CHEMICAL INDICATORS OF PECAN GERMPLASM YIELD POTENTIAL AND IRREGULAR BEARING

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CHAPTER I

INTRODUCTION

Pecans (*Carya illinoinensis* [Wang.] K. Koch) are considered to be among the most valuable nuts in North America. It is the only major tree nut native to the United States, particularly adapted to the Mississippi Valley (Cochran, 1961). Pecans have been a stable foodstuff throughout time in America. Early explorers reported that Native American Indian tribes in the Mississippi Valley used pecans as a main foodstuff. Along with the Native Americans, the early explorers noticed that pecans produced heavy crops one year and a light crop the next year. The characteristic of irregular bearing has been a major focal point for researchers (Barnett and Mielke, 1981; Monselise and Goldschmidt, 1982; Sparks, 1974, 1975, 1979, 1986, 2000, 2003; Wood. 1991; Wood et al., 2004).

Determining the causes of irregular bearing in pecans could improve pecan marketability and stabilize pecan production. Irregular bearing trees normally produce an excessive fruit load one year, followed by a year of little or no production; however, large or small crops may occur in succeeding years (Crane et al., 1934; Lockwood and Sparks, 1978; Sparks, 1974). Pecan growers suffer economic losses in both "on" and "off" years. During on years, over bearing can result in poor nut fill and kernel quality, often to the point of making the nuts unmarketable (Hunter, 1968). Over bearing also tends to reduce cold hardiness, often leading to shoot dieback or tree death (Reid, 1993; Wood, 1986). There are 492,137 acres (199,168 ha) of pecans in the United States, owned by 19,900 farm families, in 24 states. This provides a significant source of income for the family farm. Nationwide production fluctuates from more than 350,000,000 lbs (158,757,330 kg) during on years to less than 200,000,000 lbs (90,720,000 kg) in an off year. Fluctuating yields are reflected in the in-shell prices paid to producers, and ranged from $1.51 (off year) to $0.39 (on year) per pound, and wholesale prices of kernels from $4.15 (off year) to $2.50 (on year) per pound. This erratic production also makes the pecan supply very unstable. The irregular production of pecans leads to surpluses and low prices during on years and shortages and high prices during off years. This drastic variability in prices has limited pecan marketing and curtailed the growth of the industry as a whole.

Irregular bearing in pecans has received substantial attention (Barnett and Mielke, 1981; Monselise and Goldschmidt, 1982; Sparks, 1974, 1975, 1979, 1986, 2000, 2003; Wood. 1991; Wood et al., 2004), but the cause has yet to be identified. Some of the environmental conditions inducing irregularity are readily observable. Severe drought throughout the growing season (Hunter, 1963) and short-term drought during kernel development (Alben, 1958; Sparks, 1992) are conditions that may induce irregular bearing. Another observation indicates that early defoliation (Crane, 1930; Isbel, 1928; Sparks and Bract, 1970) induces irregular bearing, possibly by decreasing carbohydrate reserves (Sitton, 1933; Smith and Waugh, 1938).

The mechanisms that regulate irregular bearing are still debated. It has been suggested that assimilate reserves largely regulate irregular bearing in pecans (Crane et al., 1934; Isbel, 1928; Malstrom, 1974; Smith and Waugh, 1938; Sparks and Brack, 1972; Wood, 1989, 1991; Worley, 1979a, 1979b). A two-level regulation of flowering by a balance of plant hormones and carbohydrate reserves during flower induction and development has been proposed (Amling and Amling, 1983; Smith et al., 1986; Wood, 2003; Wood and McMeans, 1981; Wood et al., 2003, 2004). Flowers that produce the next year's crop are initiated during the time that the current season's crop is maturing (Amling and Amling, 1983). Therefore, stress during this time may affect the next year's crop. Carbohydrate reserves stored in roots and shoots are utilized in the spring growth flush and in the terminally positioned pistillate inflorescence (Lockwood and Sparks, 1978). If stored carbohydrates are insufficient, shoot growth lacks vigor, flower development and fruit set are suppressed and the tree is considered to be "off". If carbohydrate reserves are high, shoot growth is vigorous, the pistillate inflorescence is strong and the tree is considered to be "on" (Sparks, 1983, 1992).

Sparks (1983) suggested that the degree of flower formation was determined by the level of carbohydrate reserves that were accumulated in storage tissues during the previous growing season. This suggestion was supported by several observations: high carbohydrate accumulation usually proceeds an "on" year and low accumulation precedes an "off" year, carbohydrate reserves decrease during the spring growth flush due to their movement into the new growth, and factors that are expected to increase carbohydrate production and accumulation, such as leaf efficiency factors, leaf area per fruit, and leaf retention, promote flowering and minimize irregular bearing (Wetzstein and Sparks, 1986). Irregular bearing seems to be alleviated by factors that favor carbohydrate accumulation, such as healthy leaves, longer leaf retention after maturity (Hinrichs, 1962), longer shoot growth with greater leaf area (Wood, 1995), and by factors that reduce the production of flower inhibitors (Smith et al., 1986), like fruit thinning (Smith et al., 1993).

In order for fruit thinning to maximize return bloom, the fruit must be thinned at the time that the ovule is at half expanded. Fruit thinning after the dough stage did not substantially improve return bloom (Reid et al., 1993; Smith et al., 1993). Return bloom of fruiting shoots was less than that of same season vegetative shoots (Malstrom and McMeans, 1982; Smith et al., 1986). Return bloom of lateral shoots was substantially more sensitive to over-fruiting than return bloom of terminal shoots (Wood, 1995). Mechanical fruit thinning can be used to manage crop loads to improve fruit quality and return bloom, plus alleviate other disorders (Reid et al., 1993; Smith and Gallott, 1990, Smith et al., 1993; Sparks et al., 1995).

Leaf area per fruit, the period of leaf retention in the fall, and the efficiency of the leaf affects the level of stored carbohydrates (Sparks, 1992). A low leaf to fruit ratio reduces the nut quality during the current “on” year and pistillate flower production, fruit set, and shoot growth may be decreased during the following “off” year. When the nuts reach maturity, maintaining photosynthetically competent leaves remains critical for maximizing crop production the following year because carbohydrates continue to accumulate in storage tissues (Sparks, 1992).

Nonstructural carbohydrate concentration in the roots (Crane et al., 1934; Sparks, 1974), but not the shoots (Smith et al., 1986; Wood and McMeans, 1981), was positively correlated with return bloom of pecans. This may be a useful tool to predict production potential and irregular bearing intensity. Pecan kernels are up to 70% oil and the majority of oil is accumulated during a three-week period prior to maturation (Worley, 1979a). Since oil contains twice the caloric content of carbohydrate, this represents a tremendous expenditure of tree resources in the form of translocated carbohydrate. Perhaps the discrepancy in return bloom, following "on" or "off" years, is associated with the amount of energy dedicated to fruit development and the short time period during which it must be expended.

Limited data has suggested that cultivars with early fruit ripening have a lower alternate bearing tendency than late ripening cultivars (Smith et al., 1986). Early ripening might allow trees to allocate carbohydrates for storage rather than fruit development after the fruit ripened. Some cultivars with early season fruit maturation, such as 'Osage', exhibit strong alternate bearing in the northern locations and only a moderate alternate bearing in southern areas (Conner et al., 2000), and some later ripening cultivars, such as 'Desirable', have a low alternate bearing tendency (Conner et al., 2000). This may be related to the above referenced amount of energy a cultivar expends during the short period of oil accumulation. Do cultivars that have a low alternate bearing index produce smaller fruit with fewer fruit/cluster than those with a high alternate bearing index? If this is true, then targeting smaller fruit clusters might substantially improve consistency in annual bearing.

Clearly return bloom is reduced on previous year fruiting shoots compared with vegetative shoots on the same tree (Reid et al., 1993; Smith et al., 1986; Smith et al., 1993). Defruiting affects return bloom of lateral shoots about 2-4 weeks earlier than terminal shoots. However, there is no data that relates cluster size to return bloom. It is often suggested that quality and consistent production of ‘Desirable’ can be attributed to its large fruit drop, resulting in one and two nut clusters by the dough stage. This may be related to the carbohydrate demand of the fruit, or phytohormone-like growth regulators that inhibit flower induction proportionately to the fruit or cluster size. A small fruit or cluster size may be desirable to promote consistent production and high quality nuts.

Essential elements have also been shown to affect the developmental phases of flowering. Nitrogen depletion by large crops occurs in pistachio (Brown et al., 1995; Rosecrance et al., 1998; Weinbaum et al., 1994) and is believed to have a similar effect on pecans that might inhibit flower induction or cause substantial flower abortion (Crane, 1930; Crane et al., 1934; Finch and Crane, 1931; Sparks, 1974). Storage protein accounts for most of the nitrogen utilized during the initial spring growth flush and flowering (Kraimer et al., 2001; Kraimer et al., 2004; Weinbaum et al., 1994). Stored nitrogen is also likely to affect flower initiation and abortion. In pistachios, organically bound stored nitrogen during the winter is closely associated with the “on” and “off” bearing cycles (Picchioni et al., 1997; Rosecrance et al., 1996).

Potassium is essential for photosynthesis, carbohydrate and protein synthesis and enzyme activation (Marschner, 1995). Kernel oil content is closely correlated with potassium levels (Hunter, 1956). Potassium is transported preferentially to the fruit (Diver et al., 1984) and deficiencies may limit carbohydrate synthesis and storage.

The objectives of the study were (1) to determine if return bloom is inhibited proportionally to mature cluster size, (2) to determine if cultivars with strong alternate bearing tendencies produce larger amounts of kernel per shoot resulting in a greater total energy expenditure than cultivars with a low alternate bearing index, (3) to determine if potassium levels affect carbohydrate synthesis and storage, and (4) to determine if nitrogen levels are associated with irregular bearing tends.

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Chapter II

Effects of Cluster Size and Shoot Type on Selected Pecan Characteristics.

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ABSTRACT. Whole fruit clusters of pecan [*Carya illinoinensis* (Wang.) C. Koch.] were collected from three shoot types: terminal and lateral shoots without a secondary growth flush, and shoots that had an early-season secondary growth flush. Fruit per cluster were counted and nuts were individually harvested, weighed, shelled and graded. Bloom the following year was determined for the same shoots where clusters were collected. Wafers (cotyledons that failed to develop) were not associated with cluster size or shoot type. When wafers were included in the data, nut weight, kernel percentage and return bloom were not affected by cluster size or shoot type. However, when wafers were excluded from the data there were significant relationships of cluster size and shoot type with the dependent variables. Cluster size on lateral shoots was negatively related to nut weight and kernel percentage. Cluster size on terminal shoots without a secondary growth flush was inversely related to kernel percentage, but not related to nut weight. When shoots had a secondary growth flush, cluster size was not related to kernel percentage or nut weight. There was a positive linear relationship between cluster size and total kernel weight for the three shoot types. Return bloom of terminal shoots without a secondary growth flush was negatively related to cluster size, but cluster size did not affect return bloom of the other shoot types. The number of shoots that developed the following year was positively related to cluster size for terminal and lateral shoots, but not for shoots with a secondary growth flush. Shoots with a secondary growth flush produced substantially more shoots with larger fruit clusters the next year than the other shoot types.

Pecan fruit production is irregular, typified by high production one year followed by one or more years of low production (Sparks, 1986). Irregular production is typically associated with a lack of return bloom rather than flower or fruit abortion. Crane et al. (1934) reported a leaf to fruit ratio of 8 to 10 leaves per fruit was required, and suggested that cultivars with a large cluster size might have a lower percentage of return bloom than those with a smaller cluster size. Reid (1986) speculated that cultivars with large fruit clusters typically had poorer fruit quality than cultivars with small clusters. It is often suggested by scientists working with pecans that quality and consistent production of ‘Desirable’ can be attributed to its large fruit drop, resulting in one or two fruit per cluster by the dough stage. This may be related to the fruit carbohydrate demand, or phytohormone-like growth regulators that inhibit flower induction proportionately to the fruit or cluster size.

