# Mitigation of Hurricane Damage in Pecan Orchards

by

James Daulton Messer

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 12, 2020

Keywords: Abscission, Defoliation, Hurricane, Orchard Management, Pecans, Wind Damage



Approved by

Wheeler G. Foshee III, Chair, Associate Professor of Horticulture
Jeff L. Sibley, Professor of Horticulture
Tyler A. Monday, Research Fellow, Department of Horticulture

## Abstract

Hurricanes make landfall in the southeastern United States, the center of the majority of worldwide pecan production, on an annual basis. Hurricanes cause severe damage to orchards and reduce yield dramatically for years following. Defoliating pecan trees may mitigate injury caused by excessive rainfall and wind speeds of hurricanes by reducing the drag coefficient ($C_D$) of the tree crown. Chemical defoliation was first developed for the cotton industry; however, it may have application in protecting pecan trees by reducing the $C_D$ below the major damage threshold. To determine the effectiveness of defoliation for reduction of $C_D$ in pecans, wind force measurements were recorded at five hand defoliation percentages. Results showed 50% defoliation equated to 50% reduction in midpoint wind pressure to 7.92 lbs/ft$^2$, enough to avoid major limb breakage and uprooting according to the Coder Wind Scale. After preliminary screening, the safest and most effective defoliants were evaluated at varying mixtures and concentrations to determine percent defoliation efficacy with time. Thidiazuron (6.4 oz/100 gallons of water) with ethephon (3.2 oz/100 gallons of water) and chelated copper with urea ammonium nitrate (UAN) and a nonionic surfactant showed the highest defoliation percentages at 67% in 72 hours and 88% in 96 hours respectively. This series of studies establishes defoliating pecan trees prior to hurricane conditions could prevent breakage of major scaffold branches and uprooting.

Acknowledgements

First, I would like to give God all the glory, honor, and praise. He alone is worthy of our worship in all aspects of life. He has graciously reconciled to Himself rebellious people through the all sufficient sacrifice of His Son Jesus Christ our Lord. Heb sovereignly orchestrates all things in our lives for His glory and our good. Second, I extend my gratitude to my parents for instilling in me the work ethic necessary to complete this research. Third, I would like to thank Dr. Foshee, Dr. Sibley, and Dr. Monday for giving me the opportunity and instruction to better myself through this research. And lastly, I would like to thank my friends and church for supporting and encouraging me on this journey.

Table of Contents

List of Tables

List of Figures

# Chapter 1

## Literature Review

On an annual basis, hurricanes make landfall in the highest production region of pecans in the world, the southeastern United States, causing severe damage to much of the pecan industry both in the current season, and for years to come (Wood, 2007; Wood, et al., 2001). Pecan orchards are highly susceptible to hurricane damage due to the anatomy and physiology of the pecan tree (Coder, 2008; Koizumi, et al., 2010; Mayer, 1987; Wood, 2007; Wood, et al., 2001). Research has shown that defoliating trees reduces their drag coefficient ($C_D$) (Koizumi, et al., 2010; Mayer, 1987). Therefore, it may be possible to reduce the $C_D$ of pecan trees enough via chemical defoliation prior to hurricane conditions to mitigate damage to pecan orchards and losses in the pecan industry.

The pecan, *Carya illinoinensis*, is indigenous to North America and Mexico where it has had a major impact on the way of life and culture for centuries (Celiz, 1935; Wood, et al., 2001; Worley, 2002). Recordings of many noteworthy individuals and advancements in technology throughout history shed light on the pecan industry's growth and current impact (Crawford et al., 2001; Nadler, Chen, and Lu, 2019; Wood et. al., 2001; Worley, 2002). Thanks to developments in cultural practices, the United States pecan industry has been the leader in world pecan production and continues to dominate the industry today with an estimated average of 250 million pounds of in shell production, approximately $550 million, per year since 2010 (Fig. 1.1) (Crawford et al., 2001; Wood et. al., 2001; Worley, 2002). Production and prices rise and fall markedly every year due in large part to the alternate bearing nature of pecans (Fig.1.1) (Wells, 2007). This, along with disease and pest pressure and the initial investment required provide formidable obstacles for entering the pecan industry (Brock and Bertrand, 2007; Hudson, 2007; Wells, 2007). However, these are not the only risk factors for which pecan growers must account. Because pecan production in the U.S. is centered in southeastern coastal states, pecan growers face the threat of losing their orchard to hurricanes annually (Wells, 2007; Wood et al., 2001). Chemical defoliation of pecan trees prior to hurricane conditions could provide pecan growers a method to mitigate the economic loss experienced from hurricane damage.

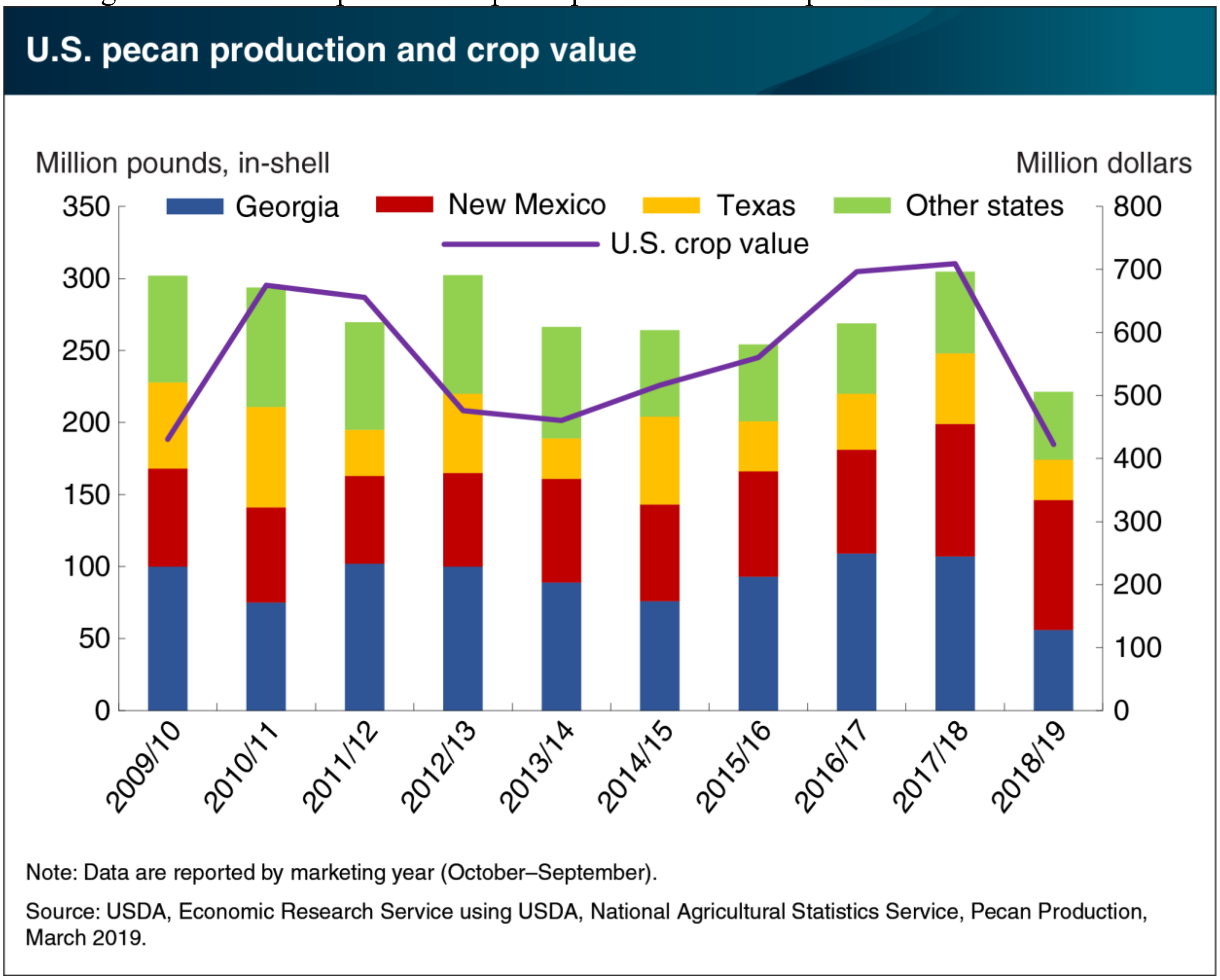
Hurricanes are some of the most powerful storms on the face of the planet with several making landfall in the southeastern United States on an annual basis. At times, these massive storms permanently change the landscape leaving behind billions if not trillions of dollars in economic loss (Fig. 1.1; Strobl, 2011; Wood et al., 2001). Historically, little could be done to protect pecans from hurricanes; thus, the industry has been extremely susceptible to major damage from these intense storms (Wood, 2007; Wood et al., 2001). Hurricane Camille wiped out approximately 73% of Mississippi's pecan production in 1969 (Wood et al., 2001). In 1995, hurricane Opal made landfall in Alabama destroying most of Alabama's pecan industry (Wood et al., 2001). Georgia has been home to an average of over 30% of utilized U. S. pecan production for the past decade (Capps and Williams, 2019; Fig. 2). Most of its production region is farther inland and was once thought to be safe from the devastating effects of hurricanes (Coder, 2008). However, Georgia along with southeast Alabama and Florida were devastated by Michael, a category 5 hurricane, in 2018 (Wilkins, 2018). Miller (2018) records an interview of Auburn University Research Associate Bryan Wilkins just days following hurricane Michael "From all of the information that I can gather, I estimate that pecan loss in southeast Alabama will total somewhere between $300,000 and $500,000 just in crop loss." Alabama and Mississippi were hit again just two years later in 2020 by hurricane Sally, leaving south

