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USDA Forest Service Eastern Region

Oak Wilt Suppression Program

Participation Guidelines

Forest Service
Eastern Region
State and Private Forestry
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USDA Forest Service Eastern Region Oak Wilt Suppression Program Participation Guidelines

Compiled by Eastern Region Forest Health Protection

Forest Pathology Staff

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Cover: Forest Service illustration by Juliette Watts

Pesticide Precautionary Statement
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CONTENTS

OAK WILT SUPPRESSION PROGRAM

Federal Guidelines for Participating State and Federal Agencies within the Eastern Region

I. Introduction

State agencies may request Federal cost-share funding for a suppression or eradication project when the anticipated costs of the project exceed available state, local, or private funds. These guidelines were compiled to provide one reference for State agencies participating in oak wilt suppression or eradication projects funded by the U.S. Department of Agriculture, Forest Service, Eastern Region State and Private Forestry.

Federal agencies also request Federal assistance with oak wilt suppression when necessary activities are not funded through their normal operating budget. The funding and reporting process used for Federal land management agencies is different from State agencies; specific questions should be directed to the local Forest Service Forest Health Protection field office.

Implementing biologically effective treatments that protect the oak resource is the top priority for the Forest Service oak wilt suppression program. Forest health specialists need to be committed to educating landowners about the biology of oak wilt, the necessity of proper root graft barrier placement, and subsequent removal of potential spore-producing trees. Seeking the cooperation and full participation of multiple landowners is required if a suppression program is to be successful on the landscape.

II. History and Status of Oak Wilt Disease

Oak wilt is the single most important disease of oaks in the eastern half of the United States. Since the 1950s, millions of trees have been killed by oak wilt throughout the Eastern U.S. where the disease is prevalent (figure 1). The disease has increased in importance in recent years as the distribution of the disease has expanded, as people continue to move into wooded areas dominated by oak stands, and as high-value forested areas have become infected. Trees in residential, recreation, and forest production areas are infected through wounding and insect-vectored spread. Many of these infection centers involve multiple ownerships and cover large areas, making control efforts difficult. Preventing initiation of new disease centers and controlling the spread of existing centers can only be achieved by a coordinated effort involving key partners and affected landowners.

III. Oak Wilt Suppression Programs: Goals, Prevention Activities and Suppression Treatments, Suggested Priorities, and Process for Prioritizing Funds

A. Goals: Protect the Resource

The main goal of Federal prevention and suppression cost-share grants is to protect the resource where insect pests and pathogens are threatening important ecosystem components. In the case of oak wilt disease, this is accomplished by the control of individual infection centers in areas where the oak resource is threatened.

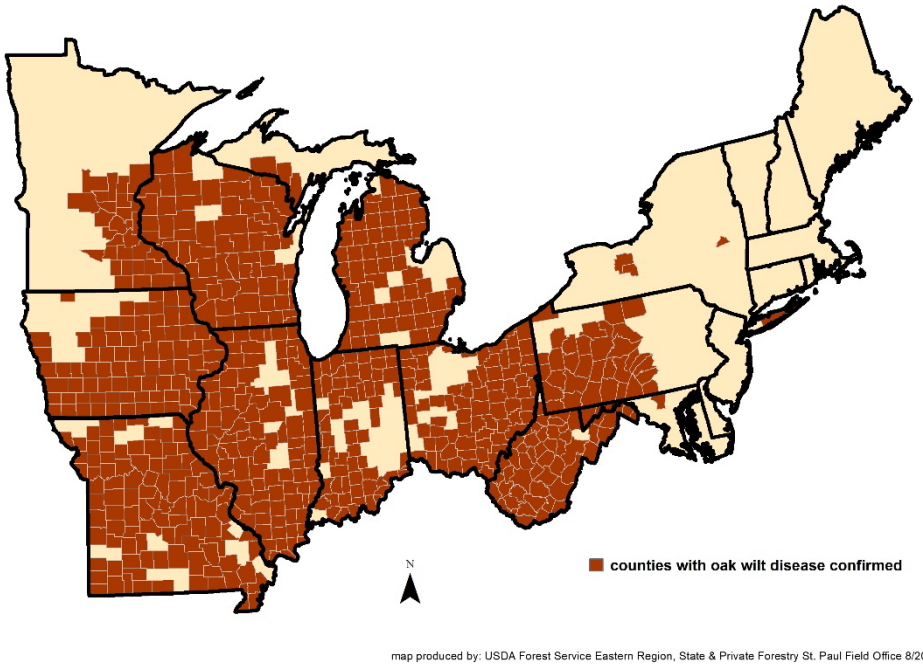


Figure 1. Distribution of oak wilt by county, 2019.

Oak wilt suppression treatments should be conducted in situations with a high likelihood of reducing future disease impact. In those situations, the density of oak wilt is within manageable levels and it is feasible to successfully protect the oak resource and sustain it as an important component of the urban/suburban or woodland ecosystem. Because the intent of the program is to protect the oak resource on a community, township, or larger resource scale, concerns about saving individual trees are secondary.

Broadly, the Eastern Region oak wilt suppression program is focused on the biological effectiveness of treatments and financial accountability. However, specific goals of the program are as follows:

- Ensure that oak wilt treatment plans are designed to have a high probability of success. Identify high-priority treatment areas and fund treatments that meet criteria described in this document.
- Ensure that treatments are implemented correctly and timely.
- Ensure that the program is accomplishing biological goals by evaluating treatment efficacy through monitoring of treated sites.
- Ensure proper reimbursement of treatment costs. Confirm that treatments eligible for Federal cost-share funds are implemented correctly and are reimbursed in a timely manner.

B. Oak Wilt Prevention Activities and Suppression Treatments

Federal prevention and suppression funds must be used for activities and treatments to reduce the impacts of oak wilt disease. This section will discuss prevention activities and suppression treatments that the Eastern Region has determined to be eligible (biologically effective) or ineligible

for Federal cost-share reimbursement. A comprehensive table of potential oak wilt management activities and the supporting literature are presented in appendix A and appendix B, respectively.