Return bloom of fruiting shoots was reduced compared to vegetative shoots (Malstrom and McMeans, 1982; Smith et al., 1986). Return bloom of lateral shoots was substantially more sensitive to over-fruiting than return bloom of terminal shoots (Wood, 1995). Mechanical fruit thinning can be used to manage crop loads to improve fruit quality and return bloom, plus alleviate other disorders (Reid et al., 1993; Smith and Gallott, 1990, Smith et al., 1993; Sparks et al., 1995).

Although scientists have hypothesized that a small cluster size is desirable to produce high quality nuts and promote consistent production, no data exist relating cluster size to nut quality and return bloom; therefore, this study establishes those relationships. We also determined if shoot position or shoots with a secondary growth flush affected nut quality and if these different shoot types had similar return bloom characteristics.

Materials and Methods

Three 13-year-old 'Pawnee' trees growing in a Teller sandy loam (fine-loamy, mixed, active, thermie, Udic Argiustolls) in a commercially managed orchard near Charlie, Texas were selected based on uniformity of size, vigor, crop load, and location within the orchard. Trees were spaced 12.2 x 12.2 m apart and had 19.7 ± 2.1 cm diameter trunks measured 1.4 m above the ground. The entire orchard floor was maintained vegetation-free throughout the growing season with glyphosate [N –(phosphonomethyl) glycine]. Trees were irrigated with micro-sprinklers and received ample nitrogen annually. Pest management followed extension recommendations for a commercial orchard (von Broembsen et al., 1997).

Whole fruit clusters from thirty shoots each of three shoot types on each tree were individually harvested and shoots were tagged at shuck split to monitor return bloom. The three shoot types were bearing shoots without a secondary growth flush in the terminal and lateral positions on the 1-year-old branch, and bearing shoots, primarily in the terminal position, with a secondary growth flush. The number of fruit per cluster (cluster size) was recorded from each shoot and nuts were harvested at shuck split, dried, individually weighed, and shelled. A total of 270 fruit clusters were harvested ranging in size from 1 to 11 fruit per cluster for a total of nearly 1300 nuts. The following spring, total current season shoots per 1-year-old branch and the percentage of 1-year-old branches that produced one or more shoots with pistillate flowers was determined. Various models were fitted to the data and the most appropriate significant model was chosen for each variable.

Results and Discussion

Cluster size was not related to nut weight, kernel percentage or return bloom for any shoot type when nuts with undeveloped cotyledons (wafers) were retained in the data (data not shown). Percentage of wafers was not associated with cluster size for any shoot type (Fig. 1). Wafers were excluded from the data, and cluster size was recalculated along with weight/nut, kernel percentage and total kernel weight/shoot. The relationship of cluster size for each shoot type was then determined for the dependent variables.

The most frequent occurring cluster size on terminal shoots was 3 or less fruit per cluster (Fig. 1). On shoots with a secondary growth flush 5 fruit per cluster occurred more frequently than other sizes. The number of flowers per cluster was probably similar between these two shoot types, suggesting that substantially more flowers aborted on the less vigorous terminal shoots. Lateral shoots were intermediate in cluster size with 3 to 4 fruit per cluster dominating.

Cluster size was not related to average nut weight on terminal shoots and shoots with a secondary growth flush (Fig. 2). However, on lateral shoots average nut weight decreased about 18% as cluster size increased from 1 to 8 fruit per cluster. These data suggest that nuts are more likely to be smaller on lateral shoots than on terminal shoots or on shoots with a secondary growth flush as cluster size increases. The average weight per nut was 8.2 g, 8.3 g, and 8.0 g for terminal shoots, shoots with a secondary growth flush and lateral shoots, respectively. The leaves on a shoot primarily support fruit development on that shoot (Davis and Sparks, 1974). Few carbohydrates are transported from surrounding shoots to support fruit development; therefore, shoots with more leaves should to support larger fruit clusters. Terminal shoots and shoots with a secondary growth flush tend to be longer with more leaves than lateral shoots, so nut weight was only affected by cluster size on the shorter lateral shoots. Additionally, because of their location on the branch more shading of lateral shoots occurs, reducing photosynthesis and consequently nut weight.

Cluster sizes was negatively related to kernel percentage on terminal and lateral shoots, but not on shoots with a secondary growth flush (Fig. 3). On terminal shoots, kernel percentage was reduced about 5% (from 56.9% to 53.8%) and about 6% on lateral shoots as cluster size increased from 1 to 8 fruit per cluster. Kernel percentage of terminal shoots and shoots with a secondary growth flush averaged 55.8 % and 55.4 %, respectively. Nuts from lateral shoots averaged 55.0 % kernel.

Total kernel weight per shoot increased linearly as cluster size increased (Fig. 4). More fruit in a cluster should increase kernel weight per shoot. However, kernel weight increased linearly with cluster size for each shoot type. This suggests that even at 8 or 9 fruit/cluster, the shoot had not reached its maximum carrying capacity. A curved relationship would suggest that shoots were approaching their maximum fruit carrying capacity with the larger fruit cluster sizes. A reduction in kernel percentage with greater cluster size (Fig. 3) suggests that terminal and lateral shoots are nearer their carrying capacity than indicated by total kernel weight. Alternatively, shell weight may be increased disproportionately to kernel weight when cluster size is increased, and this is reflected in kernel percentage on terminal and lateral shoots.

Return bloom was negatively related to cluster size on terminal shoots, although the correlation was weak, but not on the other shoot types (Fig. 5). This suggests that return bloom on lateral shoots and shoots with a secondary growth flush was unaffected by cluster sizes from 1 fruit to 8 fruit per cluster. However, on terminal shoots return bloom was 60% with 1 fruit/cluster and reduced to 17% fruiting with 8 fruit/cluster. Return bloom, averaged over all cluster sizes, was 70% on shoots with a secondary growth flush, 33% for lateral shoots, and 43% terminal shoots.

Total shoots per 1-year-old branch increased linearly as cluster size increased on terminal and lateral shoots, but not on shoots with a secondary growth flush (Fig. 6). Values for total shoots per 1-year-old branch, averaged over all cluster sizes, were 4.2 on shoots with a secondary growth flush, 2.4 for lateral shoots, and 2.4 for terminal shoots. Cluster size was not related to total fruits per 1-year-old branch produced the following year for any shoot type (data not shown). However, shoots with a secondary growth flush produced over twice as many fruits per branch as the other shoot types. The average overall cluster sizes for total fruits per branch produced the following year was 5.7 on shoots with a secondary growth flush, 1.7 for lateral shoots, and 2.4 for terminal shoots.

These data suggest that a large cluster size on lateral shoots negatively impacts nut weight and kernel percentage. Similarly, kernel percentage was reduced by large fruit clusters on terminal shoots. Shoots with a secondary growth flush supported up to nine fruit per cluster with no effect on nut size or kernel percentage. Additionally, shoots with a secondary growth flush gave rise to more shoots with large fruit clusters the next year than other bearing shoot types. It is evident from these data that vigorous trees with substantial amounts of shoots with a secondary growth flush are more likely to produce fruit consistently. Also, vigorous shoots can carry larger fruit clusters than less vigorous shoots with little, if any, effect on quality. Note that the secondary growth flushes in this study began in June, early in the growing season. Thus the additional leaf surface area was present as the fruit developed. Pecan trees occasionally make a late season growth flush in September or early October. These are typically non-irrigated trees that have experienced summer drought followed by abundant September rainfall. Our observations suggest that a secondary growth flush in September or October is detrimental to kernel quality since the rapid shoot growth competes directly with developing cotyledons. We expect early-season and late-season growth flushes to affect nut quality and return bloom differently.

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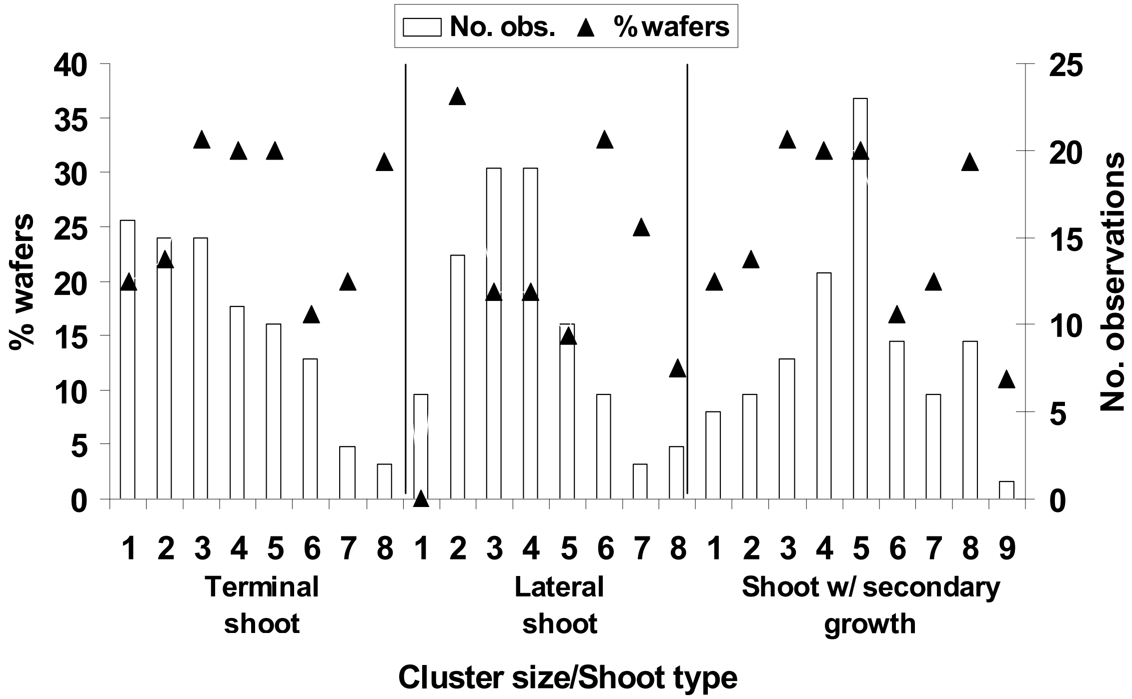

Fig 1. The number of observations for each shoot type and cluster size (vertical bars), and the relationship of cluster size and shoot type with incompletely developed cotyledons (wafers) (scatter diagram).