Alabama's pecan industry demolished (Wilkins, 2020). Cultivar selection and training trees to central leaders with wide crotch angles has been shown to significantly reduce the amount of damage during less severe storms (Reighard, et al., 2001; Wells, 2007; Wood et al., 2001). However, due to the amount of labor involved with such training most orchards are trained to a multi-leader canopy with many acute crotch angles (Reighard, et al., 2001; Wells, 2007; Wood et al., 2001). Therefore, no legitimate protection from hurricane damage is currently available for pecan growers. Hurricanes not only bring catastrophic economic loss to the pecan industry, they also change the lives of pecan growers (Nesbit and Wells, 2007; Reighard et al., 2001; Wood et al., 2001).

Compared with many other crops, pecan orchards often suffer the greatest from hurricanes due to the amount of damage sustained as a result of the anatomy and physiology as well as the cultural practices of pecans (Nesbit and Wells, 2007; Reighard et al., 2001; Wells, 2007; Wells, 2007; Wood et al., 2001). Pecan trees grow up to 30+ meters high and bear a crop load of 50 to 100 kilograms. Since pecan trees are usually trained to a multileader canopy with acute crotch angles, the major scaffold branches are highly susceptible to breaking even in less severe storms with wind speeds of only 30 mph. When these scaffold branches are broken, production in the following years is significantly decreased (Burkette, 2020; Reighard et al., 2001; Wells, 2007; Wood, et al., 2001). Pecans are also relatively shallow rooted without a strong taproot (Reighard, et al., 2001; Wells, 2007). As the enormous above ground portion of the tree acts like a sail in the wind, not only are nuts and leaves stripped off and limbs easily broken, but the root system is subjected to extreme stress and often sustains injury reducing yield in the years following (Coder, 2008; Reighard et al., 2001). In addition to potential injury from this stress, when storms dump 13 to 23 centimeters of rainfall over a six to 12 hour interval as is common during hurricanes, the soil approaches its plastic or liquid limit becoming more malleable and fluid in nature. This dramatically decreases its ability to hold a pecan tree upright (Coder, 2008; Reighard et al., 2001; Wells, 2007). During this scenario, with shallow root systems, the sustained winds of a hurricane continue to pound the crown of pecan trees and the force of the winds eventually overcomes the soil's shear limit uprooting the trees (Coder, 2008; Reighard, et al., 2001; Wells, 2007). Such damage not only wipes out the harvest of the current season, causing hundreds of thousands of dollars in losses for growers, but sets back production for years to come. When hurricane conditions lead to uprooting, often most, if not all of the orchard is uprooted (Reighard, et al., 2001; Wells, 2007; Wood et al., 2001). When trees are uprooted it is possible to right them, but it is usually most economically advisable to replant, that is, if the long term investment of pecan production is still of interest to the grower (Nesbit and Wells, 2007; Reighard et al., 2001). Miller (2018) reports from the interview of Wilkins, "At this time, there is no way to determine the long-term impact due to tree loss. It is safe to say that by the time you figure the current replacement price of a tree and the subsequent years of crop loss until the trees come into bearing, we are looking at losses in the tens of millions of dollars." However, in reality the cost of replacing a pecan tree of any size is hard to calculate when the initial investment factors such as, land preparation, planting, fertilizer, water, pruning, orchard mowing, and the land cost itself are factored out over each tree are considered (Nesbit and Wells, 2007; Sibley, 2020; Wells, 2007). Even that does not take into account the amount of profit lost as trees mature to full production potential, which is actually when trees are most susceptible to being uprooted by a hurricane and takes an average of 7 years (Nesbit and Wells, 2007; Wood, et al., 2001). Since orchard recovery from a hurricane takes about a decade, replanting is simply too much of an investment for many pecan growers. In itself, the amount of time to recover from hurricane damage is enough to destroy a pecan grower's way of life, not to mention the end result being losses in the range of tens of millions of dollars, if not more (Nesbit and Wells, 2007; Miller 2018; Reighard et al., 2001; Wells, 2007). Thus, one can justify the need for a method of mitigating the damage caused by hurricanes in pecan orchards even in the slightest degree.

Existing literature shows defoliating trees reduces the drag coefficient ($C_D$), which in turn lowers the amount of wind force acting on tree crowns (Coder, 2008; Koizumi, et al., Mayer, 1985). Chemical defoliants have become common agricultural practice in the cotton industry and have shown to be effective in defoliating fruit and nut trees prior to winter pruning (Bi, et al., 2005; Crawford, et al., 2001; Cooper et al., 1968; and Gerdts, et al., 1977; Tranbarger et al., 2017; Xu, et al., 2019). Thus, the research presented here seeks to provide the foundation for developing a management strategy to minimize damage and loss caused by hurricanes in pecan orchards via chemical defoliation.

Figure 1.1: USDA report of U.S. pecan production and crop value from 2009 to 2019.



## Literature Cited


Bi, G., C.F. Scagel, L. Cheng, and L.H. Fuchigami, 2005. Effects of copper, zinc and urea on defoliation and nitrogen reserves in nursery plants of almond. Horticultural Sci. and Biotechnology 80(6); pp.746-750.

Brock, J. and P. Bertrand 2007. "Diseases of Pecans in the Southeast," in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 171-192. Univ. of Georgia Coop. Ext. 2007.

Burkette, J. 2020. Personal Communication.

Capps Jr, O., and G.W. Williams. 2019. Economic Benchmark Model and Analysis of the Effects of the Chinese Tariff on the US Pecan Industry. Forecasting and Business Analytics, L.L.C.

Celiz, F.F. 1935. Diary of the Alarcon expedition into Texas, 1718–1719. Quivira Soc. Publ. 5:12–21. (Trans. I.C.F.L. Hoffman).

Coder, K. D. 2008. Storm Wind Loads and Tree Damage. Warnell School, Univ. of Georgia WSF&NR08-24.

Cooper, W. C., G.K. Rasmussen, B.J. Roger, P.C. Reece, and W.H. Henry. 1968. Control of abscission in agricultural crops and its physiological basis. Plant Physiology. 43: 1560–1576.

Crawford, S.H., J.T. Cothren, D.E. Sohan, and J.R. Supak. 2001. "A history of cotton harvest AIDS," in Cotton Harvest Management: Use and Influence of Harvest Aids, J. R. Supak and C. E. Snipes, Eds.: pp. 1–19, The Cotton Foundation, Cordova Memphis, Tenn, USA, 2001.

Gerdts, M., G. Obenauf, J. LaRue, and G. Leavitt. 1977. Chemical defoliation of fruit trees. California Agriculture, 31(4), pp.19.

Hudson, W. 2007. "Insects and Mites Associated with Pecans," in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 137-170. Univ. of Georgia Coop. Ext. 2007.

Koizumi, A., J.I. Motoyama, K. Sawata, Y. Sasaki, and T. Hirai. 2010. Evaluation of drag coefficients of poplar-tree crowns by a field test method. Wood Sci. 56(3), pp. 189-193.

Mayer, H. 1987. Wind-induced tree sways. Trees, 1(4), pp.195-206.

Miller, J. 2018. Storm Hits Alabama Pecan Crops. http://news.aces.edu/blog/2018/10/18/storm-hits-alabama-pecan-crops/ (accessed Nov 16, 2018).

Nadler, S., A.N. Chen, and H.K. Lu. 2017. Pecan Production, Exporting, and Its Future: From a Multi-Country Perspective. Journal of Applied Business and Economics, 19(8).

Nesbit, M. and L. Wells. 2007. "Estimation of Pecan Tree Value," in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 135-136. Univ. of Georgia Coop. Ext. 2007.

Reighard, G. L., M. L. Parker, G. W. Krewer, T. G. Beckman, B. W. Wood, J. E. Smith, and J. Whiddon. 2001. Impact of Hurricanes on Peach and Pecan Orchards in the Southeastern United States. HortScience 36: 250-252. doi:10.21273/hortsci.36.2.250

Sibley, J. 2020. Personal Communication.

