the next season if they are not eliminated(Abd-elgawad, 2025). In certain places, farmers burn or bury contaminated waste deeply. Because weeds serve as nematodes' alternate hosts, weed control is also crucial. Over time, nematode populations accumulate less in clean areas(Senthil et al., 2025). Crop health and general soil hygiene are enhanced by this approach. Crop rotation and organic amendments are frequently used in conjunction with it. During training programs, agricultural extension services place a strong emphasis on sanitation. Despite being straightforward, it dramatically lowers nematode carryover. It encourages sustainable soil management over the long run(Gorny, 2025).

Soil Solarization

In parts of India's irrigated soybean regions, soil solarization is an environmentally benign technique. During hot months, it entails covering wet soil with clear polyethylene sheets(Abd-elgawad, 2025). The temperature of the soil is raised by solar radiation to a point where nematodes cannot survive. This method efficiently eliminates eggs, larvae, and other soil pathogens. It functions well in India's climate during the hottest summer months(Kumar, 2025). Additionally, it lessens fungal infections and weed seeds. Better soil conditions for soybean seeding are advantageous to farmers. It is particularly helpful in high-value crop areas and nurseries. However, because to the expense and manpower required, it might not be employed extensively. It is a successful non-chemical control strategy despite several drawbacks(Swain, 2025).

Proper Irrigation and Drainage

Controlling the spread of nematodes in soybean fields requires effective irrigation and drainage management. Nematode migration and infection are facilitated by excessive soil moisture(Jjagwe et al., 2024). In India, farms with inadequate drainage frequently exhibit greater levels of nematode infection. Root stress and water stagnation are avoided with controlled watering. Effective drainage lowers the frequency of illness and increases the amount of oxygen available to roots(Yadav, 2017). When feasible, farmers are encouraged to adopt drip or scheduled irrigation systems. Plant resistance to nematodes is improved by balanced water management. Additionally, it enhances crop growth and nutrient uptake. Bund management and field leveling are advised by agricultural experts. It is a helpful technique that increases the efficacy of other control strategies(Lavhe et al., 2019).

2. Resistant Soybean Varieties

Resistant Varieties

One key tactic utilized in India to control production losses brought on by plant-parasitic nematodes is the use of soybean cultivars resistant to nematodes. Soybean cultivars resistant to soybean cyst nematodes (SCN) and root-knot nematodes (Meloidogyne spp.) have been created by research organizations like ICAR. These types lessen nematode multiplication and penetration in plant roots(Abhishek, 2023). Crop damage and production loss are thereby greatly reduced. These improved varieties are encouraged to be used by farmers in places like Maharashtra, Madhya Pradesh, and Rajasthan that cultivate soybeans. Additionally, resistant cultivars lessen reliance on chemical nematicides. However, persistent monocropping and nematode adaptability may occasionally cause resistance to crumble(Shinde et al., 2018). As a result, it is advised to switch out kinds on a regular basis. These types thrive in situations with moderate infestation levels. They play a crucial role in integrated nematode management. Their use increases soybean farming's sustainability and production(Nisha, 2024).

Improved Seed Selection

In India's soybean production systems, better seed selection is crucial to reducing nematode infestation. It is recommended that farmers choose certified, superior, and regionally specific soybean seeds. Better flexibility, increased yield potential, and resistance to soil-borne pests are the reasons behind the breeding of these seeds. Poor-quality or farm-saved seeds raise the danger of disease and nematode proliferation in several Indian farming locations(Sharma, 2014). Strong early root development and consistent germination are guaranteed by improved seeds. Plants with robust root systems are better able to fend off nematode assaults. Agricultural experts advise replacing seeds every season or two. Protection is further improved by treating seeds with bioagents or authorized chemicals. Access to improved cultivars is facilitated by government seed distribution programs. This method lowers the danger of early-stage infection while increasing crop stand. It's an easy and cost-effective preventive strategy(Abhishek, 2023).

3. Biological Control Methods

Fungal Bioagents

In India, fungal bioagents like Paecilomyces lilacinus and Trichoderma spp. are frequently employed to manage plant-parasitic nematodes in soybean fields. By attacking nematode eggs and juveniles, these fungi lower the number of nematodes in the soil. By boosting plant growth and nutrient uptake, they also improve root health. These bioagents are frequently used in Indian agriculture as soil or seed treatments. They don't damage beneficial soil organisms and are environmentally benign. Combining them with organic amendments like compost or neem cake boosts their efficacy(Abd-elgawad, 2025). Farmers who use fungal bioagents report improved crop vigor and less root gall formation. However, temperature and soil conditions might affect how well they work. For optimal effectiveness, they need to be handled and stored properly(KVVS, 2021). Their application under Integrated Pest Management (IPM) is encouraged by agricultural extension services. These bioagents are an environmentally friendly substitute for chemical nematicides(Abhishek, 2023).

Beneficial Bacteria

In India, beneficial bacteria like Bacillus subtilis and Pseudomonas fluorescens are frequently employed as biological control agents to manage nematodes in soybeans. By creating harmful compounds and strengthening plant resilience, these bacteria reduce nematode activity. They establish a defense against nematode invasion by colonizing the root zone(Abd-elgawad, 2025). Typically, application is carried out using biofertilizers, soil soaking, or seed treatment. Their usage in organic and sustainable farming systems is encouraged by Indian agricultural research agencies(Lima et al., 2017). Additionally, they enhance microbial diversity and soil fertility. Following spraying, farmers report better root growth and fewer indications of illness. Combining them with organic manure increases their efficacy. However, their efficacy may be impacted by shelf life and storage circumstances. They are economical, safe, and good for the environment. Their application in integrated nematode management is growing(Shinde et al., 2018).

Natural Predators

In Indian soybean fields, nematode numbers are largely suppressed by natural predators and helpful soil organisms. These include beneficial microfauna found in healthy soils, nematode-trapping fungi, and predatory fungi. By consuming eggs, juveniles, or adult worms, they naturally control nematode populations(Senthil et al., 2025). In India, organic farming methods promote the development of these advantageous organisms. Their activity is increased by using compost, green manure, and fewer chemical inputs. Long-term insect control and increased soil biodiversity are advantageous to farmers(Kumar, 2025). In undisturbed soils with a high organic content, natural predator activity is frequently higher. However, these helpful creatures may be harmed by overuse of pesticides. They play an indirect but crucial function in preserving ecological equilibrium. They encourage long-term, sustainable nematode control(Yadav, 2017).

4. Chemical Control Measures

Seed Treatment

In Indian soybean farming, treating seeds with nematicides or bio-based compounds is a standard procedure. It guards against early nematode infection in seeds and young plants. Stronger root development and improved germination are displayed by treated seeds. This approach is particularly helpful in areas where nematode issues are known to exist(Abd-elgawad, 2025). In India, authorized chemicals or biological agents are frequently used for seed treatment. It offers defense while the soybean is at its most vulnerable growing stage. Because it is inexpensive and simple to implement, farmers favor it. It increases plant stand uniformity and decreases early crop losses(Lima et al., 2017). Careful dose is advised by agricultural guidelines to prevent toxicity. For better outcomes, it is frequently combined with other management techniques. In extension programs, this approach is heavily emphasized(Kigeso et al., 2024).

Soil Application of Nematicides

In extensively infested soybean fields in India, nematicides are applied to the soil to rapidly lower worm numbers. Fluopyram and other chemicals are utilized in accordance with established norms(Yadav, 2017). Nematodes in the soil are immediately affected by these nematicides, which lower their activity and reproduction. Depending on the degree of infestation, farmers apply them either before or during sowing. Nematodes can be quickly but momentarily controlled with this technique. It is typically employed when cultural and biological approaches are inadequate(Sharma, 2014). On the other hand, excessive use can deteriorate soil health and pollute the ecosystem. The use of some substances is regulated by the government. It is advised to wear protective gear when applying. In cases of severe infestation, it works well as a temporary fix(Lavhe et al., 2019).

Controlled Chemical Use

Sustainable soybean production practices in India depend on the controlled application of chemical nematicides. It is recommended that farmers use chemicals at recommended dosages and only when absolutely necessary. Overuse can result in environmental risks, soil toxicity, and the emergence of resistance(Sharma, 2014). Extension services encourage the use of chemicals in conjunction with biological and cultural techniques. Farmers are urged to closely adhere to label guidelines. Efficiency is increased and costs are decreased with controlled application. Additionally, it shields beneficial soil organisms from harm. In India, awareness campaigns emphasize the dangers of using pesticides carelessly. Success is mostly dependent on time and dosage. This strategy guarantees more secure and long-lasting nematode control(Abhishek, 2023).

