**NE2140**

***Title:*** Sustainable Management of Nematodes in Plant and Soil Health Systems

***The need.***  Plant-parasitic nematodes cause significant crop losses, damage and loss of quality on almost all agronomic and horticultural crops. Agronomic and horticultural cropping systems and their respective nematode pathogens are very diverse in the northeastern United States and relate to specific problems in other US states. The nematodes of concern include root-knot, root lesion and dagger nematodes as well as foliar, stem and bulb, cyst nematodes, and multiple nematode genera that attack turf. In the absence of traditional chemical nematicides, management of these nematodes in diverse cropping systems is challenging, especially when the goal is to concomitantly increase nematode community structure, which is considered an indicator of soil health. Climate change places additional stress on production in agricultural systems of the Northeast because higher regional temperatures and more erratic moisture patterns have exacerbated nematode damage. Traditionally minor nematode problems are exerting major negative influences on crop productivity as growing seasons lengthen and plants experience more growing degree-days. A regional comprehensive assessment of the impact of nematode control recommendations on nematode community structure and soil health for specific agronomic and horticultural production systems is urgently needed. This proposed new, five-year multistate project will build on progress made in developing ecologically based nematode control practices that are compatible with soil and plant health management in the current multistate project.

***Importance of work and consequences if not done.*** United States consumers demand high quality, readily available and inexpensive agricultural and horticultural products. For this to be achieved by Northeastern producers it is imperative that damaging nematodes are managed sustainably and soil health is maintained, increased or restored. High population densities of plant-parasitic nematodes result in low yields of poor-quality produce, making farming unprofitable. In general, high numbers of plant-parasitic nematodes are a key component of poor-quality soil. It is important to reduce negative impacts of plant-parasitic nematodes while fostering bacterial-feeding, fungal-feeding, omnivores and predatory nematodes, which are key components of soil food webs and are essential for optimal plant nutrition and biological control. Northeastern farmers are very interested in managing plant-parasitic nematodes in a sustainable manner while fostering soil health. For this, they seek significantly improved tools for nematode and soil management. In addition, new invasive nematodes such as that causing beech leaf disease are spreading through the Northeast, presenting a major threat to forest and ornamental trees. Similarly, endemic species from the southern states (such as FL, CA, HI) may potentially spread to other areas of the US. Without the research and education programs associated with this proposed project, the economic viability and soil health of the farms and forests of the Northeast region will be at risk of degradation to unacceptable levels.

***Technical feasibility of work.*** The significant progress made by researchers contributing to the ongoing Multistate Research Project over the last few years is a strong indication that many plant-parasitic nematodes can be managed in a reliable manner with cultural controls based on host resistance, nematode-antagonistic cover crops for rotations, soil amendments, biological control agents, and low-risk pesticides. Research on management systems will include investigations of their ecological impacts. In the spirit of truly integrated systems, commercial nematicides are integrated into cultural and biological systems to evaluate their impacts on nematodes and nematode community structure and soil health. Members of the current project are currently working closely with sustainable plant and soil health management teams.

***Advantages of a multistate effort****.* Agriculture in the Northeast is extremely diverse and individual farms often grow multiple crops, increasing complexity of management decisions. The diverse nematode pathogens in these systems exacerbate management challenges. Grower education can also be complicated. Despite the great diversity of nematodes and cropping systems, there are relatively few nematologists in the Northeast and agricultural programs are smaller than those at Mid-western and Southern research institutions. Individual scientists are challenged to develop expertise on the biology, management and ecological aspects of all of the nematodes on all of the crops grown in their state. The project leverages on a strong network of nematologists from multiple states which allows for mutual learning and support on specific nematode problems. Scientists in this project that work on nematodes in similar systems outside the region contribute to the group’s knowledge. For example, important crops studied in the project include small fruits and tree fruits, diverse vegetables, row crops, turf, nursery and landscape ornamentals and even forest trees. Sharing knowledge and experience from areas that have larger focus on crops that are only minor in another state can lead to coordinated educational opportunities. Such synergism is very important for both research and outreach efforts. The current multistate project sponsored a nematology short course for agri-business that addressed the role of nematodes in crop losses and nematode management with rotation and cover crops as well as breeding crops for resistance to nematodes; conducted nematology short courses for turfgrass in Michigan and Rhode Island, presented a short course on agronomic crop nematodes for crop consultants in New York, and routine nematode management lectures for new farmers training program, [GoFarm Hawaii](https://gofarmhawaii.org/) (https://gofarmhawaii.org/), as well as a cover crop short course for farmers through an online Tovuti platform in Hawaii. These short-courses were received extremely well by growers who favor this type of outreach and value direct contact. Future efforts will benefit from the interaction among scientists which is invaluable for developing efficient and collaborative research projects with scientists across states and institutions.

The NE regional nematology project has provided nematology leadership since its inception in 1954 and continues to provide a strong multistate foundation for nematologists from academia and USDA to work together on common research and education initiatives of significance to the overall well-being of the region. Private sector enterprises and government agencies do not have the nematology resources and institutional structures necessary to fulfill this critical need in a satisfactory manner.

**Related Current and Previous Work**

A CRIS Review found 23 current projects that mention “nematodes”. Of these, only three appear to have a portion of their subject matter similar to the proposed NE-2140 project. However, these other projects differ from the work proposed here as they generally do not address the same nematodes or assess the diversity of cropping systems considered in our project. The limited overlap with the nematode pests and cropping systems between these projects and our proposal highlights the research gaps and grower needs that are not adequately addressed in the absence of our proposal.

**NC1197**. Management of nematodes on corn, soybeans and other crops of regional importance. This project shares a focus on management, as well as soil health, but their primary focus is on pathogen interactions. The description of the soil health focus is on pathogen interactions and fertilizer use efficiency. Haddish Melakeberhan overlaps on both projects.

