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THE POTENTIAL OF TRENCH INSERTS FOR OAK WILT SUPPRESSION

A. Dan Wilson
USDA Forest Service
Southern Hardwoods Laboratory
P.O. Box 227 (432 Stoneville Road)
Stoneville, MS 38776-0227
Email: dwilson02@fs.fed.us

ABSTRACT

Trench inserts are physical barriers used to control root transmission of *Ceratocystis fagacearum* which provide a significant new strategy and technology for oak wilt suppression in the U.S. This cultural control method has been shown experimentally to significantly extend the effective life and utility of trenches in Texas. The utilization of trench inserts also has increased the effectiveness of trenches as physical barriers to root transmission. Water-permeable trench inserts are more effective barriers than trenches alone because they prevent new root graft formation in trench-backfill soil indefinitely. Trench inserts may provide greater insurance against future trench breakouts in backup trenches when original trenches fail. Water-impermeable trench inserts are not as effective because, in some cases, they tend to direct root growth around (usually above) the insert when inserts are buried too deeply. Trench inserts may be installed at a fraction of the costs of primary trenches and may not significantly increase total trenching costs. The use of trench inserts could potentially save millions of dollars through protection of uninfected trees, avoidance of tree removal costs, and reductions in property value depreciations for Texas landowners. This technology is equally applicable in other areas of the U.S. affected by this disease. Some potential problems associated with the installation of trench inserts are discussed.

Key words: *Ceratocystis fagacearum*, direct control, root barriers

Oak wilt, caused by *Ceratocystis fagacearum* (Bretz) Hunt, is probably the most destructive disease of oak species in the United States (Gibbs and French 1980, Appel 1995, Tainter 1995, Wilson 2001). The disease annually kills numerous oaks throughout the eastern half of the country, particularly those in the red/black oak group (subgenus *Quercus* section *Lobatae*) due to greater susceptibility to the disease and differences in physiology and microscopic anatomy of sapwood (Tillson and Muller 1942, Nixon 1993, Tainter 1995, Wilson, Lester and Oberle 2005). The semievergreen live oaks, including plateau live oak (*Q. fusiformis* = *Q. virginiana* var. *fusiformis*) and coastal live oak (*Q. virginiana*), are considered the most valuable woodland and urban tree species in central Texas (Appel et al. 1986, Martin, Maggio and Appel 1989). Although live oaks are intermediate in susceptibility to oak wilt, they are the most seriously affected oaks in terms of disease incidence and rate of spread. The natural growth tendencies of live oaks to form root sprouts from mother trees, giving rise to large clusters of clonal trees (motts) with extensive root grafts and interconnected common root systems, increase the predisposition of live oaks to root transmission (Muller 1951, Appel, Anderson and Lewis 1986, Davies 1992, Wilson 1995). Oak wilt disease incidence is often high in live oaks because of these growth-form predispositions, the formation of extensive shallow root systems, and the abundance and high density of live oaks in both urban and rural forest stands of central Texas.

Most live oaks defoliate and die within six months after the initial appearance of oak wilt symptoms. Consequently, there is very little time to initiate effective disease-control measures to save individual infected trees after symptoms first appear. Any tactics developed to halt disease spread must consider that disease development often occurs rapidly and the oak wilt fungus can move up to 50 m or more per year through grafted root systems at the edge of expanding oak wilt infections centers.

Trenching to cut root connections between healthy and diseased trees continues to be the principal means of controlling the spread of the oak wilt fungus through root transmission in the U.S. (Himelick and Fox 1961, Cameron and Billings 1995, Gehring 1995, Billings et al. 2001, Haugen et al., this proceedings). Trenching has been a particularly important tool for dealing with the disease in highly-valued live oak stands because root grafts and extensively interconnected root systems allow the disease to spread rapidly by root transmission. The Texas Oak Wilt Suppression Project (TOWSP), administered by the Texas Forest Service since 1988, has installed over 3.4 million linear feet of trench to combat the disease in 2,466 oak wilt infection centers found within 61 of 254 Texas counties (Billings, this proceedings). However, trenching is not totally effective in containing the disease, partly due to new root connections that form across the trench and allow disease centers to continue to expand beyond trench barriers. TOWSP post-suppression evaluations showed that about 33% of trenches installed prior to 1995 had at least one breakout (infected trees beyond the trench), although seldom is the entire trench a failure (Gehring 1995).

A 7-year study was initiated in 1993 to look at the feasibility of improving the effectiveness and longevity of trenches using trench inserts (Wilson and Lester 2002). A significant finding in this study was that small oak feeder roots, formed from roots severed by trenching, grew into the loose backfill soil within trenches allowing new root graft connections to form across the trench. The results showed favorable indications that trench inserts could provide significant improvements in the performance of trenches by preventing the formation of these new root grafts that allow inoculum (conidia and hyphal fragments) of the oak wilt fungus to move beyond the trench. Preliminary research demonstrated the efficacy of trench inserts in stopping the expansion of oak wilt infection centers beyond the trench up to six years after trenching (Wilson and Lester 1996a-c).

This paper explains why improvements in trenching technologies are needed to more effectively control root transmission of *C. fagacearum*, how trench inserts improve trench effectiveness and longevity, what additional expenses are associated with utilizing trench inserts, the comparative performance of different types of trench inserts, and some potential problems involved in the installation of trench inserts for oak wilt control. Recommendations also are provided that explain ways to more effectively and efficiently implement the use of trench inserts within existing oak wilt suppression programs.

TRENCHING EFFECTS ON SOIL STRUCTURE AND ROOT INTERATIONS

The first essential information needed for improving trenching technologies for oak wilt control is to determine why trenches fail or why trench breakouts occur. The principal reasons why trench breakouts occur usually vary with time after trench installation. Breakouts that occur within two years after trenching usually result from placing the trench too close to the infection center or not trenching deeply enough to sever all roots. Breakouts that occur after 2-3 years are likely the result of root regrafting across the trench. Trenching causes changes in the physical properties of soil structure and subsequent root interactions that occur in trench backfill soil after trenching. These effects of trenching on soil structure and oak-root interactions set into motion a dynamic process that ultimately increases the chances for trench breakouts over time following trenching.