Figure 3 Management Strategies for Nematode Infestation in Soybean

Despite the development of numerous management techniques, including chemical nematicides, biological control agents, resistant cultivars, and cultural practices, their uptake and efficacy under regional field circumstances are still uneven. Without a thorough scientific grasp of integrated nematode control, many farmers continue to use old methods(Kigeso et al., 2024). Furthermore, there is a dearth of region-specific data on farmers' actual degree of awareness, the intensity of infestations currently occurring, and the efficacy of management techniques implemented in soybean fields(Senthil et al., 2025). Consequently, this study is required to identify gaps in present methods, evaluate their efficacy under local agroclimatic conditions, and thoroughly examine the management strategies and control activities employed by soybean producers. The results of this study improved soybean productivity and farmer livelihood in the study area by suggesting realistic, affordable, and sustainable nematode management strategies.

2. Literature Review

One of the most unseen risks to soybean production globally is plant-parasitic nematodes, which significantly reduce output and degrade crop quality. The root system is harmed by species like Meloidogyne incognita and soybean cyst nematode (SCN), which leads to poor nutrient uptake, stunted development, chlorosis, and decreased production(Lavhe et al., 2019). Nematode infestation in soybean fields is further increased by ongoing monocropping, inappropriate soil conditions, and ignorance, according to research. To reduce nematode populations and crop loss, a number of management techniques have been developed, such as cultural practices, resistant varieties, biological control agents, organic amendments, and chemical nematicides(Swain, 2025). Due to environmental concerns about excessive chemical use, integrated nematode management approaches that combine sustainable and eco-friendly methods have become more important recently. Therefore, increasing soybean yield and creating sustainable nematode management techniques require an understanding of the efficacy of various control measures(Abd-elgawad, 2025).

Swadhin Kumar Swain [2025], investigated crop protection and integrated nematode management. Global agriculture faces a significant threat from plant-parasitic nematodes. Although chemical treatment is still effective, integrated pest management (IPM) is required due to its negative environmental effects. A sustainable method of managing nematodes can be achieved by combining cultural methods, biological control, and resistant crop cultivars. Future studies on plant-derived nematicides and gene-editing technologies will improve our capacity to manage these covert agricultural risks.

Adrienne Gorny [2025], investigated the control of soybean nematodes. Nematodes are tiny roundworms without segments. They are a very varied collection of organisms with a wide range of eating habits, including nematodes that parasitize plants and "free-living" helpful nematodes. In order to survive and procreate, soilborne plant-parasitic nematodes consume plant tissues. Their eating may cause harm to the roots, which could impair root function and reduce yield. Soybean-affecting nematodes live on or within root tissues and travel through water films between soil particles in search of a host plant. Nematodes are so little that they can only migrate up to five feet a year through the soil on their own. However, they could be spread across greater distances by planting or tillage machinery moving from field to field or by natural disasters like wind and flooding that shift the soil they live in.

Shubham Malekar [2025], This study examines the impact of plant-parasitic nematodes on the health of soybean crops in a specific region of India. To assess management tactics, crop damage, yield loss, infestation levels, and awareness, primary data was collected from farmers using a standardized questionnaire. The results show that Meloidogyne incognita, which produces root knots (47%), leaf yellowing (29%), and stunted development (18%), is the most prevalent nematode species (52%). Particularly in sandy soils (52%), infestations were most prevalent during the germination (41%) and vegetative (33%) phases. Nematode proliferation brought on by ongoing monocropping resulted in significant output losses (>40%) for 61% of farmers (43%). 63% of farmers were still dissatisfied with yields despite the application of cultural practices such crop rotation (53%) and deep plowing (29%), as well as chemical (Fluopyram, 46%) and biological (Paecilomyces lilacinus, 58%) controls. The study highlights the need for integrated nematode management methods, improved farmer awareness, and institutional support to boost soybean productivity and reduce financial losses.

Mahfouz M. M. Abd-Elgawad [2025] Examining the real dangers associated with biopesticides is still necessary to facilitate economical formulation, registration, farmer awareness, and use globally. However, tank mixing that guarantees legality and prevents incompatibilities based on chemical and physical agro-inputs can also offer better benefits. The goal is to design pesticides that are safe, effective, and well-formulated by deciphering the intricate interactions involved in applying many inputs. To overcome such constraints and difficulties, sophisticated strategies should be used. These methods would use bioinformatics, RNA-Seq in pesticide synthesis, microencapsulation, nanopesticides, and volatile organic chemicals as signals for soil dwellers.

P Senthil kumar [2025], explains the main nematode species that influence crops grown under protection, their effects on agricultural productivity and health, their ecological relationships, and different integrated management techniques. To lessen the threat posed by plant parasitic nematodes, integrated management techniques using biological, chemical, and cultural methods are crucial. A comprehensive strategy to effectively manage nematode populations and maintain the productivity of protected cultivation systems includes cultural practices like crop rotation and soil solarization, chemical treatments with nematicides, and biological control using biocontrol agents and natural predators.

Nisha [2024], investigated the control of nematodes in spices and plantation crops. Perennial crops including coconut, arecanut, coffee, betelvine, cardamom, black pepper, ginger, and turmeric are grown on the same plot of land in Kerala's mixed cropping systems. In agricultural systems based on coconuts, plant parasitic nematodes seriously harm crops, resulting in lower yields and financial losses. An environmentally benign substitute for chemical nematicides is the selection of nematode-tolerant domesticated or wild animals and the adoption of resistance through breeding. In Kerala's mixed cropping systems, fungal and bacterial antagonists have been shown to be effective against root-knot nematodes. In mixed cropping systems with plantation crops, using organic manures, mulching, and cultivating antagonistic crops can help lower nematode populations and enhance soil health. Since the degree of control varies with environmental conditions, crop, and targeted nematode, integrated management programs should be developed in multi-crop production systems based on the effect of the control strategy on nematode population and benefit-cost ratio.

Andrea Malima Kigeso [2024], Seven treatments using a CRD design were inoculated with 1000 J2 of M. incognita and duplicated six times in a study carried out in Mwanza, Tanzania. The number of galls decreased from 104 in 0.0 kg BSFF/inoculated to 3 in 1.0 kg BSFF/inoculated, with 6.33, 23.67, 51.51, and 52.50 galls in 0.75 kg BSFF/inoculated, 0.5 kg BSFF/inoculated, 50mL chitosan/inoculated, and 0.25 kg BSFF/inoculated, respectively. Additionally, symptoms like chlorosis decreased from nine leaves in 0.0 kg BSFF/inoculation to zero in 1.0 kg BSFF.

Pius Jjagwe [2024], investigated the effects of soybean cyst nematode (SCN) infestation on the yield of susceptible and resistant seed variants as well as soybean production. In comparison to resistant variety (SCN populations: 0 to 340), susceptible types had higher SCN populations (20 to 1080) and worse yields and crop vigor recovery. The Green Normalized Difference Vegetation Index (GNDVI, $r = -0.6$) and blue band reflectance ($r = 0.58$) had the most link with the SCN populations, according to high-resolution (1.3 cm/pixel) aerial multispectral imaging. However, the best indicators of plant vigor and those with the strongest association with SY were GDNVI, Green Chlorophyll Index (GCI), and Normalized Difference Red Edge Index (NDRE) ($r = 0.59$–0.75). Then, utilizing two statistical and four machine learning (ML) models at ten distinct train–test data split ratios (50:50–95:5), reflectance (REF) and VIs were employed for SY estimate. The accuracy of SY estimation was significantly impacted by the ML models and the train-test data split ratio. The best and most reliable model was Random Forest (RF) (r: 0.84–0.97, rRMSE: 8.72–20%), however the ML models performed worse when the train–test split ratio was larger. Out of all the models, the 95:5 train–test ratio performed the best; this ratio would be appropriate for modeling across smaller or medium-sized datasets.

Youness Arjoune [2022], Describe the stages of soybean vegetation and reproduction, the life cycles of SCN, and the factors that affect this disease. The impact of SCN on soybean yield loss and the difficulties in detecting it are highlighted by the author. The author outlines direct sampling techniques for obtaining and analyzing soil samples in order to assess SCN egg numbers. After outlining the benefits and drawbacks of these direct approaches, the author reviews computer vision and remote sensing-based detection techniques, including data collection via satellite, aerial, and ground methods, and machine learning techniques for image analysis-based soybean cyst nematode detection. In high-performance and huge data situations, the author emphasizes the evaluation techniques and benefits of the overall detection workflow. The author talks about a number of management techniques, including fertilization, crop rotation, SCN-resistant cultivars like PI 88788, and SCN's growing resistance to these tactics. The authors examine machine learning methods for predicting soybean crop yields and the impact of fertilizers, insecticides, and herbicides on reducing SCN infection.

K Kranti KVVS [2021], Even though the harm caused by plant parasitic nematodes is rarely apparent to the unaided eye, research on their significance cannot be understated. Nematodes quickly accumulate large population densities in vegetables, potatoes, sugar beets, tobacco, and other perennial fruit crops like citrus, grapes, bananas, pineapples, etc. due to their short life cycle and rapid rates of reproduction. Because crop rotation is not possible, the population stays constant. Because plant parasitic nematodes are microscopic (length 0.5–1.5 mm; diameter 30–50 μm), they live in soil and harm the root system. As a result, their damage is frequently underestimated because a cursory examination of the crop from the outside does not immediately reveal the detrimental effects on the plant's growth.

