Performance of pecan (*Carya illinoinensis*) cultivars grown in Alabama

by

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Abstract

Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama [E.V. Smith] and Gulf Coast Research and Extension Center in Foley, Alabama [Gulf Coast] in either a low or high input environment. High input orchards received irrigation and pesticide, herbicide, fungicide, and fertilizer treatments. Low input orchards received an initial fertilizer treatment based on soil test recommendations and no irrigation or chemical treatments. From 2010 to 2013, nuts from each graft were collected on an annual basis. Data collected for each cultivar included: nut grade, percent kernel, total yield, pounds of nuts per cultivar, leaf retention, and percentage of nut scab, shuck split and leaf scab. Additionally, in the fall of 2014, nuts from ‘Desirable’, ‘Elliott’, ‘Gafford’, ‘McMillan’, and ‘Syrup Mill’ cultivars were collected for total triglyceride and fatty acid profiles.

The cultivar ‘Desirable’ was set as the control due to its established high quality and long term presence within the industry.

In the high input orchard at E.V. Smith orchard, seven cultivars had more No. 1 pecans than ‘Desirable’. Additionally, ‘Desirable’ had more foliage scab, stem scab, and nut scab than all other cultivars. There was no difference in foliage retention rate among cultivars in the high input orchard. In the high input orchard at Gulf Coast, ‘Sioux’ had more No. 1 pecans than ‘Desirable’.

In the low input orchard at E.V. Smith, nine cultivars all had more No. 1 nuts than 'Desirable'. Every cultivar except 'Staten' had less leaf scab and less stem scab than 'Desirable'. Several cultivars exhibited greater foliage retention than 'Desirable'. In the low input orchard at Gulf Coast, 10 cultivars had a difference when compared with 'Desirable'. In both low input orchards, 'Desirable' did not perform as well as other cultivars. Several cultivars had more No. 1 nuts, higher percent kernel, and fewer rejects than 'Desirable'.

Regardless of input environment, 'Desirable' had the highest total lipid weight of all cultivars in the fatty acid analysis. 'Syrup Mill' had the lowest total lipid weight of all cultivars.

These findings suggest that although 'Desirable' performs well in a high input environment, it does not perform well in a low input environment and other cultivars are more suitable for a low input orchard.

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Isaiah 40:31

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List of Abbreviations

ALA	α-linolenic acid
ANOVA	Analysis of variance
avg	Average
C	Celsius
cm	Centimeter
DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
ft	Foot/Feet
Fig	Figure
g	Gram
GC-MS	Gas Chromatography-Mass Spectrometry
GLA	Gamma linolenic acid
HSD	Honest Significant Difference
kcal	Kilocalorie
km	Kilometer
LA	Linoleic acid
Lat	Latitude
lb	Pound/Pounds
Long	Longitude

mg	Milligram
mL(s)	Milliliter
mm	Millimeter
Mn	Manganese
N	North
N	Nitrogen
Ni	Nickel
No.	Number
ppm	Parts per million
W	West
wt	Weight
Zn	Zinc

Style Manual used: The Journal for the American Society of Horticultural Science

CHAPTER I

Introduction and Literature Review

Classification

Pecan, *Carya illinoinensis* (Wagenh.) K. Koch, is a deciduous, riparian species in the hickory family *(Juglandaceae*) belonging to the hickory family section *Apocarya*. Members of the *Apocarya* are diploid (n = 16) while members of the *Carya* (true hickories) include diploid and tetraploid species (n=32) (Thompson and Grauke, 1991). Pecans are native to the United States, northern Mexico, and found abundantly in the alluvial valleys of the Mississippi River and tributaries (Latitudes N16º to N26º) (Fig 1.1) (Grauke, 1990). Pecans can be divided into two groups: native and improved cultivars. Native trees are those indigenous to an area. Improved cultivars have been selected from native for superior phenotypic traits such as larger fruit, disease resistance, longevity of production, and fruit yields per specimen.

Climate

Pecan prefers a humid climate and requires supplemental water when grown in more arid environments. The minimum average annual rainfall in pecan's native range is 760 mm, and the maximum reaches 2,010 mm. Annual snowfall varies from 0 cm to 50 cm. Mean summer temperatures range as high as 27° C with extremes of 41° to 46° C. Average winter temperatures vary from 10° to -1° C with extremes of -18° to -29° C (Adams and Thielges, 1977; Putnam and Bull, 1932).

Given pecans longevity and wide range of production, exposure to severe weather events is virtually guaranteed. Thunderstorms, hail storms, and strong winds can cause damage on the local level. However, larger weather events can cause damage on a regional level. The most prevalent weather threat to pecan production in the Southeast is hurricanes. Historical records indicate orchards within 100 km of the coastline have a 60% to 100% chance of being exposed to a hurricane over a 10 year period (The University of Georgia Cooperative Extension, 2013). Because pecan orchards can exist for several hundred years, these orchards will be exposed to multiple hurricanes over their lifetime. In the northern part of pecans range, ice storms can cause widespread damage. Ice storms occur at least once every 10 years in areas north of the fall line with ice damage being as severe as tornado damage (The University of Georgia Cooperative Extension, 2013).

Soil

Pecan prefers several feet of well-drained loam soils which are not subject to extended flooding (Goff, 1996). However, pecan can survive in heavy textured soils with heavy soils being defined as those with a high clay content. In heavy soils, pecan is best adapted to ridges and/or well-drained flats. Pecan rarely grows on low and poorly drained clay flats (Adams and Thielges, 1977; Putnam, 1951). On upland sites, more inputs such as nitrogen (N), zinc (Zn), and water are typically needed to produce satisfactory yields. Regardless of soil type, pecans prefer several feet of permeable topsoil, good drainage, and available moisture (Goff, 1996).

Before establishing a pecan orchard, soil tests are typically performed to examine soil texture and nutrient content. Soil sampling procedures consist of taking a composite sample of 12 to 15 cores at a depth of 8 to 12 inches over the area being sampled (The University of Georgia Cooperative Extension, 2013).

History, Distribution, and Value

Pecans were a staple in the diet of Native Americans for hundreds of years (Hall, 2000). The first Europeans to be introduced to pecans were Spanish, calling the nut "pecan" which loosely translates from Algonquin to mean "hard shelled nut" (Hodge, 1912). William Bartram was the first to scientifically document pecan labeling it as *Juglans exalata* (Bartram, 1791).

Pecans were initially harvested from native trees. However, given the rise in demand, production in high quality nuts increased across the southern United States (W. Goff, unpublished data). Pecan production on a large scale started in the 1880's along the Mississippi river. Since then, U.S. pecan production has expanded to Georgia, Alabama, Mississippi, California, Arizona, New Mexico and Texas. Seventy five percent of global production of pecans occurs in the United States followed by Mexico, Australia, Israel and South Africa (Herrera, 2002; Johnson, 1998).

Pecan, *Carya illinoinensis* (Wangenh.) K. Koch, is one of the most economically relevant nut crops grown in the United States (Wood, 2000; NASS, 2014). U.S pecan production contributes not only to agricultural based economies but also to gross domestic product. The U.S. pecan industry is a competitive free market because the industry is not state or federally funded by subsidies that would influence the supply or value of the commodity (Wood, 2000). The 2013 industry report indicates a crop of approximately 236,330,000 lb with a value of $460,390,000 (NASS, 2014).

Most commercially grown pecans are now found in southern states outside of their native range (Alabama, Georgia, Louisiana, and Mississippi). Annually, Georgia produces the largest amount of pecans with a 2013 crop of 89,000,000 lb valued at $170,120,000. However, 2013 production was down compared with 2012 (100,000,000 lb at a value of $191,192,000) and 2011 (102,000,000 lb at a value of $264,600,000).

With the use of irrigation, expansion of crop land mass has come to include arid environments. New Mexico produced 72,000,000 lb in 2013 and 65,000,000 lb in 2012. Arizona produced 22,500,000 lb in 2013 and 20,000,000 lb in 2012. Australia, South America, South Africa, and the Middle East have also established regions of pecan production (Johnson, 1998).

The increased distribution of pecans leads to exposure to different environmental conditions thus providing increased risk of exposure to pathogens, as well as other effects of climate. The increased distribution also allows a crop to occur in some regions unaffected by environmental concerns where neighboring states have suffered loss in a particular year.

Pecan Breeding

Historically, the two primary pecan breeding programs in the United States have been the United States Department of Agriculture, Agricultural Research Services (USDA/ARS) research station in Brownwood, Texas and the University of Georgia, College of Agricultural and Environmental Sciences research station in Tifton, Georgia (The University of Georgia Cooperative Extension, 2013). Both stations follow the same guidelines of regulated pollination to control both the male and female interactions.

Pecans are monoecious with female flowers located at the tip of new growth and male flowers (catkins) at the base of the current season's growth (Fig 1.2). This flower arrangement typically allows gametes (male and female) to be isolated easily during pollination. In breeding programs, female flowers are enclosed in bags before they become receptive (Fig 1.3) (CAES

UGA, 2012). Once female flowers are receptive, a hypodermic needle is used to introduce pollen to the female flower. The offspring are examined for characteristics including quality, vigor, cold hardiness, yield, and scab resistance. Seedlings judged to better than parent material undergo evaluation in experimental plots across the growing region. If the seedling retains parental quality characteristics, it may be selected as a cultivar for further evaluation.

Improved cultivars are typically more profitable than native trees. Aesthetically pleasing attributes in pecan nuts of improved cultivars are superior size, shell color, and kernel color. Consumer demand for these desired traits has increased the price per pound average over native trees. The average price per pound of native nuts nationally in 2013 was $0.92 while the average price per pound of nuts for improved cultivars in 2013 was $1.90 (NASS, 2014). Due to the increased profit from cultivar trees, there is a trend toward growing improved cultivars. In 2013, total pounds of harvestable pecans were 266,333,000 of which 222,000,000 lb were from cultivars and 46,330,000 lb from native trees (NASS, 2014).

Nutritional Requirements of the Pecan Tree

Growers of native pecan orchards typically use little, if any, inputs due to low quality and profit from native pecan production. Native trees are often found on alluvial soils typically having higher natural fertility levels, resulting in fewer inputs being needed when compared with upland areas. Improved cultivar orchards however, are often planted in upland areas requiring several inputs to compensate for higher nutritional needs.

Three nutrients critical to high nut yields are: N, Zn, manganese (Mn), and nickel (Ni). N is a macronutrient often deficient in pecans. Trees deficient in N typically show increased tendencies to alternate bear and chlorotic leaves on old growth (Fig 1.4 and 1.5) (Acuna-

Maldonado, et al., 2003). Alternate bearing is a fluctuation of high/low crop yields from one season to the next. Pecans remove a considerable amount of N from the soil with 1,000 lb of nuts removing 20 lb of actual N from the soil (Goff, 1996). Typically, N is considered sufficient in leaf samples at 2.5 to 3.9% (Table 1.1). N is typically applied in the forms of urea and ammonium nitrate.

Zn is a micronutrient that is often deficient in pecans with deficiency symptoms evident from yellowing of new growth, undersized leaves, and clustered shoots (Fig 1.6). Shoot clustering is also known as ‘zinc rosette’ (Goff, 1996; Alben and Bogs, 1936). In southeastern states where soil pH is low, Zn can be applied via soil applications. In western states where soil pH is high, supplemental Zn is most often applied as a foliar application. Leaf sample sufficiency for Zn ranges from 50 to 1000 ppm (Table 1.1).

Mn deficiency decreases photosynthetic potential due to a decrease in chloroplast in mesophyll cells (Henriques, 2004). Manganese is used in photosystem II during photosynthesis and deficiencies disrupt the thylakoid membrane. Mn is also an enzyme cofactor (Salisbury and Ross, 1992). However, high concentrations of Mn can lead to deficiencies in Zn (Goff, 1996). Thus, Mn toxicity can appear to be Zn deficiency. Leaf sample sufficiency for Mn ranges from 100 to 2000 ppm (Table 1.1).

Ni deficiency leads to a disorder called mouse-ear (Barker and Pilbeam, 2007). Nickel is used by an enzyme to convert urea to ammonia. Mouse-ear symptoms include: blunt leaflet tips, smaller leaflets, poorly developed roots, rosetting, delayed bud break, and loss of apical dominance. Additionally, Ni can defend plant tissues from herbivores and pathogens (Davis et al, 2001; Reeves et al, 1981; Martens and Boyd, 2002).

Since most critical nutrients are delivered via mass flow, drought stress is a primary cause of low production in orchards. Pecans use around 51 inches of water annually with more being needed as orchards mature (Table 1.2) (Goff, 1996). Thus, sufficient water is critical to nut quality and yield. Supplemental watering via the use of irrigation systems is often used to offset naturally occurring deficiencies in water.

Common Diseases and Insects of Pecan

The most prevalent diseases of pecan trees are scab, anthracnose, vein spot, and leaf scorch, which collectively account for millions of dollars' worth of damage annually (Goff, 1996). Pecan scab is incited by the fungus *Fusicladium effusum* formerly classified as *Cladosporium caryigenum* (Seyran, et al., 2010). *Fusicladium effusum* is the most damaging fungal pathogen in the majority pecan growing regions. Pecan scab tends to be more prevalent during periods of heavy rain (Louisiana Cooperative Extension Service, 2005). A high percentage of scab can lead to increased probability of shuck infection earlier in the season, resulting in early fruit drop, poor fruit quality, or total crop loss (Gottwald and Bertrand, 1983) (Fig 1.7 and 1.8). Anthracnose is incited by the fungus *Glomerella cingulate*, and vein spot is incited by the fungus *Gnomonia nerviseda*. Both fungi are detrimental to pecan production, but can be controlled by fungicide application (Rand, 1914). Bacterial leaf scorch is caused by the bacterium *Xylella fastidiosa* and can lead to nutrient deficiencies, environmental issues, and susceptibility to other pathogens (Sanderlin and Heyderich-Alger, 2000). Insect pests such as pecan nut casebearer (*Acrobasis nuxvorella)*, pecan phylloxera (*Phylloxera sp*.), and weevil (*Curculio caryae)* cause serious damage to the fruit and foliage and can severely reduce crop yield (Goff, 1996).

Classification of *Fusicladium effusum*

Pecan scab was first found on mockernut hickory (*Carya tomentosa*) by Winter in 1885. From this specimen, Winter identified the pathogen causing pecan scab as *Fusicladium effusum* (Winter, 1885). The fungus was reclassified as a *Cladosporium* sp. based on the presence of chains of conidia (Demaree, 1928). The name *Cladosporium effusum* was already assigned to a fungus that infects other members of the genus *Carya* (Ellis and Everhart, 1888). Later, the pathogen causing pecan scab was verified to be *Fusicladium effusum* based on the conidiophore structure and the lack of similarity to *Cladosporium herbarum* (Lentz, 1957). Currently, the accepted taxonomic classification has reverted back to *F. effusum* Wint. This more recent classification is based on rDNA evidence comparing *Venturia* and *Cladosporium* (Schnabel, et al., 1999). Phylogenetics has given further evidence of the relationship between *Venturia* and *Cladosporium.* Phylogenetic trees clustered *F. effusum* with *Venturia* showing the two being 92% similar based on Cytochrome b gene sequences (Seyran, et al., 2010).

Evaluation of Pecan Cultivars

Testing pecan cultivars is a multi-year process. Generally, five to 10 years after a cross is made, can the resultant hybrid can be evaluated (Madden, 1968). Resistance of pecan cultivars to pathogens varies and generally declines over time (University of Georgia Cooperative Extension, 2013; Goff, 1996; W. Goff, unpublished data). Because of this pathogen resistance variability, pecan cultivars need to be evaluated at various locations throughout their cultivated range. The major criteria in southeastern pecan breeding programs are: large nut size, high percentage kernel, consistently high yields, elimination of alternate bearing, light-colored kernels high in oil, early harvest date for gift pack sales, and resistance to scab and other leaf diseases (Andersen, 2014; University of Georgia Cooperative Extension Service, 2012).

Auburn University Pecan Evaluation

Auburn University has conducted research for approximately 50 years on two pecan orchards: E.V. Smith Research Center in Shorter, Alabama and Gulf Coast Research and Extension Center in Foley, AL (Alabama Agricultural Experiment Station, 2011; Foshee, et al., 1995; Goff, et al., 1998; Latham, et al., 1972; Marcus and Amling, 1973). Since the late 1990's, long term research has focused on approximately 40 cultivars developed by the USDA and Auburn University. Additionally, short term studies have been performed on cultivar scion wood grafted onto mature trees. Research evaluations within these two orchards has been multifaceted ranging from scab resistance, scion wood survival, effects of floor crops, effects of soil compaction, as well as cultivar evaluations (Foshee, et al., 2008; Foshee, et al., 1995; Foshee, et al., 1996; Foshee, et al., 1997; Nesbitt, et al., 2002; Thompson, et al., 1997). Long term studies conducted at both locations have focused on low input and high input orchards. Low input is defined as adding fertilizer based on soil test recommendations with no supplemental watering or spraying. High input is defined as using fertilizer based on a soil test, supplemental water, and spraying for pest and pathogens, as needed. Since most Alabama pecan orchards are smaller than orchards in surrounding states, there is less economic incentive to spray intensively than in larger orchards (W. Goff, unpublished data). The largest pecan orchard in Alabama is approximately 700 acres, and no other orchard in Alabama is larger than 400 acres. Orchards of 200 acres in size or larger are rare in Alabama with many orchards being 80 acres or smaller in size (Goff, 2008). Therefore, low input orchard studies have become important to Alabama pecan growers.

However, some cultivars that do not do well in a low input environment might work well within an intensive spray program. Potential new cultivars are evaluated using a rating scale that encompasses seventeen categories ranging from pest resistance to fruit yield (Table 1.3).

Auburn University Scab Resistance Evaluations

Alabama's climate is conducive to pecan scab, with annual rainfall of 48 inches at E.V. Smith Research Center and 65 inches at Gulf Coast Research and Extension Center (Goff, 2008). Additionally, tropical storms have caused major scab infection periods in summer months (University of Georgia Cooperative Extension, 2013; Goff, 2008). Scab symptoms occur on leaves, twigs, and shucks on pecan (University of Georgia Cooperative Extension, 2013). Juvenile tissues are typically more susceptible with resistance becoming more prevalent on mature foliage. Lesions on leaves and shucks are typically small: 1 to 5 mm across. Scab resistance is grouped into four categories of scab resistance, based on observations in cultivar trials (W. Goff, unpublished data). The category ratings are: excellent, good, mediocre, and poor. Excellent resistance exhibits no scab or minor occurrence of scab in the total absence of sprays in wet seasons. Good resistance consists of observed damaging scab in the total absence of sprays in wet seasons or in wet years with a modest spray program of two to four sprays. Mediocre resistance includes serious losses observed in wet seasons in the absence of sprays, but the disease causes little risk with a normal eight to ten spray fungicide program. Poor resistance is defined as total crop loss almost every season under normal southeastern conditions if no sprays are applied, and considerable risk of loss in wet years even when a regimented spray program is followed (W. Goff, unpublished data).

Literature Cited

Acuna-Maldonado, L.E, M.W. Smith, N.O Maness, B.S. Cheary, B.L. Carroll, and G.V. Johnson. 2003. Influence of N application time on N absorbtion, partitioning, and yield of pecan. J. Amer Soc. Hort. Sci. 128:155-162.

Adams, J.C. and B.A. Thielges. 1977. Research underway on pecan timber improvement. Louisiana Agriculture 20(2):14-15.

