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Chapter 16

Impact of climate change on plant nematodes and disease complexes

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Abstract

Food security and nutrition availability are globally threatened by climate change and require immediate actions to protect crops from emerging abiotic and biotic challenges. This is in association with other activities to reach the sustainable development goal of a world without hunger by 2030. As climate variability develops, plant – nematode interactions must be observed more closely to study the potentially new mechanisms involved in nematode parasitism, tolerance and resistance. Further, climate change may also influence intricate interactions between nematodes and other pathogens, and the development of disease complexes.

Critical actions in protecting the plants via developing more adaptable resistance cultivars, effective multifaceted nematode biocontrol agents, innovative agricultural practices, and sustainable farming strategies will be required under climate change. A holistic management approach, where a comprehensive assessment is employed to identify the new patterns of nematode distribution, pathogenicity and ecology in emerging climatic conditions, can help to ensure the best practices to overcome the challenges. This chapter highlights the future challenges for nematode control and the importance of nematode management under global climatic variabilities.

Introduction

The Unite Nation proposed The 2030 Agenda for Sustainable Development https://www.un.org/sustainabledevelopment/development-agenda/) for a global sustainable future based on 17 Development Goals (SDGs) https://www.un.org/sustainabledevelopment/). Of these Climate Action and Zero Hunger are most relevant to sustainability in food security.

According to the definition provided by the FAO, "To be sustainable, agriculture must meet the needs of present and future generations, while ensuring profitability, environmental health, and social and economic equity" (https://www.fao.org/sustainability). However, agricultural sustainability is jeopardised by climate variability (https://www.fao.org/documents/card/en/c/cb1928en), typically presented as rising temperature, rainfall changes, extreme weather, increasing and prolonged drought, elevated CO2 and changes to sea levels (Wheeler & von Braun, 2013). Climate change is also characterised by fluctuations in temperature, changes in precipitation patterns and the unpredictability of extreme weather conditions.

Sünnemann et al. (2023) showed that the factors associated with global warming will negatively affect soil functionality in both croplands and grasslands. This is in addition to the intensification of land use due to the global food demands, which threaten services provided by soil including carbon sequestration, microbial diversity and water storage (Kopittke et al., 2019). Changes in temperature and rainfall patterns can impact plant growth and crop production (Lesk et al., 2016). Changes in plant growth and productivity can influence the interaction between the pathogens and their host plants resulting in variability in disease severity and the development of new disease situations (Velásquez et al., 2018). This may lead to shifts in the selection of crop cultivars or species, leading to an increase in crop diseases and pests, including plant-parasitic nematodes (PPNs) and disease complexes. Climate changes can negatively affect the soil microbes and subsequently, microbial biodiversity, and their contribution to the delivery of ecosystem services, like nutrient cycling and water regulation (Bardgett & van der Putten, 2014; Kopittke et al., 2019; Trivedi et al., 2022). Changes in soil ecosystems may also lead to alteration in disease suppressiveness in soil (Banerjee & van der Heijden, 2023). Soil suppressiveness plays a role in the natural control of PPNs. Any potential changes in microbial communities of disease-suppressive soils could exponentially increase the pressures of pests and pathogens on plant health and growth especially in an ecosystem where it has been already exposed to global warming-associated factors such as higher temperature or prolonged dryness (Sikora et al., 2021).

Global warming (rising temperature), changes in rainfall, drought and humidity patterns may directly influence population dynamics, reproduction rate, virulence and invasion, abundance, and epidemiology of PPNs (Bristol et al., 2023; Colagiero & Ciancio, 2011; Khanal & Land, 2023). Higher temperatures under changing climatic conditions can increase the severity of plant disease (Cohen & Leach, 2020). For example, higher temperature can influence the development and reproduction rate of *Globodera* spp. (Jones et al., 2017b). Another study on two nematode species *Rotylenchulus reniformis* and *Meloidogyne floridensis* showed that higher temperatures in soil (<32 °C) significantly impacted the survival, reproduction, nematode virulence and disease severity of *M. floridensis*, while *R. reniformis* was not affected. (Khanal & Land, 2023).