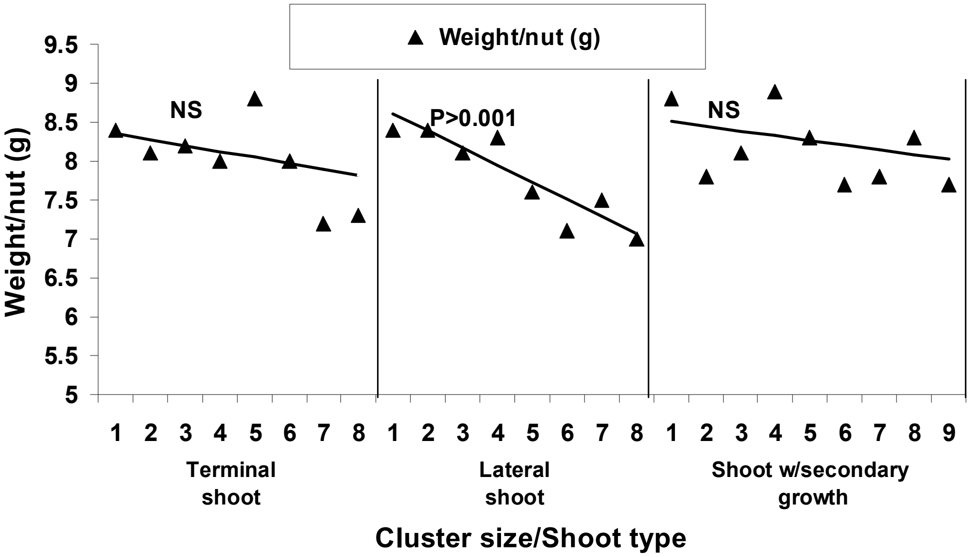

Fig 2. Relationship of cluster size and shoot type with weight per nut. Triangles are the average of 3 to 37 observations for each cluster size and shoot type. Terminal: Wt./nut (g) = 8.4 – 0.077 (cluster size), r^2 = 0.178. d.f. = 79, p > F 0.2374; lateral: Wt./nut (g) = 8.8 – 0.221 (cluster size), r^2 = 0.13, d.f. =78, p > F 0.0010; secondary growth flush: Wt./nut (g) = 8.6 – 0.061 (cluster size), r^2 = 0.02, d.f. =79, p > F 0.2735.

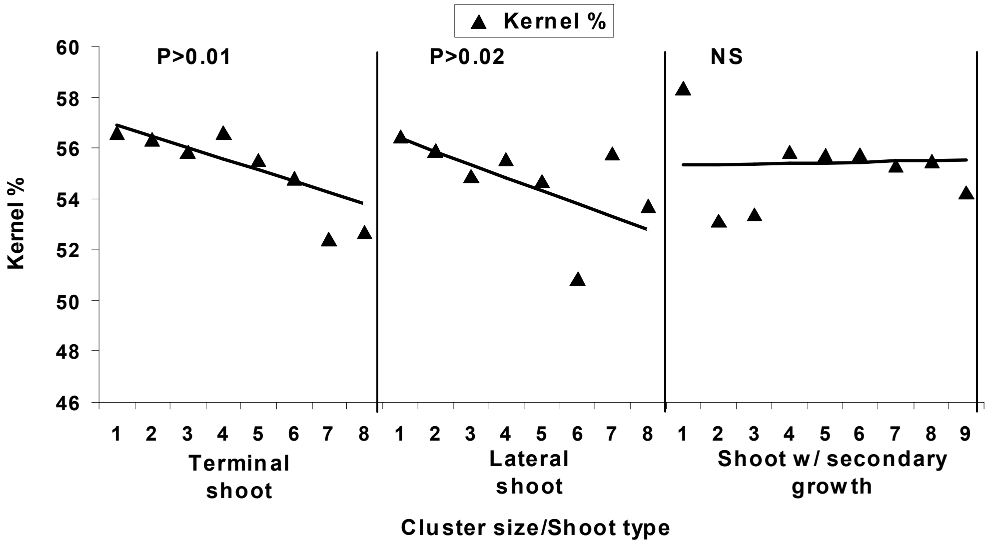

Fig 3. Relationship of cluster size and shoot type with kernel %. Triangles are the average of 3 to 37 observations for each cluster size and shoot type. Terminal: % kernel = 57.33 – 0.440 (cluster size), $r^2 = 0.08$. d.f. = 79, p > F 0.0105; lateral: % kernel = 56.87 – 0.512 (cluster size), $r^2 = 0.06$, d.f. =78, p > F 0.0237; secondary growth flush: % kernel = 55.29 + 0.025 (cluster size), $r^2 = 0.00$, d.f. =79, p > F 0.8524.

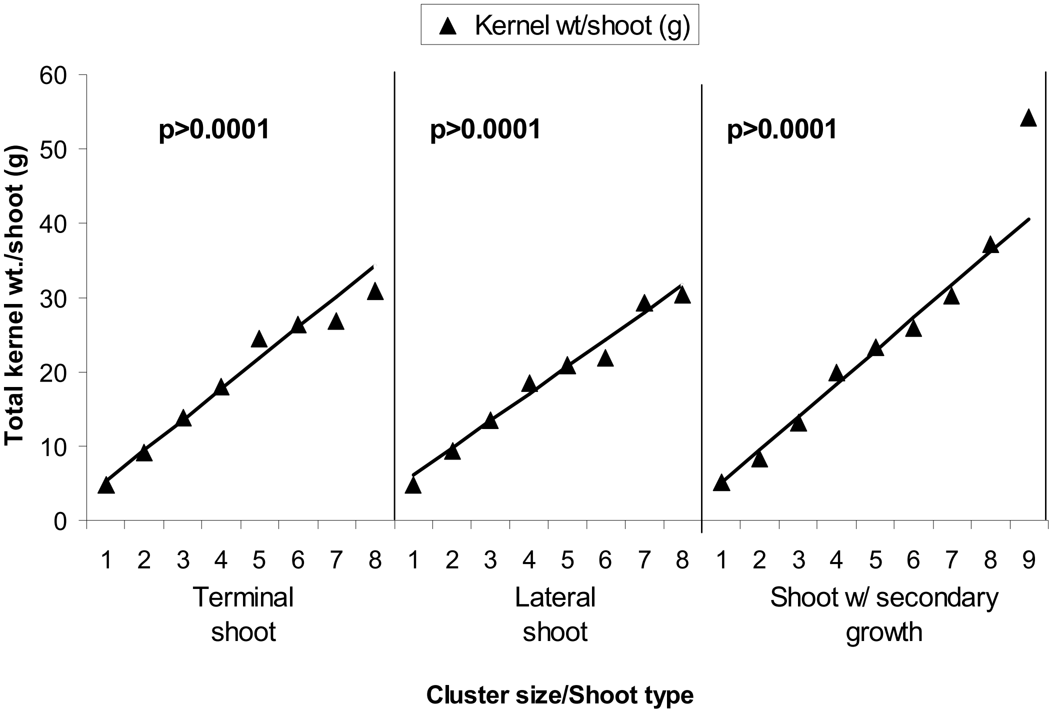

Fig 4. Relationship of cluster size and shoot type with total kernel weight/shoot. Triangles are the average of 3 to 37 observations for each cluster size and shoot type. Terminal: Total kernel wt. (g) = 1.1 + 4.17 (cluster size), $r^2 = 0.88$. d.f. = 79, $p > F$ 0.0001; lateral: Total kernel wt. (g) = 2.5 + 3.64 (cluster size), $r^2 = 0.84$, d.f. =78, $p > F$ 0.0001; secondary growth flush: Total kernel wt. (g) = 0.68 + 4.43 (cluster size), $r^2 = 0.90$, d.f. =79, $p > F$ 0.0001.

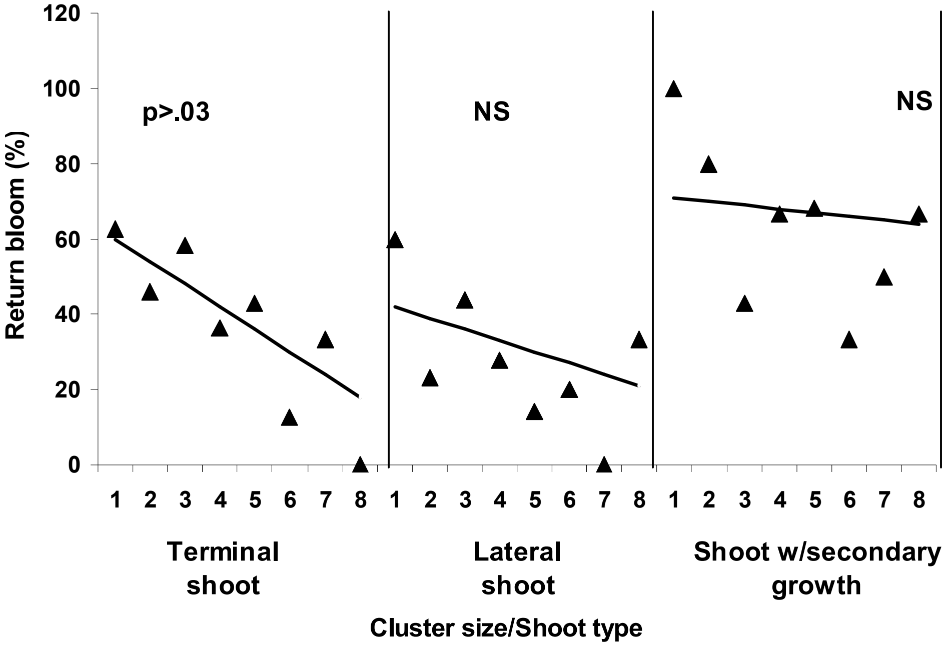

Fig 5. Relationship of cluster size with percentage of one-year-old branches producing fruiting shoots with pistillate flowers the subsequent year. Triangles are the average of 3 to 37 observations for each cluster size and shoot type. Terminal: % return bloom = 66.0 – 6.08 (cluster size), r^2 = 0.62. d.f. = 6, p > F 0.0366; lateral: % return bloom = 45.3 - 3.27 (cluster size), r^2 = 0.25, d.f. =6, p > F 0.2507; secondary growth flush: % return bloom = 72.4 – 0.98 (cluster size), r^2 = 0.01, d.f. =8, p > F 0.7672.

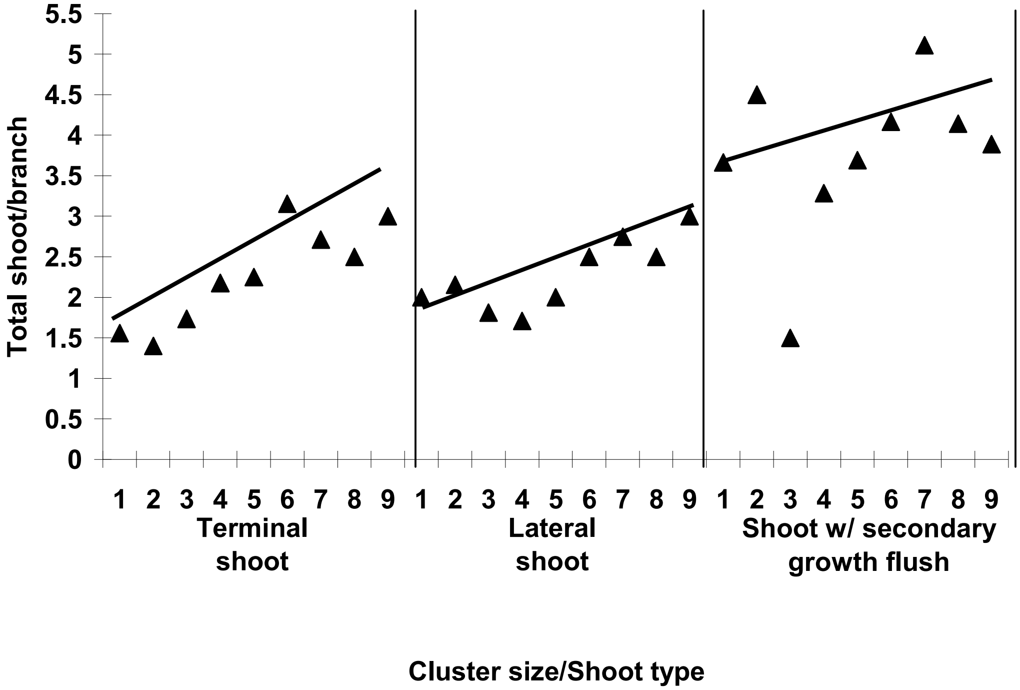

Fig 6. Relationship of cluster size and shoot type with the total shoots produced per one-year-old branch the subsequent year. Triangles are the average of 3 to 37 observations for each cluster size and shoot type. Terminal: shoots/branch = 1.64 + 0.22 (cluster size), $r^2 = 0.27$. d.f. = 71, $p > F$ 0.0001; lateral: shoots/branch = 1.83 + 0.14(cluster size), $r^2 = 0.08$, d.f. =68, $p > F$ 0.0154; secondary growth flush: shoots/branch = 3.57 + 0.134 (cluster size), $r^2 = 0.03$, d.f. =73, $p > F$ 0.1141.

