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18. Sustainable Nematode Management in Potato Crops: Challenges and Solutions

Shyam Lal, Subham Chaudhary

Department of Plant Pathology,
CSA University of Agriculture and Technology,
Kanpur, U.P.

Mayank Tiwari

Department of Genetics and Plant Breeding,
Govind Ballabh Pant University of Agriculture and Technology,
GBPUA&T, Pantnagar Uttarakhand

Abstract:

The cultivated potato, scientifically known as Solanum tuberosum Linn., originated in the Andes mountains in South America. It was introduced to Europe in the 16th century and subsequently spread worldwide. Today, it is cultivated in nearly every country and is recognized as the most significant tuber crop globally, playing a crucial role in meeting the food needs of people, particularly in developing countries. Designated as the 'International Year of Potato' by the United Nations in 2008, it is considered one of the top high-value crops. The global production of potatoes amounts to approximately 320 million tonnes, with China (72 MT), the Russian Federation (35 MT), and India (26 MT) being the major producers.

In our nation, potatoes are grown in nearly all states, adapting to diverse ecological conditions. Although traditionally cultivated in colder regions, the adaptability of the crop has been effectively leveraged by developing varieties suited to various agro-climatic zones in India. Primary challenges in potato cultivation include the impact of insect pests, nematodes, and diseases, leading to a global yield loss of approximately 37%. Diseases and nematode parasites alone contribute to 23% of this loss. Notable pests affecting potato crops in India include late blight (Phytophthora infestans), bacterial wilt (Ralstonia solanacearum), tuber moth (Phthorimaea operculella), root-knot nematodes (Meloidogyne spp.), and cyst nematodes (Globodera spp.), false root-knot nematode, the potato rot nematode and root lesion. In India, the root-knot nematode (R.K.N) and potato cyst nematode (P.C.N) are particularly significant among the 90 parasitic nematodes associated with the potato rhizosphere, exhibiting a highly adapted, obligate plant parasitic life cycle (Krishna Prasad, 1993). In this chapter we have discus the major nematode disease of potato corps viz. Root-knot nematode (R.K.N), Potato cyst nematode (P.C.N) with their causes, symptoms and management

Keywords:

Potato, Nematode, Globodera spp., Managemnt

18.1 Introduction:

The cultivated potato, scientifically known as *S. tuberosum Linn.*, originated in the Andes mountains in S. America. During the 16th century, it was brought to Europe and later propagated globally Jones and Haegeman (2008). Currently, it is grown in almost every nation and is acknowledged as the primary root crop worldwide, playing a vital role in addressing the food requirements of populations, especially in developing nations Bohl and Hetrick (1998). Designated as the 'International Year of Potato' by the United Nations in 2008, It is considered one of the leading high-value crops Castagnone-Sereno and De Luca (2015). The global production of potatoes amounts to approximately 320 MT, with China (72 MT), the Russian Federation (35 M T), and India (26 MT) being the major producers. In our nation, potatoes are grown in nearly all states, adapting to diverse ecological conditions. Although traditionally grow in temperate regions, the versatility of the crop has been efficiently utilized by creating varieties tailored to different agro-climatic zones in India Van der Waals and Stolk (2011). Hence, potatoes are cultivated in the extended daylight of summer months in the mid-hills of the Himalayas, in the brief daylight of winter months in the North-West plains of Punjab, H.R, U.R, Bihar, and W.B, under equinox conditions on the Deccan Plateau during the rainy seasons, and nearly year-round in the mild climate of the Tamil Nadu hills. The flexible farming practices have elevated potatoes to a crucial dietary staple, placing them as a major food source, following only paddy, wheat, and maize in our nation O'Brien and Eason (2014). Primary challenges in potato cultivation include the impact of insect pests, nematodes, and diseases, leading to a global yield loss of approximately 37%. Diseases and pathogenic Nematode alone contribute to 23% of this loss (Háněl 2008). Notable pests affecting potato crops in India include late blight (*P. infestans*), bacterial wilt *(R. solanacearum*), tuber moth (*P. operculell*a), root-knot nematodes (*Meloidogyn*e spp.), and cyst nematodes (*Globodera spp.*). Unlike insect pests or diseases, nematode infections pose a challenge in identification and diagnosis, often being mistaken for nutrient deficiencies. In the context of India, the root-knot nematode (R.K.N) and potato cyst nematode (P.C.N) are especially significant among the 90 parasitic nematodes associated with the potato rhizosphere. These nematodes exhibit a highly specialized, mandatory plant-parasitic life cycle, as outlined by Rodriguez-Kabana (1991). Additional significant nematode parasites present in the potato rhizosphere include spiral nematodes (*Helicotylenchus spp*.), stunt nematodes (*Tylenchorhynchus* spp; *Quinsulcius* spp.), lesion nematodes (*Pratylenchus* spp.), reniform nematodes (*R. reniformis*), and pin nematodes (*Paratylenchus spp.*). These nematodes feed on potato roots, leading to notable reductions in yield (Maurya *et al*., 2023 a).