Strobl, E. 2011. The economic growth impact of hurricanes: evidence from U.S. coastal counties. Rev. Economics and Statistics 93: pp. 575-589. Harvard College and the Massachusetts Inst. Of Tech. May, 2011.

Tranbarger, T. J., M. L. Tucker, J. A. Roberts, and S. Meir. eds. 2017. Plant Organ Abscission: From Models to Crops. Lausanne: Frontiers Media. doi: 10.3389/978-2-88945-328-3.

Wells, L. 2007. “Establishing a Pecan Orchard,” in Southeastern Pecan Growers’ Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 19-26. Univ. of Georgia Coop. Ext. 2007.

Wells, L. 2007. “Pecan Physiology,” in Southeastern Pecan Growers’ Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 1-8. Univ. of Georgia Coop. Ext. 2007.

Wilkins, B. 2018. Personal Communication.

Wilkins, B. 2020. Personal Communication.

Wood, B. 2007. “Storm Damage: Prevention and Recovery,” in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 2007. 978-0-9746963-5-5: pp. 129-134 Univ. Georgia Coop. Ext. 2007.

Wood, B. W., W. Goff, and M. Nesbitt. 2001. Pecans and hurricanes. HortScience 36: 253 258. doi:10.21273/hortsci.36.2.253

Worley, R. E. 2002. Compendium of Pecan Production and Research. Edwards Bros. Ann Arbor, Mich. pp. 1-13

Xu, J., L. Chen, H. Sun, N. Wusiman, W. Sun, B. Li, Y. Gao, J. Kong, D. Zhang, X. Zhang, and H. Xu. 2019. Crosstalk between cytokinin and ethylene signaling pathways regulates leaf abscission in cotton in response to chemical defoliants. J. Experimental Botany 70 pp.1525-1538.

## Chapter II:

## Evaluation of Foliar Applied Defoliants to Container Grown Pecan Trees at Paterson Greenhouse Complex, Auburn, AL.


### Abstract

Hurricanes make landfall in the southeastern United States on an annual basis severely reducing the majority of worldwide pecan production. Chemical defoliation has been an agricultural practice for many years. Defoliating pecan trees may prevent injury caused by excessive wind speeds of hurricanes by reducing wind drag. Several chemicals were evaluated for defoliation on container grown pecan trees by foliar application via backpack sprayer at Paterson Greenhouse Complex, Auburn, AL. Force measurements were also taken on trees to measure the amount of drag reduction via defoliation. Results showed that trees require defoliation to roughly 50% to 60% in order to prevent major limb breakage and uprooting. No treatment resulted in sufficient defoliation in 24 to 48 hrs. However, in August 2020, all treatments that included CuEDTA resulted in sufficient defoliation in 144 h. In September, treatments including 5% UAN, 25% UAN, and 25% 18-0-0-3 provided sufficient defoliation in 144 h, while the treatment including 15% 18-0-0-3 yielded sufficient defoliation in 120 h.


### Introduction

Hurricanes make landfall on an annual basis in the southeastern United States, the highest production region of pecans in the world, causing severe damage to much of the pecan industry both in the current season, and for years to come (Capps and Williams, 2019; Wells, 2007; Wood, et al., 2001). Pecan orchards are highly susceptible to hurricane damage due to the anatomy and physiology of the pecan tree (Coder, 2008; Koizumi, et al., 2010; Mayer, 1987;

Wells, 2007; Wood, 2007; Wood, et al., 2001). Chemical defoliation has been available as a harvest aid in the cotton industry since 1938 and has more recently begun to be investigated as an in aid dormant season pruning of fruit and nut trees (Bi et al., 2005; Crawford et al., 2001; Gerdts et al., 1977). Research has shown that defoliating trees reduces their $C_D$ (Koizumi, et al., 2010; Mayer, 1985). Therefore, it may be possible to reduce the $C_D$ enough via chemical defoliation prior to hurricane conditions to mitigate damage to pecan orchards and losses in the pecan industry.

Pecan trees are deciduous, naturally shedding their leaves every fall (Wells, 2007). Chemical defoliation involves the manipulation of this natural process of a pecan tree shedding its leaves known as abscission. Abscission, the separation of an organ from the plant, is a highly regulated and complex process that involves many internal as well as external factors (Kim et al., 2016). Research on the abscission process goes back farther than a century; however, recent advancements in technology and methodology have provided a much greater understanding of the process (Cooper et al., 1968; Crawford, et al., 2001; Tranbarger et al., 2017). Tranbarger et al., (2017) provides a general four phase model for plant organ abscission as 1) the differentiation of the abscission zone (AZ), 2) the acquisition of AZ cells to become competent to respond to various abscission signals, 3) response to signals and the activation of molecular and cellular processes that lead to cell separation in the AZ, and 4) the post-abscission events related to the protection of exposed cells after the organ has been shed. Although this four phase framework sheds light on the process of abscission, each step is extremely complex, and the mechanisms controlling and affecting each step vary, not only from plant to plant, but from organ to organ within an individual plant itself (Tranbarger et al., 2017). Given the complexities of regulation, the task of studying this process is quite formidable, and there has been slow progress in understanding abscission on a more botanical and molecular level (Tranbarger et al., 2017). However, the discovery of ethylene and other plant growth regulators (PGR) along with technology advancements in genetics, biochemistry, and the agricultural industry have helped propel forward understanding this biological process (Cooper et al., 1968; Crawford et al., 2001; Tranbarger et al., 2017; Xu, 2019). As a result, products have been developed that successfully desiccate, defoliate, and induce senescence of different plant organs including leaves and fruit (Cooper et al., 1968; Crawford et al., 2001). Several of these products have been developed further to include mixtures of PGRs, PGR inhibitors, and herbicides that enhance these properties (Crawford et al., 2001; Tranbarger et al., 2017). However, due to the nature of cultivation and production of pecans, no research on chemical defoliation of pecan trees currently exists.

In 1805, Sir Francis Beaufort developed the Beaufort Wind Scale (BWS), which assigns a numerical force value to wind speeds and the effects produced (Coder, 2008). According to the BWS, forces damaging to trees are produced as wind speeds begin to reach 40 mph (17 m/s), trees are uprooted at speeds around 55 mph (25 m/s), and winds in excess of 72 mph (32 m/s) are considered hurricane force winds. These 72+ mph hurricane force winds are categorized by the Saffir-Simpson Hurricane scale; however, Coder (2008) explains the mechanics behind the forces applied to tree crowns from storm winds are better understood in terms of pressure values (lbs/ft$^2$) rather than wind speeds. Koizumi et al. (2010) was able to characterize the $C_D$ of poplar trees in a wind tunnel experiment. Koizumi et al., (2010) also found that the variation of $C_D$ no longer increased with values of $U$ over 10 m/s. In this experiment $C_D$ was used to assess the amount of wind force exerted on a tree crown ($P_W$) given a wind velocity ($U$), the horizontal crown area (A), and the air density (ρ) as displayed in Equation 1 (Koizumi et al., 2010).

Eq. 1. $P_w = \frac{1}{2} C_D \rho A U^2$

The equation displays the direct relationship between $C_D$ and $P_W$ and thereby shows that reduction in $C_D$ results in reduction of $P_W$. $C_D$ depends on crown area and density as well as overall tree rigidity (Koizumi, et al., 2010; Mayer, 1987; Mayhead 1973). Conifers that had greater foliage density and a more supple nature were shown to have a lower $C_D$ than more rigid species (Mayer, 1985). Koizumi et al. (2010) also showed that defoliated poplar tree crowns not only had less variation in $C_D$, but also a significantly lower $C_D$ than foliated tree crowns. Removing leaves reduces the surface area and canopy density making the trees more aerodynamic (Coder, 2008; Koizumi et al., 2010; Mayer, 1987; Mayhead 1973). No experiments have been done to calculate the $C_D$ for pecan trees; however, pecan crowns can be expected to behave similarly to those of poplars. Thus, it may be possible to protect pecan trees from damaging hurricane force winds by reducing the $C_D$ and thereby $P_W$ applied to pecan crowns through chemical defoliation (Coder, 2008; Koizumi et al., 2010).

Defoliation would ultimately mean the loss of the current season's crop; however, it could mean preventing trees from major limb breakage and uprooting. If this potential is realized, not only will an immeasurable amount of economic loss be prevented, but the way of life of pecan growers will be preserved. The research presented here evaluates the amount of force reduction achieved with increasing defoliation as well as products that have proven as successful defoliants in other agricultural industries for their application in defoliating pecan trees. Due to the complex and intricate process of abscission, much research to fully understand and elucidate the various mechanisms involved in abscission is still needed (Crawford et al., 2001; Rademacher, 2015; Tranbarger et al., 2017; Xu et al., 2019). As these advancements are made, it is certain the application of defoliation can be refined further. Even still, the work presented here indicates the potential to protect pecan trees from the destructive combination of the wind and rain from a hurricane via chemical defoliation.