CHAPTER III

The Influence of Crop Load and Shoot Position on Return Bloom, Nut Quality, Non-structural Carbohydrate Concentration, Organically Bound Nitrogen and Potassium Concentration of Pecan.

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ABSTRACT. Trees with similar crop loads were hand thinned to 1, ≤ 2, or ≤3 fruit per cluster or not thinned when the ovule was about one-half expanded. Vegetative shoots, fruiting shoots in the terminal and lateral position, and fruiting shoots with a secondary growth flush were tagged in October, and flowering was determined the following year. Shoots and roots were sampled while dormant and then analyzed for organically bound nitrogen, potassium and non-structural carbohydrates. Lateral shoots had a lower return bloom and a smaller cluster size than other shoot types. Unthinned trees produced fewer flowers than trees thinned to 2 fruit/cluster or less. Organically bound nitrogen and potassium concentration during dormancy in the roots and shoots was not affected by crop load. Carbohydrate concentrations in the roots were not affected by crop load. Shoots that produced a secondary growth flush had a lower carbohydrate

concentration than shoots without a secondary growth flush. We suggest that carbohydrate reserves were not closely related to the current season's crop load nor were they closely related to subsequent flowering.

Irregular bearing in pecans has received substantial attention (Barnett and Mielke, 1981; Monselise and Goldschmidt, 1982; Sparks, 1974, 1975, 1979, 1986, 2000, 2003; Wood. 1991; Wood et al., 2004), but the cause has yet to be identified. Some of the environmental conditions inducing irregularity are readily observable. Severe drought during the growing season (Hunter, 1963) and short-term drought during kernel development (Alben, 1958; Sparks, 1992) are conditions that may induce irregular bearing. Another observation indicates that early defoliation (Crane, 1930; Isbel, 1928; Sparks and Bract, 1970) induces irregular bearing, possibly by decreasing carbohydrate reserves (Sitton, 1933; Smith and Waugh, 1938).

The mechanisms that regulate irregular bearing are still debated. It has been suggested that assimilate reserves largely regulate irregular bearing in pecans (Crane et al., 1934; Isbel, 1928; Sparks and Bract, 1974; Smith and Waugh, 1938; Malstrom, 1974; Sparks and Brack, 1972; Wood, 1989, 1991; Worley, 1978, 1979a, 1979b). A two-level regulation of flowering by a balance of plant hormones and carbohydrate reserves during flower induction and development has been proposed (Amling and Amling, 1983; Smith et al., 1986; Wood, 2003; Wood and McMeans, 1981; Wood et al., 2003, 2004). Flowers that produce the next year's crop are initiated during the time when the current season's crop is maturing (Amling and Amling, 1983). Therefore, stress during this time may affect the next year's crop. Carbohydrate reserves stored in roots and shoots are utilized in the spring growth flush and in the terminally positioned pistillate inflorescence (Lockwood and Sparks, 1978). If stored carbohydrates are insufficient, shoot growth lacks vigor, flower development and fruit set are suppressed and the tree is considered to be “off”. If carbohydrate reserves are high, shoot growth is vigorous and the pistillate inflorescence is strong and the tree is considered to be “on” (Sparks, 1983, 1992).

Sparks (1983) suggested that the degree of flower formation was determined by the level of carbohydrate reserves that were accumulated in storage tissues during the previous growing season. This suggestion was supported by several observations: high carbohydrate accumulation usually proceeds an “on” year and low accumulation precedes an “off” year, carbohydrate reserves decrease during the spring growth flush due to their movement into the new growth, and factors that are expected to increase carbohydrate production and accumulation, such as, leaf efficiency factors, leaf area per fruit, and leaf retention, promote flowering and minimize irregular bearing (Wetzstein and Sparks, 1986). Irregular bearing seems to be alleviated by factors that favor carbohydrate accumulation, such as healthy leaves, longer leaf retention after maturity (Hinrichs, 1962), longer shoot growth with greater leaf area (Wood, 1995), and by factors that reduce the production of flower inhibitors (Smith et al., 1986), like fruit thinning (Smith et al., 1993).

Leaf area per fruit, the period of leaf retention in the fall, and the efficiency of the leaf affects the level of stored carbohydrates (Sparks, 1992). A low leaf to fruit ratio reduces the nut quality during the current “on” year and pistillate flower production, fruit set, and shoot growth may be decreased during the following “off” year. When the nuts reach maturity, maintaining photosynthetically competent leaves remains critical for maximizing crop production the following year because carbohydrates continue to accumulate in storage tissues (Sparks, 1992).

Nonstructural carbohydrate concentration in the roots (Crane et al., 1934; Sparks, 1974), but not the shoots (Smith et al., 1986; Wood, 1981), was positively correlated with return bloom of pecans. This may be a useful tool to predict production potential and irregular bearing intensity. Pecan kernels are up to 70% oil and the majority of oil is accumulated during a short three-week period prior to maturation (Worley, 1979a). Since oil contains twice the caloric content of carbohydrate, this represents a tremendous expenditure of tree resources in the form of translocated carbohydrate. Perhaps the discrepancy in return bloom following “on” or “off” years was associated with the amount of energy dedicated to fruit development and the short time period during which it must be expended.

Fruit must be thinned at the time that the ovule is at half expanded to maximize return bloom. Fruit thinning after the dough stage did not substantially improve return bloom (Reid et al., 1993; Smith et al., 1993). Return bloom of fruiting shoots was less than that of same season vegetative shoots (Malstrom and McMeans, 1982; Smith et al., 1986). Return bloom of lateral shoots was substantially more sensitive to over-fruiting than return bloom of terminal shoots (Wood, 1995). Mechanical fruit thinning can be used to manage crop loads to improve fruit quality and return bloom, plus alleviate other disorders (Reid et al., 1993; Smith and Gallott, 1990, Smith et al., 1993; Sparks et al., 1995).

Essential elements have also been shown to affect the developmental phases of flowering. Nitrogen depletion by large crops occur in pistachio (Brown et al., 1995;

Rosecrance et al., 1998; Weinbaum et al., 1994) and is believed to have a similar affect on pecans that might inhibit flower induction or cause substantial flower abortion. Storage protein accounts for most of the nitrogen utilized during the initial spring growth flush and flowering (Weinbaum et al., 1994). Stored nitrogen is also likely to affect flower initiation and abortion. Stored nitrogen has been found in the largest quantity in roots ≥ 1 cm diameter (Acuna-Maldonado et al., 2003). In pistachios, organically bound stored nitrogen during the winter was closely associated with the "on" and "off" bearing cycles (Picchioni et al., 1997; Rosecrance et al., 1996). Kraimer (2004) reported that an increased accumulation of storage nitrogen by late-season fertilizer application may reduce the depletion of nitrogen caused during an "on" year and may moderate the alternate bearing trend in pecan by providing a greater reservoir of nitrogen the following year (Kraimer et al., 2004). Potassium is essential for photosynthesis, carbohydrate and protein synthesis and enzyme activation (Marschner, 1995). Kernel oil content is closely correlated to potassium levels (Hunter, 1957). Potassium is transported preferentially to the fruit (Diver et al., 1984) and deficiencies may limit carbohydrate synthesis and storage.

Although scientists hypothesized the causes of pecan irregular bearing, it remains unclear what regulates this phenomenon. This study examines the relationships of non-structural carbohydrates, organically bound nitrogen and potassium on return bloom along with the affects that shoot position and shoots with an early-season secondary growth flush have on return bloom characteristics.

Materials and Methods

Twelve 13-year-old ‘Pawnee’ trees growing in a Teller sandy loam (fine-loamy, mixed, active, thermic, Udic Argiustolls) in a commercially managed orchard near Charlie, Texas were selected based on uniformity of size, vigor, crop load (85% to 90% bearing shoots), and location within the orchard. Trees were spaced 12.2 x 12.2 m apart and had 19.7 ± 2.1 cm diameter trunks measured 1.4 m above the ground. The entire orchard floor was maintained vegetation-free throughout the growing season with glyphosate [N – (phosphonomethyl) glycine]. Trees received supplemental irrigation from micro-sprinklers April through October. Nitrogen (in the form of urea) was surface-applied in 2001 in a split application at the rate of 112 $kg \cdot ha^{-1}$ N in March, 112 $kg \cdot ha^{-1}$ N in June and 84 $kg \cdot ha^{-1}$ N in October and NO_3-contaminated water was used for irrigation (no measurement collected). In 2002 and 2003 nitrogen was not applied on the surface, only through the NO_3-contaminated irrigation water which provided 141 $kg \cdot ha^{-1}$ N in 2002, and 191 $kg \cdot ha^{-1}$ N in 2003. Five foliar Zn applications were made between budbreak and July all three years at 2.4 $kg \cdot ha^{-1}$ Zn from 36% $ZnSO_4$. Pest management followed extension recommendations for a commercial orchard (von Broembsen et al., 1997).

Treatments were a factorial combination of four crop load levels by four shoot types. Crop load treatments were trees in which all fruit bearing shoots were hand thinned to 1, ≤ 2, or ≤ 3 fruit per cluster or not thinned when fruit were at about one-half ovule expansion, in early August. In 2001, trees were selected with a similar crop load and then treatments were assigned to trees at random and remained the same throughout the study.

Shoot types were (1) vegetative shoots, (2) bearing shoots in the terminal position without a secondary growth flush, (3) bearing shoots in the lateral position without a secondary growth flush, and (4) bearing shoots, primarily in the terminal position, with a secondary growth flush. Thirty shoots of each type per tree were tagged at shuck split to monitor return bloom. Shoots were selected at random throughout the canopy. The following spring the number of dead 1-year-old branches, new shoots/1-year-old branch, cluster size, and number of clusters that developed on the current season's growth arising from the 1-year-old tagged shoots were determined. Forty nuts of each tree were collected and nut weight, nut width, nut length, kernel percentage and grade was determined. Nut grade was based on a scale 1 to 4; 1 being a perfectly colored and filled kernel; 2 slightly discolored and/or not completely filled; 3 discolored and/or over half kernel unfilled; 4 being a reject do to discolor of kernel and/or lack of kernel fill. Total yield per tree was measured annually.

In January while trees were dormant, root and shoot samples were collected. Root samples were collected from a 1 m wide 2 m long hole by about 0.5 m deep that was 2-3 m from the trunk. A new location was chosen each time roots were sampled. Roots were separated into samples of < 1 cm and ≥ 1 cm in diameter, and then washed in tap water to remove adhering soil. The four shoot types described earlier were collected from the canopy periphery. Shoots with a secondary growth flush were divided into the primary shoot and the secondary growth flush. Both roots and shoots were stored at 0°C until they were freeze-dried to a constant weight. Samples were then ground in a Wiley mill to pass through a 20-mesh screen. Samples were stored in an airtight glass jar at 0° C until analyzed. Organically bound nitrogen was analyzed by the macro-Kjeldahl method (Horowitz, 1980) and potassium was analyzed using atomic absorption spectroscopy. Carbohydrates (starch, reducing and non-reducing sugars) were determined using Nelson's modification of Somogyi's method (Hodge and Hofreiter, 1962), which has been used on pecan tissue (Smith et al., 1986; Wood, 1984).