Prolonged drought alters microbial abundance and distribution that could result in a shift of microbial communities including nematodes (Franco et al., 2019; Jansson & Hofmockel, 2020). In general, nematode communities are sensitive to environmental changes including temperature and soil moisture (Wilschut & Geisen, 2021). Long-term drought or increased frequency of dry years can lead to an increase in populations of PPNs for example due to decrease of the populations of nematode predators. This shift in predator-prey balance can subsequently reduce plant performance via higher levels of plant infection with PPNs (Stevnbak et al., 2012; Franco et al., 2019).

Climate change would also alter the insect communities and dispersion (Harvey et al., 2023). This may potentially reshape the incidence of insect-transmitted PPNs including one of the most devastating species, *Bursaphelenchus xylophilus* (Jones et al., 2013; Giblin-Davis et al., 2003). Potentially new nematode incidence could endanger forests worldwide when this group of PPNs are vectored to new habitats.

Our understanding of how soil ecosystems will respond to newly introduced nematodes under changed climatic factors is still growing. We are still not fully aware of how soil ecosystems in temperate regions will respond/react to the newly introduced PPNs and their interactions with other soil microbes, and how host plants will be challenged with nematodes in this altered ecosystem. Perhaps more experiments under new conditions will be needed to predict nematode behaviour.

In this chapter, we highlighted the future challenges for nematode control and the importance of nematode management under global climatic variabilities. An overview of the ongoing recommendations describing impact of climate change on PPNs is described in the flow diagram in Fig. 16. 1.

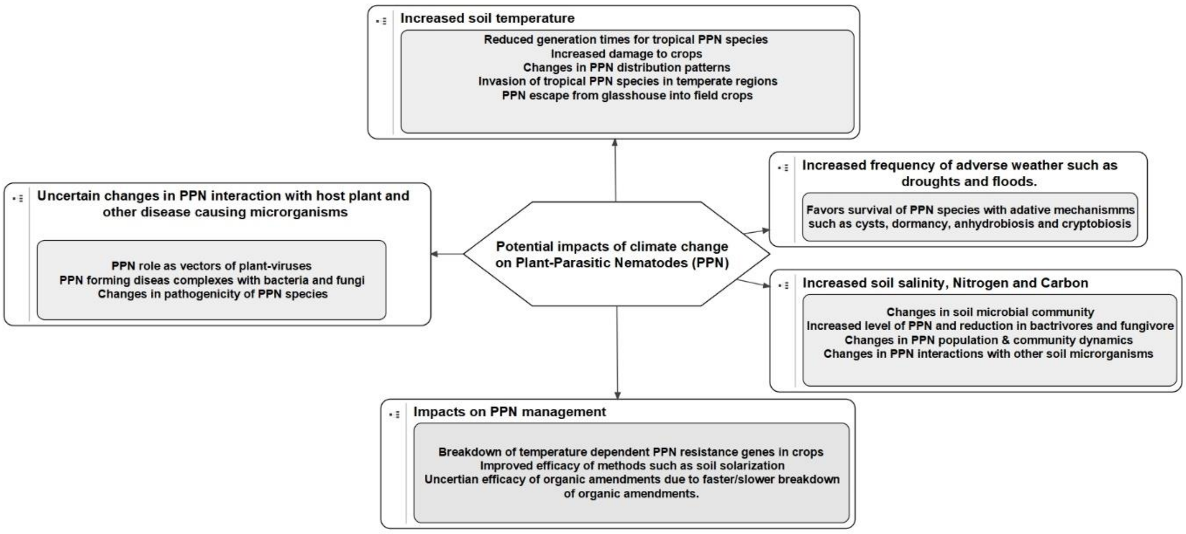

Figure 1. A diagram outlining the potential impacts of climate change on plant-parasitic nematodes …