18.1.1 Crop Loss Due to P.P.N (Plant Parasitic Nematode):

Globally, plant-parasitic nematodes (P.P.N) are responsible for an estimated 12.2% yield loss in potatoes. In the context of India, the presence of just two root-knot nematode (R.K.N) larvae per gram of soil can lead to a substantial 42.5% reduction in overall yield. Additionally, potato cyst nematode (P.C.N) infestation results in an even more significant loss, accounting for 65% of the total yield reduction**.** Tubers affected by RKN exhibit pimple-like blisters, and the detection of only two infected tubers per 80 kg seed potato bag is adequate for rejection from export in H.P, a state adhering to potato seed certification standards **(**Hwang and Overstreet 2004; Maurya *et al*., 2023 b).

18.2 Root-Knot Nematode (R.K.N):

Globally, approximately 90 recognized species of Root-Knot Nematodes (R.K.N) exist, with *M. incognita, M. javanica, M. arenaria, and M. hapla* being prevalent in over 95% of soil samples. These nematodes exhibit various races, parasitizing over 2000 plant species and causing considerable harm to worldwide agriculture. Tropical regions commonly harbor *M. incognita*, followed by *M. javanica* and *M. arenaria*, while cooler climates host *M. hapla*, *M. chitwoodi*, *M. fallax*, and *M. thamesi. Notably, M. chitwoodi* is a significant threat to potatoes in temperate areas like North America, Europe, and Australia, particularly causing damage to tubers at temperatures below 6 °C (Jaffee and Ruppel 1987). In India, *M. incognita* poses a threat to potatoes in both hilly and plain regions, whereas *M. javanica* affects potatoes in the mid-hills and plains of northern India. *M. hapla* is found in Uttarakhand, H. P, J&K, Assam, and T.N, while *M. arenaria* is distributed in the plains of U.P (Maurya *et al*., 2020).

18.2.1 Symptoms of Root -Knot Nematode:

The visible symptoms above ground, such as the stunting and yellowing of plants with chlorotic leaves, are caused by a decline in the absorption of water and nutrients by the roots. Issues related to the roots are evident in the form of characteristic swellings known as "galls." The presence of nematodes leads to the formation of warty, pimple-like lesions on tubers, diminishing their commercial value and storage quality. When tubers are sliced, brown patches appear in the flesh due to nematode infestation. A complete infestation of tubers, starting with 200 juveniles (J2s) per 100 ml of soil, resulted in a 40% reduction in overall production (Maurya *et al*., 2018).

Figure 18.1: Symptoms of Root -Knot Nematode

Symptoms due to root-knot nematode (*Meloidogyne spp.*) on Potato tubers:

18.2.2 Yield Loss Due to Root-Knot Nematode (R.K.N):

The annual damage inflicted by the Root-Knot Nematode (R.K.N) amounts to 29–30% of vegetable harvests, as it forms a root system that encourages plant growth and aids in the expansion of the invading nematode population. In India, the decline in potato yield exceeds

12.2%. These nematodes can engage with other microorganisms present in the soil like fungi, bacteria, and viruses, resulting in significant crop losses. One of the most impactful interactions involves R.K.N and *R. solanacearum*, leading to "pseudomonas wilt" in tomatoes, eggplant, and potatoes. Additionally, it has been noted that *M. javanica* is a causative factor in the deformation of potato tubers.