## Materials and Methods

Preliminary screening of a wide range of defoliants was conducted on small, field grown pecan saplings in the summer and fall of 2018 at E.V. Smith Research Center orchards in Tallassee, AL, and an unproductive orchard at Turnipseed-Ikenberry Research Station in Union Springs, AL. Defoliants causing excessive damage to trees were discarded from further testing. Defoliants with the highest percent defoliation in the shortest time were selected for treatment enhancement testing via rate increases, combining defoliants, and addition of surfactants or crop oil concentrates.

*2019 Run*

In the spring of 2019, 30 7-gal (26.5 liters) container-grown 'Elliot' pecan trees were purchased from Bass Pecan Nursery in Raymond, Mississippi. Trees were maintained at Paterson Greenhouse Complex on the campus at Auburn University according to recommended practices (Wells, 2007). These trees were utilized to evaluate selected defoliating materials for the reduction of force (in foot-lbs of pressure applied to the tree) when exposed to approximately 75 mph winds the following fall.

On August 27, 2019, a completely randomized split-plot experiment was designed with 3 replications of 4 treatments to evaluate the amount of force that could be reduced with previously screened defoliants. Defoliant treatments included 1) 1.75% v/v zinc sulfate ($ZnSO_4$), 2) 1% v/v chelated copper (CuEDTA), 3) 1000 ppm ethephon + 0.5% v/v CuEDTA, and 4) Untreated. Each treatment was applied to the point of runoff using a backpack sprayer. Tree crown area was measured as well as trunk caliper before application of treatments. Force measurements were recorded 24 and 48 h post treatment application using a model FB 5k Torbal force gauge (Fig. 2.4) and accompanied data logging software and a Toro Pro Force commercial blower to simulate hurricane force winds. The Toro Pro Force commercial blower was elevated by a frontend loader attached to a tractor to direct the wind at the center of the tree canopy. Using an EXTECH AN100 CFM/CMM thermos-anemometer (Fig. 2.3), proper tree placement distance from the blower was determined to achieve wind speeds on average of 75 mph. The base of each tree was secured using 3 cinder blocks in a c shaped arrangement (Fig. 2.1), and the tree was blown to simulate hurricane force winds. The force gauge was connected to the trunk at 42 inches above the soil level of the tree container using a cable and large carabineer (Fig. 2.2). Force measurements were recorded every 1s for 60s using the Torbal force gauge and data logging software. The middle 30s recorded were analyzed to ensure accuracy and precision of data.

Defoliation ratings were taken immediately following exposure to the hurricane force winds, and again at 144 hours post application. Trees were then maintained to monitor health, recovery, and bud break the following spring.

During this experiment, trees were also manually defoliated to record wind force exerted on the tree at varying defoliation percentages (Fig. 2.5), which was then converted to midpoint wind pressure values (Fig. 2.6). Leaves were counted and hand removed in successive intervals to evaluate defoliation percentages at 0%, 25%, 50%, 75%, and 100% defoliation via the same force measurement procedure described above.

*2020 Run*

On September 29, 2020, a completely randomized experiment was conducted to evaluate defoliants from previous tests. Four replications of six treatments were randomly assigned to the same container grown pecan trees previously noted. Treatments included 1) 5% urea ammonium nitrate (UAN), 2) 10% UAN, 3) 25% UAN, 4) 15% 18-0-03, 5) 25% 18-0-03, and 6) untreated. All treatments except the Untreated contained 1% silicone surfactant and 1% chelated copper. Force measurement and defoliation ratings were taken as mentioned above in the study from 2019 (Fig 2.1) for each treatment replication at 24 h post treatment application.

All data were analyzed with generalized linear models with the use of the GLMMIX procedure of SAS 9.4. Tukey's Studentized Range Test ($\alpha$=0.10) was utilized for means comparisons.

**Results & Discussion**

*2019*

The results of the hand defoliation trial showed that each defoliation rating reduced measured force by an average of approximately 25% (Figures 2.2 and 2.3). Specifically, at 50% defoliation, forces were measured at an average of 10 lbs correlating to approximately 8 lbs/ft$^2$ of midpoint wind pressure. According to Coder (2008), wind pressure needs to be under approximately 8 lbs/ft$^2$ to reduce major limb breakage and blow over (Figs. 2.7 and 2.8). This sets the benchmark to protect pecan trees from most hurricane damage at approximately 50 to 60% defoliation (Fig 2.5 and 2.6). The next step was to identify defoliants capable of reaching this defoliation percentage 24 to 48 hours post-application.

Table 2.1 shows defoliant treatments yielded a difference in defoliation when compared to the untreated, but showed few significant differences across defoliants for defoliation efficacy until 144 h. No significant differences were detected across defoliant treatments at 24 h, but at 48 h, the 1000 ppm ethephon + 0.5% v/v CuEDTA produced greater defoliation compared to all other defoliant treatments. Although no treatment resulted in successful defoliation in the desired time frame of 24 h to 48 h, both treatments containing CuEDTA provided sufficient defoliation at 144 h with the tank mix of CuEDTA + ethephon eliciting the highest amount of defoliation. These results indicated that treatments containing CuEDTA and ethephon had potential as effective defoliants for pecans and warranted further testing to determine if its defoliation rate could be enhanced. The average force measurements on tree crowns displayed the expected reduction in force for the hand defoliated trees when compare with the untreated. Table 2.1 shows a few significant differences among the average force measurements on tree crowns; however, this variation is likely due to differences in original tree crown area and density rather than resulting from a reduction in $C_D$ from defoliation when considering the results from the hand defoliation trial and the defoliation results for each treatment.

*2020*

Table 2.2 shows the results of the efficacy trial with selected rates of UAN and 18-0-0-3. No significant defoliation occurred at the 24 h post treatment application time of blowing and force recording for any treatment (data not shown). Though significant differences were detected across treatments 72 h post-treatment, sufficient defoliation was not achieved by any treatment.

Results show that defoliant treatments elicited significantly higher rates of defoliation at 72 h post treatment application compared to untreated. At 72 h post-application, the 15% 18-0-0-3 treatment had the highest defoliation rating at 35%, in contrast to the untreated, which produced only 4% defoliation. This trend continued at each rating interval. At 144 h post application, 15% 18-0-0-3 elicited the highest percent defoliation at 86%, compared to the untreated which was 7.5% defoliated. Additionally, 15% 18-0-0-3 resulted in 57.5% defoliation of trees at 120 h post application, while trees treated with all other treatments were under 50% defoliation at this time.

Since no significant defoliation occurred during the time of blowing and the change in measured force from beginning to end of measurements is small (less than 1 lb), the slightly lower than expected force measurements were likely due to less dense more spindly crowns produced from growing in tight spacing over the previous year to minimize blow over in the nursery complex. Therefore, no significant force reduction due to defoliation can be concluded, and differences in measured force across treatments is likely due to differences in crown shape and density.

Figure 2.1: Force Measurement Setup.

Figure 2.2: Caribineer attaching FB 5k Torbal force gauge to pecan sapling at 42 inches above soil line.

Figure 2.3: EXTECH AN100 CFM/CMM thermos-anemometer.


Figure 2.4: FB 5k Torbal force gauge.

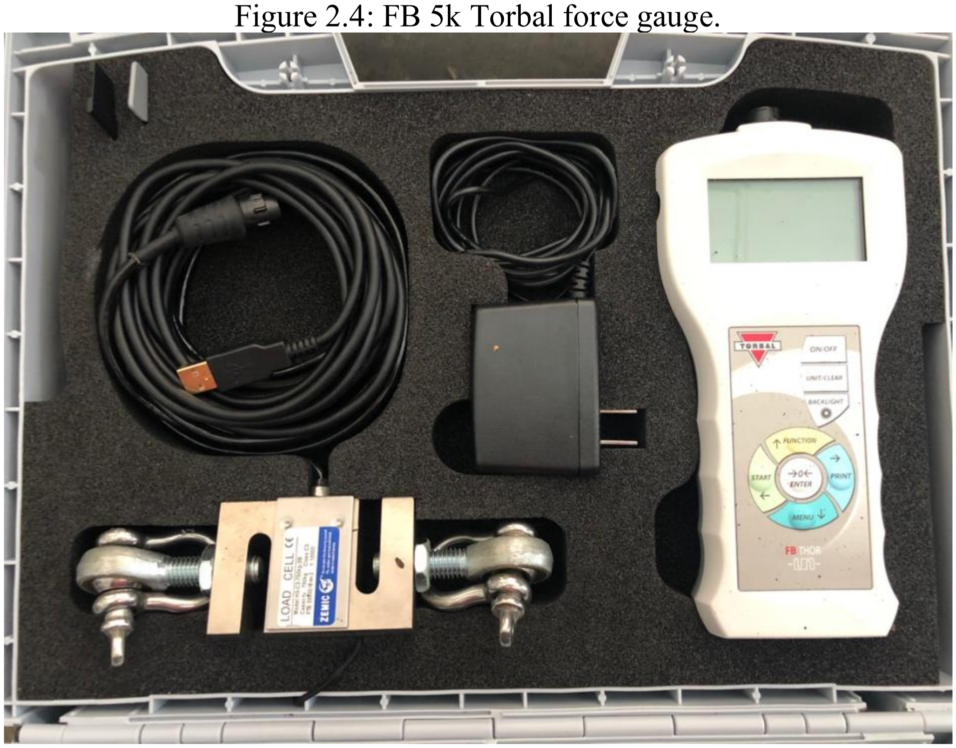


Figure 2.5. Measured pounds of Force exerted on hand-defoliated container grown pecan trees by simulated hurricane force winds.

