

Report and Recommendations

NORTHEAST MULTISTATE ACTIVITIES COMMITTEE

September 8, 2026 (virtual)

Members: Puneet Srivastava (Maryland-Chair), Beth Gugino (Pennsylvania), Chris Smart (NY-Geneva), Lee Hecker (Maine), Bill Miller (MA/NEED), Ali Dunigan (NEED)

Non-voting, ex officio: Rick Rhodes (agInnovation NE), David Leibovitz (agInnovation NE)

Discussion of Peer Reviewed Multistate Activities (MAC to provide recommendations)

- NE_TEMP2605: Eastern White Pine as an Iconic North American Tree: Evolving Dynamics and Future Opportunities, 10/01/2026-09/30/2031 [AA: Lee Hecker, Maine]
 - New project related to Eastern White Pine
 - Outreach plan and methods for tracking modern threats to Eastern White Pine were expanded in response to peer review
 - Objectives 2 and 4 are implicit activities of a multistate research project. Should they be revised or could they be removed?
 - NIMSS project language is crawled by search engines and is discoverable. An explicit call out to the development of research proposals that imply leveraging multistate funds might be worth retaining in the multistate project.
 - Under the header of “Importance of the work”; the MAC recommended drafting a statement that specifically ties this forestry-related proposal to agriculture: e.g., language about interconnected landscapes, working lands, agroecosystems, rural economic development.
 - **The MAC recommends the following revisions be made to the proposal:**
 - **Revise objective 4 to remove “Submit research proposals”**
 - **Draft language under “The importance of the work” that serves as a direct articulation of how this proposal relates to agriculture.**
 - **A motion was introduced to recommend revisions to the proposal as outlined above, and subsequently approval of NE_TEMP2605. The motion was approved unanimously.**
- NE_TEMP2650: *Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities*, 10/01/2026-09/30/2031 [AA: Lee Hecker, Maine]
 - The proposal covers a broad range of issues related to the equine industry. Revisions have been made to narrow its focus by removing objectives and refining project language.
 - The Northeast has an active equine industry, and this proposal has an appropriate fit into the region’s multistate research portfolio.
 - This project would also have a strong outreach component.

- The NE2202 *Equine Microbiome* project is intended to sunset. We should extend the invitation for members of that group to join the new equine project. The microbiome project activities would fit into the larger, more broad new proposal concept. This would provide NE2202 with an opportunity to sunset effective fall 2026 if interested.
- **A motion was introduced to recommend approval of this proposal. The existing NE2202 should be encouraged to join this newly formed equine project and recommended for sunsetting. This motion was approved unanimously.**
- NE_TEMP2640: *Effective Management of Nematodes in Plant and Soil Health Systems*, 10/01/2026-09/30/2031 [AA: Anton Bekkerman, New Hampshire]
 - The group retained its large number of outcomes and milestones as were mentioned in peer review.
 - Public engagement related to integrated nematode management, including training of nematologists, was an important element of this proposal.
 - The group will need to ensure that individual project activities are knit together into cohesive annual reports.
 - **A motion was introduced to recommend approval of this proposal. This motion was approved unanimously.**
- NE_TEMP2603: *Advancing high tunnel specialty crop production*, 10/01/2026-09/30/2031 [AA: Anton Bekkerman, New Hampshire]
 - The team's revisions in response to peer review were strong; the statement of issues and justification was edited for clarity.
 - Consideration of additional tunnel design elements, including movable tunnels, was a strong component of this proposal.
 - **A motion was introduced to recommend approval of this proposal. This motion was approved unanimously.**

Multistate Activities Seeking Administrative Adviser Assignments (for association discussion)

- NE2206: Green Stormwater Infrastructure and Agriculture (formerly Josh Kohut) – ends 9/30/2027
- NE2334: Genetic Bases for Resistance and Immunity to Avian Diseases (formerly Chris Ashwell and Bob Taylor) – ends 9/30/2028
- NECC29: Corn Improvement Conference (formerly Margaret Smith) – ends 9/30/2028
- NECC2202: Formal Structure for the Minor Use Animal Drug Program (formerly Margaret Smith) – ends 9/30/2027
- NRSP13: Artificial Intelligence for Agricultural Autonomy (formerly Josh Kohut) – ends 9/30/2030
- NE2201: Mycobacterial Diseases of Animals (currently Rick Rhodes) – ends 9/30/2027
- NECC2312: Northeast Coordinating Committee on Soil Testing (currently Rick Rhodes) – ends 9/30/2028
- NRSP9: National Animal Nutrition Program (currently Rick Rhodes) – ends 9/30/2030

Multistate Activities Ending 9/30/2026 (For information only)

- NEERA2104: Northeast Region Technical Committee on Integrated Pest Management
- NECC2103: High tunnel specialty crop production
- NE2140: Sustainable Management of Nematodes in Plant and Soil Health Systems
- NE2101: Eastern White Pine Health and Responses to Environmental Changes

Multistate Activities Ending 9/30/2027 (For information only)

- NE1962: Outdoor Recreation, Parks and Other Green Environments: Understanding Human and Community Benefits and Mechanisms (AA: Anton Bekkerman)
- NE2201: Mycobacterial Diseases of Animals (AA: Rick Rhodes)
- NE2202: The Equine Microbiome (AA: Chris Smart)
- NE2203: Legal Issues in Agriculture and Natural Resources (AA: Puneet Srivastava)
- NE2204: A regional network of social, behavioral, and economic food systems research (AA: Ock Chun)
- NE2206: Green Stormwater Infrastructure and Agriculture (AA: to be determined)
- NE2210: Improving Forage and Bioenergy Crops for Better Adaptation, Resilience, and Nutritive Value (AA: Eric Bishop von Wettberg)
- NE2220: Multi-state Coordinated Evaluation of Grape Cultivars and Clones (AA: Anna Katharine Mansfield)
- NE2227: Contribution of Ovarian Function, Uterine Receptivity, and Embryo Quality to Pregnancy Success in Ruminants (AA: Dave Townson)
- NE2231: Collaborative Potato Breeding and Variety Development Activities to Enhance Farm Sustainability in the Eastern US (AA: Anton Bekkerman)
- NE2248: Mastitis Resistance to Enhance Dairy Food Safety, Milk Quality, and Animal Welfare (AA: Ock Chun)
- NE2249: Sustainable and Inclusive Rural Economic Development to Enhance Housing, Health, Entrepreneurship, and Equity (AA: Anton Bekkerman)
- NE2251: Tourism Resilience and Community Sustainability: Adaptation and Recovery of Rural Businesses and Destinations (AA: Anton Bekkerman)
- NECC2202: Formal Structure for the Minor Use Animal Drug Program (AA: to be determined)

USDA Multistate Research Project –Proposal Draft

March 1, 2026

Title: Eastern White Pine as an Iconic North American Tree: Evolving Dynamics and Future Opportunities

Start Date: October 1, 2026 **End:** September 30, 2031

Overall hypothesis or goal: Characterize the current stand development of eastern white pine (EWP) across its range and how that will likely influence future management and health of the species.

Specific objectives (Long-term underlined, short-term follow)

1. Use FIA data to quantify the range of forest composition and growth of EWP where EWP has significant development. The initial analysis will be on data for Maine followed by data for other members of the Multi-state Project, first being New Hampshire, Vermont, and New York. Next will be analyses for North Carolina and Michigan. Finally, analyses will be completed for other states with significant volume of EWP including Massachusetts, Connecticut, Pennsylvania, Virginia, and Wisconsin.
2. Assess the current status of EWP and future opportunities. The Project members will write a review paper that will provide the basis for guiding future research and management of the species.
3. Revise silvicultural recommendations and forest management to improve EWP productivity, health, and economic return. The first recommendations will be developed for Maine after which recommendations will be developed for use in states of other Project members.
4. Improve our understanding of EWP development and how to manage the species.

The need as indicated by stakeholders.:

Eastern white pine is an iconic species for northeastern North America: Iconic species resonate with the public and can be used to engender broader public support for desired outcomes (Davies and Tippler 2024). Iconic species differ from indicator or keystone species because of the public connection; iconic species are not only biologically and ecologically important but also are part of a community's culture.

Eastern white pine's cultural connection to Indigenous Nations' traditions (Mausel, Waupoichick, and Pecore 2017) and the European settler's development (D. R. Foster, Motzkin, and Slater 1998) is probably a partial result of its abundance due to regeneration across multiple environments, ability to grow larger and taller than any other species in the east, and wood that was suitable for lumber (Lancaster and Leak 1978; Wendel and Smith 1990).

White pine has enormous economic value throughout its range. Over the region, the net volume of white pine saw logs is over 186 billion board feet (USDA Forest Service, Forest Inventory and Analysis). With a typical market price of \$100/1,000 bd ft, the potential value of standing white pine is \$18.6 billion.

From an ecological perspective, white pine has significant impact on the eastern forest (Wendel and Smith 1990). White pine attains the largest dimensions of any eastern tree serving as a critical habitat for many species of wildlife that depend on emergent crowns and large snags and downed woody debris. In many parts of the range, EWP was the primary species that

recolonized abandoned fields as farmers moved to more productive lands. This resulted in “old field pine”, stands dominated by EWP (Marshall 2009).

Silviculture and management of EWP has recommended developing stands that are dominated by EWP on sites where hardwoods are not aggressive (Lancaster and Leak 1978). However, after analyzing USDA Forest Service Forest Inventory and Analysis (FIA) plots in Maine (unpublished data), only about 5% of the plots were dominated by EWP (> 75% of the stems) (Maeve). Analysis of FIA data in Maine indicates that 15% of EWP commercial volume is in the spruce/fir (SF) type and another 31% is in the commercial hardwood (CH) types equaling the volume (44%) found in the EWP types. Additional analysis shows EWP volume growth is highest in the SF type and among the highest in the CH types resulting in EWP becoming the dominant species in stands with large diameters (12-18 in). About 30% of the regenerating EWP samplings occur in the SF, 53% in CH, and 19% in the pine type, a regeneration abundance that contradicts earlier impressions of eastern white pine becoming less dominant in mixed stands (Marshall 2009); the future of EWP in Maine will be in mixed species types.

For many decades, white pine health has been adversely affected by the non-native white pine blister rust (*Cronartium ribicola*) and the native white pine weevil (*Pisodes strobi*) (Costanza et al. 2018). More recently a stem canker pathogen, *Caliciopsis pinea*, and the pine bast scale, *Matsucoccus macrocitrices*, have occurred separately or together in association with EWP decline, dieback, and mortality. Managing EWP stands can be effective in reducing risks and losses due to these fungal pathogens and insect pests (Livingston et al. 2019). A recent study (Noone-Price 2025) indicates that an alternative approach to reduce white pine weevil damage is to manage EWP in mixtures.

More information is needed on EWP dynamics in mixed species stands so that silvicultural and management guidelines can be developed to improve EWP regeneration, growth, health, and economic value.

Evolving dynamics of cultural, biological adaptations, and ecological interactions has made eastern white pine an iconic tree species for the forests of northeastern North America that is 1) culturally relevant, 2) covers a broad geography, 3) highly resilient and productive which 4) could be improved with effective management.

The importance of the work, and what the consequences are if it is not done.

Future supply of EWP is essential in states where there is commercial demand for the wood, and assurance of future availability will make the species more attractive for commercial investment in other states. Efforts are needed immediately to reduce the uncertainty about where and how to manage EWP across its range so that its health, growth, and value can be maintained or improved.

Although the multiple stress agents associated with EWP health issues make it a challenge to grow, strategies aimed at improving white pine health are readily available for stands dominated by EWP (Livingston et al. 2019). White pine has long been successfully regenerated using silvicultural methods, such as shelterwood and seed tree cuts, and responds very well to thinning, and recommended management strategies can reduce health risks (Lancaster and Leak 1978). However, as explained above, about half of the current volume of EWP occurs in stands mixed with other species, and it is not known if current recommendations on EWP health are appropriate for the mixed-species stands. By gaining a better understanding of how EWP is

developing in the mixed species stand and how it can be managed along with associated species, we will be able to recommend silvicultural treatments that improve EWP growth and value and reduce the risk of white pine damage due to common stressors.

There are concerns about future development and availability of EWP and uncertainty on how the species will respond to a changing climate with some predicting reduced importance (L. Iverson, Prasad, and Matthews 2008; Prasad et al. 2020), and others are predicting stable habitat amounts (Yang et al. 2015; L. R. Iverson et al. 2019; U.S. Department of Agriculture, Forest Service. 2026). The uncertainty on the future range of EWP needs to be addressed to help with making future management decisions for the species.

The Hatch Act of 1887 funds investigations supporting rural economies by maximizing contribution by agriculture to the welfare of the consumer. As an iconic tree species, EWP is a model system where improved knowledge and understanding can significantly improve the species' economic and ecological contributions to rural communities throughout most of the eastern US. As the following narrative will establish, EWP has proven economic value but is underutilized in much of its range. Our Multi-state effort will strengthen the confidence of land owners and industry that EWP will thrive in the future and be a source of economic prosperity to the region.

[The technical feasibility of the research, the advantages of doing the work as a multistate effort.](#)

The USDA Forest Service FIA program has provided a data resource from which the current status of EWP can be defined for states throughout its range. The length of data collection varies by state. Maine's current FIA data set from the same sample plots begins in 1999, and the entire 3000+ plots were remeasured on a 5-year cycle such that most plots have been measured 5 times by 2023. Other states started to measure plots at a similar time but usually have a 7-year cycle for remeasuring plots. The raw data files can be downloaded from the FIA "Datamart" in comma delimited format such that it can easily provide input to R-studio and Excel for analysis.

Given the complexity and extent of EWP issues across a large range, it is unlikely that major advances will be accomplished by any single state's group working in relative isolation; such advances require collaboration among groups working in parallel. Collectively, potential project members have an enormous amount of expertise in various aspects of tree management and health. Bringing members together in a structured and active arrangement would create a synergism in analyses and interpretation efforts, thereby increasing research efficiency and productivity, with the ultimate goal of improving EWP's management and health throughout the region.

Currently, the potential project members include researchers and outreach professionals from Land Grant Universities in Maine, New Hampshire, Vermont, New York, Michigan, and North Carolina. Many of these participants work directly with stakeholders. Creating the multistate project will allow project members to:

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- 1) Review, synthesize, and share information from analyses of FIA data.
 - 2) Identify critical knowledge gaps that currently hamper efforts to improve EWP management.
 - 3) Avoid unnecessary duplication of research effort.
 - 4) Develop additional multi-institutional research proposals for national-level grants in order to bolster and build upon this initial work.
 - 5) Develop silvicultural prescriptions and other management recommendations to help mitigate potential white pine threats.
 - 6) Ensure that new findings are communicated with land managers.

What the likely impact will be from successfully completing the work.

Bringing together region-wide expertise on EWP issues will allow assessment of the species' responses to a changing environment. The combination of land use changes and climate events may be initiating transformations in white pine's responses to its environment that may dramatically alter the appropriate management prescriptions for the future. The proposed working group will initiate this assessment and develop a range-wide understanding of the future of EWP in the region's forests. Finally, our goal of using this initial project to motivate an additional multi-institutional, national-level grant could lead to much broader impact than that outlined above.

Related, Current, and Previous Work:

Eastern white pine is an iconic species for northeastern North America

Iconic species resonate with the public and can be used to engender broader public support for desired outcomes (Davies and Tippler 2024). Iconic species differ from indicator or keystone species because of the public connection; iconic species are not only biologically and ecologically important but also are part of a community's culture. Eastern white pine's connection to Indigenous Nations' traditions (Mausel, Waupochick, and Pecore 2017) and the European settler's development (D. R. Foster, Motzkin, and Slater 1998) is probably a partial result of its regeneration across multiple environments and ability to grow larger and taller than any other species in the east (Lancaster and Leak 1978). Evolving dynamics of cultural, biological adaptations, and ecological interactions has made eastern white pine an iconic tree species for the forests of northeastern North America that is 1) culturally relevant, 2) covers a broad geography, 3) highly resilient and productive which 4) could be improved with effective management.

Historical Importance: Evolving Dynamics of an Iconic Tree

Cultural relevance

As stated by René H. Germain and colleagues, "the historical importance of eastern white pine (*Pinus strobus*) is legendary" (Germain, Nowak, and Wagner 2016). For European settlers, EWP was the "King's pine", reserved for use by the English Navy for its ships (Keating 2024). EWP is also considered the "Tree that built America" the species was the primary tree that European colonizers used for building settlements, and the transport of the large logs down the region's rivers (Wilson 2005) was legendary, providing the basis for Paul Bunyan stories that began in Maine and spread westward (Croker 2009).

Eastern white pine has cultural significance to indigenous nations, and is well documented for the Menominee Tribe in Wisconsin (Mausel, Waupochick, and Pecore 2017). “The Tribe calls themselves ‘Maeqtetuahkihkiw Kew Kana^hwihtahqua,’ which translates to “The Forest Keepers,” and they recognize that the forest must remain for their unborn children’s children, a land ethic integral to Tribal identity.”

High resiliency and productivity across a broad range explained by eastern white pine’s biology and ecology

Eastern white pine has intermediate shade tolerance such that it can respond to a range of disturbances, such as growing after fires under the light shade of birch and aspen (Peterson and Squiers 1995) and taking advantage of gaps in forest cover due to windthrow or harvesting of large trees (Raymond et al. 2006). Periodic “cone crops” with prolific seed production help ensure establishment of the species across suitable habitats (Wendel and Smith 1990).

The species is fast growing compared to other associated species indicating that it can outcompete most other plants for resources (Wendel and Smith 1990). Growth of EWP does not slow down until after age 90 and will continue to add sawtimber volume at 100 years, allowing the species to become super-dominant in the canopy.

Range of EWP is determined by evapotranspiration: Precipitation must exceed evapotranspiration (Jacobson and Dieffenbacher-Krall 1995) which limits species to moister, cooler climates.

During the last glaciation the species was found in the current regions of North Carolina/Virginia western border, and as glaciers retreated, EWP spread up coast to its current range limit in Canada (Om P. Rajora, Andrew J. Eckert, John W. R. Zinck 2016). The species also spread inland and westward to the Great Lakes Region.

The species competes on a wide range of soils that are generally well drained (Wendel and Smith 1990). Hardwoods, such as the maples (*Acer*), are competitive on more nutrient-rich soils, but EWP is still part of mixture in hardwoods types (Eyre and Society of American Foresters 1980). The species becomes dominant on dryer soils, many times associated with red oak (Pine/Oak type). On drier, sandy soils, EWP is associated with hard pines (red pine, pitch pine).

As a consequence of EWP’s ability to compete on a wide range of soils and with many species, EWP’s was widely distributed in northern Maine prior to European colonization but at low densities, perhaps averaging about 1 large EWP per acre. However, it’s ability to develop into large trees across the range of conditions resulted in a massive amount of available timber for harvesting by European colonists, an amount that was three times more than the amount of standing EWP in the 2001 FIA inventory for that part of the state (Wilson 2005). The contrast in amount of EWP timber present in northern Maine over 200 years ago compared to the amount found today indicates the importance of understanding why these changes have occurred and if the past abundance of EWP is indicative of its future potential.

How EWP has maintained its presence across the landscape is dependent on its regeneration. which is associated with disturbance (Lancaster and Leak 1978; Wendel and Smith 1990). Regeneration of EWP will be successful if:

1. Moderate light, > 20%, is available such as in:
 - a. Gap openings associated with windthrow or harvesting.

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- b. An overstory allowing light to filter through, e.g., as developing stands of aspen/birch (Peterson and Squires 1995), red maple (R. W. Foster 1959), and red pine that can develop after stand replacing fires or other disturbances.
 2. Soils are disturbed resulting in minimal duff layer and vegetative competition (Lancaster and Leak 1978; Wendel and Smith 1990).
 3. A seed source is available (Kromholz, Webster, and Hyslop 2025).

In locations where fire is a rare disturbance such as in northern Maine (Lorimer 1977), EWP regenerated in hardwood stands typically as solitary trees that could out-grow the surrounding vegetation, or as small clumps of trees that could exclude regeneration of other species, or as released saplings when overstory trees died or blew over (Hibbs 1982). Outside of New England, fire likely helped maintain EWP in some forests, but in combination with logging of all seed trees and deer browsing, the disturbance could help reduce EWP abundance (Abrams 2001).

After regeneration, EWP stems must become established in the developing canopy. In hardwood stands, establishment of EWP and maintaining the stems in the canopy can be difficult in young ages when hardwood competitors can grow faster than EWP (Lancaster and Leak 1978; Wendel and Smith 1990; Smith and Ashton 1993; Leak 1995). However, once established in the canopy, EWP can maintain its position or emerge resulting in improved stand productivity ((R. W. Foster 1959; Hibbs 1982; Peterson and Squires 1995; Raymond et al. 2006; Arseneault et al. 2011; Waskiewicz et al. 2013; Waterman et al. 2020; Clark and D'Amato 2021; Copenheaver, Frye, and Deane 2025; Kromholz, Webster, and Hyslop 2025). Interestingly, one study found EWP growth to increase when growing closer to aspen (*Populus grandidentata* and *P. tremuloides*) than other EWP (Peterson and Squires 1995) indicating that a EWP tree competing with other EWP stems is more stressful than competing with stems of other species.

In softwood mixtures, EWP probably becomes established with eastern hemlock (*Tsuga canadensis*) and red spruce (*Picea rubens*) in manners similar to hardwood mixtures as described above (Orwig et al. 2022), with a few EWP trees emerging above the other species (Mary Ann Fajvan and Seymour 1993) which can increase overall stand volume (M. A. Fajvan and Seymour 1999). In addition, spruce budworm (*Choristoneura fumiferana*) defoliation can increase EWP regeneration and growth when growing with spruce and fir (*Abies balsamiae*) (Lavoie et al. 2026).

Another type of EWP stand development became present after European colonization when agricultural fields within EWP's range were abandoned in the 1800's and early 1900's. EWP could compete with the grasses better than other tree species (D. R. Foster, Motzkin, and Slater 1998) such that many old fields regenerated to almost pure stands of EWP. When these stands mature, they are frequently replaced by mixtures of other species.