Food production under climate change in the presence of nematode pests

Multiple studies have reported on the effect of climate-related factors on PPNs including increased temperature (Ghini et al., 2008; Jones et al., 2017a), CO_2 enrichment (Berliner et al., 2023; Sticht et al., 2009), and altered rainfall (Fleming et al., 2016). Climate-related responses in PPN communities are not fixed but vary depending on the three-way interactions between hosts, parasites, and the environment. More specifically, factors related to the host (e.g., population density and adaptability) and the PPNs (e.g., specificity and complexity of life cycle) are influenced by changes in the environment (Dutta & Phani, 2023). For example, a simulation study by Gendron St-Marseille et al. (2019) predicted that the increase in temperatures and the linked production of soybeans in Quebec (Canada) will by 2050 result in up to five generations of soybean cyst nematodes per growing season. Currently, soybean cyst nematodes complete between one and three generation cycles per growing season in Quebec (Gendron St-Marseille et al., 2019). Another example is the change in the distribution of the emerging PPN *Meloidogyne enterolobii* in subtropical and tropical regions. According to Pan et al. (2023), climate change will result in this nematode's range of ideal habitats expanding and moving towards higher latitudes in future climate scenarios.

It is projected that altered environmental conditions will intensify PPNs damage by promoting their abundance, spread, reproduction, and generation, along with enhanced plant growth and weakened plant defences (Dutta & Phani, 2023). But opposing effects such as sex reversal, entering cryptobiosis, and decreased survival may counterbalance this impact (Dutta & Phani, 2023). A meta-analysis on soil nematode responses to global change factors concluded that global warming had only minor effects on soil nematode communities (Zhou et al., 2022). The authors suggested that a possible explanation for this is that the positive effects of increased temperatures on plant growth were counteracted by the negative effects of increased temperatures on soil moisture. Nonetheless, under simulated and experimental conditions, increased pathogenic potential has been recorded for *Meloidogyne incognita* in coffee plantations (Ghini et al., 2008), increased abundance of *Globodera rostochiensis* in potatoes (Jones et al., 2017a), and increased juvenile and egg production of *Heterodera carotae* in carrots (Colagiero & Ciancio, 2012). Interestingly, the Zhou et al. (2022) analysis showed that elevated atmospheric CO_2 can significantly increase (22% on average) PPNs abundance in especially croplands and grasslands. This was attributed to higher CO_2 levels which typically decrease plant stomatal conductance, leading to reduced water absorption from the soil and more soil water. Secondly, increased CO_2 can boost aboveground plant growth resulting in more plant litter (Zhou et al., 2022).

There are also more indirect effects of climate change on PPNs pressure and prevalence. For example, nematode communities including beneficial nematodes play a major role in the ecological functioning of soils by influencing decomposition, nutrient cycling, and pest and disease regulation, among other functions (Creamer et al., 2022). Siebert et al. (2020) studied the effects of simulated climate change on nematode communities and functional groups, revealing clear ecological implications. For example, the interaction between future climate scenarios and intensive land use will likely result in increased nematode populations of opportunistic and PPN species at the cost of reduced diversity and structure within the nematode community (Siebert et al., 2020). This clearly poses a threat to the ability of soil ecosystems to contribute towards pest and disease regulation.

Emerging patterns of nematode pathogenicity and biology with changing climates

Climate change is an imminent threat to global food security due to its impacts on agriculture, forestry, fisheries and aquaculture (Bezner Kerr et al., 2022). It is anticipated that climate change will differently affect crops and associated pests and diseases in tropical, subtropical and temperate areas (Bezner Kerr et al., 2022; Skendžić et al., 2021). Except for central Asia, much of the remaining areas in the world are already or will experience negative impacts on the production of major food crops due to climate change (Bezner Kerr et al., 2022). A changing climate can also have a multitude of impacts on pests and diseases of crops (Bradford et al., 2019; Lamichhane et al., 2015; Nethi & Prasad, 2012; Skendžić et al., 2021; Sutherst et al., 2011).

