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INVASIVE PLANT SERIES

# Tree of Heaven, *Ailanthus altissima*

## Description

Tree-of-heaven (ToH), also known as Chinese sumac, varnish tree, or stink tree, is a large, rapidly growing deciduous tree native to parts of China. Tree-of-heaven was introduced to North America as early as the late 1700s and has since become invasive in most areas of the United States (Figure 1). Tree-of-heaven can be found, sometimes in abundance, in both urban and rural environments. The tree spreads through abundantly produced wind-scattered seeds from female trees, and sprout colonies arising from established trees, in some cases producing monoculture stands of the species. ToH has also been shown to produce allelopathic chemicals that can inhibit the growth of neighboring plants, providing an additional competitive advantage.

Tree-of-heaven can be a large tree over 80 feet tall and 3 or more feet in diameter, outpacing the growth rate of most native tree species on a wide range of sites. Long, alternately arranged compound leaves with up to 25 leaflets are borne on stout twigs (Figures 2 and 3, page 2). Leaflets typically have one or more small glandular teeth located at the base (Figures 4 and 5, page 2). Species with similar leaves, such as

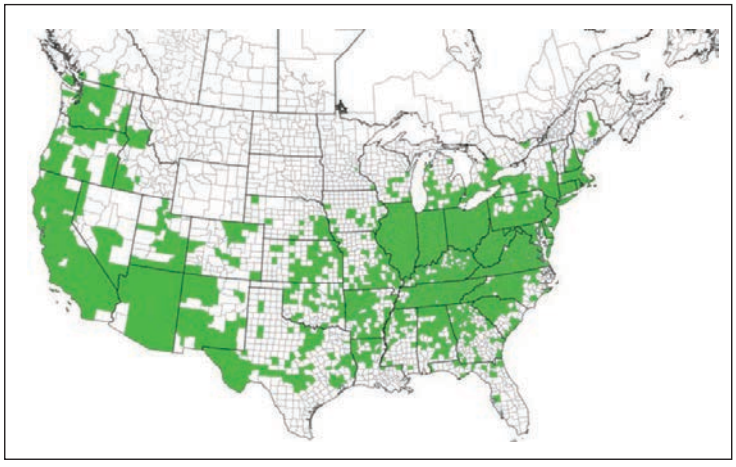

***Figure 1.*** *Reported range of tree-of-heaven by county in green. EDDMapS. 2023. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/; last accessed May 30, 2023*

***Figure 2.*** *Tree-of-heaven seedling leaves. Photo by Lenny Farlee*

***Figure 3.*** *Tree-of-heaven leaf and leaflets. Photo by Ron Rathfon*

***Figure 4.*** *Tree-of-heaven leaflet margins and glands. Photo by Lenny Farlee*

***Figure 5.*** *Tree-of-heaven underside of leaflet showing gland. Photo by Lenny Farlee*

***Figure 6.*** *Winged sumac leaflet margins. Photo by Lenny Farlee*

***Figure 7.*** *Smooth sumac leaflet margins. Photo by Lenny Farlee*

***Figure 8.*** *Black walnut leaflet margins. Photo by Lenny Farlee*

***Figure 9.*** *Tree of heaven twig with leaf scars and buds. Photo by Ron Rathfon*

***Figure 10.*** *Left, tree-of-heaven sapling bark. Right, large tree-of-heaven parent tree in a sprout colony. Photos by Purdue Extension.*

black walnut or native sumac species, lack this feature, having smooth leaflet margins, or teeth along the full length of the leaflet (Figures 6, 7, and 8). Twigs are stout with very large V or heart-shaped leaf scars and large tan or brown spongy pith in the center (Figure 9). When crushed or damaged, all parts of the plant have a foul odor, sometimes described as smelling like rancid peanut butter. Bark on young trees is smooth and medium gray with lighter wormy gray markings. Older bark may take on a texture similar to the skin of a cantaloupe or be furrowed and gray (Figure 10).

Twisted, winged seeds are borne in clusters on female trees. The seeds are green, turning yellow to reddish-orange later in the growing season. They may persist on trees into winter in clusters and turn tan to gray-brown (Figures 11, 12 and 13, page 3). Mature trees may produce hundreds of thousands of seed each year.