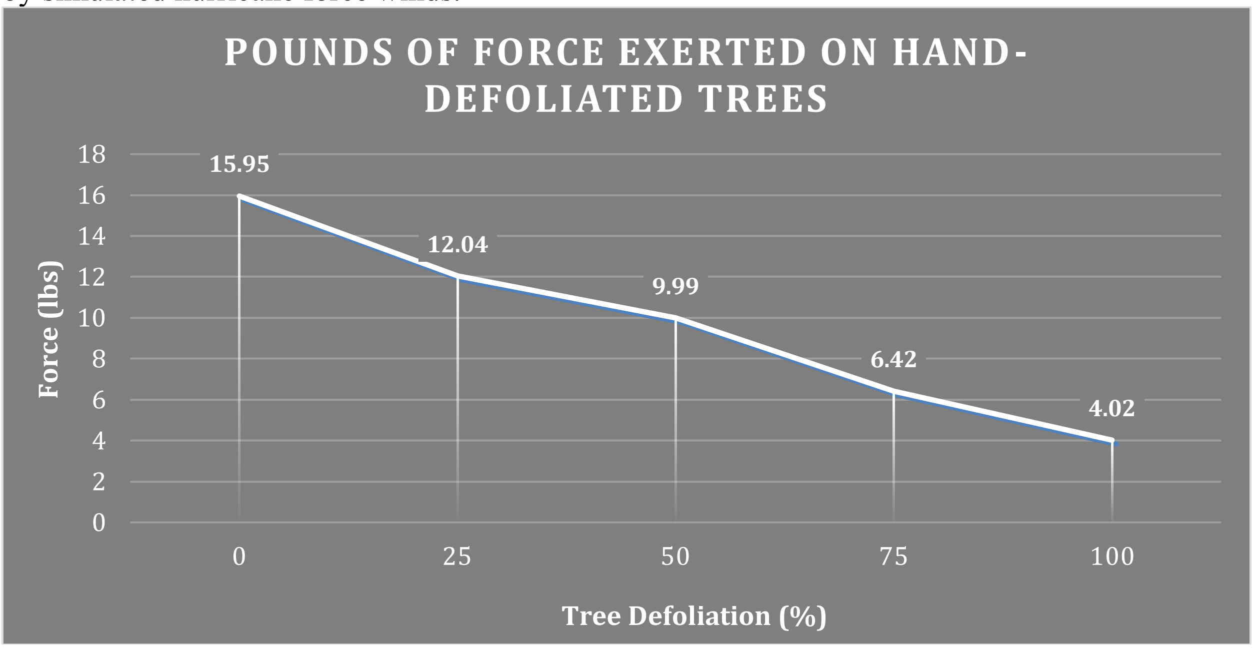



Figure 2.6. Midpoint wind pressure in lbs/ft$^2$ on hand-defoliated container grown pecan trees by simulated hurricane force winds. Calculated from measured pounds of force by adapting the Coder equation. (Coder, 2008).

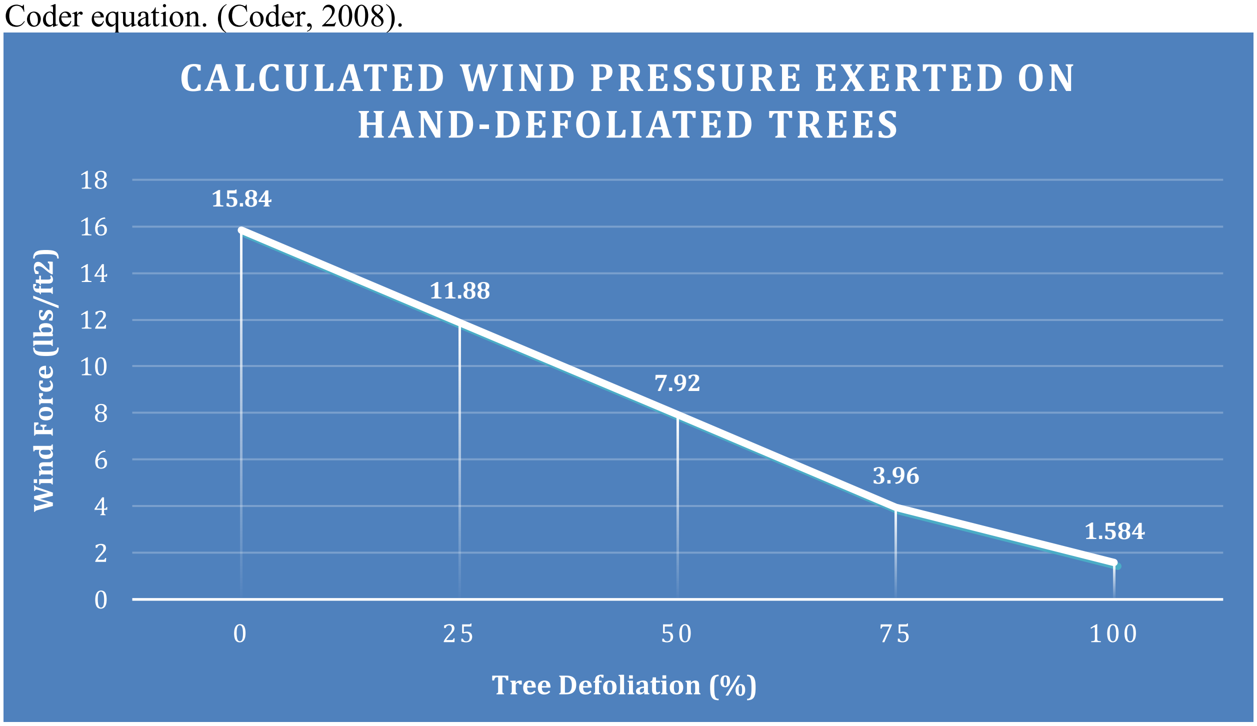


Figure 2.7: Table 7 from Coder (2008). Estimated wind pressures in pounds per square feet ($lbs/ft^2$) calculated under standard conditions for various wind velocities in miles per hour (mph).

| wind velocity (mph) | pounds per square feet ($lbs/ft^2$) | wind velocity (mph) | pounds per square feet ($lbs/ft^2$) |
|---|---|---|---|
| 5 | 0.1 | 80 | 17 |
| 10 | 0.3 | 85 | 19 |
| 15 | 0.6 | 90 | 21 |
| 20 | 1.1 | 95 | 24 |
| 25 | 1.7 | 100 | 26 |
| 30 | 2.4 | 110 | 32 |
| 35 | 3.2 | 120 | 38 |
| 40 | 4.2 | 130 | 45 |
| 45 | 5.3 | 140 | 52 |
| 50 | 6.6 | 150 | 59 |
| 55 | 8.0 | 175 | 81 |
| 60 | 9.5 | 200 | 105 |
| 65 | 11 | 225 | 133 |
| 70 | 13 | 250 | 165 |
| 75 | 15 | 275 | 199 |

wind pressure in pounds per square foot = (0.013) X ( wind speed in mph X (0.45) )$^2$

Figure 2.8: Table 10 from Coder (2008). Coder Index of Tree Crown Reconfiguration giving index value symbol, wind speed in miles per hour, wind pressure in pounds per square feet, a tree crown reconfiguration description, and a tree crown reconfiguration percentage.

| index value | wind speed (mph) | wind pressure (lbs/ft$^2$) | tree crown reconfiguration descriptor | tree crown reconfiguration |
|---|---|---|---|---|
| C0 | 0 | 0 | gravity impacts only | 0 % |
| CI | 10 | 0.3 | petiole & blade deforming, & twig swaying | 5 % |
| CII | 19 | 1.0 | leaves rolled back & large peripheral twigs sway | 10 % |
| CIII | 28 | 2.0 | twigs pulled back & peripheral branches sway | 25 % |
| CIV | 37 | 3.6 | branches pulled back & stem swaying | 45 % |
| CV | 46 | 5.6 | twig breakage, stem pushed / held downwind | 70 % |
| CVI | 55 mph | 8.0 lbs/ft$^2$ | twig & branch breakage (~ T1 threshold from Table 8 & 9) | 100 % |

