



Deep Root Zone Affects Probability of Oak Wilt Breakouts in Central Texas

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Abstract. Oak wilt, caused by *Bretziella fagacearum*, is a significant threat to oak trees in Texas. The pathogen can be spread by underground root grafting of trees, and this means of transmission is the most effective and damaging means of spread for the live oak (*Quercus fusiformis* and *Q. virginiana*) mottes in central Texas. Trenches are created between disease centers and healthy trees in the hope to sever or disrupt root connections to limit the spread of the pathogen. This study subsampled 275 from a total dataset of 2,124 installed trenches to evaluate the effect of soil factors, specifically root zone depth and particle size, on the probability of trench breakouts in central Texas. Pathogen transmission breakout data created from 1990 to 2020 under the Texas Oak Wilt Suppression Project cost-share was used to determine if soil particle size and/or rooting depth could predict the success or failure of trenching in slowing the spread. Our results showed that for the subsampled trenches, the overall breakout of oak wilt was 39% compared to a 19% measured breakout for the entire dataset. Root zone depth and soil particle size significantly influenced breakout likelihood. Deeper root depth was associated with a higher probability of trench breakouts, particularly in clayey soils, while finer and silty soils demonstrated a lower risk. The findings highlight the importance of considering soil characteristics when implementing trenching strategies to control oak wilt spread. This study is the first to explore soil-related factors affecting oak wilt management in Texas and suggests that additional environmental variables could further improve predictive models of trench success.

Keywords. Forest Health; IPM; Oak Wilt; Pathogen.

INTRODUCTION

Oak wilt is one of the most devastating tree diseases in the Eastern half of the United States, severely impacting oak trees (*Quercus* spp.) (Juzwik et al. 2011). Since its first detection in Texas in 1961, it has been found in 76 counties throughout the state (Dooling 1961; Texas A&M Forest Service 2025). Belowground spread of the pathogen (*Bretziella fagacearum*) is possible due to root grafts between oaks (Juzwik et al. 2010; Koch et al. 2010). Interconnected roots of live oaks (*Q. fusiformis*, *Q. virginiana*) play a critical role in the belowground spread of the pathogen across central Texas (Appel 1995). This means of pathogen spread results in large, rapidly expanding centers of mortality and is considered to be responsible for the majority of tree losses.

Integrated pest management approaches for oak wilt include rapid detection of new oak wilt infections followed by prompt root graft severing, tree removal,

and/or root flare systemic injections with propiconazole (Appel et al. 1990; Billings et al. 2001; Blaedow et al. 2010; Koch et al. 2010). In some cases, girdling and herbicide treatment is used as a less resource intensive alternative to graft severing and tree removal (Bronson et al. 2023). Creating trenches, based on severing root connections, is recommended to limit the expansion of those disease centers by stopping the spread between the root systems of diseased and healthy trees (Himelick and Fox 1961). The success rate of trenching ranges from 67% to 88% in Texas (Appel 2001; Billings et al. 2001; Koch et al. 2010).

Although trenching is an effective method, its implementation can pose economic challenges for landowners (Billings 2008). Through the Texas A&M Forest Service Oak Wilt Suppression Project, landowners may apply to cost-shares for trenching, reducing the economic cost of the management strategy (Billings 2008). More than \$2.9 million of

federal cost-shares have been delivered to participating landowners since 1988 as an incentive to treat expanding oak wilt centers. To date, the Suppression Project has installed more than 3.6 million ft (680 mi) (1,094 km) of trenches to control 3,118 oak wilt centers. As part of the project, post-suppression evaluations are conducted to evaluate the effectiveness of trenches 5 to 7 years following installation.

Few studies have looked at the influence of soils on the distribution and management of oak wilt in Northern states. Bruhn et al. (1991) observed that belowground spread took place more frequently in sandier soils in Michigan and among oaks with larger diameters. Gearman and Blinnikov (2019) observed a significant relationship between *B. fagacearum* incidence and 2 specific soil orders in Minnesota: sandy riverine soils and fibrous, high-organic-matter wetland soils. More recently, Stevens et al. (2023) showed that spatial dependence, the distribution of oak forests, and soil bulk density had a significant role in the distribution of oak wilt in Wisconsin.