N. V. Lavhe [2019], The presence of plant parasitic nematodes was assessed in 737 soil samples taken from 16 agricultural systems over 119 talukas. The regions where the population of the reniform nematode R. reniformis surpasses the damage threshold (200/100cc soil) were located and charted. Yavatmal district had the most samples from cotton crops with high reniform nematode population densities, followed by Buldhana, while Nagpur and Gadchiroli had lower populations. Yavatmal had the most high-density places for the pigeon pea crop, followed by Buldhana and Amravati, while Gadchiroli had the lowest. Variation in population density may probably be correlated to gradual spread of irrigation availability through drip irrigation.

Laxmikant V. Shinde [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.

Usha Yadav [2017], covers the most modern ways for controlling nematode populations, including the use of biological control techniques, integrated pest management, cropping system design, host plant genetic alteration, and the creation of naturally occurring nematicides. Priorities for research and development in the field of applied nematology must be set immediately because these alternatives are more target-specific and have biological origins, which will better preserve the environment and variety.

Table 1 Comparative Table for Previous Work done

Author & Year	**Methodology**	**Key Results**	**Research Gap**
Swadhin Kumar Swain (2025)	Review of integrated nematode management and crop protection approaches including cultural, biological, and resistant variety strategies.	Highlighted that plant-parasitic nematodes are major agricultural threats. Integrated Pest Management (IPM) combining cultural practices, biological control, and resistant varieties offers sustainable control. Future prospects include gene-editing and plant-derived nematicides.	Limited field-level validation of advanced technologies such as gene editing and botanical nematicides under diverse agro-climatic conditions.
Adrienne Gorny (2025)	Descriptive study on soybean nematodes, their biology, movement, and spread mechanisms.	Explained nematode feeding behavior, root damage, yield loss, and dispersal through water, flooding, wind, and machinery. Emphasized the importance of understanding nematode ecology in soybean production.	Lack of practical large-scale management strategies and region-specific control recommendations for soybean farmers.
Shubham Malekar (2025)	Farmer survey using standardized questionnaires to assess infestation, crop loss, and management strategies in soybean-growing areas of India.	Identified Meloidogyne incognita as dominant species (52%). Severe yield losses (>40%) observed due to monocropping. Existing cultural, chemical, and biological methods were insufficient for many farmers.	Need for improved farmer awareness, institutional support, and more effective integrated management packages.
Mahfouz M. M. Abd-Elgawad (2025)	Review of biopesticide applications, pesticide interactions, and advanced formulation technologies.	Emphasized benefits of biopesticides and tank mixing. Suggested use of microencapsulation, nanopesticides, volatile organic compounds, RNA-Seq, and bioinformatics for safer and more effective pest management.	Limited awareness, high formulation costs, and inadequate registration frameworks hinder widespread adoption of biopesticides.
P Senthil kumar (2025)	Review of nematode species affecting protected cultivation and integrated management strategies.	Integrated approaches involving crop rotation, soil solarization, nematicides, and biological agents effectively reduced nematode populations and maintained productivity.	Need for location-specific integrated management protocols under protected cultivation systems.

Nisha (2024)	Review of nematode management in mixed cropping systems involving plantation crops and spices in Kerala.	Resistant varieties, fungal and bacterial antagonists, organic manures, mulching, and antagonistic crops improved soil health and reduced nematode populations.	Lack of economically optimized integrated management programmes suitable for multi-crop systems and varying environments.
Andrea Malima Kigeso (2024)	Experimental CRD study in Tanzania using different levels of Black Soldier Fly Frass (BSFF) against Meloidogyne incognita.	BSFF significantly reduced gall formation and chlorosis symptoms in soybean plants. Higher BSFF doses showed better nematode suppression.	Further field-scale validation and economic feasibility studies are required before commercial recommendation.
Pius Jjagwe (2024)	Combined field trials, multispectral aerial imaging, vegetation indices, and machine learning models for soybean cyst nematode (SCN) assessment.	Resistant soybean varieties performed better than susceptible ones. Random Forest model showed highest prediction accuracy for soybean yield estimation.	Need for scalable and cost-effective remote sensing systems for real-time SCN detection in large agricultural fields.
Youness Arjoune (2022)	Review of SCN detection methods including soil sampling, computer vision, remote sensing, and machine learning.	Discussed advantages and limitations of direct sampling and AI-based SCN detection methods. Reviewed management strategies including resistant varieties and crop rotation.	Limited integration of AI technologies into practical field-level SCN monitoring systems.
K Kranti KVVS (2021)	General review on significance and impact of plant-parasitic nematodes on crops.	Highlighted rapid nematode multiplication, hidden root damage, and severe crop losses in annual and perennial crops.	Need for better diagnostic and monitoring techniques due to invisible nature of nematode damage.
N. V. Lavhe (2019)	Large-scale soil survey of 737 samples across 16 crop systems in Maharashtra.	Identified high population density of Rotylenchulus reniformis in cotton and pigeon pea fields, especially in Yavatmal district.	Need for continuous monitoring and correlation studies between irrigation practices and nematode spread.
Laxmikant V. Shinde (2018)	Field investigation of soybean nematodes in Jalna District, Maharashtra during 2010–2011.	Recorded two major nematode species: Meloidogyne incognita and Rotylenchulus reniformis associated with soybean.	Limited information on seasonal population dynamics and effective control measures in soybean ecosystems.
Usha Yadav (2017)	Review of modern nematode control approaches including genetic manipulation, IPM, biological control, and natural nematicides.	Suggested eco-friendly and target-specific alternatives to chemical nematicides for sustainable nematode management.	More applied research is needed to commercialize biological and genetic control methods for field conditions.

3. Research Gap

There are still a lot of unanswered questions about nematode management in soybean production, especially in areas like Washim District where soybeans are an important crop. The majority of earlier research has concentrated on broad nematode management techniques, but there hasn't been much done on infestation patterns unique to a given area, farmer knowledge, or the efficacy of integrated control strategies in the agroclimatic circumstances of the Washim district. The frequency of significant nematode species like Meloidogyne incognita and Rotylenchulus reniformis in Washim's soybean-growing regions and their direct effect on yield losses are not well understood. Furthermore, there is also a lack of information regarding local farmers' acceptance and financial viability of environmentally friendly strategies such biological control agents, organic amendments, resistant cultivars, and integrated pest management (IPM) techniques. Moreover, sophisticated methods such as bio-based nematicides, machine learning-based detection, and remote sensing have not been adequately assessed for practical application in soybean farming in this area. Thus, in order to prevent nematode infestation in soybean production in the Washim district of Maharashtra, India, comprehensive study on sustainable, economical, and location-specific management measures is required.

4. Methodology

In order to gather information about nematode infestation, its effects on soybean yield, and farmers' management strategies, the study used both primary and secondary data sources. A systematic questionnaire was created and distributed to soybean farmers in the chosen study area in order to gather primary data. Using appropriate sampling approaches, a total sample size of 210 farmers was chosen. Awareness of nematode infestation, symptoms seen in soybean crops, yield losses, management techniques used, application of chemical and biological controls, crop rotation techniques, and difficulties farmers encounter in managing nematodes were all included in the questionnaire. In order to comprehend the real infestation conditions and control techniques used in the fields, personal inspections and field trips were also carried out.

A variety of published and unpublished sources, including journal articles, research papers, government reports, internet databases, agricultural websites, books, and earlier studies on nematode infestation and soybean yield, were used to gather secondary data. In order to derive significant findings about efficient management techniques and control measures for nematode infestation in soybean agriculture, the gathered data was examined using suitable statistical and descriptive techniques.