Table 2.1. Defoliation (%) and average force measurements yielded from defoliant application to container grown 'Elliot' pecan trees at Paterson Greenhouse Research Center at Auburn University, Auburn, AL, in August, 2019.

| Defoliation and Exerted Force on Pecan Trees - 2019 Run | | | | | | |
|---|---|---|---|---|---|---|
| **Trt No.** | **Treatment** | **Time of Blowing (H)** | **% Defoliation** | | | **Avg. Force Exerted on Tree (lbs)** |
| | | | **24 H** | **48 H** | **144 H** | |
| 1 | Untreated | 24 | 2.3c[1] | | 8.3c | 14.5ab |
| 2 | 100% Hand Defoliated | 24 | 100a | | 100a | 4.0c |
| 3 | ZnSO4 1.75% v/v | 24 | 5.7bc | | 18.3c | 8.7bc |
| 4 | CuEDTA 1% v/v | 24 | 9.0b | | 76.6b | 15.5a |
| 5 | 1000 ppm ethephon + 0.5% v/v CuEDTA | 24 | 8.3b | | 91.0ab | 17.3a |
| 6 | ZnSO4 1.75% | 48 | | 6.7b | 25.0c | 13.4ab |
| 7 | CuEDTA 1% v/v | 48 | | 5.7b | 86.6ab | 11.3ab |
| 8 | 1000 ppm ethephon + 0.5% v/v CuEDTA | 48 | | 11.3a | 83.3ab | 14.0ab |

[1]Means were compared using Tukey's Studentized Range Test at α=0.10

Table 2.2. Defoliation (%), average force measurements, and change in force from beginning to end of measurement recording yielded from defoliant application to container grown 'Elliot' pecan trees at Paterson Greenhouse Research Center at Auburn University, Auburn, AL, in August, 2020.

| Defoliation and Exerted Force on Pecan Trees - 2020 Run | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Trt No.** | **Treatment** | **Defoliation (%)** | | | | **Avg. Force Exerted on Tree (lbs)** | **Force (∆) Exerted - Beginning of Run to End (lbs)** |
| | | **72 H** | **96 H** | **120 H** | **144 H** | | |
| 1 | 5% UAN | 18.7abc | 22.5bc | 37.5a | 51.2ab | 7.56 | 0.57 |
| 2 | 10% UAN | 13.7bc | 26.2abc | 36.2a | 47.5a | 8.27 | 0.15 |
| 3 | 25% UAN | 28.7ab | 36.2ab | 41.2a | 71.0ab | 10.04 | 0.37 |
| 4 | 15% 18-0-0-3 | 35.0a | 42.5a | 57.5a | 86.0a | 13.04 | 0.77 |
| 5 | 25% 18-0-0-3 | 22.5ab | 37.5ab | 41.2a | 63.7ab | 10.46 | 0.73 |
| 6 | Untreated | 4.0c | 7.5c | 7.5b | 7.5b | 7.56 | 0.73 |

[1]Means were compared using Tukey's Studentized Range Test at α=0.10

**Literature Cited**

Bi, G., C.F. Scagel, L. Cheng, and L.H. Fuchigami, 2005. Effects of copper, zinc and urea on defoliation and nitrogen reserves in nursery plants of almond. Horticultural Sci. and Biotechnology 80: pp.746-750.

Coder, K. D. 2008. Storm Wind Loads and Tree Damage. Warnell School, Univ. of Georgia WSF&NR08-24.

Cooper, W. C., G.K. Rasmussen, B.J. Roger, P.C. Reece, and W.H. Henry. 1968. Control of abscission in agricultural crops and its physiological basis. Plant Physiology 43: 1560–1576.

Crawford, S.H., J.T. Cothren, D.E. Sohan, and J.R. Supak. 2001. "A history of cotton harvest AIDS," in Cotton Harvest Management: Use and Influence of Harvest Aids, J. R. Supak and C. E. Snipes, Eds.: pp. 1–19, The Cotton Foundation, Cordova Memphis, Tenn, USA, 2001.

Gerdts, M., G. Obenauf, J. LaRue, and G. Leavitt. 1977. Chemical defoliation of fruit trees. California Agriculture 31: pp. 19.

Kim, J., J. Yang, R. Yang, R. C. Sicher, C. Chang, and M. L. Tucker. 2016. Transcriptome analysis of soybean leaf abscission identifies transcriptional regulators of organ polarity and cell fate. Front. Plant Sci. 7:125. doi: 10.3389/fpls.2016.00125.

Koizumi, A., J.I. Motoyama, K. Sawata, Y. Sasaki, and T. Hirai. 2010. Evaluation of drag coefficients of poplar-tree crowns by a field test method. Wood Sci. 56: pp.189-193.

Mayer, H., 1987. Wind-induced tree sways. Trees 1: pp.195-206.

Mayhead, G.J., 1973. Some drag coefficients for British forest trees derived from wind tunnel studies. Agricultural Meteorology 12: pp.123-130.

Nesbit, M. and L. Wells. 2007. “Estimation of Pecan Tree Value,” in Southeastern Pecan Growers’ Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 135-136. Univ. of Georgia Coop. Ext. 2007.

Rademacher, W. 2015. Plant growth regulators: backgrounds and uses in plant production. Plant Growth Regulation. 34: pp.845-872.

Tranbarger, T. J., M. L. Tucker, J. A. Roberts, and S. Meir. eds. 2017. Plant Organ Abscission: From Models to Crops. Lausanne: Frontiers Media. doi: 10.3389/978-2-88945-328-3.

Wells, L. 2007. “Pecan Physiology,” in Southeastern Pecan Growers’ Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 1-8. Univ. of Georgia Coop. Ext. 2007.

Wood, B. 2007. “Storm Damage: Prevention and Recovery,” in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 2007. 978-0-9746963-5-5: pp. 129-134 Univ. Georgia Coop. Ext. 2007.

Wood, B. W., W. Goff, and M. Nesbitt. 2001. Pecans and hurricanes. HortScience 36: 253 258. doi:10.21273/hortsci.36.2.253

Xu, J., L. Chen, H. Sun, N. Wusiman, W. Sun, B. Li, Y. Gao, J. Kong, D. Zhang, X. Zhang, and H. Xu. 2019. Crosstalk between cytokinin and ethylene signaling pathways regulates leaf abscission in cotton in response to chemical defoliants. J. Experimental Botany 70 pp.1525-1538.

## Chapter III

## Evaluation of Foliar Applied Defoliants on Young Pecan Trees at E. V. Smith Research Center, Tallassee, AL.


### Abstract

Hurricanes make landfall in the Southeast United States on an annual basis, severely reducing the majority of worldwide pecan production. Chemical defoliation has been an agricultural practice for many years. Defoliating pecan trees may prevent injury caused by excessive wind speeds of hurricanes by reducing their $C_D$. Several chemicals were evaluated for defoliation on small pecan trees by foliar application via backpack sprayer and blowing via an air blast sprayer at E.V. Smith Research Center, Tallassee, AL. No treatment resulted in sufficient defoliation in 24 h to 48 h. However, treatments including CuEDTA and UAN provided sufficient defoliation in 96 h and treatments of thidiazuron and ethephon yielded proper defoliation in 72 h.


### Introduction

Hurricanes make landfall in the highest production region of pecans in the world, the southeastern United States, causing severe damage to much of the industry both in the current season, and for years to come (Capps and Williams, 2019; Nesbit and Wells, 2007; Strobl, 2011; Wood, et al., 2001). Although pecan orchards are highly susceptible to hurricane damage, research has shown that it may be possible to reduce $C_D$ enough via chemical defoliation prior to hurricane conditions to mitigate major damage to pecan orchards (Coder, 2008; Koizumi, et al., 2010; Mayer, 1987; Nesbit and Wells, 2007; Wood, et al., 2001). Due to unpredictability in forecasting the path of a hurricane, identification of defoliants able to achieve approximately 50% defoliation in 24 h would allow for effective determinations to be made on whether or not orchards should be defoliated (Alemany, et al., 2019; Cox, et al., 2013). The research presented here investigates defoliants currently available in various agricultural industries for their defoliation time efficacy.