PROBLEMS WITH TRENCHING

One of the biggest problems associated with the mechanical cutting of trenches for oak wilt control involves the effects of trenching on soil structure and characteristics within the trench. Trenching creates a soil environment highly favorable for root growth. Farmers till the soil in their fields before planting for this very reason. Tilling the soil reduces the bulk density of soil by breaking up soil aggregates into smaller particles, rendering the soil friable and more favorable for root growth, penetration by rainfall, and infiltration by fertilizers and nutrients. For the same reason, no-till cultivation has been adopted as a farming practice in many areas of the U.S. to reduce soil erosion and weed growth stimulated by the loosening of soil structure that facilitates root growth of competitive weed plants. Trenching has the same effects on soil structure as tilling the soil. Backfill soil within the trench is loosened significantly (bulk density 1.22 g/cm^3) relative to the compacted surrounding soil (bulk density 1.62 g/cm^3) (Backhaus 2005).

There are several consequences that result from these changes in soil structure due to trenching. Roots from the surrounding compacted soil seek to grow in this loose backfill soil because it provides the path of least resistance for root growth, expansion, and branching. Consequently, roots proliferate and penetrate into this loose trench backfill soil much more rapidly than in the adjacent, compacted soil on either side of the trench. The loosened backfill soil within newly-cut trenches also is a natural sink for water and nutrient flow into the ground, again because it is the path of least resistance. Water and dissolved nutrients tend to collect and accumulate within the loosened trench soil, further enhancing and stimulating new root growth from roots adjacent to the trench. The natural influx of tree root growth into this more favorable trench soil is promoted by all of the improvements in soil conditions that result from the trenching process.

The cutting of oak roots by trenching induces the formation of fine (<5 mm-diameter), feeder roots in trench soil due to the loss of apical dominance. This same phenomenon occurs when apical meristems are cut in the upper parts of the tree resulting in the loss of apical dominance and the production of sucker sprouts on trunks and lateral epicormic branches. The production of lateral roots, due to the loss of apical root dominance in roots severed by trenching, leads to the proliferation of fine feeder roots in the loose backfill soil of newly-cut trenches. These feeder roots begin forming within a few inches of the severed ends of roots as soon as soil moisture becomes available. Trenches are generally backfilled immediately during the trenching process, allowing new root growth to begin forming usually after the next rain event. Most feeder roots are found within the top 18 inches (46 cm) of the soil surface where soil moisture is most available following a rain. Feeder roots also form from the cut ends of deeper roots severed by trenching, up to 6 feet (1.8 m) or more below the soil surface depending on soil depth.

The very high tendency of Texas live oaks to form root grafts and common root systems allows these species to utilize the ideal conditions within newly-cut trenches to initiate the formation of new fine feeder roots that readily graft with roots of other live oaks with which they come in contact. Because live oaks on both sides of the trench have roots severed by trenching, these trees send out an abundance of new feeder roots into trench soil creating conditions very favorable for the formation of new root grafts across the trench. It is for this reason that the

TOWSP recommends uprooting all trees and disrupting or extracting the root system inside the trench in rural areas.

TRENCH BREAKOUTS – WHY THEY OCCUR

The majority (60.1 %) of oak wilt breakouts from TOWSP trenches have occurred during the first two years after trench installation (Table 1), due to factors other than regrowth of roots across the trench (Gehring 1995). The rate of new trench breakouts decreases rapidly over time after two years resulting in negative slope curves for breakouts beyond two years after trenching. Nevertheless, up to 40% or more of all trench breakouts occur after two years following trenching. Even though trench breakout rates continue to decrease after two years, breakouts have been recorded to occur up to fifteen years or more after trench installation, far beyond the time normally expected for *C. fagacearum*-inoculum to move through existing root grafts across the trench. The expanding edges of oak wilt infection centers are known to move up to 80 feet (25 m) or more per year in Texas live oaks. Because trenches normally are installed within a 100-feet (30 m) buffer zone beyond the advancing front of the infection center, it usually takes a maximum of two or three years for *C. fagacearum*-inoculum to move through any preexisting root connections that were not severed by the trench.

Breakouts that occur after two years are increasingly more likely to be due to transmission of the fungus through new root grafts that formed after trenching (Table 2). The delayed timing of later breakouts is due to the time required for new root grafts to form and provide a route for inoculum in the roots to pass beyond the trench barrier. Most breakouts occurring within the first two years after trenching have been attributed to inoculum passing through pre-existing root grafts either due to 1) insufficient trench depth, 2) insufficient buffer distance set up between the visible (symptomatic) advancing edge of the infection center and the positions selected for trench placement, or 3) a discontinuous trench (Gehring 1995).

Trenches that are not cut to sufficient depth allow the fungus to pass through roots that were not severed under the trench. This occurrence is common where the soil depth to bedrock in localized areas is greater than the depth normally encountered in that area or when soil depth is greater than the depth recommended by suppression-operation criteria. Cutting the trench too close to the infection center, without leaving a sufficient buffer zone, can also be a problem. Trenches placed too closed to diseased trees fail because the fungus has already moved through roots by the time the trench is installed. Discontinuous trenches, often caused by the need to avoid buried utility lines, provides opportunities for inoculum to pass through gaps in the trench where roots were not severed. Obviously, the rates of trench breakouts, due to discontinuous trenches, tend to increase in urban areas.

The TOWSP does not cost-share continuous trenches unless the utility lines have been installed at least four feet deep with the past four years. Even though most trench breakouts occurring after two years following trenching occur due to new root graft formation, some breakouts occasionally may occur due to movement of *C. fagacearum*-inoculum across the trench by insects or other vectors (Table 2). The movement of red oak firewood from infected trees within infection centers to areas outside of the trench also may explain some jumps or gaps in infection patterns in the vicinity of trenches. There is also the possibility that unknown root-feeding or stem-feeding insect vectors may be carrying inoculum of *C. fagacearum* across trench barriers.