1. Prevention Activities Eligible for Federal Cost-Share Reimbursement

Preventing the establishment of new oak wilt infection centers is highly efficient economically because it avoids the cascading costs of suppression treatments. Prevention activities specific to oak wilt may include an education and public information component (e.g., public service announcements, billboards, fliers, and other information products). Public information campaigns usually aim to avoid the establishment of oak wilt infection centers that occur because of human activity. They are integral to an effective oak wilt management program. Examples include:

- Programs to advocate for the avoidance of unnecessary injury to trees during the high-risk period for overland spread during the spring of each year.
- Don't move firewood campaigns.
- Proper pruning techniques and wound treatments necessary to prevent overland spread.
- Training sessions to provide information on the proper treatment and disposal of wood from potential spore-producing trees.

Federal support for public information campaigns to increase awareness of oak wilt may be available through prevention/suppression funds or from regional Forest Service Forest Health Protection funds. Contact the Forest Health Protection staff in the Eastern Region Regional Office or local field office for assistance with funding prevention activities related to oak wilt management in conjunction with disease suppression.

2. Suppression Treatments Eligible for Federal Cost-Share Reimbursement

To be eligible for Federal cost-share, a suppression treatment method must have demonstrated biological effectiveness in reducing the spread and/or impact of oak wilt disease. Since oak wilt disease spreads both above ground by insect vectors and underground via root grafts (figure 2), effective oak wilt management programs must include a two-tiered treatment approach that addresses both modes of disease transmission, unless the treatment itself interrupts the disease cycle prior to initiation of below-ground infection (Rapid Response). Treatments that are effective at interrupting this cycle as well as their eligibility for Federal cost-share are further explained in appendix A. All references and literature cited are listed in appendix B.

a. Mitigate Underground Spread:

Oak wilt underground spread is reduced by installing root graft barriers (RGBs) to disrupt root graft connections. The RGB line(s) needs to be installed according to an accepted method of barrier line placement for disruption of root graft spread of the pathogen. The methods of establishing an RGB line that are eligible for Federal cost-share include these:

- Vibratory plow (recommended effective depth of root disruption 60 inches or greater).
- Trenching (recommended effective depth of root disruption 60 inches or greater).
- Root rupture at the stump or root collar with backhoe/bulldozer. Complete 360-degree root disruption of each tree is recommended.
- Frill girdle and application of an approved herbicide.
- Tree removal with cut stump application of an approved herbicide.

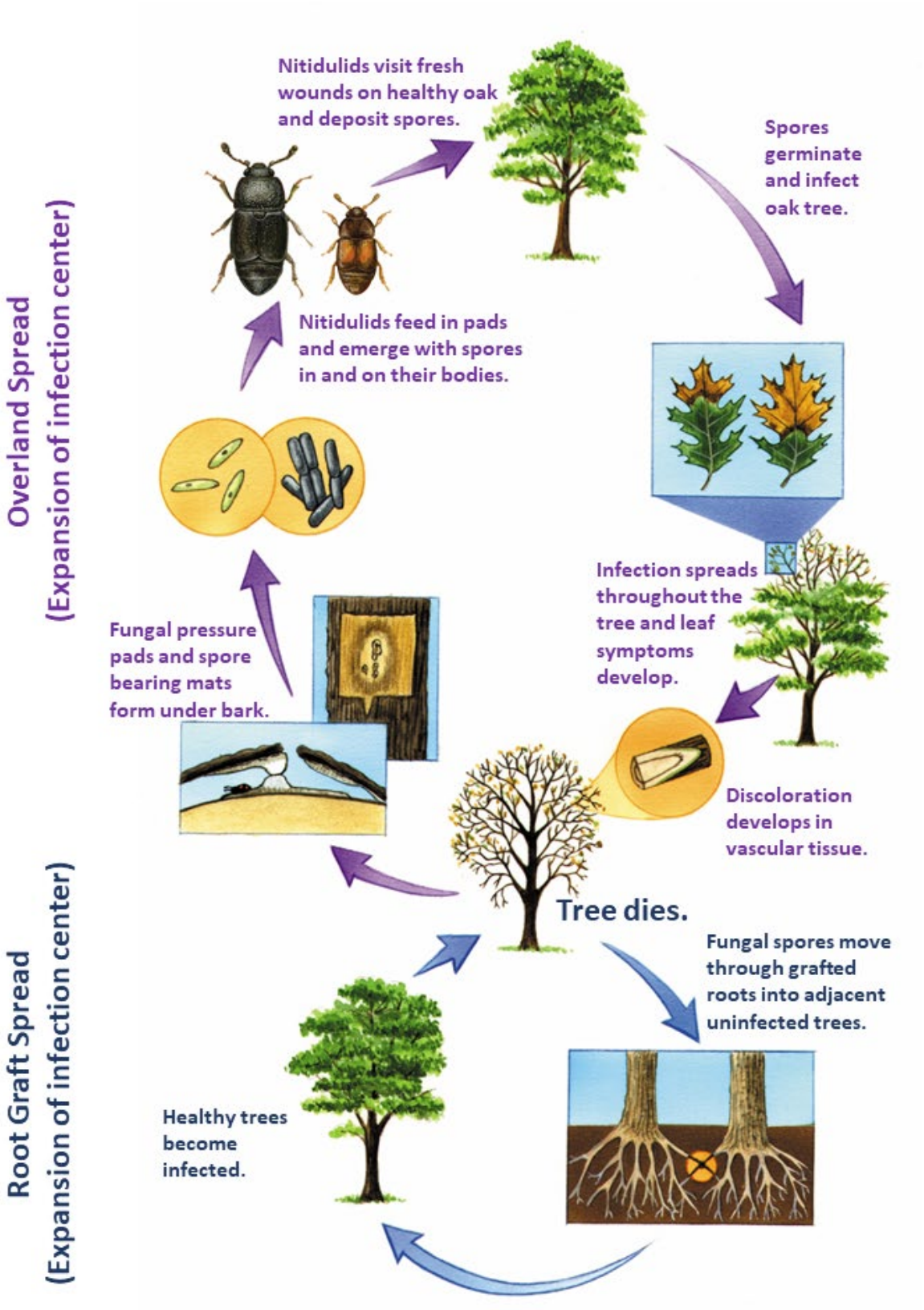


Figure 2. Disease cycle of oak wilt disease.

b. Mitigate Overland Spread:

Preventing insect transmission of disease effectively mitigates overland spread. While all oak trees inside the primary root graft barrier (RGB) have a chance of becoming infected and supporting the development of spore mats, and are thus considered potential spore-producing trees (PSPTs), the most critical PSPTs are infected red oaks (and in some situations bur oaks) that wilted within the previous year. Removal of PSPTs is eligible for Federal cost-share reimbursement if accomplished prior to spore mat formation and nitidulid beetle flight in the spring.