**W4147** Managing plant microbe interactions in soil to promote sustainable agriculture. The focus of this project is on biopesticides and the “phytobiome”. Their efforts include identification, and characterization of biocontrol agents, and the role of cultural practices and organic amendments. The primary effort is to determine the function of biocontrol agents, and to develop IPM-based management practices compatible with soil health management. Their efforts include research on *Dactylella oviparasitica* on sugar beet cyst nematode, and biocontrols for non-nematode pathogens such as potato scab (*Streptomyces scabies*) and *Rhizoctonia* in wheat. The project also includes assessment of brassica seed meals for mitigation of the apple replant problem and nematodes on vegetables.

**NC140** Improving tree fruit rootstocks. This project includes as a minor component breeding peach rootstocks for resistance to root knot and Peach Tree Short Life syndrome.

Two other projects identified in the CRIS search appear to be relevant, but on closer review, do not overlap with our proposal.

**W4186.** Variability, Adaptation and Management of Nematodes Impacting Crop Production and Trade. This project focuses on understanding nematode genetic variability and adaptation in warm and temperate cropping systems. Root knot and cyst-forming nematodes are the primary focus. Haddish Melakeberhan overlaps this project.

**NE 1602** Turfgrass phytobiome. This project mentions nematodes as pests of turfgrasses but does not appear to have active work in nematology or nematode management.

**Related Research**

Diverse nematode parasites of crop plants occur in the Northeast region and contribute to crop losses in a wide range of production systems. Major plant parasites include root-knot *Meloidogyne* spp.), lesion (*Pratylenchus* spp.) and dagger (*Xiphinema* spp.) nematodes. These have a broad host range and affect many horticultural and agronomic crops. Cyst nematodes are more host-specific, but species pathogenic on soybean, potato sugar beet and tobacco cause yield losses throughout the region. Specialty crops, including turf grasses, garlic, and various ornamentals, are threatened by their own unique nematode pathogens.

For many years, soil fumigants and broad-spectrum nematicides were the tools of choice for many growers but the loss of these multi-purpose chemicals has re-focused attention on strategies such as host resistance, nematode-antagonistic cover crops, soil amendments, and biological control agents (Hirunsalee et al., 1995; McSorley and Dickson, 1995; McSorley and Gallaher, 1992; Rodriguez-Kabana and Kloepper, 1998; Weaver et al., 1995). Cropping systems using these approaches are more knowledge-intensive and often require crop- or soil-specific approaches that integrate management practices with promoting soil microbial communities that suppress pathogens. In these systems, free-living nematodes have been used as indicators to characterize soil disturbance or soil quality (Bongers, 1990; Ferris et al., 2001; Neher, 1999, Ugarte et al., 2013). Increasing microbial activity in soil tends to favor biological control agents that suppress pathogenic nematodes but harnessing this beneficial biology will require a deeper understanding of the ecological interactions involved. This will allow management practices to give a competitive advantage to beneficials over the pathogens (Philippot et al., 2013).

Host plant resistance appeals as an ideal management practice where available. Resistance genes limit reproduction of the target nematode pathogen. The root-knot nematode-resistant pepper Carolina Cayenne was effective as a rotation crop for managing M. incognita in susceptible bell peppers (Thies et al., 1998). In one study of the economic benefits, the $1 million cost of developing a soybean cultivar resistant to cyst nematodes was far surpassed by $400 million in benefit (Bradley and Duffy, 1982).  In cyst nematodes, resistant hosts can serve as trap crops, stimulating egg hatch and invasion while preventing maturation and reproduction (Dandurand et al. 2019; Halford et al., 2008).

Biological control agents are widespread in soils and a number have been commercialized. Spore-forming bacteria (*Bacillus*, *Pasteuria*, etc.) have benefits of longer shelf-life and ease of application (Kerry, 1998; Meyer et al., 2001; Wilson and Jackson, 2013). Indigenous agents include predatory nematodes (e.g., *Mononchus* spp.), fungi (*Arthrobotrys*, *Dactyllela*) and soil invertebrates (mites, earthworms) all impact nematode populations, but management techniques that encourage these native organisms are not well known.

Soil health has been defined as **“the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans”** (Natural Resources Conservation Service – USDA-NRCS, 20122; Soil Renaissance, 2014). The Cornell Comprehensive Assessment of Soil Health (Moebius-Clune et al., 2017) enumerates the characteristics of healthy soils and measures to evaluate physical, chemical and biological characteristics. Soil health is an increasingly important concept for managing agricultural systems; however, biological indicators are underrepresented in routine measurements, (Moebius-Clune et al., 2017). While chemical and physical parameters are useful, these measures do not evaluate nematode suppressiveness of soils, or the activity of specific nematode biocontrol agents. Chemical and microbial biomass indicators explain only 23 % of the variation in nematode community composition (Neher and Campbell 1994). Our long-term goals include both practical management strategies for growers, as well as the deeper understanding of nematode ecology essential to managing soil health in a sustainable manner.

**Critical review**

1. **Work Accomplished under the original Project**

Members of the current project (NE-1640) have identified nematode-antagonistic rotation and cover crops including rapeseed (*Brassica napus*), marigold (*Tagetes* spp.), forage and grain pearl millet (*Pennisetum typhoides*), *Rudbeckia hirta*, sudangrass (*Sorghum bicolor*) and sorghum-sudangrass. However, no single plant species was effective against all plant-parasitic nematodes in the Northeast. Some species were more practical than others as rotation or cover crops due to agronomic traits, ability to compete with weeds (which are often hosts of the target nematodes) and ability to fit into cropping systems. We continue to investigate potential new plants with nematicidal or nematode-antagonistic properties. For example, preliminary results from microplot experiments in CT indicate that the legumes partridge pea and purple clover reduced lesion nematode populations in microplot experiments.

1. **Degree to which objectives were accomplished**

The current NE-1640 project has three objectives:

1. Develop and integrate management tactics for control of plant-parasitic nematodes including biological, cultural (such as rotation or cover crops and plant resistance), and chemical controls.
2. Determine the ecological interactions between nematode populations, nematode communities, ecosystems and soil health.
3. Outreach and communication - Compile and present/ publish guidance on nematode management and management effects on soil health for different crops under different conditions.