Alabama Agricultural Experiment Station. 2011. Pecans. 15 October 2014. <http://www.aaes.auburn.edu/research/pecans.php>.

Alben, A.O. and H.M. Bogs. 1936. Zinc content of soils in relation to pecan rosette. Soil Science 41:329-332.

Andersen, P.C. 2014. Pecan cultivars for north Florida, Gainesville: IFAS Extension.

Barker, A.V. and D.J. Pilbeam. 2007. Handbook of plant nutrition. London: CDC Press.

Bartram, W. 1791. Travels through North and South Carolina, Georgia, East and West Florida, the Cherokee Country, the Extensive Territories of the Muscogulges or Creek Confederacy, and the Country of the Chactaws. Containing an account of the soil and natural productions of those regions; Together with observations on the manners of the Indians. Philadelphia: James and Johnson.

CAES UGA. 2012. georgiapecan.org. 15 September 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/papers/documents/PecanBreedingOverview-Part1.pdf>.

Davis, M. A., J. F. Murphy, and R. S. Boyd. 2001. Nickel increases susceptibility of a nickel hyperaccumulator to turnip mosaic virus. J. Environ. Qual. 30:85-90.

Demaree, J.B. 1928. Morphology and taxonomy of the pecan scab fungus *Cladosporium effusum*. J. Agric. Res. 37:181-187.

Ellis, J.B. and B.M. Everhart. 1888. New species of fungi from various localities. J. Mycol. 4:121-124.

Foshee, W.G., E.K. Blythe, W.D. Goff, W. H. Faircloth, and M.G. Patterson. 2008. Response of young pecan trees to trunk and foliar applications of glyphosate. HortScience 43:399-402.

Foshee, W.G., W.D. Goff, M. G. Patterson, and D.M. Ball. 1995. Orchard floor crops reduce growth of young pecan trees. HortScience 30:979-980.

Foshee, W.G., W.D. Goff, K.M. Tilt, and J.D. Williams. 1996. Organic mulches increase growth of young pecan trees. HortScience 31:811-812.

Foshee, W.G., R.L Raper, W.D. Goff, and M.G. Patterson. 1997. Orchard floor practices affect soil compaction around young pecan trees. HortScience 32:871-873.

Goff, W. 2008. Update on pecan cultivar tests in Alabama, Auburn: Alabama Cooperative Extension Service.

Goff, W. 1996. Pecan production in the Southeast. Second ed. Auburn: Auburn University.

Goff, W. 1984. Pecan production, Auburn: Alabama Cooperative Extension Service.

Goff, W., M. Nesbitt, R. Mullenax, and F. Rasberry. 1998. Pest resistant cultivars as a way to reduce input costs. Proc. Southeastern Pecan Growers Assn. 91:56-63.

Gottwald, T.R. and P.F. Bertrand. 1983. Influence of temperature, leaf wetness period, leaf age, and spore concentration on infection of pecan leaves by conidia of *Cladosporium caryigenum*. Phytopathology 75:190-194.

Grauke, L.J. 1990. The development of selection criteria for pecan seedstocks. First national pecan workshop proceedings. Washington, U.S. Dept. Agr., Agr. Res. Serv. ARS-96:125-136.

Hall, G.D. 2000. Pecan food potential in prehistoric North America. Economic Botany 54(1): 103-112.

Henriques, F. S. 2004. Reduction in chloroplast number accounts for the decrease in the photosynthetic capacity of Mn-deficient pecan leaves. Plant Science 166:1051-1055.

Herrera, E. 2002. Buyers and custom shellers in the Western pecan-growing region, Las Cruces: New Mexico State University, Cooperative Extension.

Hodge, F.E. 1912. Handbook of American Indians North of Mexico, Washington: Bureau of American Ethnology.

Johnson, D.C. 1998. Economic trends in the U.S. pecan market with an overview of the U.S. and world tree nut complex. Washington: United States Department of Agriculture.

Latham, A.J., U.L. Diener, and F.E. Garrett. 1972. Plant disease resistance in Alabama. 1st ed. Auburn University.

Lentz, P.L. 1957. Taxonomy of pecan scab fungus. Mycologia 49:874-878.

Louisiana Cooperative Extension Service. 2005. Pecan scab disease. Baton Rouge: Louisiana Cooperative Extension Service.

Madden, G.D. 1968. Potential varieties for the Southeast through the United States Department of Agriculture pecan breeding program. Southeastern Pecan Growers Asso. 61:27-52.

Marcus, K.A. and H.J. Amling. 1973. *Escherichia coli* field contamination of pecan nuts. Appl. Envion. Micro. 26: 279-281.

Martens, S. and R.S. Boyd. 2001. The defensive role of Ni hyper accumulation by plants: a field experiment. Ameri. J. Botany. 89:998.

NASS. 2014. Noncitrus Fruits and Nuts. Washington: United States Department of Agriculture.

Nesbitt, M.L., W.D. Goff, L.A. Stein. 2002. Effect of scoinwood packing moisture and cut-end sealing on pecan graft success. HortTechnology 12:257-260.

O'Barr, R.D. and J.M. McBride. 1980. Pecan leaf sampling for commercial growers. Pecan South 7(3):42-44.

Plank, C.O. 1989. Plant analysis handbook for Georgia. Athens: University of Georgia Cooperative Extension Service.

Putnam, J.A. 1951. Management of bottomland hardwoods. USDA Forest Service, Occasional Paper 116:60.

Putnam, J.A. and H. Bull, 1932. The trees of the bottomlands of the Mississippi River Delta Region. USDA Forest Service p. 207.

Rand, P. 1914. Some diseases of pecan. J. Ameri. Agricul. Res. 1:303-338.

Reeves, R.D., R.R. Brooks, R.M. Macfarlane. 1981. Nickel uptake by Californian Streptanthus and Caulanthus with particular reference to the hyperaccumulator *S. polygaloides* Gray (*Brassicaceae*). American J. Bot. 68:708-712.

Salisbury, F.B. and C.W. Ross. 1992. Plant Physiology 4th ed . Belmont: Wadsworth.

Sanderlin, R.S. and Heyderich-Alger. 2000. Evidence that *Xylella fastidiosa* can cause leaf scorch disease of pecan. Plant Disease 84:1282-1286.

Schnabel, G.E., L. Schnabel, and A.L. Jones. 1999. Characterization of ribozomal DNA from *Venturia inaequalis* and its phylogenetic relationship to rDNA from other fruit *Ventruia* species. Phytopathology 89:100-108.

Seyran, M.C, K.J. Nischwitz, K.J. Lewis, R.D. Gitaitis, T.B. Brennaman, K.L. Stevenson. 2010. Phylogeny of the pecan scab fungus *Fusicladium effusum* G. Winter based on the cytochrome b gene sequence. Mycological Process 9:305-308.

The University of Georgia Cooperative Extension Service. 2012. Pecan Varieties for Georgia Orchards. 15 October 2014. <http://extension.uga.edu/publications/detail.cfm?number=C898>.

The University of Georgia Cooperative Extension. 2013. Southeastern Pecan Growers Handbook. Athens: University of Georgia.

Thompson, T.E. and L.J. Grauke. 1991. Pecans and other hickories. Acta Hort. 290:839-904.

Thompson, T.E., W.D. Goff, M.L. Nesbitt, R.E. Worley, R.D. O’Barr, and B.W. Wood. 1997. 'Creek' Pecan. HortScience 32:141-143.

University of Georgia CAES. 2014. Pecan Scab. 17 October 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/cultivars/pecan_scab.html>.

Winter, G. 1885. New north American fungi. J. Mycol. 1:101-102.

Wood, B.W. 2000. Price: Production relationship and production characteristics of U.S. pecan industry. Southeastern Pecan Growers Assoc. 117-132.

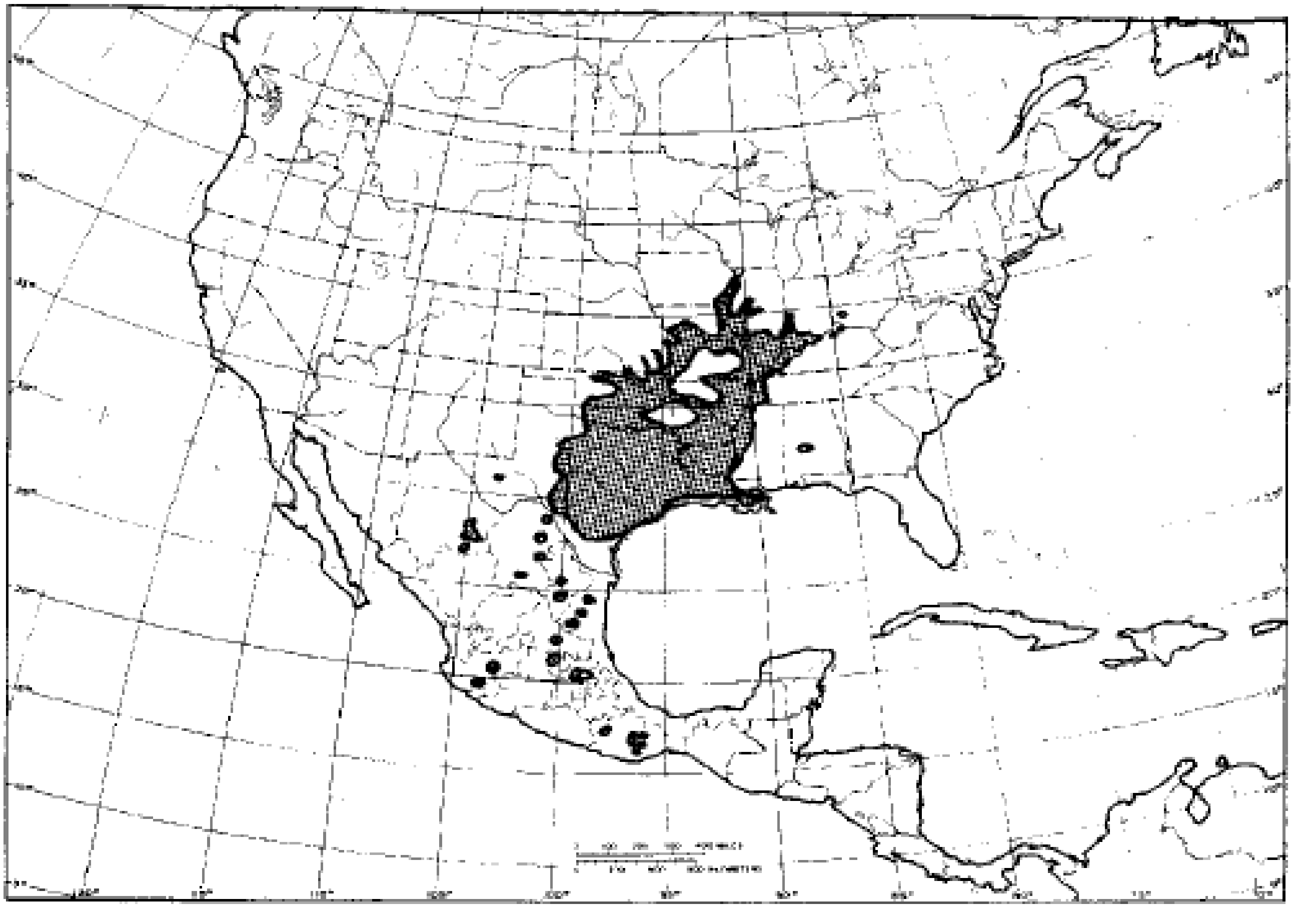

Figure 1.1. Native Distribution of Pecans (Thompson and Grauke, 1991. Pecans and other Hickories. *Acta Hort.*, Volume 290:839-904.)

Figure 1.2. Catkins on pecan (CAES UGA, 2012. georgiapecan.org. 15 September 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/papers/documents/PecanBreedingOverview-Part1.pdf>.)

Figure 1.3. Female flower in bag after pollination (CAES UGA, 2012. georgiapecan.org. 15 September 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/papers/documents/PecanBreedingOverview-Part1.pdf>.)

Figure 1.4. Nitrogen deficient leaves compared with N sufficient leaves. (Alabama Cooperative Extension System, 1996. Pecan Production in the Southeast. Second ed. W. Goff. Auburn: Auburn University.)

Figure 1.5. Nitrogen deficient pecan tree. (Alabama Cooperative Extension System, 1996. Pecan Production in the Southeast. Second ed. W. Goff. Auburn: Auburn University.)

Figure 1.6. Zinc (Zn) deficiency in pecans. (Alabama Cooperative Extension System, 1996. Pecan Production in the Southeast. Second ed. W. Goff. Auburn: Auburn University.)

Figure 1.7. Pecan nuts showing symptoms of pecan scab. (University of Georgia CAES, 2014. Pecan Scab. 17 October 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/cultivars/pecan_scab.html>.)

Figure 1.8. Pecan leaf showing symptoms of pecan scab. (University of Georgia CAES, 2014. *Pecan Scab*. 17 October 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/cultivars/pecan_scab.html>.)

Table 1.1. Leaf sample sufficiency ranges for essential nutrients for pecan.[z]

	Sufficiency Range by State		
Macronutrients	Alabama	Georgia	Louisiana
(N) Nitrogen	2.70% - 2.90%	2.50% - 3.90%	2.50% - 3.00%
(P) Phosphorus	0.12% - 0.30%	0.12% - 0.30%	0.00% - 0.20%
(K) Potassium	0.75% - 0.95%	0.75% - 2.5%	1.00% - 2.00%
(Mg) Magnesium	0.40% - 0.60%	0.30% - 0.60%	0.30% - 0.60%
(Ca) Calcium*	0.70% - 1.50%	0.70% - 1.75%	0.70% - 2.00%
(S) Sulfur*		0.20% - 0.50%	0.18% - 0.25%
Micronutrients	Alabama	Georgia	Louisiana
(Zn) Zinc	500-1000 ppm	50-100 ppm	50-150 ppm
(Fe) Iron	50-330 ppm	50-300 ppm	50-300 ppm
(Mn) Manganese*	100-800 ppm	100-800 ppm	100-2000 ppm
(B) Boron*	20-45 ppm	15-50 ppm	20-45 ppm
(Cu) Copper*	10-30 ppm	6-30 ppm	6-20 ppm
(Mb) Molybdenum*			
(Cl) Chlorine*			

[z]Goff W, 1984. Pecan Production. Plank, C.O. 1979, Plant Analysis Handbook of Georgia. O'Barr O.D., and J.M. McBride, 1980, Pecan Leaf Sampling for Commercial Growers.
*Not commonly deficient.

Table 1.2. Water requirements for pecan of different ages.[z]

Diameter of tree canopy and approximate age of tree	Gallons needed per tree per day	Avg gallons of water applied per tree per day during month of:						
		April	May	June	July	August	September	October
< 5 ft (1-3 years)	1-2	1	1	1-2	1-2	1-2	1	1
5 ft (3 years)	2	1	1	1-2	1-2	1-2	1	1
10 ft (4-7 years)	6	3	4	4	4	3	3	2
15 ft (6-8 years)	14	7	8	10	9	8	7	5
20 ft (8-10 years)	25	13	15	17	15	12	12	10
25 ft (10-12 years)	39	20	23	27	24	23	19	15
30 ft (12-13 years)	56	29	33	39	34	32	27	22
35 ft (15 years)	76	39	45	52	46	44	37	30
40 ft (25 years)	99	51	59	68	60	57	48	39
50 ft (40 years)	155	80	92	107	94	90	75	61
60 ft (50 years)	223	115	132	153	136	129	108	87
70 ft (60 years)	303	156	180	208	185	175	147	118
80 ft (70 years)	396	204	235	272	241	229	192	155

[z]Alabama Cooperative Extension System, 1996. *Pecan Production in the Southeast.* Second ed. Goff. Auburn: Auburn University.

Table 1.3. Sample of grading matrix for pecan cultivars.

Category	Rating/Unit
Nut scab rating (Percent of nut shuck covered)	0-100%
Leaf scab rating (Percent of leaf covered)	0-100%
Black aphids (Count of lesions on worst leaf)	0-10+
Yellow aphids (Count of aphids of worst leaf)	0-10+
Sooty mold rating (1-5, 1 as lightest)	1-5
Percent foliage on tree	0-100%
Crop load (1-10, 10 heaviest)	1-10
Percent terminals w/ fruit 2012	0-100%
Average number of nuts/clusters 2012	0-10+
Average number of nuts/clusters 2013	0-10+
Nuts per pound	lb
Shell thickness	mm
Percent shucksplit	0-100%
Estimated harvest date	September-December

CHAPTER II

Pecan Cultivar Nut Quality

Abstract

Nut quality standards contribute to economic value when establishing a price for pecans. Pecan quality is reflected in price paid to growers. Therefore a process to identify high nut quality is needed to quantify the quality. From 2010 to 2013, 40 nuts from grafted cultivars were collected on an annual basis from either a high or low input environment. Data collected for each cultivar included nut grade (No.1, No. 2, No. 3, reject), percent kernel, and total yield in pounds. 'Desirable' was set as the standard cultivar because of its widespread use in the Southeast United States. Observations suggest several cultivars performed better than 'Desirable' in both high and low input environments.

Introduction

U.S. pecan production contributes considerably not only to agricultural based economies but also to gross domestic product. The U.S. pecan industry is a competitive free market because the industry is not state or federally funded by subsidies that would influence the supply or value of the commodity (Wood, 2000). The 2013 industry report indicates a crop of approximately 236,330,000 lb with a value of $460,390,000 (NASS, 2014). Nut quality standards contribute to economic value when establishing a price for pecans (Florkowski et al., 1992). These standards establish a consistent grade where buyers and sellers can complete a transaction without physically inspecting an entire crop. These well-defined standards for grades contribute to the market being more efficient. A need to deliver a consistent quality of pecans through improved grading and cultivar evaluation has been established (Jones et al., 1932). Pecan quality is reflected in price paid to growers. The pecan industry indicated shell-out ratio, count, and kernel color were major criteria in evaluating quality (Hubbard et al., 1990). The shell-out ratios vary between 42 to 63% (Goff, 1989). Market value tends to increase with the increase in the shell-out ratio.

Testing pecan cultivars is a multi-year process. Generally, as much as five to 10 years pass after a cross is made, before resultant hybrids can be evaluated (Madden, 1968). The major criteria in determining nut quality in breeding programs include but are not limited to: large nut size, high percentage kernel, consistently high yields, light-colored kernels high in oil, early harvest date for gift pack sales, and resistance to scab and other leaf diseases (Andersen, 2014; University of Georgia Cooperative Extension Service, 2012).

Most Auburn University pecan research has been conducted at two pecan orchards, E.V. Smith Research Center in Shorter, Alabama and Gulf Coast Research and Extension Center in Foley, AL, for approximately 50 years (Alabama Agricultural Experiment Station, 2011; Foshee et al., 1995; Goff et al., 1998; Latham et al., 1972; Marcus and Amling, 1973). Since the late 1990's, long term research has focused on approximately 40 cultivars developed by the USDA and Auburn University for which yield data have been collected. Studies conducted at both locations have focused on low input and high input orchards. Low input is defined as adding fertilizer based on soil test recommendations with no supplemental watering or spraying. High input is defined as using fertilizer based on a soil test, supplemental water, and spraying for pest and pathogens as needed.