Plant-parasitic nematodes are a major constraint to crop production worldwide and cause damages of over USD 157 billion per annum (Abad et al., 2008). They attack all major food crops including cereals, pulse, vegetables oil seed, fibers beverage crops, fruit crops, ornamentals, forests and inhabit a wide range of environments. Currently, PPNs have distinctive distribution patterns influenced by a wide range of factors such as temperature, soil type, crop species, cultivation practices and anthropogenic factors, etc. (Song et al., 2017). Out of the over 4100 described PPN species (Decraemer & Hunt, 2006), the majority have limited distributions and are known from mainly agricultural areas (Sikora et al., 2018; Zasada et al., 2019). Of these, a few hundred species are widely distributed affecting economically important crops worldwide in tropical, sub-tropical and temperate regions (Bebber et al., 2014; Singh et al., 2014).

Changes in the soil temperature (1 to 2.5˚C) and moisture regimes are likely to affect the distribution pattern of pests and diseases and the severity of damage on associated crops. Soil temperature, moisture, pH, and soil carbon are major factors that affect PPN lifecycle and can be used to determine their likely distribution and damage potential (Pan et al., 2023; Singh et al., 2022). In this section, we consider the known and likely impacts of climate change on PPN distribution, abundance and damage to crops.

Under controlled conditions, it has been demonstrated that several PPN species (e.g. *Meloidogyne floridensis*, *Rotylenchulus reniformis*, *Ditylenchus weischeri* and *D. dipsaci*) under warmer conditions have reduced generation times and as a result their population levels may increase quickly in the presence of a suitable host and warmer climatic conditions (Hajihassani et al., 2017; Khanal & Land, 2023; Leach et al., 2009). Using CLIMEX models (https://www.hearne.software/Software/CLIMEX-DYMEX/Editions), which use existing species distribution records and species phenology such as generation times, cold stress, heat stress, wet stress and dry stress, it is estimated that there will be range expansion and distribution shifts among several species of PPN (Singh et al., 2022; Yeates et al., 1998).

Certain nematode species, such as *Meloidogyne* spp., *Pratylenchus* spp., *Helicotylenchus* spp., and *Ditylenchus dipsaci*, have experienced a shift toward northern latitudes since 1960s (Bebber et al., 2013). *Meloidogyne enterolobii* is predicted to shift towards higher latitudes and large areas in Africa, South America, Asia and North America between 30˚S to 30˚N that could be suitable for its survival (Pan et al., 2023). Under a warmer climate, tropical PPN species pose a greater risk of establishment and damage in subtropical and temperate areas. Plant-parasitic nematode species such as *Meloidogyne* which are currently major pests under glasshouse conditions (Gamon & Lenne, 2012; Wesemael et al., 2011) could establish and spread in areas under natural cultivation in temperate regions under warmer conditions (Wesemael et al., 2011). In addition, changes in cultivation practices and the growing of novel crops in new geographical areas as a result of changing climatic conditions are likely to provide opportunities for the invasion of PPN species in new areas (Pan et al., 2023; Sheppard et al., 2011)..

Experimental studies on *M. enterolobii*, *M. floridensis* and *M. incognita* under increased soil temperatures showed that they were able to complete their lifecycle in shorter time frames at 30 °C (Velloso et al., 2022). In addition to the effect on lifecycle duration, temperature also influences the effectiveness of resistance genes in plants andunder increased temperatures expression of resistance genes is affected (Trudgill & Blok, 2001) thus rendering the plants susceptible to attack and damage. The above observations reveal that under changing climate conditions different nematode species may dominate and continue to cause damage to crops.

Plant-parasitic species are known for their ability to quickly adapt to changing soil conditions and have various survival mechanisms (anhydrobiosis, cryptobiosis, cyst formation, dormancy stages) which enable them to survive adverse conditions such as prolonged droughts, temperature extremes and flooded conditions (Perry & Moens, 2011). With these adaptive mechanisms, PPN have a good chance of survival under extreme weather conditions and increased soil salinity (Renčo et al., 2022; Wharton, 1995; Wharton, 2004) under climate change conditions (United Nations, https://www.un.org/en/climatechange/what-is-climate-change).