Significant progress has been made on all three. Non-host or antagonistic rotation crops, composts and other soil amendments, and anaerobic soil disinfestation were evaluated for suppression of multiple plant-parasitic nematodes and other soil-borne pathogens. For example, suppressive rotation crops have reduced severity of strawberry black root rot without the need for nematicides or soil fumigation. Microbial biocontrol agents including *Pasteuria penetrans* were associated with suppressive soils. Free-living nematodes were assessed as indicators of soil health in several long-term crop rotations trials, with significant findings on the impact of environmental stresses on the soil food web. The efficacy of multiple new nematicidal products was evaluated, with the findings that different nematodes varied in their response and their potential impact on soil health. Multiple grower education seminars and workshops were conducted in participating states.

1. **Work that is incomplete or areas that need further investigation**

The incredible biodiversity of soil microflora, discovery and introduction of new potential nematode pests, and the interaction with evolving agricultural markets and a changing environment make nematode management complicated. Key findings indicate that many of the crop-pest-soil community interactions behave in unique patterns meaning a “one-size-fits-all” approach to nematode management will not suffice.

Certain outreach activities scheduled for 2020 and 2021 under NE-1640 fell victim to restriction from the COVID-19 pandemic. These include a Tree Fruit and Small Fruit nematology workshop and similar activities related to nematode biocontrol and management.

As one example of on-going research, the garlic industry in New York consists of over 400 growers producing a crop worth $27 M - $43 M annually from approximately 300 acres. Bloat nematode (*Ditylenchus dipsaci*), was introduced on seed into garlic farms throughout New York in 2010, and estimated to cause on-farm losses of up to 80% and financial loss of $1.2 M in 2010 alone. Previous projects (e.g. SCBG & SARE ONE11-149) identified the extent of the bloat nematode problem in New York garlic and provided subsidized testing and an education campaign through Cornell Co-operative Extension. However, testing for bloat nematode often fails to detect low populations in seed. Low numbers of nematodes in seed may not present visible symptoms, but following planting, populations can quickly build to cause economic loss. Therefore, bloat nematode remains a problem, e.g. 25% of samples tested by PI Hay (Cornell University) tested positive in 2016. SARE project LNE11-306 attempted to provide high-quality seed from tissue cultured plants for growers in Maine, but was unable to produce suitable material.

Management of nematodes in perennial crops such as turf grasses and perennial fruits likewise remains challenging. For example, new nematicides for fruit orchards have generally not been evaluated for the nematode pests (e.g., *Xiphinema* spp.) in the Northeast. Turfgrass systems actually represent a wide range of grass species in extremely diverse soils and environments, with numerous nematode pests present. The development of management practices to promote suppressive soils will require a deeper understanding of the responses of soil microbial communities to practical management approaches.

A further need for new investigations comes from the discovery of new or introduced species. The beech leaf disease associated with *Litylenchus crenatae* is one striking example that threatens this important forest tree. Newly discovered or newly described nematode pests on turf grasses represent another case of an emerging pest problem. Emergence of foliar nematodes (*Aphelenchoides* spp.) in ornamental production is yet another example of nematode pests with potential to cause enormous economic losses. New crops such as hemp also present unique challenges for growers and nematologists, as few pesticides of any kind are available for pest management, and few research studies have been published.

**Objectives**

1. Develop and integrate management tactics for control of plant-parasitic nematodes including biological, cultural (such as rotation or cover crops and plant resistance), and chemical controls.
2. Determine the ecological interactions between nematode populations, nematode communities, ecosystems and soil health.
3. Detect, and evaluate the distribution and movement of invasive and emerging nematode pests.
4. Outreach, Public Relations and Extension - Compile and present/ publish guidance on nematode management and management effects on soil health for different crops under different conditions.

**Methods**

**Objective 1: Develop and integrate management tactics for control of plant-parasitic nematodes including biological, cultural and chemical controls**.

This objective combines plant genetics with mitigating strategies. Investigations of plant-parasitic nematode management on numerous crops will use techniques such as chemical treatment, bionematicides, cultural techniques, cover cropping, green manures and other practices.

Chemical controls are not always a sustainable approach to long-term nematode control but they often reduce nematode damage and produce economically viable cropping systems. As fumigants and other broad-spectrum materials become less attractive or available, new nematicides have been developed that have reduced mammalian toxicity, less impact on bees and fish, and less environmental risk. Project participants will experiment with these materials and explore additional crops and methods of using them (Baidoo et al.; 2017; Crow et al., 2017; Myers et al., 2020). Researchers (CA, CT, HI, FL, RI, etc.) will examine the efficacy of fluopyram on nematodes such as *Hoplolaimus, Helicotylenchus,* multiple *Meloidogyne* spp. and others. Some chemical nematicides have been effective against *P. vulnus* and *Meloidogyne* spp. in preplant treatment strategies in tree fruit crops but will need to be optimized for this new type of use in various crops. Dagger nematodes are a major issue in peach orchards and researchers from WV will assess new materials registered in these perennial systems and will evaluate integration of nematicides with cover crops to manage Peach Stem Pitting disease.

Biological nematicides also play a role in nematode management. Techniques such as papaya seed biofumigation and chitinolytic compounds as a soil amendment against root-knot nematodes will be investigated in HI (Waisen et al., 2020). Researchers from multiple states will screen new bionematicides, nematode resistance-inducing materials, and reduced-risk nematicides against nematodes that damage turfgrasses and ornamental plants, and aid in the development of practical application methods (CT, MA, FL, RI).