Problems of trenching associated with improper trench depth and buffer distance can be largely solved by increasing trench depth when possible and increasing the buffer zones used for determining trench placement. These adjustments have been made several times in the operational criteria used for trench installation in TOWSP operations. Unfortunately, modifications in trench designs and placements do not solve the problem of breakouts due to other causes, particularly the formation of new root grafts in the loose trench backfill soil. Trenches alone are not permanent by design. They cease to become a barrier as soon as new root grafts form across the trench. The very high tendency of live oaks to form root grafts, coupled with the greater incidence of root growth and root graft formation in trench backfill soil, increasingly favors the ability of *C. fagacearum*-inoculum to eventually move through a new root graft connection to the other side of the trench over time.

The actual likelihood that new root grafts will form in the trench backfill soil in any one location is dependent on a number of factors, including weather and rainfall patterns, the presence and density of trees on both sides of the trench, the amount of inoculum-pressure put on the trench (determined by the size of the infection center being contained), the rate of movement of the infection front, the depth of the soil and/or trench, soil texture and fertility, and slope of the terrain. However, the rate of new root graft formation in trench soil is probably most determined by available soil moisture in the trench, the density of live oaks on both sides of the trench, and the depth of the soil in the trench. These three factors probably have the greatest effect on feeder-root density, and thus determine the likelihood that new root grafts will form across the trench.

An alternative explanation has been proposed to explain breakouts that occur beyond two years after trenching. This explanation suggests that these breakouts may be due to insufficient trench depth instead of the formation of new root grafts in the trench soil. The theory implies that roots occur under the trench by which the oak wilt fungus eventually passes, but that the movement of *C. fagacearum*-inoculum in the roots is delayed by insufficient rainfall, inadequate tree transpiration, or other factors that somehow slow down the movement of inoculum in the root system and delay trench breakouts. The problem with this explanation is that the movement of water carrying *C. fagacearum*-inoculum in the transpiration stream of roots through root grafts is controlled mostly by the transpiration of healthy trees outside of the trench that pulls water from the root systems of diseased trees inside of the trench.

Transpiration rates in the stems of oak wilt-infected trees are slowed due to vascular plugging by the fungus. Consequently, transpiration rates are higher in healthy trees that have no vascular plugging. This is the reason why transpiration water tends to flow mostly away from diseased trees (at the expanding edge of the infection center) toward uninfected healthy trees (outside of the trench) that still have substantial transpiration occurring. This is the only reasonable explanation to account for the often rapid rates (75-150 feet or 23-46 m per year) of expansion observed in Texas oak wilt infection centers. Given this strong outflow of transpiration water through preexisting root grafts, that were not severed between diseased trees at the edge of infection centers and healthy trees outside of the trench, there should be a very low probability that *C. fagacearum*-inoculum would not pass through one of these preexisting root grafts within the first two years after trench installation.

The movement of transpiration water through root grafts to healthy trees can be slowed by drought conditions. However, if there is a root connection path (root graft) around or under the trench for inoculum to pass through, it should occur within two years because movement of transpiration water is analogous to water running downhill by gravity. Healthy trees cannot survive for very long without transpiration. Anything being carried by the water, whether it is dissolved nutrients or *C. fagacearum*-inoculum, is moved in the transpiration stream and taken up by the roots of healthy trees outside of the trench. Therefore, it is reasonable to assume that breakouts that occur beyond two years after trenching are due to newly formed root grafts in the trench because all old preexisting root connections were effectively severed by trenching. In the absence of an extended drought, the delay in trench breakouts beyond two years is increasingly more likely caused by the delay in formation of new root-connection paths across the trench by which inoculum can be carried to healthy trees outside of the trench. The only other appreciable factor that could lead to a delay in trench breakouts beyond two years after trenching is placement of the trench significantly more than 100 feet beyond the infection center. In this case, it would take longer for the fungus to traverse the greater distance through connected root systems to challenge the trench. The greater time required before the trench is challenged provides more time for new root grafts to form across the trench, increasing the chances for trench breakouts when inoculum of the fungus finally arrives at the trench. More evidence for trench breakouts due to new root graft formation is provided under the section Trenching Results in a Metropolitan Area.

EXPERIMENTAL EVIDENCE FOR TRENCH INSERT EFFECTIVENESS

A 7-year USDA-Forest Service research study was initiated in 1993 near Austin, TX to evaluate the efficacy for using trench inserts as a new cultural control method for the management of oak wilt in Texas (Wilson and Lester 2002). This study addressed the need to reduce the incidence of trench breakouts that occur beyond the first two years after trench installation due to causes other than improper trench placement or insufficient depth. The failure of primary trenches to prevent root transmission of *C. fagacearum* usually requires the installation of expensive backup trenches to attempt to contain further expansion of these unchecked oak wilt infection centers.

Sometimes even backup trenches fail, leading to additional costly trench breakouts that may be too large and expensive to contain. The larger an oak wilt infection center becomes, the more expensive it is to contain because approved trenching projects require installation of a suppression trench completely around the infection center. One of the key objectives of this 7-year trenching study was to determine why trench breakouts occur beyond the first two years after trenching when trench breakouts are normally expected to occur. A better understanding of trench breakouts and how they occur was needed in order to find new ways to extend trench utility and effectiveness beyond two years, and thus avoid costly trench breakouts.

The effects of trenching on soil structure in the trench and resulting root growth in trench backfill soil following trenching was evaluated with an experimental trench having different treatment segments set up along its length. Treatment segments consisted of four types of trench inserts, trench alone, and no trench controls to determine whether trench breakouts were affected by the presence or absence of trench inserts. The experimental hypothesis being tested was whether trench inserts affect the number and timing of trench breakouts relative to trench alone or no trench controls. If a difference in timing of breakouts could be detected between treatments, this would indicate that there must be a fundamental difference in the process or timing of root transmission events that explains the common delays in trench breakouts that are often observed with trenching treatments compared with no-trench controls.

PERFORMANCE OF WATER-PERMEABLE VS. WATER-IMPERMEABLE TRENCH INSERTS

The efficacy of trench inserts in preventing root transmission of *C. fagacearum* was tested in order to determine the effects of different types of trench inserts on trench performance. Four types of trench inserts, consisting of two water-permeable materials and two water-impermeable materials, were tested and compared to trenches alone and no trenching segments. These six treatments each were replicated three times in a random sequence along the full length of a continuous 0.75-mile (1.2 km) trench located 100 feet (30 m) beyond the expanding edge of a large oak wilt infection center.