The fastest growth of EWP is found in the southern part of its range. In western North Carolina and adjacent parts of Virginia, EWP reaches merchantable age in 25-50 years (Balmer and Williston 1983) compared to 50-75 years in the Northeast (New York, New England, eastern Canada) (Lancaster and Leak 1978). Volume growth in southern Appalachia (Balmer and Williston 1983) is about 7,000 cubic feet per acre (site index 60, age 35) which is nearly twice the amount found in the Northeast (Lancaster and Leak 1978) at 4,000 cubic feet per acre (site index 60, age 40). Growing season conditions are similar between the two regions (Table 1) but winters are warmer in the south such that roots likely remain active for two additional months each year when compared to the Northeast (Figure 1). With EWP habitat area being stable in the

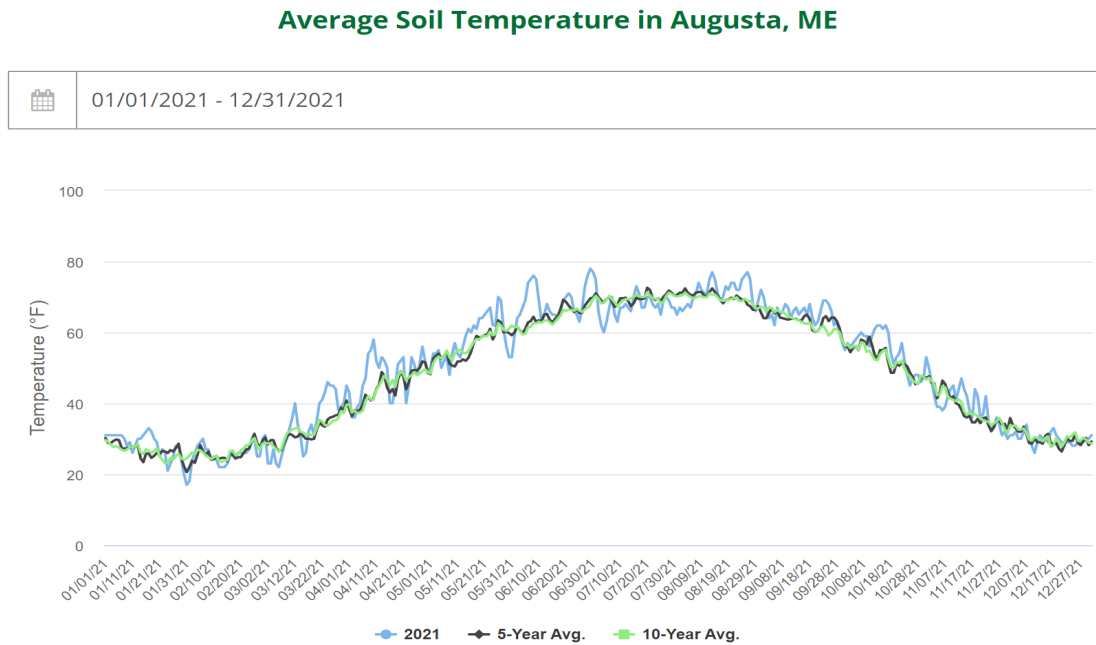
future (L. R. Iverson et al. 2019), there is a potential that EWP productivity will increase as winters become warmer.

Table 1. Climate data for Maine and the Blue Ridge Plateau (VA and NC, National Weather Service data).

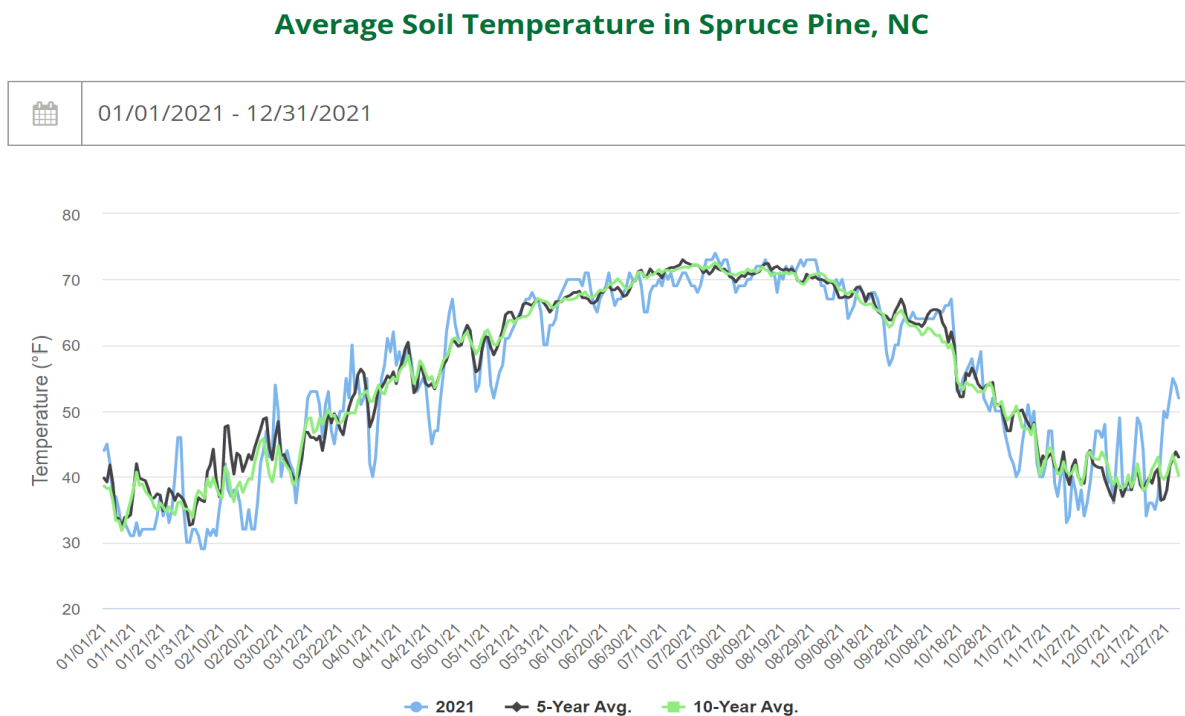
Location	July high avg (°F)	January low avg (°F)	Annual precip. Avg (in)	Total Snow Accum. Avg. (in)	Last spring frost	First fall frost
Augusta, ME	79	8	44	67	May 1	Oct 1
Galax, VA	82	21	43	16	Apr 29	Oct 11
Spruce Pine, NC	81	22	53	13	Apr 29	Oct 11

Figure 1. Soil temperature estimates or (a.) Augusta, ME, and (b.) Spruce Pine, NC. Data from *Open-meteo.com Weather API*. Zenodo. <https://doi.org/10.5281/ZENODO.7970649>

a.



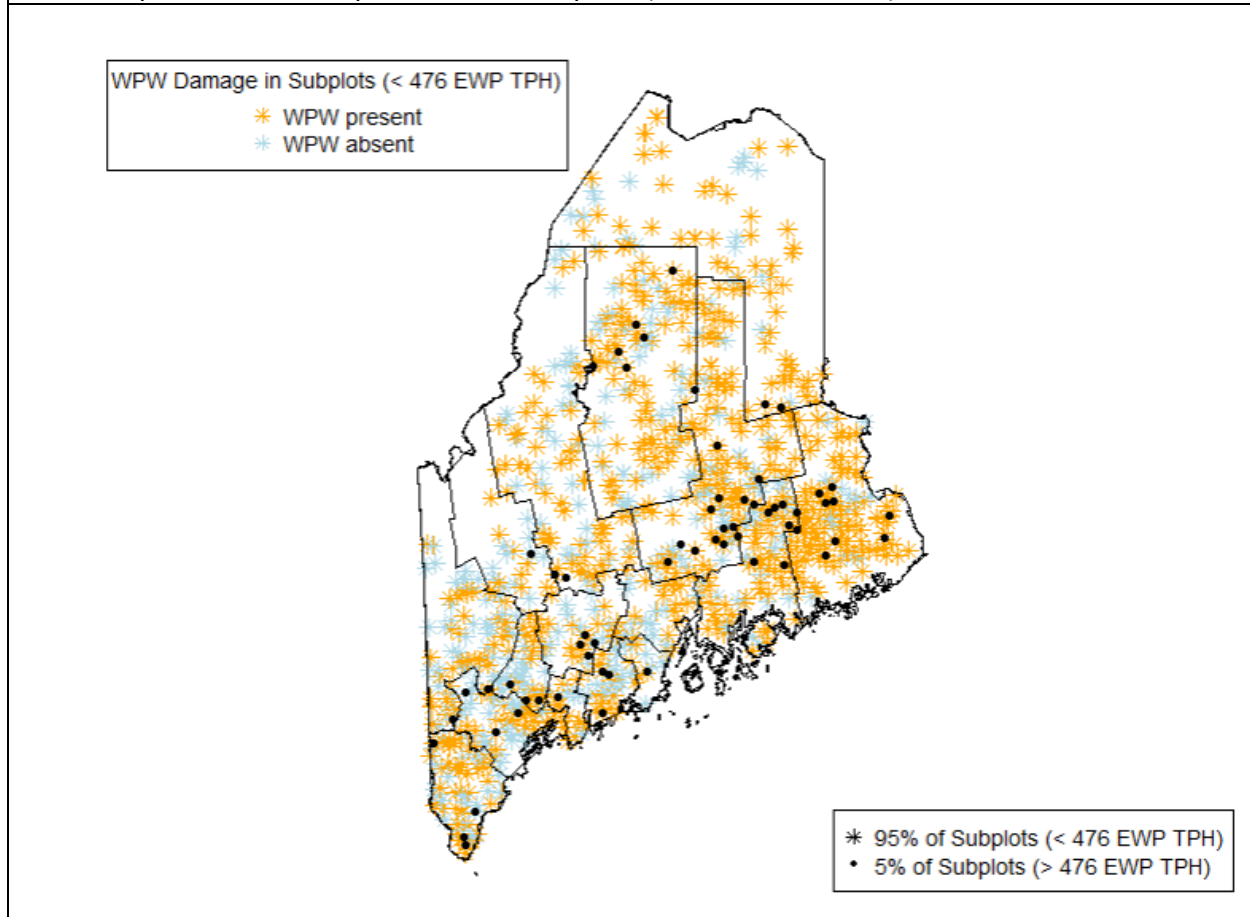
b.



Health Issues

Eastern white pine has experienced a number of health issues that can affect its regeneration, establishment and growth (Costanza et al. 2018). White pine blister rust pathogen, *Cronartium ribicola*, was introduced from Europe on EWP seedlings in the early 1900's, and the fungus is currently found throughout the range but is not considered a limiting factor in EWP regeneration and growth. White pine weevil (*Pisodes strobi*) kills the terminal leaders of developing white pine resulting in deformed stems and loss of economic value. Seventy percent of 1,757 FIA subplots across Maine with at least one EWP had observed white pine weevil damage (Noone-Price 2025). However, if white pine composition was over 75%, all plots had damage (Figure 2). There was a slight spatial association between white pine weevil damage and water surplus index with damage decreasing as the water surplus index increases (Noone-Price 2025).

Figure 2. White pine weevil (WPW) damage across Maine U.S. for subplots with high or low values of EWP TPH. Subplots with > 476 EWP TPH (192 EWP trees per acre ($n = 75$)) are considered high. Subplots with < 476 EWP TPH ($n = 1,682$) are considered low. Low EWP TPH values represent the 95th percentile of subplots (Noone-Price 2025).

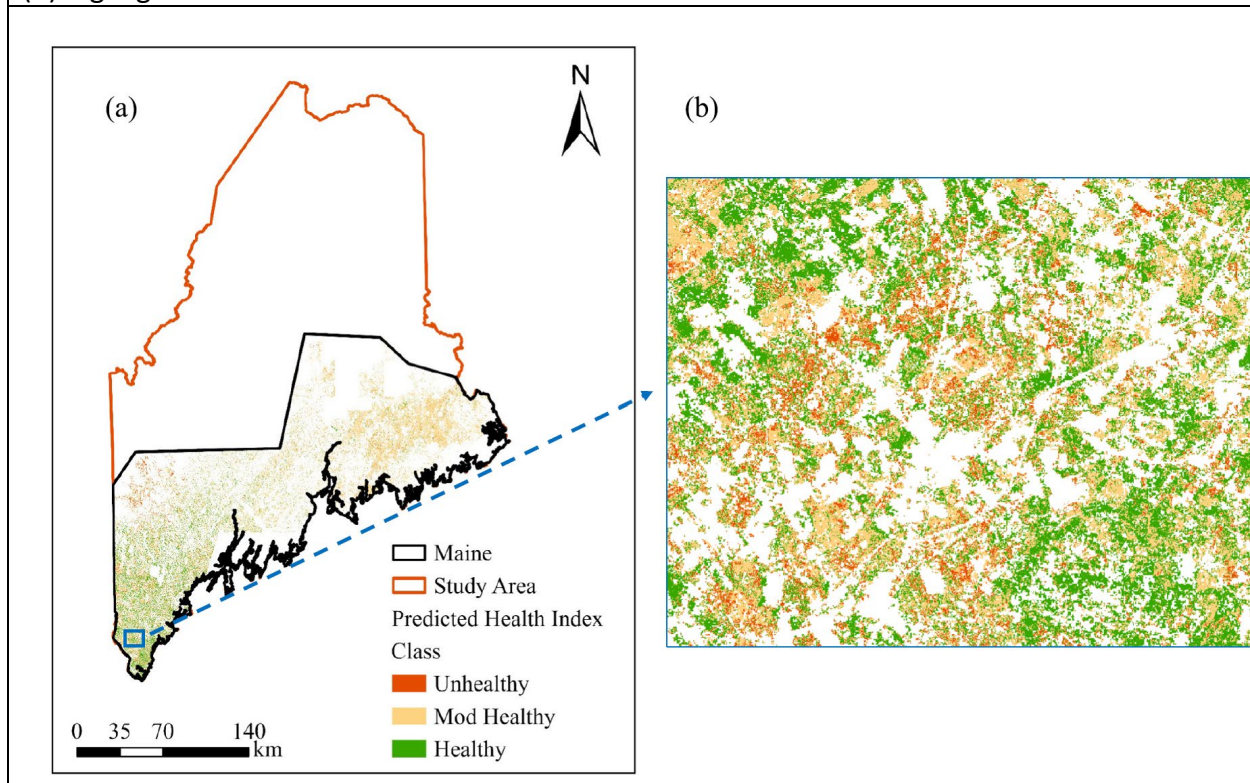


In contrast to the northern part of EWP's range, white pine weevil causes minor damage in the southern part of its range (Katovich and Mielke 1993), possibly associated with shallow duff layer (Noone-Price 2025).

White pine declines, that is, prolonged periods of reduced growth followed associated with diebacks and mortality, occur periodically throughout its range(Costanza et al. 2018). In Maine, a drought incited mortality in EWP stands that were overstocked and on sites with shallow roots(Livingston and Kenefic 2018). Additional stressors associated with EWP declines include *Caliciopsis* pinea canker and pine bast scale (*Matsucoccus*), and needle damage associated with infections by four pathogenic fungi (Costanza et al. 2018).

Use of remote sensing techniques can be used to measure white pine health (Meneghini et al. 2022; Das et al. 2024). Microwave (Sentinel-1) and optical (Sentinel-2) remote sensing data were used to predict leaf area index and live crown ratio. The predictions were integrated with canopy height and stand density to develop a novel health index map for EWP. The resulting health index map successfully delineated patches representing various health categories (Figure 3). The map can indicate trees that are suffering from stresses such as white pine needle damage (Das et al. 2024).

Figure 3. Eastern white pine (EWP) stand health index map for (a) southern Maine, USA, and (b) highlighted over an area.



Forest management can improve EWP resilience, productivity, and wood quality, but the species is mostly underutilized.

The states with the most volume of EWP are in Figure 4. Total volumes, however, do not necessarily equate to the level of management and degree of utilization. For example, North Carolina has the third highest harvest volume of EWP but has the eighth highest total volume

(Figures 4 and 5). Across the New England states of ME, NH and VT the EWP resource is intensively harvested and utilized. These states are harvesting approximately 1.5% of the standing volume on an annual basis, resulting in growth to harvest ratios of less than 2:1 (Figure 5). This indicates an equilibrium between harvesting and growth which allows for a sustained yield of forest products from EWP timberlands.

Most of the remaining states across EWP's range are harvesting less than one percent of the standing volume; the species is underutilized. A case in point is NY, the state with the most EWP of any state in the country has a growth to harvest ratio of 4:1. Wood quality is a problem (Germain, Nowak, and Wagner 2016). As characterized by the USFS, approximately three quarters of the stumpage is classified as low grade (#3 or lower). These stems will generate primarily low-grade logs with a value of roughly \$150/mbf which in turn produce low-grade lumber such as standard and industrial grade. Sawmills avoid processing low grade EWP logs because of the poor grade yield. The balance (25%) of the NY EWP stumpage is characterized by stems with a grade 1 or 2 butt log with a value of \$200 - \$400/mbf which provides a better opportunity to generate better lumber grades of premium, finish and select. But even high quality EWP stems can produce a significant amount of standard and industrial grade lumber due to the high frequency of black knots in the upper logs. Intensive management using low-density thinning at an early age can increase crown ratios and replace degrading black knots with red knots, significantly improving lumber grade yields(Germain, Nowak, and Wagner 2016). There is substantial, unrealized potential for increasing management and utilization of EWP.

Figure 4. Net **merchantable bole volume** of live trees (at least 5 inches d.b.h./d.r.c.), in cubic feet, on forest land.

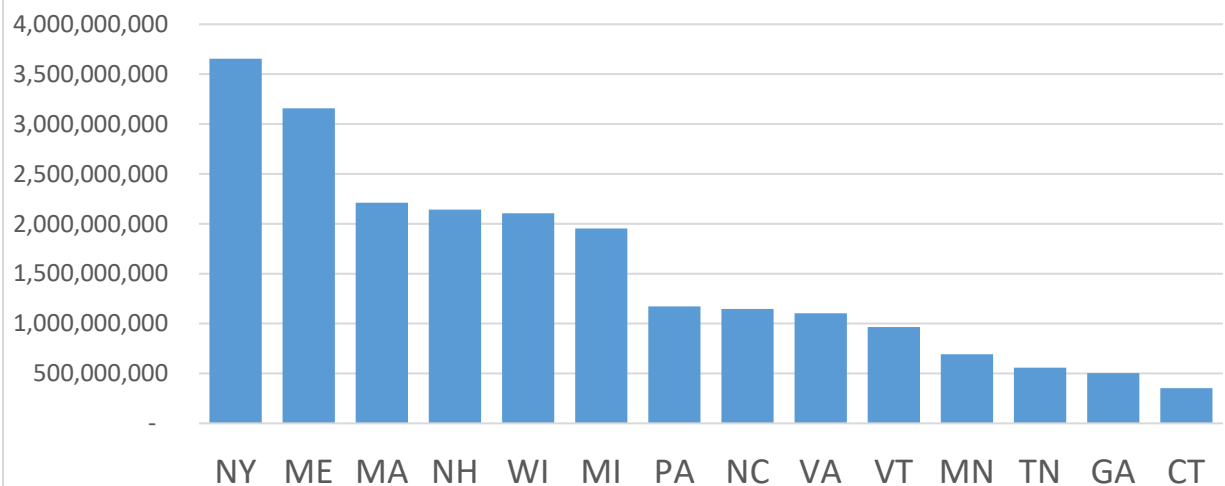
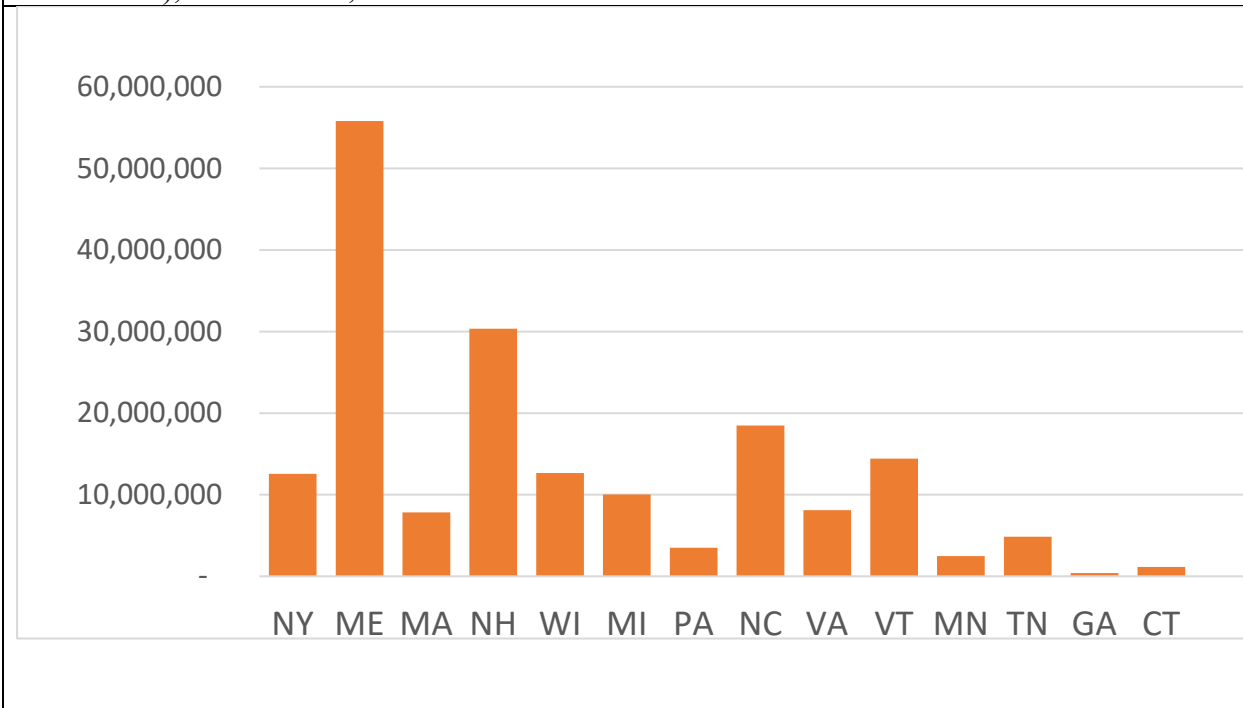


Figure 5. Average annual harvest removals of sound bole volume of trees (at least 5 inches d.b.h./d.r.c.), in cubic feet, on forest land.