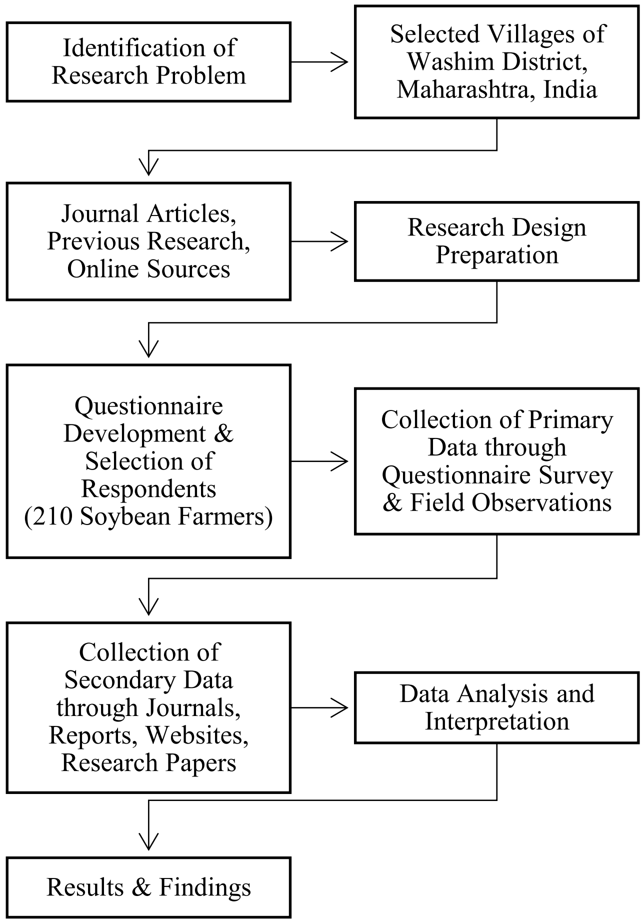
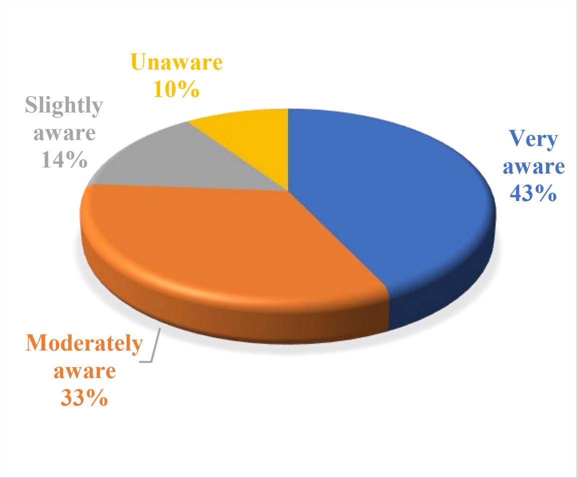


Figure 4 Methodology Flowchart

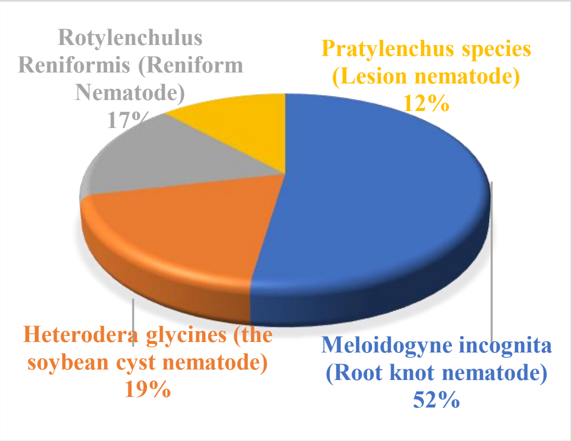
5. Analysis and Results

The study's analysis focuses on comprehending the control measures and management approaches used by soybean farmers in Washim District to deal with nematode infestation. In order to assess farmer awareness, infestation levels, crop losses, and the efficacy of various management strategies, the data gathered from 210 farmers via questionnaires and field observations was methodically categorized, tabulated, graphically displayed, and evaluated. The main obstacles faced by farmers were determined using both primary and secondary data, and the contribution of cultural, biological, and chemical management techniques to lowering nematode infestation and raising soybean productivity was evaluated.



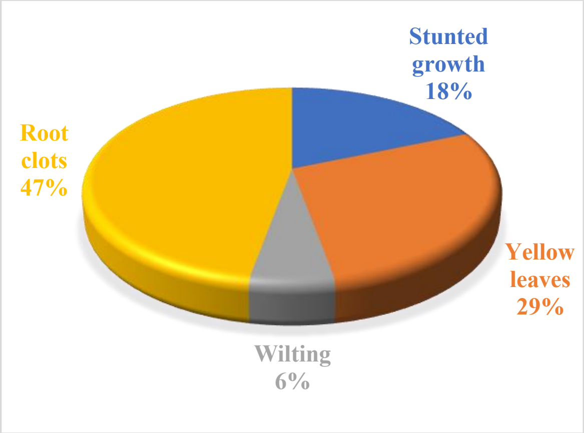
Graph 1 familiar are you with nematode-related diseases in soybean crops

Ninety farmers (43%) are extremely aware of nematode-related diseases in soybeans, according to the data on farmers' awareness, suggesting good knowledge among a sizable percentage of respondents. Approximately 70 farmers (33%) have a moderate level of awareness, indicating a partial comprehension of the issue. In the meantime, 30 farmers (14%) know very little about nematode problems. There is a knowledge gap, as evidenced by the fact that only 20 farmers (10%) are ignorant about nematode-related illnesses. Overall, the results show that although awareness is generally high, extension and training programs still need to be strengthened in order to increase farmers' comprehension and early detection of nematode infestation.



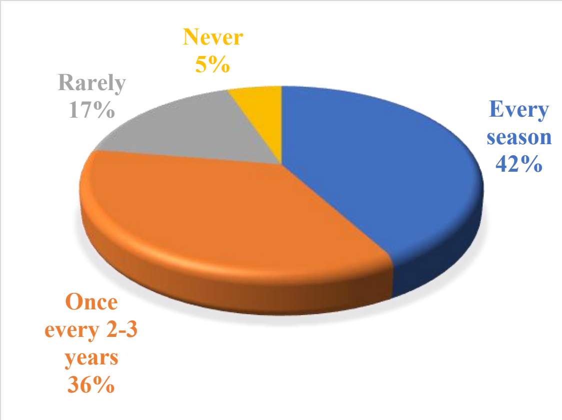
Graph 2 plant-parasitic nematode is typically linked to soybean damage in India

According to the analysis, Meloidogyne incognita, also known as the root-knot nematode, was cited by 110 respondents (52%) as the primary pest causing damage to soybeans. This suggests that the most frequently seen and identified issue in soybean fields is the root-knot nematode. Forty farmers (19%) identified the soybean cyst nematode, Heterodera glycines, indicating a moderate level of awareness of this species. 35 farmers (17%) reported Rotylenchulus reniformis (reniform nematode), but only 25 farmers (12%) reported Pratylenchus species (lesion nematode). Overall, the results show that the most common and dominating species harming soybeans in the research area is the root-knot nematode, whereas knowledge of other nematode species is still relatively limited.



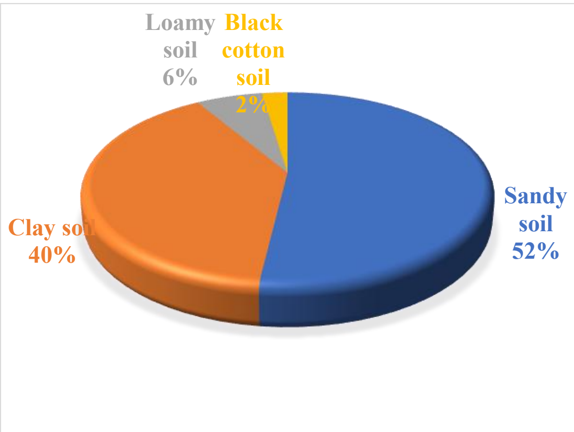
Graph 3 most prevalent symptoms of nematode-affected soybean plant

According to 99 farmers (47%), root galls or clots are the most frequently reported symptom of nematode-infected soybean plants, indicating significant root-knot nematode activity in the field. Following this, 60 farmers (29%) saw yellowing of the leaves, which is indicative of a nutrient shortage brought on by damaged root systems. 39 farmers (18%) reported stunted growth, indicating decreased plant development as a result of inadequate nutrient and water intake. Wilting signs were recorded by a smaller percentage of 12 farmers (6%), suggesting serious infestation in a small number of cases. Overall, the results show that the most common signs of nematode infestation in soybean crops are root damage symptoms, particularly root galls and yellowing.



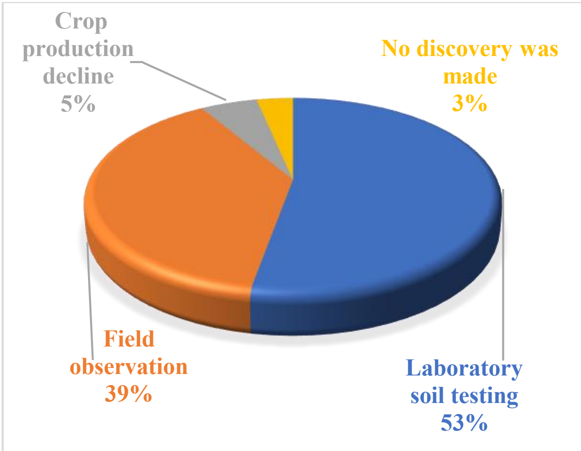
Graph 4 experience nematode infections on the soybean crop

Nematode infestation of soybeans is a common issue in the study area, according to the data. The plurality of farmers, 88 respondents (42%), stated that they were infected with nematodes each season, showing ongoing pressure from soil-borne pests. According to 75 farmers (36%), infestation happens once every two to three years, with a moderate recurrence based on agricultural techniques and field conditions. A smaller subset of 36 farmers (17%) reported infrequent nematode issues, which may indicate improved field management or reduced infection levels. Just 11 farmers (5%) said they had never been infected by nematodes. Overall, the results unequivocally show that nematode infestation is a persistent problem in soybean farming, necessitating consistent and efficient treatment techniques.