The two water-permeable inserts consisted of 4 oz. (113 gm) (1×) Typar, a spun polypropylene landscape fabric, and Biobarrier which contains the same fabric as Typar, but also contains trifluralin-impregnated 10-mm diameter, controlled-release hemispherical pellets (54% polyethylene, 18% carbon black, and 28% trifluralin by weight) bonded to polypropylene fabric with uniform 3.8-cm spacing or 688 pellets per square meter (Reemay Inc., Old Hickory, TN). The water-impermeable insert materials consisted of polyethylene Rufco Geomembrane liners (Raven Industries, Springfield, OH) of two thicknesses (20 and 30 mil), namely Rufco 2000B, and Rufco 3000B, respectively. Trench inserts were placed into trenches in 15.2 or 30.5 m lengths, mounted with 15 cm steel or aluminum pins to the wall of the trench on the side closest to the infection center, and additionally supported by backfilling the trench with soil removed during construction of the trench, followed by leveling with a backhoe scoop blade (see Wilson and Lester 2002).

The occurrence of new trench breakouts of oak wilt disease by year for six years following trenching provides a comparison of performance of the six treatments (Table 3). The study was established during an extended period of drought which caused trench breakouts to be somewhat delayed as a result of reduced transpiration in test trees. The first appearance of oak wilt beyond a no-trench segment occurred the second year after trenching. A second appearance of oak wilt beyond a no-trench segment occurred the third year. One trench segment of Geomembrane 20 (Geo 20) also had a disease breakout the third year. Two trench breakouts occurred in Geo 20 segments the fourth year after trenching. Excavations of Geo 20 trench breakout segments indicated that small roots had grown across the trench in the soil above the trench inserts. Apparently, the Geo 20 trench inserts were buried too deeply in these segments allowing new root grafts to form between feeder roots across the trench above the insert material that resulted in trench breakouts.

One trench-only segment had a trench breakout the fourth year after trenching, also likely due to new root grafts forming across the trench in the loose backfill soil. The last trench breakout recorded in the study occurred the fifth year after trenching in the no-trench segment. However, none of the nine trench segments containing Typar, Biobarrier, or Geo 30 inserts had breakouts of oak wilt during the entire six years of this test. Based on these limited number of treatment replications, the water-permeable inserts (Typar and Biobarrier) appeared most effective in preventing the formation of new root grafts across the trench in trench backfill soil up to six years after trenching

The breakouts occurring in the water impermeable Geo 20 segments may have occurred as a result of the diversion of root growth around the trench insert (toward the surface) after roots came in contact with the material. This diversion of root growth tends to occur with water impermeable materials because the roots cannot obtain moisture through the insert material and continue to grow whereas the presence of moisture through the barrier (as in the water permeable inserts) causes the roots to branch dichotomously against the barrier instead of continuing to elongate in search for moisture. Consequently, water-permeable inserts generally are more effective barriers to root graft formation because they do not cause significant diversion of root growth after contact with the material.

TRENCHING RESULTS IN A METROPOLITAN AREA

The causes of oak wilt trench breakouts in urban and suburban trenching projects that did not install trench inserts were investigated further to see if more information could be deduced from the results of trenching at different depths using conventional trenching methods recommended by the TOWSP. A series of 24 trenches installed over a 17-year period (1989-2006) by the city of Lakeway, Texas was selected as a model system for this investigation. These trenching projects were placed into two categories, based on trench depth, for the purpose of data interpretation: 1) ten 30 to 36"-deep trenches installed from 1989-1999; and 2) fourteen 39 to 48"-deep trenches installed from 1997-2006. The relative effectiveness of trenches, within these two trench-depth categories, in preventing trench breakouts over time following trenching, is summarized based on observations as of May 2007 (Table 4).

Among trenches in the 30-36" category, 10% held up with no trench breakouts up to 8 years after trenching, 50% had trench breakouts within the first two years after trench installation, and 40% exhibited breakouts 5-14 years after trenching. By comparison, trenches in the 39 to 48" category had significantly higher percentage (42.9%) of trenches without breakouts up to five years after trenching than trenches in the shallower category over the same time interval. A significantly lower percentage (21.4%) of deeper trenches had breakouts within the first 2.5 years than the shallower trenches. However, there was no significant difference in the percentage of trench breakouts between shallow vs. deep trenches that occurred three or more years following trench installation. This surprising discovery indicates that increasing trench depth provides little benefit in reducing trench breakouts that occur more than two years after trenching when trench inserts are not used.

The absence of a difference in breakouts with trenching depth after two years suggests that there is a fundamental different event that is occurring after three years and beyond that is the cause of breakouts which is different from those occurring within the first two years after trenching as indicated by Gehring (1995). The most probable explanation for this result is the formation of new root grafts across the trench which can occur regardless of trench depth in the trench backfill soil. Because most feeder roots are found in the top 18 inches below the soil surface, this is the area of the soil profile where most new root grafts likely form after trenching. Nevertheless, feeder roots are also found at the ends of deep roots that can form new root grafts across the trench following the installation of deeper trenches. Even though deeper trenches appear to be a benefit primarily within the first two years after trenching (when most breakouts occur), the installation of deeper trenches probably does provide greater long-term protection against trench breakouts when trench inserts are utilized. The greater trench depths with inserts will provide assurance that the deeper feeder roots will not form new root grafts across the trench beyond the second year after trenching.

Additional evidence to support the assertion that greater trench depth is an important factor in improving the long-term effectiveness of trenches with trench inserts is forthcoming from TOWSP trenches installed since 2004 by Texas landowners under the direction of TFS employees in Bandera and Kerr Counties. So far, over 20,000 linear feet of trench have been installed with the Typar insert material in trenches ranging from 5-14 feet (1.5-4.3 m). In the past three years, none of these trenches with Typar inserts have had trench breakouts of oak wilt. However, long-term observations will be required to fully assess the efficacy of trench inserts. As the numbers and linear feet of trenches with Typar inserts expands, the TOWSP personnel will be able to better evaluate the effectiveness of these water-permeable inserts in actual oak wilt suppression trenches.