Appropriate cover crops can significantly reduce nematode populations, while improving soil quality and dramatically reducing soil erosion. Researchers will evaluate mixtures of rotation crops against multiple genera of plant parasitic nematodes which often occur in the same field. *Aster* and *Rudbeckia* are resistant to *M. hapla* (LaMondia, 1997), and *Rudbeckia* and marigold reduced lesion nematode densities and potato early dying. However, these crops are difficult to establish, and *Rudbeckia* was a good host for dagger nematodes. Combining *Aster* and *Rudbeckia* with legumes such as partridge pea or purple clover or grasses such as sudangrass or millet (effective against *P*. *penetrans* and *M. hapla*) may increase establishment and efficacy against a wider range of nematodes. Incorporating these plants as green manures also may impact their nematode-antagonistic effects (Halbrendt, 1996; LaMondia and Halbrendt, 2003). The solanaceous weed *Solanum sisymbriifolium* is an effective trap crop against potato cyst nematodes (Dandurand et al., 2019). *S. sisymbriifolium* is a non-host of *Pratylenchus goodeyi* and has nematicidal properties when incorporated into soil (Pestana et al., 2014). The effects of this plant on *P. penetrans* and the northern root-knot nematode *Meloidogyne hapla* as a rotation/green manure antagonistic crop will be investigated in CT. Researchers in CA have observed that cereal rye was beneficial in almond orchards but further studies exploring its implementation compared to other nematode antagonistic plants are needed.

Bloat nematode (*Ditylenchus dipsaci*) has emerged as a devastating disease of the garlic industry and researchers will evaluate seed treatments combining chemical methods with physical practices such as heat and nematicides (NY).

Germplasm screening will be a major activity of the proposed project. Participants will screen crops for nematode resistance including examining: warm-season turfgrass germplasm for resistance and tolerance to sting, root-knot and lance nematodes (FL), evaluation of hemp varieties for resistance to *M. hapla,* *M. incognita, Pratylenchus spp.,* and *Rotylenchulus reniformis* (OH, TN, WV), and the evaluation of Boxwood cultivars (*Buxus* spp.) for susceptibility to *M. incognita*, a growing problem in commercial boxwood operations (OH, TN).

Of all the commodities project participants will investigate, soybeans are clearly the most economically important and widely planted, suffering significant losses to soybean cyst nematodes (SCN). Researchers from MI and IL will develop and evaluate a new cover crop system for management of SCN based on soybean lines derived from PI-437654. This source of resistance has not been widely used in commercial production cultivars yet, and it is not commercially available therefore resistance should not be a problem in the short term. This would be used as a cover crop to reduce SCN numbers in the field. In current trials, this trap crop soybean is planted in mid summer after wheat harvest and we are evaluating the effect on this on SCN hatch and population reduction Cultural practices are being evaluated, along with selection and development of SCN-resistant soybean cultivars using sources of resistance other than PI 88788 (MI, MS, IL, RI) in addition to evualating the effect of rotating with different sources of resistance. Goals are to integrate SCN resistance with hardiness traits and acceptable yield.

**Objective 2: Determine the ecological interactions between nematode populations, nematode communities, ecosystems and soil health.**

Participants will engage in a holistic ecological analysis of nematode communities and their interactions with other soil organisms. The goal is to assess changes in plant parasitic nematode populations resulting from environmental stimuli and agroecological practices, better predict development of suppressive soils as a component of soil health.

The use of cover crops produces numerous effects on the soil community. Nematode suppressive cover crops also impact soil fertility, non-target organisms, and interactions with weed and arthropod pests. Effects of cover crops on the nematode community will be assessed in field experiments (HI, IL, MI, WV, USDA-TN). Soil quality aspects will also be assessed in some of these trials (HI, IL, MI). Chemical, physical, and biological soil quality indicators will be measured. Examples of the chemical parameters to be measured are electrical conductivity, pH, nitrates. Some examples of physical indicators of soil quality to be measured are soil slaking, bulk density, aggregate stability, and infiltration. Finally, examples of biological indicators to be measured are nematode community structure, particulate organic matter, and soil respiration.

Soil amendments such as manure or compost increase soil microbial activity, resulting in a cascade of population changes through the soil food web that may suppress plant-parasitic nematodes. Soil food web responses to these amendments will be assessed in studies with organic grains (IL, MI, WV); and with vegetables (HI, VT). Nematode community analyses will be employed as indicators of soil health.

Nematode communities will be characterized in commercial hemp fields (TN) and in turfgrasses where effects of nematicides on non-target nematodes will be examined (FL). Impacts of Anaerobic Soil Disinfestation on nematode communities will be evaluated in organic farms and orchards (VT). Interactions with other pathogens, for example, *Xylaria* in soybean (TN) and soilborne fungi in vegetables (VT), will also be evaluated.

A combination of the soil food web model (Ferris *et al*., 2001), and the fertilizer use efficiency model (Melakeberhan and Avandano, 2008), will be applied to identify sustainable outcomes. We hope to identify parameters of soil conditions related to location-specific and/or broad approaches to nematode communities and soil health objectives (Melakeberhan *et al*., 2018).

A number of these long-term studies (HI, IL, MI, VT, WV) will be carried out in organic farming systems, either on commercial farms or at experiment farms. Organic farming systems provide ideal locations to assess impacts of farming practices on nematode communities as organic growers avoid use of disruptive pesticides and focus on developing the soil community as an intrinsic component of their pest management approaches. Understanding the effects of farming practices (*i.e.* tillage, cover crops, pesticide use), on nematode predators and biocontrol agents, and the extent to which they contribute to nematode-suppressive soils, are key components of these ecological studies. Nematode suppressive soils are soils where nematodes do not increase to damaging levels because of biological, physical, or chemical soil characteristics. We will attempt to asses the effect of farming practices on nematode suppression. As an example mulching or no-tillage can have an effect of increasing soil moisture and increasing fungi that might be pathogenic to nematodes. Certain cover crops can also suppress nematodes by being poor or non-host among several other benefits.

**Objective 3: Detection, diagnosis and management of new and emerging nematode pests and pathogens**

Many efforts of previous projects of these states (e.g., NE1640) focused on plant-parasitic nematodes that have been major problems for decades, and rightly so. However, global climate change, human activity, over-reliance on individual sources of resistance, and loss of certain chemical treatments have contributed to the rise of new nematode challenges. Because these emerging nematode pests are not well characterized, a brief summary of the state of the art and justification of the need for this new effort is included below.