18.3 Management of Root- Knot Nematode:

Under given following methods use to manage the R.K.N. Cultural practices: Reducing Root-Knot Nematode (R.K.N) infestations can be achieved through various measures. Utilizing high-quality seed tubers, implementing thorough ploughing during summer, maintaining field cleanliness, and ensuring a weed-free environment are effective practices. Crop rotation with non-host crops like maize or wheat can diminish nematode damage, with rotations lasting at least 4 years and incorporating robust weed management. To mitigate R.K.N damage, resistant crops such as oats, cotton, and grasses can be included in rotations with potatoes. For managing *M. javanica*, resistant crops like sorghum, maize, and castor bean have been used in rotation strategies (Caveness and Meyer 1990). *Brassic*a crops, including cabbage, cauliflower, mustard, and Chinese cabbage, are commonly rotated with potatoes. Proposed management techniques involve regular and timely soil cultivation, immediate destruction of volunteer potato plants and tubers, planting certified potato tubers, selecting planting dates to avoid high R.K.N populations during tuber development, shortening the potato cycle with early maturing cultivars, and judicious use of certified nematicides before, during, and after planting (John *et al*., 2019 a)**.** Given the prevailing lower temperatures during the crop period, early planting of spring crops in the first week of January and late planting of fall crops in the second and third weeks of October are recommended to minimize nematode infection in potatoes. Additionally, incorporating antagonistic crops like French marigold *(T. patula*) in alternate rows with potatoes is suggested to reduce nematode populations.

18.3.1 Resistance in Host Plants:

Genetic resistance from the wild potato species *Solanum sparsipilum* is being employed in a breeding program aimed at creating potato cultivars resistant to *M. incognita, M. javanica, and M. arenaria.* The RMc1 (blb) protein, derived from *Solanum* section Petota, serves as the encoded protein for the nematode-resistant gene, effectively countering various races of *M. chitwood*i. The wild potato species *S. sparsipilum*, utilized in the development of resistant potato cultivars, has demonstrated resistance against *M. incognita, M. javanica, and M. arenaria* (The International Potato Center-CIP). Notably, the *Mc Cramick* and *Golden* potato varieties exhibit resistance to *M. chitwoodi,* while Oronek, ORA, and Suzanna varieties display moderate resistance (Sipes and Bowers 2001)**.**

18.3.2 Organic Amendments of Soil:

In agriculture, organic amendments are commonly utilized to restore energy and nutrients to the soil, simultaneously improving soil conditions to support plant growth**.** Some organic amendments play a role in suppressing plant diseases, while others effectively manage plant parasitic nematodes.

Certain toxic plant components like phenols, alkaloids, polyphenols, and allochemicals indirectly inhibit phytopathogens and plant-parasitic nematodes by enhancing the soil microbiota**.** For instance, powder derived from *Avicennia marina* (mangrove) demonstrated the ability to inhibit the knots caused by *M. javanica* and root-infecting fungus. Furthermore, incorporating organic matter from *T. minuta*, *Ricinus communis*, and *D. stramonium* was observed to heighten the parasitic activity of *P. lilacinus* against *M. javanica* eggs (John *et al*., 2019 b)**.**

18.3.3 Use of Botanicals:

Phytochemicals or active constituents with nematicidal properties, identified in various parts of plants, have proven effective in reducing nematode infestations on plants discovered anti-inflammatory effects on the egg hatching of *M. incognita* through the tuber extract of *Dioscorea floribunda*. *Azadirachtin,* present in leaf and seed extracts of *Azadirachta indica*, was found to enhance juvenile mortality of potato root-knot nematodes (RKN). Various plant extracts, including Spanish cherry *(Mimusops elengi L), Lantana camara, Nicotiana tabacum, Syzygium aromaticum*, water hyacinth, and devil pepper *(Rauvolfia tetraphylla*) leaves, have demonstrated effectiveness in managing *Meloidogyne* populations**.** Marigolds *(Tagetes species*) producing polythienyls have been identified as agents capable of suppressing nematodes (Pandey *et al*., 2022 a).