COSTS ASSOCIATED WITH TRENCH INSERTS

Any assessment of the efficacy of a new disease-control method must not only consider the effectiveness of the control method, but also the necessary additional costs that would be required to implement and utilize the new method. A full-scale economic assessment is not suggested here, but rather an examination of the probable costs of materials alone in the absence of variable costs such as additional labor and equipment modifications needed for implementation. The approximate costs of trench insert materials currently available for oak wilt suppression are provided and compared as a percentage of the average TOWSP trenching costs in urban ($16.85/linear foot) and suburban ($3.47/linear foot) environments since 2004 without trench inserts (Table 5). Trenching costs can be much higher in some cases. These estimated material costs are based on trenches that are at least 48 inches deep (with inserts at least 48 inches wide) at current prices.

The Typar and Geomembrane materials cost $1.20 or less per linear foot and represent only 2-7% of urban trenching costs and 11-34% of suburban trenching. The Biobarrier products with the slow-release trifluralin herbicide nodules cost $7-9 per linear foot representing 41-53% of urban trenching costs and twice as much as suburban trenching costs, significantly more than the other materials. Even though Biobarrier is more expensive than Typar alone, it does provide the additional protection of stopping root growth and elongation, precluding root contact with this material. Thus, Biobarrier provides a chemical barrier in addition to the physical barrier provided by the Typar fabric of which it is composed.

Theoretically, this integrated control with Biobarrier, utilizing two different strategies (chemical and physical), should be more effective than a physical barrier alone. As a statement of confidence, the manufacturer (Reemay Inc., Old Hickory TN 37138) guarantees this material will prevent root punctures up to 15 years. Another advantage is that trifluralin herbicide is water insoluble and will not contaminate groundwater aquifers. All of these trench insert materials have very similar puncture strengths, but the Typar material was the lightest (4 oz. per linear foot) among those tested, and performed as well as the Biobarrier products in experimental tests. The water permeable Typar material also was the cheapest material (only 40¢/linear foot) that was tested experimentally. As implied earlier, these costs do not include the additional labor costs required for installing the trench inserts or the additional costs associated with backfilling the trench by equipment other than the original trencher.

A more comprehensive list of commercially-available Typar products shows that this geotextile material comes in a wide range of weights, puncture strengths, and widths (Table 6). The landscape-grade Typar materials are most appropriate for trench-insert applications in oak wilt suppression, particularly Typar 3401 which comes in 48 and 60 inch widths, the most common trench depths used in oak wilt suppression. For deeper soils, trenches cut greater that 60 inches deep should utilize the Typar 3341 or a similar product because it is available at a width of 151 inches and may be cut down to appropriate widths at the factory if requested. Typar products in the 3500 and higher series are generally designed for more heavy-duty applications such as for road and storm drain construction, and are probably overkill for most oak wilt suppression applications, although some oak species under certain situations may be able to exert sufficient root puncture pressure to warrant use of these stronger materials.

PRECAUTIONS IN SELECTING AND USING TRENCH INSERTS

New roots forming from severed roots after trenching can grow both over and under the insert material, especially with water impermeable trench inserts which have a tendency to direct root growth along the face of the material and around the barrier. By contrast, water permeable inserts tend to cause these new roots to branch and form finer roots that stop elongating, once they come in contact with these inserts, because the roots are able to obtain moisture through the material. Consequently, water-permeable inserts tend to perform better than water-impermeable inserts. Trench inserts should be installed carefully so that the top edge of the material is even with the soil surface to prevent root growth over the top of the buried insert. Some insert materials such as polypropylene geotextile fabrics breakdown readily in the sunlight over a relatively short time. Consequently, materials such as Typar must be fully covered by soil to protect them against sunlight. Thus, it is equally important to not bury trench inserts so shallowly that the material is not covered and subject to degradation by sunlight or exposure to the elements, but extends as deeply as possible in the trench.

There are two major types of geotextile fabrics, spun and woven, that are available for landscape applications. Spun fabrics have greater stretching capacity, are more flexible, and have greater water permeability due to greater numbers of micropores. However, woven fabrics have greater total puncture strength (50%) than spun fabrics, but do not stretch appreciably and are less flexible than spun fabrics. Woven landscape fabrics have holes between the weave that sometime allow fine roots to penetrate. Thus, spun fabrics generally are more durable due to flexibility, and have are more effective in preventing root penetrations than woven landscape fabrics.

The utilization of untested trench insert materials should be considered with much caution because they may potentially lead to trench failures, poor results, and greater tree mortality than would have occurred without any trench inserts. Failures associated with the use of untested insert materials can reduce landowner confidence in trench inserts as an oak wilt suppression tool. Previously, untested landscape fabrics have been used that proved to be ineffective because they decomposed in the soil (lacked durability), had little root-puncture resistance, or were water-impermeable.

DIFFICULTIES IN APPLYING TRENCH INSERTS

The current foremost obstacle to utilizing trench inserts for the suppression of oak wilt root transmission is the fact that most rock saws commonly used in central Texas for trenching are designed to back fill the trench immediately after it is cut, precluding the installation of trench inserts. The trench must be left open temporarily after trenching to permit the installation of inserts along the wall of the trench. The cost of retrofitting a typical rock saw to leave the trench open can cost thousands of dollars. Thus, to be efficient, trenchers designed to leave the trench open must be used and dedicated for this purpose. Backhoes that are often used to dig trenches deeper than five feet favor the installation of trench inserts because the trench can be left open as long as needed.

Ultimately, the best solution would be to design a trencher that not only cuts the trench and leaves it open, but also contains a vertical post on the back for dispensing the insert material into the trench so that the insert can be secured to the wall of the trench, and the trenched backfilled immediately by a bulldozer with a grading blade that follows behind. The two pieces of equipment working together may be able to get the job done faster and perhaps more cheaply due to less rental time. If a bulldozer is used to dig the trench, it should also be used to refill it.