## Impact

The numerous windblown seed, prolific root-sprouting, rapid growth rate and allelopathic chemical production make ToH a serious threat as an invasive species in many habitats or untended areas (Figure 14, page 3). Some people have had physical reactions to the sap of ToH, so caution should be exercised when managing this species. ToH roots may damage roads, sidewalks, foundations, and other infrastructure.

ToH is also the preferred host for the invasive spotted lanternfly, an insect capable of damaging many woody plant species through sap-feeding in large numbers (Figure 15, page 3). Reducing tree-of-heaven numbers on the landscape may help with the management of spotted lanternfly by limiting the availability of a preferred food source. ToH male trees may also be good potential trap trees for monitoring the presence of spotted lanternfly,

***Figure 11.*** *Immature seeds. Photo by Lenny Farlee*

***Figure 12.*** *Maturing seed. Photo by Ron Rathfon*

***Figure 13.*** *Mature seeds. Photo by Lenny Farlee*

***Figure 14.*** *Tree-of-heaven sprout colony Photo by Don Carlson*

***Figure 15.*** *Spotted lanternfly, Lycorma delicatula, on tree-of-heaven. Photo by Richard Gardner, Bugwood.org*

***Figure 16.*** *Tree of-heaven 2nd year seedling outpacing tuliptree and other natives in a forest opening. Photo by Lenny Farlee*

and applying insecticide treatments to selected trap trees may help reduce spotted lanternfly numbers. Female trees should not be used so as to prevent the production and spread of additional seed.

## Management

Controlling tree-of-heaven can be challenging. Preventing the introduction of ToH to new areas is dependent on controlling seed production and spread. The windblown seed may travel more than 650 feet from parent plants and remain viable in the soil for longer than five years (Rebbeck & Jolliff, 2010). ToH seed responds positively to many forms of forest disturbance that expose soil or allow more sunlight into the forest understory (Figure 16). USDA Forest Service researchers have recommended elimination of seed-producing ToH six years prior to timber harvests to limit the capacity of stored seed in the soil to germinate and produce new populations. Identifying and killing any seed-producing ToH as soon as possible is an important preventive activity. Considering the distance that the seed may disperse, cooperation among property owners may be required to effectively limit seed spread.

Be aware of other sources of seed spread, such as floodwaters, fill or refuse materials, or soil on equipment that may contain seeds. Monitor forest and wildland areas regularly to detect new infestations, particularly edge and disturbed areas where bare soil or sunlight is available. The color differences between seed and foliage on female ToH may facilitate scouting in summer for infestations from the ground and possibly from the air as well. Act quickly when ToH or other invasive plants are found to eliminate seed production and begin a control program to manage the infestation. This process of early detection and rapid response can prevent large infestations, keep control and management costs from exploding, and limit the ecological impact of the invasive plants in the area.

Existing populations of ToH will require evaluation and development of a management program for control. An assessment of the size and density of the ToH and the site conditions of the area to be managed will help inform the techniques and materials to be used to control the population. Combining several management techniques over a period of time is often necessary to effectively control and manage ToH.

Mechanical treatments alone are typically not effective at controlling ToH. Some small seedlings may be pulled, but root fragments left behind may produce new plants (Figure 17). It can also be difficult to tell seedlings from root sprouts, which are not easily controlled with pulling. Cutting down or girdling stems will produce significant stump and root sprouts, multiplying populations. This may be effective at killing ToH stems and preventing seed production if repeated on a regular basis, but it will not control the root systems. The stump and root sprouting response prompted by cutting or girdling can occur even when herbicides are used on the cut stump or in a girdling cut. Fire may kill the tops of seedlings or saplings, but root systems will not be killed and can produce abundant sprouts. There may be situations where felling ToH is warranted, to limit seed production and spread, or for safety considerations. In these cases, treatments

***Figure 17.*** *Tree-of-heaven sprouts from a root fragment. Photo by Ron Rathfon*

***Figure 18.*** *Applying herbicide in a hack-and–squirt cut. Photo by Steve Manning, Invasive Plant Control, Bugwood.org*

***Figure 19.*** *Hack-and-squirt herbicide application. Evenly distributed cuts with uncut spaces left between and herbicide applied to the cut surfaces. Photo by Lenny Farlee*

***Figure 20.*** *Basal bark application of ester herbicide and oil mixture applied to the lower 15-18 inches of stem. Photo by Purdue University.*