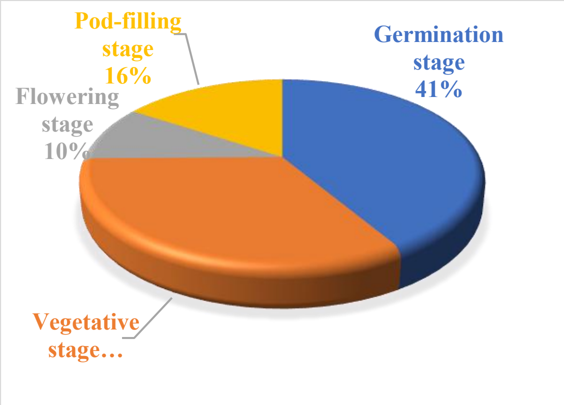
Graph 5 soil type in the region is the most easily affected by nematode infestation

The analysis indicates that sandy soil is most vulnerable to nematode infestation, with 109 respondents (52%) reporting it as highly affected. This is followed by clay soil, reported by 83 farmers (40%), suggesting moderate susceptibility due to moisture retention conditions. Loamy soil was identified by 13 farmers (6%), indicating comparatively lower risk of nematode attack, while black cotton soil was least affected, reported by only 5 farmers (2%). Overall, the findings show that light-textured soils, especially sandy soils, are more prone to nematode infestation due to better aeration and easier movement of nematodes, highlighting the need for targeted soil management practices in such regions.



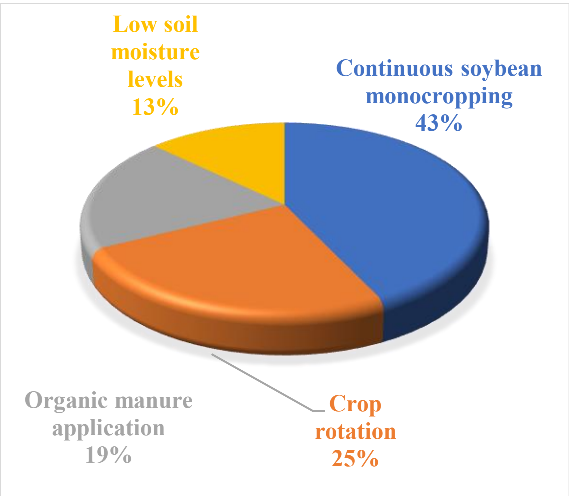
Graph 6 strategy for identifying nematode infestation

According to 111 respondents (53%), laboratory soil testing is the most popular method farmers use to detect nematode infestation, indicating an increasing dependence on scientific diagnosis. After that, 81 farmers (39%) employ field observation to spot indications like root damage and stunted development. A smaller subset of 11 farmers (5%) rely on a drop in crop production as a sign, which means that infestation is only discovered after yield loss. Merely 7 farmers (3%) stated that they had not found nematode infestation, indicating either a lack of awareness or the absence of obvious signs in their farms. Overall, the results show that traditional and reactive identification techniques are still commonly used, despite the growing adoption of scientific methodologies.



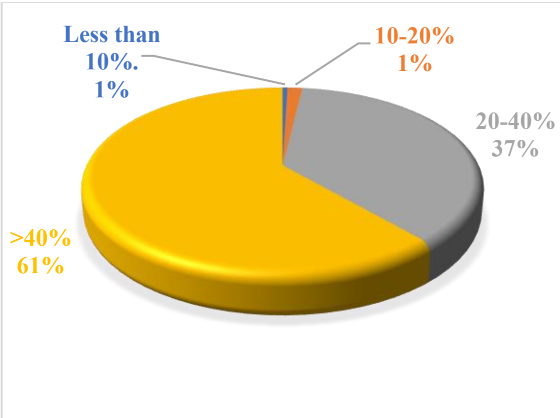
Graph 7 phase of soybean development do nematodes have the greatest impact

Because young seedlings are particularly susceptible to early root damage, the study shows that nematodes have the biggest effect during the germination stage, as indicated by 87 farmers (42%). The vegetative stage, where nematode feeding impacts plant growth and development, comes next, according to 70 farmers (34%). Twenty farmers (10%) claimed that the flowering stage had the least impact on yield formation, while 33 farmers (16%) classified the pod-filling stage as having a moderate impact. Overall, the results show that early growth stages especially germination and vegetative phases are most vulnerable to nematode infection, which, if left unchecked, can result in large output losses.



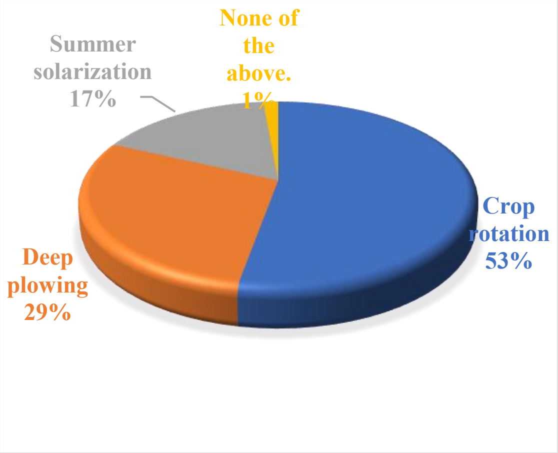
Graph 8 element raises nematode growth in soybean crops

The analysis shows that continuous soybean monocropping is the most significant factor increasing nematode growth, reported by 90 farmers (43%), as repeated cultivation allows nematode populations to build up in soil. This is followed by crop rotation, identified by 52 farmers (25%), which is generally a control practice but may be ineffective when not properly implemented. Organic manure application was reported by 41 farmers (20%), indicating that in some cases it may not be sufficient alone to suppress nematodes if not well decomposed or properly applied. Low soil moisture levels were mentioned by 27 farmers (12%), showing comparatively lesser influence. Overall, the findings suggest that poor cropping practices, especially continuous monocropping, play the major role in increasing nematode infestation in soybean fields.



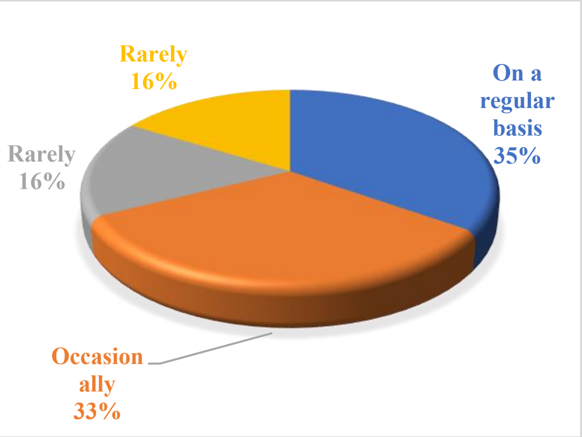
Graph 9 estimated yield loss owing to nematode attacks

The analysis indicates that nematode infestation causes significant yield losses in soybean production. A majority of farmers, 129 respondents (61%), reported more than 40% yield loss, showing severe impact on crop productivity. This is followed by 77 farmers (37%) who experienced 20–40% yield loss, indicating moderate damage levels in many fields. A very small proportion of 3 farmers (1%) reported 10–20% loss, while only 1 farmer (0.5%) observed less than 10% loss, suggesting minimal impact in rare cases. Overall, the findings clearly reveal that nematode infestation is a major constraint in soybean cultivation, leading to substantial economic losses and highlighting the urgent need for effective management strategies.



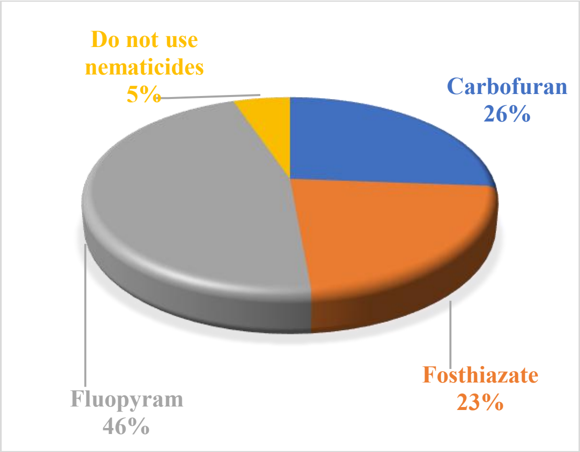
Graph 10 cultural practices do you use to control nematodes

According to the analysis, crop rotation is the most popular cultural method for controlling nematodes, as stated by 111 farmers (53%), demonstrating its widespread use in soybean farming. Deep plowing, which is used by 61 farmers (29%), comes next and helps lower nematode survivability by exposing them to heat and predators. Due to financial and meteorological limitations, 35 farmers (17%) employed summer solarization, indicating a limited but noteworthy uptake. Nearly all farmers use at least one cultural method, as only 3 farmers (1%) reported not utilizing any of the aforementioned techniques. Overall, the results show that cultural methods are widely used, with crop rotation being the most favored nematode management tactic.