The design was completely randomized with each tree serving as a replication for the variables yield, nut size, kernel yield, root and shoot carbohydrate concentration, nitrogen and potassium. Each treatment was replicated three times. When the influence of shoot type was considered on return bloom then the design was a split plot with shoot type nested within thinning treatment, and the thirty shoots of each type serving as the sub-samples. Main effects and interactions were tested using analysis of variance followed by the protected LSD where appropriate.

Results

Yield data collected during the study indicates that the trees were showing signs of irregular bearing (Table 1). The 2002 crop on unthinned trees was 20% larger than the 2001 crop and 11% larger than the 2003 crop. Thinning to 3 fruit/cluster increased cumulative yield 11% compared to not thinning.

Total number of current season shoots that developed from a 1-year-old branch was not influenced by the cluster thinning treatment (data not shown). However, there was a significant interaction between year and shoot type affecting the number of new shoots per branch (Table 2). Shoots with a secondary growth flush produced more current season shoots than the other shoot types all three years. The other shoot types produced a similar number of current season shoots per branch.

Shoots with a secondary growth flush produced more flowers per 1-year-old branch than bearing shoots in the lateral position (Table 2). Total flowers produced by other shoot types were similar. Unthinned trees produced fewer flowers the next year than thinned trees two of the three years (Table 3). Trees thinned to 1 fruit/cluster produced an average of 86% more flowers than unthinned trees the next year. Thinning to 3 fruit/cluster resulted in an average 52% increase in subsequent year's flowers compared to not thinning.

There was no interaction between thinning treatments and shoot types affecting flowering of 1-year-old branches the next year (data not shown); however, there was a significant interaction between year and cluster thinning treatment affecting the percentage of 1-year-old branches flowering the next year (Table 3). Unthinned trees had substantially fewer branches flowering the next year than thinned trees. Thinning clusters to 1 or 2 fruit increased the percentage of branches with flowers two of three years compared to 3 fruit/cluster or unthinned.

Trees thinned to 1 fruit/cluster had a higher percent fruiting on current season shoots the next year than the other cluster thinning treatments all three years (Table 3). Unthinned trees had a lower percent fruiting on current season shoots than other cluster thinning treatments two of the three years. There was no interaction between thinning treatment and shoot type on percent of current season shoots fruiting the next year (data not shown).

Shoots in the terminal position on trees thinned to 2 fruit/cluster or less had a higher percent flowering on current season shoots the next year than other shoot types

(Table 4). Vegetative shoots on trees thinned to 3 fruit/cluster or on unthinned trees had a higher percent flowering on current season shoots than other shoot types.

Shoots with a secondary growth flush produced a cluster size that averaged over 19% larger than the other shoot types (Table 2). Cluster size on shoots from lateral branches tended to be smaller than those from vegetative branches, but similar in size to those from terminal branches. There was no interaction between cluster thinning treatment and year or shoot type (data not shown).

Organically bound nitrogen and potassium concentrations during dormancy in the roots were not affected by crop load or cluster thinning treatments (data not shown). However, there were differences in organically bound nitrogen and potassium concentrations in various shoot types. Organically bound nitrogen in the first flush section of the shoots with a secondary growth flush had the lowest nitrogen concentration all three years (Table 5). Terminal shoots had higher percent nitrogen than the other shoot types all three years. The secondary flush of shoots with a secondary growth flush, was second highest behind the terminal shoots, two of the three years; however, in 2003 when lateral shoots were included the lateral shoots were higher than the secondary flush (Table 5).

Trees thinned to 3 fruit/cluster had a lower concentration of organically bound nitrogen in the shoots than the other thinning treatment two of the three years (Table 6). The nitrogen concentration in other shoot types was similar.

The first flush section of the shoots with a secondary growth flush had a lower potassium concentration than the other shoot types in 2001 and 2002, but in 2003 had the highest percent (Table 5). Terminal shoots had a higher potassium concentration than vegetative shoots two of the three years, and in 2003 had the same concentration. There were no consistent differences in potassium concentrations among cluster thinning treatments (Table 6).

When carbohydrate concentration of the roots was measured there was no significant difference among treatments, for either roots < 1 cm (avg.= starch 1.18 % dry weight, nonreducing sugar 14.06 % dry weight and reducing sugar 8.06 % dry weight) and ≥ 1 cm (avg.= starch 3.54 % dry weight, nonreducing sugar 11.16 % dry weight and reducing sugar 6.52 % dry weight) in diameter. Carbohydrate concentration was not influenced by the cluster thinning treatment (data not shown). However, there was a significant difference among the shoot types. Vegetative shoots had a higher concentration of starch than the secondary flush section of shoots with a secondary growth flush two of the three years. In 2003, the secondary flush section had the highest starch concentration (Table 7). Non-reducing sugar concentration was lower in the secondary flush section of shoots with a secondary growth flush then the vegetative shoots and bearing shoots in the terminal position all three years. The secondary flush section of shoots with a secondary growth flush had a lower concentration of reducing sugars than vegetative shoots and bearing shoots in the terminal position two of the three years. Total carbohydrate concentration of the secondary flush section of shoots with a secondary growth flush were lower than the other vegetative shoots and bearing shoots in the terminal position, and bearing shoots in the lateral position in 2003 all three years. There was no interaction between cluster thinning treatments and shoot type on carbohydrate concentrations (data not shown).

When nut quality was analyzed the interaction between cluster thinning treatment and year was significantly different in regard to kernel weight, with trees thinned to 3 fruit/cluster having lighter kernels than the unthinned trees (Table 8). All other cluster thinning treatments had similar kernel weights. There was no significant interaction between year and nut weight (avg. = 8.34 g/nut), width (avg. = 23.57 mm) of nut, length (avg.= 39.15 mm) of nut, grade (avg.= 1.14) or kernel percentage (avg.= 56.77%).

Discussion

Carbohydrate reserves have been implicated in pecan alternate bearing, i.e. large crops deplete carbohydrate reserves resulting in small crops the following year (Smith and Waugh, 1938; Sparks, 1974; Sparks and Brack, 1972; Wood, 1989, 1995; Wood et al., 1987; Worley, 1979a 1979b). Since larger crop loads require more carbohydrates to develop than small crop loads, the large crop loads should deplete carbohydrates and cause greater return bloom suppression. This study indicates that carbohydrate supply was not a major factor controlling return bloom. Another study found that the total non-structural carbohydrates in the fall, during dormancy and at budbreak of current-season fruiting shoots were greater or equal to vegetative shoots, yet return bloom of vegetative shoots was significantly greater than fruiting shoots (Smith et al., 1986). Thus carbohydrates appear to play a minor role in regulating return bloom.

Organically bound nitrogen in the fruiting shoots in the terminal position was 15% higher than the other shoot types in 2002 and 2003, with the exception of the fruiting shoots in the lateral position in 2003. Terminal shoots in 2003 were 4% higher in nitrogen than the lateral shoots. However, the return bloom on the fruiting shoots in the terminal position was not different from the other shoot types in those years. This indicates that nitrogen was not limiting flower initiation or increasing flower abortion, and was not the cause of irregular bearing in pecans, as suggested for pistachios (Picchioni et al., 1997; Rosecrance et al., 1996).

Potassium concentration in the shoots was not closely associated with the carbohydrate concentrations in the shoots. For example the first flush section of shoots with a secondary growth flush had the lowest potassium concentration in 2001 and had the highest total carbohydrate concentration. In 2003, the first flush section had the highest potassium concentration and the lowest total carbohydrates. The secondary flush section had a higher potassium concentration in 2001 than the first flush section, and had a lower total carbohydrate concentration. However, in 2003 the secondary flush section had a lower potassium concentration than the first flush section and had a similar total carbohydrate concentration. This indicates that potassium was not limiting carbohydrate accumulation.

Shoots in the lateral position had at least an 8% decrease in the percent of return bloom on 1-year-old branches and 11% on current season shoots compared to other shoot types. Cluster sizes on lateral shoots were at least 15% smaller than those of vegetative shoots and shoots with a secondary growth flush. Unthinned trees produced nearly 38% fewer flowers on 1-year-old branches as did trees thinned to 2 fruit/cluster or less. Unthinned trees also had a 25% decrease in return bloom on 1-yr-old branches and nearly a 34% decrease on current season shoots compared to trees thinned to 2 fruit/cluster or less. Carbohydrate concentrations in the roots were not affected by crop load and concentration in the shoots was only affected if the shoot was from a vigorous shoot that produced a secondary growth flush. Therefore, carbohydrate reserves appear to be important in determining tree survival (Wood, 2001) and the ability to flower (Smith et al., 1986) rather than controlling flowering

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Table 1. Total tree yield affected by cluster thinning treatments.

Fruit cluster	Yield (kg/tree)			
thinning treatment	2001	2002	2003	Cumulative
1	6.4 ± 0.7	15.0 ± 1.4	11.6 ± 1.1	32.9
≤ 2	9.2 ± 4.4	21.9 ± 4.9	11.6 ± 3.5	42.6
≤ 3	13.8 ± 6.1	29.4 ± 3.2	10.9 ± 6.1	54.2
unthinned	15.0 ± 4.5	17.9 ± 8.1	16.1 ± 2.9	49.0

Table 2. The influence of year and shoot type on return bloom and cluster size.

Year	Shoot type/position	Total shoots/1 yr-old branch	Total flowers/1 yr-old branch	Cluster size
2002	Vegetative	2.06	5.80	4.36
	Fruiting, terminal position	2.37	5.53	4.05
	Fruiting, lateral position	2.20	4.36	3.95
	Fruiting, secondary growth flush	4.10	10.70	4.89
2003	Vegetative	2.09	4.70	4.51
	Fruiting, terminal position	2.15	3.40	3.73
	Fruiting, lateral position	1.74	2.21	3.50
	Fruiting, secondary growth flush	3.08	4.89	4.30
2004	Vegetative	1.99	6.28	5.65
	Fruiting, terminal position	2.59	7.13	4.70
	Fruiting, lateral position	2.13	5.23	4.53
	Fruiting, secondary growth flush	3.84	8.38	5.68
LSD $_{.05}$ Year for same shoot type		0.54	2.37	0.63
LSD $_{.05}$ Shoot type for the same or different year		0.64	2.55	0.66

Table 3. The influence of year and thinning treatment on return bloom.

Year	Fruit cluster thinning treatment	Total flowers/1 yr-old branch	Percent flowering/1 yr-old branches	Percent flowering on current season shoots
2002	1 fruit/cluster	8.05	93.5	69.2
	2 fruit/cluster	7.60	91.3	65.5
	3 fruit/cluster	8.25	87.5	62.9
	Unthinned	3.32	53.0	31.9
2003	1 fruit/cluster	5.64	86.2	56.7
	2 fruit/cluster	3.45	66.4	41.6
	3 fruit/cluster	2.02	39.8	23.0
	Unthinned	3.57	66.1	39.6
2004	1 fruit/cluster	7.52	88.6	61.4
	2 fruit/cluster	7.37	86.9	55.5
	3 fruit/cluster	7.46	89.3	57.3
	Unthinned	4.79	66.6	38.9
LSD $_{.05}$ Year for same thinning treatment		2.37	4.3	3.3
LSD $_{.05}$ Thinning treatment for the same or different year		2.55	4.2	3.3

Table 4. The influence of thinning treatment and shoot type on return bloom.