There are reports of increased damage from previously benign species of PPN in new areas. For instance, the foliar nematode *Litylenchus crenatae mccannii* has been reported to cause damage to Beech trees (Beech leaf disease) in the state of Ohio USA and has more recently spread to western and northern Pennsylvania, New York, and Ontario Canada (Carta et al., 2020; Ewing et al., 2019; Marra & LaMondia, 2020). In Japan this species is a pest of beech and causes galls, however, the disease is not as severe (Kanzaki et al., 2019). Whether the increase in pathogenicity of *Litylenchus crenatae mccannii* is due to genetic differences or climatic factors or other factors is not yet known. Similarly, *Bursaphelenchus xylophilus* which causes pine wilt disease is not as damaging in its native range in North America but causes major damage to pine trees in Asia (Mota & Vieira, 2008). *Bursaphelenchus xylophilus* continues to spread in Europe (Vicente et al., 2012) and greater parts of Asia and is predicted to further increase from its current geographical range under climate change conditions (H. Li et al., 2022; Z. Li et al., 2022; Ouyang et al., 2022). Therefore, it is plausible that nematode species distributions as well as their pathogenicity can change with changing climatic conditions.

Based on different stages in their lifecycle, PPNs exhibit different levels of adaptation to changing climatic conditions and availability of resources such as host plants, and competition with other species. For example, under resource constraints, it is known that *Meloidogyne* spp. are able to alter the sex ratio of their progeny, *i.e.* more males under resource constraint conditions vs more females when sufficient resources are available (Castagnone-Sereno et al., 2013; Triantaphyllou, 1973). While there is still uncertainty on how exactly PPN populations may behave under changing climatic conditions, existing studies (Perry & Moens, 2011; Wharton, 2004) indicate that PPNs have a variety of adaptation mechanisms which may enable them to cope or even survive better under future climate conditions.

Ecological solutions to nematode pest regulation

Novel and innovative technologies will likely play a major role in responding to climate-driven changes in PPN prevalence and pressure. However, promoting ecological intensification through enhancing natural processes is also recognised as fundamental to building resilience against the future effects of climate change in agricultural systems (Raj et al., 2021; Tittonell, 2014).

Disease and pest regulation is one of four major soil ecosystem functions, the other being carbon and climate regulation, water regulation and purification, and nutrient cycling (Creamer et al., 2022; Zwetsloot et al., 2021). According to Creamer et al. (2022) two main sub-functions influence disease and pest regulation. The first is disease suppression and pest control which involves more direct processes including antibiosis, competition, predation, parasitism, and microbial grazing. The second sub-function is plant health promotion where the ability of a crop to resist and build defences against pests and diseases is promoted (Creamer et al., 2022). Most scientists agree that greater ecological functioning coincides with promoting soil health (Bünemann et al., 2018; Creamer et al., 2022), which is also captured in the most widely used and accepted definition of soil health, namely “the continued capacity of a soil to **function as a vital living ecosystem** that sustains plants, animals and humans” (NRCS, 2023).

However, promoting soil health and ecological functioning is not straightforward with different proposed approaches and systems including agroecology (Wezel et al., 2020), conservation (Thierfelder et al., 2018) and regenerative agriculture (Lal, 2020), and organic farming (Tully

& McAskill, 2020). There is much debate about the real-world benefits of these systems. This is because often claims are made with little or no concrete scientific evidence. Another issue is that the success of any implemented agricultural system will be highly contextual and based on the local environment (Giller et al., 2021). Thus, rather than advocating for a particular system, our discussion will centre on highlighting selected practices that are scientifically validated to enhance soil health and ecosystem functioning with a specific focus on nematode pest regulation. We recognise, however, that the effectiveness of these practices is contingent upon the specific environmental conditions of each locality.

Considering the previously mentioned processes linked to disease suppression and pest control, some play an important role in nematode pest regulation. This includes **parasitism** of PPNs (e.g., nematophagous fungi), **predation** of PPNs, and ecological **competition** for resources.