Managing tree densities can minimize risks to white pine health and value, and pruning will increase wood quality. Shelterwood cuts can establish high densities of sapling and reduce damage associated with white pine weevil. Afterwards, thinning stands to low densities avoids competition stress and reduces decline risk (Livingston et al. 2019).

Managing EWP in stand mixtures also offers future opportunities. In addition to good productivity as described earlier, wood quality could be improved. Incidence of white pine weevil damage is reduced in Maine in stand mixtures. Weevil damage incidence is 100% of the locations with high EWP densities (> 192 EWP/ac) compared to 70% incidence in locations with lower EWP densities (Noone-Price 2025). Stem quality could also be improved on emergent EWP due to possible self-pruning of branches that are within the canopy.

Eastern white pine plantations are frequently used in North Carolina and Virginia where white pine weevil damage is low. Old fields or harvested sites are prepared for planting, sometimes with prescribed fire, and seedlings are planted at wide spacing, such as 10 ft to 12 ft spacing and harvested after about 50 years (Balmer and Williston 1983).

Menominee Tribal Nation in Wisconsin emphasizes sawlog quality and quantity. Eastern white pine is the primary commercial species, but structural and compositional diversity are part of management plans so that trees are grown to old age and large diameters using uneven-aged management or extended rotations in even-aged management.

Lack of markets for white pine pulpwood limits management options in all regions for removing small diameter stems to reduce stand densities.

The future of eastern white pine as an iconic species

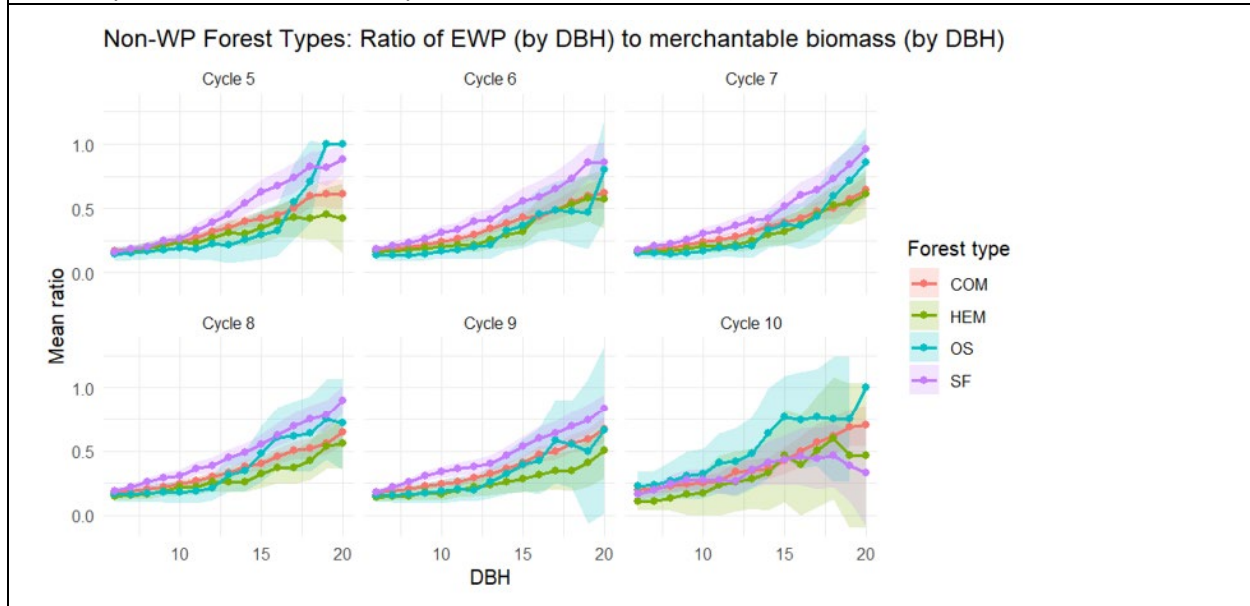
Forest Management and EWP Development

Forest management objectives for EWP will determine its future development across its range. Field abandonment will no longer be a major source of developing stands dominated by EWP. Therefore, future stands with high amount of EWP will depend on plantations and shelterwood management. As indicated by the pre-colonial distribution of EWP, lack of silvicultural intervention will likely result in EWP developing in low densities among other species across a broad range of forests. These stands have fewer EWP per acre, but the area is extensive and a future source of EWP timber. Therefore, forest land managers across much of the EWP range will have the opportunity to manage for EWP over a range of conditions. There are good guidelines for managing EWP dominated stands (Lancaster and Leak 1978, Balmer and Williston 1983, Livingston et al. 2019). For the mixed species stands, there are silvicultural recommendations if the manager wants to increase the presence and development of EWP in hardwoods (Lancaster and Leak 1978). Silvicultural recommendations for EWP growing in conifer mixtures, such as the spruce/fir types in Maine, are lacking, but one study suggests emulating spruce budworm outbreaks by using shelterwood ((Lavoie et al. 2026). In mixed stands, EWP is less likely to be damaged by white pine weevil which should result in better stem quality (Noone-Price 2025).

In general, EWP can be regenerated across different forest types if seed trees are present, partial light (> 20%) is available, and the soil is scarified. Increasing the composition and growth of EWP can be accomplished by removing competitors through managing stand densities (Livingston et al. 2019) and using crop tree management (Raymond et al. 2003) and low densities (R. S. Seymour and Smith 1987; Leak and Lamson 1999; R. S. Seymour 2007).

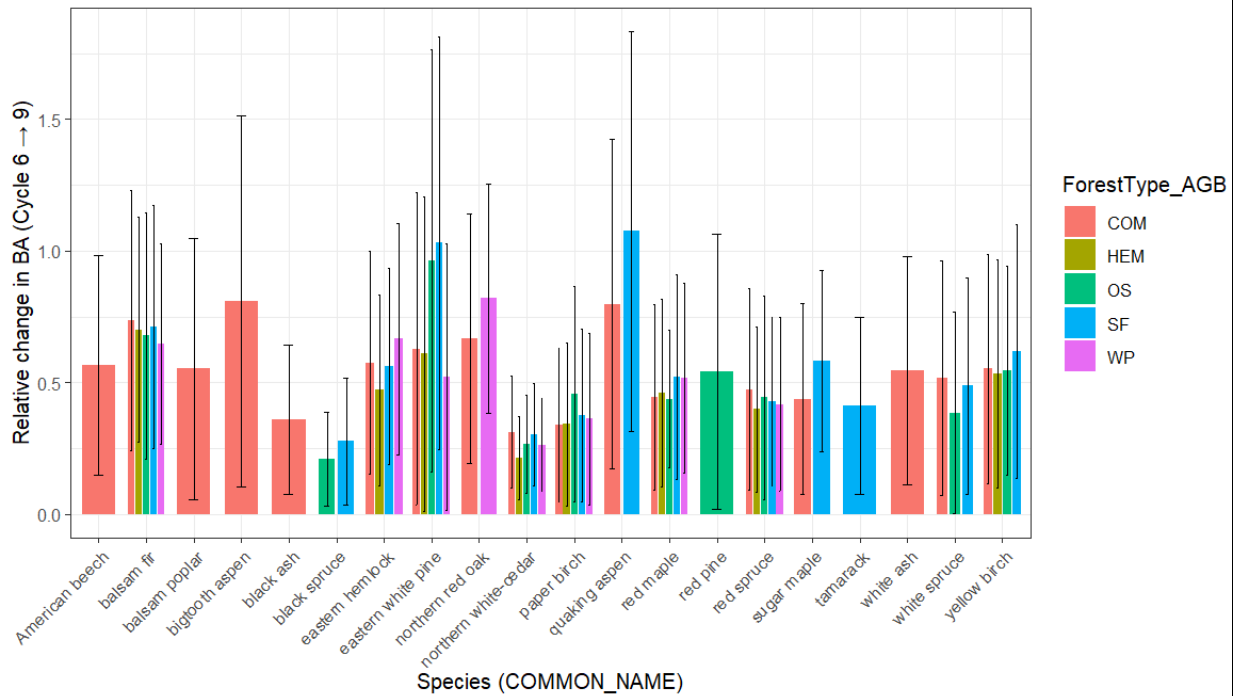
A more detailed analysis of FIA EWP data has begun in Maine across 25 years of FIA data collection in the state (Zhao 2025), and the data confirms EWP's ability to develop across a wide range of conditions and can compete well in many forest types. The data was organized into cycles, a 5-year period during which all inventory plots were measured. The number of plots that had consecutive measurements at 5-year intervals from 1999 to 2023, were less than 140 years old, and contained $\geq 90\%$ tree coverage totaled 2,980 out of 3,236 plots. The plots were divided into 6 forest types based on the majority of stand composition based on biomass measurements from 2002-2006; white pine (WP), spruce-fir (SF), other softwoods (OS, mostly wet sites), commercial hardwoods (COM), and other hardwoods (OH, mostly wet sites). About half of the EWP stems used in the analysis are in the WP forest type, nearly a third is in the COM type, about 12% in is SF, and 4% in OS. EWP rarely occurs on the OH type and is not included in the analyses. In the SF type, EWP biomass begins to exceed SF biomass when stems are larger than 12 inches DBH (Figure 6). Even in the COM type, EWP biomass begins to exceed the hardwood biomass at 18 inches DBH (Figure 6). Even though EWP on the mixed-species sites is only about 2 to 4% of the stems used in the analysis, EWP can dominate the larger diameter classes.

Figure 6. EWP's relative importance increases with DBH across all non-WP types, indicating that EWP tends to occupy (and persist to) larger size classes. SF shows the earliest and most persistent EWP dominance, while HEM requires the largest sizes for EWP to become dominant. COM and OS are intermediate but differ at small-mid diameters (COM higher than OS). Forest types based on biomass in 2002-2006: COM = commercial hardwoods, HEM = hemlock, OS = other softwoods, SF = spruce/fir. From Cycle 5 = 1999-2003 measurement, Cycle 6 = 2004-2008, Cycle 7 = 2009-2013, Cycle 8 = 2014-2018, Cycle 9=2019-2023, and Cycle 10 = 2024. (Zhao 2025)



Zhao and Livingston (unpublished data) have made preliminary analysis of FIA data to quantify the growth of trees over 5 inventory cycles and compared the trees samples during FIA inventory cycle 5 (1999-2003) with inventory cycle 9 (2019-2023). Basal area (BA) increase per tree is quantified by calculating a relative basal area (Figure 7); $(BA_{\text{Cycle 9}} - BA_{\text{Cycle 5}}) / BA_{\text{Cycle 5}}$ such that a double in BA results in a Relative BA =1. The relative basal area increments for EWP had the highest value for conifers in the OS, SF, and WP types, and was among the higher values in the COM type (Figure 7). One major surprise is that EWP basal area increment was the highest in OS and SF types, almost 30% more than in the WP type (Figure 7). Relative BA increment is associated with larger diameters. The DBH of EWP pine was about 13 inches with diameters about a half inch larger in softwood types and about 1.5 inches smaller in the hardwood COM type. These diameter averages are the largest for the species in the softwood stands and among the highest in the COM stands.

Figure 7. Relative change in basal area (BA) as calculated using $(BA_{\text{Cycle 9}} - BA_{\text{Cycle 5}}) / BA_{\text{Cycle 5}}$ such that a double in BA results in a Relative BA =1. Measurements are based individual tree changes over 20 years as completed in FIA Cycle 5 (1999-2003) to Cycle 9 (2019-2023). Forest types based on biomass in 2002-2006: COM = commercial hardwoods, HEM = hemlock, OS = other softwoods, SF = spruce/fir. From Cycle 5 = 1999-2003 measurement, Cycle 6 = 2004-2008, Cycle 7 = 2009-2013, Cycle 8 = 2014-2018, Cycle 9=2019-2023, and Cycle 10 = 2024.



EWP growth in mixed stands is competitive or exceeds the growth of other species. As a plus, there is less weevil damage in the mixed-species stands (Noone-Price 2025). The status of other EWP pests in the mixed-species stands is not known.

Seymour (R. Seymour 2021) summarized the occurrence of 2 in DBH saplings in the FIA dataset and found 18% in the pine types, 30% in the spruce-fir types, and 52% in the hardwood types.

Given the above, EWP will remain present and productive in the Maine forest. A more detailed analysis of EWP status is needed in other states to understand which trends in Maine can be documented elsewhere, and if states are experiencing different trends in EWP development.

In Maine, future development of the majority of the EWP resource will occur outside of stands dominated by EWP. There is a need to understand the economic, ecological, and silvicultural implications of EWP in mixed-species stands.

Future Conditions

In addition, future conditions may be favoring EWP in Maine. EWP in the southern Appalachians has nearly twice the growth rate as in the northeastern US (Lancaster and Leak 1978; Balmer and Williston 1983). When looking at climate data, summer conditions are similar between the two regions (Table 1), but winters are warmer, such that soil activity at > 40 F is probably 2 months longer in the southern region (Figure 1). Therefore, warmer winters could favor EWP growth in the future. Also, the warmer winter temperatures allow more decomposition of the litter layer, a factor associated with less white pine weevil damage (Noone-Price 2025).

USFS Tree Atlas (L. R. Iverson et al. 2019) estimates that eastern white pine will maintain its current importance in the forest by 2100. Increased water use efficiency due to higher CO₂ levels could also help eastern white pine remain competitive in parts of its current range (Handler 2014). “Common garden” studies indicate that the population in southern Appalachia will grow faster under warmer conditions compared to northern populations (Chhin et al. 2018).

Eastern white pine is likely to remain available for economic use with the potential to expand into new markets where it is under-utilized.

Future challenges:

The above information provided the basis for future questions requiring additional assessment of current information and research to provide needed information. Such questions include:

1. Most future white pine will be in mixed stands; how should they be managed?
 - a. What is likelihood of white pine regeneration with current and future management practices in mixed-species stands?
 - b. Is regeneration shifting from where it is currently present?
 - c. How well will white pine compete in mixed-species stands? Can EWP in mixed-species stands be managed to make them more valuable economically and ecologically?
2. What are good options for growing EWP dominated stands?
 - a. Is shelterwood economically feasible given the need to manage stem densities without markets for small diameter stems?
 - b. Can seed sources from southern Appalachia produce trees with higher volume production in northern areas?
 - c. Will EWP plantations become feasible if tree improvement and climate changes reduce WPW damage?
3. Can remote sensing be used to quantify geographic distribution of stresses from competition, drought, and pests (e.g., Figures 2 and 3) and used to identify potential strategies to mitigate adverse impacts on EWP?
4. Can new markets for young EWP be developed, such as pine-tipping, to help improve EWP management and utilization?
5. How can EWP saw-log trees be better utilized across its range?
- 6.

Related work from CRIS projects

There are no active EWP projects in the CRIS database except for NE 2101 which is ending.

A couple of projects do establish a communications network for developing and improving forest management across states.

S1091: Forest Health and Resilience

Facilitate further integration of the forest health programs at land grant Universities, and provide science-based solutions to land managers and regulators.

WCC1003: Coordination of Western Regional Extension Forestry Activities

Coordinates Extension Foresters in the Western states to enable more efficient and effective use of limited resources available for educating about natural resource management in a collaborative manner.

Objectives:

1. Use FIA data to quantify the range of forest composition and growth of EWP where EWP has significant development. The analysis will be completed for each state represented in the Multi-state project.
2. Assess the current status of EWP and future opportunities. The Project members will write a review paper that will provide the basis for guiding future research and management of the species.
3. Revise silvicultural recommendations and forest management to improve EWP productivity, health, and economic return. The first recommendations will be developed for Maine after which they will be modified for use in states of other Project members.
4. Improve our understanding of EWP development and how to manage the species.

Methods:

1. Use FIA data to quantify the range of forest composition and growth of EWP where EWP has significant development. The initial analysis will be completed using data for Maine followed by data for other members of the Multi-state Project, first being New England (New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island) and New York, Next will be analyses for North Carolina and Michigan. Finally, analyses will be completed for other states with significant volume of EWP including Pennsylvania, Virginia, and Wisconsin. Starting with the first annual meeting and continuing with additional online meetings as needed, the Multi-state members will develop a set of parameters for use in the analysis including forest type definitions, relative measures to compare species over time such as DBH, BA, biomass volume, cut volume, and relative basal area. Figures 4-7 provide examples. Dr. Livingston at the University of Maine will lead the analysis effort, and other committee members will have the opportunity to review results and recommend additional analyses at annual meetings or on a more frequent schedule if desired.
2. Assess the current status of EWP and future opportunities. First, the Project members will write a review paper entitled, "Eastern White Pine as an Iconic North American Tree: Evolving Dynamics and Future Opportunities". The objective of the manuscript is to define the current status of EWP knowledge, indicate how the species will likely develop in the next 100 years, and explore future challenges, opportunities, and research needs to better manage the species. At the first annual meeting, members of the Multi-state project will review a manuscript draft by Dr. Livingston and decide on who will focus on a topic for additional development. Manuscript drafts will be reviewed by all project members until a manuscript is submitted to a national journal, such as the Journal of Forestry. Online tools (Google Docs, Paperpile) to facilitate collaborative work on a manuscript. If

the length of the manuscript is a concern, project members can recommend development of a manuscript series to address the important issues.

3. Revise silvicultural recommendations and forest management to improve EWP productivity, health, and economic return. Outputs from Objectives 1 and 2 will be used to develop silvicultural and management guidelines for EWP. The Project members will need to decide if a single manual is appropriate or if separate manuals are needed for different regions, such as New England, New York, Lake State, and Southern Appalachians.
4. Submit research proposals to improve our understanding of EWP development and how to manage the species. Results from Objectives 1 and 2 will be used to develop research proposals to address the key needs identified in

Measurement of Progress and Results:

Outputs

1. Standardization of FIA analysis among states (Objectives 1):
 - Forest types
 - Measures of growth
 - Relative measures to compare species
2. Publication on the future of EWP (Objective 2).
3. Silvicultural and management recommendations (Objective 3).
 - Presented at professional meetings
 - Documents available for download.
4. Research proposals submitted.

Outcomes or Project Impacts:

Roles of white pine health issues in the forest ecosystem are better understood and help to explain forest responses to land use changes and climate changes. From this understanding, effective management recommendations can be made. Probable impacts are:

- 1) Review manuscript is accepted for publication in a national journal. New perspectives on EWP management become available to a national audience.
- 2) New silvicultural and management guidelines become available for use by landowners and forest managers.
- 3) Research proposals are funded to advance knowledge on EWP growth, health, and management.

Milestones:

- Year 1
 - Basis for FIA analysis and review paper are agreed to by Project members
 - Draft of review paper is submitted
 - FIA analysis completed for New England
- Year 2:
 - Review paper is published
 - Proposal developed for a major program, such as USDA's Sustainable Agriculture Systems.
 - FIA analysis completed for New York, North Carolina, and Michigan.
 - Silvicultural and management recommendations developed for New England.
- Year 3

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- FIA analysis completed for Virginia, Pennsylvania, and Wisconsin
 - Silvicultural and management recommendation developed for New York
 - Proposal development continues until funding is achieved.
 - Year 4
 - Silvicultural and management recommendations developed for southern Appalachia (NC, VA), Pennsylvania, and Lake States (Michigan, Wisconsin).
 - Proposal development continues until funding is achieved.
 - Year 5
 - Proposal development continues until funding is achieved.

Outreach Plan:

The goal of the outreach plan is to provide a two-way communication process so that new information can be shared with external partners and the external partners can share their needs with the research team.

Information developed in the project will be shared with the Northeast Extension Forest Resources Educator Council (NEFREC) and the Northeast Silviculture Institute with the primary contact being Steven Roberge, Extension Forestry Specialist & Professor at the University of New Hampshire Cooperative Extension.

The format for offerings by the Northeast Silviculture Institute for Foresters involves planning a field workshop event at which videos can be made for future use (see <https://extension.unh.edu/northeast-silviculture-institute-foresters/about>). Each of the workshops includes at least:

- Silvics of individual species & Stand Dynamics including land use history
- Silvicultural Systems and Practices including growth, yield, quality and regeneration
- Economics, utilization & markets
- Forest Health
- Wildlife Considerations specific to forest type
- Soils
- Site Quality and Productivity
- Sample prescriptions
- Legal, landowner objectives & carbon considerations
- Field Trip into forest type

For EWP, the workshop will need to deal with EWP's wide range of stand development, such as EWP dominated stands (plantations, old fields), EWP in hardwood mixtures, and EWP in conifer mixtures.

A workshop on EWP management in mixed species stands is being developed in cooperation with the University of Maine's Cooperative Forest Research Unit which depends on financial support of organizations that own and/or manage forested land in the state. Developing the workshop includes interviewing external partners on their existing plans for managing EWP in mixed stands and what questions and needs they have about the management. The first workshop will be given by June 2027, and the workshop will form the basis of a proposal to add EWP management in mixed species stands as an update to the Northeast Silviculture Institute program.

Project personal will continually provide project information updates at presentations at professional meetings such as the New England Society of American Foresters annual meetings.

A paper that summarizes findings of the FIA analyses will be submitted for publication by the end of 2026. A full review paper on EWP as an iconic species will be submitted for publication in the Journal of Forestry by the end of 2027.

Organization and Governance:

The project will use the standard form of governance. Participating institutions will send at least one representative to an annual meeting, and meeting attendees will be considered the Technical Committee. The Technical Committee will elect officers of chair, chair-elect, and secretary at the annual meeting. The chair-elect normally succeeds to chair the following year. Each officer is eligible for re-election. Sub-committees focused on particular objectives. Meetings will confer as needed by teleconference or in-person to plan and coordinate details of the multi-state project.