Despite these studies having looked at the influence of soil factors influencing pathogen transmission in Northern states, no studies have been conducted in the Southern distribution of oak wilt. Moreover, soil factors related to the success or failure of trenching to reduce the spread of oak wilt in Texas are unknown. Here we studied the effect of root zone depth and particle size on the probability of trench breakouts in central Texas.

METHODS

Site

This study includes post-suppression evaluations of cost-shared trenches under the Oak Wilt Suppression Project (Billings 2008). Trenches on properties located in 21 counties across Texas were installed at a depth of 122 cm (4 ft) from 1990 to 2020, and disease breakouts were evaluated one time 5 to 7 years post-trenching at each location. Trenches were installed 30.5 m (100 ft) from the edge of the advancing disease in live oak centers, defined as the outermost symptomatic tree, given that the fungus moves 2.29 m (75 ft) a year on average in Texas (Appel et al. 1989; Billings et al. 2001; Appel et al. 2008).

Trench Evaluation

Evaluation of trenches consisted of visual inspection of oaks following the trench perimeter to detect oak

wilt signs and symptoms. If symptoms appeared on the healthy side of the trench, a breakout would be recorded, and the trench would be considered a failure. Trained Texas A&M Forest Service foresters performed trench evaluations. Each trench was sampled only once, ensuring that all samples were independent.

Data Acquisition and Analysis

Soil particle size and root zone depth for every trench were obtained from the Soil Survey Geographic Database (Web Soil Survey 2019). All analyses were conducted in R version 4.2.2 (R Foundation, Vienna, Austria). The trench breakout was modeled as a function of root zone depth and particle size using a generalized linear model. The response variable was breakout (binary: presence or absence of oak wilt symptoms on the healthy side of the trench) and was modeled as a logistic regression using the logit link function. The explanatory variables included in the model were: particle size (soil particle size) as a categorical (with 9 levels) and root zone depth as a continuous variable. Zone depth was defined as the depth from which roots may successfully collect resources. Because the interaction between explanatory variables was not significant, we tested the simple effect of each explanatory variable on the response variable. The parameters on the final model were estimated by the *glm* function of the stats package (version 4.2.2) including only the significant variables. Particle size and zone root depth had a significant effect on the response variable and therefore were kept in the model. Assumptions were checked and met, including linearity of the link function, independence of observations, and no overdispersion. The adequacy of the fitted model was evaluated through a detailed visual inspection of residual plots. To calculate the probability of an outbreak, we used the function *ggpredict* for each significant term.

RESULTS

A total of 2,124 trenches were assessed between 1990 and 2020, yielding an efficacy rate of 81% (1,727 trenches were deemed successful). The analysis was based on 286 georeferenced post-suppression evaluations that met the required criteria (trench depth, evaluation date, field confirmation, etc.), with 111 instances (38%) recording a breakout. A summary of breakouts, categorized by particle size and root zone depth, is presented in Table 1.

Table 1. Summary of breakouts and PSE by particle size and root zone depth (cm). PSE (post-suppression evaluation).

Particle size	Total PSE	Breakouts	Root zone depth (mean)	Root zone depth (min)	Root zone depth (max)
Clayey	42	21	40.69	25	82
Clayey-skeletal	65	25	33.02	16	150
Coarse-loamy	5	3	150.00	150	150
Fine	37	15	145.46	66	150
Fine-loamy	19	12	123.58	60	150
Fine-silty	11	1	131.82	91	150
Loamy	84	28	43.73	30	150
Loamy-skeletal	17	6	42.88	20	61
Very-fine	4	0	80.75	71	89

Table 2. Summary of binomial generalized linear model for trench breakouts, with estimated parameters of the logistic regression presented as R syntax in logit scale.

	Estimate	Std. error	z-value	P	
(Intercept)	-0.56	0.42	-1.33	0.183	
Clayey-skeletal	-0.37	0.41	-0.90	0.366	
Fine	-1.83	0.87	-2.10	0.036	*
Fine-loamy	-0.57	0.80	-0.72	0.475	
Fine-silty	-3.60	1.29	-2.79	0.005	**
Loamy	-0.74	0.39	-1.91	0.057	
Loamy-skeletal	-0.64	0.60	-1.07	0.283	
Root zone depth	0.01	0.01	1.97	0.049	*
Observations	275.00				

Note: significance level = 0.05, * $P < 0.05$, ** $P < 0.001$.