Fruit cluster thinning treatment	Shoot type/position	Percent flowering on current season shoots
1 fruit/cluster	Vegetative	62.2
	Fruiting, terminal position	69.2
	Fruiting, lateral position	62.2
	Fruiting, secondary growth flush	56.0
2 fruit/cluster	Vegetative	55.5
	Fruiting, terminal position	59.1
	Fruiting, lateral position	53.6
	Fruiting, secondary growth flush	48.5
3 fruit/cluster	Vegetative	54.5
	Fruiting, terminal position	47.4
	Fruiting, lateral position	45.6
	Fruiting, secondary growth flush	43.5
Unthinned	Vegetative	48.1
	Fruiting, terminal position	38.8
	Fruiting, lateral position	30.4
	Fruiting, secondary growth flush	29.9
LSD $_{.05}$ Thinning treatment for same shoot type		3.3
LSD $_{.05}$ Shoot type for the same or different thinning treatment		3.3

Table 5. The influence of year and shoot type on N and K concentration in shoot samples.

Year	Shoot type/position	% dry weight	
		N	K
2001	Vegetative	0.98	0.36
	Terminal fruiting	1.03	0.41
	First flush	0.91	0.29
	Secondary flush	1.00	0.41
2002	Vegetative	0.87	0.38
	Terminal fruiting	1.05	0.46
	First flush	0.83	0.33
	Secondary flush	0.89	0.42
2003	Vegetative	0.89	0.45
	Terminal fruiting	1.11	0.46
	First flush	0.83	0.60
	Secondary flush	0.94	0.41
	Lateral fruiting	1.07	0.52
LSD .05 Year for same shoot type		0.02	0.02
LSD .05 Shoot type for the same or different year		0.02	0.02

Table 6. The influence of year and fruit cluster thinning treatment on N and K concentration in shoot samples.

Year	Fruit cluster thinning treatment	% dry weight	
		N	K
2001	1	1.00	0.34
	≤ 2	0.99	0.36
	≤ 3	0.93	0.40
	unthinned	0.99	0.37
2002	1	0.92	0.42
	≤ 2	0.92	0.38
	≤ 3	0.88	0.39
	unthinned	0.93	0.40
2003	1	0.99	0.47
	≤ 2	0.96	0.51
	≤ 3	0.97	0.50
	unthinned	0.95	0.47
LSD .05 Year for same thinning treatment		0.02	0.02
LSD .05 Thinning treatment for the same or different year		0.02	0.02

Table 7. The influence of year and shoot type on carbohydrate concentration in the shoot samples

Year	Shoot type/position	Carbohydrate concentration (% dry weight)			
		Starch	Non-Reducing sugar	Reducing sugar	Total carbohydrates
2001	Vegetative	0.91	11.80	4.66	17.44
	Fruiting, terminal position	0.49	12.24	4.11	16.84
	Fruiting, first flush section	1.01	12.57	5.68	19.26
	Fruiting, secondary flush section	0.39	7.29	1.05	8.72
2002	Vegetative	1.20	11.06	3.63	15.89
	Fruiting, terminal position	0.91	9.57	3.82	14.30
	Fruiting, first flush section	0.28	6.54	3.87	10.69
	Fruiting, secondary flush section	0.27	5.48	2.95	8.70
2003	Vegetative	0.43	9.73	3.92	14.08
	Fruiting, terminal position	0.45	9.31	4.32	14.08
	Fruiting, first flush section	0.97	4.26	5.64	10.87
	Fruiting, secondary flush section	1.20	4.47	5.63	11.30
	Fruiting, lateral position	0.41	7.25	7.08	14.73
LSD $_{.05}$ Year for same shoot type		0.11	0.59	0.31	0.67
LSD $_{.05}$ Shoot type for the same or different year		0.12	0.64	0.34	0.75

Table 8. The influence of year and fruit cluster thinning treatment on kernel weight.

Year	Fruit cluster thinning treatment	kernel weight (g)
2001	1	4.84
	≤ 2	4.57
	≤ 3	4.21
	unthinned	5.02
2002	1	4.95
	≤ 2	4.96
	≤ 3	5.13
	unthinned	4.89
2003	1	4.69
	≤ 2	4.60
	≤ 3	4.42
	unthinned	4.34
LSD $_{.05}$ Year for same cultivar		0.47
LSD $_{.05}$ Shoot type for the same or different year		0.63

Chapter IV

The Influence of Cultivar and Shoot Position on Return Bloom, Nut Quality, Non-structural Carbohydrate Concentration, Organically Bound Nitrogen and Potassium Concentration of Pecan.

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ABSTRACT. Four cultivars were chosen based on their alternate bearing tendency. The cultivars were 'Colby' and 'Peruque' (low to medium alternate bearing index) and 'Osage' and 'Giles' (high alternate bearing index).Vegetative shoots and fruiting shoots in the terminal and lateral position were tagged in October, and flowering was determined the following year. Shoots and roots were sampled while dormant then analyzed for organically bound nitrogen, potassium and non-structural carbohydrates. Trees displayed the classic alternate bearing pattern. On trees with a high alternate bearing index vegetative shoots produced more current season shoots than other shoot types. Trees with a low alternate bearing index produced more fruit the next year on the bearing shoots in the terminal position, than the other shoot types. Potassium concentration in the shoots was higher in ‘Peruque’ trees than in the other cultivars all three years of the study. Vegetative shoots also had a lower potassium concentration than the other shoot types all three years. There were no significant differences among cultivars in non-structural carbohydrates in the roots and the differences in the shoots showed no pattern through the three years of the study. We suggest that carbohydrate concentration in dormant tissues was not related to alternate bearing tendency and that carbohydrate reserves were not triggers of irregular bearing in pecan trees.

Fruit trees have a tendency to be alternate or biennial bearing, which is producing fruit in a cycle where a large crop is followed by little or no crop. This is especially severe in pecan (Monseilise and Goldschmidt, 1982). Unlike other fruit crops pecan fruit matures late in the season, leaving little time for carbohydrate storage to occur before leaf fall. Carbohydrate reserves stored in roots and shoots are utilized in the spring flush of shoot growth and in the terminally positioned pistillate inflorescence (Lockwood and Sparks, 1978). If stored carbohydrates are insufficient, shoot growth lacks vigor, flower development and fruit set are suppressed and the tree is considered to be “off” (Sparks, 1983, 1992). If carbohydrate reserves are high, shoot growth is vigorous and the pistillate inflorescence is strong and the tree is considered to be “on”.

Limited data has suggested that cultivars with early fruit ripening have a lower alternate bearing tendency than late ripening cultivars (Smith et al., 1986). Early ripening might allow trees to allocate carbohydrates for storage rather than fruit development after the fruit ripened. Nonstructural carbohydrate concentration in the roots (Crane et al., 1934; Smith and Waugh, 1938; Sparks, 1974; Wood, 1989; Worley, 1979b), but not the shoots (Smith et al., 1986; Wood and McMeans, 1981), was positively correlated with return bloom of pecans, and may be a useful tool in predicting production potential and alternate bearing intensities. However, some cultivars with early season fruit maturation, such as 'Osage', exhibit strong alternate bearing in the northern locations and only a moderate alternate bearing in southern areas (Conner et al., 2000), and some later ripening cultivars, such as 'Desirable', have a low alternate bearing tendency (Conner et al., 2000). This may be related to the amount of energy a cultivar expends in fruit development. Pecan kernels are about 70% oil, and the majority of oil is accumulated during a short 3 week period prior to maturation (Worley, 1979a). Since oil contains twice the calorie content of carbohydrate, this represents a tremendous expenditure of tree resources in the form of translocated carbohydrate. Perhaps the discrepancy in return bloom is associated with the amount of energy dedicated to fruit development. Do cultivars that have a low alternate bearing index produce smaller fruit with fewer fruit/cluster than those with a high alternate bearing index? If this is true, then targeting smaller fruit clusters might substantially improve consistency in annual bearing.

Essential elements have been shown to affect the developmental phases of flowering. Nitrogen depletion by large crops occurs in pistachio (Brown et al., 1995; Rosecrance et al., 1998; Weinbaum et al., 1994). Storage protein accounts for most of the nitrogen utilized during the initial spring growth flush and flowering (Kraimer et al., 2001; Kraimer et al., 2004; Weinbaum et al., 1994). Stored nitrogen is also likely to affect flower initiation and abortion. Stored nitrogen has been found in the largest quality in roots ≥ 1 cm diameter (Acuna-Maldonado et al., 2003). In pistachios, organically bound stored nitrogen during the winter was closely associated with the "on" and "off" bearing cycles (Picchioni et al., 1997; Rosecrance et al., 1996). Kraimer (2004) reported that an increased accumulation of storage nitrogen by late-season application may reduce the depletion of nitrogen caused during an "on" year and may moderate the alternate bearing trend in pecan by providing a greater reservoir of nitrogen the following year (Kraimer et al., 2004).

Potassium is essential for photosynthesis, carbohydrate and protein synthesis and enzyme activation (Marschner, 1995). Kernel oil content was closely correlated to potassium levels (Hunter, 1957). Potassium was transported preferentially to the fruit (Diver et al., 1984) and deficiencies may limit carbohydrate synthesis and storage.

Although scientists hypothesized controls of irregular bearing in pecans, it remains unclear what triggers this phenomenon and what effect non-structural carbohydrate, nitrogen and potassium concentration have on return bloom, and nut quality. This study uses two cultivars with a low to medium alternate bearing index and two cultivars with a high alternate bearing index to determine the relationship of non-structural carbohydrates, nitrogen and potassium concentrations on flowering. We also determine how shoot types and position affect subsequent flowering on these four cultivars.

Materials and Methods

Four cultivars, located at the Kansas pecan research station, near Chetopa, Kansas, were chosen in 2001 based on their alternate bearing tendency. The cultivars with a low to medium alternate bearing index were 'Colby' and 'Peruque' and those with a high alternate bearing index were ‘Osage’ and ‘Giles’. Trees were 20-years-old and chosen to have a similar crop load (60% to 70% bearing shoots) at the beginning of the study. Trees were spaced 12.2 x 12.2 m apart and had 20.8 ± 3.0 cm diameter trunks measured 1.4 m above the ground. Nitrogen was surface-applied in March at 112 $kg \cdot ha^{-1}$ N from urea. Pest control practices followed standard recommendations.

Shoot types were (1) vegetative shoots, (2) fruit bearing shoots in the terminal position, (3) fruit bearing shoots in the lateral position. Thirty shoots of each shoot type per tree were tagged at shuck split to monitor return bloom. Shoots were selected at random throughout the canopy. The following spring the number of dead 1-year-old branches, new shoots/1-year-old branch, cluster size, and number of current season’s growth with female flower clusters were determined. Forty nuts from each tree were collected and nut weight, nut width, nut length, kernel percentage and grade were determined. Total yield per tree was measured annually.

In January while trees were dormant, root and shoot samples were collected. Root samples were collected from a 1 m wide 2 m long hole by about 0.5 m deep that was 2-3 m from the trunk. A new location was chosen each time roots were sampled. Roots were separated into samples of < 1 cm and ≥ 1 cm in diameter, and then washed in tap water to remove adhering soil. The three shoot types described earlier were collected from the canopy periphery. Both roots and shoots were stored at 0°C until they were freeze-dried to a constant weight. Samples were then ground in a Wiley mill to pass through a 20-mesh screen. Samples were stored in an airtight glass jar at 0° C until analyzed. Organically bound nitrogen was analyzed by the macro-Kjeldahl method (Horowitz, 1980) and potassium was analyzed using atomic absorption spectroscopy.

Carbohydrates (starch, reducing and non-reducing sugars) were determined using Nelson’s modification of Somogyi’s method (Hodge and Hofreiter, 1962), which has been used on pecan tissue (Smith et al., 1986; Wood, 1984).

The design was completely randomized with each tree serving as a replication for the variables yield, nut size, kernel yield, root and shoot carbohydrate, nitrogen and potassium concentration. Each treatment was replicated five times. When the influence of shoot type was considered on return bloom the design was a split plot with shoot type nested within cultivar, and the thirty shoots of each type served as the sub-samples. Main effects and interactions were tested using analysis of variance with mean separation by the protected LSD.