The reimbursement-eligible approaches to selecting PSPTs for removal are these:

- Cut-to-the-line: Remove all oaks of the affected group (white or red oak group) that are within the primary RGB, and if possible, treat stumps with approved herbicide. To reduce the chance of RGB failures, stumps of removed PSPTs and buffer trees that are removed in cut-to-the-line procedures should be treated with an approved herbicide. Herbicide treatment of stumps helps prevent resprouting and continued root growth. Treatment of stumps with an approved herbicide is eligible for Federal cost-share reimbursement.
- RGB/PSPT Removal/Monitoring ("Monitor and Remove"): Annually inspect and remove all PSPTs within the RGB for a 5-year period, regardless of whether residual oaks are treated with a fungicide. Note: fungicide injection can be a component of treatment within the RGB, but fungicide costs are not eligible for Federal cost-share.

Appropriate methods of disposal/treatment of PSPTs/infected wood include:

- Utilization of all wood with a diameter greater than 4 inches as firewood if firewood is cut and split prior to mid-September.
- Utilization for timber products if trees are removed and processed in a timely manner before spore production and the nitidulid beetle flight period in the spring.
- Removal to a waste disposal site where material is buried or chipped.
- Onsite burning of felled trees; bark should be completely charred and treatment completed before spore production and the nitidulid beetle flight period in the spring.

c. Rapid Response and monitoring

It is possible to mitigate development of a new disease center if a tree is identified and treated in the year it was infected via overland spread, before the pathogen enters the root system. A good candidate for this "Rapid Response" treatment is an oak that a manager is confident has been overland-infected in the current year (as indicated by an obvious fresh wound and rapid onset wilt) and no other suspected infected and previously killed oaks are within root graft distance of the suspect tree. Two potential response approaches are these:

- The bark and outer wood of the candidate tree should be girdled immediately and treated with herbicide, with or without removal of the tree prior to late fall of that year.
- Alternatively, the candidate tree can be cut as soon possible and the stump treated with herbicide.

All aboveground parts should be treated as a PSPT and disposed of as outlined above. This treatment is eligible for Federal cost-share if the treatment site is part of a larger oak wilt suppression program. As with all treatments, monitoring of the treatment site is required.

d. Special Cases:

There may be cases where conventional oak wilt treatments are not feasible. If a State land manager believes a non-traditional treatment may be effective, consult with a State agency forest health specialist. For Federal lands, contact the local Forest Service Forest Health Protection field office. To be considered cost-share eligible, the treatment requires a letter from the Forest Service approving the treatment and authorizing cost-share for the specific situation.

e. Monitoring

Treatment sites should be inspected annually to detect failures in the root graft barrier line. This data is used to evaluate treatment effectiveness and identify candidate sites for retreatment. Monitoring for at least 5 years following the last treatment is recommended, although this may extend beyond the timeframe of any grant agreements. Effective monitoring of treatments requires a plan for collecting tracking data from the onset of the project. The Forest Service field office has forms and templates available to assist in monitoring.

Monitoring data should be provided to the Forest Service to enable post-treatment evaluation of the effectiveness of treatments and effective use of Federal funding.

3. Suppression Treatments Not Eligible for Federal Cost-Share Reimbursement

Other suppression treatments can be attempted in the management of oak wilt disease, but they are not eligible for Federal cost-share reimbursement, nor can the cost of applying these other treatments be used to meet the requirement of matching funds. These treatments are not eligible because they have not demonstrated biological effectiveness, they have limited or negative effects on the overall status of oak wilt disease on a landscape scale, or the use of suppression funding for the stated purpose is prohibited by Federal mandate.

Examples of treatments that are not eligible for Federal cost-share reimbursement include:

- Cutting a buffer zone of living trees to establish a root graft barrier (RGB) without application of herbicide
- RGB installation without removal or treatment of potential spore-producing trees (PSPTs)
- Removal or treatment of PSPTs without RGB installation (unless Rapid Response)
- Removal of dead, non-PSPTs (dead for over 1 year) or other treatments not specified in the treatment plan
- Stump grinding
- Replanting or reforestation
- Any application of fungicide

C. Suggested Priorities for Oak Wilt Prevention Activities and Suppression Treatment Areas

In this section, we discuss prevention activities that have been successful. We identify suppression treatments that are biologically effective and priority treatment areas that demonstrate a high probability of success in protecting the oak resource and sustaining it as an important component of the ecosystem.

1. Priorities for Prevention Activities Related to Oak Wilt

Since they can avoid the cascading costs of suppression treatments, prevention activities (outreach, fliers, billboards, other education resources) are considered a high priority for an efficient and effective oak wilt suppression program. The following prevention activities (listed in order of prioritization) may be eligible for Federal cost-share:

1. Education and public information campaigns
2. Establishing a program to monitor spore mat production and nitidulid beetle activity in spring to delineate the beginning of the high-risk period for overland spread in a particular area

2. Priorities for Treatment Areas

To protect the oak resource and sustain it as an important component of the urban/suburban or woodland ecosystem, suppression treatments should be targeted to high-priority areas where the density of oak wilt is within manageable levels and the probability of successfully protecting the resource is high.

The following example lists treatment areas, ranked by suggested priority for treatment (1 = highest priority, 6 = lowest priority):

1. Areas with high red oak basal area or environmental significance and small numbers of recent introductions of oak wilt with an oak wilt eradication plan.
2. Areas with high red oak basal area or environmental significance where oak wilt is established in limited areas and a treatment plan that demonstrates the eradication in a local or regional area is feasible as a long-term goal.
3. Areas where oak wilt is established, but recent outlier infection centers exist that can be eradicated.
4. Areas where oak wilt is established and in communities that have a city forester or forestry consultant on staff and a resource-level treatment plan in place that includes a nuisance tree ordinance that can be used to mandate the removal of PSPTs.
5. Areas where oak wilt is established and in communities that have a city forester or forestry consultant on staff and a resource-level treatment plan in place, but do not have a nuisance tree ordinance that can be used to mandate the removal of PSPTs.
6. Areas where oak wilt is established and treatments are applied on an ad hoc or individual landowner basis.