The probability of having an oak wilt breakout was significantly predicted by the simple effect of root zone depth and particle size; the estimated parameters (logit scale) are shown in Table 2. Regardless of soil particle size, chances of a breakout increased with root zone depth (Figure 1), with 26% probability at 20 cm to 80% probability at 200 cm on average for all particle sizes. Regarding particle size, clayey particle size had the highest probability of breakout (58%), and fine and fine-silty soil types had a significant lower probability than clayey on breakouts. Clayey-skeletal soils had a 49% probability to breakout, followed by fine-loamy (44%), loamy-skeletal (42%), loamy (39%), fine soils (18%), and fine-silty (4%), respectively. The model explained 4.6% total

deviance or observed variation. No tendency or correlation was found on the residuals.

DISCUSSION

Trenching for oak wilt management aims to prevent belowground spread by severing root connections between infected and healthy oak trees. Inadequate depth or poor placement of the trench often leads to treatment failure (Juzwik et al. 2011). Successful trenching relies on regional equipment availability and cost, and the placement of the primary line must extend beyond the radius of infected trees to be effective (Koch et al. 2010; Juzwik et al. 2011). Underground spread of *B. fagacearum* leads to expansion of existing infection centers, affected by the distance

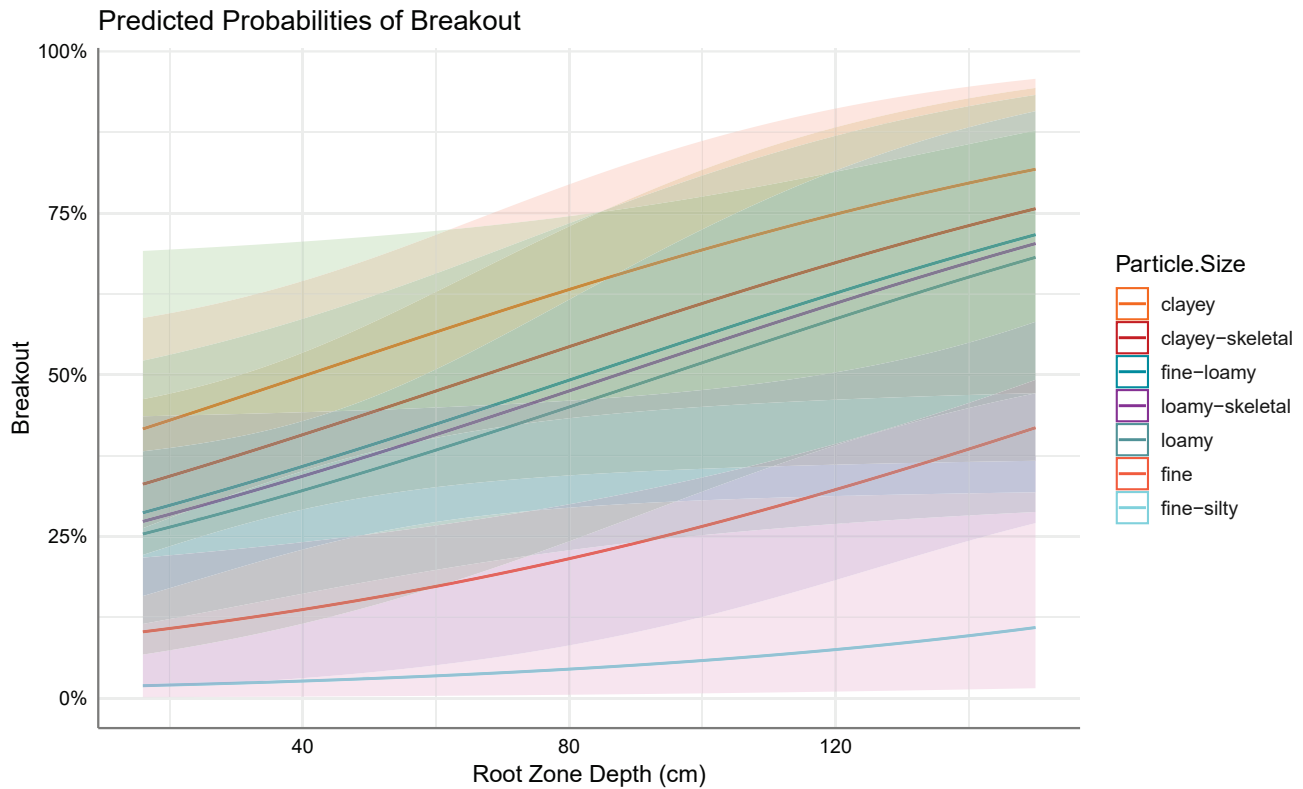


Figure 1. Predicted probabilities of breakout for different root zone depth (cm) and soil particle size. Shaded areas represent confidence intervals around the predicted values.

between infected and susceptible trees, root graft frequency, oak species composition, and environmental conditions, especially soil type.

Our results suggest that root zone depth and particle size are relevant variables in trench failure in Texas. All soil particle sizes showed the same slope of root zone depth, with lower probability of breakouts in shallower rooting depth. Following cost-shared trench guidelines, trenches are standardized to a depth of at least 122 cm (4 ft). Because chances of breakout increase with root zone depth, areas with deeper soil should be carefully evaluated to make sure that root connections are being severed. Our study suggests that even when trenches are installed in a low root zone depth, lower probability of breakout is expected depending on soil type, with fine soils and fine-silty soils showing the lower probability for breakouts. On the other hand, clayey soils show higher chances of breakout. This pattern could be explained by the differences in vertical rooting patterns across soil types. Studies on *Quercus* sp. have shown that in clayey sites, a relatively large fraction