The additional labor, equipment, and fabric costs associated with the installation of trench inserts may be sufficiently large to impact the decision to install trench inserts. For example, the rising cost of urban trenching may, in some cases, prohibit the addition of any further expenses because additional costs may exceed the available budget of a trenching project. Other additional trenching costs may include the necessary removal of soil from trench sections that collapse or cave-in before the inserts can be installed. Many of these additional expenses sometimes can be handled more cheaply by landowners that have access to the proper equipment, such as a backhoe to cut the trench, and have the skill to operate rented or borrowed equipment for this purpose. Relatively little skill and effort is needed to manually install Typar inserts because they are lightweight and require the same skills used in the installation of common garden and landscape fabrics for weed control. The only difference is that trench inserts are secured vertically in the trench with pins inserted at the top of the wall of the trench, instead of perpendicular to the ground surface as with landscape fabric.

Most rocksaw trenchers used in residential neighborhoods or urban areas cut relatively narrow trenches that may be too narrow to allow easy installation of trench inserts. Rocksaws are the main trencher type used in cities because they are small enough to maneuver within the tight spaces found in neighborhoods and they do not tear up the ground and lawns as badly as the large, heavy chain trenchers or back hoes. One possible solution is to attach small clip-on weights to the bottom edge of the fabric (at intervals along the full length) to help the fabric fall to the bottom of the trench. Also, long lightweight poles such as bamboo, wooden dowels, or half-inch PVC pipes could be used to help push the fabric to the bottom of the trench. Keeping the fabric pulled tightly as it is being installed also helps in lowering it down into the trench. Trenches cut with a backhoe or the larger chain trenchers are much wider than those cut with rocksaws and allow a person to climb down into the trench to straighten and work the fabric to the bottom of the trench.

Another common problem in urban areas is the difficulty of installing trench inserts where there is an abundance of buried utility pipes. This problem involves the question of how to cut the insert material and then get a good seal around utility pipes to prevent roots from growing through these breaks in the fabric. A good approach is to assess whether the pipes are closest to the top or the bottom of the trench. The insert fabric should be cut from the edge of the material that is closest to the pipe to minimize the length of the cut required. The fabric at the cuts should then be overlapped a few inches and stapled, followed by taping with a very sticky wide tape after the insert material is secured with pins into the upper wall of the trench. If the utility pipes are concentrated in a short section of the trench, it may be easiest to just install the inserts in the long continuous sections of the trench that have no utility pipes. There is a low probability that a trench breakout will occur in a very short section of the trench with utility pipes compared with longer sections of the trench.

DISCUSSION AND CONCLUSIONS

Most oak wilt specialists acknowledge that the formation of new root grafts across an oak wilt suppression trench may eventually occur, leading to a breakout some years after a trench is installed. In the author’s opinion, this phenomenon is not only common, but increasingly prevalent three or more years after trenching, even in dry sites, especially for live oaks that have such a strong propensity to form root grafts in the shallow soils of central Texas. Oak roots in this region on the Edwards Plateau commonly grow through layers of limestone permeated by pockets of soil. Soil usually fills holes in the rock formed by the percolation of ground water through the limestone. Nevertheless, the limestone bedrock layer tends to restrict and concentrate oak root growth above it, increasing the chances for root graft formation between the roots. In this situation, trenches alone are not intended to provide long-term protection against root transmission because new root grafts are expected to form over time between these concentrated roots that grow within trench backfill soil.

The current oak wilt breakout rate for TOWSP trenching projects ranges from 21-40% (on a whole-trench basis), depending on location and conditions, suggesting that there is still room for significant improvements in trenching technologies utilized for oak wilt suppression. These rates of trenching failures (breakouts) may not appear very high, but they are very significant for a highly-damaging necrotrophic fungal pathogen that is capable of killing living trees in a relatively short period of time (less than a year) after infection. The ability of *C. fagacearum* inoculum (spores and hyphal fragments) to travel within the transpiration water of oak roots up to 100 feet (30 m) or more per year, beyond the expanding edge of infection centers, further exacerbates the accumulation of damage and mortality to oaks caused by this disease.

Given the current rate of trench breakouts, the oak wilt pathogen has at least one chance in three (during the first two years) of passing beyond any one individual suppression trench installed in Texas using conventional TOWSP methods and trenching recommendations. This rate of disease breakout from trenches is sufficient to maintain the growth of *C. fagacearum* inoculum in oaks and keep the epidemic expanding, especially because numbers of trench breakouts continue to increase over time. For example, there are certain localized areas in Texas where the oak wilt epidemic has expanded to largely unmanageable proportions (Billings et al. 2001). In these areas of very high oak wilt density, the best chance for slowing the epidemic has been for the disease to simply burn itself out as a result of high oak mortality, leaving relatively few susceptible trees to maintain the expansion of the epidemic. Thus, new significant trenching methodologies are sorely needed to further decrease the failure rate of trenches and reduce the spread of individual oak wilt centers. The utilization of new integrated methods besides trenching, such as statewide restrictions on the intercounty transport of firewood from counties with oak wilt and the development of advanced epidemiological models to track movement of the pathogen, also would be useful to focus control implementations to help prevent the spread of oak wilt into other Texas counties and possibly other southern states.

Trench inserts provide a significant new method for improving trenches for oak wilt suppression in the U.S. The benefits of trench inserts could be substantial if they prove to be an effective means for reducing the rate of trench breakouts over long time periods. There are at least two possible strategies for utilizing trench inserts for oak wilt control. The first strategy could be used in situations where the additional costs of applying trench inserts would not pose a significant financial burden due to an abundance of available funds for the trenching project. In this case, trench inserts could be installed in every instance where the available funds for a trenching project are not limited, and the minimal extra expense for inserts could provide greater insurance against future trench breakouts. The second strategy takes into consideration that funds available for the trenching project are limited and the additional costs of trench inserts would pose a significant financial burden. In this case, trench inserts would not be used in the primary trench, but would only be considered if the primary trench failed in the future. Then, trench inserts could be installed in the new backup trench to enclose the breakout and improve long-term security against a secondary breakout. This approach is much more practical and feasible in the majority of oak wilt trenching projects where funding is limited.