Materials and Methods

Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama (Lat N32^{o}26’, Long W85^{o}54’) and Gulf Coast Research and Extension Center in Foley, Alabama (Lat N30^{o}32’, Long W87^{o}53’) in either a low input or high input environment. High input orchards received irrigation, pesticide treatment, herbicide treatment, fungicide treatment and fertilizer when needed. Low input orchards received an initial fertilizer treatment based on soil test recommendations and no irrigation or chemical treatments. Trees in the high input orchards at both locations were spaced at 40 feet between rows and 30 feet within rows. Trees in the low input orchards at both locations were spaced at 30 feet between rows and 40 feet within rows. Cultivars were grafted in a random design within each plot (Fig 2.1). Soil type in the high and low input orchard at E.V. Smith Research Center consisted of loams and sandy loams primarily of the Kalmia loamy sand, Kalmia sandy loam and Cahaba sandy loam series (USDA/NRS, 2016). From 2010 to 2013, 40 nuts from each graft were collected on an annual basis. A study period of four years was chosen to minimize the effects from pecans’ tendency to alternate bear. Data collected for each cultivar included: nut grade (No.1, No. 2, No. 3, reject) as a percentage of the crop weight, percent kernel, and total yield in pounds. Nut grade was accessed using the USDA-ARS pecan kernel rating system (Fig 2.2) (Thompson et al., 1996; United States Department of Agriculture, 1969). Data were analyzed using ANOVA and Tukey HSD test in SAS JMP (SAS Institute Inc., Cary, NC).

Results and Discussion

In the high input E.V. Smith Research Center orchard, No.1 yields ranged from ‘Leander’ 11.97% to ‘Excel’ 53.23% of the total yield (Table 2.1). ‘Giftpack’, ‘Elliott’, ‘Bond 11’, ‘Zinner’, ‘Gafford’, ‘Kanza’, and ‘Cherryle’ all had more No. 1 pecans than ‘Desirable’ (Table 2.1). No. 2 nuts ranged from ‘Excel’ 0.0% to ‘Shotts’ 31.08% of the total yield (Table 2.1). There were no cultivars with more No. 2 nuts than ‘Desirable’. However, ‘Elliott’ had fewer No. 2 nuts than ‘Desirable’ (Table 2.1). No. 3 nuts ranged from ‘Excel’, ‘Oconee’, and ‘Question’ < 1% to ‘Barton’ 16.04% of the total yield (Table 2.1). ‘Barton’ and ‘Shotts’ had more No. 3 nuts when compared with ‘Desirable’ (Table 2.1). Rejects ranged from ‘Leander’ 12.57% to ‘Elliott’ 0.0% of total yield (Table 2.1). ‘Giftpack’, ‘McMillan’, ‘Gafford’, and ‘Elliott’ all had fewer rejects than ‘Desirable’ (Table 2.1). Percent kernel ranged from ‘Leander’ 34.20% to ‘Shotts’ 57.99% (Table 2.1). Four year total yield in pounds ranged from ‘Shotts’ 136 lb to ‘Jenkins’ 296 lb.

In the low input E.V. Smith Research Center orchard, No. 1 yields ranged from ‘Desirable’ 5.01% to ‘Adams 5’ 57.31% of the total yield (Table 2.2). ‘Adams 5’, ‘Carter’, ‘Elliott’, ‘Farley’, ‘Gafford’, ‘Jenkins’, ‘Kanza’, ‘McMillan’, and ‘Miss L’, all had more No. 1 nuts when compared with ‘Desirable’ (Table 2.2). No. 2 nuts ranged from ‘Mount’ 45.01% to ‘Carter’ 0.37% of the total yield (Table 2.2). ‘Mount’ was the only cultivar with more No. 2 nuts than ‘Desirable’ (Table 2.2). No. 3 nuts ranged from ‘Register’ 9.91% to ‘Adams 5’, ‘Elliott’, ‘Kanza’, ‘Miss L’, and ‘Mount’ < 1% of the total yield (Table 2.2). No cultivar had more No. 3 nuts when compared with ‘Desirable’ (Table 2.2). ‘Carter’, ‘McMillan’, ‘Elliott’, and ‘Miss L’ all had fewer No. 3 pecans when compared with ‘Desirable’. Reject grade ranged from ‘Syrup Mill’ 10.91% to ‘Elliott’ 0.44% of the total yield (Table 2.2). ‘Curtis’, ‘Kanza’, and ‘Syrup Mill’ were the only cultivars to have more rejects when compared with ‘Desirable’ (Table 2.2). Percent kernel ranged from ‘Adams 5’ 57.31% to ‘Desirable’ 32.08% (Table 2.2). Only ’Creek’, ‘Kanza’, ‘Stuart’, and ‘Syrup Mill’ had lower percent kernel when compared with ‘Desirable’ (Table 2.2).

In the high input settings at E.V. Smith Research Center, ‘Giftpack’ and ‘Elliott’ had more No. 1 nuts and higher percent kernel of whole nut when compared to ‘Desirable’. This observation suggests these cultivars are well suited for high-end markets and can possibly demand a higher price per pound than ‘Desirable’. Also, ‘Giftpack’ has an early harvest date of mid-October which is a desired characteristic in pecan production (W. Goff, unpublished data). ‘Gafford’ and ‘Elliott’ were different with more No. 1 nuts and fewer reject nuts when compared with ‘Desirable’ (Table 2.1). ‘Elliott’ and ‘Gafford’ also had fewer No. 3 nuts. However, ‘Elliott’ is prone to alternate bearing cycles, thus, having low yield years and excessive yield years (W. Goff, unpublished data). It should also be noted ‘Elliott’ is not as precocious as other cultivars (Goff, 1985) thus taking more years for a grower to reach a profit. Additionally, ‘Elliot’ produces small nuts, is susceptible to yellow aphid, and has an early budbreak making it prone to frost/freeze damage (Sparks, 1992). ‘Gafford’ tends to have more kernel weight, later nut production, and a smaller nut size when compared with ‘Giftpack’ (W. Goff, unpublished data).

In the low input setting at E.V. Smith Research Center, ‘Desirable’ did not perform as well as several other cultivars. ‘Adams 5’, ‘Miss L’, ‘Elliott’, ‘Gafford’, ‘Carter’, ‘Jenkins’, ‘Farley’, and ‘McMillan’ all had more No. 1 and percent kernel while having fewer rejects (Table 2.2). Out of the group with more No. 1 and fewer rejects, ‘Gafford’, ‘Elliott’, ‘Carter’, ‘McMillan’, and ‘Miss L’ also had fewer No. 3 nuts which suggest a better quality crop (Table

2.2). It should be noted, ‘Carter’ and ‘Miss L’ are not recommended for commercial use due to small nut size (W. Goff, unpublished data). Although ‘McMillan’ out performed ‘Desirable’ in several categories, the nuts from ‘McMillan’ do not bring a high value to market due to a very dark coloring (W. Goff, unpublished data).

In the high input orchard at the Gulf Coast Research and Extension Center, No. 1 yields ranged from ‘Creek’ 15.00% to ‘Sioux’ 41.12% of the total yield (Table 2.3). ‘Sioux’ had more No. 1 pecans when compared with ‘Desirable’. No. 2 ranged from ‘Caddo’ 9.35% to ‘Creek’ 26.32% of the total yield (Table 2.3). No. 3 yield ranged from ‘Caddo’ 0.47% to ‘Giftpack’ 3.62% of the total yield (Table 2.3). Reject grade yield ranged from ‘Headquarters’ 1.94% to ‘Desirable’ 10.38% of the total yield (Table 2.3). There was no difference among all cultivars in relation to No. 2, No. 3, and reject pecans.

In the low input setting at the Gulf Coast Research and Extension Center, No. 1 yield ranged from ‘Carr’ 20.00% to ‘Sumner’ 43.04% of the total yield. ‘Sumner’, ‘Kanza’, ‘Prilop’, ‘Elliott’, ‘Adams5’, ‘BabyB’, ‘Gafford’, ‘Headquarters’, ‘Syrup Mill’, and ‘Carter’ all had a difference when compared with ‘Desirable’ (Table 2.4). No. 2 yields ranged from ‘Kanza’ 4.2% to ‘Sumner’ 20.73% of the total yield. ‘Farley’ and ‘Curtis’ had more No. 2 pecans when compared with ‘Desirable’ (Table 2.4). No. 3 yields ranged from ‘Adams5’ 0.08% to ‘BabyB’ 9.23% of the total yield (Table 2.4). ‘Baby B’ and ‘Jenkins’ both had more No. 3 pecans than ‘Desirable’. Reject yields ranged from ‘Carr’ 2.31% to ‘Desirable’ 13.06% of the total yield. All cultivars except ‘Jenkins’, ‘Kanza’, and ‘Sumner’ had more rejects when compared with ‘Desirable’ (Table 2.4). As with the high input orchard at E.V. Smith Research Center, ‘Giftpack’ had the highest percent kernel in the high input orchard at the Gulf Coast Research and Extension Center (Table 2.4). In both low input orchards, ‘Desirable’ did not perform as well as other cultivars. There were several cultivars with more No. 1 nuts, higher percent kernel, and fewer rejects than ‘Desirable’. This observation suggests that although ‘Desirable’ performs well in a high input environment, it does not perform well in a low input environment and may not be suitable for growers who operate a low input orchard. Additionally, the benefit of having a high input environment compared to a low input environment can be seen when comparing both yield and quality.

Literature Cited

Alabama Agricultural Experiment Station. 2011. Pecans. 15 October 2014. <http://www.aaes.auburn.edu/research/pecans.php>.

Andersen, P.C. 2014. Pecan Cultivars for North Florida, Gainesville: IFAS Extension.

Florkowski, W.J., J.C. Purcell, and E.E. Hubbard. 1992. Importance for the U.S. pecan industry of communicating about quality. HortScience 27:462-464.

Foshee, W.G., W.D. Goff, M. G. Patterson, and D.M. Ball. 1995. Orchard floor crops reduce growth of young pecan trees. HortScience 30:979-980.

Goff, W. 1985. Performance of pecan varieties commonly found in older orchards in the southeast: a survey of grower experiences. Proc. Southeastern Pecan Growers Assoc., 78:137-145.

Goff, W.D. 1989. Pecan Production. Auburn: Alabama Cooperative Extension Service.

Goff, W., M. Nesbitt, R. Mullenax. and F. Rasberry. 1998. Pest resistant cultivars as a way to reduce input costs. Proc. Southeastern Pecan Growers Assoc.. 91:56-63.

Hubbard, E.E., W.J. Florkowski, and J.C. Purcell. 1990. Pecan value and quality perception. Helen: National Pecan Workshop.

Jones, S. A., V.C Childs, R.S. Washburn, B.H. Thibodeaux, W.J. Park, and H.E. Rutland, 1932. An economic study of the pecan industry. Washington: United States Department of Agriculture.

Latham, A.J., U.L. Diener, and F.E. Garrett. 1972. Plant disease resistance in Alabama. 1 ed. Auburn University.

Madden, G.D. 1968. Potential varieties for the southeast through the United States Department of Agriculture pecan breeding program. Proc. Southeastern Pecan Growers Assoc. 61: 27-52.

Marcus, K.A. and H.J. Amling. 1973. *Escherichia coli* field contamination of pecan nuts. Appl. Environ. Micro. 26: 279-281.

NASS. 2014. Noncitrus fruits and nuts. Washington: United States Department of Agriculture. 6 June 2016. <http://usda.mannlib.cornell.edu/usda/current/NoncFruiNu/NoncFruiNu-07-17-2015.pdf>.

Sparks, D. 1992. Pecan cultivars, The orchard's foundation. 1st ed. Pecan Production Innovations, Watkinsville, GA.

The University of Georgia Cooperative Extension. The pecan growers handbook. 2013. University of Georgia. Athens.

Thompson, T. E., L.J. Grauke, and E.F. Young. 1996. Pecan kernel color: Standards using the Munsell. J. Amer. Hort. Sci. 121:548-553.

The University of Georgia Cooperative Extension Service. 2012. Pecan varieties for Georgia orchards. 15 October 2014. http://extension.uga.edu/publications/detail.cfm?number=C898>.

United States Department of Agriculture/ Natural Resource and Conservation. 2016. Soil Series Mapping Tool. 15 August 2016. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>.

United States Department of Agriculture. 1969. United States standards for grades of shelled pecans. Washington: Agricultural Marketing Service.

Wood, B.W. 2000. Price: Production relationship and production characteristics of U.S. pecan industry. Proc. Southeastern Pecan Growers Assoc. 93: 117-132.

COLUMN	A	B	C	D	E	F	G	H	I	J	K	L
18	2	17	67*	34	39	29*	68*	NG	18	NG	66*	45
17	31	62*	60*	8	15	14	32*	62*	59*	37	3	NG
16	38	47	65*	NG	11	69*	63*	NG	6	1	4	32
15	20	69*	44	1	8	34	S	1	1	11	14	46*
14	NG	2	11	53	5	NG	NG	64*	58*	35	2	20
13	19	1	42	NG	43*	11	5	3	8	59*	1	45
12	66*	15	39	58*	S	1	3	15	3	2	11	54
11	64*	6	68*	47	54	63*	8	NG	42	68*	15	29*
10	1	14	1	3	2	NG	59*	8	32*	15	67*	61*
9	24	44	6	64*	14	15	11	5	58*	55	60*	31
8	19	11	2	NG	6	8	69*	57*	NG	5	5	18
7	67*	5	8	14	3	4	1	14	53	61*	65*	24
6	NG	29*	14	35	43*	S	37	35	NG	57*	43*	57*
5	NG	3	S	35	1	2	NG	NG	61*	29*	66*	29
4	17	8	43*	NG	S	5	2	11	15	6	6	1
3	2	32*	46	15	34	S	15	6	2	NG	8	45
2	63*	4	5	2	46	6	54	2	5	NG	2	34
1	37	39	2	18	42	29	31	20	65*	1	55	27
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
	ROW											

Cultivar Key			
1	Desirable	**25**	Oswego
2	Elliott	**26**	Lakota
3	Jenkins	**27**	Tobbaco
4	McMillan	**28**	Byrd
5	Syrup Mill	**29**	MandenU
6	Gafford	**30**	Pippin 09-1
7	Mount	**31**	Pippin 09-2
8	Prilop	**32**	Pippin 09-3
9	Seminole	**33**	Pippin 09-4
10	GRE29_1	**34**	U91-22-12
11	Baby B	**35**	U93-5-5
12	Headquarters	**36**	Pippin 09-7
13	Carter	**37**	U97-20-17
14	Sumner	**38**	Ellis
15	Curtis	**39**	Hickory's Major
16	Melrose	**40**	U1993-6-83
17	Farley	**41**	U1993-6-3
18	8217_680	**42**	U1993-2-272
19	Pippin99_5	**43**	U1992-32-46
20	Adams5	**44**	U1986-3-615
21	Kanza	**45**	U1993-2-304
22	Amling	**46**	U1993-6-68
23	Excalibur	**47**	U1997-9-12
24	Excel	**48**	U1992-1-640
NG	Not Grafted		
S	Seedling Planted Spring 2013		
*****	Grafted Spring 2013		

Figure 2.1 Example layout for pecan cultivar trials at Gulf Coast Research and Extension Center, 2013.

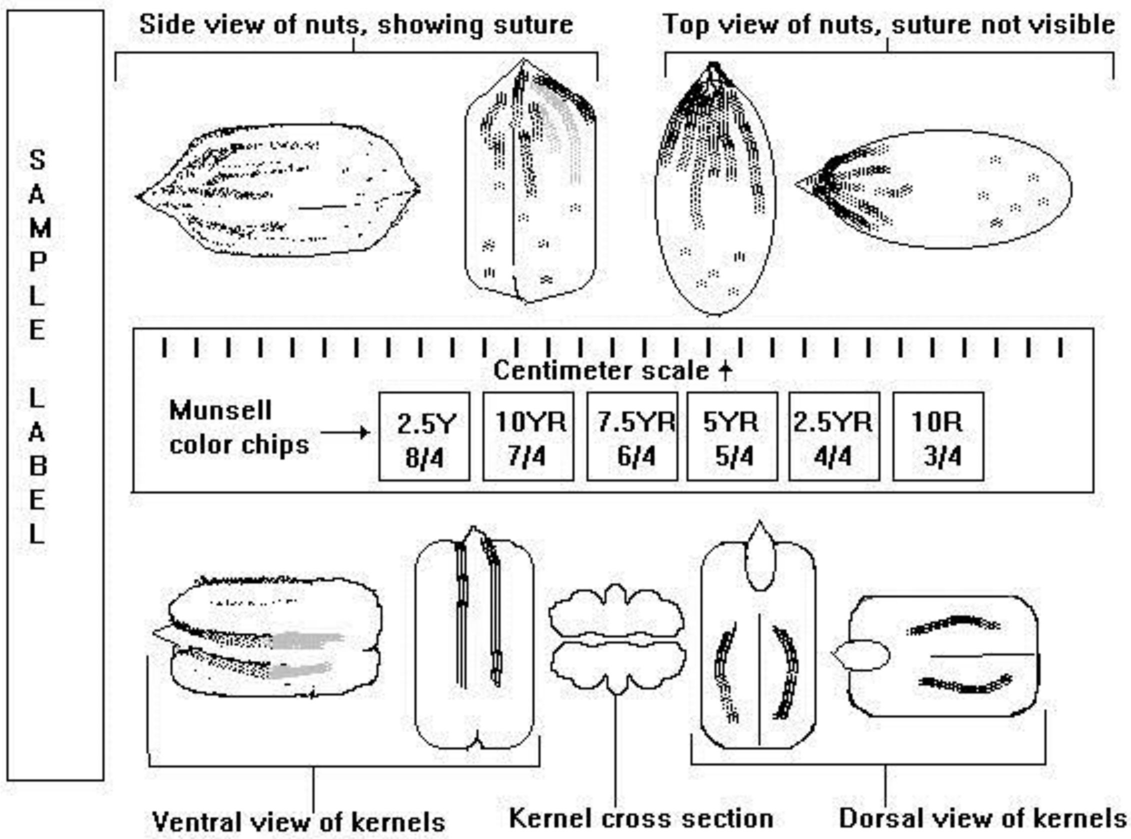

Figure 2.2. USDA-ARS pecan kernel color rating system. USDA, 2007. Pecan Nut Quality. July 15, 2017. <http://www.ars.usda.gov/Research/docs.htm?docid=15380>..