**Emerging Nematode Issues:**

Beech leaf disease was recently shown to be caused by a new nematode species, *Litylenchus crenatae* (Carta et al., 2020). Beech leaf disease was first reported in Ohio in 2012, but has since been confirmed in CT, PA, NY, and Ontario, Canada. The disease causes defoliation and death of beech trees and is a great threat to the forestry industry and the natural environment in the northern US. The dispersal mechanism of this nematode is unknown.

Foliar nematodes, *Aphelenchoides* spp. are problems in ornamental plant nurseries and landscapes, and certain agricultural crops such as rice and strawberry. Losses from these nematodes are increasing after the phase-out of insecticides that gave incidental control of foliar nematodes. A newly described species, *A. pseudobesseyi* (Subbotin et al., 2020), has become an emerging challenge to soybean production in Brazil (Meyer et al., 2017). While it has not yet been reported from soybean in the US, this species is capable of infecting ornamental plants in nurseries and landscapes in Florida and could become a problem in soybean as well. Another species, *A. besseyi,* is an emerging problem on strawberry originating from transplants from infested nurseries (Desaeger and Noling, 2017). Effective treatments are lacking, and problems caused by foliar nematodes are expected to increase.

Global climate change impacts nematode problems on golf course turfgrasses in multiple ways, including increased turf stress, more severe damage, allowing additional generations and increasing nematode numbers. Golf courses in the northern US primarily use cool-season grass species such as bluegrass, bentgrass and fescue, while southern US golf courses depend on warm-season grasses such as bermudagrass and zoysia. The range for warm-season grasses is expanding with climate warming (Hatfield, 2017). Warm-season grasses are often more susceptible to damage from plant-parasitic nematodes such as sting or root-knot nematodes than cool-season grasses. Cool-season grasses are mostly seeded, while warm-season grasses are generally propagated vegetatively by sod or sprigs (grass stems or runners without soil). Sod and sprigs are likely to spread nematodes. As warm-season grasses are adopted farther north, golf course superintendents are faced with new nematode problems they are ill-equipped to deal with.

Soybean cyst nematode (SCN) *Heterodera glycines* is well known as the primary soilborne pathogen of soybean, and management relies heavily on use of SCN-resistant soybean cultivars. However, most SCN-resistant soybeans derive their resistance from a single source of resistance, PI88788. This has led to the emergence of populations of SCN (referred to as HG types) (Tylka, 2016) that overcome this resistance. Global warming leads to additional generations of SCN each year, accelerating the development of resistance-breaking HG types (St. Marseille et al., 2019). In some areas, HG types of SCN that reproduce readily on cultivars using resistance derived from PI 88788 are rapidly increasing (McCarville et al., 2017). Soybean cultivars with resistance from other sources are needed, or SCN will increase as a major limitation, and management will become increasingly reliant on chemical nematicides.

The tropical root-knot nematode species *Meloidogyne enterolobii* and *M. floridensis* are of particular importance because the resistance genes being used for management of other root-knot nematode species in vegetables are ineffective against these two species (Castagnone-Sereno, 2012). *Meloidogyne enterolobii* has been found in Florida, Louisiana (Hare, 2019), South Carolina (Rutter et al., 2019) and North Carolina (Schwartz et al., 2020), and *M. floridensis* has recently been detected in California (Westphal et al., 2019), and more recently in GA and SC.

**Planned Monitoring, Outreach and Training Activities:**

Several members of NE 2140 are involved in plant diagnostics, extension education, and some are affiliated with the National Plant Diagnostics Network (NPDN). These individuals are likely first detectors of invasive and emerging nematode pests and/or trainers of first detectors of invasive and emerging nematode pests.

Plant diagnosticians at several state, university, and private plant diagnostic and regulatory laboratories have expressed a need for training in speciation of root-knot nematodes, particularly *M. enterolobii* and *M. floridensis*. Most diagnosticians have had basic training in identification of nematodes to the genus, but not the species level. The University of Florida Nematode Assay Lab (NAL) regularly speciates root-knot nematodes using molecular and classical morphological methods. The NAL maintain stock cultures of the root-knot nematodes common in the southern US: *M. incognita*, *M. javanica*, *M. arenaria*, *M. enterolobii*, *M. floridensis*, *M. graminis*, and *M. marylandi* and teach speciation of these nematodes as part of graduate courses. In 2022 the NAL will offer a hands-on, 2.5-day root-knot nematode identification short course, where attendees will speciate several species using classical morphological techniques and mitochondrial haplotyping.

University of Hawaii Nematology Lab and Sustainable Pest Management Lab will also survey for detection of *M. enterolobii* and *M. floridensis* on coffee, guava, and sweet potato using molecular identification tools. As a transit point between Asia and the US mainland, and as a tropical/subtropical environment growing many hosts of *M. enterolobii* and *M. floridensis*, the chance for introduction and establishment of these nematodes in Hawaii is great.

For Tennessee, solanaceous crops (primarily tomato) grown along the NC and GA borders will be surveyed for presence of *M. enterolobii*. County agents will be solicited for reports of root-knot infestations, and especially for reports of resistant cultivar failures.

Foliar nematodes in plant nurseries are an increasingly important threat, and the discovery that these nematodes can cause significant damage to agronomic crops has increased the need for monitoring and diagnosis. Unfortunately, very few plant diagnosticians, and even nematologists, are trained in the speciation of foliar nematodes. In 2023, the NAL will conduct a hands-on 2.5-day workshop on diagnosis and speciation of *Aphelenchoides* spp. using morphological techniques and molecular sequencing. An in-service training will be conducted in MI to educate extension personnel and other stakeholders of the threat from foliar nematode to soybean.

NE-2140 members in coordination with SCN Work Group will monitor SCN HG types in multiple states for changing risks. As cultivars with new sources of resistance become available, we will educate extension personnel and growers on how to incorporate them into rotations.

Half-day training events will focus on diagnosis and management of nematodes on warm-season turfgrasses, with an emphasis on training golf course superintendents on how to diagnose and manage nematode problems. These training events will be held in conjunction with the Carolina’s Golf Course Superintendent meeting in 2021, at the Golf Course Superintendents Association of America educational conference in in Orlando, FL in 2022, and in Tennessee in conjunction with the Tennessee Turfgrass Conference in 2023.