***Figure 21.*** *Tree-of-Heaven treatment area showing non-target understory plant damage from volatilized triclopyr basal bark application. Photo by Don Carlson*

the following growing season to control the sprouts with foliar herbicide applications will be a critical step to success. Waiting more than one or two growing seasons may result in sprouts too tall to efficiently or effectively treat by ground-based foliar methods

When possible, use the hack-and-squirt technique in place of felling or complete girdling cuts around the circumference of the stem (Figure 18 and 19). Hack-and-squirt treatment, combining spaced cuts with herbicide application in the cuts, may reduce the number of root-sprouts produced. Using a narrow cutting tool, like a shingle hatchet or a hatchet ground down to a 2-inch blade, make evenly spaced cuts at a 45-degree angle around the circumference of the tree. The number of cuts should be approximately the diameter of the tree in inches, with uncut spaces between the cuts. Spray one to two milliliters (one to two squirts from a trigger squirt bottle; check your bottle application rate) of herbicide in each cut immediately after making the cuts. Avoid overapplication – herbicide that runs down the stem is not impacting the target-tree and may damage nontarget plants nearby.

Basal bark application of triclopyr ester herbicides is a very effective control method for TOH. This method does not require any cutting tools. A mixture of an oil and ester herbicide is applied to the lower 15-18 inches of the trunk of the tree to be controlled, covering the bark and root flares (Figure 20). The oil acts as a penetrant, carrying the herbicide into the plant. This treatment greatly reduces the number of sprouts produced by tree-of-heaven. This application is very effective during the last half of the growing season, but care should be taken to avoid applications during hot weather above 85 degrees F, as volatilization of the herbicide/oil mixture can occur, impacting non-target plants and potentially reducing application efficacy (Figure 21). Personal communications from some land managers indicated

volatilization could happen at lower temperatures when the treated areas are exposed to intense sunlight. Some sources also recommend this treatment for late winter to early spring as well, but it should not be used when there is snow cover or stems are wet. Reduced efficacy has been reported, so discontinue basal bark applications later in spring when sap is moving up in the trees. You may also consider treating the ToH with a basal bark or hack-and-squirt herbicide treatment at least 30 days prior to felling the trees, when that is needed to reduce seed spread or for safety considerations. This allows herbicide to move to and kill the root system prior to cutting the tree, limiting the root sprouting response.

Foliar application of herbicides to actively growing leaf area may be a very effective control technique for smaller plants. Large sprout patches or taller stems may be treated if high-pressure sprayers or aerial equipment are available (Figure 22). This is also an effective follow-up treatment to control root sprouts and seedlings. Complete coverage of the live leaf area is needed for effective control.

For very dense or large infestations, using tree and brush clearing equipment, such as rotary grinders mounted to skid-steer machines, may be the most efficient approach to start the control process (Figure 23). Since root systems are not controlled using this approach, a follow-up foliar herbicide treatment of all sprouts will be needed the next growing season. Failing to do a follow-up treatment to kill sprouts often results in an increased number of fast-growing stems per acre, negating gains made against the infestation. Operators should also be protected from sap and sawdust because ToH can irritate skin and eyes and in some cases produce a serious rash or other reactions.

The use of a combination of prescribed fire in the spring and hack-and-squirt herbicide applications was also very effective at controlling ToH stems and limiting root sprouting.

The decision of what technique(s) to use depends on several factors:

- What equipment and materials are available for treatments
- Size, number, density and accessibility of plants to control
- Desired timing of the control work
- Potential for collateral damage to desirable vegetation
- Labor and budget capacities
- Safety considerations

***Figure 22.*** *High-pressure foliar herbicide application. Photo by Great Smoky Mountains National Park Resource Management , USDI National Park Service, Bugwood.org*

***Figure 23.*** *Rotary grinders and other clearing equipment may be used to start control of dense tree-of-heaven patches, but follow-up herbicide applications will be needed to control the root and stump sprouts resulting from this treatment. Photo by Lenny Farlee*

## Herbicides to Use for Tree-of-Heaven Control

DISCLAIMER: REFERENCE TO PRODUCTS IS NOT INTENDED TO BE AN ENDORSEMENT TO THE EXCLUSION OF OTHERS WHICH MAY HAVE SIMILAR USES. ANY PERSON USING PRODUCTS LISTED IN THIS ARTICLE ASSUMES FULL RESPONSIBILITY FOR THEIR USE IN ACCORDANCE WITH CURRENT DIRECTIONS OF THE MANUFACTURER.