18.3.4 Chemical Control:

Originally, substances such as DD (1-3 Dichloropropane1-2 dichloropropene), EDB (Ethylene di bromide), MBr (Methyl bromide), DBCP (Dibromochloropropene), and Dorlone (a blend of DD and EDB) were employed to manage root-knot nematodes (RKN) and potato cyst nematodes (PCN). The application of Carbofuran 3G at a rate of 1–2 kg active ingredient per hectare proves effective in decreasing nematode infestation and promoting higher yields. Improving the chemical's efficacy in controlling root-knot nematodes (RKNs) can be achieved by dividing the application, with one part during planting and the other during earthing up, as suggested (Pandey *et al.*, 2022 b).

18.3.5 Integrated Management of RKN:

Using a single control strategy is both economically impractical and insufficient for effective nematode management. Hence, achieving better management involves a judicious combination of multiple strategies. The adoption of Integrated Nutrient Management (INM) over a two-year period proves to be an efficient and cost-effective approach to root-knot nematode control (Pant *et al*., 2023).

18.4 Potato Cyst Nematodes (*Globodera Spp.*):

Globodera rostochiensis, also referred to as the golden nematode, golden eelworm, or yellow potato cyst nematode, is a type of plant pathogenic nematode. This nematode is known to be a pest affecting plants in the *Solanaceae* family, with a primary impact on potatoes and tomatoes. Additionally, it can infest various other root crops (John *et al.*, 2019).

18.4.1 Symptoms and Yield Loss:

When the soil has low population densities of the Potato Cyst Nematode (PCN), there are typically no visible above-ground symptoms in potato crops, as most plants can withstand the nematode invasion. However, as the degree of invasion intensifies, the plant's ability to compensate diminishes, leading to a variety of symptoms.

In cases of intense and localized infestation, small patches of poorly growing plants emerge in the field, and wilting may occur, particularly during the hot sunny hours of the day. As the season progresses, the lower leaves turn yellow/brown and wither, leaving only the young leaves at the top. The entire plant takes on a "tufted head" appearance, ultimately resulting in premature plant death. The browning and withering of foliage gradually extend to the withering of the entire plant. The root system becomes poorly developed, and depending on the level of infestation, both the yield and size of the tubers decrease (John *et al*., 2020).

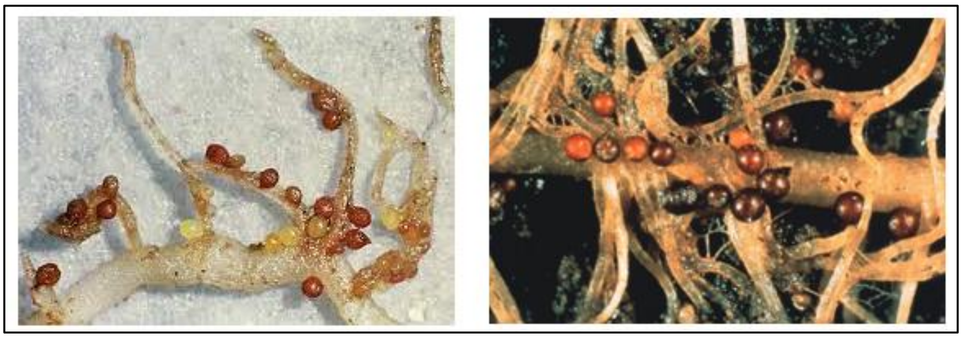

Figure 18.2: Symptoms and yield loss

The required soil population tolerance limit for Potato Cyst Nematode is outlined as follows: 1.3 to 2.1 eggs per gram. Evans and Stone estimate that the economic threshold is around 20 eggs per gram of soil. Previous studies found a 30% global yield loss, with estimated losses higher than 12%. According to official estimates, yield losses in high-infestation areas of India might range from 5 to 80%.

18.4.2 Management of Potato Cyst Nematode:

Eradicating Potato Cyst Nematodes (PCN) from contaminated soil is a formidable challenge once they have taken hold. Since no individual control measure can fully achieve the desired level of nematode suppression, a comprehensive nematode management approach is recommended.

This integrated module involves a judicious combination of strategies, including host resistance, Nematicide applications, biological controls, and agronomic practices. This comprehensive strategy seeks to reduce the Potato Cyst Nematode (P.C.N) population to levels that allow for economically viable potato production (Simon *et al*., 2021).