Projected Participation:

Include a completed Appendix E

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Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2605: Eastern White Pine as an Iconic North American Tree: Evolving Dynamics and Future Opportunities

Rate the technical merit of the project:

- 1. Sound Scientific approach:
Approve/continue project
 - 2. Achievable goals/objectives:
Excellent
 - 3. Appropriate scope of activity to accomplish objectives:
Excellent
 - 4. Potential for significant outputs(products) and outcomes and/or impacts:
Excellent
 - 5. Overall technical merit:
Excellent
- Comments

The proposal presents a clear, well-structured, and scientifically rigorous plan for addressing the evolving dynamics of eastern white pine across its range. The research team articulates a sound scientific approach grounded in extensive FIA data analysis, coupled with a thoughtful integration of silviculture, forest health, and ecological context. The objectives are achievable, logically sequenced, and appropriately scaled for a multistate collaboration.

As a forest pathologist who has worked extensively on health issues affecting eastern white pine, I recognize the importance and timeliness of this coordinated effort. The proposal accurately identifies the major biotic and abiotic stressors influencing EWP productivity and resilience, and it outlines a framework that will meaningfully advance our understanding of how to manage this species in both pure and mixed stands. The emphasis on synthesizing regional expertise, developing updated management recommendations, and generating future research proposals further strengthens the project’s potential impact.

Overall, the project is technically strong, well justified, and positioned to deliver significant outcomes for forest managers, researchers, and stakeholders across the region. I fully support the proposed work.

Your Recommendation:
Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2605: Eastern White Pine as an Iconic North American Tree: Evolving Dynamics and Future Opportunities

Rate the technical merit of the project:

- 1. Sound Scientific approach:
Approve/continue project
- 2. Achievable goals/objectives:
Good
- 3. Appropriate scope of activity to accomplish objectives:
Excellent
- 4. Potential for significant outputs(products) and outcomes and/or impacts:
Excellent
- 5. Overall technical merit:
Good

Comments

Overall, I think this is well written with logical objectives. I see the value in which this research can provide stakeholders who manage for Eastern White Pine. I would like to see more detail on the extension/ outreach regarding how these findings will be disseminated. I would also recommend spatial representations of where trees are being impacted by pests, namely white pine weevil, to see the geographic distribution of this pest and identify potential strategies to mitigate its adverse impacts on health and growth.

Your Recommendation:
Approve/continue project

NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Status: Submitted As Final

Duration 10/01/2026 to 09/30/2031
Admin Advisors: [Lee Hecker]
NIFA Reps:

Non-Technical Summary

The U.S. equine industry contributes \$177 billion in value and supports 2.2 million jobs (American Horse Council, 2023), yet rising costs of keeping horses are threatening the long-term viability of equine owners, businesses, and welfare organizations. Stakeholder surveys across multiple Northeast states identify financial challenges as the top barriers to sustainable horse ownership and management. Without coordinated regional research and educational support, these barriers will continue to limit participation in the equine industry, reduce welfare outcomes, and weaken rural economies.

The goal of this project is to build a more resilient equine economy by generating data-driven solutions that reduce costs, improve horse health, and enhance decision-making among horse owners, professionals, and welfare organizations. Objectives include: (1) conducting a multistate longitudinal survey to assess economic pressures, horse health, and management practices; (2) developing research and outreach on cost-effective pasture, forage, nutrition, and climate-adaptive management; (3) assess horse nutrition practices and develop cost-saving feeding strategies based on survey data; (4) development of extension resources.

Target audiences include horse owners, managers, veterinarians, welfare organizations, educators, and industry partners. Stakeholders will benefit through data-driven recommendations, cost-saving decision tools, improved welfare outcomes, and earlier detection of health issues that lead to substantial economic losses.

By integrating research, technology development, and coordinated multistate outreach, this project will generate actionable knowledge and tools that directly reduce the financial burden of horsekeeping and strengthen the economic and social sustainability of equine communities.

Statement of Issues and Justification

Overview: Stakeholders across the U.S. equine industry report rising costs as the top barrier to sustainable horse ownership and operation. Recent needs assessments from Pennsylvania, Kentucky, New Jersey, Maine, Delaware, and other states consistently identify rising expenses, such as feed, veterinary care, and facility maintenance as the top challenges facing owners and equine businesses. These concerns align with national trends: the annual cost of horse ownership has tripled or more since 2003 (American Horse Council, 2023), and general operating expenses now exceed inflation-adjusted 2012 values by 86–128% in some regions (Kentucky Equine Survey, 2022). Without intervention, these challenges will continue to reduce participation in the equine industry, strain welfare organizations, and negatively impact rural economies that depend on equine activity.

The consequences of inaction include declining horse welfare, reduced economic output, and the continued accumulation of preventable expenses associated with poor nutrition and inefficient management. Another factor reducing equine systems profitability is poor pasture management. Improper pasture management (e.g., overgrazing, inadequate nutrient and stocking-rate management, and lack of resting) reduces forage quantity and quality, increases reliance on purchased supplemental feed, such as hay and concentrates, and thereby raises feeding and overall horse-production costs (Macleay and Buckley, 2019; Ringmark et al., 2019).

A multistate approach is essential because economic pressures and management decisions are influenced by climate, forage systems, regional feed costs, facility designs, and state policies. A coordinated effort enables comparative analysis, broader applicability of findings, and collectively developed educational tools that can be disseminated regionally. Successful completion will result in improved cost efficiency, enhanced welfare outcomes, more resilient equine businesses, and better-informed decision-making across diverse equine communities.

1. Rising expenses in horse operations

Justification: Despite the overall industry growth, costs associated with horsekeeping have surged, placing increasing financial pressure on individual owners and operations. According to a report comparing 2003–2016 data from the American Horse Council, the annual cost of owning a horse in the U.S. rose during that period: for show horses, from US\$3,186 (2003) to US\$24,239 (2016); for recreational horses, from US\$2,319 to US\$6,710 (datapaddock.com) Even under modest care regimes, the combination of feed, facility maintenance, veterinary care, and other routine expenses places horse ownership far beyond a casual hobby for many.

These rising costs have been confirmed by stakeholder feedback. An unpublished 2024 equine needs assessment conducted at Penn State University identified the top three most important and challenging issues in the equine industry. The most frequently chosen issues were all related to costs of horse-keeping. These responses reflect on-the-ground realities: owners, small operations, and welfare organizations increasingly struggle with escalating feed prices, maintenance, veterinary bills, and facility overhead.

2. Assess horse nutrition practices and develop cost-saving feeding strategies

Justification: Forage access and feeding efficiency are primary cost drivers for nearly all equine operations. Systematic monitoring of hay markets, coupled with research on feeding efficiency and waste reduction, is critical to improving producer financial resilience. These efforts provide producers with reliable benchmarks, predictive insights, and actionable recommendations. In years of drought or supply shortages, timely data help prevent urgent welfare compromises by informing early purchasing, storage, and pasture strategies. Without this objective, financial strain and preventable welfare issues related to forage scarcity will continue to escalate.

3. Grazing land management:

Justification: Pastures represent the most cost-effective and nutritionally valuable feed resources to horse owners, making grazing land a central economic pillar of equine operations. Yet many farms struggle to implement effective grazing practices, leading to wasted forage, higher feeding expenditures, and declining pasture productivity and persistence. Rising feeding prices, high veterinary and care costs, and the limitations of small or suburban acreage make efficient forage use even more critical for horse owners. Challenges such as uneven grazing pressure, poor soil fertility, and lack of management knowledge often translate into preventable financial losses and reduced overall farm resilience.

Feed remains one of the largest recurring expenses in any livestock operation, and poorly managed pastures increase dependence on costly hay and concentrates, particularly during winter or drought periods. Improving grazing-land management through strategies like rotational grazing, integrating warm- and cool-season forages, and optimizing soil fertility can extend the grazing season, improve forage quality, and reduce the need for supplemental feed. Research across forage systems shows that practices enhancing pasture productivity, nitrogen-use efficiency, and plant persistence yield strong economic returns, and these benefits directly apply to equine farms where even modest reductions in supplemental feeding can significantly lower annual operating costs. Together, these points highlight the need for strong, coordinated research, outreach, and education in grazing-land management to help horse farms stay economically viable, reduce their dependence on purchased feeds, and build more resilient equine businesses.

4. Multistate Extension resources

Justification: While academic publications provide essential information and rigor, they are not the primary information source for most horse owners or managers. Rather, this group depends on Extension bulletins, webinars, workshops, podcasts, and short-form digital resources that can be readily applied in daily operations. A multistate dissemination effort will close the gap between research and producer-level application. Additionally, this approach ensures that educational resources reflect diverse management systems and economic realities. The development and dissemination of Extension resources are an essential part of this multistate effort. These materials serve as the primary mechanism through which research findings reach stakeholders, influence management practices, and generate measurable improvements in economic resilience and equine welfare.

Related, Current and Previous Work

This project builds directly on prior multistate collaborations focused on equine nutrition, grazing systems, welfare, and decision-support tools (NE1041, NE1441, NE1941). These projects have generated foundational knowledge on pasture management, forage quality, climate impacts, and the economics of livestock systems. The present proposal extends this work by integrating economic resilience and environmental considerations specifically relevant to the equine sector.

Previous studies demonstrate meaningful economic impacts from management education. Skelly et al. (2011) showed that 31% of participants in Michigan adopted cost-saving practices, while Delaware and Midwest studies reported substantial interest in nutrition, pasture management, biosecurity, and disease prevention- all areas where improved management results in measurable financial benefits (Wickens et al, 2011; Mastellar et al., 2018).

Together, these activities provide a coordinated platform to address the multifaceted drivers of cost and risk in horsekeeping.

Grazing land management:

Implementing thoughtful grazing management strategies is essential not only for maintaining pasture health but also for strengthening the economic sustainability of equine operations. Research has consistently shown that managing the area available for grazing through rotational systems can substantially improve forage production and nutritive value compared with continuous grazing (Williams et al., 2020). Studies across cool-season (Webb et al., 2009; Kenny, 2016), warm-season (Webb et al., 2011), and mixed-species pastures (Daniel et al., 2015) indicate that rotational stocking increases total forage mass and lengthens the grazing period. These improvements reduce the need to purchase hay or concentrate feeds, thereby lowering operating costs. Rotational systems have also been linked with healthier pasture composition, including a greater presence of desirable forage species (Virostek et al., 2015) and improved ground cover (Kenny, 2016), which can decrease the long-term expenses associated with pasture renovation efforts.

Building on these benefits, overseeding can serve as an additional strategy to maintain productive, high-quality stands. Sod-seeding, introducing compatible species into existing pastures, offers a sustainable approach to rejuvenate forage systems and enhance botanical diversity without the cost or soil disturbance associated with complete renovation (Rueda-Ayala and Höglind, 2019). By filling gaps in thinning stands and improving overall forage availability and nutritive value, overseeding helps extend grazing capacity and delay more expensive renovation interventions, supporting both pasture longevity and economic efficiency.

Beyond improving pasture composition and productivity, adjusting the number of hours horses are allowed to graze each day is another strategy that supports forage conservation and economic efficiency. Limiting grazing time helps match feed intake to nutritional requirements, preventing excess energy consumption while slowing pasture depletion. Evidence shows that mature idle light-breed horses grazing between 9 and 12 hours per day typically consume enough to meet maintenance digestible energy needs without exceeding them (Dowler et al., 2012; Siciliano, 2012; Bowman et al., 2017). This reduction in daily intake, estimated at about 5 kg of dry matter for a 500-kg horse when access is restricted to 9–12 hours (Siciliano, 2012), can equate to roughly 20 additional grazing days within a single month. Extending grazing time in this way directly cuts back on supplemental feed purchases, providing clear financial benefits.

Incorporating alternative forage species can also contribute to greater economic resilience. Studies examining annual grasses, including teff, show that these species can effectively lengthen the grazing season in northern regions (DeBoer et al., 2017; Grev et al., 2017). Teff, in particular, has been associated with more favorable glucose and insulin dynamics in horses during the fall and late fall (DeBoer et al., 2018), which may have longer-term health and management advantages. In the Southeast, incorporating rhizoma peanut into bahiagrass pastures enabled a 75% reduction in nitrogen fertilizer use without affecting forage production. This mixed system also improved forage nutritive value and produced similar or more favorable fecal and blood metabolites compared with high-fertilizer bahiagrass monocultures in equine grazing systems (120 kg N ha⁻¹; Vasco et al., 2023; 2025).

Collectively, practices such as rotational stocking, overseeding, controlled grazing duration, and the use of alternative forages enhance forage efficiency, reduce feed costs, and support the economic sustainability of horse operations while maintaining horse and pasture health.

Objectives

1. Conduct a multistate longitudinal survey to identify major social and cost drivers, management practices, welfare concerns, and economic pressures across diverse equine operations.
2. Assess horse nutrition practices and develop cost-saving feeding strategies, including hay price monitoring and decision-support tools.
3. Develop and evaluate cost-effective pasture, forage, climate-adaptive management strategies to reduce feed-related expenses and improve forage utilization.
4. Develop and disseminate multistate Extension resources (webinars, fact sheets, tools) targeted at reducing horsekeeping costs and improving welfare outcomes.

Methods

Objective 1:

Survey Development: Penn State University (PSU), in collaboration with university economics faculty, will lead survey design and IRB development. The survey will include validated question types (Likert items, ranking questions, cost-reporting and management practices fields). Survey topics will include: Top equine operational expenses; Forage, feed, and pasture management practices; Facility management costs; Health-related expenditures; Perceived barriers to implementing cost-saving strategies; Welfare concerns and resource gaps; Climate-related impacts on forage availability and costs. Draft survey tools (e.g. Qualtrics) will undergo review by the multistate technical committee and pilot testing (n=5-10 participants). Revisions will be made based on participant feedback.

Survey Administration: Each participating institution (UMaine, Penn State, Kentucky, Florida, Montana, and partners) will distribute the survey through Extension networks, equine associations, social media, email listservs, and industry events. Multiple dissemination efforts (initial email, 1-week reminder, 3-week reminder) will maximize response rates. Sampling will target a broad cross-section of equine owners, trainers, boarding facilities, welfare organizations, rescues, and industry professionals. Each state will aim for 75 responses, generating a projected dataset of 375 respondents across the project.

Longitudinal Design: The survey will be repeated every two years to track: Changing cost structures; Adoption of cost-saving practices; Emerging welfare and management needs; Economic impacts of feed prices, climate variability, veterinary costs, and facility investments; The effectiveness of educational interventions; and shifts in operational financial resilience.

Unique (non-identifying) participant codes will allow voluntary participation while protecting confidentiality.

Data Analysis: Confidential data will be pooled into a shared multistate repository. Analysis, guided by economic faculty partners, will include: Descriptive statistics of costs and practices; Multivariate regression linking cost outcomes to management decisions; Mixed-effects modeling for longitudinal changes; Correlation of forage and hay pricing with geography and climate indicators; Pre/post comparisons of adoption of recommended best practices. All institutions will participate in data interpretation and multistate synthesis.

Objective 2:

Hay Price Monitoring and Modeling: Participating states will collect annual hay and forage price data from farm surveys, Extension reports, and agricultural market listings. A standardized protocol will capture bale type, weight, forage species, quality grade, and regional availability. These data will be integrated into economic models that estimate feeding costs under varying forage qualities, supply constraints, and seasonal fluctuations.

Feeding-Efficiency Research: Feeding-efficiency studies evaluating storage losses, feeding systems (round-bale feeders, slow-feed nets, rationed vs. free-choice), and supplemental feeding requirements relative to forage quality. Data will include dry-matter intake, waste percentage, time budgets, and cost per unit of nutrition delivered. One specific project is listed below.

Project #1: Investigate the effect of different proportions of alfalfa-bermudagrass hay as single sources of nutrition in diets of mature horses. The objectives of this study are to evaluate the effect of these proportions on diet cost effectiveness, diet digestibility, blood and fecal variables, and feeding behavior of mature horses. This study also aims to identify the optimum proportion of alfalfa-bermudagrass for maximum diet utilization and welfare. **Project #1 methodology:** Dietary treatments will consist of four hay treatments with different proportions of alfalfa (*Medicago sativa* L.) and Bermudagrass [*Cynodon dactylon* (L.) Pers.], with increasing levels of alfalfa as: 0, 34, 66, and 100 % alfalfa. Treatments will be tested in a replicated 4 × 4 Latin square with 20-day experimental periods using eight mature horses and offered at 2% of horses' body weight into three meals. Horses will have free access to fresh water and be provided with vitamin and mineral supplementation daily. Within each experimental period, after a 14-day adaptation phase, a 24-h time-budget behavioral observation (Martin & Bateson, 2007), and bite and chew rates, will be conducted on day 14. On days 15-19, total fecal and urine collection will be conducted for measuring diet digestibility and nitrogen and water balance (Vasco et al., 2021). On day 20, fecal and blood variables pre- and post-feeding responses will be measured in blood samples (insulin, glucose, blood urea nitrogen, total plasma protein and lactate) that will be collected by jugular venipuncture and fecal samples (dry matter, lactate, pH, short-chain fatty acids, and ammonia-nitrogen) that will be collected directly from rectum (Vasco et al, 2026). Diet cost-effectiveness will be measured as cost per unit of nutrient [digestible energy (DE) and crude protein (CP)] supplied, feed cost per day per horse, hay efficiency ratio (DE or CP delivered/cost of hay, estimated cost of health risk reduction - which will be measured based on the pre- and post-feeding responses of the fecal and blood variables, and cost efficiency of nitrogen use and environmental economics (value of reduced economic excretion and water balance), among others. Data will be tested for normal distribution using the Shapiro-Wilk test and submitted to analysis of variance using the GLIMMIX procedure in SAS (SAS Inst. Inc, Cary, NC). Data from the 24-hour time budget assessment will be submitted to ANOVA with repeated measures using the MIXED procedure with the REPEATED statement in SAS (SAS Inst. Inc., Cary, NC). The model will include square, period, treatment, hour, and treatment x hour as fixed effects and horse(square) as random effect when testing the effect of hay and time of day on mean hourly feeding, inactivity, and other activities duration. For hay treatment effect on diurnal, nocturnal, and total daily duration of feeding, inactivity, and other activities, chew rate, bite rate, and frequency of drinking, urination, and defecation, data will be submitted to ANOVA using the MIXED procedure in SAS. Square, period, horse(square), and hay treatment will be included in the model as fixed effects. Nutrient intake and digestibility variables, as well as the economical analysis variables, will be calculated by day, and statistical analysis will be performed on the 5-d average for each collection within a period. The model will include square, period, horse(square), and hay treatment as fixed effects. Data from the fecal and blood variables post-feeding responses, data will be analyzed as a replicated Latin-square design with repeated measures arrangement using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Square, horse(square), hay treatment, and period will be considered blocking factors in the replicated Latin-square design. The model for repeated measures analysis will include square, period, hay, hour, and hay x hour as fixed effects, with hour as the repeated measure. Horse(square) will be considered a random effect. A Tukey's post hoc test will be used to determine differences between the means for all significant effects.

Decision-Support Tools and Business Resources: Economic modeling results will be used to develop user-friendly decision-support resources such as ration-cost calculators, hay-price dashboards, and feeding strategy comparison tools. Additional business planning materials (i.e., budget templates, cash-flow tools, and modules for the online Equine Business Course) will be collaboratively authored, piloted by equine managers, and disseminated across states.

Objective 3:

Grazing Research and Field Trials: Plots and large-scale grazing studies will be conducted to evaluate forage species and pasture establishment, or renovation, effects on system economic and overall sustainability. **Project #1:** Determine the effect of sod-seeding aged perennial-warm season grass plots with different legumes on forage productivity, nutritive value, and ecosystem services. Grazing tolerance of these forage systems will also be determined by mob grazing them. **Project #1 methodology:** plots of brome grass (*Bromus* spp.) alone or sod-seeded with alfalfa (*Medicago sativa* L.), sainfoin (*Onobrychis viciifolia* Scop.), birdsfoot trefoil (*Lotus corniculatus* L.) will be replicated three times in a randomized complete block design and repeated for two years. To allow for measurements of grazing tolerance, each third of the 23 ft x 148 ft plots will be randomly assigned to one of the three grazing treatments: non-grazed (control), cattle grazed, or horse grazed in a split-plot design. Grazed treatments will be mob grazed. Grazing frequency and data collection will be determined by forage phenology. Three to five grazing events/data collection are expected per year. Forage measurements will include herbage mass, botanical composition, NIRS nutrient composition, biological nitrogen fixation, and root mass. In vitro digestibility assay will be conducted using bovine and equine inocula. Soil characteristics will include carbon and nitrogen, using an elemental analyzer, and soil compaction, that will be measured as soil strength. The most successful mixture will be advanced to a large-scale grazing study (Project #2). **Project #2:** Determine the effect of sod-seeding aged perennial-warm season grass pastures with different legumes on forage productivity, nutritive value, animal performance and ecosystem services. **Project #2 methodology:** treatment pastures will include brome grass alone or sod-seeded with the successful legume from project #1. Pastures will be replicated three times in a randomized complete block design and repeated for two years. Each pasture will be divided into three paddocks and assigned to one of the grazing treatments: non-grazed (control), cattle grazed, or horse grazed in a split-plot design. Paddocks will be grazed using the rotational stocking method. Animals will be removed from the pastures when recommended post-grazing stubble height is achieved and kept in a dry lot and supplemented with hay while pastures are ready to be grazed again, which will be determined by forage phenology. Forage measurements frequency will be determined by forage phenology and include herbage mass, botanical composition, NIRS nutrient composition, biological nitrogen fixation, and root mass. Soil characteristics will include carbon and nitrogen, using an elemental analyzer, and soil compaction, that will be measured as soil strength. Intake and digestibility will be measured using the dual marker technique. Animal performance will be measured as frequently as forage measurements and determined by body weight and condition score. **Project #3:** Determine the nutritive value and acceptability of limpograss [*Hemarthria altissima* (Poir.) Stapf & C.E. Hubb.] for horses and compare it to forages commonly used in horse pastures in the Southeast (bermudagrass and bahiagrass). **Project #3 methodology:** Limpograss plots will be established in different horse operations and measured for forage yield, nutritive value, and acceptability/preference. Before the grazing events, forage yield and nutritive value samples will be collected by hand plucking random duplicate 20 x 20 in areas to a height of 10 inches. Samples will be dried at 60°C for 24 hours to determine dry matter and subsequently ground at 2 mm and shipped to a commercial laboratory for nutritional composition. Digestibility will be measured in vitro using equine fecal fluid as the inoculum for incubation. Initiation of the grazing season will be determined based on forage phenology and the grazing duration in hours will be determined based on estimated available forage (Glunk & Siciliano, 2011). Forage acceptability will be determined by visually assessing the percentage of available forage biomass removal on a scale of 0 (no grazing activity) to 100 (100% of the existing vegetation grazed down to 10 cm) as described by Allen et al. (2013).