of roots is found in deeper soil layers, whereas at silty sites, the rooting pattern was most superficial (Thomas 2000). Therefore, given that standard trenching guidelines recommend a depth of at least 122 cm (4 ft), our results underscore that this depth may be insufficient in areas with deeper root zones, particularly where the inherent soil properties, such as those found in clayey soils, promote more extensive vertical root development.

Because *B. fagacearum* does not interact, spread, or have any relationship with the soil, the results of this analysis do not imply a relationship between soil texture (percent of clay, loam, or sand) and pathogen spread but rather examines how soil type and texture may play into the root zone depth which could predict trenching success. However, water holding capacity can be affected by texture and might impact root growth and grafting due to differences in moisture availability. Clay-rich soils, for example, hold more moisture than sandy soils, with enhanced woody biomass and higher fertility (Kramer and Boyer 1995; Laurance et al. 1999). This may contribute to more

extensive and deeper root system development, which, in turn, could explain the increased likelihood of trench breakouts observed in these soil types in our study, as these deeper connections are harder to sever effectively with standard trenching depths. Another key factor to consider is the formation of a shared root system in live oaks, which directly influences how the pathogen spreads across the landscape. To fully understand the variables involved, it is likely essential to distinguish between the biological processes of grafting and those of sprouting, along with the subsequent survival of the interconnected trees.

Our findings align with previous research indicating the significant influence of soil characteristics on oak wilt dynamics. Recent findings in oak wilt research in the Northeastern United States highlight the importance of considering soil and landscape features when developing management strategies. In Wisconsin, Stevens et al. (2024) suggested that oak wilt spreads more rapidly in sandy soils and flat terrain due to increased root grafting between trees. In contrast, clay-rich soils and uneven topography tend to slow the disease's progression in that region. While Stevens et al. (2024) observed a faster spread in sandy soils in Wisconsin due to increased root grafting, our findings in central Texas suggest that the deeper rooting patterns characteristic of clayey soils may increase the probability of trench breakouts by allowing root connections to persist below the standard trenching depth, even if the overall disease progression rate might differ. Moreover, in Minnesota, land cover and soil type were important variables contributing to the prediction of the distribution of oak wilt (Gearman and Blinnikov 2019). While studies in Northern states like Michigan and Wisconsin have highlighted the role of sandy soils or specific soil orders in pathogen transmission, our study provides novel insights into how root zone depth and particle size, particularly in clayey soils, impact the success of trenching in the unique central Texas environment.