Read the label to check active ingredient (ai) concentration and all safety and application instructions. Adjust rates accordingly for labels with different ai concentrations. Listed below are application techniques and herbicide options for each.

**Foliar applications:** Applied when leaves are fully expanded and actively growing. The second half of the growing season may provide the best results, but avoid periods of drought when plant activity may be reduced. If the herbicide product does not already contain an adjuvant, add non-ionic surfactant or methylated seed oil to enhance herbicide penetration and uptake into the leaves, following label directions. All leaf surfaces of the target plant should be covered with herbicide while avoiding excessive runoff onto the ground as much as possible.

Glyphosate (Roundup, Accord XRT II, Imitator Plus and others) – 2-3% (41-50% ai) concentrate in water. Treat hard or high pH water with conditioners like spray-grade ammonium sulfate prior to mixing to enhance glyphosate effectiveness. Expect collateral damage to nearby plants exposed to overspray.

Triclopyr amine (Garlon 3A, Triclopyr 3, Element 3A and others) – 1.5 to 2% concentrate (44.4% ai) in water. Expect collateral damage to nearby broadleaved plants, but typically not damaging to many grasses.

Triclopyr ester (Triclopyr 4, Garlon 4 Ultra and others) – 1 to 2% concentrate (60-62% ai) in water. Expect collateral damage to nearby broadleaved plants, but typically not damaging to many grasses.

Metsulfuron methyl (Escort XP and others, 60% ai) – For low volume foliar applications (less than 30 gallons of tank mix per acre), 4 to 8 oz in 100 gallons of water, or 1.1 to 2.2 grams per gallon of water. Due to soil activity, overall application rates should not exceed 1 oz per acre in forest environments to avoid non-target plant injury. Requires frequent agitation to keep herbicide suspended in water.

Imazapyr (Arsenal, Arsenal Powerline, Chopper and others) – 0.5 to 1% concentrate (26.7% ai) in water. Use only where collateral damage of other vegetation is not a concern. Imazapyr has persistence and high activity in soil, resulting in possible damage to non-target vegetation where applied – use caution or leave applications of this material to professionals. Arsenal AC, Imazapyr 4SL and others is 53.1% ai.

**Basal bark applications:** Applied to the lower 15 to 18 inches of stems and root flares with complete coverage of the bark. Most effective during the last half of the growing season and into fall and winter.

Triclopyr ester - 20% concentrate in oil. Basal oil is recommended, but refer to the label for other labeled oils. Avoid applications during periods over 85 degrees F. Most effective on trees up to 6 inches diameter. Larger trees may be controlled by increasing the treated stem area up to 24 inches from the ground.

Imazapyr – 6-9% concentrate in oil. Basal oil is recommended, but refer to the label for other recommended oils. Avoid applications during periods over 85 degrees F. Use only where collateral damage of other vegetation is not a concern. Imazapyr has persistence and high activity in the soil, resulting in possible damage to non-target vegetation where applied. Use caution or leave applications of this material to professionals. Imazapyr and Triclopyr may be combined for basal bark applications at a rate of 15% triclopyr, 5% Imazapyr and 80% oil as indicated on label.

**Hack-and-squirt treatments (also called stem injection):** This is the recommended treatment for stems larger than those normally treated by basal bark application – 6 inches or more in diameter, although smaller stems may be treated with this method if desired. Make at least one cut for every inch of diameter, but a minimum of two cuts, using a hatchet or other narrow cutting tool at a 45-degree downward angle, penetrating bark and cambium into the sapwood. Immediately apply the recommended herbicide into the pocket created by the cut. Leave a space of at least 1 to 2 inches between the cuts, creating an evenly spaced set of cuts and uncut areas around the circumference of the tree.

Triclopyr amine – Use 100% concentrate, squirting 1-2 milliliters into each cut. The most effective application period to reduce sprouting is summer, with increased sprouting reported otherwise.

Imazapyr – (3-5% Arsenal AC or similar, 53.1% ai) squirting 1-2 milliliters into each cut in late summer to early fall. In one trial, treatment areas were monitored for two years with no observable symptoms on non-target vegetation within 5 meters of treated Ailanthus stems. Late growing season (July to October) timing of the herbicide application was critical to eliminate Ailanthus

root and basal sprouting. Check the label for different formulations and ai concentrations.