**Management of new and emerging nematode pests:**

For many invasive and emerging nematode pests, management strategies have not yet been developed, and, in some cases, basic knowledge is lacking. Effective nematicides and knowledge on how to best use nematicides are similarly lacking. Nematode management tactics used for root-parasitic nematodes in agriculture are often not suited for use on nematodes parasitizing aboveground plant parts, or on non-agronomic crops such as trees, ornamental plant nurseries, or turfgrasses. Members of NE-2140 will conduct research on the biology, behavior, ecology and means of dispersal of emerging nematode pests to gain the knowledge needed to develop effective IPM strategies. They will also work closely with stakeholders and agencies to secure labels for existing and new nematicides for emerging nematode problems.

NE-2140 members in Florida will undertake research on the newly described *Aphelenchoides pseudobesseyi*, including its feeding behavior, host range, and risks to US agriculture. They also will evaluate existing pesticides such as fluopyram, spirotetremat, and chlorfenapyr, and work with agriculture chemical companies to evaluate new chemistries, for management of *A. pseudobesseyi* on ornamental nursery plants.

**Objective 4: Outreach Public Relations and Extension - Compile and present/ publish guidance on nematode management and management effects on soil health for different crops under different conditions**.

The NE-2140 multimedia process is based on the experiences of the highly successful and national public relations-award winning Soybean Cyst Nematode Coalition and the publication by Markel et al. (2020). New findings and general information will be made available to the agricultural community and other citizens through a dynamic multimedia media approach. The focal point of the system will be a NE-2140 website maintained by the Extension-Outreach-Public Relations Coordinator (Marisol Quintanilla, assisted by George Bird). Each member of the Technical Committee will be contacted monthly for current information appropriate for updating the website. NE-2140 information will also be forwarded to college communications offices of participating states for development of news releases and media events. Trade journal media personnel will be requested to develop articles about the activities of NE-2140.

NE-2140 Extension-Outreach-Public Relations activities will include grower-clientele meetings, demonstration field days, state and local media events, Extension bulletins and other publications, short courses and direct grower-clientele contacts. The Outreach-Public Relation-Extension Objective will involve outreach-public relations initiatives from all 12 participating states. Participation in each of the seven activity areas is documented in the table below.

|  |  |
| --- | --- |
| **NE-2140 Extension-Outreach-Public Relations** | **Participating States** |
| NE-2140 Website Participation | CA, CT, FL, HI, MA, MI, NY, OH, IL, RI, TN, VT, WV |
| Grower-Clientele Meetings | CA, FL, HI, MI, NY, OH, RI |
| Demonstration Field Days | CA, CT, FL, HI, MI, RI |
| Local, State and Regional Media Events | MI |
| Extension Bulletins-Other Publications | FL, HI, MI, NY, TN |
| Short Courses | FL |
| Direct Grower-Clientele Contacts | CA, CT, FL, HI, MA, MI, NY, OH, IL, RI, TN, VT, RI, WV |

As an example, HI will partner Hawaii’s largest new farmers’ training program, GoFarmHawaii, with Western SARE PDP program coordinators through their annual ag-professional conference using a train-the-trainer approach. Vimeo videos will be produced to be broadcast through Virtual Field Day events, or posted on Wang’s [Sustainable Pest Management website](https://cms.ctahr.hawaii.edu/wangkh/Research-and-Extension/Sustainable-Pest-Management-Projects) as well as in the University of Hawaii’s [Sustainable and Organic Agriculture Program (SOAP) resources website](https://cms.ctahr.hawaii.edu/soap/Events/PastEvents) (<https://cms.ctahr.hawaii.edu/soap/>) and quarterly newsletter, [Hānai’Ai](https://cms.ctahr.hawaii.edu/soap/).

Additional details are described as part of the Monitoring, Outreach and Training activities included in Objective 3.

**Measurement of Progress and Results**

***Outputs***

* At least one manuscript per year will be produced by each PI related to objectives 1-3, and at least two extension articles will be produced in most states each year.
* At least one graduate student will be trained and graduated by most PIs during these 5 years. These will be capable of serving as the next generation of nematologists/soil health promoting scientists.
* The NE2140 website will be created and maintained to upload products from this multistate project.
* Recommendations for cover crops that suppress nematodes and enhance soil health will be available.
* Recommendations for use of new reduced-risk nematicides will be available. Previous work has shown that some of these materials, unlike earlier nematicides, do not have the broad spectrum of activity against diverse nematode species, and pest-specific evaluations are needed.
* Results of grower surveys of, and management strategies for, bloat nematode (*Ditylenchus dipsaci*) in garlic will be communicated to growers via grower magazines and on-line articles.
* Three articles will be published on efficacy of Anaerobic Soil Disinfestation and refinements in its applications.
* Trap crops for Soybean Cyst Nematode will be available in multiple states.
* Thirty additional hemp cultivars will have been characterized for susceptibility to southern root-knot nematode (*Meloidogyne incognita*), lesion nematode (*Pratylenchus scribneri*) and reniform nematode (*Rotylenchulus reniformis*).
* Ten to 15 boxwood cultivars will have been evaluated for susceptibility to the southern root-knot nematode, *M. incognita*.
* Results of screening turf grass cultivars for resistance to sting, lance and root knot nematodes will be available.
* A working understanding of nematode community dynamics in commercial hemp fields, organic vegetables, and organic grain production will be developed.
* The relationship of important soybean-parasitic nematodes to *Xylaria* Taproot Decline (synergistic, neutral or antagonistic) will be developed.
* The composition of plant-parasitic nematodes in commercial boxwood fields will be characterized.
* Sampling for nematodes in commercial solanaceous production fields, beech forests, and production facilities for ornamentals (among others) will provide up-to-date understanding of nematode distributions and possible spread of new and emerging nematode pathogens.
* Routine nematode management lectures for a new farmers training program, [GoFarm Hawaii](https://gofarmhawaii.org/) (https://gofarmhawaii.org/), and periodic cover crop short courses will be offered to farm communities or soil conservationists in Hawaii through the online Tovuti platform.