Economic Analysis of Grazing Strategies: For the plot and grazing projects performed, economic metrics computed will include: establishment cost per acre (seed, sod-seeding labor, fertilizer and herbicide costs), annual maintenance cost per acre (dragging, fertilizer, herbicide, reseeding, and labor), forage yield per acre, grazing days per acre, and hay saved (lb and \$/horse/grazing season), cost per unit of ecosystem services (\$ per t of CO₂ sequestration, \$ per lb of N biologically fixed, and \$ saved with avoided fertilizer), ecosystem services per dollar invested, and total feeding cost per animal per day, among others.

Objective 4:

Resource Development and Dissemination: Each institution will develop educational resources tailored to their regional clientele, including fact sheets, webinars, budget tools, pasture tools, and business planning guides. Materials will reference data collected through surveys and applied research, focusing on actionable cost-saving strategies. States will share resources, and each institution will disseminate materials within their geographic region. An annual conference will be held to share results with equine stakeholders.

Measurement of Progress and Results

Outputs

- **Analyzed Survey Results Comments:** A multistate longitudinal dataset will be developed to capture detailed information on equine management costs and evolving industry needs. These data will be complemented by analyzed survey reports produced every two years, providing ongoing insight into economic and management trends.
- **Forage and Hay Price Monitoring Tools Comments:** Forage and hay price data from local and regional sources will be collected regularly and will be available in a user-friendly format for equine managers.
- **Asynchronous Business Course Comments:** An online asynchronous business course will be developed and disseminated to equine industry practitioners.
- **Extension Outreach and Resources Comments:** Extension-focused outputs will consist of educational materials such as fact sheets, webinars, written articles, business-planning tools, and podcasts designed to deliver practical, research-based guidance to producers. Research findings will be prepared for submission to peer-reviewed journals, ensuring scientific rigor and broad dissemination. Annual conferences held across the participating states that will bring stakeholders together to learn about project results. The project will culminate in a final multistate integrated report summarizing economic, welfare, and management findings across all participating regions.

Outcomes or Projected Impacts

- **Short-Term** Short-term outcomes include measurable increases in producer awareness of cost-effective horsekeeping strategies and documented adoption of recommended best-management practices (BMPs) related to feeding, forage selection, pasture care, welfare efforts, and facility design. Stakeholders will gain improved capacity to interpret economic trends such as hay price fluctuations and veterinary cost inflation.
- **Medium-Term** Medium-term outcomes are expected to include quantifiable cost savings among equine operations that adopt evidence-based management strategies. Welfare outcomes will improve among equine rescues and welfare organizations as a result of better resource allocation and diagnostic clarity. Increased financial resilience among small and mid-size equine operations will reflect more efficient management and better-informed decision-making.
- **Long-Term** Long-term impacts include strengthened regional and national equine economic stability. Ultimately, these impacts contribute to a more sustainable, economically viable, and welfare-centered equine industry. Progress will be assessed using quantitative indicators such as percentage reductions in feeding and forage costs, and changes in adoption rates of recommended BMPs. Additional indicators include the percentage of operations reporting improved financial stability and the total dollar value of documented cost savings across longitudinal survey efforts.

Milestones

(2027): Milestone 1 (Oct 2026–Sept 2027): (a) Survey Instrument Development, Testing, IRB Approvals, and Initial Distribution; (b) IACUC Approval and Some Project Activities. (a) During the first project year, the multistate team will collaboratively design the longitudinal survey instrument, incorporating economic, welfare, and management measures. Activities include pilot testing, instrument refinement based on stakeholder feedback, and completion of all required Institutional Review Board (IRB) approvals across participating institutions. Upon approval, states will coordinate the initial survey distribution using Extension networks, industry partners, and equine organizations. Completion of this milestone is essential before data collection, longitudinal tracking, and subsequent modeling can begin. (b) Project leaders will work on their individual Institutional Animal Care and Use Committee (IACUC)/Agriculture Animal Care and Use Committee (AACUC) before initiation of any research activity with animals. Some projects will be implemented in 2027, such as project #1 listed under objective 2.

(2028): Milestone 2 (Oct 2027–Mar 2028): (a) Initial Survey Data Cleaning, Analysis, Multistate Synthesis, and Results Dissemination; (b) Additional IACUC Approval and Other Project Activities. (a) Following data collection, participating institutions will collaboratively clean, verify, and pool responses into a shared multistate repository. Initial analyses will include descriptive statistics, regional comparisons, and identification of priority economic and welfare challenges. This milestone enables the team to determine early patterns in management costs, forage access, facility investments, and welfare concerns. Completion of this analysis is necessary for refining research directions, prioritizing field studies, and informing the development of educational resources. Results from the initial survey effort will be shared via Extension pathways, such as webinars or articles. (b) Project leaders will work on their individual Institutional Animal Care and Use Committee (IACUC)/Agriculture Animal Care and Use Committee (AACUC) before initiation of any research activity with animals.

(2029): Milestone 3 (Apr 2028–Sept 2029): (a) Development and Implementation of Follow-Up Research (Nutrition & Forage Studies); (b) Biennial Survey Re-Administration and Longitudinal Trend Analysis. (a) Building on initial survey insights, the team will launch targeted research initiatives across states after IACUC/AACUC approval. These include forage and hay price monitoring, feeding-efficiency studies, and pasture and grazing system evaluations. Completion of these research activities is required before developing national recommendations and decision-support tools. (b) At the project midpoint, the survey will be repeated to track shifts in economic pressures, adoption of best management practices, changes in welfare challenges, and impacts of earlier Extension interventions. Completion of this milestone enables longitudinal modeling and measurement of overall project impact.

(2030): Milestone 4 (Oct 2029–Sept 2030): Development of Extension Tools and Producer Resources. As research outputs emerge, the team will generate coordinated educational materials, including fact sheets, webinars, producer guides, feeding calculators, and forage budgeting tools. An online asynchronous business course will be developed. Multistate collaboration ensures consistency across regions while allowing for climate-specific adaptations. Completion of this milestone is essential prior to broad dissemination and evaluation of producer adoption.

(2031): Milestone 6 (Oct 2030–Sept 2031): Final Multistate Integration, Impact Assessment, and Report Development. In the final project year, data from all research streams—survey results, forage and nutrition studies, pasture management trials, footing modeling, and technology validation—will be synthesized into a comprehensive multistate report. This milestone supports development of policy recommendations, industry guidance documents, and final Extension outputs. Completion of this milestone marks the end of the project and establishes the foundation for future multistate collaborations.

Outreach Plan

Results will be disseminated through a coordinated multistate Extension network using webinars, fact sheets, digital tools, producer workshops, peer-reviewed publications, and presentations at regional and national equine industry conferences. Tools such as cost calculators, budgeting templates, and footing decision models will be made freely accessible online. Educational materials will be developed to meet accessibility standards, including plain-language summaries and closed-captioned video formats.

Special emphasis will be placed on reaching underserved rural communities, small-scale owners, and equine welfare organizations that experience disproportionate financial strain. Partnerships with state horse councils, rescues, Cooperative Extension, and community groups will ensure broad outreach. The project will engage peer groups to facilitate rapid translation of research findings into practice. Multistate collaboration ensures that outputs serve diverse ecological and economic contexts.

Organization/Governance

Committee of the Whole

Chair- Dr. Robert Causey, UMaine

Secretary- Dr. Rachel White, UMaine

Survey Subcommittee

Nutrition Subcommittee

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Land Grant Participating States/Institutions

ME,FL,MT,PA

Non Land Grant Participating States/Institutions

Participation

Participant	Is Head	Station	Objective	Research			Extension
				KA	SOI	FOS	KA

Response to Reviewer Comments for Proposal NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

1. Scope Too Broad

Reviewer Comment Summary: Two reviewers noted that the project scope was too broad and recommended focusing on a single theme, ideally feed, forage, nutrition, and economic resilience. Reviewers indicated there was strong evidence of capability and feasibility for investigating: (1) economic pressures, horse health, and management practices; (2) cost-effective pasture, forage, nutrition, and climate-adaptive management; (3) horse nutrition practices and cost-saving feeding strategies; and (6) extension and outreach activities. However, reviewers found insufficient evidence of capability and feasibility for objectives related to arena footing design and early lameness detection technologies. They recommended removing Objectives 4 and 5.

Response: We agree that the original scope was ambitious. The primary objectives focused on economic pressures, management practices, nutrition, grazing, and extension outreach represent a cohesive and complementary research and extension program. In response to reviewer feedback, we have removed Objective 4 (arena footing) and Objective 5 (early lameness detection technologies). The revised proposal is now more focused on improving the economic resilience of equine operations through management, forage, nutrition, and outreach efforts.

Specific Comments on Removed Objectives:

Objective 4: Reviewers noted that while the need for evaluating arena footing was well justified, the objective lacked sufficient detail regarding how horse health, rider safety, and operational viability would be quantified. This objective has been removed from the proposal.

Objective 5: Reviewers requested additional information regarding Fit Gait technology, ownership, project implementation, and anticipated outcomes. This objective has also been removed from the proposal.

2. Objectives Vary in Detail and Formatting

Reviewer Comment Summary: Objectives varied considerably in depth, detail, formatting, and citation practices. Some objectives contained substantial methodological information and references, while others lacked sufficient detail, creating a piecemeal appearance.

Response: We recognize that contributors provided varying levels of detail across objectives during proposal development. With the removal of Objectives 4 and 5, we have revised the remaining objectives to improve consistency in organization, level of detail, and formatting. Additional methodological information has been incorporated where appropriate to provide a clearer understanding of proposed activities.

We also reviewed and corrected citations throughout the proposal. References that were no longer relevant or cited have been removed, and remaining citations have been standardized to improve consistency and readability.

3. Omissions

A) Milestones (IRB but not IACUC)

Reviewer Comment Summary: Milestones referenced IRB approvals but did not address IACUC approvals.

Response: Discussion of IACUC approvals has been added to Milestones 1 and 2, where applicable, to ensure that all necessary regulatory approvals are clearly identified within the project timeline.

B) Comparison of Motion Detection Technologies

Reviewer Comment Summary : The proposal did not clearly describe how motion detection technologies would be compared.

Response: The project involving motion detection technologies was associated with the former lameness detection objective, which has been removed from the revised proposal. Therefore, this concern is no longer applicable.

C) Outputs and Milestone Alignment

Reviewer Comment Summary: Outputs were not completely aligned with milestone years. For example, survey data could become available before 2030, yet no corresponding outputs were listed until later years.

Response: We revised the timeline to better align outputs with anticipated project milestones. Outputs associated with survey collection, data analysis, and extension products will now be identified in years that more accurately reflect when results are expected to become available.

4. Editorial and Consistency Issues

Reviewer Comment Summary: Numerous editorial inconsistencies were identified throughout the proposal, including inconsistent heading formats, missing punctuation,

repeated sentences, inconsistent capitalization, and references included in the literature cited section that were not cited within the proposal.

Response: We conducted a comprehensive editorial review of the proposal to improve consistency in formatting, organization, and style. Revisions included:

- Standardizing headings and subheadings throughout the document.
- Correcting punctuation errors.
- Removing duplicated text.
- Standardizing capitalization and formatting conventions.
- Reviewing all references and removing sources that were not cited within the proposal.
- Ensuring consistency between objectives and corresponding sections in the "Related, Current, and Previous Work" section.

5. Objective 2 – Consideration of Vitamins and Minerals

Reviewer Comment Summary: Will vitamins and minerals be considered? Beyond digestible energy requirements, micronutrients are often the primary reason commercial concentrates are recommended. It is generally recognized that many cool-season grass hays, particularly those containing alfalfa, can adequately meet energy and protein requirements.

Response: We agree that vitamin and mineral nutrition is an important component of equine feeding programs. When evaluating forage quality, digestibility, and intake, commercial concentrates that primarily supply energy and protein should not be included because they may confound evaluation of the forage itself. However, appropriate vitamin and mineral supplementation will be provided as necessary to meet animal requirements throughout all studies.

To clarify this distinction, we revised the project descriptions within Objective 2. The revised language distinguishes between evaluation of forage-based feeding strategies and the nutritional management practices required to maintain animal health. Consideration of potentially limiting nutrients and micronutrient deficiencies will be incorporated into project-specific analyses based on forage composition and the physiological class of horses participating in each study.

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Rate the technical merit of the project:

- 1. Sound Scientific approach:
Approve/continue project with revision
- 2. Achievable goals/objectives:
Good
- 3. Appropriate scope of activity to accomplish objectives:
Good
- 4. Potential for significant outputs(products) and outcomes and/or impacts:
Good
- 5. Overall technical merit:
Good

Comments
The proposal addresses an important and highly relevant issue for the equine industry, and the overall vision of strengthening economic resilience is both timely and impactful. After reviewing the proposal, I believe the overall scope is currently too broad and would benefit from strategic narrowing to strengthen feasibility, cohesion, and depth of impact. As written, the project spans multiple largely independent domains, including longitudinal economic surveys, nutrition and forage systems, grazing ecology, arena footing engineering, lameness detection technology validation, and commercialization, each of which could reasonably stand alone as a full multiyear project. This breadth risks diluting scientific depth, overextending personnel and resources, and creating concerns about integration and the likelihood of successful completion. To improve clarity and competitiveness, I recommend focusing the project on a single cohesive theme, ideally feed, forage, and nutrition-driven economic resilience, since feed represents the largest recurring cost in equine operations and aligns strongly with existing expertise and methodological strengths. Concentrating on nutrition, grazing efficiency, and economic decision support tools would create a tightly integrated framework with clear outcomes, measurable impact, and a stronger probability of successful execution, while removing the arena footing modeling and lameness technology commercialization components would substantially improve focus and feasibility.

Your Recommendation:
Approve/continue project with revision

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project with revision

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Good

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Good

Comments

This multistate project proposal aims to improve economic resiliency within the equine industry by investigating and addressing common challenges facing horse owners, equine professionals, and related businesses. By employing an integrated, collaborative approach that builds on prior multistate efforts, the research team plans to generate meaningful knowledge and practical tools that reduce costs and foster sustainability across the equine community. The work is both timely and important, as recent years have brought sharp increases in operational expenses for equine enterprises that reflect broader trends across the U.S. economy. The team argues successfully that failure to meet these economic challenges may result in reduced industry participation, negative horse health and welfare outcomes, and/or decline in rural communities that depend on equine activities.

In general, this proposal has significant potential to deliver products and impacts that would benefit the intended stakeholders. Objectives are clearly stated, the questions addressed concern more than one state or region, and the timeline and anticipated deliverables appear reasonable. However, some parts of the proposal are more successful than others. Specific concerns include:

1. An inconsistent level of detail in methodology described. For example, Objective 2 states ‘Some specific projects are listed below’ for the feeding-efficiency research, but then describes only one project, in somewhat granular detail (albeit without statistical methodology described). This contrasts with Objective 4, which is painted with such a broad brush it is difficult to assess how modeling will be done or whether it will be successfully accomplished. Additionally, references are cited for some objectives but not others. While each objective will of course require a different approach, this lack of consistency, combined with differences in formatting between objectives, sadly contributes to a piecemeal effect in this section.

2. Potential omissions. Milestones include IRB approval, but not IACUC approval. How will you compare data from the force-based kinetic gait analysis system (FitGait) to data from motion-based kinematic gait analysis systems like Sleip (or other IMU/OMC/computer vision systems)? Will you field validate FitGait against other force-based systems (e.g., TekScan, force shoes, other force plates)? No cost analysis for adoption and utilization of FitGait vs. Sleip or other systems is proposed, yet the overarching theme of the proposal is one of increasing cost effectiveness for the benefit of the horse owner. If any of the listed outputs are to be produced during the life of the project, they should be included in their respective milestone years; as written, it appears there will be no outputs expected for any objectives until at least 2030, but it would seem like at least the initial survey data/results would be available before then?

3. Editorial issues. While admittedly this is a more minor concern, the proposal contains many, many formatting, capitalization, and punctuation issues that make this proposal appear to be a draft, rather than a final version. Some of these appear to be cut-and-paste issues related to the online submission process, but others are not. For example, in the ‘Statement of Issues and Justification’ section, (1) one of the bold headings has a colon while the others don’t; (2) descriptions for each start with ‘Justification:’ except for one; (3) there is a missing period after ‘escalate’ in the ‘Assess horse nutrition practices and develop cost-saving feeding strategies’ section; and (4) a sentence is repeated under the ‘Technologies for early lameness detection’ section. As another example, in the ‘Related, Current and Previous Work’ section, (1) some of the bolded subheadings have all capital letters and others don’t; (2) two end with a colon and the other with a period; and (3) only three of the previous five topic areas/objectives are presented here vs. five in the previous section. Numerous additional inconsistencies are found throughout the rest of the document. Additionally, the literature cited includes several references which are, in fact, not cited at all. A more critical editorial eye will reduce these unnecessary mistakes and distractions.

Your Recommendation:

Approve/continue project with revision

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Excellent

3. Appropriate scope of activity to accomplish objectives:

Excellent

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Excellent

Comments

The proposed Multi-State project has great potential to support equine industry in the Northeast through targeted research efforts and clear plan for outreach and dissemination of results. The coordinated efforts of the project will no doubt support continued profitable equine operations in the region.

Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project with revision

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Good

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Good

Comments

The overall breadth of this multistate proposal is strong and provides good justification for investigating feed and footing from an economic standpoint. Questions/Comments:

Objective 2 - Will vitamins/minerals be considered? Beyond DE requirements, micronutrients are the main reason why commercial concentrates are recommended. It seems well known that most cool season grass hay, especially with alfalfa inclusion, provides adequate energy/protein.

Objective 4 - The authors make a strong case for evaluating footing in the introduction, but this objective is weak/needs expansion. How will health, "viability of the equine operation", and "protection of horse and rider" be quantified?

Objective 5 - Is Fit Gait proprietary technology? Who owns it? The project seems sound but needs more details. Project 3 is confusing. Will this group realize profits? Overall, this objective needs expansion.

Your Recommendation:

Approve/continue project with revision

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2650: Building a Resilient Equine Economy: Sustainable Pathways for Horses and Communities

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project with revision

2. Achievable goals/objectives:

Fair

3. Appropriate scope of activity to accomplish objectives:

Fair

4. Potential for significant outputs(products) and outcomes and/or impacts:

Good

5. Overall technical merit:

Good

Comments

This multistate project offers six objectives, all of which are timely and important. However, I have substantial concerns regarding the proposals scope. There is strong evidence for the teams capability and feasibility to investigate (1) economic pressures, horse health, and management practices; (2) cost-effective pasture, forage, nutrition, and climate-adaptive management; (3) horse nutrition practices and cost-saving feeding strategies; and then communicating these findings via extension (6). However, there is poor evidence in capability and feasibility for the two other objectives (4) modelling cost-effective arena footing designs; and (5) technologies for early lameness detection.

My recommendation, if this project is to move forward, is to remove the arena surface and lameness objectives. These are two large and independent projects in their own right; that could be conducted together if there was more information about their integration. Barely a paragraph was included on the methods for these objectives, so it is unclear how exactly they will be conducted. Pertinent references, particularly on the work already being conducted on lameness detection, are also missing.

Focus on advancing knowledge, assessing strategies, decision support tools, and developing extension resources surrounding the goal of sustainable feeding for equine health and welfare should be the goal of this project. If this project were to be revised with this reduction in objectives and one major goal in mind, then more thorough expansion of the methods surrounding these objectives would strengthen the proposal.

Your Recommendation:

Approve/continue project with revision

NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Status: Submitted As Final

Duration

10/01/2026 to 09/30/2031

Admin Advisors:

[\[Anton Bekkerman\]](#)

NIFA Reps:

Non-Technical Summary

Nematodes are unsegmented roundworms that comprise about 70% of the animals on earth. Most of these are very small, requiring a microscope to see them. While small, nematodes serve a variety of functions in the environment, and a balanced nematode community is a key component of soil health. Certain nematodes are plant-parasites that damage plants and contribute to food insecurity and economic losses. The objective of this project is to protect agricultural, horticultural, and forestry crops from harmful plant-parasitic nematodes while maintaining balanced nematode community structure and soil health. Project researchers in multiple states will conduct research to develop nematode management strategies that are effective, practical, and economical. The results will be communicated to public stakeholders using multiple methods depending on the target stakeholder group.

Statement of Issues and Justification

The need. Plant-parasitic nematodes are a major constraint to crop production, causing significant yield losses, quality degradation, and economic damage across nearly all agronomic and horticultural crops. In the northeastern United States, cropping systems and associated nematode pests exhibit a high degree of diversity, reflecting a wide range of region-specific challenges that also align with issues faced in other parts of the country. Key nematode groups of concern include root-knot, lesion, dagger, foliar, stem and bulb, cyst nematodes, and various genera that affect turfgrass. With the phase-out of many older chemical nematicides, discovery of resistance to some of the newer nematicides (17), and nematodes overcoming plant resistance in certain major crops, managing these pests in complex cropping systems has become increasingly difficult—particularly when the goal is to enhance nematode community structure, a recognized indicator of soil health (23, 25). There is an urgent need for controlled environment or high tunnel crop production, and urban agriculture, to cope with these changes. Thus, a comprehensive evaluation of how nematode management strategies influence both nematode community dynamics and soil health across open-field or controlled-environment agricultural systems is needed. This proposed five-year multistate initiative aims to build upon the current project's progress in developing ecologically sound nematode management practices that align with broader goals of soil and plant health.