18.4.3 Quarantine:

Legal restrictions are implemented in almost every country concerning plants, plant products, and commodities to prevent the introduction of pests and diseases by humans, ensuring the safeguarding of agriculture and the environment. Strict import controls at both regional and national levels have resulted in the localized elimination of P.C.N. However, continuous monitoring programs are in operation to supervise the status of the pest. Despite these stringent measures, there are repeated occurrences of new P.C.N outbreaks, even in regions heavily reliant on potato production. Notably, *G. pallida* was detected in Idaho, a significant potato – cultivated area in the United States, leading to extensive efforts to contain and eliminate the outbreak. The significance of P.C.N discoveries in various sub-Saharan African countries, as emphasized could be even more notable (Ravishankar *et al*., 2023).

The movement of potato seed tubers from areas affected by P.C.N to non-infested regions is prohibited by domestic quarantine measures. The Ministry of Agriculture and Farmers Welfare in India, under Section 4A of the Destructive Insects and has issued a notification to restrict the transportation of seed potatoes from P.C.N-infested areas to other states and union territories. As cysts are stationery and incapable of independent movement, their potential spread primarily occurs through the movement of soil rather than through the planting of an infected field.

Implementing rigorous biosecurity measures is the most effective strategy to prevent such spread, encompassing measures like preventing soil movement through farm equipment, tires, shoe soles, propagated materials, and both domestic and wild animals. A crucial aspect of managing P.C.N populations is understanding their biology, including their life cycle, dispersal mechanisms, and the likelihood of detection at county, local farm, and field levels. This understanding is essential for interpreting laboratory findings and guiding growers in preventing the spread of PCN throughout their fields.

18.5 Utilization of Officially Approved Seed Varieties:

A fundamental concept within the **EU PCN Directive 2007/33/EC** involves restricting the planting of certified seed potatoes to fields that have undergone inspection and confirmed to be free of P.C.N. This measure aims to prevent the initial and subsequent introductions of P.C.N into cultivated areas.

18.5.1 Crop Rotation:

The key concept behind crop rotations is to maintain PCN population densities below harmful levels. In various regions, such as Peru, Ecuador, and Cochabamba, the sequence of maize and lima beans has proven to be the most efficient in influencing P.C.N density, potato yield, and profitability. In Western Europe, it is recommended to have a 7-year gap between the cultivation of susceptible potato varieties**.** The use of crop rotation with non-solanaceous crops is a common strategy for P.C.N management due to their limited host range.

A substantial decrease (98.7–99.9%) in P.C.N after a four-year crop rotation involving potatoes, French beans, and peas, accompanied by a yield increase of over 90%. The implementation of resistant varieties in a four-year crop rotation program alone resulted in a yield increase of 67–78%. Introducing non-host crops between host crops contributed to a reduction in PCN population density. Crop rotation with non-host crops such as radish, cabbage, cauliflower, turnip, garlic, and carrot, as well as green manure crops like lupin for three to four years, led to a 50% reduction in cyst population (Maurya *et al*., 2023)**.**

Radish exhibited a decline in cysts by 19.6–21.0% and a reduction in the number of eggs per cyst by 12.2–16.2% compared to other non-solanaceous plants. Garlic showed a decrease in cysts by 15.9–17.7% and a decline in the number of eggs per cyst by 10.3–11.6%. Barley, when incorporated into crop rotation, showed a reduction of up to 87% in *G. rostochiensis*. Extended rotations are commonly utilized to manage PCN, taking advantage of natural attrition through PCN's hatching and mortality in the absence of a host plant, leading to a 20–30% population decline annually. However, the effectiveness of these strategies can be influenced by factors such as soil composition, type, aeration, and moisture. Despite these benefits, farmers in hilly areas often hesitate to adopt these practices due to the lucrative nature of potatoes as a cash crop.

18.5.2 Inter-Cropping:

When French beans are cultivated alongside potatoes in a 3:2 ratios, discovered an elevated potato equivalent yield and a diminished cyst population. Intercropping potatoes and mustard in a 1:1 plant ratio, coupled with the application of carbofuran, resulted in a decrease in P.C.N infestation and an increase in potato yield**.** The successful reduction of the P.C.N population (Rf: 0.99) was also observed when potatoes were intercropped with radish at a 2:1 ratio.