D. Forest Service Process for Prioritizing Funds for Oak Wilt Prevention and Suppression Funding Requests

Forest Health Protection staff review funding requests to consider the likelihood that the proposed actions will accomplish the mission of protecting the oak resource from oak wilt on a community, township, or larger resource level.

To accomplish the mission of protecting the oak resource, oak wilt suppression proposals should:

1. Include both prevention and suppression components in their management approach.
2. Implement biologically effective treatments that manage the disease on a resource level using a two-tiered treatment approach (installation of a root graft barrier and removal and proper treatment of PSPTs) and implement treatments on a community, township, or larger resource scale.
3. Target suppression treatments in high-priority areas where the density of oak wilt is within manageable levels and the probability of successfully protecting the oak resource and sustaining it as an important component of the urban/suburban or woodland ecosystem is feasible.

IV. How States Participate in the Cooperative Prevention or Suppression Program

The Forest Service Forest Health Protection (FHP) Program requests that State agencies identify Federal cost-share funding needs for prevention or suppression projects annually. Currently, the maximum Federal share of project costs is 50 percent for projects of all sizes on all land ownerships (i.e. 1:1 match). If a State decides to request Federal prevention and suppression cost-share funding, there are different sets of requirements to meet for different parts of the process. These requirements include (when necessary) documentation to comply with the National Environmental Policy Act of 1969 (NEPA) and other Federal acts, project planning documents, request for financial assistance documentation, and accountability/reporting documentation.

A. Documentation to Comply with NEPA and other Federal Acts

If funded with Federal tax dollars, State suppression or eradication projects must address several different Federal acts: NEPA, the Endangered Species Act (ESA), the National Historic Preservation Act (NHPA), and the Civil Rights Act of 1964. Since the time necessary to address these acts may be significant, it is highly recommended that States begin working with their respective Forest Service field office and other agencies 9 to 12 months before initiating an oak wilt suppression program.

1. The National Environmental Policy Act of 1969 (NEPA)

When the Forest Service provides funding for non-Federal activities, the action may be subject to NEPA analysis. The key to determining whether or not an action is subject to NEPA analysis is determining whether the Forest Service exercises control over the implementation of the action to be funded and to what degree implementation of the action is dependent on Forest Service funding. If the Forest Service is funding a program, but does not control the specific projects the funds will be used for, then environmental analysis under NEPA is not needed. Similarly, where the Forest Service provides only a small percentage of the funding for a project, it is unlikely that environmental analysis will be required under NEPA due to limited control and responsibility. See the section on NHPA below for further discussion on the need for NEPA analysis. Whether or not NEPA analysis is required, there is still a minimum need to conduct a Biological Evaluation and keep an analysis file.

2. The Endangered Species Act (ESA)

To comply with the ESA, the Forest Service or its designee must determine if federally listed species or designated critical habitats may be affected by a proposed project, and follow

appropriate consultation processes with the US Fish and Wildlife Service. In addition, the State agency must work with the State Fish and Wildlife agencies to ensure that no state-listed threatened and endangered species are affected.

3. The National Historic Preservation Act (NHPA)

To comply with NHPA, the Forest Service must identify and document that "historic properties" (buildings, archaeology sites, traditional cultural properties, etc.) will not be adversely impacted by the proposed program or projects. The State agency that is implementing the oak wilt control program is responsible for a written description of the scope of the project, and the proposed treatment actions and treatment locations. This information will be provided to the State Historic Preservation Officer and Forest Service for review of the proposed project for any potential impacts to historic properties pursuant to Section 106 of the NHPA. FHP staff will initiate Tribal consultation as soon as the documents are received by the local field office. Note: Tribal nations have 120 days from receipt of notice to inform the Forest Service if they desire formal consultation. Therefore, if treatments are scheduled prior to October 30 of a given year, all site information as well as detailed scope of work need to be submitted for Tribal consultation prior to June 30.

Special Note: The process of complying with the NHPA can be complicated and time consuming. Consider this early in the process and contact FHP as soon as practical.

4. The Civil Rights Act of 1964 (CRA)

State agencies that participate in a cooperative suppression or eradication program must demonstrate that they are in compliance with Title VI of the CRA. Title VI protects persons from discrimination based on their race, color, or national origin in programs or activities that receive Federal financial assistance.

5. More about the Analysis File

As soon as a State agency decides to initiate an oak wilt suppression project, they should begin an analysis file to document all steps taken to comply with NEPA. The analysis file is important if the project is challenged in court. Should litigation occur, the court will demand full disclosure of all records relating to the project being litigated. The agency has an obligation to prepare a complete, well-indexed, and understandable file of materials as background for the analysis.

At a minimum, the analysis file should include the following:

- Public comments (by phone and open house meetings)
- Comments from other agencies
- Internal communications
- Draft of EA
- Laws and regulations
- Maps
- Biological data
- References cited in the environmental analysis

A list of what is included in the analysis file should be sent to the Forest Service prior to beginning treatments. The final EA (if created) must be completed and the decision notice signed before any treatments can be implemented**.**

B. Guidelines for Accountability and Reporting

Funds for cooperative oak wilt suppression projects are disbursed to States as a grant and are subject to the reporting guidelines outlined by the Eastern Region Grants and Agreements staff. In addition to administrative information (dollars spent, match, etc.), progress reports from cooperators should include specific information relevant to oak wilt suppression, including:

- Number of infection centers treated
- Number of infection centers successfully treated (treatment implemented and subsequent monitoring indicating no underground spread)
- Status of previously treated sites (monitoring information; annual monitoring of treatment areas is suggested for at least 5 years after treatment)
- Number of sites retreated due to unsuccessful initial treatment

C. Other Resources to Help with the Process

When a State or other entity participates in the Federal suppression program, they should be working closely with the Forest Health Protection staff of the field office that serves them. The FHP staff have access to sample reports, monitoring forms/templates, and other resources that can be provided as needed.