Importance of work and consequences if not done. Consumers across the United States expect agricultural and horticultural products to be of high quality, affordable, and readily available. To meet these demands, producers in the Northeastern region must manage damaging nematodes effectively while maintaining, enhancing, or restoring soil health. Elevated populations of plant-parasitic nematodes lead to reduced yields and poor-quality crops, threatening farm profitability and food security. Imbalanced nematode communities are also a hallmark of degraded soils. Effective management must therefore focus on suppressing harmful nematodes while promoting beneficial groups—such as bacterial-feeding, fungal-feeding, omnivorous, and predatory nematodes—that play vital roles in soil food webs, nutrient cycling, and biological control.

Farmers are increasingly committed to sustainable nematode management strategies that support soil health. However, they urgently need improved tools and technologies to achieve these goals. Compounding the challenge, invasive nematodes like those responsible for beech leaf disease, and resistance breaking root-knot nematode, *Meloidogyne enterolobii*, are spreading across the region, posing serious threats to forest and ornamental tree health. Additionally, endemic nematode species from southern states (e.g., Florida, California, Hawaii) have the potential to expand into new areas of the U.S., further complicating management efforts.

Without the research and education initiatives outlined in this proposed project, the economic viability and ecological integrity of farms and forests in the Northeast would face potentially devastating challenges.

Technical feasibility of work. Significant progress has been made in the ongoing Multistate Research Project (NE2140) over the past 5 years where we have been demonstrating that many kinds of plant-parasitic nematodes can be reliably managed using ecologically based cultural practices. A partial list of the resulting refereed publications are listed in the reference section These include host-plant resistance (4, 35) nematode-antagonistic cover crops for rotation (3,22, 30, 31, 32, 33, 39,), targeted soil amendments (2, 8, 9, 14, 15, 21, 28, 34, 38, 42, 43, 44), biological control agents (9, 14, 20, 28, 29, 33, 34), and low-risk pesticides (6, 14, 15, 37).

Current research efforts are expanding to assess the ecological impacts of these management systems, with a particular focus on their influence on nematode community structure and overall soil health. In keeping with the principles of integrated pest and soil health management, commercial nematicides, biological controls, soil amendments, cover crops, and resistance genes are being evaluated within cultural and biological frameworks to better understand their compatibility and long-term effects. Project members are among the leaders in fields of nematode management, nematode diagnostics, nematode-microbe interactions, nematode-plant interactions, and nematodes in soil health. Project members are also involved in extension to ensure that research outcomes translate into practical, resilient solutions for growers.

Advantages of a multistate effort. Agriculture in the Northeastern United States is highly diverse, with individual farms often cultivating multiple crops—adding complexity to management decisions. This diversity is mirrored in the wide range of nematode pathogens affecting these crops, further complicating both pest management and grower education. Despite the breadth of cropping systems and nematode challenges, the region has relatively few nematologists, and its agricultural programs are generally smaller than those in the Midwest and South. As a result, individual scientists face the daunting task of developing expertise in the biology, management, and ecological interactions of numerous nematode species across a wide array of crops within their state.

To address these challenges, the project capitalizes on a robust multistate network of nematologists, fostering mutual learning and collaborative problem-solving. Scientists working on similar cropping systems outside the Northeast contribute valuable insights, enriching the group’s collective knowledge. Similarly, identified advances, practices, and solutions have positive impacts in other U.S. regions. Crops studied within the project span small and tree fruits and nuts, diverse vegetables, row crops, turfgrass, nursery and landscape ornamentals, and forest trees. Sharing expertise across regions—especially where certain crops are major commodities in one state but minor in another—enables coordinated educational initiatives and strengthens outreach.

This synergistic approach has already yielded impactful results. The current multistate project has sponsored nematology short courses for agribusiness professionals, focusing on crop losses due to nematodes and management strategies such as rotation, cover cropping, and breeding for resistance. Additional short courses have been delivered for turfgrass professionals in Michigan and Rhode Island, agronomic crop consultants in New York, at the national golf course superintendent’s meetings, and new farmers through Hawaii’s GoFarm training program. These educational efforts have been well received by growers, with capacity audiences in attendance and post-training surveys showing high levels of audience adoption of recommended practices.

Looking ahead, continued collaboration among scientists across states and institutions will be essential for developing efficient, integrated research and education programs that address the evolving nematode management needs of Northeastern agriculture.

What the likely impacts will be from successfully completing the work. Agricultural, horticultural, and forestry industries in the U.S. will be better equipped to manage plant-parasitic nematodes while sustaining soil and environmental health. Members of this group will make strides in the development, integration, and implementation of biorational methods by the contribution of this “think-tank”. By working collaboratively, utilizing the strengths and expertise of the individual members to benefit the efforts of the whole, they will achieve more positive outcomes and make greater impacts for stakeholders than working independently.

Related, Current and Previous Work

While a few other NIMSS projects address nematode management issues, only a small number share partial overlap with the subject matter of the proposed NE2640 project. These projects do not focus on the same newly emerging nematode pests, nor do they consider the broad diversity of cropping systems encompassed by NE2640. This limited alignment underscores critical research gaps and unmet grower needs that would remain unaddressed without the implementation of our proposed project.

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 soil health focus is on pathogen interactions and fertilizer use efficiency. Senyu Chen and Haddish Melakeberhan overlap on both projects.

S1092/S1096. Biology, ecology, and management of emerging nematode threats in the Southern United States. This project focuses on Southern region of the U.S. which is different from our Northeastern region focus. No members overlap on both projects.

W5186. 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. Soil health is not a focus on W5186. Root-knot and cyst-forming nematodes are the primary focus. Haddish Melakeberhan overlaps this project.

Objectives

1. 1. Develop new sustainable nematode management strategies through judicious use of nematicides, biological control and bionematicides, deployment of resistant varieties and rootstocks, strategic cover cropping and crop rotation, and soil amendments for open field as well as high tunnel and protected agriculture.
Comments: Overreliance on a single nematode management tool, whether chemical or genetic, has been shown to be unsustainable for most agricultural systems. Members of our group have recently detected nematicide resistance in several species of plant-parasitic nematodes resulting in grower overuse of a single class of new-generation nematicides. Similarly, soybean cyst nematode management has relied on a single source of plant resistance whose long-term use has selected for resistance breaking nematode populations. Therefore, our investigations of plant-parasitic nematode management will focus on the development of multiple tactics and integrating them into effective, economical, and sustainable programs using strategies discussed below.
 2. 2. Determine the impacts of nematode management on environmental health by using nematodes as bioindicators of soil health.
Comments: Participants will assess changes in nematode community structure in response to different agricultural practices or using entomopathogenic nematodes as biocontrol agents against insect pests.
 3. 3. Understanding nematode-microbe interactions for: a. plant disease management, b. stimulation of plant defense, and c. development of suppressive soil.
Comments: Use of biological control of plant pests is increasingly important due to public demand for reduced reliance on pesticides.
 4. 4. Exploring new and emerging nematode problems impacting agriculture, horticulture, and forestry, including but not limited to beach leaf disease, b. tropical root-knot nematodes in protected agriculture systems, c. foliar nematodes in horticulture crops, c. and invasive nematode spread into new regions.
Comments: Extreme weather patterns, human activity, over-reliance on individual sources of resistance, and loss of certain nematicides have contributed to the rise of new nematode challenges. Because these emerging nematode pests are not well characterized, this project will target on addressing emerging problems in nematode management.
 5. 5. Public engagement related to integrated nematode management: a. Nematode diagnostics, b. Stakeholder education and training, c. Resource development and delivery, i.e. extension publications, web, social media, SCN Coalition, etc.
Comments: Our end goal is not just to investigate, but to produce transformational results that are used by stakeholders to enhance their economic and environmental sustainability.
-

Methods

Objective 1: Develop new sustainable nematode management strategies through judicious use of nematicides, biological control and bionematicides, deployment of resistant varieties and rootstocks, strategic cover cropping and crop rotation, and soil amendments for open field as well as high tunnel and protected agriculture.

Group members (FL, RI) will continue to study nematicide resistance and resistance management in turfgrass systems. Long-term nematicide rotations experiments have been initiated to evaluate integration of different nematicides and bionematicides in programs to effectively manage plant-parasitic nematodes on turf while avoiding nematicide resistance. Another project is to identify the mechanisms and genetics involved in nematicide resistance to develop rapid resistance detection protocols for use in diagnostic settings for rapid resistance detection.

Members Our members (FL, RI, MI, CA, PA) will work with industry partners evaluating new nematicide and bionematicide active ingredients and formulations for use against plant-parasitic nematodes in our relevant cropping systems. Members in CA, GA, HI, MI and elsewhere will study biological mechanisms of nematode suppressive soil (bacteria, fungi, tc.) and ways they can be manipulated to induce nematode suppression. Some of our members work largely with minor-use, specialty, and forestry crops that are considered niche markets by large pesticide manufacturers and not given much effort by them. Therefore, our efforts provide a key service to our stakeholders, assisting to bring them nematode management tools and developing the information on how these tools can be best used in their specific situations.

Some of our members (MI, GA) work with large agricultural crops like soybean, peanut, potato, and cotton, others work primarily with small diverse farms with high-value crops (PA, HI, CA, RI, FL). We plan to continue our ongoing efforts to evaluate crop rotations and cover crops that can be used to manage plant-parasitic nematodes and promote soil health. We will work with public and private plant breeders to develop and test nematode resistance in our stakeholder's crops. Our members will continue evaluating soil amendments for nematode suppression and how they can be used effectively and economically by our stakeholders.

Objective 2: Determine the impacts of nematode management on environmental health by using nematodes as bioindicators of soil health;

Participants will assess changes in nematode community structure in response to different agricultural practices or using entomopathogenic nematodes as biocontrol agents against insect pests (3, 41).

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 (40). Effects of cover crops on the nematode community will be assessed in field experiments (HI, MI, GA). Soil quality aspects will also be assessed in some of these trials.

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 in potato (MI); turfgrass (FL), and vegetables (HI). Nematode community analyses will be employed as indicators of soil health. The nature of the organic amendments tested will vary by state depending on the availability of local materials, crops grown, and local conditions, but will include locally sourced composts, biofumigation crops, agriculture waste materials, manures, and biochar.

A combination of the soil food web model and the fertilizer use efficiency model (25), will be applied to identify sustainable outcomes (MI). We hope to identify parameters of soil conditions related to location-specific and/or broad approaches to nematode communities and soil health objectives and manipulate these under field conditions

Objective 3: Understanding nematode-microbe interactions for: a. plant disease management, b. stimulation of plant defense, and c. development of suppressive soil.

A number of long-term studies (HI, MI), either through cover cropping, soil amendment, conservation tillage practice, shelterbelt planting, or sheet mulching, will be conducted in organic farming systems, either on commercial farms or at experiment stations, to address the increasing needs of organic pest management strategies. In GA, different crop rotations will be evaluated for enhanced suppression of root-knot nematodes by the bacterial nematode-parasite *Pasteuria penetrans*. Understanding the effects of farming practices on changes in soil microbiomes or an increase in predatory nematodes that can eventually contribute to nematode-suppressive soils is a key component of this objective.

The recycling of organic farm waste for nematode management is becoming more popular. Additional effort will also be explored to investigate the potential of using soil organic amendments to enhance plant-growth-promoting rhizobacteria (PGPR), while triggering the induced systemic resistance (ISR) pathway in plants will also be studied. For example, research in FL will seek to identify specific actinomycete strains present in nematode-suppressive compost that enhance plant defenses to nematodes.

In HA organic wastes including manure, nut processing residues, and vegetable processing residues will be evaluated for biofumigation and nematode suppressive effects. Group members in PA, CA, HI, and MI will conduct experiments evaluating anaerobic soil disinfestation (ASD) using locally available organic materials with or without addition of target microbes to enhance the anaerobic conditions. In HA and CA residues from nematode antagonistic cover crops such as sudangrass ‘Piper’, crotalaria, and velvetbean will be evaluated as substrates for ASD. In PA, biochar together with *Trichoderma* spp., *Bacillus* spp., *Paenibacillus* spp. will be evaluated for enhanced nematode suppression in high-tunnel vegetable production.

Objective 4. Exploring new and emerging nematode problems impacting agriculture, horticulture, and forestry: a. Beech leaf disease, b. tropical root-knot nematodes in protected agriculture systems, c. foliar nematodes in horticulture crops, c. invasive nematode spread into new regions.

Beech leaf disease was first reported in Ohio in 2012 and diagnosed to be caused by a new nematode species, *Litylenchus creatae*. The disease has since been spread to beech trees in Pennsylvania, New York, Connecticut, 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 and its management will be evaluated in forestry, landscape, and nursery settings (PA, RI, OH).

Foliar nematodes, *Aphelenchoides* spp. are problems in ornamental plant nurseries and landscapes, with *A. pseudobesseyi* being a major problem in tropical regions like FL and *A. fragaria* being common in temperate regions like the NE US. Additionally, studies of beech leaf disease have found an unknown species of *Aphelenchoides* associated with beech leaf nematode, but the relationships and interactions between these two nematodes are unknown. Studies will be conducted to better understand the dispersal of these nematodes, the threats they cause, and their management (FL, PA, OH, MI).

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 new pattern of weather (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 due to its vegetative mode of propagation. As warm-season grasses are adopted farther north, golf course superintendents are faced with new nematode problems. Our research will seek ways to slow the spread of these nematodes and to identify managements tactics for them relevant to the NE region (RI, FL).

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. Preemptive measures need to be in place before these nematodes are detected in HI. Further, the tropical species *M. javanica* has recently been identified as a major problem in high-tunnel production in PA. The dispersal and management of these tropical nematodes in protected agriculture will be studied (PA, RI, HI, FL, MI).

Week-long short-courses for plant diagnosticians will be conducted in PA and FL to enhance diagnosticians skill in identifying plant-parasitic nematodes with emphasis on emerging and invasive pest nematodes. These trainings will be conducted in collaboration with the National Plant Diagnostic Network.

Objective 5. Public engagement related to integrated nematode management: a. Nematode diagnostics, b. Stakeholder education and training, c. Resource development and delivery, i.e. extension publications, web, social media, SCN Coalition, etc.

Measurement of Progress and Results

Outputs

- • At least one manuscript per year will be produced by each PI related to objectives 1-4, and at least two extension articles will be produced in each state each year (Objective 5).
- • At least one graduate student will be trained and graduated by most PIs during this 5 years. These will be capable of serving as the next generation of nematologists/soil health promoting scientists.
- • Recommendations for cover crops that suppress nematodes and enhance soil health will be available via referred publication and extension publications in member states.
- • Recommendations for use of new reduced-risk nematicides and bionematicides will be available through extension publication in member states.
- • Nematicide resistance detection protocols will be developed and implemented.
- • Results of screening turfgrass cultivars for resistance to sting, lance and root knot nematodes will be available.
- • Recommendations for using soil amendments for nematode management will be available through extension publication in member states.
- • The composition of plant-parasitic nematodes in high-tunnel production in member states and appropriate management practices for them will be known.
- • Dispersal of beech leaf nematode will be better understood.
- • 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/>), and extension newsletter articles to update research conducted on sheet mulching and nematode survey for Hawaii will be shared with stakeholders.

Outcomes or Projected Impacts

- • Use of a soybean cyst nematode trap crop will be adopted in multiple states.
- • A combined remote and ground truth nematode sampling protocol will become accepted by the discipline of nematology.
- • Tree fruit producers will have new recommendations for managing dagger nematode and Peach Stem Pitting disease.
- • High-tunnel producers will be aware of the current problem with root-knot nematodes and have management strategies for them.
- • Understanding of nematicide resistance will facilitate adoption of rotation of active ingredients and integrated pest management.
- • 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

(2026): • Initiate studies on resistance detection in plant-parasitic nematodes • Continue field studies on resistance management in golf turf. • Initiate studies of microbial components of nematode suppression in compost • 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. • Maintain nematode diagnostic services for growers and extension specialists. • Select high-tunnel cooperators for sampling nematode communities.

(2027): • 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 plant-parasitic nematodes. • 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, webinars, field days, conduct site visits. • Complete studies on resistance detection. Submit for publication. • Publish preliminary results

(2028): • 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. • 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 • Deducing relationships between cover crop rhizosphere and microbial communities. • Conduct NPDN workshop on nematicide resistance detection

(2029):• 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

(2030):• 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 • Continue grower education • Summarize and update Cover Crop recommendation website (<https://cms.ctahr.hawaii.edu/wangkh/Research-and-Extension/Cover-Crops>)

Outreach Plan

Nematode diagnostics: Several members (FL, PA, RI) are formally involved in nematode diagnostics, while most others assist with diagnostics to various degrees. As diagnosticians, these serve as first-detectors for new and invasive plant-parasitic nematodes and nematode-host associations, and monitors of nematode geographical dispersal. As new detections and observations are made these members will inform the relevant state and federal regulatory agencies in real time through established protocols, the scientific community through refereed publications and presentations at scientific meetings, and stakeholders through cooperative extension programing. As individual diagnoses are conducted, the best nematode management practices resulting from the project research will be communicated directly to the stakeholders.

Short-courses: Nematode identification short-courses for diagnosticians will be conducted through coordination with the National Plant Diagnostics network in the Southern region (FL) and the Northeastern region (PA). These workshops will prepare diagnosticians to know how to properly process plant and soil materials from different crops in the region, how to identify and diagnose common pest nematodes that threaten agriculture in the region, and how to recognize invasive pest nematodes when they occur.

Nematicide resistance detection methodologies being developed by members in FL will be immediately implemented by the Florida Nematode Assay Lab as a standard service. The methodologies will be disseminated to the scientific community through referred publication and presentations at scientific meetings. Further, an online workshop for diagnosticians nationwide will be hosted by members in FL through the National Plant Diagnostic Network.

Resource development and delivery: Specific to the soybean cyst nematode outreach plan, new findings and general information will be made available to the agricultural community and other stakeholders through participation in the Soybean Cyst Nematode Coalition as well as through individual members extension programs.

Other NE-2640 Extension and Outreach 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 participating states. Participation in each of the seven activity areas is documented in the table below. Members in FL and RI will jointly conduct 4-hour training on nematode management on golf courses with warm and cool-season grasses for golf-course superintendents nationwide at the Golf Course Superintendents of America annual conference

NE-2640 Extension-Outreach-Public Relations	Participating States
Grower-Clientele Meetings	CA, FL, HI, MI, PA, OH, RI.
Demonstration Field Days	CA, FL, HI, MI, PA, RI, GA
Local, State and Regional Media Events	MI, PA, FL, HI, RI
Extension Bulletins-Other Publications	FL, HI, MI, PA
Short Courses	FL, PA
Direct Grower-Clientele Contacts	CA, FL, PA, HI, MI, OH, RI, TN.

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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Land Grant Participating States/Institutions

PA,TN,HI,CA

Non Land Grant Participating States/Institutions

Participation

Participant	Is Head	Station	Objective	Research			Extension
				KA	SOI	FOS	KA

NE 2640 Response to reviewer comments

- Regarding Objective 2, will soil microbiome analyses be conducted? Will organisms such as bacteria and fungi be considered in the nematode-suppressive soils? Will the work under this objective be more observational or manipulative in nature?
 - Our members are focused on effects of agriculture practices on nematode communities rather than the entire microbiome. Our members might evaluate microbiomes impacts as projects develop with collaborators outside NE 2640 directly, but with no definite plans for doing so at this time, we decided to leave that out of the proposal.
 - Regarding suppressive soils, that falls more under Objective 3. We added information to Objective 3 in the Methods section to address this.
- In Objective 4, will systematic surveys for these emerging species be conducted in the participating regions? Will training on morphological and molecular identification of these species be given? Will mechanisms of preventing spread be researched?
 - We currently have no plans for systematic surveys. Instead, we are relying on our members that are involved with nematode diagnostic labs and their connections through the National Plant Diagnostic network for detection and monitoring of emerging species.
 - Yes, we will conduct workshops in FL and PA for diagnosticians to enhance their morphological and molecular nematode diagnostic skills. We have already been in communication with the Southern and Northeastern coordinators of NPDN about this. We added detail on these workshops in the Methods section of Objective 4 and in the Outreach sections.
 - We added to the Methods section of Objective 4 to address the dispersal question.
- One objective refers to the use of organic soil amendments (what kind?) to enhance plant-growth-promoting rhizobacteria (PGPR), but does not specify the types of amendments to be evaluated. Or how the induced systemic resistance (ISR) pathways would be studied. There are so many different projects that it feels like information is missing. For example, the first impact listed refers to the adoption of trap crops for soybean management, yet trap crops are not clearly described elsewhere in the proposal.

- We added content to Objective Methods to provide more detail.
- The group reports that there was significant progress over the last 5 yrs (Technically feasible work section), but no specific pubs or reports. Was this an oversight?
 - The resulting publications from NE 2140 are now listed in the reference section
- There is mention of a nematode short course, and it was successful. How was success measured? Number of people in attendance, number of states represented. If that data was not captured and is proposed again, how will it be captured in the next five years?
 - We added a sentence to address this.
- In the statement of issues and Justification, I would suggest one word change. The sentence, "There is an urgent need for controlled environment or high tunnel crop production, and urban agriculture, to cope with these changes. I would change this to read, There is an urgent need for scientifically based environment or high tunnel crop production, and urban agriculture, to cope with these changes."
 - Done
- Are there any specific projects that individual groups are working on together, or a uniform protocol? There are a lot of projects or such a small group. Is this practical?
 - We believe the strength and uniqueness of our project is its diversity. While some multi-state projects are focused on a single problem on a single crop, we work primarily on unaddressed problems on niche commodities. We are located in different regions, working with different crops in different environments, making uniform protocols all but impossible, However, we are united by common objectives of improving agriculture profitability and sustainability by managing pest nematodes effectively and responsibly. We learn from each other, collaborate, and exchange ideas, many of which are outside-the-box. We do have a number of joint projects between several group members in different states, that we tried to make more evident in the edited proposal, but no single project that all members are working on.