Our model explained 4.6% of the observed variation; besides root zone depth and particle size, there might be other relevant variables influencing trench success, including equipment used to conduct the trench, length of the trench, and history of oak wilt in the area that can be included in future analysis. Historic trenching data from post-suppression evaluations compiled by this study since the inception of the Oak Wilt Suppression Project suggests that trenching

has an overall success of 81%. Evaluation of cost-shared trenches in the early 1990s suggested that equipment used (rocksaw vs. bulldozer with ripper bar vs. chain trencher), month of treatment, and land category might affect the breakout probability (Gehring 1995). Interestingly, the author reports similar findings with 80% of the treated centers holding without any breakouts. Additionally, more breakouts were observed in urban environments with rocksaws compared to rural environments with bulldozer with a ripper bar.

This study provides the first quantitative evaluation of trench efficacy in Texas, extending prior research concentrated in the Upper Midwest (Juzwik et al. 2011; Stevens et al. 2024). These findings offer critical insight for regional adaptations of oak wilt suppression protocols. Other variables are needed to understand not only trench failure but the spread of oak wilt in Texas. Spatial modeling including all mortality centers recorded through the Oak Wilt Suppression Project could be developed, adding additional factors such as weather, terrain, and soil properties. Because clayey soils are more conducive for breakout, trench installation and management could also be explored, including backfilled materials and depth of trenches for these types of soils. In addition, future studies can identify differences in spatial dynamics of *B. fagacearum* driven not only by forest community but by latitude, soil types, and management practices.

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Résumé. Le flétrissement du chêne, causé par *Bretziella fagacearum*, est une menace importante pour les chênes du Texas. Le pathogène peut se propager entre les arbres par greffage des racines et ce mode de transmission est le plus efficace et le plus dommageable pour les massifs de chênes verts (*Quercus fusiformis* et *Q. virginiana*) dans le centre du Texas. Des tranchées

sont creusées entre les foyers de la maladie et les arbres sains dans l'espoir de restreindre ou de perturber les connexions racinaires afin de limiter la propagation de l'agent pathogène. Cette recherche a sous-échantillonné 275 tranchées installées sur un total de 2 124 afin d'évaluer l'effet des facteurs pédologiques, en particulier la profondeur de la zone racinaire et la dimension des particules, sur la probabilité d'invasion via les tranchées dans le centre du Texas. Les données sur la transmission des agents pathogènes recueillies de 1990 à 2020 dans le cadre du Texas Oak Wilt Suppression Project à frais partagés ont été utilisées pour déterminer si la dimension des particules du sol et/ou la profondeur d'enracinement pouvaient prédire le succès ou l'échec du creusement de tranchées en vue du ralentissement de la propagation. Nos résultats ont montré que pour les tranchées sous-échantillonnées, la propagation globale du flétrissement du chêne était de 39%, alors que la transmission mesurée pour l'ensemble des données était de 19%. La profondeur de la zone racinaire et la dimension des particules du sol ont influencé de manière significative la probabilité de transmission. La présence de racines plus profondes a été associée avec une plus grande probabilité d'invasion via la tranchée, en particulier dans les sols argileux, tandis que les sols plus fins et limoneux ont montré un risque plus faible. Les résultats soulignent l'importance de prendre en compte les caractéristiques du sol lors de la mise en œuvre de stratégies de creusement de tranchées afin de lutter contre la propagation du flétrissement du chêne. Cette étude est la première à explorer les facteurs liés au sol affectant la gestion du flétrissement du chêne au Texas et suggère que d'autres variables environnementales pourraient améliorer les modèles prédictifs de l'efficacité des tranchées.