Midwest States (Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, and Missouri)
St. Paul Field Office
1992 Folwell Avenue
St. Paul, MN 55108
ATTN: Sunny Lucas, Group Leader
651-649-5108
Email: sunny.l.lucas@usda.gov

Mid-Atlantic States (Ohio, West Virginia, Pennsylvania, Maryland, Delaware, New Jersey, and Washington, DC)
Morgantown Field Office
180 Canfield Street
Morgantown, WV 26505
ATTN: Rick Turcotte, Group Leader
304-285-1544
Email: richard.m.turcotte@usda.gov

New York and New England States (New Hampshire, Vermont, Maine, Massachusetts, Connecticut, and Rhode Island)
Durham Field Office
271 Mast Road
Durham, NH 03824
ATTN: Mike Bohne, Group Leader
603-868-7708
Email: michael.bohne@usda.gov

V. National Forest and Other Federal Agency Participation in Suppression and Prevention Projects

The local Forest Service field office (FHP staff) is responsible for conducting a biological evaluation to justify the need for treatment. The agency receiving funds is responsible for complying with their agency's NEPA requirements. In addition to assisting with the biological evaluation, local FHP staff should ensure that a work plan and safety plan have been prepared for the project, and should conduct a post-suppression evaluation. All treatments on Federal lands (including those administered by the Bureau of Indian Affairs), or those that are supported with Federal funds or permits, should comply with the treatment guidelines described in this document.

VI. List of Appendices for Oak Wilt Suppression Guidelines

Appendix A. Potential Control Methods for Oak Wilt Disease: Scientific Basis and Information About Practicality

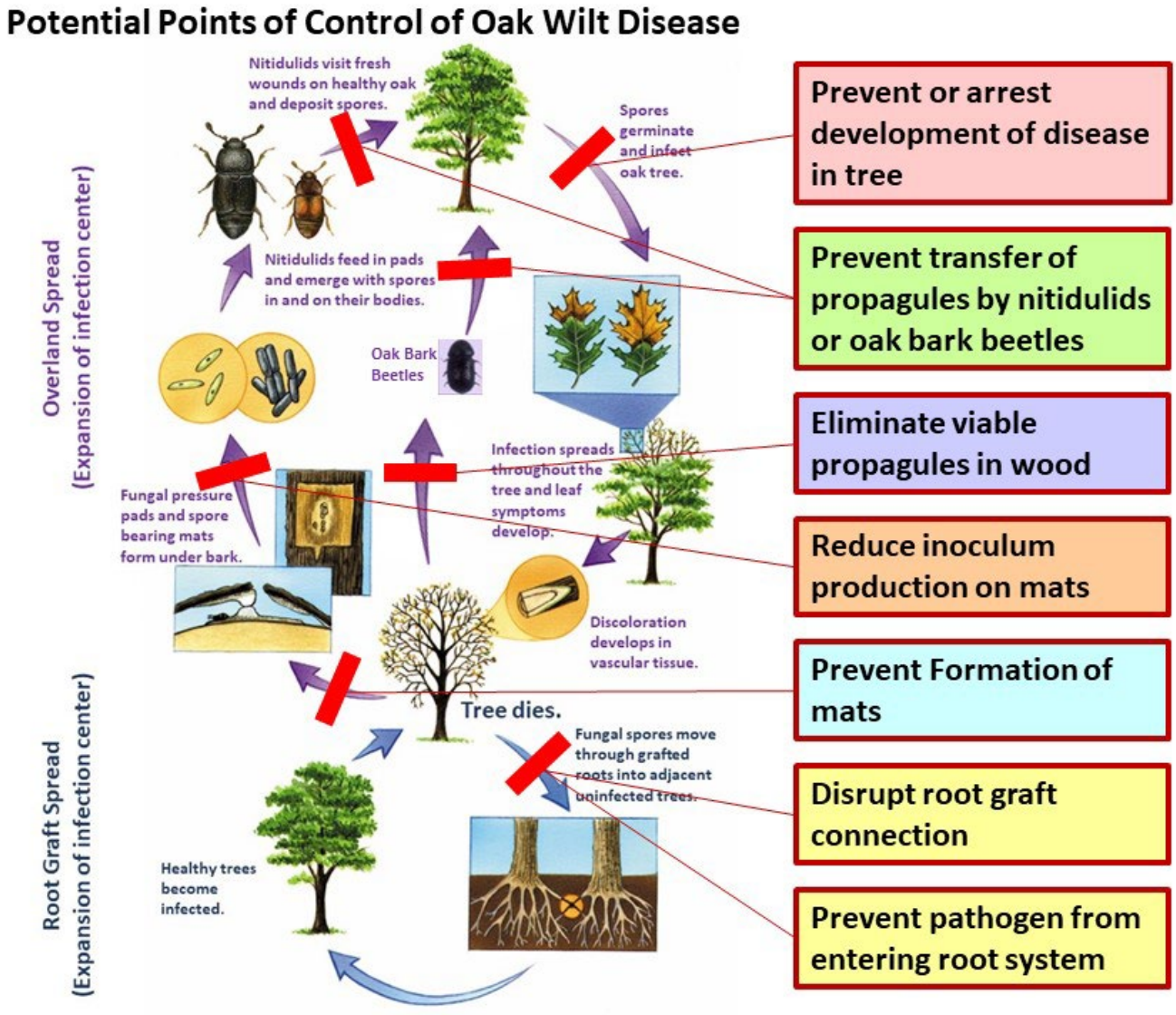
This is a tabular summary of the methods proposed to control oak wilt grouped by the point at which they interrupt the disease cycle that includes the scientific basis for the method and information about practicality.

Appendix B. Listing of Relevant Literature

This is a list of key references used to compile these guidelines and references that can be used to create an effective suppression program.

Appendix A. Potential Control Methods for Oak Wilt Disease: Scientific Basis and Information about Practicality

The potential points of control of oak wilt disease (color coded in the diagram below) are discussed in the similarly color-coded table on the following pages, both as a tool to understand why certain practices are allowed under the program and also to point the reader to sources of additional information. All references are listed in Appendix B.



Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
Placement of root graft barrier (RGB)	YES	Disrupt root graft connection	Placement of an RGB line is key to stopping movement of the fungus from diseased trees into healthy trees. There are several methods/models described for RGB line placement. • The "rule of thumb" model (sometimes called the French model) places secondary RGBs between the currently wilting trees and the nearest (within root grafting distance) healthy appearing trees. Primary RGBs (the most important) are placed between the first and second tier of apparently healthy trees outward from the infected trees.[1] • Predictive equations of oak wilt spread based on combined diameter and distance are available.[2] The "Bruhn model"[3,4,5] is for RGB line placement on sandy and loamy sand soils based on diameters of infected and healthy trees and distances between the two.	The "rule of thumb" approach is commonly used in Minnesota. The "Bruhn model," particularly the Grayling (sandy) soil variation, is more aggressive to remove a larger number of oaks. A commonly used table of the 95% confidence distances for the "Bruhn model" in sandy and loamy sand soils also adds a less aggressive column calculated for 80% confidence of spread in sandy loam/loam soils.[5] The hypothetical number of trees removed through the application of the "rule of thumb" method (similar to the Bruhn sandy loam/loam column) was compared to Bruhn's Pemene (loamy sand) soil model, demonstrating that many more trees would be removed under the more aggressive model.[6] Soil type, land form, and predominant tree species affect the root grafting distance, so local knowledge and experience are valuable in selecting and implementing the most effective model for line placement. Tolerance to risk, willingness to sacrifice trees, and ability to re-treat line failures are also factors in choosing line placement.	[1]French and Stienstra 1980 [2]Menges and Kuntz 1985 [3]Bruhn et al. 1991 [4]Bruhn and Heyd 1992 [5]Cummings-Carlson et al. 2010 [6]Juzwik et al. 2010

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
Vibratory plow	YES	Disrupt root graft connection	The principle of this method is to cut the roots to break the connection between diseased and healthy trees, preventing the movement of the fungus through grafted roots. This method was first developed and used effectively in Wisconsin in 1951 and has been used extensively in Minnesota since the late 1970s.[1] A vibratory plow with a 5-foot blade is the most common method of disrupting grafted root systems in the Lake States.[2] It is generally presumed that significant root grafts will not form again for at least 3 years.	Very effective, particularly on sandy soils where root grafts are common. Not appropriate for the following situations: • rocky soils (due to skips in line) • steep hills (due to equipment limitations) and areas with underground utilities. Wheeled or tracked vehicles are used depending on steepness of terrain. This treatment may be less expensive when multiple sites are treated over a limited time period.	[1]Kuntz and Riker 1951 [2]O'Brien et al. 2011
Trencher	YES	Disrupt root graft connection	Similar biological basis to vibratory plow. Trench inserts may be used to extend the effective duration of the root graft barrier.[1]	This is used in areas where vibratory plow and suitable blade are not available. The maximum depth is usually 4 feet. It is slower to install and fill in the trench compared to vibratory plow.	[1]Wilson and Lester 2002
Backhoe and/or bulldozer	YES	Disrupt root graft connection	Effectively break the root connections between trees by excavating the stumps and attached root mass. This can be accomplished by trenching around trees with a backhoe, then pushing over stumps of infected and buffer zone trees with a bulldozer. Alternatively, a backhoe equipped with a “frost tooth” can be used to pry the root mass from the ground.	This method has successfully been used in Wisconsin on the Chequamegon-Nicolet National Forest and Menominee Tribal Forest.[1] The level of site disturbance is high and may not be acceptable on sensitive or archaeological sites but may also provide good seedbed for oak regeneration. In Texas, a bulldozer with 3-foot ripper bar is used to create RGB and stumps	[1]Anna Yang 2020, personal communication [2]Gehring 1995

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
				are then pushed out of the ground by a bulldozer to further disrupt root systems.[2]	
Accelerate deterioration of stumps and roots by stump treatment with herbicides	YES	Disrupt root graft connection	In trees that have been killed by oak wilt, the fungus can persist in the roots for several years, until the roots deteriorate.[1] Depending on the chemical used, stump treatment can prevent sprouting and hasten deterioration of the root system.[2,3]	Observations in Michigan verify that oaks from stump sprouts persisted on treated sites and may serve as a reservoir of oak wilt disease to infect the next stand[4], affirming the importance of herbicide treating the stumps.	[1]Amos and True 1967 [2]Bruhn et al. 2003 [3]Skelly and Wood 1974 [4]Simeon Wright 2019, personal communication
Soil fumigant	NO	Disrupt root graft connection	Vapam (metam sodium or SMDC) and methyl bromide effectively kill oak roots.[1,2,3]	This method was tested and found to be biologically effective to kill a barrier zone of roots; however, it is rarely used now due to chemical and operational hazards.	[1]French and Stienstra 1980 [2]Himelick and Fox 1961 [3]Kuntz and Drake 1960
Girdle and herbicide treat a buffer zone of trees	YES	Disrupt root graft connection	Living oaks in a buffer zone outside oak wilt-killed trees are treated with herbicides so that roots will die and disease center expansion will be arrested. Most available chemicals do not kill roots quickly even if stems are killed. The chemicals that most consistently lead to root death include trichlopyr and imazapyr. The rate of root mortality following herbicide treatment is slow and irregular; thus, a larger buffer zone may be needed to effectively halt root graft spread.[1]	In Texas, treatment of red oaks with silvicides did not halt the root graft spread of the pathogen.[2] In Wisconsin, aggressive models (e.g. Bruhn model for sandy soils) for RGB placement are generally used to define the zone of treatment, and trees are girdled and herbicide treated with trichlopyr. Operational trials of the method indicate high success in containing underground spread, and a replicated study has been installed to document the success rate.[3] This method can be applied on sites where other methods are not feasible.	[1]Bruhn et al. 2003 [2]Gehring 1995 [3]WI DNR 2020, personal communication