***Outcomes / Impacts of work****.*

The proposed multistate research project will: 1) enhance the economic viability of farms by reducing crop losses due to nematodes 2) reduce the reliance on nematicides and other pesticides while increasing the sustainability of farms and fostering environmental stewardship and 3) provide extension and outreach to result in increased integrated management strategies against nematodes, thereby increasing the plant and soil health of small, medium and large farms throughout the northeastern region as well as other participating states such as California, Hawaii, Florida, Illinois, Tennessee etc. In addition, farmers will have a better overall understanding of the nature of nematodes, the damage they can cause, and the key roles that these soil-dwelling animals play in soil food webs and food security. These synergistic efforts will be critical for discovering new knowledge added to nematology.

Monitoring and surveying efforts will result in rapid detection of new agricultural and environmental threats from emerging or invasive plant-parasitic nematodes. Once detected, the project efforts will help limit distribution of these new threats, and thereby limit the damage they cause. The proposed research will result in rapid deployment of management strategies for these nematodes. Our extension efforts to promote cover cropping and conservation agricultural practices will enhance sustainability of farmlands and protection of our natural resources.

Changes in knowledge and behavior will be measured through surveys.  We expect that 40% of agricultural professionals and growers to adopt our recommended practices and 70% to report an increase of knowledge or awareness.  Our work has historically led to an increase of awareness and management changes in nematodes such as Soybean Cyst Nematode among many others, so we expect our work to lead to increases in nematode control and therefore profitability.

Specific outcomes we expect will include:

* At least 50% of garlic growers in New York will be aware of improved techniques for managing bloat nematode (*Ditylenchus dipsaci*), and at least 20% of garlic growers in New York will have adopted improved techniques for managing bloat nematode (*Ditylenchus dipsaci*).
* Development of Soybean Cyst Nematode populations that can overcome the plant resistance from new sources (other than PI 88788 and PI 548402) will be avoided.
* Use of a Soybean Cyst Nematode trap crop will be adopted in multiple states.
* The number of soybean producers testing their fields for Soybean Cyst Nematode will increase by 10 %.
* Soybean growers with potential nematode problems will know if they are an exacerbating factor should they find Xylaria Taproot Decline in their fields.
* A combined remote and ground truth nematode sampling protocol will become accepted by the discipline of nematology.
* Hemp cultivars resistant or tolerant to the tested nematodes will be available for recommendations to growers, as we expect that continued hemp cultivation will likely lead to nematode problems not yet recognized.
* Tree fruit producers will have new recommendations for managing dagger nematode and Peach Stem Pitting disease.
* Boxwood producers will be aware of the current problem with root-knot nematode and have resistant cultivars recognized for field production.
* Understanding of non-target impacts of nematicides will improve sustainability of nematicide recommendations.
* Growers will have increased confidence in use of cultural practices such as manure and compost amendments, Anaerobic Soil Disinfestation, and nematode-suppressive cover crops.
* Reports on superior efficacies of some soil treatment options will have led to their registration and broad use patterns.
* Cover crop management recommendations will have been vetted under commercial conditions, and two cover crops fit for multiple nematode infestations are available for use.

**Milestones**

2022

* Initiate or continue long-term experiments to examine new soil amendment materials and techniques against *Meloidogyne* spp. in vegetables, and other nematodes in grain crops.
* Evaluate the effects of identified non-host or nematode-suppressive rotational crops against different nematodes in multiple states under field conditions.
* Screen for nematode suppressive soils
* Evaluate new nematicidal products for efficacy in turfgrass, perennial and field crops
* Begin germplasm resistance screening in multiple crops
* Begin/continue long-term experiments to examine non-target effects of nematode treatments on soil biology
* Initiate experiments using physical practices such as heat and anaerobic soil disinfestation on nematode populations
* Begin screening for new and emerging nematode pathogens
* Conduct grower education, annual short courses, webinars, field days
* Assess the efficacy of at least five chemical or physical treatments for eradicating bloat nematode (*Ditylenchus dipsaci*) from garlic seed cloves. Communicate management strategies for bloat nematode to at least 50 garlic growers in New York.
* Maintain nematode diagnostic services for growers and extension specialists.
* Test 10 hemp cultivars for relative susceptibility to *M. incognita*. Additional cultivars will be tested in 2023 and 2024.
* Select hemp fields for sampling nematode communities.
* Elucidate the relationship of root-knot nematode and *Xylaria* Taproot Decline (XTD).
* Conduct a hands-on 2.5-day workshop on diagnosis and speciation of *Aphelenchoides* spp. using morphological techniques and molecular sequencing.
* Conduct an in-service training in MI to educate extension personnel and other stakeholders of the threat from foliar nematode to soybean, how to recognize their symptoms, and what to do if symptoms are observed.

2023

* Screen for nematode suppressive soils
* Test nematode management practices for potential to induce suppressive soils.
* Adjust cover- and rotation-crop experimental designs based on previous results
* Continue experiments to examine non-target effects of nematode treatments on soil biology
* Continue experiments on soil amendment materials and techniques against *Meloidogyne* spp.
* Continue experiments using physical practices targeted against nematode populations
* Adjust and expand germplasm resistance screening in multiple crops
* Evaluate new nematicidal products for efficacy in turfgrass, perennial and field crops. Integrate effective products into management systems
* Screen for new and emerging nematode pathogens, expand screening as practical
* Conduct grower education, annual short course, webinar, field days, conduct site visits
* Test 10 hemp cultivars for susceptibility to reniform nematode. Should any of those cultivars prove susceptible to the nematode, another 10 cultivars will be tested in 2024 and 2025.
* Sample boxwood fields for plant-parasitic nematodes and report results.
* Test boxwood cultivars for susceptibility to *M. incognita*. If promising, additional cultivars will be tested in future years.
* Elucidate the relationship of *Xylaria* Taproot Decline to soybean cyst nematode (*Heterodera glycines*).
* Maintain and update NE-2140 website.
* Report efficacy of fluopyram against coffee root-knot nematode.