Wilson and Lester (2002) reported some experimental evidence demonstrating the efficacy of trench inserts for increasing the effectiveness and longevity of trenches, and providing long-term oak wilt control beyond the first few years after trenching. This article was published at the completion of a 6-year trenching study during which preliminary results of the trench-insert tests were reported (Wilson and Lester 1996a-c, 1997, 1999). The utility of trench inserts has been shown to lie primarily in the prevention of oak wilt root transmission by precluding the formation of new root grafts across the trench within trench backfill soil, two or more years after trenching. The effectiveness of trench inserts in oak wilt suppression programs is being further evaluated by the TOWSP. Trench inserts have been installed in more than 20,000 linear feet (6,153 m) of oak wilt suppression trenches installed by TFS personnel, working within the TOWSP since 2004. Because more than two years are required for roots to grow across trenches and for inserts to show efficacy, the impact of these inserts has yet to be determined. Data from future post-suppression evaluations in the coming years hopefully will provide more conclusive evidence of the performance and effectiveness of trenches containing trench inserts compared with conventional TOWSP trenches without inserts.

The Typar trench insert material is recommended here as the best, most cost-effective material currently available as a water-permeable physical barrier for installation within oak wilt suppression trenches. This lightweight material is relatively easy to install (compared with the other trench-insert materials), comes in a variety of widths, is very cheap (only 40¢ per linear foot), and works as well as Biobarrier based on experimental tests (Wilson and Lester 2002). Typar is a spun fabric that probably performs better than woven fabrics due to the potential for root tips to penetrate holes between the weave in some woven fabrics. Other water-permeable insert materials may have utility as trench inserts, but no other materials besides Typar are currently recommended until they can be properly tested and evaluated both experimentally and in TOWSP field trials.

There are a number of advantages of utilizing water-permeable trench inserts over conventional methods of installing trenches without inserts. Trench inserts eliminate the need for expensive backup trenches, required when primary trenches fail and oak wilt breakouts occur beyond the trench. Trench inserts also provide greater security (insurance) against breakouts in high-hazard sites with large valuable trees, or where symptomatic trees are not removed inside the trench. The additional cost of the Typar water-permeable trench insert is low, on a percentage basis (2-11%), relative to conventional average TOWSP trenching costs in urban, suburban, and rural sites. Typar is available in a variety of thicknesses and prices, providing a range of root-puncture resistance for applications with various oak species, and varying levels of protection against root penetrations. The most expensive trench insert barrier, giving the greatest protection against oak wilt root transmission, is provided by Biobarrier (Typar with trifluralin nodules) which delivers both herbicide and physical barriers to root penetrations.

There is also a strong advantage of having trench inserts installed when trenches must be placed (because of land-access constraints and multiple property lines) far out in front of the infection center; over 150 feet beyond symptomatic trees (not recommended or approved by TOWSP). The longer the time it takes for the trench to be challenged, as inoculum of the fungus approaches the trench in the root system, the more advanced new root grafts will be developed when the fungus finally arrives at the trench. This is the reason why it is not normally recommended to have buffer zones greater than 100 feet from the infection center to conventional trenches without trench inserts.

The ultimate success of integrating trench inserts into the trenching process for oak wilt suppression depends on whether progress can be made in overcoming logistic hurdles such as achieving public awareness of this new disease control strategy, communicating cogent explanations of trench-insert applications and effectiveness, and resolving problems associated with effective implementation (such as trenchers that backfill the trench immediately). First, increasing public awareness and education on trench-insert alternatives and the large potential for improved performance of trenches provided by trench inserts are essential. The inclusion of discussions on trench-insert installations within oak wilt suppression training courses and seminars is needed. Continued expanded field testing of trench inserts within the TOWSP as opportunities arise will facilitate the evaluation of efficacy vs. conventional trenching methods. Also, greater utilization of trench inserts by private oak wilt suppression businesses, and familiarity by trenching contractors will be necessary to streamline the integration of trench insert installation methods into mainstream suppression practices as much as is possible in urban and rural settings.

Ultimately, the development of new trenchers designed to cut trenches and dispense trench insert materials into the trench in one simultaneous operation would be most beneficial. It should be possible to design a trencher system that contains a lightweight, detachable trailer (in tandem) with a vertical post containing a bolt of trench insert material that could be dispensed as the trench is being cut. The trailer could be detached from the trencher when the trencher is serviced or moved to a new location. The advantages of simultaneous installation of trench inserts during the trenching operation include the avoidance of trench cave-in problems and hazards associated with leaving the trench open for extended periods of time.

Trenching as a disease-control strategy continues to be the easiest and most effective option for reducing oak wilt root transmission and tree mortality in localized areas. The direct control of insects or other potential vectors that carry the pathogen, presumably involved in the creation of new oak wilt infection centers, is not readily feasible other than to avoid the wounding of trees when vectors are active. Applying chemical or biological agents to reduce contact between potential vectors and inoculum sources such as fungal mats also is not feasible because of the very large number of red oaks that must be treated. Some currently unknown vectors may have the potential to directly penetrate bark and transmit the pathogen (Wilson, Lester and Edmonson 2000). If this is occurring randomly in forest and urban stands, then there is no feasible means of protecting trees from primary infections. The best opportunities for control in such cases would be to eliminate the sources of *C. fagacearum*-inoculum from which vectors acquire the fungus. However, this may not be feasible if there are too many sources of infected trees in a localized area, but it should be feasible in areas where oak wilt-infected trees are rare in the landscape.

I previously proposed the implementation of state quarantines to prevent the intercounty transport of *C. fagacearum*-infested firewood into counties not affected by the disease (Wilson 1995). This strategy, if implemented, would help eliminate the dispersal of inoculum by human means and reduce the incidence of inoculum transport and vector transmission by natural causes. Although there have been some research efforts to identify oak wilt resistance in live oaks (Greene 1995, McDonald et al. 1998, Gray, this proceedings), none has led to the development of oak wilt resistant lines because no resistance genes have been identified. Host resistance generally is a good long-term disease-control strategy, but in the case of oak wilt, sufficient time does not exist to regenerate resistant or tolerant mature oaks because current rates of oak mortality probably are eliminating mature susceptible trees from the landscape at a rate faster than mature oak wilt-resistant or tolerant oaks could be generated – ranging from 50 to 80 years

(Jacobs 2006). Planting fast-growing native hardwood species immune to oak wilt is a better strategy.