Table 2.1. Difference in pecan grades of a high input orchard in east central Alabama 2010-2013.[zyxw]

Cultivar	No. 1	No. 2	No. 3	Rejects	High Input Percent Kernel of Whole Nut	Total yield
Barton	22.12 abcdefgh	3.65 abc	16.04 a	9.33 abc	41.81 bcde	150
Bond 11	51.19 abc	0.59 bc	0.44 cd	0.79 bc	52.23 abcd	157
Cherryle	41.16 abcde g	10.15 abc	1.61 cd	2.08 bc	53.36 ab	264
Desirable	27.68 f h	12.97 ab	4.05 c	5.61 ab	44.70 cde	220
Elliott	51.27 a	0.23 c	0.12 d	0.63 c	51.61 ab	277
Excel	53.24 abcdef	0.00 abc	0.00 cd	0.00 bc	53.24 abcd	*
Gafford	43.73 abcde	4.20 bc	0.14 cd	0.97 c	48.07 bcde	201
Giftpack	52.40 ab	4.59 bc	0.08 cd	2.53 bc	57.07 a	149
Houma	12.24 h	20.61 ab	6.51 abcd	6.30 abc	39.37 de	217
Jenkins	42.28 abcdefgh	6.76 abc	1.90 cd	3.41 abc	50.93 abcde	296
Kanza	42.26 abcde g	6.13 abc	1.01 cd	2.19 bc	49.41 abcd	200
Kiowa	14.51 defgh	27.13 ab	2.24 bcd	7.44 abc	43.89 abcde	*
Leander	11.98 gh	15.83 abc	6.39 abcd	12.75 a	34.20 e	174
McMillan	31.23 cdefgh	15.30 ab	0.69 cd	1.58 c	47.22 bcde	164
Moreland	33.08 abcdefgh	14.05 abc	3.41 cd	1.40 bc	50.54 abcd	252
Oconee	51.61 abcdefg	0.64 abc	0.00 cd	3.32 abc	52.26 abcde	220
Question	36.24 abcdefgh	17.04 abc	0.00 cd	1.40 bc	53.28 abc	*
Shotts	13.10 efgh	31.08 a	13.81 ab	0.12 bc	57.99 abc	136
Surprize	32.35 bcdefgh	10.74 abc	4.57 bcd	2.99 bc	47.66 abcde	*
Syrup Mill	42.17 abcdefg	4.89 abc	1.68 cd	1.16 bc	48.74 abcde	160
Zinner	46.49 abcd	3.66 bc	0.38 cd	2.15 bc	50.52 abcd	224

[z]Tukey's HSD test. Difference shown by different letters at $p=0.05$.
[y]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26', W85º54').
[x]*Denotes unavailable or incomplete data set.
[w] Total yield is total 4 year harvest weight from 2010-2013

Table 2.2 Difference in pecan grades of a low input orchard in east central Alabama 2010-2013.[zyx]

Cultivar	No. 1	No. 2	No. 3	Rejects	Low Input Percent Kernel of Whole Nut	Total yield
Adams 5	57.51 a	21.14 abcd	0.10 abc	0.10 cd	57.31 ab	118
Carter	42.07 ab	0.37 d	0.80 c	2.60 cd	43.24 bcd	17
Creek	23.32 abcdef	22.90 abcd	1.51 abc	1.30 bcd	47.72 abcde	75
Curtis	23.73 abcdef	20.07 abcd	3.27 abc	3.50 abcd	47.08 abcd	73
Desirable	5.02 f	19.83 bc	7.96 ab	9.88 a	32.80 ef	21
Elliott	46.86 a	3.19 cd	0.00 c	0.44 d	50.05 ab d	322
Farley	38.14 abcd	5.92 cd	0.48 bc	1.84 cd	44.55 abcd	86
Gafford	42.55 ab	4.37 cd	0.29 c	0.72 d	47.21 abcd	144
Jenkins	39.75 ab	7.78 cd	2.39 bc	3.97 bc	49.93 a	344
Kanza	42.29 abcde	5.23 bcd	0.10 abc	2.43 abcd	47.52 abcde	44
McMillan	37.22 abc	10.44 cd	0.31 c	0.71 d	47.97 abcd	232
Miss L	48.58 a	1.49 cd	0.00 c	0.17 d	50.06 abcd	210
Mount	6.72 ef	45.01 a	0.01bc	0.33d	51.73 abc	49
Naomi	11.91 ef	31.67 ab	2.42 abc	0.33 d	46.00 abcd	2
Register	19.71 cdef	14.72 bcd	9.91 a	2.90 bcd	44.34 abcd	13
Stuart	17.18 def	18.37 bcd	4.80 abc	2.21 cd	40.34 c e	275
Syrup Mill	34.03 abcdef	5.47 bcd	2.60 abc	10.91 ab	34.03 def	72

[z]Tukey's HSD test. Difference shown by different letters at $p=0.05$.
[y]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26', W85º54').
[x] Yield is total 4 year harvest weight from 2010-2013

Table 2.3 Difference in pecan grades of a high input orchard in south Alabama 2010-2013.[zyx]

Cultivar	No. 1	No. 2	No. 3	Rejects	High Input Percent Kernel of Whole Nut	Total yield
Apalache	27.19 ab	21.19 a	2.77 a	8.11 a	44.43 a	*
Caddo	30.82 ab	9.35 a	0.47 a	4.39 a	48.49 a	*
Cherryle	20.23 ab	22.71 a	1.34 a	2.53 a	45.37 a	*
Creek	15 ab	26.32 a	3.00 a	3.78 a	51.63 a	*
Desirable	15.57b	23.4 a	3.31 a	10.38 a	45.30 a	*
Giftpack	25.46 ab	13.75 a	3.62 a	5.52 a	52.14 a	*
Headquarters	29.06 ab	13.08 a	0.88 a	1.94 a	50.89 a	*
Oconee	26.91 ab	16.89 a	1.58 a	4.92 a	46.18 a	*
Sioux	41.12 a	10.08 a	0.607 a	3.10 a	52.13 a	*

[z]Tukey's HSD test. Difference shown by different letters at p=0.05.
[y]Orchard located at Gulf Coast Research and Extension Center, Foley, Alabama (N30º 32', W87º 53').
[x]*Denotes unavailable or incomplete data set

Table 2.4 Difference in pecan grades of a low input orchard in south Alabama 2010-2013.[zyx]

Cultivar	No. 1	No. 2	No. 3	Rejects	Low Input Percent Kernel of Whole Nut	Total yield
Adams5	29.98 abcdefgh	18.92 ab	0.77 cdef	3.93 c	50.26 abcde	*
BabyB	29.51 abcdefgh	8.77 abc	9.28 a	7.17 bc	41.75 efgh	*
Carr	20.00 abcdefghi	9.82 abc	1.00 bcdef	2.31 c	34.40 fgh i	*
Carter	25.46 cdgh	14.81 ab	5.47 bc	7.39 bc	37.81 gh	*
Curtis	21.92 abcdefghi	19.79 a	2.86 bcdef	6.52 bc	43.54 abcdefgh	*
Desirable	8.50 i	14.37 ab	2.31 cdef	13.06 a	25.43 i	*
Elliott	38.02 a	4.85 c	2.21 f	4.18 c	44.65 abcdef	*
Farley	16.10 efghi	20.18 a	1.17 cdef	4.17 c	37.12 bcdefgh	*
Gafford	28.88 abcdefgh	12.21 abc	2.57 cdef	4.26 c	44.10 abcdef	*
Headquarters	25.80 abcdefgh	16.17 ab	2.89 cdef	5.37 c	45.35 abcdef	*
Jenkins	21.12 bcdfghi	14.62 ab	7.40 ab	10.60 ab	40.62 defgh	*
Kanza	41.83 abcdefgh	4.2 abc	3.80 abcdef	6.42 abc	46.77 abcdefgh	*
McMillan	22.11 abcdefghi	15.18 abc	2.17 cdef	4.95 bc	38.29 cdefgh	*
Prilop	38.08 a	8.09 bc	1.97 ef	6.04 c	48.95 a	*
Sumner	43.04 abcd	20.73 ab	7.167 abcdef	5.26 abc	38.87 abcdefgh	*
Syrup Milll	25.61 dh	9.57 abc	1.87 def	4.64 c	38.44 fh	*

[z]Tukey’s HSD test. Difference shown by different letters at p=0.05.
[y]Orchard located at Gulf Coast Research and Extension Center, Foley, Alabama (N30° 32’, W87° 53’).
[x]*Denotes unavailable or incomplete data set

CHAPTER III

Pecan Scab

Abstract

Pecan scab is one of the most detrimental fungal diseases of pecans. A primary concern to growers is fruit condition during scab infections. Pecan scab leads to the reduction of yield and quality of kernels. Pecan scab infestation rate is mainly dictated by environmental conditions including temperature, moisture, wind, and rain. In general, proximity to the Gulf of Mexico leads to higher infestation rates. Between 1996 and 1999 pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama and Gulf Coast Research and Extension Center in Foley, Alabama in either a low input or high input environment. From 2010 to 2013, scab data were collected from each graft on an annual basis. Data collected for each cultivar included percent leaf scab, percent nut scab, percent foliage retention, and percent shuck split. 'Desirable' was set as the control due to its establishment as a standard cultivar in the southeast United States. In the high and low input studies, observations suggests there are several cultivars that perform better than 'Desirable'.

Introduction

Pecan scab was first found on mockernut hickory (*Carya tomentosa*) by Winter in 1885. From this specimen, Winter identified the pathogen causing pecan scab as *Fusicladium effusum* (Winter, 1885). The fungus was reclassified as a *Cladosporium* sp. based on the presence of chains of conidia (Demaree, 1928). The name *Cladosporium effusum* was already assigned to a fungus that infects other members of the genus *Carya* (Ellis and Everhart, 1888). Later, the pathogen causing pecan scab was verified to be *Fusicladium effusum* based on the conidiophore structure and the lack of similarity to *Cladosporium herbarum* (Lentz, 1957). Currently, the accepted taxonomic classification has reverted back to *F. effusum* Wint. This more recent classification is based on rDNA evidence comparing *Venturia* and *Cladosporium* (Schnabel et al., 1999). Phylogenetics has given further evidence of the relationship between *Venturia* and *Cladosporium.* Phylogenetic trees clustered *F. effusum* with *Venturia* showing the two being 92% similar based on Cytochrome b gene sequences (Seyran et al., 2010).

Pecan scab is one of the most detrimental fungal diseases of pecans. The disease begins on leaves where lesions form and appear in the vascular tissue (Demaree, 1928). A primary concern to growers is fruit condition during scab infections. Pecan scab leads to the reduction of yield and quality of kernels. Scab can also lead to fruit drop and a reduction in fruit (Gottwald and Bertrand, 1983). Scab development can begin between three and 24 days after infestation. Young vegetation and fruit are typically more susceptible (Turechek and Stevenson, 1998).

Pecan scab occurrence rate is mainly dictated by environmental conditions including temperature, moisture, wind, and rain. In general, proximity to the Gulf of Mexico leads to higher occurrence rates (Gottwald and Bertrand, 1983). In this region, relative humidity and temperatures are higher during the growing season. Additionally, localized rainfall events tend to keep relative humidity high, and winds coming off the Gulf of Mexico bring warmer, humid air from the tropics creating an environment that is ideal for the growth of many fungal diseases including scab (Demaree, 1928; Gottwald and Bertrand, 1983).

Materials and Methods

Between 1996 and 1999 pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama (Lat N32º26', Long W85º54') and Gulf Coast Research and Extension Center in Foley, Alabama (Lat N30º32', Long W87º53') in either a low input or high input environment. High input orchards received irrigation, pesticide treatment, herbicide treatment, fungicide treatment, and fertilizer when needed. Low input orchards received an initial fertilizer treatment based on soil test recommendations and no irrigation or chemical treatments. Trees in the high input orchards at both locations were spaced at 40 feet between rows and 30 feet within rows. Trees in the low input orchards at both locations were spaced at 30 feet between rows and 40 feet within rows. Cultivars were grafted in a random design within each plot (Fig 3.1). Soil type in the high and low input orchard at E.V. Smith Research Center consisted of loams and sandy loams primarily of the Kalmia loamy sand, Kalmia sandy loam and Cahaba sandy loam series (USDA/NRS, 2016). From 2010 to 2013, scab data were collected from each graft on an annual basis. Data collected for each cultivar included percent leaf scab, percent nut scab, percent foliage retention, and percent shuck split. Data were analyzed using ANOVA and Tukey's HSD test in SAS JMP (SAS Institute Inc., Cary, NC). The cultivar 'Desirable' was set as the control due to its establishment as a standard cultivar in the southeast United States since its introduction in 1914.

Results and Discussion

In the high input study, 'Clark II' had more foliage scab and 'Desirable' had more stem scab than all other cultivars (Table 3.1). There was no difference in foliage retention rate among cultivars in the high input orchard (Table 3.2).

In the low input study, every cultivar except ‘Staten’ had less leaf scab than ‘Desirable’ (Table 3.3). Every cultivar except ‘Staten’ had less stem scab than ‘Desirable’ (Table 3.3). Several cultivars exhibited greater foliage retention when compared to ‘Desirable’ (Table 3.4).

There is a correlation between foliage retention and a cultivars chance of alternate bearing (Sparks, 1975). In the high input study, there was not a difference with foliage retention among cultivars. This result could be explained with the use of fungicides and pesticides prolonging the retention of leaves. However, in the low input study, differences were found among cultivars. The cultivars displaying a difference could potentially lead to a reduced likelihood to alternate bear and be a viable alternative for small orchards with limited resources.

It should also be noted that nut and foliage decline are not limited to incidence of scab. Insect pests including yellow aphids (*Monellia careyella*), black aphids (*Melanocallis caryaefoliae*), and pecan leaf scorch mites (*Eotetranychus hicoriae*) can cause foliage damage (Tedders, 1978). Additionally, other fungal diseases, such as sooty mold (*Capnodium spp.*) can cause damage to the foliage and nut of pecans (Sparks, 1992). There are multiple strains of the fungal pathogen that causes pecan scab and although a pecan cultivar may exhibit resistance to one strain it may be susceptible to others. Thus, a cultivar may falsely show resistance but will become infected at another location with a different strain of the fungal pathogen. For example, ‘Sumner’, ‘Melrose’, and ‘Pointe Couppe #2’ were initially thought to have excellent resistance to the fungal pathogen but exhibited susceptibility to the fungal pathogen when grown in different locations (Goff et al. 1998). Additionally, a cultivar that shows resistance to the fungal pathogen at a location may develop susceptibility over time at that same location. For example, Goff et al., (2003), showed ‘Curtis’ as having no stem scab over a five-year period and no leaf scab three out of five years. However, our study at the same location contradicted these findings with ‘Curtis’ incidence of scab increasing when compared to Goff et al., (2003) (Table 3.3). This illustrates cultivars previously thought to have excellent scab resistance can develop susceptibility to scab and the need for ongoing research into scab resistance.

Historically, scab evaluations have been made in a low-pressure environment due to favorable weather and spray programs (Goff, 2003). This can lead to a false presumption of scab resistance. For example, ‘Cheyenne’, ‘Wichita’, and ‘Western’ were once thought to have scab resistance (Sparks, 1992). However, once these were planted as a monoculture scab incidence increased and control was not economically feasible. Thus, most of these orchards were cut down or regrafted to more scab resistant cultivars (Sparks, 1992). Some studies question if there is a true scab resistant cultivar of pecan, with scab resistance being explained as pecan cultivar not being exposed to a fungal strain to which it is susceptible (Littrell and Bertrand, 1981). However, one must consider cultivars such as ‘Elliot’ which was introduced around 1925 and still exhibits only minor scab incidence in the southeastern United States. This would suggest long term resistant cultivars can be found if the correct study program is available.

Given the warm and humid growing season found in the Southeast, it is imperative to identify pecan cultivars that exhibit scab resistance. Several of the cultivars evaluated in this study initially show resistance to scab. However, most still need to be evaluated for a longer period of time and at several locations in order to insure consistent findings with this study.

Literature Cited

Demaree, J.B. 1928. Morphology and taxonomy of the pecan scab fungus *Cladosporium effusum*. J. Agric. Res. 37:181-187.

Ellis, J.B. and B.M. Everhart. 1888. New species of fungi from various localities. J. Mycology 4:121-124.

Goff, W.D., M. Nesbitt, R. Mullenax, F. Rasberry, and B. Graves. 1998. Pest resistance cultivars as a way to reduce input costs. P. 79-89 In: B. Mcgraw, E.H. Dean, and B.Wood (eds.). Pecan industry: Crreunt situation and future challenges. 3rd Natl. Pecan Workshop Proc. USDA Agr. Res. Serv. RC-1998-04.

Goff, W.D., M.L. Nesbitt, C.L. Browne. 2003 Incidence of scab and foliage condition on pecan cultivars grown without fungicides or insectiside sprays in a humid region. Hort. Tech. 13(2): 381-384.

Gottwald, T.R. and P.F. Bertrand. 1983. Influence of temperature, leaf wetness period, leaf age, and spore concentration on infection of pecan leaves by conidia of *Cladosporium caryigenum*. Phytopathology 75:190-194.

Lentz, P.L. 1957. Taxonomy of pecan scab fungus. Mycologia 49:874-878.

Littrel, R.H. and P.F. Bertrand. 1981. Management of pecan fruit andfoliar diseases with fungicides. Plant Dis. 65(9):769-773.

Schnabel, G.E., L. Schnabel. and A.L. Jones. 1999. Characterization of ribozomal DNA from *Venturia inaequalis* and its phylogenetic relationship to rDNA from other fruit *Ventruia* species. Phytopathology 89:100-108.

Seyran, M., C. Nischwitz, K.J. Lewis, R.D. Gitaitis, T.B. Brennaman, and K.L. Stevenson. 2010. Phylogeny of the pecan scab fungus *Fusicladium effusum* G. Winter based on the cytochrome b gene sequence. Mycological Process 9:305-308.

Sparks, D. 1975. The alternate fruit bearing in fruit trees. J. Amer. Soc. Hort. Sci. 101:23-25

Sparks, D. 1992. Pecan cultivars, The orchard's foundation. 1st ed. Pecan Production Innovations, Watkinsville, GA.

Tedders, W.L. 1978. Important biological and morphological characteristics of the foliar-feeding aphids of pecans. USDA Tech. Bul. 1579.

Turechek, W.W. and K.L. Stevenson. 1998. Effects of host resistance, temperature, leaf wetness, and leaf age on infection and lesion development of pecan scab. Phytopathology 88:1294-1301.

United States Department of Agriculture/ Natural Resource and Conservation. 2016. Soil Series Mapping Tool. August 15 2016. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>.

Winter, G. 1885. New North American Fungi. J. Mycology 1:101-102.

COLUMN												
18	2	17	67*	34	39	29*	68*	NG	18	NG	66*	45
17	31	62*	60*	8	15	14	32*	62*	59*	37	3	NG
16	38	47	65*	NG	11	69*	63*	NG	6	1	4	32
15	20	69*	44	1	8	34	S	1	1	11	14	46*
14	NG	2	11	53	5	NG	NG	64*	58*	35	2	20
13	19	1	42	NG	43*	11	5	3	8	59*	1	45
12	66*	15	39	58*	S	1	3	15	3	2	11	54
11	64*	6	68*	47	54	63*	8	NG	42	68*	15	29*
10	1	14	1	3	2	NG	59*	8	32*	15	67*	61*
9	24	44	6	64*	14	15	11	5	58*	55	60*	31
8	19	11	2	NG	6	8	69*	57*	NG	5	5	18
7	67*	5	8	14	3	4	1	14	53	61*	65*	24
6	NG	29*	14	35	43*	S	37	35	NG	57*	43*	57*
5	NG	3	S	35	1	2	NG	NG	61*	29*	66*	29
4	17	8	43*	NG	S	5	2	11	15	6	6	1
3	2	32*	46	15	34	S	15	6	2	NG	8	45
2	63*	4	5	2	46	6	54	2	5	NG	2	34
1	37	39	2	18	42	29	31	20	65*	1	55	27
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
	ROW											

Cultivar Key			
1	Desirable	**25**	Oswego
2	Elliott	**26**	Lakota
3	Jenkins	**27**	Tobacco
4	McMillan	**28**	Byrd
5	Syrup Mill	**29**	MandenU
6	Gafford	**30**	Pippin 09-1
7	Mount	**31**	Pippin 09-2
8	Prilop	**32**	Pippin 09-3
9	Seminole	**33**	Pippin 09-4
10	GRE29_1	**34**	U91-22-12
11	Baby B	**35**	U93-5-5
12	Headquarters	**36**	Pippin 09-7
13	Carter	**37**	U97-20-17
14	Sumner	**38**	Ellis
15	Curtis	**39**	Hickory's Major
16	Melrose	**40**	U1993-6-83
17	Farley	**41**	U1993-6-3
18	8217_680	**42**	U1993-2-272
19	Pippin99_5	**43**	U1992-32-46
20	Adams5	**44**	U1986-3-615
21	Kanza	**45**	U1993-2-304
22	Amling	**46**	U1993-6-68
23	Excalibur	**47**	U1997-9-12
24	Excel	**48**	U1992-1-640
NG	Not Grafted		
S	Seedling Planted Spring 2013		
*****	Grafted Spring 2013		

Figure 3.1 Example layout for pecan cultivar trials at Gulf Coast Research and Extension Center, 2013.