Though there has been slow progress in understanding abscission, developments in the cotton industry led to the discovery and production of chemicals that aid harvest by desiccation, defoliation, and induction of senescence and have helped propel forward understanding the mechanisms behind this biological phenomenon (Cooper, et al., 1968; Crawford et al., 2001; Tranbarger et al., 2017). Several of these products include mixtures of PGRs, plant growth regulator inhibitors (PGRi), and herbicides that have been developed to further enhance these properties (Crawford et al., 2001; Cooper, et al., 1968). Recent advancements in genetics and biochemistry have added to the evidence that abscission is tightly regulated through an interplay between plant hormones such as ethylene and auxin (Abeles and Rubinstein, 1964; Addicott, 1982; Jensen and Valdovinos, 1967; Osborne, 1989; Tranbarger et al., 2017; Xu et al., 2019). Auxin was discovered through a series of experiments that established the phototropism of plants depends the PGR indole acetic acid (IAA), the most abundant plant auxin (Srivastava, 2002). According to the hormone balance flow for leaf abscission, depletion in the polar flow of auxin results in a decrease of transcript abundance for many genes regulating auxin activity increasing the AZ’s sensitivity to ethylene and paving the way for PGRi as defoliants (Addicott, 1982; Gao et al., 2016: Taylor and Whitelaw, 2001). Ethylene has been shown to induce three pathways of abscission through specific ethylene receptors that control a downstream signal cascade (Binder, 2008; Srivastava, 2002; Stepanova and Alonso, 2009; Tranbarger et al., 2017). Ethephon, ((2-

chloroethyl) phosphonic acid), when metabolized in plant releases ethylene, phosphate, and chloride, and is contained in many commercial defoliants (Arshad and Frankenberger, 2002; Crawford, et al., 2001; Tranbarger et al., 2017; Xu et al., 2019). Thidiazuron mimics the cytokinin phytohormone, which also induces defoliation through a number of synergistic mechanisms involving crosstalk with auxin and ethylene pathways (Xu, et al., 2019). Defoliation in fruit and nut trees has also begun to be explored in order to manipulate the timing of dormant season pruning in several *Prunus* species with chelated copper (CuEDTA) as well as zinc sulfate ($ZnSO_4$) proven to be effective defoliants (Bi et al., 2005; Gerdts, et al., 1977). Previous experiments have shown the efficacy of defoliants to depend heavily upon environmental conditions with the best results yielding sufficient defoliation in 120 h to 168 h when night temperatures remain above 63 degrees Fahrenheit (Bi et al., 2005; Cooper et al., 1968; Crawford et al., 2001). However, due to the nature of cultivation and production, no research defoliating pecan trees currently exists. Previous applications of defoliants do not require defoliation to occur in such a time sensitive manner and do not account for external forces as large as storm winds aiding in leaf drop (Bi et al., 2005; Crawford et al., 2001; Cooper et al., 1968; Gerdts et al., 1977; Tranbarger, et al., 2017; Xu, et al., 2019). Due to the complex and intricate process of abscission, much research to fully understand and elucidate the various mechanisms involved in abscission is still needed (Crawford et al., 2001; Rademacher, 2015; Tranbarger et al., 2017; Xu, et al., 2019). As these advancements are made, it is certain the application of defoliation can be refined further. The work presented here indicates the potential to mitigate damage produced by hurricanes in pecan trees via chemical defoliation. Defoliation would ultimately mean the loss of the current season's crop; however, it could mean preventing trees from major limb breakage and uprooting. If this potential is realized, not only will an immeasurable amount of economic loss be prevented, but the way of life of pecan growers will be preserved. The research presented here evaluates defoliants currently available in various agricultural industries for their defoliation time efficacy on pecan trees.

## Materials and Methods

*2019*

The first defoliation efficacy trial was designed as a completely randomized block of 5 defoliation treatments randomly assigned to 3 trees per treatment in September, 2019. Treatments included 1) 1% CuEDTA + 1% NIS, 2) 1% CuEDTA + 3% UAN + 0.5% NIS, 3) 0.5% diquat + 3% UAN + 0.5% NIS, 4) carfentrazone (Aim) (2 oz/A) + 3% UAN + 1.5% MSO, and 5) untreated, and were applied using a backpack sprayer to the point of run-off. All thidiazuron mixtures included 0.5% v/v crop oil concentrate. The trees were then blown with an empty air blast sprayer to simulate hurricane force winds at 24, 48, and 72 h intervals for 60 s. Trees were subsequently evaluated for percent defoliation after each blowing event.

The second defoliation efficacy trial was also designed as a completely randomized block of 5 defoliation treatments randomly assigned to 3 trees per treatment in September, 2019. Treatments included 1) 6.4 oz/A thidiazuron (Takedown SC), 2) 6.4oz/A thidiazuron + 21oz/A ethephon (Finish 6 Pro), 3) 3.2 oz/A thidiazuron + 32oz/A ethephon, 4) 6.4 oz/A thidiazuron + 32 oz/A ethephon. Each treatment followed the same application and evaluation procedure described above.

In October 2019, a third defoliation efficacy trial evaluated CuEDTA at varying concentrations and surfactant mixes in a completely randomized block design. Each treatment received 3 replications and followed the same application and evaluation procedure described above. The treatments included 1) 2% CuEDTA (Copper Tri-E) + 1% DUO Stick, 2) 3% CuEDTA + 2% DUO Stick, 3) 2% CuEDTA + 3% Nitro-Surf, 4) 3% CuEDTA + 3 % Nitro-Surf, and 5) 4% CuEDTA + 3% Nitro-Surf.

Trees were then maintained to monitor health, recovery, and bud break the following spring. Trees were evaluated for leaf-out in late spring and early summer of 2020.

*2020*

A completely randomized block design of 5 treatments was assigned to 3 young fruiting pecan trees per treatment. Treatments included 1) 25% 18-0-0-3, 2) 50% 18-0-0-3, 3) 75% 18-0-03, 4) 100% 18-0-0-3, and 5) untreated. Treatments were applied with an air blast sprayer on September 22, 2020 at a rate of 100 GPA. Observations were recorded the following day, September 23, 2020, at 8:00 am, 10:00 am, 12:00 pm, 2:00 pm and 4:00 pm and at 48 h post treatment application. Trees were then blown with the air blast sprayer to simulate hurricane force winds 72 h post treatment application on September 25, 2020. Defoliation ratings were recorded following the blowing of the trees. All data were analyzed with generalized linear models with the use of the GLIMMIX procedure of SAS 9.4. Tukey’s Studentized Range Test ($\alpha$=0.10) was utilized for means comparisons.

**Results**

*2019*

In the first efficacy trial at EVS (Table 3.1) in September 2019, no significant defoliation was observed immediately following treatment application. Treatments of 1% CuEDTA plus a nonionic surfactant (NIS) mixed with and without 3% urea ammonium nitrate (UAN) yielded significantly better defoliation percentages at 48 h than the other treatments; however, percent defoliation was not high enough to be considered effective in reducing $C_D$ at 21.66%. Treatments of CuEDTA + UAN and CuEDTA did result in sufficient defoliation to 88.33% and 68.33% respectively at 96 h with the defoliation of CuEDTA + UAN being significantly greater. Less than 50% defoliation was observed for the other treatments and were thus deemed insignificant and removed from further evaluation.

The second efficacy trial at EVS in September 2019, (Table 3.2) yielded increasing defoliation rates with increasing rate mixtures of thidiazuron and ethephon. No significant defoliation took place at 24 h and 48 h. At 72 h post treatment 6.4 oz thidiazuron + 32 oz ethephon, 3.2 oz thidiazuron + 32 oz ethephon, and 6.4 oz thidiazuron + 21 oz ethephon showed significant differences in percent defoliation. The highest rate mixtures of ethephon, 32 oz, were the only treatments to yield sufficient defoliation in 72 h, and the 32 oz tank mixes of ethephon produced increasing rates of defoliation with increasing rates of thidiazuron, 3.2 oz and 6.4 oz, at 50% and 66.67% defoliation respectively. All other treatments resulted in less than 50% defoliation at 72 h, were deemed ineffective, and were removed from further evaluation. However, all treatments including thidiazuron and ethephon were removed from further evaluation in lieu of safer and more affordable defoliants.

In October 2019, the third efficacy trial at EVS yielded no significant differences among treatments or sufficient defoliation in 72 h (data not shown).

*2020*

No significant reduction in leaf out was observed in trees used to evaluate defoliants in 2019 from data recorded on April 10, 2020, or May 5, 2020 (data not shown).

No immediate defoliation was observed following treatment application on September 22nd. However, leaves and nuts had browned, begun drying, and had a honeydew like substance on them. Browning increased with respect to increasing 18-0-0-3 concentration. As time progressed, browning, drying, and amount of honeydew like substance present also increased; however, no significant defoliation occurred (data not shown).

Figure 3.1: Photo of air blast sprayer simulating hurricane force winds at EVS Research Center.