Healthy and structured soil ecosystems are characterised by higher-level trophic organisms, e.g. carnivorous nematodes, mites, and tardigrades, capable of general suppression of PPNs (Timper, 2014). An experimental study by Timper et al. (2021) evidenced a 55% reduction in *Meloidogyne incognita* J2 by the native soil community, as well as a positive relationship between the relative abundance of omnivore and carnivore nematodes and J2 suppression. Unfortunately, carnivorous nematodes are often sensitive to perturbations including tillage and agrochemical use (Bongiorno et al., 2019; Timper, 2014). Therefore, reduced tillage and the judicious use of agrochemicals are highly recommended for promoting soil health and ecosystem functioning (Thierfelder et al., 2018). Crop diversification also shows the potential to promote food web structure and reduce PPNs prevalence and pressure. A meta-analysis by Puissant et al. (2021) revealed that cover cropping increased the abundance of omnivore and predator nematodes by 80%, while crop rotation reduced the abundance of PPNs by 47%.

Nematode management with novel approaches under climate change Nematodes have evolved from free-living marine species to sedentary endoparasites (Poinar, 2014) making them one of the most versatile living organisms on the earth. The PPNs having the capacity to co-evolve with the environment and to colonize almost all ecosystems, seem to keep adapting themselves to the changing environment so they can colonise their hosts and reproduce efficiently (Holterman et al., 2019; Sapir, 2021). Based on the current argument some of which were presented earlier in this chapter, nematodes most likely will have the ability to colonise the host plants in the warmer soil and given the higher susceptibility of crops due to heat stress, crop damage caused by nematode infection will likely be substantially higher than the current estimated amount.

Research aiming at nematode management in newly emerging climatic conditions should consider the effect of soil moisture and temperature as nematode biology and physiology are very dependent on these two factors. Therefore, fluctuation in any of the two factors may have a strong effect on nematode biological activity more specifically their reproductive potential which certainly leads to different outcomes of management strategies. Rashidifard et al. (2019) reported that increasing the average temperature in a greenhouse by 2 ˚C resulted in a substantially higher reproduction rate recorded for *M. enterolobii*, *M, incognita* and *M. javanica* populations. It is worth mentioning that nematodes require certain heat units to complete their life cycle which is commonly referred to as degree days (DD), increasing temperature means that nematodes reach the required DD quicker and have a shorter life cycle duration (Collett et al., 2024). Previous research have indicated resistance breakdown in tobacco and tomato cultivars carrying resistant genes against RKN at temperatures above 32 ˚C (Abdul-Baki et al., 1996; Pollok et al., 2023). Hence, given the high adaptability of nematodes to environmental changes (Khanal & Land, 2023), increasing global temperature could lead to higher abundance of certain nematode pests due to quicker population build-up in the soil. On the other hand, loss of resistance in host plants could lead to greater nematode damage to agriculture production. Some adverse conditions may also negatively impact nematode reproduction, survival abilities and pathogenicity. Therefore, while certain alterations could work in favour of nematodes, others may have conflicting outcomes, making it difficult to make a definitive conclusion and prediction about future trends. Under these fluctuating environmental factors, thesustainable control techniques must be related upon as the focus has shifted toward smart management tactics that promote soil health and have minimum negative impact on beneficial organisms besides reducing crop damage.

Integration nematode management (INM): This is an approach that employs a combination of various management practices such as botanical, biological, chemical, cultural and physical to contain the population density of PPNs under the economic threshold level (Dutta & Phani, 2023; Sikora et al., 2023). Within an integrated nematode management framework, nematologists have already highlighted the needs that could help moving forward toward nematode control strategies, which are more sustainable and have less negative impact and damage to the ecosystem (Desaeger et al., 2021; Sikora et al., 2021). It is crucial to select a combination of tactics based on available resources and environmental factors to meet the need of growers and their agricultural production systems. The use of cover crops especially those with nematode antagonistic potential (e.g. grain sorghum, millets, oil radish, Mulato grass, sorghum-sudangrass, ryegrass and daikon radish) could be a multipurpose tactic to reduce nematode infestation (Acharya et al., 2021 ; Asmus et al., 2008; Khanal & Harshman, 2022), enhance soil fertility, prevent soil erosion, improve nutrient and water availability, and more importantly to boost soil microbial diversity and activities (Sharma et al., 2018).