Results

Average dates of 50% shucksplit at Chetopa, Kansas for the four cultivars were as follows: ‘Osage’ – September 18; ‘Peruque’ – September 23; ‘Colby’ – September 25; and ‘Giles’ – October 30. Total production per cultivar was collected and indicates that the cultivars were in an irregular bearing pattern. The cultivars with the high alternate bearing index (‘Giles’ and ‘Osage’) both showed extreme differences among years in total production (Table 9). ‘Giles’ had the greatest alternate bearing with a 44-fold difference between the high and low production years. ‘Osage’ had a four-fold difference in the high and low year yields. Total production of ‘Peruque’ (low alternate bearing index) was similar in 2001 and 2002, and was 24 percent higher in 2003 than the previous years (Table 9). Production of ‘Colby’ (low alternate bearing index) decreased each year (Table 9).

Total number of current season shoots that developed from a 1-year-old branch was influenced by cultivar. In 2002 ‘Giles’ produced more current season shoots than ‘Peruque’ (Table 10). The other cultivars had a similar number of current season shoots. In 2003 all cultivars produced a similar number of current season shoots. ‘Colby’, in 2004, produced more current season shoots than ‘Giles’.

In 2002, bearing shoots in the lateral position had fewer shoots on 1-year-old branches than the other shoot types (Table 11). All shoot types produced a similar number of current season shoots in 2001 and 2003. Total number of current season shoots that developed from a 1-year-old branch was not influenced by shoot type within each cultivar (data not shown).

Total flowers produced on 1-year-old branches indicated that ‘Giles’ produced nearly twice the flowers in 2002 as the other cultivars; however, in 2003 ‘Giles’ produced four to ten times less flowers than the other cultivars (Table 10). During the “on” year (2003) ‘Colby’ had fewer flowers than ‘Peruque’ or ‘Osage’. Flower number of ‘Colby’ was similar to ‘Peruque’ and ‘Osage’ during the other two years. Flower numbers (Table 10) were closely related to yield (Table 9).

There was an interaction between cultivar and shoot type affecting the number of flowers produced on 1-year-old branches. On trees with a high alternate bearing index (‘Giles’ and ‘Osage’) vegetative shoots produced more flowers than other shoot types (Table 12). Trees with a low alternate bearing index (‘Colby’ and ‘Peruque’) produced more flowers the next year on the bearing shoots in the terminal position, than the other shoot types (Table 12). Bearing shoots in the lateral position tended to produce fewer flowers the next year than the other shoot types; however, differences were not always significant.

The percent flowering on 1-year-old branches was not influenced by shoot type (data not shown); however, there was an interaction between cultivars and year. Irregular bearing of ‘Giles’ was apparent since trees had a higher percent flowering in 2002 and then again in 2004, while 2003 was low. Both ‘Peruque’ and ‘Osage’ had a higher percent flowering in 2003, while 2002 and 2004 was low. ‘Colby’ percent flowering increased each year (Table 10). Cultivars with a high alternate bearing index had a similar percent flowering on 1-year-old branches as low alternate bearing index cultivars (74% and 73%, respectively) during the “on” years. During the “off” years, cultivars with a low alternate bearing index had a 61% higher percent flowering on 1-year-old branches than the high alternate bearing cultivars (50% and 31%, respectively). Bearing shoots in the terminal position had a higher percent flowering on 1-year-old branches of ‘Osage’ and ‘Peruque’ than the other shoot type (Table 12). Vegetative shoots had a higher flowering percentage than the other shoot types on ‘Giles’ and there was no influence of shoot type on percent flowering on 1-year-old branches of ‘Colby’ trees (Table 12).

In 2002, there were not significant differences in cluster size among cultivars; however, in 2003 and 2004 ‘Giles’ produced smaller clusters than the other cultivar (Table 10). ‘Osage’ had smaller clusters than ‘Colby’ in 2004. Otherwise, cluster size was similar among cultivars. There was an influence on cluster size with respect to shoot type and cultivar, but the differences did not exhibit a discernable pattern (Table 12).

Organically bound nitrogen was different among the cultivars. These differences had no pattern (Table 13). Potassium concentration was higher in 'Peruque' trees all three years than in the other cultivars (Table 13). Vegetative shoots also had a lower potassium concentration than the other shoot types all three years (Table 14).

There were no significant differences among cultivars in non-structural carbohydrates in roots < 1 cm diameter (avg.= starch 1.86 % dry weight, nonreducing sugar 7.42 % dry weight and reducing sugar 8.68 % dry weight) and > 1 cm diameter (avg.= starch 4.46 % dry weight, nonreducing sugar 7.29 % dry weight and reducing sugar 6.87 % dry weight). However, there was a significant difference among the shoot types. Vegetative shoots had a higher starch concentration than the other shoot types two of the three years, and bearing shoots in the lateral position had a lower concentration than bearing shoots in the terminal position all three years (Table 15). Starch concentration was different among cultivars with 'Osage' having a lower starch concentration than the other cultivars two of the three years (Table 16). The other cultivars had similar concentration of starch. In regard to non-reducing, and reducing sugars and total carbohydrates there was no influence of cultivars (Table 16). There were differences in the shoot types; however, the differences were random throughout the years and showed no pattern among shoot types (Table 15).

There was a significant interaction between cultivar and year affecting nut width and grade. 'Osage' had wider nuts than 'Colby' and 'Giles' all three years (Table 17). The only significant difference in grade was in 2003, 'Giles' grade was twice as high as the other cultivars (Table 17). There were no significant interactions between year and cultivar affecting nut weight, length of nut, or kernel percentage (data not shown).

However, there was significant difference among cultivars in regard to nut weight, length and kernel percentage. ‘Colby’ had 23% heavier nuts than ‘Giles’ and ‘Osage’, and 37% heavier nuts than ‘Peruque’ (data not shown). ‘Colby’ also produced a longer nut than all the other cultivars (data not shown). However, ‘Colby’ had the lowest kernel percentage when compared to the other cultivars. ‘Peruque’ had the highest kernel percentage with a 10% larger percentage than ‘Osage’ and ‘Giles’, and a 23% larger percentage than ‘Colby’ (data not shown).

Discussion

It has been suggested that cultivars with early fruit ripening have a lower alternate bearing tendency than late ripening cultivars (Smith et al., 1986). This may be because early ripening allows trees to allocate carbohydrates for storage after the fruit ripened. However, some cultivars with early season fruit maturation, such as ‘Osage’, exhibit strong alternate bearing (Conner et al., 2000) and some later ripening cultivars, such as ‘Desirable’, have a low alternate bearing tendency (Conner et al., 2000). This may be related to the amount of energy a cultivar expends in fruit development. Pecan kernels are high in oil, and the majority is accumulated during a short 3 week period prior to maturation (Worley, 1979a). Since oil contains more calories than carbohydrates, this represents a tremendous expenditure of tree resources in the form of translocated carbohydrate. Therefore the amount of energy dedicated to fruit development may influence return bloom. ‘Peruque’ a low alternate bearing cultivar produced 26% more flowers than the high alternate bearing cultivars and had a 10% larger kernel percentage. However, ‘Colby’ the other low alternate bearing cultivar produced a similar amount of fruit as the high alternate bearing cultivars, but ‘Colby’ had a 12% lower kernel percentage than the high alternate bearing cultivars. ‘Colby’ also produced the heaviest nut, 23% heavier than the ‘Giles’ and ‘Osage’, and 37% heavier than ‘Peruque’. ‘Giles’ a high alternate bearing cultivar produced the smallest cluster size, 19% smaller than the other cultivars. This data suggests that fruit size and cluster size is not related to fruit ripening dates, or alternate bearing tendencies.

Organically bound nitrogen and potassium concentrations during dormancy in the roots were not affected by cultivar. There were differences among shoot types. Organically bound nitrogen was slightly different among cultivars; however, no pattern was evident. This suggests that organically bound nitrogen was not limiting and thus not contributing to alternate bearing.

Shoots of ‘Peruque’ had a 7% higher potassium concentration in 2001 and 13% higher in 2002 and 2003, than the other cultivars. Vegetative shoots had a 16% lower potassium concentration in 2001, 7% lower in 2002, and 26% lower in 2003, than the other cultivars. ‘Peruque’, a low alternate bearing cultivar, produced more flowers and had a higher potassium concentration than the other cultivars, suggesting that potassium may have limited flower production.

Data from this study indicates that non-structural carbohydrate concentrations are not closely linked to alternate bearing of pecans. In fact, this data supports a previous study (Wood et al., 2003) that suggests that carbohydrate concentrations in storage tissues during the dormant season were not linked to alternate bearing.

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Table 9. Total tree production of the four cultivar and their alternate bearing index.

Cultivar	Yield (kg/tree)			
	2001	2002	2003	(I)*
Colby	8.49	6.54	3.63	0.21
Peruque	8.99	8.69	11.49	0.08
Giles	4.45	10.22	0.23	0.67
Osage	11.71	3.77	14.62	0.55

* alternate bearing index $(I) = 1/(n-1) * \{|(a_2 - a_1)|/(a_2 + a_1) + |(a_3 - a_2)|/(a_3 + a_2)\}$

where n = number of years

a = production of trees

Alternate bearing index ranges from 0 to 1, the higher the index the more tendency a tree has to alternate bearing

Table 10. The influence of year and cultivar on return bloom and cluster size.

Year	Cultivar	Total shoots/1 yr-old branch	Total flowers/1 yr-old branch	Percent flowering/1 yr-old branches	Percent flowering on current season	Cluster Size
2002	Colby	1.65	1.08	35.52	23.80	3.06
	Peruque	1.56	2.22	59.42	44.19	3.07
	Giles	1.82	3.82	84.85	66.42	3.05
	Osage	1.58	1.60	48.58	34.95	2.90
2003	Colby	1.82	1.86	43.94	31.27	3.46
	Peruque	1.79	5.05	89.51	75.62	3.73
	Giles	1.75	0.51	18.54	11.92	2.87
	Osage	1.82	4.68	75.82	67.12	3.70
2004	Colby	1.69	2.09	56.48	40.09	3.79
	Peruque	1.56	1.57	54.67	46.39	3.37
	Giles	1.46	2.06	64.14	56.54	2.25
	Osage	1.72	0.46	26.10	18.48	3.05
LSD $_{.05}$ Year for same cultivar		0.23	1.34	5.26	4.39	0.31
LSD $_{.05}$ Cultivar for the same or different year		0.25	1.55	5.79	4.90	0.32

Table 11. The influence of year and shoot type on return bloom.

Year	Shoot type/position	Total shoots/1 yr-old branch	Total flowers/1 yr-old branch
2001	Vegetative	1.61	2.26
	Fruiting, terminal position	1.77	2.39
	Fruiting, lateral position	1.58	1.58
2002	Vegetative	1.98	3.95
	Fruiting, terminal position	1.85	2.78
	Fruiting, lateral position	1.54	2.37
2003	Vegetative	1.65	1.73
	Fruiting, terminal position	1.67	1.46
	Fruiting, lateral position	1.56	0.93
LSD .05 Year for same shoot type		0.23	NS
LSD .05 Shoot type for the same or different year		0.25	NS

Table 12. The influence of cultivar and shoot type on return bloom and cluster size.