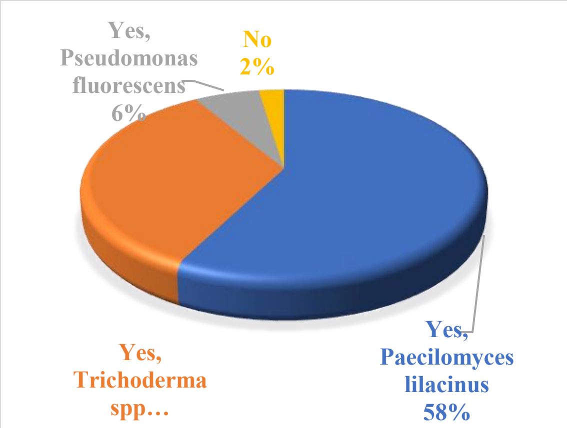
Graph 11 used nematicides on your soybean crops

The analysis indicates that the use of nematicides among soybean farmers is fairly common but varies in frequency. A total of 73 farmers (35%) reported using nematicides on a regular basis, showing a consistent dependence on chemical control methods. 69 farmers (33%) use them occasionally, indicating moderate reliance depending on infestation severity. 34 farmers (16%) reported using them rarely, while another 34 farmers (16%) also fall under the same rare-use category (as per repeated response grouping). Overall, the findings suggest that while chemical control is widely practiced in the study area, many farmers use nematicides only when necessary, reflecting a gradual shift toward more cautious and need-based application.



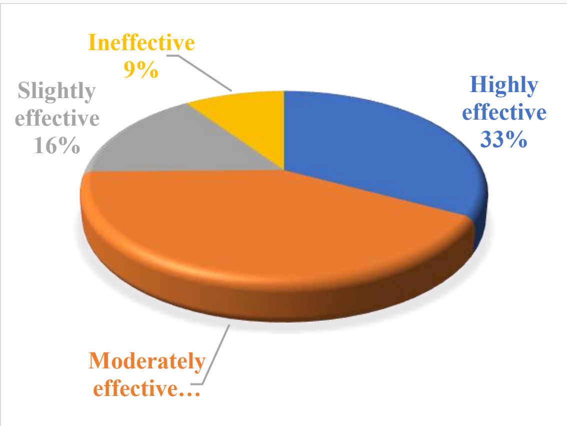
Graph 12 nematicide recommend for soybean nematode management

According to the analysis, Fluopyram is the nematicide that is most frequently advised for managing soybean nematodes, as indicated by 97 farmers (46%), demonstrating its greater efficacy and acceptance among respondents. Following this, 55 farmers (26%) advised carbofuran, and 47 farmers (22%) recommended fosthiazate, indicating a modest preference for conventional chemical choices. Eleven farmers, or 5% of the total, stated that they do not employ nematicides, indicating a preference for integrated or non-chemical methods. Overall, the results indicate that farmers continue to rely heavily on chemical nematicides, with fluopyram being the most popular choice in the study region.



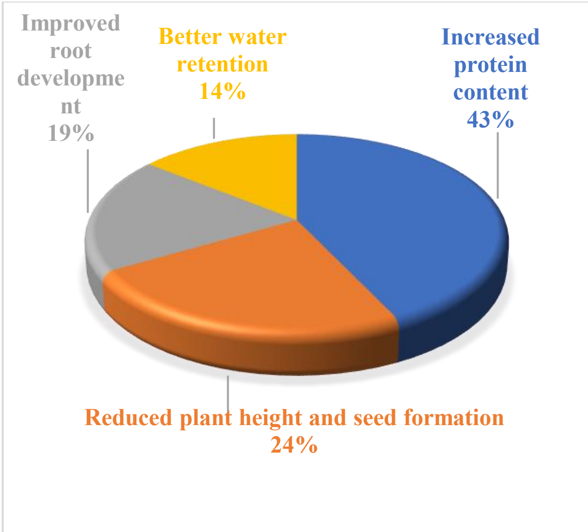
Graph 13 biological control strategies for nematode management

According to the analysis, biological control methods are frequently used in soybean farming to manage nematodes. Due to its efficacy against nematode eggs, Paecilomyces lilacinus is the most favored bioagent, as evidenced by the fact that 121 farmers (58%) reported using it. Next, 71 farmers (34%) utilize Trichoderma spp., which is also frequently used to improve soil health and inhibit soil-borne diseases. Pseudomonas fluorescens was used by a lesser percentage of 13 farmers (6%), indicating a limited but growing use of bacterial bioagents. In the research area, biological approaches are widely accepted, as evidenced by the 5 farmers (2%) who reported not applying any biological control strategies. Overall, the results show that soybean producers are strongly moving toward environmentally benign nematode management techniques.



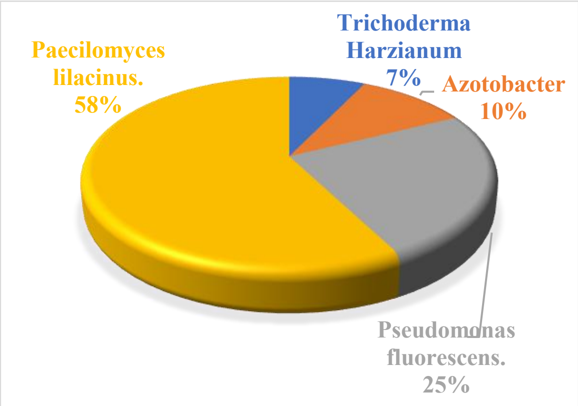
Graph 14 existing nematode management strategies

According to the analysis, farmers believe that their current methods for managing nematodes in soybean production are only somewhat effective. 88 farmers, or 42% of the total, stated that their methods are moderately effective, indicating some control over nematode infestation. Following this, 69 farmers (33%) reported that their tactics were very successful, suggesting that integrated approaches are performing well in certain areas. Twenty farmers (10%) regarded their approaches as ineffective, indicating significant management issues in some places, while 33 farmers (16%) thought they were somewhat effective, indicating limited control in certain settings. Overall, the results indicate that although current nematode management techniques offer a respectable level of control, their efficacy still has to be increased for more reliable and long-lasting outcomes.



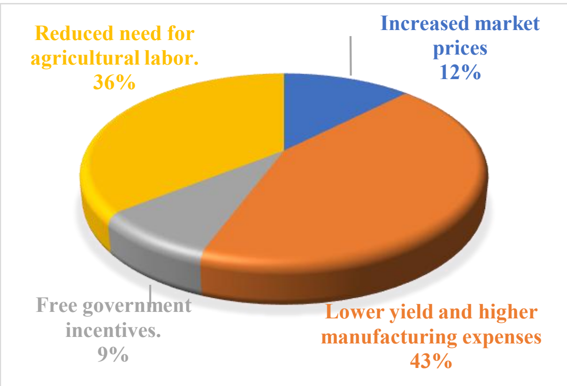
Graph 15 prevalent impact caused by nematode infestations on soybean yield

According to the analysis, 90 farmers (43%) indicated increased protein content as the most frequent effect of nematode infection. This is typically an indirect or misconstrued finding associated with stressed plant circumstances. 50 farmers (24%) reported decreased plant height and poor seed development after this, suggesting a direct detrimental impact on soybean production and output. 40 farmers (19%) reported improved root development, and 30 farmers (14%) reported better water retention. These findings are less prevalent and could be due to differences in farmer perception or field circumstances. Overall, the results indicate that nematode infestation primarily results in decreased soybean growth and production performance, while farmers' perceptions of these effects differ greatly.



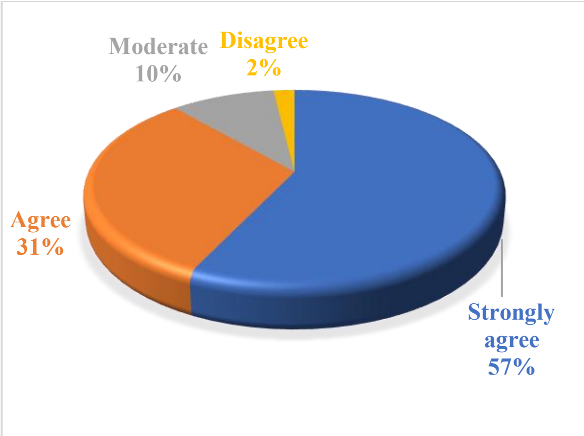
Graph 16 bio-agent is frequently used to deal with plant-parasitic nematodes

According to 121 farmers (58%), Paecilomyces lilacinus is the most commonly employed bioagent for controlling plant-parasitic nematodes, demonstrating its high efficacy and widespread use in soybean farming. Pseudomonas fluorescens, which is utilized by 52 farmers (25%), comes next, indicating its increasing use because of its ability to control nematodes and promote plant growth. Twenty-two farmers (11%) reported using Azotobacter, indicating moderate use mostly for improving soil fertility and indirectly suppressing nematodes. Despite being acknowledged for its role in soil health and pathogen management, Trichoderma harzianum was the least employed bioagent, as stated by 15 farmers (7%). Overall, the results indicate that fungal bio-agents specifically, Paecilomyces lilacinus—are strongly preferred in biological nematode management techniques.