Alteration of environmental factors such as temperature might cause changes in the interaction between PPNs and their antagonistic microbes (bacteria and fungi) in the soil. An impairment in the attachment of *Pasteuria penetrans* endospores to the cuticle of second-stage juveniles of *M. arenaria* has been reported when the nematode is exposed to 35-40 ˚C or when the bacteria incubated at 50 ˚C (Freitas et al., 1997). In contrast, a higher abundance of *Pochonia chlamydosporia* propagules and consequently increased egg parasitism against *M. incognita* were reported as a result of elevated soil temperature (Luambano et al., 2015). Additionally, altered climate factors such as elevated temperature and reduced humidity will influence the abundance of nematodes and antagonistic microbes in the soil, and their exposure to their natural enemies which may result in a mismatch between them (Dutta & Phani, 2023). Despite the evidence from relevant research, it is challenging to have a solid conclusion concerning the future trend for any modification in soil suppressiveness or biocontrol potential of nematode-antagonistic agents in response to climate change as these microorganisms are part of naturally coevolving interactions with nematodes and their host plants (Rafaluk-Mohr et al., 2018).

Chemical: The efficacy and persistence of chemical nematicides in soil can be affected by fluctuating temperatures and irregular precipitation as a result of climate change which eventually impacts the PPNs management (Delcour et al., 2015). Higher demand for using chemical nematicides by growers is expected due to the high incident and breakout of PPNs under climate change. Only a few chemical nematicides such as fluensulfone, fluopyram, fluazaindolizine, tioxazafen, ethanedinitrile, spirotetramat with a restricted range of crops are still available on the market (Desaeger et al., 2020). Hence, generating knowledge with respect to the effects of climate change on these products seems to be crucial. Furthermore, despite their effectiveness in reducing PPNs pressure in a short time, their application may not be sustainable given the current global call to reduce the application of chemical pesticides. A comprehensive search for more sustainable synthetic chemicals (Gaberthüel et al., 2021) especially with a focus on natural nematicidal compounds (Li & Zhang, 2023) can potentially result in the discovery of environmentally friendly new bioactive compounds that could sustainably safeguard plant health.

Conclusion & Future Prospects

Food safety and global food security require sustainable agriculture to meet the needs of present and future generations (https://www.fao.org/sustainability). At present, it remains difficult to predict the alteration of population dynamics of PPNs and its impact on global food security under new climate variability, but a picture is emerging that a shift in nematode distribution patterns happens, where it might affect different cropping systems, especially in temperate regions.

Altered climatic conditions will impact the abundance and diversity of nematode pests and jeopardize the efficacy of current control measures. This situation requires extra effort to establish a sophisticated pest monitoring system using novel tools or improved existing methods which ultimately results in having the adapted INM in place for the changed condition (Sikora et al., 2021). Development of prediction models, adaptation of cropping system according to the ongoing climatic changes, improvement of tools and techniques used in precision agriculture, supporting suppressive soils by paying more attention to the role of microbial communities in self-regulation of agroecosystems, use of new molecular approaches and genome editing techniques to accelerate breeding processes for development of new resistant varieties and nematode control. Discovery of new nematode antagonistic beneficial microbes, development and commercialization of biocontrol agents and improvement of application techniques to ensure sufficient effectiveness, and development of nature-based nematicidal compounds or safer and more selective chemical nematicides will adopt more comprehensive integrated nematode management to new climatic changes. Biosecurity measures preventing the human-mediated introduction of invasive PPN species into new geographical areas and regions could also be beneficial in avoiding crop losses.

Climate change is a socio-scientific issue. Therefore, public awareness and farmer training on the impact of new climatic conditions on the emergence of new nematode diseases in a post-chemical era would empower us to face and manage the challenges of climate change using more innovative approaches and to build a more sustainable world.

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