Table 3.1. Incidence of scab in a high input pecan orchard in east central Alabama, 2010-2013.[zyxwv]

Cultivar	Foliage Scab	Nut Scab	Stem Scab
Ace	0c	0c	0c
Adams	0c	0c	0c
Amling	0c	0c	0c
Apalachee	0c	0c	0c
BabyB	0c	0c	0c
Barton	0c	0c	0c
Bond 11	0c	0c	0c
Branch	0c	0c	0c
Byrd	0c	0c	0c
Caddo	0.73b	0c	0c
Carter	0c	0c	0c
Cherryle	0c	1.41b	0c
Clark II	10.76a	0c	0c
Desirable	0.08b	0a	14.36a
Elliott	0c	0c	0c
Ellis	0c	0c	0c
Excalibur	0c	0c	0c
Excel	0c	0c	0c
Gafford	2.5b	0c	0c
Giftpack	0c	3.88b	1.25b
Greenriver	0c	0c	0c
Headquarters	0c	0c	0c
HickMaj	0c	0c	0c
Houma	0c	0c	0c
Jenkins	0c	0c	0c
JumboJoy	0c	0c	0c
Kanza	0c	0c	0c

Cultivar	Foliage Scab	Nut Scab	Stem Scab
Kiowa	0c	0c	0c
Lakota	0c	0c	0c
Leander	0c	0c	0c
Mandan	0c	0c	0c
McMillan	0c	0.01b	0c
Moreland	0c	0c	0c
Oconee	0c	0c	0c
Oswego	0c	0c	0c
Pippin	0c	0c	0c
Posey	0c	0c	0c
Pounds	0c	0c	0c
Question	0c	0c	0c
Shotts	0c	0c	0c
SMC	3.3b	0c	0c
SME	0c	0c	0c
Southern	0c	0c	0c
Staten	0c	0c	0c
Surprize	0c	0.94b	0c
Syrup Mill	0c	0c	0c
Tobacco Barn	0.c	0c	0c
Wamble	0c	0c	0c
Zinner	0.31b	5.63b	0c

[z]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26’, W85º54’).
[y]Tukey’s HSD test. Difference of average percent shown by different letters at p=0.05.
[x]Foilage scab percentage expressed is worst leaflet on tree.
[w]Stem scab lesions on worst 1 ft. recorded as the # of discernable lesions.
[v]Nut scab percentage shuck affected on worst nut.

Table 3.2. Incidence of foliage retention in a high input pecan orchard in east central Alabama, 2010-2013.[zyxw]

Cultivar	Leaf Retention Mean
Amling	91.7 a
Excalibur	90.8 a
Excel	90.6 a
Leander	90.0 a
Question	90.0 a
Syrup Mill	89.6 a
Giftpack	89.1 a
Apalachee	88.8 a
Headquarters	88.8 a
Oswego	88.8 a
SME	88.3 a
JumboJoy	88.3 a
Zinner	88.1 a
Jenkins	88.1 a
Gafford	87.7 a
Southern	87.5 a
Kiowa	87.5 a
McMillan	87.0 a
Posey	86.7 a
Ace	85.9 a
Clark II	85.8 a
Lakota	85.0 a
Moreland	85.0 a
Staten	85.0 a
Tobacco Barn	85.0 a
Caddo	84.5 a
Kanza	84.4 a

Cultivar	Leaf Retention Mean
SMC	84.2 a
Mandan	83.9 a
Houma	83.8 a
Elliott	83.3 a
Question	82.5 a
Shotts	82.5 a
Cherryle	81.7 a
Surprize	81.6 a
Desirable	81.4 a
Barton	81.3 a
Adams5	80.0 a
Branch	80.0 a
Wamble	80.0 a
Ellis	78.3 a
Byrd	77.5 a
Carter	75.0 a
Pippin	75.0 a
Oconee	75.0 a
Pounds	74.2 a
BabyB	70.0 a

[z]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26', W85º54').
[y]Tukey's HSD test. Difference shown by different letters at p=0.05.
[x]Percentage of leaves retained.
[w]Average percentage of leaves retained after September 1st each year over four growing seasons.

Table 3.3. Incidence of scab in a low input pecan orchard in east central Alabama, 2010-2013.[zyxwvu]

Cultivar	Foliage Scab	Stem Scab	Nut Scab
Ace	0.0h	0.0e	0.0b
Adams	0.0h	0.0e	*
Amling	0.0h	0.0e	*
Apalachee	0.0h	0.0e	0.0b
BabyB	0.0h	0.0e	*
Barton	*	*	0.0b
Branch	*	*	0.0b
Byrd	0.0h	0.0e	*
Carter	9.08cdef	1.92d	0.0b
Cherryle	*	*	0.0b
Cunard	0.0h	0.0e	*
Curtis	4.0efg	1.33d	*
Desirable	35.54a	126.29a	60.65a
Elliott	0.0h	0.0e	0.0b
Excalibur	0.0h	0.0e	0.0b
Excel	0.0h	0.0e	0.0b
Farley	6.33defg	2.67d	*
Gafford	0.62g	0.0e	0.0b
Giftpack	5.00defg	4.00d	0.0b
Greenriver	0.0h	0.0e	*
Headquarters	0.0h	0.0e	0.0b
HickoryMajor	0.0h	0.0e	*
Houma	*	*	0.0b
Jenkins	*	0.0e	b
Jumbo Joy	0.0h	0.0e	*
Kanza	0.0h	0.0e	0.0b
Kiowa	*	*	0.0b
Lakota	*	0.0e	*
Leger 1	0.0h	0.0e	*
Leander	*	*	0.0b
Mandan	1.86g	3.29d	*
McDaniel	0.0h	0.0e	*
McMillan	4.75fg	6.38d	0.0b
Miss L	0.0h	0.0e	*
Mount	0.0h	0.0e	*

Cultivar	Foliage Scab	Stem Scab	Nut Scab
Moreland	*	*	0.0b
Naomi	*	0.0e	*
Oswego	*	*	0.0b
Pounds	0.0h	0.0e	0.0b
Question	*	*	0.0b
Register	13.33bcde	7.50d	*
Shotts	*	*	0.0b
SMC	0.0h	0.0e	*
SME	23.33b	75.00bc	*
SouthSt	0.0h	0.0e	*
Staten	40.00a	96.67ab	*
Stuart	15.75bcd	29.75c	*
Surprize	*	*	0.0b
Syrup Mill	24abc	3.00bc	0.0b
Wamble	0.0h	0.0e	*
Watson	10.00cdefg	d	*
Zinner	*	*	0.0b

[z]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26’, W85º54’).
[y]Tukey’s HSD test. Difference of average percent shown by different letters at p=0.05.
[x]Foilage scab percentage expressed is worst leaflet on tree.
[w]Stem scab lesions on worst 1 ft. recorded as the # of discernable lesions.
[v]Nut scab percentage shuck affected on worst nut.

Table 3.4. Incidence of foliage retention in a low input pecan orchard in east central Alabama, 2010-2013.[zyxw]

Cultivar	Mean	
Ace	91	ab
Adams	65	abcd
Adams5	94	a
Amling	90	abc
Apalachee	87	ab
BabyB	91	ab
Byrd	75	abcd
Carter	85	ab
Clark II	90	abc
Cunard	90	ab
Curtis	83	abc
Desirable	54	d
Elliott	69	c
Excalibur	90	ab
Excel	92	ab
Farley	88	ab
Gafford	88	ab
Gafford	80	abcd
Giftpack	83	abc
Greenriver	90	ab
Headquaters	93	ab
Hickory Major	90	abc
Jenkins	80	abc
Jumbo Joy	90	ab
Kanza	86	abc
Lakota	91	a
Leger 1	90	ab
Mandan	90	a
McDaniel	90	ab
McMillan	89	ab
Miss L	85	ab
Mount	75	abc
Oconee	75	abcd
Posey	90	ab
Pounds	90	ab
Register	88	ab
SMC	90	ab
SME	81	abc

Cultivar	Mean	
SouthSt	88	ab
Staten	78	abc
Stuart	82	abc
Syrup Mill	91	abc
Tobacco Barn	95	ab
Wamble	90	ab
Watson	90	ab

[z]Orchard located at E.V. Smith Research Center, Shorter, Alabama (N32º26', W85º54').
[y]Tukey's HSD test. Difference shown by different letters at p=0.05.
[x]Percentage of leaves retained.
[w]Average percentage of leaves retained after September 1st each year over four growing seasons.

Chapter IV

Influence of Cultivars on Alternate Bearing in Pecans

Abstract

Alternate bearing of pecan can occur within an orchard causing substantial losses in crop yields. Alternation results from low amounts of carbohydrates stored in the roots in the winter after a high yield year. Pecan fruit takes 160 days on average to reach maturity which leaves a shorter period of time to store carbohydrates after fruit development when compared with other deciduous, fruiting trees. Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama in a high input environment. From 2010 to 2013, yield data were collected from each graft in the high input orchard on an annual basis. Data collected for each cultivar included pounds of nuts per cultivar and leaf retention. Statistical analysis did show some differences amongst cultivars while other cultivars showed no difference.

Introduction

Alternate bearing in nut crops was documented as early as the sixteenth century (Sparks, 1975). Data collected between 1919-1974 indicates alternate bearing of pecan crops (Gemoets et al., 1976). Alternation can occur within an orchard causing substantial losses. Alternation results from low amounts of carbohydrates stored in the roots in the winter after a high yield year and high amounts of carbohydrates stored in the roots in the winter after a low yield year.. Carbohydrate reserves for growth and flowering are derived from the previous season’s growth (Davis and Sparks, 1974).

It takes pecan blossoms an extended time to reach maturity: 160 days on average (Wolstenholme, 1971). Because of the longer duration of fruit development, the period from maturity to defoliation is approximately 40 days less when compared with other deciduous, fruiting trees. This reduction creates a shorter time period for the tree to produce carbohydrates to support the next year's flowers and fruits. Additionally, 66% of the dry matter and approximately 70% of the lipid content in a kernel accumulates late in season further reducing the carbohydrates stored in the root (Sparks, 1975; UGA CES, 2014). The timing of defoliation is crucial to successful flowering. Early defoliation can lead to: reduced flowering the following year, reduced carbohydrate content of shoots and roots, and reduction in yield of the following year's crop (Sparks, 1975; Worley, 1979; Worley and Harmon, 1979).

Pecan is a wind pollenated nut crop which is heterodichogamous (Adriance, 1930; Thompson and Grauke, 1991). When self-pollenated, some pecan cultivars tend to be weak with a high percentage fruit abortion, suppressed nut development, and poor plant vigor (Conner, 2012; Mississippi State University Extension Service, 2014). To avoid self-pollination, pecans have male and female flowers which emerge at different times with in the early spring. Male flowers (catkins) are on the terminus of one-year-old wood. Female flowers (pistillates) are located on the terminus of new wood. Separation of male and female flowers increases cross-pollination but does not necessarily eliminate self-pollination (Wetzstien and Sparks, 1986; Conner, 2012).

An additional limitation to self-pollination is the maturing of catkins and pistillate flowers at different times. Protandrous flowering, or Type I trees, release pollen before the pistillate flower is receptive. In protogynous, or Type II trees, pistillates become receptive before the stamens release pollen. A single gene controls dichogamy with Type I being the dominant gene (P) and Type II being the recessive gene (p) (Thompson and Romberg, 1985). The only homozygous dominant (PP) cultivar known is ‘Mahan’. Thus, all seedlings from ‘Mahan’ are either homozygous dominant (PP) or heterozygous dominant (Pp) (Gruake, 2010). In native stands of pecan, there are usually 50% protogynous (PP or Pp) and 50% protandrous (pp) individuals (Conner, 2012). However, in an orchard setting where there is a majority of one or two cultivars being grown, this condition is often not the case. Many pecan orchards have poor yields as a result of reduced cross-pollination and/or abundant self-pollination (Marquard, 1988; Romberg and Smith, 1946). Weather can also factor into the time period when a tree is producing pollen or the pistillate is receptive. For example, unusually early warm weather or unusually late cold weather can sometimes effect dichogamy. Therefore, within an orchard, proper pollination is critical in achieving high yield and nut quality.

Over the past several decades, pecan production has started outside of its native range in the southeastern and southwestern United States and has become an exotic nut crop in parts of Asia (W. Goff, unpublished data; Wood and Payne, 1991). Thus, native trees that aid in pollination of orchards in the native range are not present. Studies have identified stamen and pistillate maturity windows of most available cultivars (Worley et al., 1992). However, these windows of catkin and pistillate maturity change as the tree ages (Wood, 1996; Wood, 2000). Also, location, weather patterns, and orchard health can contribute to a cultivars tendency to be Type I or Type II. Additionally, several members of the *Juglandaceae* family have a tendency to switch flowering type depending on environmental conditions within a given year, such as shagbark (*Carya ovata*; 2n = 32) and mockernut (*C. tomentosa*; 2n = 64) hickories (Mississippi State University Extension Service, 2014 ; McCarty and Quinn, 1990). These characteristics pose unique challenges to understanding gene expression and pollination timing within pecan orchards to reduce an orchard’s tendency to alternate bear.

Materials and Methods

Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama (Lat N32º26’, Long W85º54’) in a high input environment. High input orchards received irrigation, pesticide treatment, herbicide treatment, fungicide treatment and fertilizer, when needed. Trees in the high input orchard were spaced at 40 feet between rows and 30 feet within rows. Cultivars were grafted in a random design within each plot (Fig 4.1). Soil type in the high input orchard at E.V. Smith Research Center consisted of loams and sandy loams primarily of the Kalmia loamy sand, Kalmia sandy loam and Cahaba sandy loam series (USDA/NRS, 2016). From 2010 to 2013, yield data were collected from each graft in the high input orchard on an annual basis. Data collected for each cultivar included pounds of nuts per cultivar and leaf retention. Yield rates were defined as amount of pounds produced per tree. Leaf retention was defined as percentage of leaves remaining on the tree after September 1st. Total sample means from 2010-2013 were analyzed using ANOVA test to determine differences in annual yields per cultivar using SAS JMP (SAS Institute Inc., Cary, NC). Pearsons correlation was used to analyze nut yield compared to each previous year leaf retention (e.g., 2011 nut yield vs 2010 leaf retention) using SAS JMP (SAS Institute Inc., Cary, NC).

Pollination charts from four orchards in separate locations were analyzed for differences in Type I and Type II flowering among number of pecan cultivars. A pollination chart from the E.V. Smith Research Center in Shorter, Alabama (Lat N32º26’, Long W85º54’), Simpson

Nurseries in Monticello, Florida (Lat N30°32′, Long W83°52′), UGA Southwest Georgia Research and Education Center in Tifton, Georgia (Lat N31°45', Long W83°50'), and the LSU Pecan Research-Extension Station in Shreveport, Louisiana (Lat N32°47', Long W93°80') were used in the study. Soil type in the orchard at E.V. Smith Research Center consisted of loams and sandy loams primarily of the Kalmia loamy sand, Kalmia sandy loam and Cahaba sandy loam series (USDA/NRS, 2016). Soil type in the orchard at Simpson Nursery consisted of sandy loams and fine sands primarily of the Orangeburg, Pelham, and Dothan series (USDA/NRS, 2016). Soil type in the Georgia Research and Education Center orchard consisted of sandy loam and sandy clay mainly of the Tifton series (USDA/NRS, 2016). Soil type in the LSU Pecan Research- Extension Station consisted of silty clay loams and clay mainly of the Coushatta and Latanier soil series (USDA/NRS, 2016).

Results and Discussion

When comparing 2010 nut yield to 2009 leaf retention, 'Oconee' was the only cultivar to be different from 'Desirable' (Table 4.1). There was no difference when comparing 2011 nut yield in relation to 2010 leaf retention (Table 4.2). When comparing 2012 nut yield to 2011 leaf retention, 'Branch' was the only cultivar different from 'Desirable' (Table 4.3). When comparing 2013 nut yield to 2012 leaf retention, 'Oconee' was the only cultivar different from 'Desirable' (Table 4.4). Leaf retention rates for cultivars during the four year study ranged from 70% to 95%. Yields ranged from five to 55 lb per tree. The findings in this study are consistent with Sparks' (1975) which showed a correlation between leaf retention and alternate bearing of pecans. However, the highest percentage of leaf retention did not always correlate to the highest yield of nuts. For example, when comparing 2010 nut yield to 2009 leaf retention, 'Apalachee' had a leaf retention of 90% and a nut yield of 16.8 lb, whereas ‘Oconee’ had a leaf retention of 78% and a nut yield of 54.9 lb (Table 4.1). Pearson correlation results varied with leaf retention being a predictor of nut yield. During the years 2010 and 2012 a slight positive correlation was observed between the two variables (Figure 4.2, 4.4). During the years 2011 and 2013, nut yield a slight negative correlation with leaf retention being a predictor for nut yield (Figure 4.3, Figure 4.5). These observations suggest there are other variables that factor into alternate bearing such as levels of scab infestation in a given year, exposure to insect damage in a given year, fluctuations in weather patterns, and genetic variability among cultivars. The high input orchard received regular fungicide and herbicide applications, thus, increasing the likelihood of longer leaf retention when compared with trees that did not receive the same treatment.

Leaf retention data for the low input orchard were not available, so the analysis was only performed on the high input orchard. There are two main factors of growing pecans in the Southeast that can lead to occurrence of scab, warm/humid growing conditions and most small growers find it economically unfeasible to implement an extensive spray program to control scab (W. Goff, unpublished data). Therefore, future analysis should look into the correlation between leaf retention and nut yield within the low input orchard in an effort to identify cultivars that exhibit qualities favorable to producing a high grade nut with minimal inputs.

When comparing pollination type, not all cultivars expressed uniformity in being protandrous or protogynous between locations. ‘Hastings’ exhibited Type II flowering at E.V. Smith Research Center and UGA Pecan Research Center while exhibiting Type I flowering at Simpson Nurseries (Table 4.5). ‘Jackson’ expressed Type I flowering at E.V Smith, Simpson Nurseries, and the UGA Pecan Research Center but expressed pollen release and stigma receptivity at the same time at the LSU Pecan Research Center (Table 4.5). ‘McMillan’ exhibited Type II flowering at E.V. Smith Research Center and the UGA Pecan Research Center but expressed Type I flowering at the LSU Pecan Research Center (Table 4.5). ‘Surprize’ expressed Type II flowering at E.V. Smith Research Center but Type I flowering at the LSU Pecan Research Center and the UGA Pecan Research Center (Table 4.5). ‘Western Schley’ expressed Type I flowering at Simpson Nurseries but Type II flowering at E.V. Smith Research Center and the UGA Pecan Research Center (Table 4.5). It is not fully understood why there are differences in Type I and Type II flowering among different locations. Weather, soil type, nutrient inputs, genetic variability, or other external variables could be the possible cause.