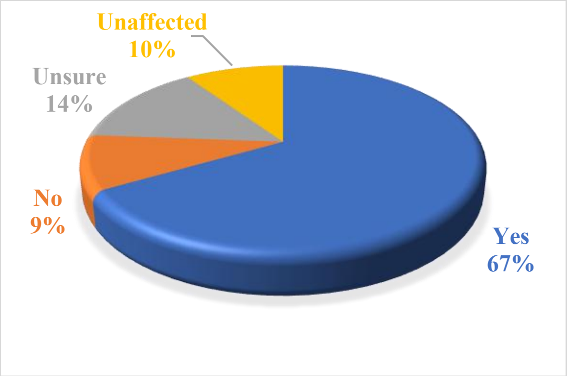
Graph 17 financial effect of a severe nematode infection on soybean farmers

According to 91 farmers (43%), the primary financial impact of a severe nematode infestation is lower yield and higher production costs. This indicates a substantial economic loss as a result of decreased productivity and higher input costs. Following this, 75 farmers (36%) reported a lower need for agricultural labor, which reflects a decline in farming activity and job prospects during severely impacted seasons. Twenty-six farmers (12%) reported higher market prices, which may indicate a shortage of supply but may not make up for yield losses. Free government incentives were noted by a lesser percentage of 18 farmers (9%), suggesting limited access to or knowledge of support programs. Overall, the results unequivocally demonstrate that nematode infection has a significant detrimental financial impact on soybean farmers, primarily due to decreased output and higher production costs.



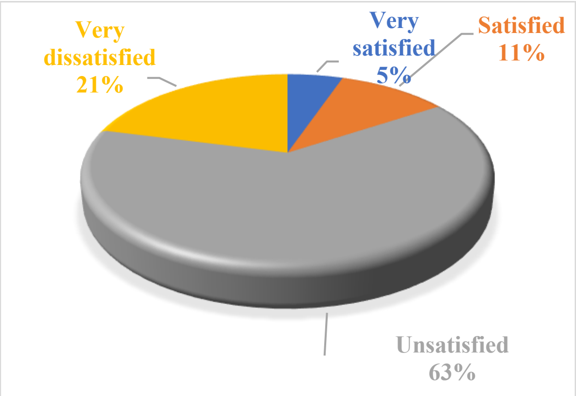
Graph 18 nematodes provide a significant danger to soybean output in India

According to the analysis, most respondents firmly believe that nematodes pose a significant risk to India's soybean crop. 120 farmers (57%) strongly concur that nematodes constitute a serious threat, demonstrating a high level of understanding of their detrimental effects on crop health and output. This is followed by 66 farmers (31%) who concur, indicating that nematode infestation is a common worry. Twenty farmers, or 10% of the total, had a moderate opinion, indicating some doubt about how serious the issue is. There is extremely little rejection of nematode-related hazards, with only 4 farmers (2%) disagreeing. Overall, the results make it abundantly evident that the majority of Indian farmers view nematodes as a significant barrier to soybean yield.



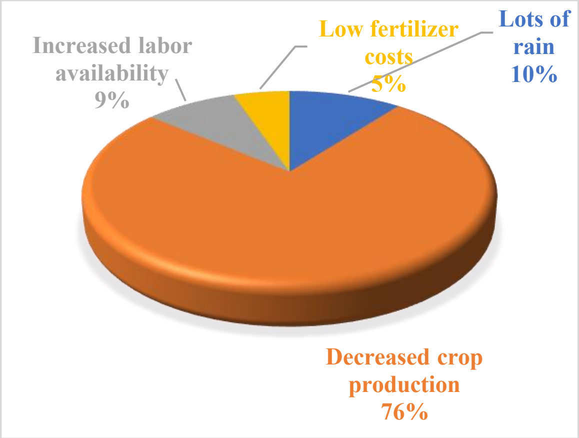
Graph 19 climate change may be increasing nematode infection in soybean crops

According to the analysis, most farmers think that increased nematode infestation in soybean crops is a result of climate change. 67% of the 140 farmers who answered Indeed, there is a strong belief that nematode activity is being increased by shifting rainfall and temperature patterns. Thirty farmers (14%) expressed uncertainty, showing a lack of clarity regarding the connection between nematode illness and climate change. Twenty farmers (10%) who said "no" and another twenty farmers (10%) who said "unaffected" indicate that a smaller proportion does not link nematode issues to climate change. Overall, the results show that farmers firmly believe that climate variability has a significant impact on nematode infection in soybean output.



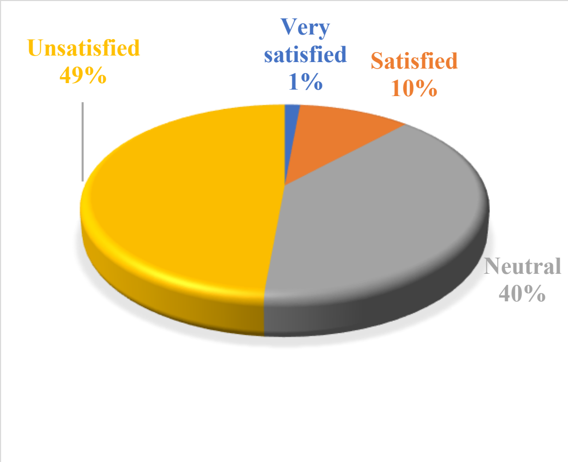
Graph 20 satisfied are farmers with the present yields from nematode-affected soybean crops

According to the data, farmers are often dissatisfied with soybean yields when nematodes are present. Nematode infection has considerably decreased crop productivity, as indicated by the majority of 133 farmers (63%) who expressed dissatisfaction. Following this, 44 farmers (21%) express extreme dissatisfaction, which is indicative of significant crop losses and financial strain. Just 22 farmers (10%) said they were happy with their yields, and just 11 farmers (5%) said they were extremely happy. Overall, the results make it abundantly evident that the majority of farmers are not happy with the current soybean yields because of nematode infestation, underscoring the need for better and more efficient management techniques.



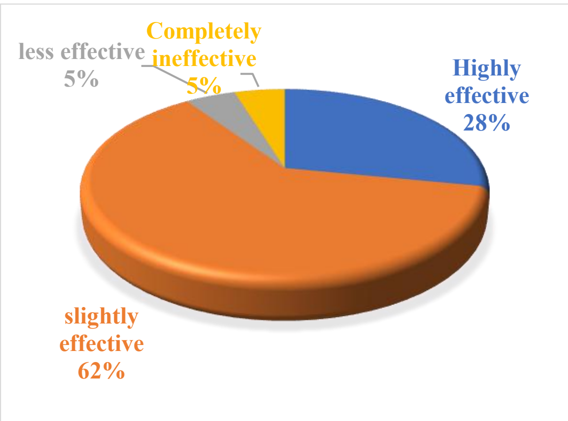
Graph 21 cause for farmer unhappy with nematode infestations

According to the analysis, 159 farmers (76%) cited reduced agricultural production as the primary cause of their discontent with nematode infection, suggesting that yield loss is the biggest worry. This is followed by a lot of rain, which 22 farmers (10%) stated, indicating that in certain situations, too much rainfall may exacerbate nematode-related field conditions. Just 11 farmers (5%) mentioned cheap fertilizer costs as a consideration, which is less directly tied to nematode impact, while a lesser percentage of 18 farmers (9%) mentioned greater labor availability. Overall, the results unequivocally show that farmer discontent in nematode-affected areas is primarily caused by decreased soybean productivity.



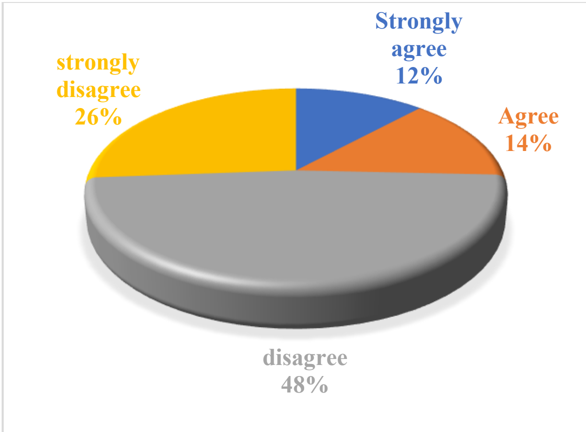
Graph 22 farmers satisfied with chemical nematicides as a solution

According to the data, farmers are generally dissatisfied with chemical nematicides as a worm management solution. Concerns regarding limited effectiveness, expense, or long-term soil consequences were expressed by the majority of 102 farmers (49%) who expressed dissatisfaction. Following this, 83 farmers (40%) express no opinion, indicating a lack of confidence in their overall performance. Three farmers (1%) were extremely satisfied with chemical nematicides, compared to just 22 farmers (10%) who said they were satisfied. Overall, the results unequivocally show that farmers are not satisfied, underscoring the need for more integrated and sustainable nematode management strategies.