Trenching will likely continue to be the most important and effective oak wilt suppression method used in the foreseeable future as oak wilt incidence continues to increase and become more important in urban areas (Wilson et al. 2004). The continuous development and implementation of new, more effective tools to monitor and control oak wilt are essential for improving our success in managing this devastating disease (Appel and Maggio 1984, Appel et al. 1989, Appel 1995, Wilson and Forse 1997, Wilson and Lester 2002, Wilson, Lester and Oberle 2004, Wilson 2005, Wilson, Lester and Oberle 2005).

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Table 1. Incidence of oak wilt disease breakouts from Texas Oak Wilt Suppression Project (TOWSP) trenches relative to time following trench installation without trench inserts.

Years after trenching	**Oak wilt breakouts[1]**	**Breakout % of total**	**Cumulative % of total**	**% change in slope**
0.5	17	6.85	6.85	–
1.0	35	14.11	20.96	105.9
1.5	47	18.95	39.91	34.3
2.0	50	20.16	60.07	6.4
2.5	33	13.31	73.38	-34.0
3.0	29	11.69	85.07	-12.1
3.5	17	6.85	91.92	-41.4
4.0	8	3.23	95.15	-52.9
4.5	4	1.61	96.76	-50.0
5.0	6	2.42	99.18	50.0
>5.0	2	0.82	100.00	-66.7
	total 248			

[1]Data are derived from TOWSP post-suppression reports on 248 trenches installed from 1988-1992 when trench depth was 32-36” deep (TOWSP, personal communication).

Table 2. Most probably causes of oak wilt disease breakouts from trenches over time following trench installation.

Trench breakouts occurring within 2 years (60 % of trench breakouts)[1]	**Trench breakouts occurring after 2 years (40% of trench breakouts)**
Improper trench placement (fungus already past; insufficient buffer zone)	Newly-formed root grafts in backfill soil (due to new root growth in trenches)
Insufficient trench depth (fungus passes under trench)	Movement across trench by vectors (above-ground transmission)
Discontinuous trench (fungus passes through gaps in the trench)	Movement across trench by other means (e.g. firewood cut from infected dead trees)

[1]Trench breakout rates are based on trench installations determined from TOWSP post-suppression data and trench-failures indicated by trench breakouts.

Table 3. Experimental incidence of oak wilt disease breakouts from trench barriers over time following trench installation with and without trench inserts.

	New oak wilt disease outbreaks beyond trench barriers					
	Years after trench installation[1]					
Trenching treatment[2]	**1**	**2**	**3**	**4**	**5**	**6**
Trench + Typar	0	0	0	0	0	0
Trench + Biobarrier	0	0	0	0	0	0
Trench + Geo 30 mil	0	0	0	0	0	0
Trench + Geo 20 mil	0	0	**1**	**2**	0	0
Trench only control	0	0	0	**1**	0	0
No trench control	0	**1**	**1**	0	**1**	0

[1]Data are derived with modifications from research publication (A.D. Wilson and D. G. Lester, 2002. Plant Dis. 86:1067-1074). The values above indicate **new** oak wilt disease outbreaks from trenches by year whereas the values in the paper indicate **cumulative** outbreaks by year that charted disease progress over time.

[2]Three replicate trench segments (320-meter mean length) were prepared for each trenching treatment.

Table 4. Oak wilt trenching project results and summary for Lakeway, TX from 1989-2006.

Years installed	Linear feet range	Trench depth	% of trenches	Post-installation result[1]
1989-1999	600-2314	30-36" deep	10.0	holding up to 8 years
		(10 trenches)	50.0	failed within 1-2 years
			40.0	failed after 5-14 years
1997-2006	465-4610	39-48" deep	42.9	holding up to 5 years
		(14 trenches)	21.4	failed within 1-2.5 years
			35.7	failed after 3-9 years

[1]Trenches that failed are defined as those that had at least one oak wilt breakout that occurred somewhere along the total length of the trench within the time periods indicated.

Table 5. Physical characteristics and costs of trench insert materials per linear foot relative to trenching costs.

Trench barrier	Mean costs $/ l.f.[1]	% of trenching costs		Puncture	Weight
		urban	suburban	strength lbs	oz/yd^2
Typar 3401	0.40	2.4	11.5	40	4.0
Geomembrane 20 mil	0.91	5.4	26.2	44	14.4
Geomembrane 30 mil	1.20	7.1	34.6	60	21.2
Biobarrier II (weed)	6.90	41.0	198.9	40	13.3
Biobarrier I (root)	8.84	52.5	254.8	40	13.3
Trenching only (suburban)	10.00	59.4	100.0	–	–
Trenching only (urban)	16.85	100.0	485.6	–	–

[1]Costs values per linear foot for trench inserts do not include additional labor costs, and are based on trench insert materials that are 60 inches wide and trenches that are 60 inches deep. Cheaper prices are possible through volume discounts when insert materials are purchased on bulk rolls and when the total linear feet of trench is increased.

Table 6. Availability and physical characteristics of Typar trench insert materials useful for oak wilt suppression.

Product type and grade	Weight oz/yd^2	Puncture strength lbs (N)	Fabric width available (inches)[1] 36	48	60	75	other widths
Landscape							
Typar 3201	1.9	18	+	+	–	+	–
Typar 3301	3.0	25	+	+	–	+	–
Typar 3341	3.4	34	–	–	–	–	151
Typar 3401	4.0	41	–	+	+	–	–
Heavy duty							
Typar 3501	5.0	56	–	–	–	–	151
Typar 3601	6.0	67	–	–	–	–	151
Typar 3631	6.3	81	–	–	–	–	151
Typar 3801	8.0	93	–	–	–	–	151

[1]Fabric width availability: (+) indicates this width of Typar fabric is available, (-) indicates this width of fabric is not available. Numerical values indicate the fabric widths available beyond 75 inches.