18.6 Use of Trap Cropping:

The initial method of using a trap crop involves cultivating potatoes, which should be uprooted 40 days after planting, before the development of P.C.N females. While this approach has been applied in the Netherlands to address high infestations, it carries the potential drawback of crop loss. The nematodes are captured and eliminated within the plant before reaching maturity, necessitating efficient plant destruction. In France, the adoption of trap crops led to an 80% annual reduction in *G. pallida* populations, and a 98.5% reduction was achieved with two trap crops combined with ethoprophos application. The Cara cultivar, recognized for its tolerance to *G. pallida*, reduced the population by 75% when grown on complete ridges for 6 weeks in heavily infested soil. However, in India, trap cropping with a susceptible potato varieties attracted more juveniles than trap cropping with a resistant cultivar, resulting in a 53% reduction in the nematode population. Nonetheless, it is essential to destroy trap crops before completing the P.C.N life cycle.

The second approach to trap cropping involves utilizing a crop related to *S. tuberosum* to interrupt the P.C.N life cycle. Various crops have been explored for this purpose, and *S. sisymbriifolium* has shown the most promise thus far (Aarti *et al*., 2021). The introduction of the wild trap plant *S. sisymbriifolium* resulted in an 80% reduction in the P.C.N population in the region (Aarti *et al*., 2016). Other species with potential include *S. tuberosum*, *S. nigrum, S. dulcamara,* and *D. stramonium*. Cultivating potatoes to stimulate P.C.N hatching and subsequently removing potato plants after nematode infestations in the potato roots can help diminish soil infestations.

18.6.1 Plant Resistance to Host Organisms:

Resistant cultivar against *Globodera spp.* have been successfully employed with a success rate of up to 95%. Currently, numerous global breeding projects are underway to identify resistance genes specifically targeting these nematodes. Specific potatoes, like Cara, demonstrate tolerance to Potato Cyst Nematodes (PCN), showing robust growth and sustaining yield even under moderately high PCN levels. The extensive cultivation of highly resistant *G. rostochiensis* varieties, such as Maris Piper, has considerably reduced the damage caused by this nematode species. In India, (Aarti *et al.*, 2017) conducted screening of various germplasm selections against PCN to identify resistance for integration into commercial potato varieties.

In India, to minimize PCN multiplication, the first *S. vernei*-derived resistant cultivar Kufri Swarna was introduced in 1985 (Aarti *et al.*, 2016), followed by Kufri Neelima, both suitable for the Nilgiri and Himalayan hills. However, conflicts persist in this region between breeders and nematodes due to the development of virulence in both species of Globodera. The most effective approach to managing PCN populations in the field is the development and expansion of resistant varieties

18.6.2 Grow Antagonistic Crops:

Initially, plants with antagonistic properties can resist nematode infection, but as they mature, inherent plant factors may hinder their continued development. In Brazil, crops such as *Crotalaria spectabilis, C. juncea, Tagetes patula, T. minuta, T. erecta*, and *Estizolobium spp*. are employed to address root-knot nematode issues in potato fields and may also serve as a means to control *Globodera* species.

18.6.3 Mechanical Intervention:

As lethal temperatures are typically reached only in the top few centimeters of soil in temperate regions, soil solarization is most effective in smaller areas with extended hot summers. In the top 10 cm layer of the soil, *G. rostochiensis* eggs (97%) failed to hatch during the hot summer period**.** The amount of *G. rostochiensis* was reduced by 95% after 62 days of soil solarization**.**

18.7 Bio-Fumigation:

Biofumigation typically involves cultivating green manure crops from the brassica family, with commonly used cultivars including Indian mustard (*B. juncea*), rocket (*E. sativa*), and oil radish (*R. sativus*). The usual growth period spans from mid-July to early November, lasting between 8 to 14 weeks. Various Brassica species, such as Indian mustard, oil radish, and rocket, have demonstrated the ability to suppress Potato Cyst Nematode (P.C.N) during the growing season. The biofumigant crops are incorporated into the soil when they reach the early to mid-flowering stage. Indian mustard (*B. juncea*) has shown field efficacy ranging from 15% to 95% in reducing the P.C.N population. A study in India conducted by (Ferris and Bongers 2006) found that biofumigation, using 1 kg/m2 of radish leaves and polyethylene sheeting, resulted in the highest yield (25.97 t/ha) and reduced the PCN reproduction factor (Rf) to 1.21.