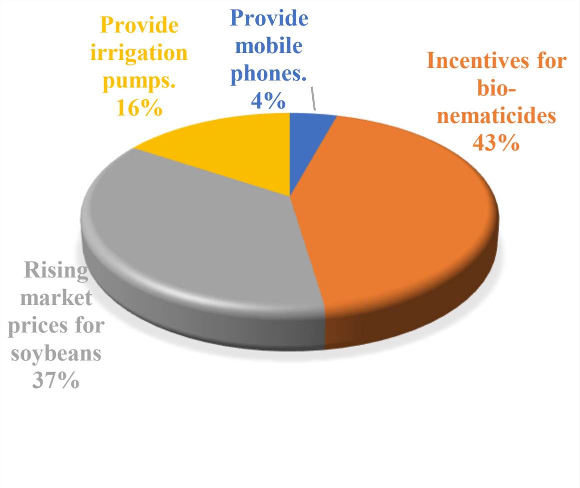
Graph 23 farmers evaluate the effectiveness of biological pesticides

According to the data, farmers believe biological insecticides are only modestly successful at controlling nematode infection in soybean crops. The majority of 131 farmers (62%) said they were only marginally effective, indicating that although they offer some control, the outcomes are not entirely satisfactory. This is followed by 59 farmers (28%) who thought they were very effective, indicating that a sizable portion of respondents accepted them. Limited discontent was shown by the lesser percentage of 10 farmers (5%) who evaluated them as less effective and another 10 farmers (5%) who deemed them wholly ineffectual. Overall, the results indicate that biological pesticides are thought to be only partially effective, with room for improvement in field-level consistency and performance.



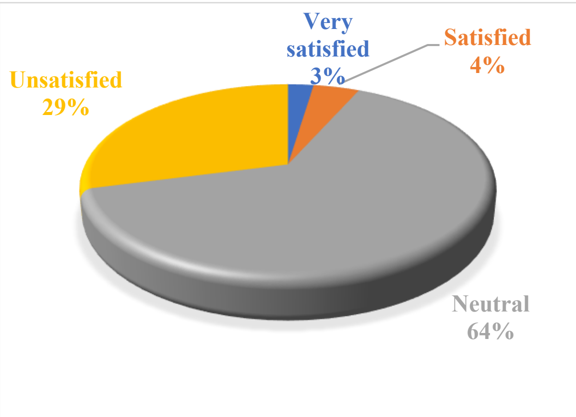
Graph 24 farmers believe that government or agricultural improvement support are sufficient

According to the analysis, the majority of farmers believe that there is not enough agricultural or governmental support for nematode management. The plurality of 101 farmers (48%) disagree, suggesting that they don't think the support programs in place are sufficient. 55 farmers (26%) strongly disagree, indicating a larger degree of discontent with institutional support. Positively, just 25 farmers (12%) strongly feel that help is adequate, compared to 29 farmers (14%). Overall, the results make it abundantly evident that the majority of farmers believe that agricultural assistance programs and the government are insufficient to effectively combat nematode infestation in soybean farming.



Graph 25 farmers feel requires further government support

According to 91 farmers (43%), incentives for bio-nematicides are the most favored sector that needs government help, demonstrating a high need for reasonably priced and environmentally compatible nematode management solutions. Following this, 77 farmers (36%) recommended higher market pricing for soybeans, indicating farmers' desire for more revenue and profitability. 33 farmers (16%) mentioned the availability of irrigation pumps, underscoring the necessity of better irrigation infrastructure to lessen crop stress and nematode severity. There is little need for digital assistance tools, as seen by the modest percentage of 9 farmers (4%) who suggested offering cell phones. Overall, the results show that improving soybean output and nematode management mostly requires financial and input-based government support.



Graph 26 farmers with existing nematode control practices for soyabean crops

According to the analysis, farmers are generally neutral to negatively satisfied with the nematode management methods currently used in soybean farming. The majority of 135 farmers (64%) said they were unsure about the efficacy of the control measures in place. This is followed by 61 farmers (29%) who are dissatisfied, which reflects worries about ongoing output losses and insufficient nematode control. Five farmers (2%) were extremely satisfied with current techniques, compared to just 9 farmers (4%) who said they were satisfied. Overall, the results show that most farmers are not entirely persuaded of the efficacy of the nematode control techniques currently in use, underscoring the need for more effective and long-lasting solutions.

The results demonstrate that farmers have a moderate to high degree of awareness about nematode infestation, with the majority of respondents being able to recognize typical symptoms like yellowing, stunted growth, and root galls. However, there is still a lack of knowledge among farmers about nematode species other than Meloidogyne incognita. Nematode infestation is also very common, according to the study, with many farmers reporting yearly or seasonal occurrences, especially in sandy soils and regularly planted soybean areas. This confirms earlier research showing that inadequate soil management techniques and monocropping greatly increase the accumulation of nematode populations. Nematodes are a major financial barrier in soybean farming, as evidenced by the largest output losses (>40%) recorded by the majority of farmers.

In terms of management practices, farmers predominantly rely on cultural methods such as crop rotation and deep ploughing, along with increasing use of biological agents like Paecilomyces lilacinus and Trichoderma spp. Chemical nematicides, especially Fluopyram, are still widely used, but farmer satisfaction with chemical control is generally low. This indicates a gradual but incomplete shift towards integrated nematode management (INM), where biological and cultural methods are gaining importance but have not fully replaced chemical dependence.

The results further show that biological pesticides are perceived as moderately effective, suggesting potential for expansion but also highlighting inconsistency in field performance. Farmers' dissatisfaction with current management practices and government support indicates the need for stronger extension services, training programs, and institutional interventions. Additionally, concerns about climate change influencing nematode outbreaks reflect growing farmer awareness of environmental impacts on pest dynamics. Overall, the study confirms that while multiple management strategies are being practiced, none provide complete control under current conditions. This shows the need for a more integrated, location-specific, and sustainable nematode management approach combining resistant varieties, biological control, improved cultural practices, and supportive government policies to enhance soybean productivity and farmer income.

6. Conclusion

Plant-parasitic nematodes are a serious and ongoing issue in Washim District's soybean-growing regions, as the study on management techniques and control measures for nematode infestation in soybean production makes abundantly evident. High infestation levels, recurrent production losses, and obvious crop damage especially from root-knot nematodes were observed by farmers. The results show that early crop stages like germination and vegetative phases, sandy soils, and continuous monocropping are the most susceptible to nematode infestation.

Plant-parasitic nematodes, of which Meloidogyne incognita is the most common species (52%), constitute a significant barrier to soybean production, according to a study conducted in Washim District. A significant percentage of farmers reported seasonal infection with output losses surpassing 40% (61%), and the majority reported obvious symptoms such root galls (47%) and leaf yellowing (29%). Monocropping techniques and sandy soils (52%) were found to be important factors raising the occurrence of nematodes. Crop rotation (53%), deep plowing (29%), and biological control agents such as Paecilomyces lilacinus (58%) were the most popular methods utilized by farmers; the most popular chemical nematicide was fluopyram (46%). Overall, the findings show that while a variety of control methods are employed, their efficacy is only moderate, underscoring the necessity of more robust integrated nematode management techniques.

Additionally, the study shows that farmers are increasingly using a mix of chemical, biological, and cultural management techniques. The most popular cultural techniques are deep plowing and crop rotation, while biological agents like Trichoderma spp. and Paecilomyces lilacinus are frequently employed. Despite the continued preference for chemical nematicides like Fluopyram, farmer satisfaction with chemical management is comparatively poor, suggesting limitations in sustainability and effectiveness. The survey also shows that farmers have a modest level of awareness and a strong belief that worms drastically lower soybean output and revenue. The majority of farmers voiced discontent with present yields, control methods, and insufficient government assistance. Thus, the study comes to the conclusion that sustainable soybean production and efficient nematode control in the area depend on integrated nematode management strategies, greater farmer training, easier access to biological inputs, and more institutional support.

7. Future Scope

In order to determine the most successful and financially feasible combinations under various agroclimatic conditions, future research can concentrate on large-scale field validation of integrated nematode management (INM) techniques combining cultural, biological, and chemical strategies. Additionally, it is imperative to create and assess nematode-resistant soybean cultivars that are tailored to the soil and climate of the area. For the early detection and prediction of nematode infestation, cutting-edge technologies including machine learning, drone-based crop monitoring, and remote sensing can be further investigated. Furthermore, molecular and biotechnological methods, including as gene editing and the creation of bio-nematicides, have encouraging prospects for long-term pest management.

To close the gap between field-level behaviors and scientific recommendations, future research should also concentrate on enhancing farmer knowledge, adoption behavior, and training initiatives. To find affordable solutions for small and marginal farmers, economic examination of various management techniques is equally crucial. Furthermore, long-term research on biodiversity, soil health, and the effects of climate change on nematode dynamics will aid in the creation of more robust soybean production systems.

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