Zusammenfassung. Die Eichenwelke, verursacht durch *Bretziella fagacearum*, stellt eine erhebliche Bedrohung für Eichen in Texas dar. Der Erreger kann durch unterirdische Wurzelveredelung von Bäumen übertragen werden, und diese Übertragungsart ist die wirksamste und schädlichste Ausbreitungsart für die Baumgruppe der Eichenarten *Quercus fusiformis* und *Q. virginiana* in Zentraltexas. Zwischen den Krankheitsherden und gesunden Bäumen werden Gräben angelegt, in der Hoffnung, die Wurzelverbindungen zu unterbrechen oder zu zerstören und so die Ausbreitung des Erregers einzudämmen. In dieser Studie wurden 275 von insgesamt 2.124 angelegten Gräben untersucht, um den Einfluss von Bodenfaktoren, insbesondere der Tiefe der Wurzelzone und der Partikelgröße, auf die Wahrscheinlichkeit von Ausbrüchen in Zentraltexas zu bewerten. Die Daten zu Ausbrüchen der Pathogenübertragung, die von 1990 bis 2020 im Rahmen des Texas Oak Wilt Suppression Project (Projekt zur Bekämpfung der Eichenwelke in Texas) mit Kostenteilung erstellt wurden, dienten dazu, festzustellen, ob die Bodenpartikelgröße und/oder die Wurzeltiefe den Erfolg oder Misserfolg von Gräben bei der Verlangsamung der Ausbreitung vorhersagen können. Unsere Ergebnisse zeigten, dass bei den untersuchten Gräben die Gesamtdurchbruchrate von Eichenwelke 39% betrug, verglichen mit einer gemessenen Durchbruchrate von 19% für den gesamten Datensatz. Die Wurzelzonentiefe und die Bodenpartikelgröße hatten einen signifikanten Einfluss auf die Durchbruchwahrscheinlichkeit. Eine größere Wurzeltiefe war mit einer höheren Wahrscheinlichkeit von Grabenausbrüchen verbunden, insbesondere in lehmigen Böden, während

feinere und schlammige Böden ein geringeres Risiko aufwiesen. Die Ergebnisse unterstreichen, wie wichtig es ist, die Bodeneigenschaften bei der Umsetzung von Grabenstrategien zur Eindämmung der Ausbreitung der Eichenwelke zu berücksichtigen. Diese Studie ist die erste, die sich mit bodenbezogenen Faktoren befasst, die das Management der Eichenwelke in Texas beeinflussen, und legt nahe, dass zusätzliche Umweltvariablen die Vorhersagemodelle für den Erfolg von Gräben weiter verbessern könnten.

Resumen. El marchitamiento del roble, ocasionado por *Bretziella fagacearum*, representa una amenaza significativa para los robles en Texas. El patógeno puede propagarse mediante injertos de raíces subterráneas, siendo este el medio de transmisión más efectivo y dañino para la dispersión en robles vivos (*Quercus fusiformis* y *Q. virginiana*) en el centro de Texas. Se hacen zanjas entre los focos de la enfermedad y los árboles sanos con la esperanza de cortar o interrumpir las conexiones de las raíces para limitar la propagación del patógeno. Este estudio submuestreó 275 de un conjunto total de 2124 zanjas instaladas para evaluar el efecto de los factores del suelo, específicamente la profundidad de la zona radicular y el tamaño de las partículas, en la probabilidad de rupturas de zanjas en el centro de Texas. Los datos de ruptura de transmisión de patógenos, generados entre 1990 y 2020 en el marco del costo compartido del Proyecto de Supresión de la Marchitez del Roble de Texas, se utilizaron para determinar si el tamaño de las partículas del suelo o la profundidad de las raíces podrían predecir el éxito o el fracaso de la excavación de zanjas para frenar la propagación. Nuestros resultados mostraron que, en las zanjas submuestreadas, la incidencia general de marchitez del roble fue del 39%, en comparación con el 19% de incidencia medida para todo el conjunto de datos. La profundidad de la zona radicular y el tamaño de las partículas del suelo influyeron significativamente en la probabilidad de incidencia. Una mayor profundidad de las raíces se asoció con una mayor probabilidad de incidencia de la zanja, especialmente en suelos arcillosos, mientras que los suelos más finos y limosos mostraron un menor riesgo. Los hallazgos resaltan la importancia de considerar las características del suelo al implementar estrategias de excavación de zanjas para controlar la propagación de la marchitez del roble. Este estudio es el primero en explorar los factores relacionados con el suelo que afectan el manejo de la marchitez del roble en Texas y sugiere que variables ambientales adicionales podrían mejorar aún más los modelos predictivos del éxito de la excavación de zanjas.