Literature Cited

Adriance, G.W. 1930. Dichogamy in the pecan. J. Ameri. Soc. Hort. Sci. 27: 435-439.

Conner, P. J. 2012. Pollination charts revisited. Georgia Pecan, Spring Edition 34-39.

Davis, J.T. and D. Sparks. 1974. Assimilation and translocation patterns of carbon 14 in the shoots of fruiting pecan trees *Carya illinoensis* Koch. J. Amer. Soc. Hort. Sci. 99:468-480.

Gemoets, E.E., L.A. Gemoets, T.E. Cannot, and R.G. McIntyre. 1976. Cycles of U.S. pecan production 1919-1974. J. Amer. Soc. Hort. Sci. 101:550-553.

Grauke L.J. 2017. Pecan Flowering. August 20, 2017. <http://cgru.usda.gov/carya/Manual/flowering.html>.

McCarthy, B. and J. Quinn. 1990. Reproductive ecology of Carya (*Juglandaceae*) phenology, pollentation, and breeding systems of two sympartric tree species. Botany. 77:261-273

Mississippi State University Extension Service. 2014. Pollination in pecans. 15 October 2014. <https://msfruitextension.wordpress.com/2014/11/13/pollination-in-pecans/>.

Monselise, S.P., E.E. Goldschmidt, and A. Golomb. 1982. Alternate bearing in citrus and ways of control. Proc. Amer. Soc. Sci. 84:141-146.

Sparks, D. 1975. The alternate fruit bearing in fruit trees. J. Amer. Soc. Hort. Sci. 101:23-25.

University of Georgia Cooperative Extension Service. 2014. 15 September 2014. <http://www.caes.uga.edu/commodities/fruits/pecanbreeding/cultivars/alternate_bearing.html>.

Romberg, L. D., and C.L. Smith. 1946. Effects of cross-pollination, and sib-pollination on the dropping, the volume, and the kernel development of pecan nuts and on the vigor of the seedlings. Ameri.Soc. Hort. Sci. 47:130-133.

The University of Georgia Cooperative Extension Service. 2012. Pecan varieties for Georgia orchards. 15 October 2014. <http://extension.uga.edu/publications/detail.cfm?number=C898>.

Thompson, T.E. and L.D. Romberg. 1985. Inheritance of heterodichogamy in pecan. J. Heredity 76:456-458.

Thompson, T. E., and L.J. Grauke. 1991. Pecans and other Hickories. Acta Hort., 290: 839-904.Wolstenholme, B.N. 1971. Development of pecan nut-some implications for orchard management. Citrus Growers and Subtrop. Fruit J. Nov. 7-10.

United States Department of Agriculture/ Natural Resouce and Conservation. 2016. Soil Series Mapping Tool. August 15 2016. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>.

Wetzstien, H.Y., and D. Sparks. 1986. Flowering in pecans (8 ed.). Hort. Review.Worley, R.E. 1979. Fall defoliation date and seasonal carbohydrate concentration of pecan wood tissue. J. Ameri. Soc. Hort. Sci. 104:192-194.

Wolstenholme, B.N., 1971. Desirable tree and nut characteristics. Fmg. S. Afr. Repr. No. 443.

Wood, B.W. 1996. Cross pollination in pecan orchards. HortScience 31:583.

Wood, B.W. 2000. Pollination characteristics of pecan trees and orchards. Hort. Tech. 10:1

Wood, B.W. and J.A. Payne. 1991. Pecan- An emerging crop. Chronical of Horticulture 31: 21-23.

Worley, R.E. 1979. Fall defoliation date and seasonal carbohydrate concentration of pecan wood tissue. J. Ameri. Soc. Hort. Sci. 104:192-194.

Worley, R.E. and S.A. Harmon. 1979. Effect of fungicides on nutlet set of pecans. HortScience 6:127-128.

Worley, R.E., S.K. Dove, B.G. Mullinax, and M. Smith. 1992. Long term dichogamy of 80 pecan cultivars. Scientia Horticulture 49:93-101.

COLUMN	A	B	C	D	E	F	G	H	I	J	K	L
18	2	17	67*	34	39	29*	68*	NG	18	NG	66*	45
17	31	62*	60*	8	15	14	32*	62*	59*	37	3	NG
16	38	47	65*	NG	11	69*	63*	NG	6	1	4	32
15	20	69*	44	1	8	34	S	1	1	11	14	46*
14	NG	2	11	53	5	NG	NG	64*	58*	35	2	20
13	19	1	42	NG	43*	11	5	3	8	59*	1	45
12	66*	15	39	58*	S	1	3	15	3	2	11	54
11	64*	6	68*	47	54	63*	8	NG	42	68*	15	29*
10	1	14	1	3	2	NG	59*	8	32*	15	67*	61*
9	24	44	6	64*	14	15	11	5	58*	55	60*	31
8	19	11	2	NG	6	8	69*	57*	NG	5	5	18
7	67*	5	8	14	3	4	1	14	53	61*	65*	24
6	NG	29*	14	35	43*	S	37	35	NG	57*	43*	57*
5	NG	3	S	35	1	2	NG	NG	61*	29*	66*	29
4	17	8	43*	NG	S	5	2	11	15	6	6	1
3	2	32*	46	15	34	S	15	6	2	NG	8	45
2	63*	4	5	2	46	6	54	2	5	NG	2	34
1	37	39	2	18	42	29	31	20	65*	1	55	27
	ROW											

Cultivar Key

1	Desirable	**25**	Oswego
2	Elliott	**26**	Lakota
3	Jenkins	**27**	Tobacco
4	McMillan	**28**	Byrd
5	Syrup Mill	**29**	MandenU
6	Gafford	**30**	Pippin 09-1
7	Mount	**31**	Pippin 09-2
8	Prilop	**32**	Pippin 09-3
9	Seminole	**33**	Pippin 09-4
10	GRE29_1	**34**	U91-22-12
11	Baby B	**35**	U93-5-5
12	Headquarters	**36**	Pippin 09-7
13	Carter	**37**	U97-20-17
14	Sumner	**38**	Ellis
15	Curtis	**39**	Hickory's Major
16	Melrose	**40**	U1993-6-83
17	Farley	**41**	U1993-6-3
18	8217_680	**42**	U1993-2-272
19	Pippin99_5	**43**	U1992-32-46
20	Adams5	**44**	U1986-3-615
21	Kanza	**45**	U1993-2-304
22	Amling	**46**	U1993-6-68
23	Excalibur	**47**	U1997-9-12
24	Excel	**48**	U1992-1-640
NG	Not Grafted		
S	Seedling Planted Spring 2013		
*****	Grafted Spring 2013		

Figure 4.1 Example layout for pecan cultivar trials at Gulf Coast Research and Extension Center, 2013.

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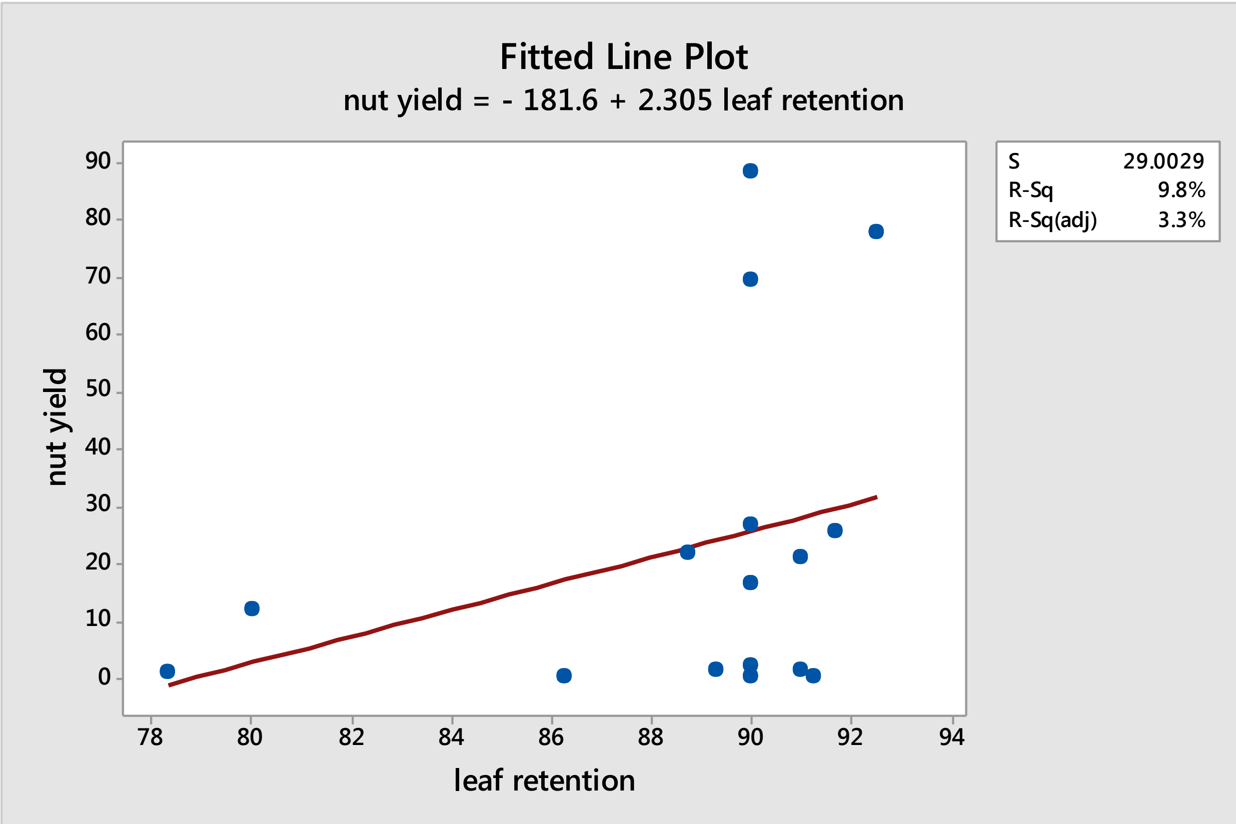

Figure 4.2 Comparison of 2010 nut yield in relation to 2009 leaf retention in a high input orchard in east central Alabama.

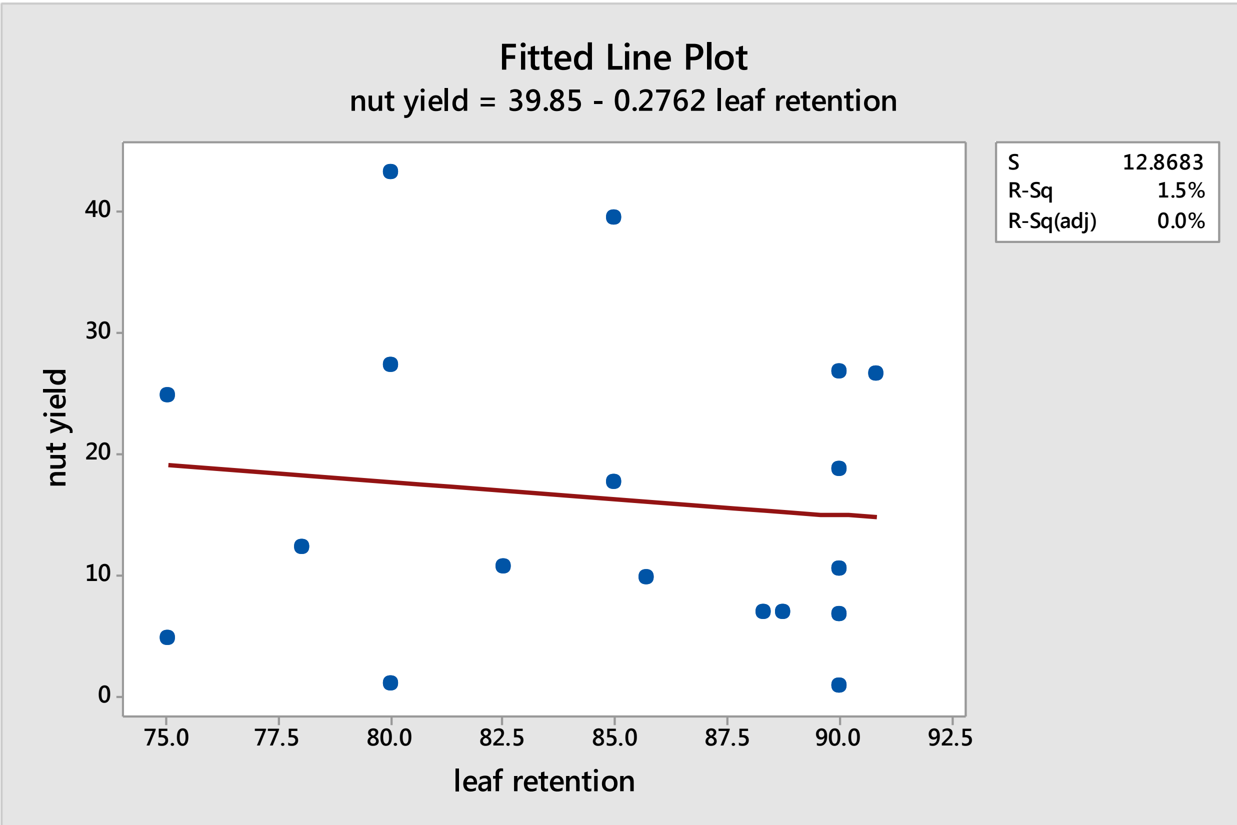

Figure 4.3 Comparison of 2011 nut yield in relation to 2010 leaf retention in a high input orchard in east central Alabama.

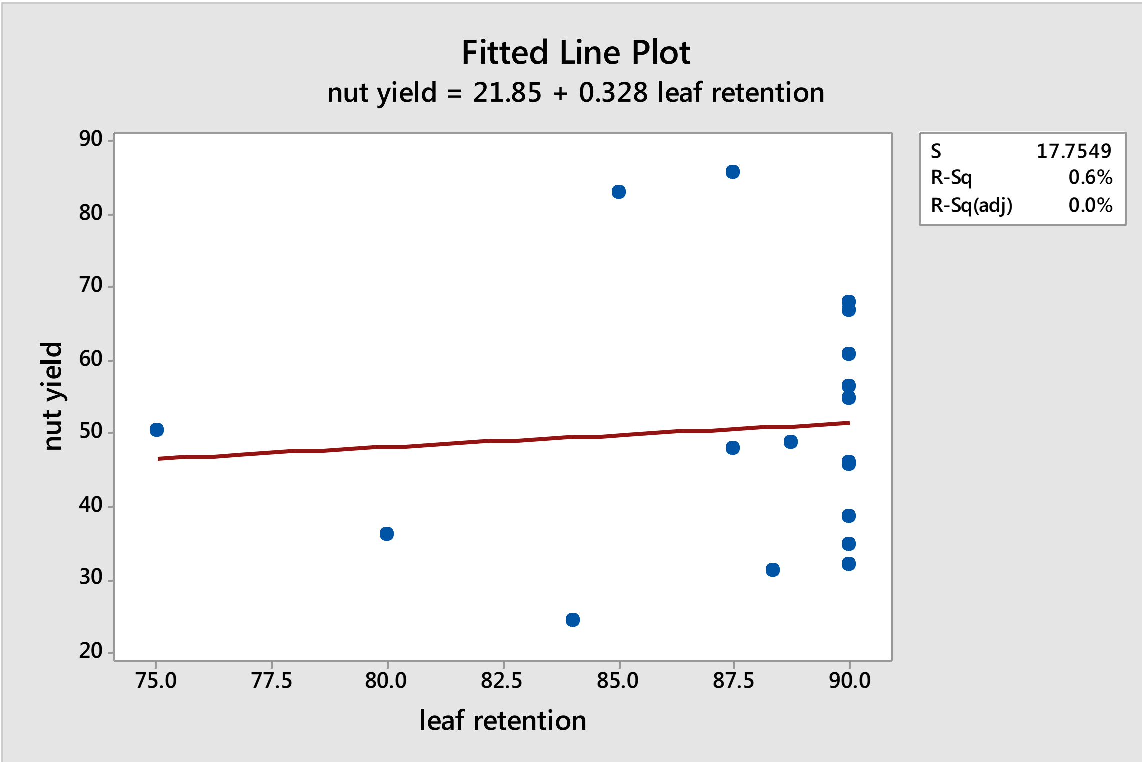

Figure 4.4 Comparison of 2012 nut yield in relation to 2011 leaf retention in a high input orchard in east central Alabama.

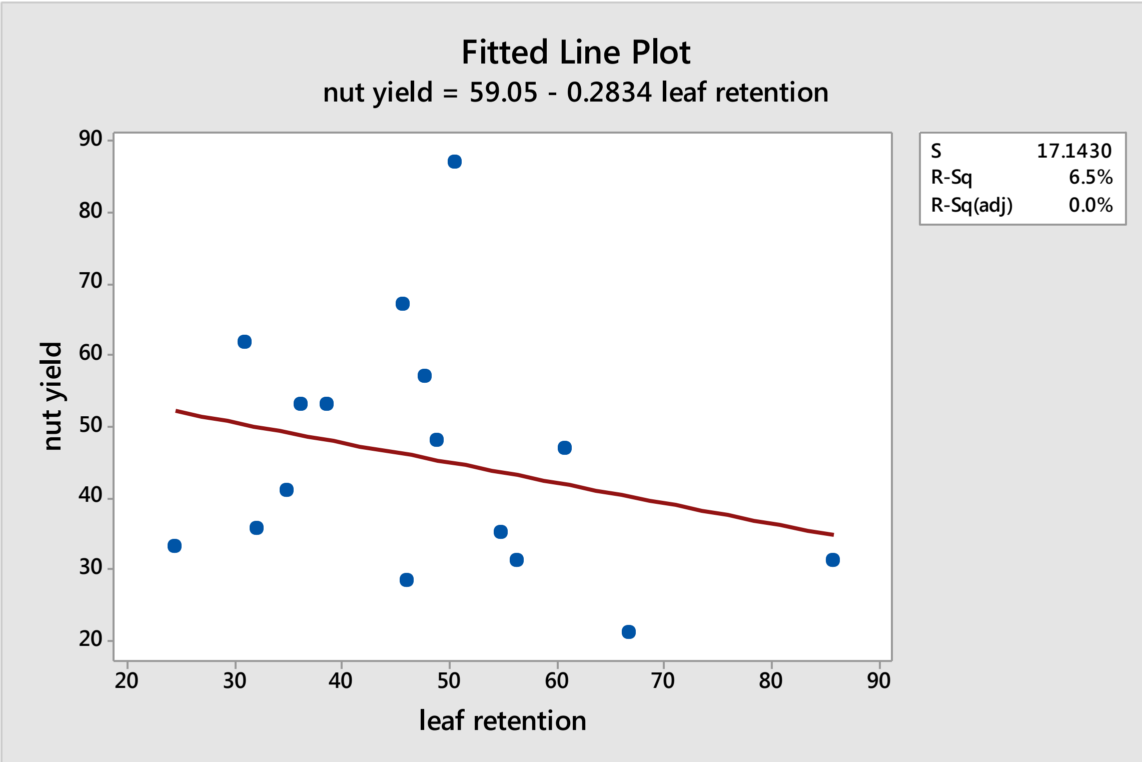

Figure 4.5 Comparison of 2013 nut yield in relation to 2012 leaf retention in a high input orchard in east central Alabama.

Table 4.1. E.V. Smith Research Center total means of 2010 pecan nut yield in relation to 2009 leaf retention.