Table 3.1. Defoliation ratings for the first September, 2019 efficacy trial at EVS Research Center in Tallassee, AL.

| Defoliation Efficacy Trial – Run 1 | | | | |
|---|---|---|---|---|
| Trt No. | Treatment | Defoliation (%) | | |
| | | 24 H | 48 H | 96 H |
| 1 | Nontreated | 2.00a | 8.33b | 10.00d |
| 2 | 1% CuEDTA + 1% NIS | 8.00a | 21.66a | 68.33b |
| 3 | 1% CuEDTA + 3% UAN + 0.5% NIS | 7.00a | 21.66ab | 88.33a |
| 4 | 0.5% Diquat + 3% UAN + 0.5% NIS | 6.00a | 11.66ab | 36.66c |
| 5 | Aim (2 oz/A) + 3% UAN + 1.5% MSO | 5.00a | 13.33ab | 46.66c |

[1]Means were compared using Tukey's Studentized Range Test at α=0.10

Table 3.2. Defoliation ratings for the second September, 2019 efficacy trial at EVS Research Center in Tallassee, AL.

| Defoliation Efficacy Trial - Run 2 | | | | |
|---|---|---|---|---|
| Trt No. | Treatment | Defoliation % | | |
| | | 24 H | 48 H | 72 H |
| 1 | Nontreated | 1.67a | 8.33a | 10.00c |
| 2 | Thidiazuron (6.4 oz) | 4.17a | 11.67a | 20.83c |
| 3 | Thidiazuron (6.4 oz) + Ethephon (21 oz) | 5.83a | 11.67a | 46.67b |
| 4 | Thidiazuron (3.2 oz) + Ethephon (32 oz) | 5.00a | 14.17a | 50.00ab |
| 5 | Thidiazuron (6.4 oz) + Ethephon (32 oz) | 5.00a | 17.50a | 66.67a |

[1]Means were compared using Tukey's Studentized Range Test at α=0.10

## Literature Cited

Abeles, F.B., and B. Rubinstein. 1964. Regulation of ethylene evolution and leaf abscission by auxin. Plant Physiol. 39: 963–969. doi: 10.1104/pp.39. 6.963.

Addicott, F.T. 1982. Abscission. Berkeley, CA: University of California Press.

Alemany, S., J. Beltran, A. Perez, and S. Ganzfried, 2019. Predicting hurricane trajectories using a recurrent neural network. In: Proceedings of the AAAI Conference on Artificial Intelligence Vol. 33, pp. 468-475.

Arshad, M., and W. T. Frankenberger. 2002. Ethylene Agricultural Sources and Applications. Kluwer Academic/ Plenum Publishers: New York, New York, 2002.

Bi, G., C.F. Scagel, L. Cheng, and L.H. Fuchigami, 2005. Effects of copper, zinc and urea on defoliation and nitrogen reserves in nursery plants of almond. The Journal of Horticultural Sci. and Biotechnology 80: pp.746-750.

Binder, B. M. 2008. The ethylene receptors: complex perception for a simple gas. Plant Sci. 175: 8–17. doi: 10.1016/j.plantsci.2007.12.001

Coder, K. D. 2008. Storm Wind Loads and Tree Damage. Warnell School, Univ. of Georgia WSF&NR08-24.

Cooper, W. C., G.K. Rasmussen, B.J. Roger, P.C. Reece, and W.H. Henry. 1968. Control of abscission in agricultural crops and its physiological basis. Plant Physiology 43: 1560–1576.

Cox, J., D. House, and M. Lindell. 2013. Visualizing uncertainty in predicted hurricane tracks. International J. for Uncertainty Quantification 3: 143–156. 2013.

Crawford, S.H., J.T. Cothren, D.E. Sohan, and J.R. Supak. 2001. "A history of cotton harvest AIDS," in Cotton Harvest Management: Use and Influence of Harvest Aids, J. R. Supak and C. E. Snipes, Eds.: pp. 1–19, The Cotton Foundation, Cordova Memphis, Tenn, USA, 2001.

Gao, Y., C. Liu, X. Li, H. Xu, Y. Liang, N. Ma, Z. Fei, J. Gao, C-Z. Jiang and C. Ma. 2016. Transcriptome profiling of petal abscission zone and functional analysis of an Aux/IAA family gene RhIAA16 involved in petal shedding in rose. Front. Plant Sci. 7:1375. doi: 10.3389/fpls.2016.01375.

Gerdts, M., G. Obenauf, J. LaRue, and G. Leavitt. 1977. Chemical defoliation of fruit trees. California Agriculture 31: pp. 19. 1977.

Jensen, T. E., and J. G. Valdovinos. 1967. Fine structure of abscission zones I. Abscission zones of the pedicels of tobacco and tomato flowers at anthesis. Planta 77: 298–318. doi: 10.1007/BF00389317

Kim, J., J. Yang, R. Yang, R. C. Sicher, C. Chang, and M. L. Tucker. 2016. Transcriptome analysis of soybean leaf abscission identifies transcriptional regulators of organ polarity and cell fate. Front. Plant Sci. 7:125. doi: 10.3389/fpls.2016.00125.

Koizumi, A., J.I. Motoyama, K. Sawata, Y. Sasaki, and T. Hirai. 2010. Evaluation of drag coefficients of poplar-tree crowns by a field test method. Wood Science 56(3), pp.189-193.

Miller, J. 2018. Storm Hits Alabama Pecan Crops. http://news.aces.edu/blog/2018/10/18/storm-hits-alabama-pecan-crops/ (accessed Nov 16, 2018).

Mayer, H. 1987. Wind-induced tree sways. Trees 1: pp.195-206.

Nesbit, M. and L. Wells. 2007. "Estimation of Pecan Tree Value," in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 978-0-9746963-5-5: pp. 135-136. Univ. of Georgia Coop. Ext. 2007.

Osborne, D. J. 1989. Abscission. Crit. Rev. Plant Sci. 8, 103–129. doi: 10.1080/07352688909382272.

Rademacher, W. 2015. Plant growth regulators: backgrounds and uses in plant production. Plant Growth Regulation. 34(4): pp.845-872.

Srivastava, L. M. 2002. Plant growth and development: hormones and environment. Academic Press: Amsterdam.

Stepanova, A. N., and J. M. Alonso. 2009. Ethylene signaling and response: where different regulatory modules meet. Curr. Opin. Plant Biol. 12, 548–555. doi: 10.1016/j.pbi.2009.07.009

Taylor, J. E., and C. A. Whitelaw. 2001. Signals in abscission. New Phytol. 151: 323–340. doi: 10.1046/j.0028-646x.2001.00194.x

Tranbarger, T. J., M. L. Tucker, J. A. Roberts, and S. Meir. eds. 2017. Plant Organ Abscission: From Models to Crops. Lausanne: Frontiers Media. doi: 10.3389/978-2-88945-328-3.

Wilkins, B. 2020. Personal Communication.

Wood, B. 2007. “Storm Damage: Prevention and Recovery,” in Southeastern Pecan Growers' Handbook, L. Wells, Ed. 2007. 978-0-9746963-5-5: pp. 129-134 Univ. Georgia Coop. Ext. 2007.

Wood, B. W., W. Goff, and M. Nesbitt. 2001. Pecans and hurricanes. HortScience 36: 253 258. doi:10.21273/hortsci.36.2.253

Xu, J., L. Chen, H. Sun, N. Wusiman, W. Sun, B. Li, Y. Gao, J. Kong, D. Zhang, X. Zhang, and H. Xu. 2019. Crosstalk between cytokinin and ethylene signaling pathways regulates leaf abscission in cotton in response to chemical defoliants. J. Experimental Botany 70: pp.1525-1538.

# Chapter IV

## Final Discussion

Results from these trials showed that defoliation reduced CD enough in container grown trees to significantly mitigate the damage caused from hurricanes; however, a defoliant that was effective within 24 h to 48 or less was not identified. A mixture of various defoliants could produce defoliation in a shorter time frame as is seen with the combination of thidiazuron and ethephon. Considering the variability of fall temperatures in the peak of hurricane season, determination of defoliants that are effective at lower temperatures or independent of temperature will likely be a major factor in identifying an effective pecan defoliant. A large amount of drift would be generated from applying a defoliant to pecan tree canopies during wind speeds increasing to hurricane conditions. Thus, a proper risk evaluation must be made of applying such a defoliant before this practice could be safely implemented. As accuracy in predicting hurricane paths increases, exploring the possibility of applying defoliants as soon as a hurricane is identified as a potential threat could be another approach. If a defoliant treatment could also hasten the ripening and shedding of the nuts it may be possible to obtain a harvest even when defoliating, which would more closely follow defoliation in the cotton industry and provide greater mitigation of loss due to hurricanes. This could also lead to a change in cultural practices leading to enhanced harvest efficiency.

Though these results showed that defoliation reduced $C_D$ enough in container grown trees to significantly mitigate hurricane damage, further research to confirm the success of this practice on mature trees is still needed. The deep complexity of the genetics and biochemistry responsible for the process of abscission may require new technology in order to achieve defoliation in the desired time frame. As the process of abscission is further understood and defoliation testing continues, it is likely that a defoliant treatment able to reach the threshold needed to protect pecans from hurricane damage will be developed.