We have a very productive group, which does make for a lot of projects for such a small group. However, all the projects listed are ones that we have already started or are planning, so yes, we believe they are practical.

- The number of outcomes and milestones is tremendous. It just seems like a lot of outputs for such a small group. Can this be justified or scaled back?
 - Yes, there are a lot of outcomes milestones, but we are a very productive group and are confident that they will be met.

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Excellent

3. Appropriate scope of activity to accomplish objectives:

Fair

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Good

Comments

This multistate project has five, mainly 1) to investigate integrated use of nematode management strategies and tactics, 2) investigate the impacts of these management strategies on environmental health using nematodes as bioindicators, 3)expanding our understanding of nematode-micro-plant interactions to leverage this knowledge for management, 4) investigate new and emerging nematode pathogens in the region, and 5) share and integrate knowledge gained through this project with stakeholders. Although each objective is distinct and rigorous in isolation, they are interwoven such that more comprehensive findings, outcomes, and impacts can be achieved when these objectives are taken together.

Strengths of the project:

This multistate project leverages diagnostic networks and stakeholder education programs that are already in place, which ensures immediate application of technical knowledge and a mechanism for dispersing findings to stakeholders.

Several of the emerging species are fairly specific to certain regions, such as the beech leaf disease nematode (*Lityenchus creanatae*) in the upper mid-west or *Meloidogyne floridensis* in California. However, it is a strength of this project for members to communicate and coordinate between regions about these emerging species, thus supporting early detection and intervention.

Currently, options are limited for plant-parasitic nematode management in organic agriculture. This multistate project addresses this shortcoming, specifically through Obj. 1 (biocontrol, resistant varieties and rootstocks, cover cropping, soil amendments), Obj. 2 (expanding knowledge of soil health), and Obj. 3 (stimulating plant defenses and promoting suppressive soils).

The Outputs and Outcomes of this project are appropriately scaled for the objectives and duration of the project. The proposed milestones appear achievable.

Suggestions:

The project write-up was a little short on methodology and specifics of how the objectives will be achieved. For example, regarding Objective 2, will soil microbiome analyses be conducted? Will organisms such as bacteria and fungi be considered in the nematode-suppressive soils? Will the work under this objective be more observational or manipulative in nature? In Objective 4, will systematic surveys for these emerging species be conducted in the participating regions? Will training on morphological and molecular identification of these species be given? Will mechanisms of preventing spread be researched?

Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Excellent

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Good

Comments

Strengths

This multistate project brings together complementary, transgenerational expertise across a wide range of cropping systems, encompassing soil health, nematode management, and nematode diagnostics. The research is timely and important given the significant impacts of plant-parasitic nematodes on agriculture and the diminishing number of management options available to growers. The emphasis on developing new tools, such as plant resistance and suppressive soils, represents particularly promising and new avenues of investigation.

The project has five objectives which reflect the strengths of the scientists on the project. These objectives are quite diverse but overall, they are unified by a common theme of sustainable nematode management and soil health-based research. The inclusion of nematode diagnostics and emerging nematode problems enhances the relevance and potential impact of the project.

Weaknesses

The project covers a very broad range of topics, and as a result, many of the methods are not well described. While this is understandable given the diversity of the project and page-length limitations, the proposal would benefit from more concrete examples of the approaches to be implemented. For example, one project refers to the use of organic soil amendments (what kind?) to enhance plant-growth-promoting rhizobacteria (PGPR), but does not specify the types of amendments to be evaluated. Or how the induced systemic resistance (ISR) pathways would be studied. There are so many different projects that it feels like information is missing. For example, the first impact listed refers to the adoption of trap crops for soybean management, yet trap crops are not clearly described elsewhere in the proposal.

Overall, this project brings together a strong and diverse group of nematologists whose combined expertise positions this hatch project for success. The authors of this renewal have done a great job integrating multiple projects under the broader themes of nematode management and soil health. Although the proposal relies at times on broad statements and would benefit from greater methodological detail, the overall intent is clear, scientifically sound, and deserving of continued support.

Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project with revision

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Good

4. Potential for significant outputs(products) and outcomes and/or impacts:

Good

5. Overall technical merit:

Good

Comments

It is clear from the multi-state research project that there is a lot of need for research described and too few to do all the work. The group reports that there was significant progress over the last 5 yrs (Technically feasible work section), but no specific pubs or reports. Was this an oversight? Similarly, there was not a lot of information in the related, current, and previous work areas, except for how this project is different from others. Again, this could use some work. For reasons above, the scientific approach is rated fair. The only place with citations is objective 4. So, it would appear that one group provided detailed feedback on one objective for the report. There is mention of a nematode short course, and it was successful. How was success measured? Number of people in attendance, number of states represented. If that data was not captured and is proposed again, how will it be captured in the next five years?

There does seem to be scientists working on the same or similar projects. Are there any specific projects individual groups are working on together, or a uniform protocol? There are a lot of projects or such a small group. Is this practical? If so, and it was completed last time, where are those pubs in the previous work area?

Some of the outcomes are very specific, like a new trap crop being used, which is interesting. Seems like some background information on this would fit in the general details on research progress, given that it has been proven by some research. Then there are very general comments about trap crops, which are hard to tell where it fits and with what project.

Lots of projects. Nematodes are the focus. The number of outcomes and milestones is tremendous. It just seems like a lot of outputs for such a small group.

Your Recommendation:

Approve/continue project with revision

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Excellent

4. Potential for significant outputs(products) and outcomes and/or impacts:

Good

5. Overall technical merit:

Excellent

Comments

Nematode management is a critical and often underestimated component of plant and soil health. This project proposal is relevant to stakeholders in the northeast, well written and the methods and objectives are adequately explained.

The team is highly experienced and well suited to achieve the objectives and milestones outlined in the proposal.

Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2640: Effective Management of Nematodes in Plant and Soil Health Systems

Rate the technical merit of the project:

- 1. Sound Scientific approach:
Approve/continue project
 - 2. Achievable goals/objectives:
Excellent
 - 3. Appropriate scope of activity to accomplish objectives:
Excellent
 - 4. Potential for significant outputs(products) and outcomes and/or impacts:
Excellent
 - 5. Overall technical merit:
Excellent
- Comments

I am pleased to accept this project. Protecting crops from harmful plant-parasitic nematodes while maintaining balanced soil health is critical for sustainable agriculture and food security. I look forward to seeing the results of the development of practical and effective management strategies.

In the statement of issues and Justification, I would suggest one word change. The sentence, "There is an urgent need for controlled environment or high tunnel crop production, and urban agriculture, to cope with these changes. I would change this to read, There is an urgent need for scientifically based environment or high tunnel crop production, and urban agriculture, to cope with these changes."

Your Recommendation:
Approve/continue project

NE_TEMP2603: Advancing high tunnel specialty crop production

Status: Submitted As Final

Duration

10/01/2026 to 09/30/2031

Admin Advisors:

[[Anton Bekkerman](#)]

NIFA Reps:

Non-Technical Summary

High tunnels systems are low-tech greenhouse-like structures that increase the length of the growing season, yield, crop quality, and nutrient uptake efficiency, and provide some climactic control compared to field production. Myriad research and extension activities related to high tunnel production are taking place across the U.S. However, due to the broad geographic dispersal of high tunnel research and extension personnel, a forum to promote coordination and collaboration is needed to support multi-state, multi-institutional, and cross-disciplinary approaches to solve common problems. Thus, this multistate research project seeks to Advance High Tunnel Specialty Crop Production. Project members aim to work in a coordinated manner to: 1) Assess high tunnel systems in the U.S. to determine rates of adoption, technology use, and impact on U.S. food production, 2) Identify and study effective crop management strategies, including pest and disease management, in high tunnel systems, 3) Identify cost-effective uses of engineering, technology, and infrastructure to improve environmental control and crop health within high tunnels, and 4) Investigate and develop strategies for sustainable soil health management in high tunnel systems.

Statement of Issues and Justification

High tunnels are portable, greenhouse-like structures with a single or double layer of plastic, with or without supplemental heat, power, or mechanical ventilation, with crops usually grown in-ground (Wells and Loy, 1993). High tunnels increase the length of the growing season, yield, fruit quality, and nutrient uptake efficiency, and provide some climactic control compared to field production (Reeve and Drost, 2012) at lower expense than heated greenhouses. High tunnel production became widespread in the 1990s and has increased dramatically in recent years as federal conservation initiatives through the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) incentivized installation of new tunnels beginning in 2009. For example, between 2017-2020, over 2000 contracts for high tunnels were awarded annually through the NRCS high tunnel initiative (Donovan et al., 2023). High tunnels funded by NRCS have specific requirements that set them apart from other protected culture practices (e.g., low tunnels, some caterpillar tunnels, and soilless hydroponic systems): 1) crops must be grown in natural soil although up to 12 inch (depth) raised beds are allowed, 2) the high tunnel must stand 6 ft tall or higher, 3) the maximum size allowed is 2,160 ft², and 4) tunnels must be built from pre-approved kits (no DIY designs allowed). Heating/cooling units or electricity is not covered by NRCS funding, but growers can install these tools on their own. This style of high tunnel dominates protected culture in the U.S., so this project will focus on developing innovative pest, soil, and climate control tools tailored to these systems.

High tunnels are typically used to lengthen the growing season for warm-season crops such as tomato, eggplant, pepper, and cucurbits (Carey et al., 2009; Fitzgerald and Hutton, 2012; Knewtson et al., 2010; Lamont, 2009; O'Connell et al., 2012; Gong et al., 2022). High tunnels also permit growers in colder climates to grow crops during times when it would otherwise not be possible, and to grow perennial crops that could not be grown in the region otherwise, thereby increasing market opportunities (Fitzgerald and Hutton 2012, Sideman unpublished data). Several studies have shown that high tunnels confer yield and quality benefits (Frey et al., 2020, O'Connell et al., 2012, and many others). In addition to increasing economic stability and earnings, farmers report better yields, easier management of some pests and diseases, and an increased quality of life when using high tunnels on their farms (Bruce et al. 2019a, 2019b).

Several regional surveys of high tunnel producers and extension professionals have identified benefits and advantages of using high tunnels, as well as challenges that define research and educational needs (Fitzgerald and Hutton 2012, Foust-Meyer and O-Rourke 2015, Bruce et al. 2019b, Sideman et al. unpublished; Nian et al. 2025). The protected environment created by high tunnels not only alters crop growth as compared with open field conditions, but also modifies soil moisture dynamics, nutrient mineralization and leaching, the environmental suitability for pest and disease development, and behavior of pathogens and both pest and non-pest organisms including natural enemies and pollinators. With their small area and high land value, high tunnel soils are often managed intensively, with heavy (and possibly excessive) inputs of fertilizer and other amendments. The many differences between high tunnel and open field production necessitate the use of crop varieties, entire production systems, and pest and disease management strategies unique to high tunnels. Management challenges also exist, such as increased labor and time requirements and increased complexity of high tunnel production (Bruce et al., 2019b). Thus, several research and outreach priorities and challenges are specific to high tunnel systems. While there are certainly regional differences, many of the high-priority challenges related to high tunnel production are common to producers across a wide geographic area.

According to Lamont (2009), the U.S. had approximately 5,000 ha of high tunnels and greenhouses combined at that time. In 2010, the USDA-NRCS began to incentivize new high tunnel installations; 9,489 high tunnels (representing at least 176 ha) were added throughout the U.S. between Jan 2010 and Dec 2013 alone (Foust-Meyer and O-Rourke 2015). However, despite increasing prevalence of high tunnels, we don't have accurate data about how many high tunnels are in operation throughout the U.S. or about their economic importance to small- and mid-sized farms. The U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) groups all protected cultivation (high-tech greenhouses and low-tech high tunnels) together. Estimates obtained through an informal survey conducted by Carey et al (2009) were highly variable, and high tunnel definitions were not consistent.

Myriad research and extension activities related to high tunnel production are taking place across the U.S. However, due to the broad geographic dispersal of high tunnel research and extension personnel, a forum to promote coordination and collaboration is needed to support multi-state, multi-institutional, and cross-disciplinary approaches to solve common problems.

In 2020, the multistate coordinating committee NECC-2103 *High tunnel specialty crop production*, was formed. The purpose of this coordinating committee was to facilitate collaboration across states to: 1) characterize the high tunnel 'landscape', e.g., to quantify high tunnel acreage and production systems, 2) research pests and diseases unique to high tunnel production systems, 3) determine adaptability of new cultivars to high tunnel production systems, 4) research strategies to optimize soil, nutrient, water, temperature, and crop management in high tunnels, and 5) share research plans to avoid duplication and inefficient use of resources, and to foster multi-institutional and cross-disciplinary research.

Since inception, this committee has met regularly and has built its membership steadily; NECC 2103 currently has 28 members from 16 states. Over the last year, the coordinating committee officers met and discussed with membership whether to continue as a coordinating committee, or to instead propose a multi-state research proposal. We decided to move forward with a proposal to create a multistate research project focused on *Advancing high tunnel specialty crop production*. Since the inception of NECC 2103, the number of faculty and extension educators in CEA has increased across the U.S., further justifying the need for this multistate project.

Related, Current and Previous Work

While representing a unique focus, the activities of this multistate project complement other projects: NE1835-*Resource Optimization in Controlled Environment Agriculture* (which is primarily focused on higher-tech greenhouses rather than lower-tech high tunnels), SERA45-*Crop Diversification Opportunities to Enhance the Viability of Small Farms*, which includes protected agriculture as one strategy for crop diversification, and NE2401-*Urban Agriculture: Innovation, Stewardship, and Local Engagement*. We envision possible linkages and information sharing between these groups.

Below, we present a short description of the situation, previous work, and needs relating to each of our four objectives.

Objective 1: Assessment of high tunnels in the U.S. to determine rates of adoption, technology use, and impact on U.S. food production

A challenge with conducting research and outreach related to HT systems is that we do not have an accurate assessment of the impact, in acreage or production value, of crops grown in these low-tech and cost-effective protected production systems. Grower surveys and other qualitative / quantitative approaches have been conducted by separate researchers in different geographic areas to try to better understand the HT landscape. For example, tomatoes were found to be the most commonly grown crop in HT systems, followed by cucumber and leafy greens, and to a lesser extent, cut flowers, eggplants, peppers, and a variety of other crops in past surveys (Fitzgerald and Hutton 2012, Carey et al. 2009, Lamont 2009). However, these surveys are quite dated and limited in describing the current role HTs have for specialty crop production at larger regional or national level. Current data relies on NRCS reporting and USDA census, the latter of which lumps high tunnel production with high tech greenhouses as the category “Crops Grown Under Glass or Other Protection”. It has been 16 years since the NRCS cost-share initiative, so there is clearly a need to survey HT production to determine impact and the importance of HTs on local food systems.

In addition, substantial advancements have been made in agricultural technology and the extent to which these innovations have been adopted by HT growers is unknown. There is a range of technologies observed in HTs including the use of movable HT technologies, supplemental heating, cooling or lighting, different types and the degree of automation of ventilation (roof vents, roll-up or roll-down sides, end-wall vents, etc.) and irrigation systems, environmental monitoring systems, the use of specialty films, energy curtains, shade cloth, insect exclusion netting, supplementary row covers, and spraying technology. We also lack concrete data on the costs and benefits of these practices, which limits our ability to help producers with data-driven decision making to guide investment decisions.

This objective will fill critical knowledge gaps in current rates of HT adoption and use of technology in HTs, at both a regional and national level. This effort will improve our understanding of HTs in our region(s) and will help ensure that research and outreach investments are made wisely and that they are most impactful to stakeholders.

Objective 2: Improvement and optimization of Crop management strategies, including pest and disease management, in HT systems.

Pest and disease management: Pest and disease complexes in HTs frequently differ from those seen in outdoor conditions, due to many factors including altered light, temperature, precipitation, humidity, length of growing season, and myriad other factors (Couture et al. 2023; Cramer et al. 2019). For example, pests can have an expanded overwinter survival range with the protection offered by HTs, and the efficacy of biological control organisms can be impacted by these environmental variables (Ingwell et al. 2018). Pest pressure in HTs often exceeds the open field because pests can establish earlier and reach thresholds faster. There is a need to better understand the biology and management of pests and diseases that are prevalent in HT systems. Current pest/disease management tools available to HT growers are restricted to those tailored to the open field or greenhouse systems. However, HT environments are unique and may not always resemble either. Many U.S. states interpret HTs as traditional greenhouses, therefore only greenhouse-labeled pesticides can be applied in HTs. There are many open-field pests/diseases present in HTs that are not included on these labels. Preventative tactics, FIFRA Section 25(b) minimum risk pesticide products, and biocontrol are sometimes the only options for HT growers. How to use these products in HTs is a large knowledge gap, as release/spray rates are likely to differ compared open-field and greenhouse systems. This objective will fill these important knowledge gaps across regions and provide more tailored guidelines for pest/disease management for HT production.

Managing abiotic disorders: The HT environment presents unique challenges and opportunities for each crop. While HTs commonly increase yield potential, they can also alter (and sometimes increase) the prevalence of disorders that reduce marketability, such as yellow shoulder in tomato (Pandey et al., 2024). Crops grown in HTs are often managed very differently than the same crop grown outdoors, to capitalize on the extended growing season and improved environmental control. Crops grown in HTs are also managed differently from the same crops grown in greenhouse systems, where even more environmental control is possible, and systems allow for precision nutrition, light, and water management. Slight differences in crop management (e.g. spacing, pruning, fruit thinning, harvest strategies, etc.) can result in large differences in crop quality and productivity (Torres-Quezada and Gandini-Taveras 2023, Reid et al. 2023, Gude et al. 2022, Aurora et al. 2024, Murariu et al. 2021). There is a need to identify cultivars adapted to HT production, as well as those with resistance or tolerance to HT pests and disease complexes.

Objective 3: Cost-effective uses of engineering, technology, and infrastructure to reduce labor requirements and improve environmental control and crop health within HT.

HT systems are commonly used on highly diversified small- to medium-scale farms, in part because they represent a relatively small investment in comparison with high-tech greenhouses. HTs offer an intermediate level of environmental control, compared with uncontrolled open-field and highly controlled greenhouses. HTs can be equipped with a wide range of technologies and infrastructure that permit ever increasing environmental control and mechanization, with varying degrees of investment required. The semi-controlled environment provided by HT systems has been shown to increase yield and quality of a wide array of specialty crops (Carey et al. 2009).

In high-tech greenhouses, a suite of technologies and infrastructure investments are used to maximize control of the crop environment and to increase labor efficiency. Technological advancements are occurring rapidly, and the cost of implementing such technologies is decreasing rapidly. While the degree to which specific innovations have been adopted in HTs has not been quantified formally, we do know that some innovations have been adopted more widely (supplemental heating, the use of supplemental row covers for winter protection) than others (sensor-driven irrigation, mechanized ventilation). There are also newer approaches being adapted for use in HT conditions. For example, environmental modification strategies such as evaporative cooling and fogging systems have been shown to mitigate heat stress, reduce physiological disorders, and increase yields in HT systems (Sharaf-Eldin et al., 2023). With rapid innovation in greenhouse technologies, continuous evaluation of the suitability of new technology for use in HT systems, and adaptation to use by diversified and small-scale producers, is needed.

Objective 4: Sustainable soil health management in HT systems.

One factor that distinguishes HT from greenhouse systems is that crops are typically grown in-ground, in heavily amended native soils. It is well established that HT soil-nutrient-water dynamics differ considerably from those in open fields in the same soil type (recently reviewed by Pierre et al., 2024; Ali et al. 2022). High fertilization rates are often used in HT systems to ensure high yields in this high-value space, and the lack of overhead rainfall creates an arid, desert-like environment in otherwise humid climates. Buildup of excess phosphorus (P), resulting from application of organic amendments to meet nitrogen (N) needs, is common. Cover cropping, especially with legume cover crops to provide N without P, could be a possible solution to some of these issues (Perkus et al., 2022), but several barriers limit widespread adoption of cover cropping in HTs. Cover cropping is especially difficult to implement in HTs that are used for year-round production, as there is a limited window to grow and terminate a cover crop before the next season's rotation. Ultimately, HT producers frequently grow the same high-value crop year after year and use crop rotation and cover cropping less frequently than they would in outdoor field soils.

Together, these factors lead to some consistent challenges in soil management in HT systems including high soluble salts and the buildup of crop-specific soilborne pests and pathogens, including weeds. The limited crop rotations and the warmer temperatures have also led to the development of several emerging soilborne pest and pathogen issues within HT (Hamal et al., 2025), which necessitate the development of new sustainable soil health management strategies applicable in HT (Frey et al., 2020; Roskopf and Di Gioia, 2023; Di Gioia et al., 2024). Considerable research and extension effort has been spent evaluating the suitability of different soil testing approaches for HT conditions and developing guidelines for sustainable soil management in HTs. Pierre et al. (2024) recently summarized knowledge and knowledge gaps in the role of soil health in high tunnels systems, and concluded that there is a need to better understand the soil-nutrient-water dynamics within HT soils, and to develop clear research-based recommendations for practices like cover cropping, anaerobic soil disinfestation (ASD), steaming, and soil testing and fertilization strategies.

Objectives

1. Assess high tunnels in the U.S. to determine rates of adoption, technology use, and impact on U.S. food production.
2. Identify and study effective crop management strategies, including pest and disease management, in HT systems.
3. Identify cost-effective uses of engineering, technology, and infrastructure to improve environmental control and crop health within HT.
4. Investigate and develop strategies for sustainable soil health management in HT systems.