Cultivar	Shoot type/position	Total flowers/1 yr-old branch	Percent flowering/1 yr-old branches	Percent flowering on current season	Cluster size
Colby	Vegetative	1.57	41.80	28.51	3.44
	Fruiting, terminal position	1.97	46.97	31.74	3.59
	Fruiting, lateral position	1.41	45.94	34.35	3.35
Peruque	Vegetative	3.09	67.21	54.93	3.70
	Fruiting, terminal position	3.47	74.07	61.36	3.47
	Fruiting, lateral position	2.42	67.28	53.29	3.27
Giles	Vegetative	2.83	65.54	53.45	2.91
	Fruiting, terminal position	1.95	57.13	45.72	2.59
	Fruiting, lateral position	1.25	46.61	36.49	2.74
Osage	Vegetative	3.10	52.27	44.79	3.76
	Fruiting, terminal position	1.76	60.42	44.73	3.23
	Fruiting, lateral position	1.67	52.50	43.74	3.10
LSD $_{.05}$ Year for same shoot type		0.23	5.26	4.39	0.32
LSD $_{.05}$ Shoot type for the same or different year		0.25	5.76	4.90	0.32

Table 13. The influence of year and cultivar on N and K concentration in shoot samples.

		% (dry weight)	
Year	Cultivar	N	K
2001	Colby	1.02	0.51
	Peruque	1.01	0.62
	Giles	0.98	0.44
	Osage	1.12	0.58
2002	Colby	0.85	0.39
	Peruque	0.85	0.53
	Giles	0.86	0.46
	Osage	0.84	0.46
2003	Colby	0.90	0.50
	Peruque	0.96	0.59
	Giles	0.90	0.51
	Osage	0.85	0.47
LSD .05 Year for same shoot type		0.02	0.02
LSD .05 Shoot type for the same or different year		0.02	0.02

Table 14. The influence of year and shoot type on N and K concentration in shoot samples.

Year	Shoot type/position	% (dry weight) N	% (dry weight) K
2001	Vegetative	1.02	0.47
	Fruiting, terminal position	1.06	0.56
	Fruiting, lateral position	1.04	0.58
2002	Vegetative	0.79	0.42
	Fruiting, terminal position	0.87	0.50
	Fruiting, lateral position	0.88	0.45
2003	Vegetative	0.82	0.40
	Fruiting, terminal position	0.95	0.54
	Fruiting, lateral position	0.93	0.61
LSD .05 Year for same shoot type		NS	0.02
LSD .05 Shoot type for the same or different year		NS	0.02

Table 15. The influence of year and shoot type on non-structural carbohydrate concentration in selected shoot types.

		Carbohydrate concentration (% dry weight)			
Year	Shoot type/position	Starch	Non-Reducing sugar	Reducing sugar	Total carbohydrates
2001	Vegetative	1.12	7.07	5.58	13.78
	Fruiting, terminal position	0.94	9.96	2.87	13.78
	Fruiting, lateral position	0.33	4.62	5.47	10.42
2002	Vegetative	0.26	7.34	5.07	12.67
	Fruiting, terminal position	0.62	6.92	8.92	16.45
	Fruiting, lateral position	0.23	7.90	6.21	14.34
2003	Vegetative	0.95	7.38	8.72	17.05
	Fruiting, terminal position	0.82	5.12	6.80	12.74
	Fruiting, lateral position	0.59	7.17	6.29	14.06
LSD $_{.05}$ Year for same shoot type		0.06	0.41	0.31	0.56
LSD $_{.05}$ Shoot type for the same or different year		0.08	0.43	0.34	0.63

Table 16. The influence of year and cultivar on non-structural carbohydrate concentration in selected shoot types.

		Carbohydrate concentration (% dry weight)			
			Non-Reducing	Reducing	Total
Year	Cultivar	Starch	sugar	sugar	carbohydrates
2001	Colby	0.82	7.34	5.47	13.64
	Peruque	0.82	7.41	4.68	12.91
	Giles	1.02	7.38	4.41	12.81
	Osage	0.53	6.77	4.17	11.46
2002	Colby	0.35	7.62	7.12	15.09
	Peruque	0.38	7.46	7.15	14.99
	Giles	0.34	7.60	6.70	14.64
	Osage	0.41	6.92	6.02	13.35
2003	Colby	0.79	6.60	7.44	14.83
	Peruque	0.83	6.58	7.36	14.77
	Giles	0.80	6.34	6.56	13.70
	Osage	0.67	6.56	7.06	14.29
LSD $_{.05}$ Year for same cultivar		0.06	NS	NS	NS
LSD $_{.05}$ Cultivar for the same or different year		0.08	NS	NS	NS

Table 17. The influence of year and cultivar on width, length and grade of nuts.

Year	Cultivar	width (mm)	length (mm)	grade*
2001	Colby	18.7	42.5	1.2
	Peruque	19.6	31.2	1.3
	Giles	18.2	36.5	1.5
	Osage	19.9	30.0	1.3
2002	Colby	17.7	38.2	1.1
	Peruque	18.1	31.0	1.0
	Giles	17.9	35.2	2.3
	Osage	19.6	29.1	1.0
2003	Colby	18.5	42.4	1.1
	Peruque	18.6	31.7	1.0
	Giles	18.3	37.0	1.0
	Osage	19.8	30.1	1.4
LSD $_{.05}$ Year for same cultivar		0.4	NS	0.6
LSD $_{.05}$ Cultivar for the same or different year		0.5	NS	0.6

*Grade is in a range 1 to 4 with 1 being a completely filled kernel and 4 being a reject.

CHAPTER V

CONCUSION

The research project discussed herein involves suggested triggers for alternate bearing in pecans. The suggested triggers investigated in the study were non-structural carbohydrate concentration, organically bound nitrogen, and potassium concentration in selected tree tissues. The selected tissues were roots with less than 1 cm in diameter, roots with greater than 1 cm in diameter, vegetative shoots, fruiting shoots in the terminal position, fruiting shoots in the lateral position, and fruiting shoots with a secondary growth flush, all during dormancy. Cultivars were also studied to determine if cultivars with different alternate bearing indexes had different or similar concentration of carbohydrate, nitrogen or potassium.

This research project required three experiments. The first study was used to determine the effects of cluster size and of different shoots on nut quality and return bloom. Whole fruit clusters were collected from three shoot types: terminal and lateral shoots without a secondary growth flush, and shoots that had an early-season secondary growth flush. Fruit per cluster were counted and nuts were individually harvested, weighed, shelled and graded. Blooms the following year were determined for the same shoots where clusters were collected. Cluster size on lateral shoots was negatively related to nut weight and kernel percentage. Cluster size on terminal shoots without a secondary growth flush was inversely related to kernel percentage, but not related to nut weight. When shoots had a secondary growth flush, cluster size was not related to kernel percentage or nut weight. There was a positive linear relationship between cluster size and total kernel weight for the three shoot types. Return bloom of terminal shoots without a secondary growth flush was negatively related to cluster size, but cluster size did not affect return bloom of the other shoot types. The number of shoots that developed the following year was positively related to cluster size for terminal and lateral shoots, but not for shoots with a secondary growth flush. Shoots with a secondary growth flush produced substantially more shoots with larger fruit clusters the next year than the other shoot types.

The second study was used to determine whether carbohydrate concentrations and potassium and nitrogen levels in tissues were associated with alternate bearing tends. Trees with similar crop loads were hand thinned to 1, ≤ 2, or ≤ 3 fruit per cluster or not thinned when the ovule was about one-half expanded. Vegetative shoots, fruiting shoots in the terminal and lateral position, and fruiting shoots with a secondary growth flush were tagged in October, and flowering was determined the following year. Shoots and roots were sampled while dormant then analyzed for organically bound nitrogen, potassium and non-structural carbohydrates. Lateral shoots had a lower return bloom and a smaller cluster size than other shoot types. Unthinned trees produced fewer flowers than trees thinned to 2 fruit/cluster or less. Organically bound nitrogen and potassium concentration during dormancy in the roots and shoots was not affected by crop load.

Carbohydrate concentrations in the roots were not affected by crop load. Shoots that produced a secondary growth flush had a lower carbohydrate concentration than shoots without a secondary growth flush. These data suggest that carbohydrate reserves were not closely related to the current season's crop load nor were they closely related to subsequent flowering.

The purpose of the third study was to determine if cultivars with strong alternate bearing tendencies produce larger amounts of kernel per shoot resulting in a greater total energy expenditure than cultivars with a low alternate bearing index. Four cultivars were chosen based on their alternate bearing tendency. The cultivars were 'Colby' and 'Peruque' (low to medium alternate bearing index) and 'Osage' and 'Giles' (high alternate bearing index).Vegetative shoots and fruiting shoots in the terminal and lateral position were tagged in October, and flowering was determined the following year. Shoots and roots were sampled while dormant then analyzed for organically bound nitrogen, potassium and non-structural carbohydrates. Trees displayed the classic alternate bearing pattern. On trees with a high alternate bearing index vegetative shoots produced more current season shoots than other shoot types. Trees with a low alternate bearing index produced more fruit the next year on the bearing shoots in the terminal position, than the other shoot types. Potassium concentration in the shoots was higher in 'Peruque' trees than in the other cultivars all three years of the study. Vegetative shoots also had a lower potassium concentration than the other shoot types all three years. There were no significant differences among cultivars in non-structural carbohydrates in the roots and the differences in the shoots showed no pattern through the three years of the study. These data suggest that carbohydrate concentration was not related to alternate bearing tendency and that carbohydrate reserves were not triggers of irregular bearing in pecan trees.

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VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: CHEMICAL INDICATORS OF PECAN GERMPLASM YIELD POTENTIAL AND IRREGULAR BEARING

Major Field: Crop Science

Biographical:

Personal Data: Born in Chester, Oklahoma, February 11, 1976, the son of Dick and Mary Rohla.

Education: Graduated from Seiling High School, Oklahoma, in May, 1994; received Bachelor of Science Degree in Animal Science from Oklahoma State University in December, 1998; received Master of Science Degree in Agriculture Education from Oklahoma State University in August, 2000; completed requirements for Doctor of Philosophy in Crop Science at Oklahoma State University in May, 2006.

Experience: Field Technician at the Fruit and Nut Research Station, Department of Horticulture and Landscape Architecture, Oklahoma State University, August, 1999 to August 2002; Research Assistant, Department of Horticulture and Landscape Architecture, Oklahoma State University, August, 2002 to October 2005.

Name: CHARLES THOMAS ROHLA Date of Degree: May, 2006

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: CHEMICAL INDICATORS OF PECAN GERMPLASM YIELD POTENTIAL AND IRREGULAR BEARING

Pages in Study: 101 Candidate for the Degree of Doctor of Philosophy

Major Field: Crop Science

Scope and Method of Study: The objectives of the study are (1) to determine if return bloom is inhibited proportionally to mature cluster size, (2) to determine if cultivars with strong alternate bearing tendencies produce larger amounts of kernel per shoot resulting in a greater total energy expenditure than cultivars with a low alternate bearing index, (3) to determine if potassium levels affects carbohydrate synthesis and storage, and (4) to determine if nitrogen levels are associated with irregular bearing tends.

Findings and Conclusions:

The number of shoots that developed the following year was positively related to cluster size for terminal and lateral shoots, but not for shoots with a secondary growth flush. Shoots with a secondary growth flush produced substantially more shoots with larger fruit clusters the next year than the other shoot types.

Organically bound nitrogen and potassium concentration during dormancy in the roots and shoots was not affected by crop load. Carbohydrate concentrations in the roots were not affected by crop load. Shoots that produced a secondary growth flush had a lower carbohydrate concentration than shoots without a secondary growth flush. These data suggest that carbohydrate reserves were not closely related to the current season's crop load nor were they closely related to subsequent flowering.

There were no significant differences among cultivars in non-structural carbohydrates in the roots and the differences in the shoots showed no pattern through the three years of the study. These data suggest that carbohydrate concentration was not related to alternate bearing tendency and that carbohydrate reserves were not triggers of irregular bearing in pecan trees.

ADVISER'S APPROVAL: Dr. Mike Smith