Dicamba and 2-4-D plus Picloram have also been reported as effective hack-and-squirt herbicides during the growing season. Consult the labels of each herbicide for application rates and further instructions. These materials may also result in damage to non-target plants in some applications.

Glyphosate – 50-100% concentrate squirting 1-2 milliliters into each cut. This treatment is recommended by several sources, but some sources report poor results for this material for reducing root sprouting in following seasons. This may be related to timing. Foliar and hack-and-squirt treatments are most effective in the last half of the growing season, before leaves begin to show fall color.

**Cut-stump treatments:** Dicamba, glyphosate, imazapyr, triclopyr and 2-4 D plus picloram have been used for treating stumps, but significant sprouting should be expected following the treatment. You may trade one large stem for many small but rapidly growing sprouts with this treatment. This may be an acceptable trade to prevent seed production and spread, or for operational safety, but follow-up treatment to control sprouts is critical to success. Another option is to use foliar, basal bark or hack-and-squirt treatments in the second half of the growing season to kill the roots. Return after 30 or more days to remove the tops.

For all the above treatment recommendations, return to the site in following growing seasons to scout for and treat sprouts and germinating seed. Even the best treatments don't prevent all sprouting, and seed from recently controlled trees or neighboring infestations may produce new plants. Foliar treatments with 2-3% glyphosate concentrate in water, and other recommended foliar treatments, are effective for this follow-up work on seedlings and sprouts.

In addition, keep good records of your control work, including timing, weather conditions, tools, techniques, and materials used to track the effectiveness of your treatments. Good record-keeping and follow-up evaluation of treatments can help tune prescriptions to improve results in future management actions.

## Is a biological control option for tree-of-heaven on the horizon?

Researchers with the US Forest Service and several other institutions have identified a native verticillium wilt fungus that is deadly to ToH, but appears to have slight or no impact on native trees and plants screened so far. *Verticillium nonalfalfae* wilt has been found killing ToH in Virginia, Pennsylvania and Ohio. Screening and field experiments have shown this fungus to be very effective at killing ToH with minimal or no adverse impacts on most native plants or cultivated crops. In greenhouse and field screenings of more than 70 species, only striped maple, staghorn sumac, poison ivy, and red elderberry showed mortality when exposed to *Verticillium nonalfalfae*. The incidence of mortality was very low for these species, with 16% for staghorn sumac at the maximum. Mortality for ToH in these tests was 100%.

Field tests using hack-and-squirt applications of *Verticillium nonalfalfae* suspension in water have resulted in control of the treated trees as well as spread of the wilt disease in stands to non-treated ToH stems, resulting in additional mortality. The spread of the disease and mortality is a gradual process resulting in significant reduction of ToH stems over a period of four or five years. Dense populations of small-diameter ToH generally show the most reduction. These promising results indicate a possible combined biological and chemical approach that uses the wilt to reduce population size, making the final chemical treatments to control stems escaping the wilt much less expensive and time-consuming.

Researchers continue to screen for any other negative impacts of the wilt on non-target plants, and licensing this material as a bio-pesticide for use on ToH is being pursued. This may take a few more years but adds promise of another tool to use in management of this aggressive invasive plant.

Landowners and land management professionals are encouraged to report any findings of wilting ToH to the Indiana DNR Division of Entomology and Plant Pathology, DEPP@dnr.IN.gov (866) NO-EXOTIC [(866) 663-9684] or use the ReportIN website, which allows photos and GPS coordinates to be submitted. Confirming *Verticillium nonalfalfae* in Indiana could help facilitate the licensing and use of this wilt disease as a bio-pesticide in the state.

## References and resources

Midwest Invasive Plant Network Control Database - https://mipncontroldatabase.wisc.edu/

Penn State University: https://extension.psu.edu/tree-of-heaven

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State of Indiana Cooperative Invasives Management, Control and Management Documents. https://www.sicim.info/control-and-management

Spotted Lanternfly Management Resources. https://extension.psu.edu/spotted-lanternfly-management-resources

Tree of Heaven Identification and Management webinar, Emerald Ash Borer University, https://www.youtube.com/@EmeraldAshBorerUniversity/videos

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