Cultivar	2009 Leaf retention[z]	2010 Nut yield[y]	Difference[x]
Apalachee	90	16.8	0.19 de
Barazza	82	17.8	0.22 e
Barton	82	18.4	0.22 e
Bond 11	86	32.8	0.38 cde
Branch	83	43.9	0.53 bcd
Caddo	88	5.60	0.06 e
Carter	83	25.9	0.31 bcd
Cherryle	85	37.2	0.44 ab
Desirable	79	33.4	0.42 bcde
Elliott	85	51.0	0.60 ab
Gafford	88	31.7	0.36 e
Giftpack	89	18.8	0.21 de
Houma	85	52.5	0.62 ab
Jenkins	85	34.0	0.40 ab
Kanza	86	27.2	0.32 cde
Leander	90	27.0	0.30 de
McMillan	88	24.3	0.28 e
Moreland	87	46.9	0.54 abc
Oconee	78	54.9	0.70 a
Zinner	90	34.9	0.39 de

[z]Percentage of leaves retained after September 1st.
[y]Number of pounds collected at time of harvest.
[x] Ratio of nut yield in relation to leaf retention Tukey's HSD test. Difference shown by different letters at p=0.05.

Table 4.2. E.V. Smith Research Center total means of 2011 pecan nut yield in relation to 2010 leaf retention.

Cultivar	2010 Leaf retention[z]	2011 Nut yield[y]	Difference[x]	
Apalachee	90	0.9	0.01	a
Barraza	78	12.4	0.16	a
Barton	80	1.0	0.01	a
Bond 11	90	6.8	0.08	a
Branch	75	4.8	0.06	a
Caddo	86	9.8	0.11	a
Carter	75	25.0	0.33	a
Cherryle	85	39.6	0.47	a
Desirable	80	43.3	0.54	a
Elliott	83	10.8	0.13	a
Gafford	91	26.7	0.29	a
Giftpack	89	7.0	0.08	a
Houma	73	*[w]	*	*[w]
Jenkins	90	26.8	0.30	a
Kanza	88	7.0	0.08	a
Leander	90	18.8	0.21	a
McMillan	90	10.6	0.12	a
Moreland	85	17.8	0.21	a
Oconee	80	27.4	0.34	a
Zinner	95	20.8	0.22	a

[z]Percentage of leaves retained after September 1st.
[y]Number of pounds collected at time of harvest.
[x] Ratio of nut yield in relation to leaf retention. Tukey's HSD test. Difference shown by different letters at p=0.05.
[w]Denotes unavailable data set.

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Table 4.3. E.V. Smith Research Center total means of 2012 pecan nut yield in relation to 2011 leaf retention.

Cultivar	2011 Leaf retention[z]	2012 Nut yield[y]	Difference[x]
Apalachee	90	34.8	0.39 bc
Barazza	84	24.4	0.29 c
Barton	90	67.8	0.75 bc
Bond	90	38.6	0.43 bc
Branch	85	83.0	0.98 a
Cherryle	90	56.3	0.63 bc
Desirable	80	36.1	0.45 bc
Elliott	88	85.8	0.98 ab
Gafford	90	46.1	0.51 bc
Giftpack	90	32.1	0.36 bc
Houma	90	66.8	0.74 bc
Jenkins	90	60.8	0.68 bc
Kanza	88	31.0	0.35 ab
Leander	90	54.8	0.61 bc
McMillan	89	48.8	0.55 abc
Moreland	88	47.8	0.54 ab
Oconee	75	50.5	0.67 abc
Zinner	90	45.8	0.51 bc

[z]Percentage of leaves retained after September 1st.
[y]Number of pounds collected at time of harvest.
[x] Ratio of nut yield in relation to leaf retention. Tukey's HSD test. Difference shown by different letters at p=0.05.

Table 4.4. E.V. Smith Research Center total means of 2013 pecan nut yield in relation to 2012 leaf retention.

Cultivar	2012 Leaf retention[z]	2013 Nut yield[y]	Difference[x]	
Apalachee	*[w]	41.0	*[w]	*[w]
Barazza	81	33.0	0.41	*[w]
Barton	70	*[w]	*[w]	*[w]
Bond 11	88	53.0	0.60	b
Branch	80	*[w]	*[w]	*[w]
Cherryle	83	31.0	0.37	c
Desirable	73	53.0	0.73	bc
Elliott	85	31.0	0.36	bc
Gafford	84	28.3	0.34	c
Giftpack	89	35.5	0.40	bc
Houma	83	21.0	0.25	c
Jenkins	90	47.0	0.52	bc
Kanza	83	61.7	0.74	c
Leander	90	35.0	0.39	bc
McMillan	83	48.0	0.58	c
Moreland	85	57.0	0.67	bc
Oconee	70	87.0	1.24	a
Zinner	88	67.0	0.76	b

[z]Percentage of leaves retained after September 1st.
[y]Number of pounds collected at time of harvest.
[x] Ratio of nut yield in relation to leaf retention . Tukey's HSD test. Difference shown by different letters at $p=0.05$.
[w]Denotes unavailable data set.

Table 4.5 Comparison of Type I[z] and Type II[y] flowering of pecan cultivars in different growing location.[zyxw]

Cultivar	E.V. Smith Research Center	Simpson Nurseries	LSU Pecan Research Center	UGA Pecan Research Center
Candy	II	II	II	II
Cape Fear	I	I	I	I
Carter	II	*[w]	*[w]	II
Cherokee	II	*[w]	II	II
Cherryle	II	*[w]	*[w]	II
Curtis	II	II	II	II
Desirable	I	I	I	I
Elliott	II	II	II	II
Excel	II	*[w]	II	II
Gafford	I	*[w]	I	I
Giftpack	II	*[w]	*[w]	II
Hastings	II	I	*[w]	II
Headquarters	II	*[w]	*[w]	II
Jackson	I	I	III[x]	I
McMillan	II	*[w]	I	II
Moneymaker	II	*[w]	II	II
Oconee	I	*[w]	I	I
Schley	II	II	II	II
Sumner	II	II	II	II
Surprize	II	*[w]	I	I
Syrup Mill	I	*[w]	I	I
Western Schley	II	I	*[w]	II
Wichita	II	*[w]	II	II
Zinner	II	*[w]	*[w]	II

[z] I indicates protandrous.
[y] II indicates protogynous.
[x] III indicates pollen shed and stigma receptivity occurred on the same day.
[w] Unavailable/incomplete data.

Chapter V

Fatty Acids of Selected Pecan Cultivars

Abstract

High lipid content is critical in having a high quality pecan kernel. The lipid content in pecan kernels varies due to cultivar, environmental factors, age of tree, available nutrients, and harvest period. Low fat content or oxidation of fat in pecan can cause nuts to become rancid, leading to an unmarketable product. Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama in either a low input or high input environment. In the fall of 2014, nuts from five cultivars were collected from both the high and low input orchards for lipid analysis. Data collected included total lipid content, total triglyceride content, and percentage of individual fatty acid in relation to the total triglyceride.

Introduction

Pecans are considered a high-energy food source: providing 691-718 kcal/100 g per kernel with lipid content as high as 75% and carbohydrate content up to 18% (Duke, 2001; Prasad, 1993; USDA, 2004). Lipids are substances not soluable in water and are subdivided into three groups: phospholipids, sterols, and fats. Phospholipids are the primary component of cell membranes, sterols are the precursors to hormones, and fats are a form of stored energy. Fats are further subdivided into: monoglycerides, diglycerides, trigylcerides, and free fatty acids.

Essential fatty acids, a type of trigylceride, are those that the human body cannot naturally produce and must be consumed in the diet. They are subdivided into α-linolenic (omega-3) and linoleic acid (omega-6). There are three types of omega-3 fatty acids: α-linolenic (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). EPA and DHA have considerable health benefits including: lowering cholesterol, altering depression, and decreasing macular degeneration (Rajaram et al., 2001; Genty and Conklin, 2014; Merle et al., 2014). EPA and DHA are typically found in greatest abundance in fish, and ALA is typically found in greatest abundance in nuts. While ALA is known to be converted in small amounts to DHA and EPA in the body by the liver, ALA's role in the body is not as fully understood as EPA and DHA (Stark et al., 2008). However, the potential benefits of ALA are known to include decreased inflammation, positive impact on the nervous system, and positive impact on cardiovascular health. Because of these benefits, nutritional guidelines for ALA have been established. For example, pecans are considered a "heart healthy" food by the American Heart Association's Heart-Check food certification program and have been found to reduce blood lipid serum profiles in both men and women (Carter, 2012; Rajaram et al., 2001).

There are 11 types of omega-6 fatty acids; however, linoleic acid (LA) is the only type found in cultivars within this study. LA's primary physiological role in the body is the building of cell membranes (Stedman, 2000). LA is converted to two other acids in the body: gamma linolenic acid (GLA) and arachidonic acid (Borberg et al., 1984; University of Maryland School of Medicine, 2017). GLA has several benefits including: reduced nerve pain associated with diabetic neuropathy, reduced pain and swelling associated with rheumatoid arthritis, and reduced hypertension (University of Maryland School of Medicine, 2017). Arachidonic acid aids in brain and muscle function (Smith et al., 2011). Moreover, LA has industrial uses which include oil paints, varnishes, and surfactants (EPA, 2017; NIH, 2017)

The lipid content in pecan kernels varies due to cultivar, environmental factors, age of tree, available nutrients, and harvest period (Eddy and Storey, 1988; Heaton et al., 1966; Santree, 1994; Wells et al., 1980). Generally, triglycerides account for up to 95% of total lipids in the kernel. Monoglycerides, diglycerides, free fatty acids and sterols typically represent < 1% of total kernel lipids (Prasad, 1993; USDA, 2004). Lipids are an important quality attribute for pecans (Heaton et al., 1966). High oil content (50% to 70%) combined with a high percentage of polyunsaturated fatty acids (25% to 27%) result in a short shelf life. Low fat content or oxidation of fat in pecan can cause nuts to become rancid, leading to an unmarketable product.

Therefore, the nutritional value and marketability of pecan are linked to high fat content. Despite the aforementioned studies, the influence of high input and low input characteristics in relation to lipid content has not been characterized to date in pecan cultivars. This information is necessary for growers in the selection of cultivars and nutritional inputs within the orchard. The objective of the study was to analyze nuts of five different pecan cultivars ('Desirable', 'Elliott', 'Gafford', 'McMillan', and 'Syrup Mill') for their lipid content in both the high and low input orchards.

Materials and Methods

Between 1996 and 1999, pecan cultivars were grafted to mature pecan trees at the E.V. Smith Research Center in Shorter, Alabama (Lat N32º26', Long W85º54') in either a low input or high input environment. High input orchards received irrigation, pesticide treatment, herbicide treatment, fungicide treatment and fertilizer when needed. Low input orchards received an initial fertilizer treatment based on soil test recommendations and no irrigation or chemical treatments. Trees in the high input orchards at both locations were spaced at 40 feet between rows and 30 feet within rows. Trees in the low input orchards at both locations were spaced at 30 feet between rows and 40 feet within rows. Cultivars were grafted in a random design within each plot (Fig 5.1). Soil type in the high and low input orchard at E.V. Smith Research Center consisted of loams and sandy loams primarily of the Kalmia loamy sand, Kalmia sandy loam and Cahaba sandy loam series (USDA/NRS, 2016).

In the fall of 2014, nuts from five cultivars ('Desirable', 'Elliott', 'Gafford', 'McMillan', and 'Syrup Mill') were collected from both the high and low input orchards. Nuts were stored in a freezer at -20° C to prevent rancidity and until analysis could be completed. Frozen samples were ground with a mortar and pestle into a powder consistency. The powder was defatted using a methanol chloroform (2 MeOH : $1CHCl_3$) method of lipid extraction to retrieve total lipid content consisting of monoglycerides, diglycerides, triglycerides, sterols, and phospholipids (Bligh and Dyer, 1959) (Fig 5.2; Table 5.1). Each powdered sample underwent lipid extraction three times to ensure total collection of lipid and aqueous solutions. After the lipid and aqueous solution separated in test tubes, the aqueous solution was removed via a pipette. The lipid solution was then immediately placed in an incubator at 35° C to remove the chloroform fraction, and lipid content was weighed. Data collected included: total kernel weight, total lipid weight, and total fat percentage (Table 5.2).

In the summer of 2017, nuts of each cultivar from the high and low input orchards were sent to the Vanderbilt University School of Medicine for total triglyceride and fatty acid profiles for analysis via gas chromatography-mass spectrometry (GC-MS). GC-MS is an analytical procedure to identify substances within a given test sample. Lipids were extracted using the method of Folch-Lees (Folch et al., 1957). The extracts were filtered, and lipids recovered in the chloroform phase. Individual lipid classes were separated by thin layer chromatography using Silica Gel 60 A plates developed in petroleum ether, ethyl ether, acetic acid (80:20:1) and visualized by rhodamine 6G. Phospholipids, diglycerides, triglycerides and cholesteryl esters were scraped from the plates and methylated using BF3 /methanol as described by Morrison and

Smith (Morrison and Smith, 1964). The methylated fatty acids were extracted and analyzed by gas chromatography. Gas chromatographic analyses were carried out on an Agilent 7890A gas chromatograph equipped with flame ionization detectors, a capillary column (SP2380, 0.25 mm x 30 m, 0.25 µm film, Supelco, Bellefonte, PA). Helium was used as a carrier gas. The oven temperature was programmed from 160 C to 230 C at 4 C/min. Fatty acid methyl esters were identified by comparing the retention times to those of known standards. Inclusion of lipid standards with odd chain fatty acids permitted quantitation of the amount of lipid in the sample. Dipentadecanoyl phosphatidylcholine (C15:0), diheptadecanoin (C17:0), trieicosenoin (C20:1), and cholesteryl eicosenoate (C20:1) were used as standards. By using GC-MS, the percent of each fatty acid in relation to the total triglyceride content could be identified.

Statistical analysis consisted of three triplicate samples (whole kernel) for each cultivar. ANOVA test was used to determine differences among cultivars using SAS JMP (SAS Institute Inc., Cary, NC). Tukey's difference test was used to illustrate significance. A factorial model was also used to compare inputs and cultivars.

Results and Discussion

'McMillan' low and 'Syrup Mill' low had the lowest total kernel weights as well as lowest total lipid weight in grams (Table 5.2). 'McMillan' low, 'Syrup Mill' high, and 'Syrup Mill' low all had lower kernel weight compared with 'Desirable' high (Table 5.2). 'Syrup Mill' low had lower total lipid weight compared with 'Desirable' high and 'Desirable' low (Table 5.2). 'Syrup Mill' had the greatest response when comparing high and low inputs for both total weight and total lipid weight (Table 5.2). 'Gafford' had the least amount of response in relation to high and low input for total weight and total lipid weight (Table 5.2). Total weight of 'Gafford' was 4.4 g for high input and 4.5 g for low input (Table 5.2). Additionally, 'Gafford' had total lipid weight of 2.5 g for both high and low input (Table 5.2). These results indicate that the response of 'Gafford' between high and low inputs may be genetic and not cultural. 'Desirable' had the highest overall lipid percentage with 68% in the high input orchard (Table 5.2). Lipid percentage was defined as lipid weight divided into total weight. 'Desirable' had highest total kernel weight 5.63 g for high input. Even though there were differences in kernel weight and total lipid weight, there was no difference among the lipid content percentage across all cultivars (Table 5.2).

'Desirable' had the highest total lipid weight of all cultivars, and 'Syrup Mill' had the lowest total lipid weight of all cultivars, however, the difference was not significant (Table 5.3). There was no difference in triglyceride weight amongst cultivars (Table 5.4). The only difference in total triglyceride with in a cultivar was between 'Syrup Mill' high and 'Syrup Mill' low (Table 5.5). This finding suggests that 'Syrup Mill' has a greater associated response to input setting than other cultivars.

Despite poor nut quality, 'Syrup Mill' low had more palmitic acid (16:0), linoleic acid (omega-6) (18:2w6), and ALA (omega-3) (18:3w3) (Table 5.5). 'Syrup Mill' low also had lower oleic acid (omega-9) (18:1w9) when compared to the other cultivars (Table 5.5). The only triglyceride weights that were different from 'Desirable' high were 'McMillan' low and 'Syrup Mill' low (Table 5.5). All cultivars contained linoleic (omega-6) (18:2w6), and α-linolenic (omega-3) (18:3w3) acids which are essential fatty acids. However, the amounts of linoleic (omega-6) (18:2w6), and α-linolenic (omega-3) (18:3w3) varied per cultivar within input setting. Within the cultivars there was a strong correlation between Omega-9 and Omega-6 (Figure5.3). The relationship between the two fatty acids is not understood but relationship could possibly be a deficiency response mechanism where if one is high the other is low or there could be differences in what fatty acids are produced by each cultivar.

Factorial design analysis of input and cultivar indicated there was no difference between cultivars or input setting in relation to percentage triglyceride content (Table 5.6). Factorial design analysis also indicated there was no difference when combining cultivar with input (Table 5.6). It is undetermined which components of the high input orchard yields the highest returns of total fatty acid content. Future analysis should focus on isolating the components, if any, produce the highest triglyceride yields at harvest. Additionally, future research needs to be conducted to understand the relationship of fatty acids and their production within the pecan.

Literature Cited

Bligh, E.G. and W.J. Dyer. 1959. A rapid method of total lipid extaction and purification. Canadian J Biochem. Physio. 37: 911-917.

Borberg, M., L.B. Croon, I.B. Gustafasson, and B. Vessby. 1984. Platelet fatty acid composition in relation to fatty acid composition in plasma and to serum lipoprotein lipids in healthy subjects with special reference to the linoleic acid pathway. Clinical Science 68: 581-587.

Carter, C. 2012. Georgia pecans earn American Heart Association Heart-Check certification. The Produce News. Oradell, NJ. The Produce News. August 15 2017. <http://www.producenews.com/category-list/7736-georgia-pecans-earn-american-heart-association-heart-check-certification>

Duke, J.A., 2001. Handbook of nuts. Boca Raton, FL: CRC Press Inc.

Eddy, M. and J.B. Storey. 1988. The influence of harvest date on oil and flavor development in Desirable and Witchita pecans. HortScience 23:782-786.

Environmental Protection Agency. 2017. Chemical data reporting under the Toxic Substances Control Act. August 19 2017. <http://www.epa.gov/chemical-data-reporting>.

Folch, J. , M. Lees, and G.H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipides from animal tissues. J. Biol. Chem. 226: 497-509.

Genty, T., and S.M. Conklin. 2014. Short-term supplementation of acute long-chain omega-3 polyunsaturated fatty acids may alter depression status and decrease symptomology among young adults with depression: A preliminary randomized and placebo controlled trial. Psychiatry Research 229:485-489.

Heaton, E.K., J.E. Marion, and J.G. Woodroof. 1966. Pecan oil is highly unsaturated. Peanut J. and Nut World 26: 809-812.

Merle B.M, P. Benlian, N. Puche, A. Bassols, C. Delcourt, and E.H.Souied. 2014. Circulating omega-3 fatty acids and neovascular age-related macular degeneration. Investigative Ophthamology and Visual Science 55:2010-2019.

Morrison W.R. and L.M. Smith. 1964. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. J. Lipid Res. 5: 600-608.

National Institute of Health. 2017. Compound summary for lenoleic acid. August 15 2017. <https://pubchem.ncbi.nlm.nih.gov/compound/linoleic_acid#section=Top>.

Prasad, R.N. 1993. Walnuts and pecans. Encyclopedia of food science and technology 7:4823-4834.