Methods

Objective 1. Assess high tunnels in the U.S. to determine rates of adoption, technology use, and impact on U.S. food production

We aim to work collectively to explore how growers are using HT in general, and specific technologies within HT systems, to better understand the costs and benefits of HT growing practices. We aim to generate concrete data about the returns on investment for particular crops and technologies to help develop effective outreach products, including guidance and decision-support tools for HT users. Addressing these information gaps in a concerted and coordinated way, at both a regional and national level, will be useful to help guide future research and outreach investments to maximize impact.

This objective will largely include extension efforts to survey HT production across participating regions in the U.S. Surveys will be written by project collaborators and distributed to extension networks in their region. Surveys will inquire about the following information:

- The approximate number and size of HTs within the region covered by each extension specialist. This information will supplement current NRCS and USDA data to track current use and rates of HT adoption.
- Dominant crops grown in HTs and key production challenges for different crops noted by growers. This information will track changes in HT cropping systems and identify priority areas for research/extension education. It will also help determine region-specific needs.
- Current use of technology in HT. There is a diversity of technological use by HT growers, but no current effort to describe these trends. This question will determine which tools (e.g., supplemental heating/cooling/climate automation) are most popular among HT growers. Objective 3 will provide more empirical data supporting cost-efficacy of these tools.

The survey instrument developed will be available in diverse formats and platforms to facilitate data collection. Our goal will be to cover all counties within participating states. Regular data will be available to the project team and extension educators participating in this survey to ensure buy-in and knowledge reciprocity. Results of the survey will be discussed during annual project meetings and published shortly thereafter as an extension article. Any revisions to the survey will also be discussed during the yearly meeting. Growers will be engaged in this objective through current extension programming.

Objective 2. Identify and study effective crop management strategies, including pest and disease management, in HT systems.

We will work in a coordinated manner to evaluate the adaptability of new crops in HT systems, and to explore cultural practices and crop management strategies that optimize productivity and crop quality for crops grown in HT. We also aim to conduct studies that enhance our understanding of how the HT environment impacts pests, pathogens, and biocontrol organisms with the ultimate goal of improving pest management and building plant resilience in HT crop production.

Studies to be undertaken include fundamental, on-farm, or applied research or outreach projects that:

1. Measure HT climates across regions. This effort will be necessary to determine environmental drivers for abiotic/biotic crop disorders. This effort will occur across participating states within research or grower HTs. Environmental loggers (temperature, humidity, light intensity) will be deployed at participating sites. Results from this sub-objective will be published in at least one peer-reviewed journal article and an extension newsletter.
2. Evaluate and compare varieties of high-value crops in HT. Tomatoes, cucumbers, and leafy greens dominate HT production, but little is known of the most popular and productive cultivars grown. Cultivars will be assessed at research or farm locations for pest / disease prevalence and crop performance. Fundamental research will identify genes and traits for cultivars underpinning these results and traditional/modern tools in plant breeding will be applied toward developing new cultivars with high performance in HT systems. The results of this sub-objective will be published in at least one peer-reviewed journal article and an extension newsletter per crop evaluated (tomato, cucumbers, leafy greens).
3. Evaluate the performance of new crops for HT production. HT crop diversification is needed to reduce risk of pest/disease buildup in HTs. Rotation options for tomatoes in particular will be evaluated in applied research studies. Strawberries, ginger, herbs, beans, cut flowers, are examples of high-value, non-solanaceous crops that could be evaluated for rotation with tomatoes. The results of this sub-objective will be published in at least one peer-reviewed journal article and extension newsletters.
4. Explore different crop management strategies, such as pruning, plant density, and timing of planting. Crop management varies considerably among growers, with many planting crops at a higher density in HTs to maximize space use. However, HTs restrict air flow, and dense plant canopies increase risk of disease. This objective will determine ideal plant spacing and pruning for common HT crops. Plant timing will also be evaluated, as some crops are planted later to avoid unpredictable spring weather or risk of pest/disease. Cucumbers, for example, are highly vulnerable to cucumber beetle damage and bacterial wilt (vectored by cucumber beetles) early in the spring that may be avoided by planting later. This sub-objective will determine optimal crop management strategies that are regionally adapted for common crops grown in HTs and will result in at least two peer-reviewed journal publications and extension newsletters for each crop evaluated (tomatoes and cucumbers are high-priority).
5. Evaluate the behavior and efficacy of pests and biological control organisms. Current biocontrol recommendations (e.g., biopesticide sprays and augmentative predators/parasitoids) are based on open-field or greenhouse production systems. This sub-objective will provide foundational data on the biology and behavior of common pests / diseases under HT environments to determine key risk factors. Common pests include aphids, thrips, spider mites, and whiteflies. Diseases include leaf mold, powdery mildew, and botrytis. However, other pests/diseases could be included in this sub-objective based on regional needs. Efficacy of current management tools under HT conditions will also be evaluated to potentially identify synergies or mismatches between pest/disease targets and intervention strategies within HT environments. A priority on biopesticides, augmentative biocontrols, and other 25(b) exempt / minimal-risk products will be made as these tools are available to all HT growers including those farming across the conventional - organic production spectrum. This sub-objective will result in at least six peer-reviewed journal publications and extension articles (split by common diseases / pests).

Objective 3. Identify cost-effective engineering, technology, and infrastructure to improve environmental control and crop health within HT

We aim to work cooperatively to bring innovations in design, mechanization, and engineering to HT production systems to improve environmental control and crop health, and to reduce labor requirements. Our approach will include evaluating and potentially adapting approaches being used in high-tech greenhouse systems for suitability in HT systems. This objective will use new tools, sensors, and technologies to measure and monitor airflow and temperature dynamics in HTs as a response to “active” and “passive” environmental controls.

Examples of studies to be undertaken include fundamental, on-farm, or applied research or outreach projects that:

1. Study “active” climate control tools . Most traditional greenhouses use “active” climate control to optimize crop productivity with electricity, fuel, and labor inputs. Active climate control tools include supplemental heating, cooling, and light fixtures. Simplified versions of these tools are available to HT growers, but many don’t use them or do so sparingly because they are expensive to run (especially supplemental heating). Overall, there is a significant knowledge gap in climate control tools in HTs, their direct benefits to crops, and how they can be optimized. This sub-objective will collect data from research and grower farms where these climate control tools across the spectrum are used and link their use to crop productivity and health performance. This will result in a minimum of two peer-reviewed manuscripts.
2. Study the use of “passive” management control tools, including row covers, shade cloth, exclusion netting, or other infrastructure to improve crop quality and protection. Most HTs rely on passive climate control tools (ventilation through open side walls) or simple infrastructure improvements (installing row covers for winter or exclusion netting to keep pests away) because they do not have access to electricity. The project team has evaluated a few of these tools (row cover and exclusion netting efficacy), but many have not been evaluated or compared across regions. Colored netting, for example, has not been evaluated for HTs but has shown to provide “optical” interference for dispersing pests in other production systems. This objective will focus on identifying passive climate and crop control tools that are accessible to all HT growers. This will result in a minimum of two peer-reviewed manuscripts.
3. Evaluate tunnel design and compatibility with growing regions. High tunnels come in several styles (gothic, Quonset) and different dimensions that are known to be more compatible with growing regions. This sub-objective will measure climates within these styles across farms to determine how well they regulate temperature and humidity conditions. Additional options, including movable tunnels, will also be considered for growing regions. This sub-objective will result in at least one extension article on choosing a high tunnel structure.
4. Create decision support tools focused on economic returns to help producers decide whether specific practices or technologies are cost effective. This research sub-objective will evaluate active and passive strategies assessed above to balance input costs with benefits. This sub-objective will merge results from 3A and 3B into an extension guideline on climate control tools in HTs.

Objective 4. Investigate and develop strategies for sustainable soil health management in HT systems

We aim to work collectively to identify and define sustainable soil health management approaches for HT systems. Specifically, we aim to study the effects of practices like cover cropping, anaerobic soil disinfestation (ASD), and steaming in HT soils, and to better understand the barriers to adopting specific practices that could improve HT soil management taking into consideration site-specific environmental and soil conditions. We also seek to build an improved understanding of soil-nutrient-water dynamics, and to develop and refine evidence-based recommendations for soil testing and fertilization in HT.

Examples of studies to be undertaken include fundamental, on-farm, or applied research or outreach projects that:

1. Identify nutrient testing methods and key indicators for soil health to assist decision-making regarding soil management strategies. Soil type and quality can be highly variable across farms, and it is critical to determine best practices for soil management. This sub-objective will evaluate best practices for rapid soil testing to guide decision making regarding soil amendments and management. The second effort will be to identify key indicators for soil health that can be monitored over time to improve management practices. This sub-objective will result in two peer-reviewed manuscripts and two extension articles to guide growers on soil testing and recognizing important parameters.
2. Study the use of cover crops as green manures and rotational crops in HT. This sub-objective will compare cover crops that are compatible with crop rotation in high tunnels. Timing of planting and termination practices will also be evaluated and followed up by soil testing to determine impact. This study will occur over multiple years to determine how soil structure / quality changes in long-term soil management and to explore the linkage between soil management practices and cash crop productivity. This sub-objective will result in a peer-reviewed manuscript and at least two extension articles on cover cropping in HTs.
3. Determine optimum fertility rates for HT-grown crops. This objective will track nutrient buildup in the soil following a continuum of fertilizer inputs recommended for HT-specific crops. Fertilizer inputs will also be evaluated based on pre-existing soil conditions. For example, fertilizers with no or low P will be evaluated in HTs where tomatoes have been consistently grown and have high P buildup. Yield and crop nutrition will be measured as responses to determine optimal rates of fertilizer. This sub-objective will result in a peer-reviewed manuscript and an extension article on fertigation programs in HTs for key crops (tomatoes, cucumbers, leafy greens).
4. Evaluate soil steaming, solarization, biofumigation, or anaerobic soil disinfestation (ASD) to manage soilborne pests and weeds. This sub-objective will span several objectives to determine how to manage soil that have soilborne pest, disease and weed emergence. Special attention will be paid to determine tradeoffs with these practices and the abundance of beneficial soil micro and macro diversity. This sub-objective will result in a peer-reviewed manuscript and an extension article for each soil management technique in HTs (3 articles).

Measurement of Progress and Results

Outputs

- Extension resources for holistic crop production in HTs Comments: We plan to write a minimum of 25 extension articles on this project and a cohesive guideline summarizing findings across objectives for high-priority crops (namely tomato and leafy greens). Team members from Purdue recently published a high-impact guide for cucumber production in HTs that we will use as a reference for other HT crops. Guidelines will be developed during the final year of the project. Results from individual objectives will also be published as they are achieved as individual articles, PowerPoint presentations, or other downloadable forms to make information sharable.
- Scientific contributions to the field Comments: The target research publication output is 22 peer-reviewed articles spanning each of our objectives over this 4-year study. The multistate team will also present research findings at scientific conferences.
- Project communication Comments: The multistate team includes researchers, educators, and Extension specialists, and we will collaborate with other Extension colleagues to share research findings and exchange information with stakeholders. This will largely occur during our annual meeting that will be held in tandem with popular Extension conferences. In addition, findings from this project will be integrated into undergraduate and graduate courses by team members who are actively involved in teaching at their institutions.
- Training and Mentorship Comments: The multistate team will train early-career professionals (including undergraduate and graduate students, postdocs, and technicians) in quantitative and qualitative research methodologies, scientific writing, and presentation skills to support their career goals. In-service training opportunities and workshops will be also offered to Extension educators working on HTs.

Outcomes or Projected Impacts

- Fill critical foundational knowledge gaps This project will contribute to discover biophysical and socio-economic dimensions of HTs that span diverse regions and production systems. This knowledge is critical to provide as HT adoption expands rapidly in the U.S.
- Knowledge exchange Members of this multistate project group will cover a range of specialized disciplines, including plant physiology, plant pathology, entomology, nematology, ecology, horticulture, soil science, organic farming, agricultural engineering, economics, sociology, etc. and will represent a broad geographical distribution. Exchange of information and ideas between group members will lead to collaborative, transdisciplinary projects, robust publications, and new and innovative specialized information. Through annual meetings, members will share information about existing projects and activities.
- An established network for rapid response to emerging HT issues By formalizing the group's goals and collaboration, we will build a stronger community doing research and outreach in HT cropping systems that will achieve longer-run objectives. This project is based on current HT issues, but our network will be used to share immediate and emerging concerns in HT production. The team will have a platform to communicate issues and lend their expertise to provide an informed and rapid response to collaborators.
- Opportunities to collaborate on competitive grants A massive strength of this team is our multidisciplinary and focus on improving HT production systems. Each year we will discuss grant ideas, priorities, and opportunities for collaboration. The multistate team will submit collaborative grant applications to external funding agencies and organizations.
- Strengthened relationships with grower stakeholders Each of our objectives span foundational to applied research and can include on-farm research. In some cases, as in Objective 1, coordination with growers will be necessary to fill important knowledge gaps regarding HT use and importance to local food systems.
- Improved confidence regarding decision making in HTs Achieving objectives of this project will provide evidence-based recommendations on HT production targeting key sectors of this holistic production system. This will allow growers to make confident choices that can achieve long-term benefits.

Milestones

(2026): Organize first group meeting (ideally in-person but, if needed, virtual). Elect group leadership. Summarize preliminary data for each objective and coordinate research efforts. Plan procedures for Objectives 1 and 2A that require regional or national efforts. Determine the timeline for Objectives 2-4 that will require a minimum of 2 years of evaluation. Build a communication infrastructure, including shared folders or a listserv that members can use to share information.

(2027): Organize annual group meeting. Elect new leadership team. Summarize progress towards outcomes, listing outputs produced. Distribute Year 1 of extension surveys through extension networks. Revisit timeline to achieve sub-objectives within Objectives 2-4.

(2028): Organize annual group meeting. Elect new leadership team. Summarize progress towards outcomes, listing outputs produced. Continue or revise surveys for Objective 1 and compile responses. Revisit timeline to achieve sub-objectives within Objectives 2-4.

(2029): Organize annual group meeting. Elect new leadership team. Summarize progress towards outcomes, listing outputs produced. Continue or revise surveys for Objective 1 and compile responses. Revisit timeline to achieve sub-objectives within Objectives 2-4.

(2030): Organize annual group meeting. Elect new leadership team. Finalize plans for project delivery, namely writing and publishing comprehensive 1st edition guidelines for HT crop production (individual guidelines for each crop). Finalize list of project outputs. Develop a plan for renewing the multistate research project that leverages the progress made over the project term. Submit the renewal.

Outreach Plan

Many of the participants are actively involved in both research and extension activities. Their research results and production recommendations will be disseminated through their state cooperative extension service.

Additionally, information will be made available by members through many regional and state growers' meetings such as the Great Lakes Fruit and Vegetable Exposition, the Mid Atlantic Fruit and Vegetable Conference, the New England Fruit and Vegetable Conference, the Empire State Expo, and the Southeast Regional Fruit & Vegetable Conference. In these meetings and other venues, our members will provide insight and recommendations for research priorities through presentations, field days and workshops, in-service trainings, newsletters, email, and websites on changes in legislation, upcoming issues, management of production, irrigation, fertility, insects, diseases, and variety choice in high tunnels.

Organization/Governance

The recommended Standard Governance for multistate activities includes the election of a Chair, a Chair-elect, and a Secretary. A new Secretary is selected at the end of the annual meeting at which point the current Secretary becomes Chair-Elect, and Chair-Elect becomes Chair for the next 12 months. The Committee Chair and Chair-Elect are responsible for organizing the annual meeting and planning the agenda, and The Secretary records the minutes at the meeting following their election.

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Land Grant Participating States/Institutions

MA

Non Land Grant Participating States/Institutions

Participation

Participant	Is Head	Station	Objective	Research			Extension
				KA	SOI	FOS	KA

Response to Reviewers

“NE_TEMP2603: Advancing high tunnel specialty crop production”

The original review is included below along with our responses in italicized text:

Comments from Reviewer 1:

Project objectives are well developed and defined, needs and opportunities are clear and well supported. Specific details regarding cooperative activities would illustrate how objective will be met. For example, how will growers be assessed – stand along surveys, event questionnaires – how many on-farm trial will be carried out per experimental question, how many factsheets, guides, journal publications, etc. will be published per objective and when will these be published. Milestones should include specific deliverable targets.

Team response: More details were added in Objective 1 that will require stakeholder engagement with extension educators. Targets were also listed in the Milestones section to map out progress of our objectives. Because this project is new, some details regarding experimental design are uncertain and will be discussed during our first project meeting. Target numbers of outputs were also listed (extension articles, guidelines, and research papers) based on a project membership number. However, the publication date is difficult to project as the review and revision timeline can vary substantially among manuscripts and journals.

Comments from Reviewer 2:

There is strong justification for the work but the approach is very broad. After the work of NEC-2013 one would hope that some more focused / prioritized issues could be presented for research and outreach. While the objectives ring true and the approaches make sense, they do not make a compelling case for generating and aggregating the data needed to develop robust improvements to high tunnel management recommendations. For example, a more cohesive approach could be presented to improve our understanding of high tunnel air management (temperature, humidity, carbon dioxide) by laying out a detailed and coordinate research agenda (rather than a few possible project examples) to assess the impact of different circulation, ventilation, shading, misting, and environmental controls systems. The same could be said for pest management – it is too early to name some key insects and diseases that high tunnel growers struggle to management, and then present a suite of research objectives for improved IPM for those? Perhaps that work will take place in future team meetings but the proposal seems like a good place to more clearly articulate specific research projects under each broad objective.

Team response: A more detailed research agenda was described for each objective. Because this project spans regions that may have unique pest/disease complexes, the pest management section was left somewhat generic to provide flexibility. However, we do know that several groups tend to be consistently problematic, and we listed them. We also tightened our pest management approach by evaluating biopesticide, biocontrol, or 25(b) exempt products as pest intervention tools of interest. These tools are important in high tunnels where spray products are not available for specific target sites/pests. Further justification for this choice was described in previous sections.

Comments from Reviewer 3:

The objectives are reasonable but they don't feel especially holistic, either in terms of interdisciplinarity or in reflecting the systems thinking needed to meaningfully change how high tunnels are currently used. A more novel and potentially impactful approach might incorporate participatory research and/or deeper integration with non-biological scientists (e.g., engineering, design, economics, sociology, or planning).

Would advances in movable tunnel design help maintain soil health by enabling more effective crops and soil rotation? If so, why not include moveable tunnels or innovative tunnel redesign as part of Objective 3? This may be a more practical strategy for addressing several persistent challenges in tunnel production because it builds on existing production frameworks, rather than requiring a full redesign of farm management practices which are often location-dependent and inherently more complex.

Finally, many growers are adopting containerized or hydroponic systems within tunnels and avoiding soil-based production altogether. Would this part be inclusive of all tunnel growers, or only those using soil-based systems? If the latter, is there a clear rationale for excluding other protected cultivation contexts, such as caterpillar tunnels, low tunnels, or other low-cost structures that fall outside the "high tunnel" category?

Team response: More detail within each objective was included to strengthen our approach and systems-approach. Our proposal is focused on the style of high tunnel funded by the NRCS High Tunnel Initiative, as many growers received their high tunnel through this cost-share program. This excludes soilless culture, low tunnels, and some caterpillar tunnels. This was more clearly articulated in the Statement of Issue and Justification section. We agree that addressing tunnel structures would be important to Objective 3 and therefore included Objective 3D to measure climate conditions across high tunnel structures, including movable high tunnels, and compatibility with local climates. However, it is important to note that although of interest for many growers, movable tunnels are not very common among commercial growers currently, for two primary reasons: 1) the higher cost

of movable tunnels, and 2) they are not always suitable for windy conditions that tend to dominate Northern states where HTs are highly popular for season extension.

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2603: Advancing high tunnel specialty crop production

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Good

4. Potential for significant outputs(products) and outcomes and/or impacts:

Good

5. Overall technical merit:

Good

Comments

The objectives are reasonable, but they don't feel especially holistic, either in terms of interdisciplinarity or in reflecting the systems thinking needed to meaningfully change how high tunnels are currently used. A more novel and potentially impactful approach might incorporate participatory research and/or deeper integration with non-biological scientists (e.g., engineering, design, economics, sociology, or planning).

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Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2603: Advancing high tunnel specialty crop production

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Fair

3. Appropriate scope of activity to accomplish objectives:

Good

4. Potential for significant outputs(products) and outcomes and/or impacts:

Good

5. Overall technical merit:

Fair

Comments

There is strong justification for the work but the approach is very broad. After the work of NEC-2013 one would hope that some more focused / prioritized issues could be presented for research and outreach. While the objectives ring true and the approaches make sense, they do not make a compelling case for generating and aggregating the data needed to develop robust improvements to high tunnel management recommendations. For example, a more cohesive approach could be presented to improving our understanding of high tunnel air management (temperature, humidity, carbon dioxide) by laying out a detailed and coordinated research agenda (rather than a few possible project examples) to assess the impact of different circulation, ventilation, shading, misting, and environmental control systems. The same could be said for pest management - is it too early to name some key insects and diseases that high tunnel growers struggle to manage, and then present a suite of research objectives for improved IPM for those? Perhaps that work will take place in future team meetings but the proposal seems like a good place to more clearly articulate specific research projects under each broad objective.

Your Recommendation:

Approve/continue project

Appendix G: Peer Review (Submitted)

Status: Complete

Project ID/Title: NE_TEMP2603: Advancing high tunnel specialty crop production

Rate the technical merit of the project:

1. Sound Scientific approach:

Approve/continue project

2. Achievable goals/objectives:

Good

3. Appropriate scope of activity to accomplish objectives:

Excellent

4. Potential for significant outputs(products) and outcomes and/or impacts:

Excellent

5. Overall technical merit:

Good

Comments

Project objectives are well developed and defined, needs and opportunities are clear and well supported. Specific details regarding cooperative activities would illustrate how objectives will be met. For example how will growers be assessed - stand alone surveys, event questionnaires - how many on-farm trials will be carried out per experimental question, how many factsheets, guides, journal publications, etc. will be published per objective and when will these be published.

Milestones should include specific deliverable targets.

Your Recommendation:

Approve/continue project