2024

* Continue testing potential nematode management practices to develop suppressive soils
* Continue cover- and rotation-crop experiments
* Analyze data on non-target effects of nematode treatments on soil biology
* Analyze data on soil amendment materials and techniques against *Meloidogyne* spp.
* Integrate effective new nematicidal products into management systems
* Integrate cover- and rotation-crops into management systems
* Adjust and expand germplasm resistance screening
* Continue screening for new and emerging nematode pathogens
* Publish preliminary results where possible
* Conduct grower education, webinars, field days, publish outreach materials, conduct site visits
* Test 10 hemp cultivars for susceptibility to lesion nematode. If any of those cultivars prove susceptible to this nematode, another 10 cultivars will be tested in years 4 and 5.
* Elucidate the relationship of XTD to reniform nematode.

2025

* Analyze and publish germplasm resistance screening results, and data on suppressive soils for potential nematode management practices
* Conclude and evaluate long-term impacts of cover- and rotation-crop experiments, and integrate into management systems
* Integrate effective new nematicidal products into management systems
* Conclude primary screening for new and emerging nematode pathogens and publish data
* Publish results
* Conduct grower education, field days, publish outreach materials, conduct site visits

2026

* Analyze data, present reports at stakeholder and professional meetings, and publish results in peer-reviewed journals.
* Publish fact sheets aimed at nematode management and soil biology of nematodes.
* Update Cover Crop recommendations website.
* Continue grower education.

**Outreach Plan**

See Objective 4 in Methods.

**Organization / Governance**

The technical committee will consist of at least one voting member from each of the participating states (Appendix E), the administrative advisor, and the NIFA representative. The technical committee will elect a chairperson, secretary, and at least one member-at-large to serve as an executive committee that will serve two years. The regional Technical committee will meet annually to report on the research results obtained, discuss and exchange information and ideas and to plan and coordinate next year’s work relating to the objectives of this proposal. A coordinator for each of the objectives may be designated to facilitate the coordination and reporting of the research being conducted by the collaborators. The technical committee may invite other scientists with experience in biological control, crop production systems, integrated pest management, sustainable agricultural practices, and others to participate in the annual meeting to provide specific information and strengthen the discussion.

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Appendix E. (Draft)

**Participants Directory**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Participant Name | Station | Objective # | KA | SOI | FOS | SY | PY | TY | FTE | Extension Program/KA |
| Westphal, Andreas  Andreas.westphal@ucr.edu | California-UCR | 1,3,4 | 212 216 | 1139  1212  1213 1219 | 1120 1070 1081 | 0.10 | 0.00 | 0.3 | 0.4 | 212 0.10 |
| LaMondia, James James.LaMondia@ct.gov | Connecticut -CT Ag Exp. Station | 1,2,3 | 212 216 | 1499 1199 | 1120 1120 | 0.50 | 0.00 | 1.00 | 1.5 | 0 |
| Crow, William T. [wtcf@ufl.edu](mailto:wtcf@ufl.edu) | Florida -Univ. of Florida | 1,2,3,4 | 212 | 2199 | 1120 | 0.2 | 0.1 | 0.3 | 0.6 | 212 |
| Wang, Koon-Hui koonhui@hawaii.edu | Hawaii-  U. Hawaii | 1,2,3,4 | 212 | 1499 | 1120 | 0.10 | 0 | 0 | 0.1 |  |
| Ugarte, Carmen [cugarte@illinois.edu](mailto:cugarte@illinois.edu) | Illinois –  U Illinois | 2, 4 |  |  |  | 0.1 | 0.1 | 0.2 |  |  |
| Wick, Robert rlwick@umass.edu | Massachusetts U Massachusetts |  | 212 | 3130 | 1120 | 0.1 | 0 | 0 | 0.1 | 0 |
| Quintanilla, Marisol marisol@msu.edu | Michigan-Michigan State University |  | 212 | 3130 | 1120 | 0.1 | 0 | 0 | 0.1 | 0 |
| Melakeberhan, Haddish melakebe@msu.edu | Michigan-Michigan State University | 1, 2, 4 | 212 | 3130 | 1120 | 0.2 | 0.1 | 0.05 | 0.35 | 212  0.15 |
| Bird, George birdg@msu.edu | Michigan State University |  | 212 | 3130 | 1120 | 0.2 | 0 | 0 | 0.2 | 0 |
| Hay, Frank [fsh32@cornell.edu](mailto:fsh32@cornell.edu) | New York Cornell Univ. | 1,4 | 212 | 3130 | 1120 | 0.4 | 0 | 0 | 0.4 | 212 |
| Taylor.1886@osu.edu | Ohio – Ohio State Univ. |  |  |  |  |  |  |  |  |  |
| Mitkowski, Nathaniel  mitkowski@uri.edu | Rhode Island | 1.3.4 | 212 | 3130 2130 | 1120 | 0.1 | 0 | 0 | 0.1 | 0.1, 212 |
| Bernard, Ernest  ebernard@utk.edu | Tennessee - U Tenn | 1,2,3, |  |  |  | 0.3 | 0.1 | 0.1 | 0.5 |  |
| Schumacher, Lesley lesley.schumacher@usda.gov | USDA-MS, Jackson, TN | 1, 2, 3 | 212 | 3130 | 1120 | 0.05 | 0.05 | 0 | 0.1 | 0 |
| Neher, Deborah dneher@uvm.edu | Vermont –  U Vermont |  | 212  212 | 3130 3130 | 1120 1070 | 0.10 | 0 | 0 | 0.1 | 0 |
| Kotcon, James jkotcon@wvu.edu | West Virginia  West Virginia Univ. | 1, 2, 3 | 212 | 3130 | 1120 | 0.2 | 0.5 | 0 | 0.7 | 0 |
|  |  |  |  |  |  |  |  |  |  |  |