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
Cut and herbicide treat stumps of a buffer zone of trees	YES	Disrupt root graft connection	This method is very similar in application to the girdle and herbicide method described above but does not result in standing dead trees.	Menominee Tribal Enterprises has treated over 65 pockets with this method and monitored them for 5 years, with similar results to the girdle/herbicide method.[1]	[1]Dave Mausel 2019, personal communication
Rapid response treatment	YES	Prevent disease from entering root system	For a single newly wilting tree that has direct evidence (e.g. recent spring storm damage) of overland infection, immediately girdle or cut the lower stem to interrupt movement of the pathogen downward through the vascular system into the roots.[1]	Monitoring of >200 individuals oaks treated by Menominee Tribal Enterprises indicates the success rate is high. Monitoring following treatment to detect root graft spread is particularly important with this method.	[1]Bruhn and Heyd 1992 [2]Dave Mausel 2019, personal communication (where would the [2] go?
Potential spore-producing tree (PSPT) removal	YES	Prevent formation of mats	Removal of all infected red oak trees and proper disposal of the material before the spring following complete tree wilt can eliminate mat production.[1] Mat formation occurs on sapwood with moisture content between 37-45%; trees that are beyond the condition for mats to form do not need to be removed.[2]	Mats can form on white and bur oak but are generally smaller and less common. Long-term control programs in Minnesota have not required removal of infected bur and white oaks. Descriptions of effective PSPT removal[3] and guidelines to visually determine suitability for mat formation based on cambial appearance are available.[4] Acceptable methods of disposal of PSPTs are described below.	[1]Rexrode and Frame 1973 [2]Campbell and French 1955 [3]Juzwik et al. 2011 [4]Juzwik et al. 2004
Destruction of potential spore-producing trees (PSPTs)	YES	Prevent formation of mats	All material from infected oak trees should be removed in the late winter or spring of the year following tree wilt, before mat production occurs. Chip, debark, or burn wood > 2 inches in diameter.	Wood between 2-6 inches in diameter has potential for fungal mat formation, but is a lower risk because the smaller diameter pieces dry out faster; thus, efforts should focus on wood greater than 6 inches in diameter.	

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
				Burying infected material or putting it into a lake to provide fish structure would also accomplish the goal of preventing mat formation.	
Logging, firewood, and other utilization	YES	Prevent formation of mats	This is a means of capturing the value of removed PSPTs.	See note above on size of material.	
Tarping		(see "prevent transfer of propagules by sap-feeding beetles")			
"Cut to the line"	YES	Prevent formation of mats	Remove all oak trees within a primary RGB line to prevent the formation of mats on recently killed trees and prevent the formation of mats on trees that are likely to die over the next few years.	This method preemptively removes the oaks within a root graft barrier line before they actually die from oak wilt.	
"Monitor and remove"	YES	Prevent formation of mats	Remove symptomatic trees within a primary RGB line, or between a secondary and primary line. Sites should be monitored annually for development of new symptomatic trees and symptomatic trees removed.	Oak wilt does not always progress to adjacent trees through grafted roots, so removing asymptomatic trees within root graft distance may result in unnecessary sacrifice of trees.[1]	[1]Juzwik et al. 2010
Cutting out pocket without disruption of root grafts	Only as a special case	Prevent formation of mats	The oak wilt fungus can persist in the root systems and move out past the harvested area if all oaks are not removed to the point of a root graft barrier or forest type change. Thus, sanitation alone did not effectively control oak wilt in Missouri.[1]	The "Pennsylvania method" (felling diseased and living oaks (of the same species) within 50 feet of the dead tree and treating all stumps with ammate) did not eliminate oak wilt from the site.[2] Monitoring over a 10-year period following cacodylic acid or deep girdling to reduce mat formation revealed that	[1]Jones and Bretz 1958 [2]Jones 1965 [3]Mielke et al. 1983

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
				the incidence of mortality in the stands due to oak wilt was not affected by the treatments, implying that reduction of mats in the absence of additional treatments to prevent root graft spread is ineffective in controlling oak wilt.[3]	
Treatment of dying trees with cacodylic acid or sodium arsenate	NO	Prevent formation of mats	Mat formation occurred on oak wilt-infected red oaks when sapwood moisture content was relatively high.[1] Chemical and mechanical treatments accelerate drying of the cambium and greatly reduce or eliminate mat formation. Chemical treatments include sodium arsenate painted on a band girdle[2,3] or cacodylic acid pressure injected by hypohatchet.[4]	There may be some concerns with utilizing cacodylic acid-treated trees for firewood; wood cut at least 70 cm above the point of injection would present no danger of arsenic release if burned.[5]	[1]Campbell and French 1955 [2]Morris 1955 [3]Ohman et al. 1959 [4]Rexrode 1977 [5]Woolson 1986
Treatment with biological control fungi	NO	Prevent formation of mats	Treatment with biological control fungi (e.g. *Trichoderma* spp. and *Gliocladium roseum*) reduced colonization of the host by the pathogen and subsequent mat production.[1]	Not recommended because labor intensive and time consuming.[1]	[1]MacDonald 1995
Frill girdling or felling of wilting trees during summer	YES?	Prevent formation of mats	Dries out the cambial area so mats do not form. Frill girdling must be done in early stages of wilt, while the dying tree still has some vascular function.[1,2] In West Virginia, mat production was reduced to low levels or to zero on infected trees girdled or felled respectively during the summer.[3] Basal girdling has also been tested in Texas.[5]	Girdling trees with early wilt symptoms helps prevent mat formation in a "monitor and remove" situation. If the girdle is done in the fall after much of the crown has wilted, an abundance of mats may occur near the girdling cuts the next spring, so the period of opportunity for this treatment does not extend into fall.[4]	[1]True and Gillespie 1961 [2]Gillespie and True 1963 [3]Rexrode and Frame 1973 [4]Jennifer Juzwik 2020, personal communication [5]Greene et al. 2008