Rajaram, S, K. Burke, B. Connell, T. Myint, and J. Sabte. 2001. A monosaturated fatty acid rich pecan enriched diet favorably alters the serum lipid profile of healthy men and women. J. Nutrition 131:2275-2279

Santree, S.K. 1994. Pecan composition. New York: Chapman and Hall.

Smith, G.I., P. Atherton, D.N. Reeds, B.S. Mohammed, D. Rankin, M.J. Rennie, and B. Mittendorfer. 2011. Omega-3 polyunsaturated fatty acids augment the muscle protein anabolic response to hyperinsulinaemia-hyperaminoacidaemia in healthy young and middle-aged men and women. Clinical Science 121: 267-278.

Stark A.H., M.A. Crawford, and R. Reifen. 2008. Update on alpha-linolenic acid. Nutritional Review 66:326-328.

Stedman, T. L. 2000. Stedman's Medical Dictionary. 27th ed. 284. Lippincott Williams & Wilkins. Baltimore, Maryland.

United States Department of Agriculture/ Natural Resource and Conservation. 2016. Soil Series Mapping Tool. August 15 2016. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>.

University of Maryland School of Medicine. 2017. Gamma-linolenic acid. August 16 2017. <http://www.ummidtown.org/health/medical/altmed/supplement/gammalinolenic-acid>.

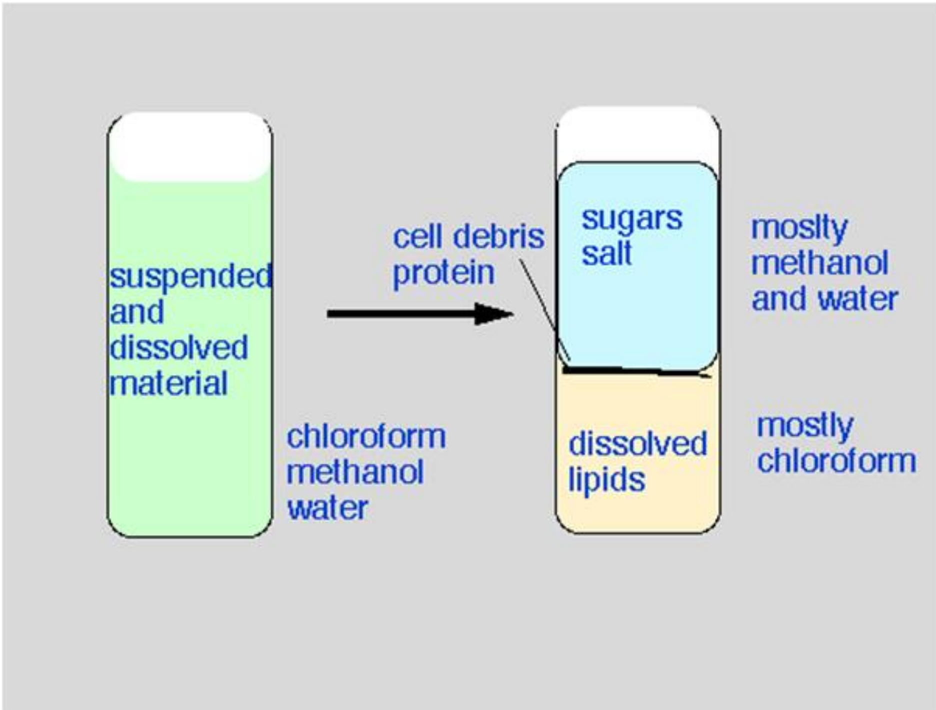
USDA. 2004. National Nutrient Database for Standard Reference, s.l.: US Department of Agriculture.

Wells, J.M., J.L. McMeans, and J.A. Payne. 1980. Pecan oil content and composition as affected by variety and orchard conditions. Proc. Southeastern Pecan Growers Assoc 71:159-162.

COLUMN	A	B	C	D	E	F	G	H	I	J	K	L
18	2	17	67*	34	39	29*	68*	NG	18	NG	66*	45
17	31	62*	60*	8	15	14	32*	62*	59*	37	3	NG
16	38	47	65*	NG	11	69*	63*	NG	6	1	4	32
15	20	69*	44	1	8	34	S	1	1	11	14	46*
14	NG	2	11	53	5	NG	NG	64*	58*	35	2	20
13	19	1	42	NG	43*	11	5	3	8	59*	1	45
12	66*	15	39	58*	S	1	3	15	3	2	11	54
11	64*	6	68*	47	54	63*	8	NG	42	68*	15	29*
10	1	14	1	3	2	NG	59*	8	32*	15	67*	61*
9	24	44	6	64*	14	15	11	5	58*	55	60*	31
8	19	11	2	NG	6	8	69*	57*	NG	5	5	18
7	67*	5	8	14	3	4	1	14	53	61*	65*	24
6	NG	29*	14	35	43*	S	37	35	NG	57*	43*	57*
5	NG	3	S	35	1	2	NG	NG	61*	29*	66*	29
4	17	8	43*	NG	S	5	2	11	15	6	6	1
3	2	32*	46	15	34	S	15	6	2	NG	8	45
2	63*	4	5	2	46	6	54	2	5	NG	2	34
1	37	39	2	18	42	29	31	20	65*	1	55	27
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
	ROW											

Figure 5.1 Low input plot layout for pecan cultivar trials at Gulf Coast Research and Extension Center, 2013.

Cultivar Key			
1	Desirable	**25**	Oswego
2	Elliott	**26**	Lakota
3	Jenkins	**27**	Tobacco
4	McMillan	**28**	Byrd
5	Syrup Mill	**29**	MandenU
6	Gafford	**30**	Pippin 09-1
7	Mount	**31**	Pippin 09-2
8	Prilop	**32**	Pippin 09-3
9	Seminole	**33**	Pippin 09-4
10	GRE29_1	**34**	U91-22-12
11	Baby B	**35**	U93-5-5
12	Headquarters	**36**	Pippin 09-7
13	Carter	**37**	U97-20-17
14	Sumner	**38**	Ellis
15	Curtis	**39**	Hickory's Major
16	Melrose	**40**	U1993-6-83
17	Farley	**41**	U1993-6-3
18	8217_680	**42**	U1993-2-272
19	Pippin99_5	**43**	U1992-32-46
20	Adams5	**44**	U1986-3-615
21	Kanza	**45**	U1993-2-304
22	Amling	**46**	U1993-6-68
23	Excalibur	**47**	U1997-9-12
24	Excel	**48**	U1992-1-640
NG	Not Grafted		
S	Seedling Planted Spring 2013		
*****	Grafted Spring 2013		



PowerPoint presentation from Dr. Subroto Chatterjee. Glycophingolipid Lecture. October 7, 2013. <http://cardiopeg.bs.jhmi.edu/SiteAssets/Pages/Techniques-in Glycobiology/Analysis%20of%20Glycosphingolipids.pptx>

Figure 5.2. Illustration of Bligh/Dyer lipid separation in test tube of pecans.

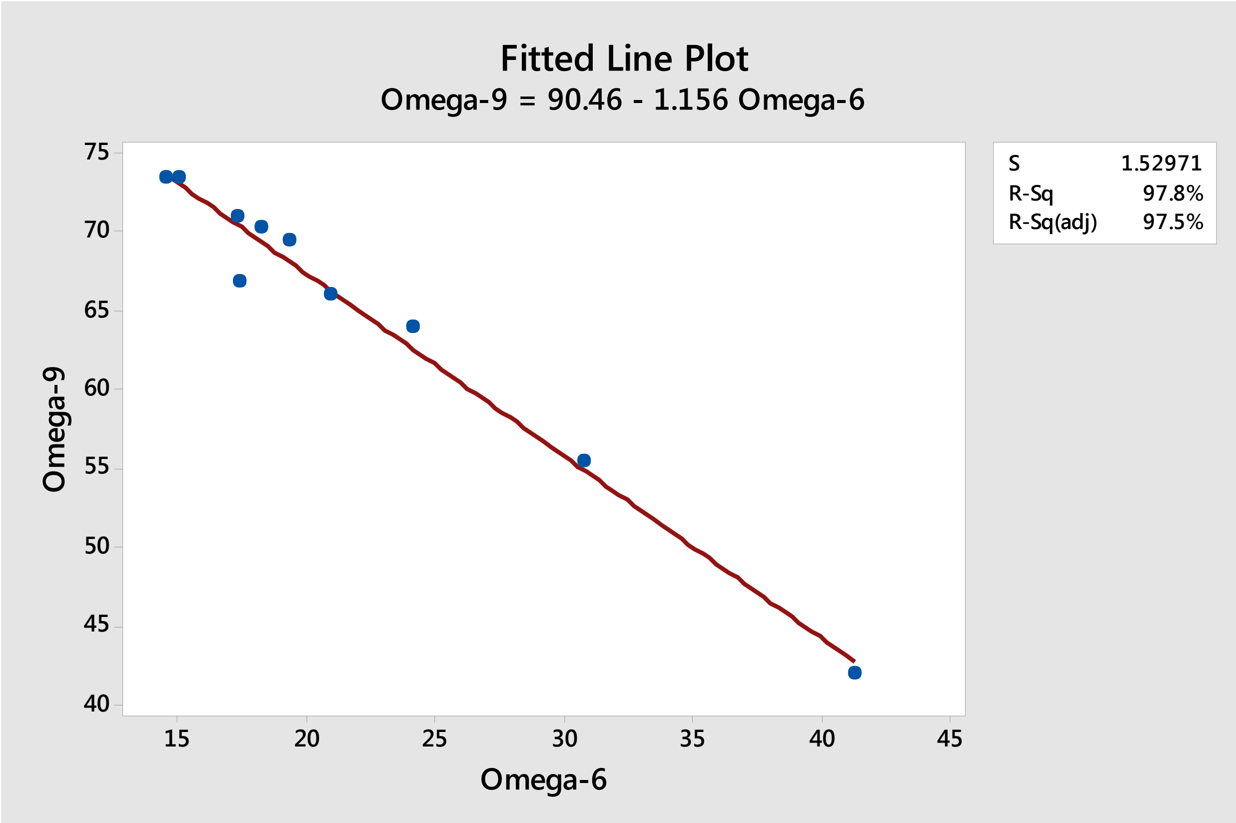


Figure 5.3 Correlation between Omega-9 fatty acid and Omega-6 fatty acids in pecan cultivars at E.V. Smith Research Center.

Table 5.1. Procedure for Bligh/Dyer Extraction of total lipids from pecans under different management plans.[z]

1. Weigh tissue sample. Grind sample with mortar and pestle into powder consistency.
2. Add tissue to test tube containing 2:1 MeOH: chloroform. Smash with glass rod.
3. Vortex for 2 minutes.
4. Add 1 mL chloroform and 1.8 mLs water.
5. Shake for 2 minutes.
6. Spin in centrifuge for 20 minutes.
7. Allow to sit if fractions have not separated.
8. Discard upper layer (aqueous phase, will contain some polar lipid species like acyl-CoAs depending on what you are after, you may need to save this layer)
9. Transfer lower layer (organic phase contains TAGs, membrane lipids and other neutral lipids) to new tube.
10. Dry until chloroform evaporates.
11. Weigh fat tissue sample.

[z]Bligh, E.G. and W.J. Dyer. 1959. A rapid method for total lipid extraction and purification. Can. J. Biochem. Physiol. 37:911-917.

Table 5.2. Cultivar and input average weight in grams and percentages of total weight and total lipid weight of pecan cultivars at E.V. Smith Research Center.[z]

Cultivar and input	Kernel wt avg[y]	Total lipid wt avg[x]	Percent lipid solution avg
Desirable High	5.63 a	3.82 a	0.68 a
Desirable Low	4.40 ab	2.39 ab	0.54 ab
Elliott High	4.20 ab	2.34 ab	0.56 ab
Elliott Low	3.57 ab	2.20 ab	0.62 ab
Gafford High	4.40 ab	2.50 a	0.57 ab
Gafford Low	4.50 ab	2.49 a	0.55 ab
McMillan High	4.36 ab	2.39 ab	0.55 ab
McMillan Low	2.30 cd	1.51 bc	0.66 ab
Syrup Mill High	3.90 b	2.46 a	0.63 ab
Syrup Mill Low	0.73 d	0.37 d	0.51 b

[z]Tukey's HSD test. Difference shown by different letters at p=0.05.
[y]Mean of total lipid in kernel (g).
[x]Total lipid weight in kernel (g).

Table 5.3. E.V. Smith Research Center pecan total lipid in relation to cultivar (g).[z]

Cultivar	Mean[y]
Elliott	2.27 a
Desirable	3.10 a
Gafford	2.48 a
McMillan	1.95 a
Syrup Mill	1.41 a

[z]Tukey's HSD test. Difference shown by different letters p=0.05.
[y]Average weight in grams.

Table 5.4. E.V. Smith Research Center pecan triglyceride content in relation to cultivar (g).[z]

Cultivar	Total Triglyceride[y]	Palmitic acid (16:0)[x]	Stearic acid (18:0)[x]	Oleic acid (omega-9) (18:1w9)[x]	Vaccenic acid (18:1w7)[x]	Linoleic acid (omega-6) (18:2w6)[x]	α-Linolenic acid (omega-3) (18:3w3)[x]
Desirable	1.46 a	6.1 b	3.80 ab	73.4 a	1.09 a	14.77 b	0.87 b
Elliott	1.27 a	6.2 b	3.28ab	68.0 ab	1.23 a	20.71 ab	1.04 b
Gafford	1.50 a	5.8 b	3.29 ab	69.9 a	1.03 a	18.77 ab	1.19 ab
McMillan	1.04 a	7.1 ab	4.10 a	61.0 ab	0.99 a	25.77 ab	1.30 ab
Syrup Mill	0.81 a	8.1 a	2.99 b	55.1 b	1.27 a	30.49 a	1.92 a

[z]Tukey's HSD test. Difference shown by different letters p=0.05.
[y]Total triglyceride average weight in grams.
[x]Fatty acids are a percent of the total triglyceride.

Table 5.5. Cultivar and input total triglyceride average and fatty acid content of pecans grown at E.V. Smith Research Center.[z]

Cultivar and input	Total Triglyceride[y]	Palmitic acid (16:0)[x]	Stearic acid (18:0)[x]	Oleic acid (omega-9) (18:1w9)[x]	Vaccenic acid (18:1w7)[x]	Linoleic acid (omega-6) (18:2w6)[x]	α-Linolenic acid (omega-3) (18:3w3)[x]
Desirable High	1.52 a	5.6 b	4.1 a	73.4 a	1.1 a	14.50 c	0.9 b
Desirable Low	1.39 ab	6.1 b	3.5 a	73.4 a	1.1 a	15.00 c	0.8 b
Elliott High	1.34 ab	6.2 b	3.3 a	71.0 ab	1.2 a	17.30 bc	0.9 b
Elliott Low	1.20 ab	6.3 b	3.2 a	64.0 ab	1.2 a	24.10 bc	1.1 b
Gafford High	1.50 a	5.4 b	3.5 a	69.5 ab	1.1 a	19.30 bc	1.1 b
Gafford Low	1.49 a	6.4 b	3.1 a	70.3 ab	1.0 a	18.20 bc	1.1 b
McMillan High	1.39 ab	7.1 b	4.0 a	66.0 ab	0.9 a	20.90 bc	1.2 b
McMillan Low	0.71 bc	7.1 b	4.3 a	55.5 bc	1.0 a	30.70 ab	1.4 b
Syrup Mill High	1.46 a	7.0 b	2.9 a	66.8 ab	1.2 a	17.38 bc	1.1 b
Syrup Mill Low	0.17 c	9.6 a	2.9 a	42.0 c	1.4 a	41.25 a	2.7 a

[z]Tukey's HSD test. Difference shown by different letters p=0.05.
[y]Total triglyceride average weight in grams.
[x]Fatty acids are a percent of the total triglyceride.

Table 5.6 ANOVA of factorial design on effects of input and cultivar on percentage triglyceride content of pecans grown at E.V. Smith Research Center.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Input[z]	1	579.3	579.3	0.17	0.687
Cultivar[y]	4	12932.9	3233.2	0.93	0.466
input*cultivar	4	6679.9	1670.0	0.48	0.750
Error	20	69508.5	3475.4		
Total	29	89700.5			

[z] Input consist of high and low input orchards.
[y] Cultivars consist of ‘Desirable’, ‘Elliott’, ‘Gafford’, ‘McMillan’, ‘Syrup Mill’.

Chapter VI

Final Discussion

Although there has been extensive research in pecans during the last several decades, there has been little published research in relation to cultivar performance in regard to high and low input environments. Because the Alabama pecan industry is comprised mainly of smaller growers without the resources to use intense spray and fertilizer programs, it is imperative to identify cultivars that are naturally resistant to insects and pecan scab that still produce a consistent, quality crop. Considering the costs of production are constantly rising, finding ways to reduce expenses while increasing the quality of the pecan crop and thereby increasing profit. Identifying cultivars with a high quality nut that require less input than current cultivars in mass production is a way to directly benefit growers. and the environment. Reducing the amount of fertilizers and pesticides used increases a grower's profit margin while at the same time reducing the amount of undesirable runoff into the surrounding environment.

Nut quality and yield are the most important aspects of pecan production to a grower since the value of their crop is directly related to the quality of the nut. With the United States' pecan market approaching $500,000,000 annually and being a free market commodity, it is imperative for a grower to produce a quality nut. However, pecan production is multifaceted and has several elements that dictate the nut quality. Further complicating quality nut production is the fact that cultivar evaluation can be a five to 10 year process. Nutrient inputs, scab resistance, leaf retention, etc. all play a vital role in the production of a quality nut product. While some cultivar attributes remain more or less constant throughout time, such as nutrient requirements, others change over time. Scab resistant cultivars have been present in the pecan industry for over a 100 years. However, leaf scab resistance is an attribute that changes over time and affects each cultivar differently. For example, 'Elliott' has exhibited minor incidences of scab for decades yet remains relatively resistant while other cultivars initially show resistance but become susceptible to development of scab over time. Because of situations like these, it is necessary to constantly evaluate potential new cultivars for scab resistance, leaf retention, and nut quality while continuing to monitor current cultivars in production. This study illustrates which cultivars may be suitable for both high and low input characteristics in relation to scab resistance. However, because a cultivar does not perform well in a low input environment does not necessarily mean it will not perform well in a high input environment.

Another factor that can affect nut yield is the tendency of a pecan to alternate bear and pecan flower dichogamy. Alternate bearing in pecans leads to inconsistent annual crop yields while dichogamy can lead to inconsistent pollination of the pistillate flower, thus lowering pollination success rates. This study compared nut yield in relation to leaf retention among cultivars and also showed inconsistency in flowering type among cultivars at different locations. The elements that govern changes in flowering type among locations is not fully understood but is a subject growers need to understand.

Given the nutritional benefits of pecan and its advertisement to the public as being a "heart healthy" food, it is necessary to understand how cultural practices, nutritional inputs, and cultivar selection affect the fatty acid profile. While fat content in pecan has been previously evaluated, fatty acid profiles in relation to cultivar and cultural input practices have not been fully understood. This study was able to identify these relationships and illustrate how cultivar and input affects fatty acid profiles.

Successful orchard production strategies are multifaceted and continued investigation is needed in cultivar selection and cultural practices to determine profitable ways to produce quality pecans with limited inputs. Determining new cultivars and improved cultural practices will provide growers with a means to reduce inputs while increasing yields and profits.