18.7.1 Use of Biocontrol Agents:

A.M fungi have demonstrated efficacy in preventing root invasion by Potato Cyst Nematodes (PCN) in lab experiments conducted in the U.K. Another fungus, *P. chlamydosporia*, which parasitizes nematode larvae, has shown promising results in some trials; however, its ability to scale up to commercial volumes has not been realized, and it may be vulnerable to field fungicides. Three additional fungi, namely *T. harzianum*, *P. cucumerina,* and *P. oxalicum*, are being investigated for their potential as predators or competitors of PCN.

Purpureocillium lilacinum, a fungus that preys on nematode eggs*, Pseudomonas fluorescens*, a rhizobacteria that enhances plant growth, *and T. viride*, an antagonistic fungus, have demonstrated potential as biocontrol agents against Potato Cyst Nematode (PCN). Neem and talc powder formulations exhibited PCN control rates of 42.6% and 58.2%, respectively. However, in recent times, various nematicidal products have been introduced to the market. Many other potential biocontrol agents are still under investigation to address implementation process challenges. The utilization of bio agents such as *P. fluorescens* and *P. lilacinus* along with organic amendments like neem cake (at 5 t/ha) combined with *T. viride* (at 5 kg/ha), resulted in a reduction in the PCN population.

18.7.2 Chemical Control:

The application of nematicides provides a dependable method for swiftly diminishing nematode populations. The effectiveness of soil fumigation is significantly influenced by soil conditions and temperature. Fumigation can be carried out at temperatures exceeding 5 °C using methyl bromide, 7 °C with 1,3-D, or 10 °C with MITC fumigants. Telone II (1,3-dichloropropene), a liquid fumigant, constitutes a substantial portion of the nematicides used by weight in managing nematodes in potato cultivation. While methyl bromide was formerly the most potent fumigant, alternative options are deemed less effective, mainly due to the cyst's defence mechanisms against juveniles. Successful fumigation treatment relies heavily on favourable soil conditions, including the appropriate temperature and moisture content during application. Timing is crucial, and it may involve applying the fumigation treatment in the rotation a year or two before the anticipated potato crop. Additionally, the effectiveness of the treatment is compromised if a proper surface seal cannot be established. A solution of Ca (ClO)2 with 9% available chlorine has proven effective in reducing the population of Potato Cyst Nematode (P.C.N) when used as a seed treatment. Another approach entails soaking unsprouted seed potato tubers infested with PCN in a 2% NaOCl solution (with 4% usable chlorine) for 30 minutes. This leads to the breakdown of all cysts without negatively impacting tuber germinability even after two months of storage.

18.7.3 Integrated Management:

The integrated use of diverse management strategies within the Integrated Pest Management (IPM) program proves effective in maintaining populations of Potato Cyst Nematodes (PCN) below the economic threshold level. A combination of practices, including five years of crop rotations with other crops, efficient soil fumigation, and the use of an effective trap crop, can effectively control P.C.N. Rapid reduction of large P.C.N populations is recommended through the application of a fumigant nematicide or a trap crop, accompanied by planting a potato crop covered with a granular nematicide**.**

Growing potatoes and mustard in an intercropping system at a 1:1 plant ratio, along with the use of carbofuran 3G (1 kg a.i./ha), led to a reduction in Potato Cyst Nematode (P.C.N) infection and an increase in potato production. Incorporating *P. fluorescens* (2.5 kg/ha), neem cake (1 t/ha), mustard intercrop (between potato rows), and carbofuran 3G (1 kg a.i./ha) resulted in an enhanced tuber yield while simultaneously decreasing the P.C.N population. Another approach involved a reduction in P.C.N population through soil solarization (4 weeks) followed by the application of neem cake (5 t/ha) along with *T. viride* (5 kg/ha).

18.8 Conclusion:

Sustainable production and healthy yields in potato crops depend on the efficient management of nematode infections. Nematicide impact can be considerably reduced by employing integrated strategies that include crop rotation, resistant types, soil health management, and targeted nematode application. For early identification and well-informed decision-making, routine soil testing and monitoring are necessary. Farmers may boost soil biodiversity, increase crop resilience, and eventually increase economic returns by using these measures. To remain ahead of emerging threats and optimize management techniques, it is imperative to engage in ongoing research and education.

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