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
Prevent wounding	YES	Prevent transfer of propagules by sap-feeding beetles	Wounds that occur on oaks in the spring are very susceptible to infection by the oak wilt fungus.[1,2] Causes of wounds include pruning, climbing irons, logging or construction damage, and wind events. Fresh wounds are attractive to sap-feeding beetles that carry oak wilt spores in and on their bodies.[3,4] If wounding is necessary or occurs during the spring, wound dressing or paint should be applied immediately to the wounded surface (including stumps).	Education efforts that have been effective in increasing awareness of this problem include billboards, newspaper articles, and public service announcements. Some organizations, like utility companies, have adopted pruning policies/guidelines that minimize wounding in spring. DNRs and Extension agencies provide specific guidelines for their respective States (web search by State of interest for most recent resources.).	[1]Drake et al. 1957 [2]Juzwik et al. 1985 [3]Juzwik et al. 2004 [4]Hayslett et al. 2008
Wound treatment with paint	NO	Prevent transfer of propagules by sap-feeding beetles	See note above. Apply paint to all fresh wounds in the spring.[1]	Generally considered a standard arboriculture practice, to be incorporated whenever wounding oaks in spring is necessary.	[1]Gibbs 1980
Wound treatment with biological control agent	NO	Prevent transfer of propagules by sap-feeding beetles	Biological control agent (*Ceratocystis picea* = *Ophiostoma quercus*) applied to fresh wounds in the spring 24 hours before the oak wilt fungus, *Bretziella fagacearum,* is introduced reduces or eliminates successful infection by the pathogen.[1]	Not considered practical. Easier for arborists and foresters to use paint to create physical barrier on wound surface to prevent transfer of spores from insect vector bodies.	[1]Gibbs 1980
Cover and seal firewood harvested from oak wilt-killed red oaks	YES	Prevent transfer of propagules by sap-feeding beetles	Logs from diseased oaks may be cut into firewood log lengths, split, and stored on-site under clear plastic that is sealed at the ground line through the field season following tree death.[1] Tarping of firewood piles prevents access of sap-feeding beetles to mats that form,	If a tree wilts in summer and firewood is cut and split before September, adequate drying of the wood should occur to prevent formation of fungal mats. However, if the wood is not cut until fall or winter following wilting, firewood should be tarped. It is essential	[1]Juzwik et al. 2011 [2]Bruhn and Heyd 1992 [3]Cook and Juzwik, in Juzwik et al. 2004

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
			and also of encourages the growth of competing fungi.[2]	to use a 4 ml or heavier plastic and seal the edges of the tarp by burying them. The tarp should be in place before spring and can be safely removed at the end of the growing season.[3]	
Pheromone trapping	Yes, for monitor-ing	Prevent transfer of propagules by sap-feeding beetles	Pheromone baits of selected nitidulid species can be used to monitor for the activity of pathogen-infested beetles in oak stands and thus contribute to annual guidelines for preventing wounding.[1,2] Degree day models have been developed to monitor nitidulid flight period.[3,4]	Currently recommended for monitoring of populations only – not for "trap out." Monitoring of flight period of nitidulids to validate degree day models or clarify risk of overland transmission is a valid application.	[1]Kyhl et al. 2002 [2]Bartelt et al. 2004 [3]Jagemann et al. 2018 [4]Dave Mausel 2019, personal communication
Don't move firewood or infected wood products to uninfested areas	NO	Prevent transfer of propagules by sap-feeding or bark beetles	The oak wilt fungus can survive in dead oak wood for up to 12 months after crown death, and thus firewood from trees killed by *B. fagacearum* should not be transported to areas where oak wilt is absent.[1] Oak bark beetles emerging from oak wilt-killed trees can carry propagules of the pathogen on their bodies.[2,3,4]	The prevention of movement of oak wilt (or other pests) to new areas in firewood is primarily accomplished through regulation and education. Oak bark beetle does not seem to be the primary vector in Minnesota, but may be of concern in other areas.[5,6]	[1]Lewis 1987 [2]Berry and Bretz 1966 [3]Rexrode and Jones 1970 [4]Rexrode and Jones 1971 [5]Ambourn et al. 2005 [6]Ambourn et. al. 2006
Kiln drying or vacuum steam heat treatment	NO	Eliminate viable fungal propagules in wood	Kiln drying (to <20% wood moisture), hot air, hot water, and vacuum steam treatments of oak logs and cut boards effectively kill the oak wilt fungus.[1,2,3]	This is primarily a regulatory issue, related to movement of diseased wood into areas without oak wilt disease, particularly Europe.	[1]Englerth et al. 1956 [2]Jones 1973 [3]Juzwik et al. 2019
Wood fumigation	NO	Eliminate viable fungal propagules in wood	Sulfuryl fluoride and methyl bromide gas eliminate or greatly reduce the presence of viable pathogen in colonized logs.[1,2,3,4]	This is primarily a regulatory issue, related to movement of diseased wood into areas without oak wilt disease, particularly Europe.	[1]MacDonald et al. 1985 [2]Schmidt and Christopherson 1997 [3]Schmidt et al. 1997 [4]Yang et al. 2019

Treatment or action	Cost-share eligible practice?	Point at which disease cycle is disrupted	Biological relevance and research basis	Practical considerations	References
Eliminate viable pathogen propagules on mats using biological control fungi	NO	Reduce inoculum production by mats	Several fungi, such as *Ophiostoma quercus* and *Gliocladium roseum*, commonly colonize oak wilt mats in nature and likely contribute to a low level of natural biological control of overland spread.[1] Augmentation sprays with these fungi to trees producing mats either had little to no effect on viable pathogen propagules available for insect acquisition.[1]	Maximum of 20% efficacy, which is not sufficient to significantly reduce the level of available inoculum.	[1]Juzwik et al. 1998
Macroinjection of fungicide as preventive treatment	NO, unless combined with other manage-ment strategies	Prevent development of disease in tree	Fungicide (propiconazole) is injected to protect healthy red oaks from developing symptoms of oak wilt disease for at least 2 years but efficacy appears to not last more than 3 years past treatment.[1,2,3] Preventive treatment of white and bur oaks is effective for at least 5 years past treatment.[3] It is also useful for control of oak wilt in live oak.[4,5]	A published summary of treatment options includes more details on injection research.[6] Fungicide injection is generally recommended only for high-value oaks. Propiconazole has been found up to 3 feet below injection sites but has not demonstrated the ability to eradicate the fungus from root systems.[2] Injection with propiconazole is not intended to prevent root graft transmission.	[1]Osterbauer and French 1992 [2]Blaedow et al. 2010 [3]Eggers et al. 2005 [4]Appel 2001 [5]Appel and Kurdyla 1992 [6]Koch et al. 2010
Microinjection (capsule) of fungicides	NO	Prevent or arrest development of disease in tree	Microinjection results in poorer distribution in tree canopy than macroinjection.[1]	Microinjection is still used as it requires less labor and time to treat.	[1]Costonis 1981
Macroinjection of propiconazole as therapeutic treatment	NO	Arrest development of disease in tree	Propiconazole generally prevents further disease symptom development in bur and white oak.[1] Therapeutic treatment of infected red oaks was only able to arrest symptom progression for trees that had < 25 percent crown wilt visible at time of treatment.[2]		[1]Eggers et al. 2005 [2]Ward et al. 2005

Appendix B. Listing of Relevant Literature

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