A LIMITED-RANGE PROVENANCE TEST OF OPEN-POLLINATED PROGENY OF CARYA ILLINOENSIS (WANGENH.) K. KOCH IN OKLAHOMA

By

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CHAPTER I

INTRODUCTION

Native sweet pecan (*Carya illinoensis* (Wangenh.) K. Koch) is becoming one of the most valuable commercial hardwood species in the United States. The natural range of pecan extends from southern Indiana and Iowa south along the Mississippi river valley to the Gulf of Mexico, and west into Texas and Oklahoma (Figure 1). Pecan grows best on moist but well drained loam soils of alluvial origin. Periodic inundation not lasting more than a few months in the dormant season, and not more than several weeks after leaf flush, can be tolerated. Within its range, pecan is generally found in mixed stands in association with sycamore (*Platanus occidentalis* L.), willow (*Salix nigra* Marsh), sweetgum (*Liquidambar styraciflua* L.), various *Populus spp*., hackberry (*Celtis occidentalis* L.), and other bottomland hardwoods (Harlow and Harrar, 1969).

Pecan is one of the largest of the native hickories. Pecan lumber is not as strong as lumber from "true hickories", but it is widely used for flooring, furniture, and panelling. Efforts to produce improved cultivars for large nut size "papershell pecan" has continued for many years. Only in the last three decades has attention turned to improving pecan for lumber production or quality.

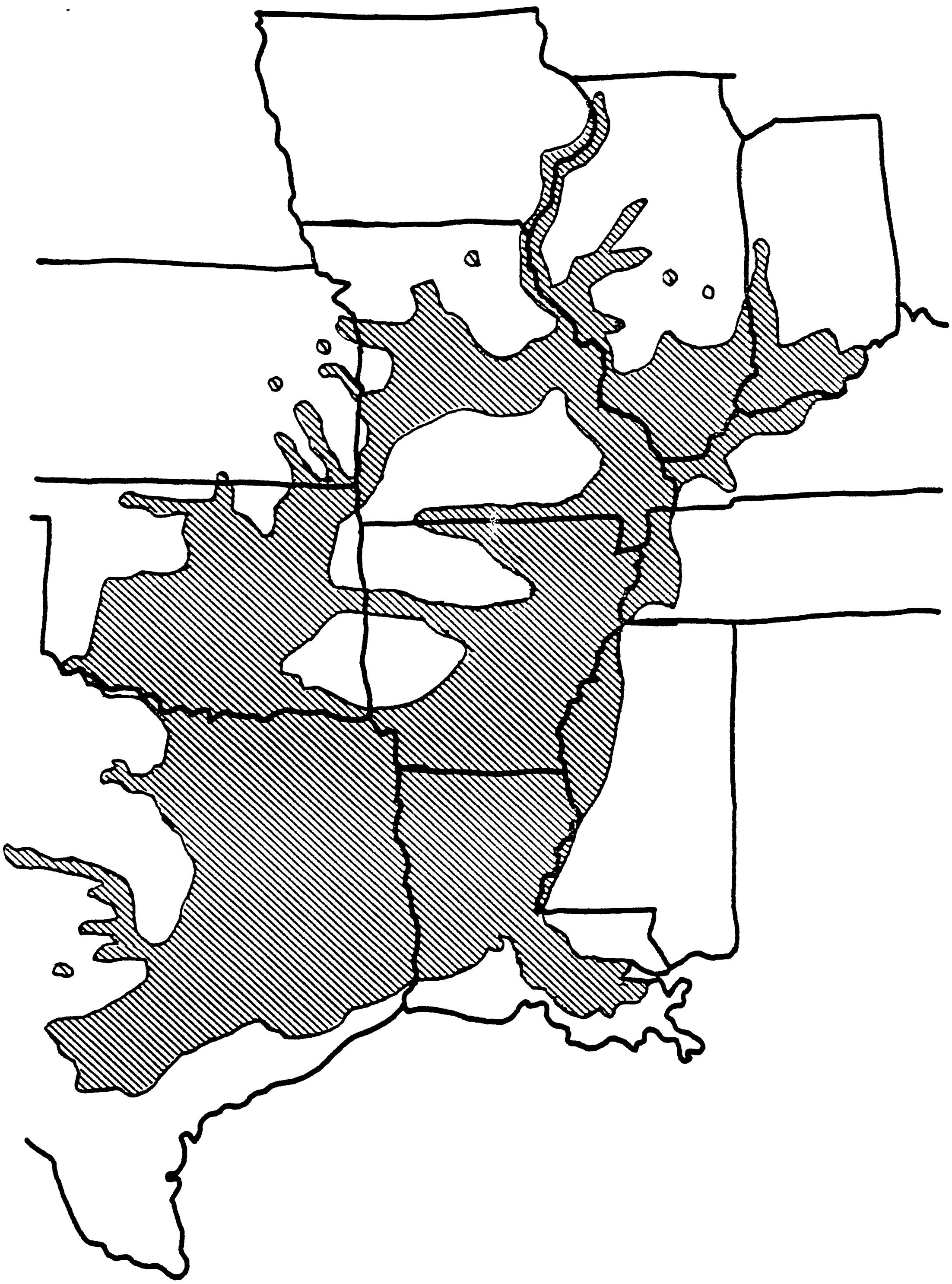

Figure 1. Natural Range of Sweet Pecan in the United States.

For commercial use, the most valuable native pecan tree has a straight, cylindrical stem, no branches for at least two or three sixteen foot logs and an even and rapid growth rate. In order to achieve this form in plantations, intensive cultural practices must be used. These practices include weed control and corrective pruning. Genetic research can aid in the production of trees of commercial quality.

Intensive management increases cost, which are carried throughout a rotation. With intensive management, the use of low quality genetic material cannot be justified. To help recover the increased cultural expense, it is important to plant seedlings with the inherent capacity to produce a high-quality tree. Studies have shown that increases in volume and quality of material grown can be achieved through selection and breeding and hybridization.

Sources of high-quality pecan seed still exist but are not readily available. Locating superior seed trees has become both time consuming and cost prohibitive. This scarcity of a quality gene pool is mostly due to the extensive cutting of pecan without regard to tree improvement or regeneration. Until the last ten years, interest in regeneration of commercial species such as black walnut (*Juglans nigra* L.), red and white oaks (*Quercus spp*.), and native pecan in Oklahoma has been minimal. The demand for commercial quality pecan has increased the selection pressure on the remaining natural stands. This pressure has created a need to locate, select, and preserve phenotypically superior individuals and stands.

CHAPTER II

LITERATURE REVIEW

Research developments in genetic improvement of pecan have formerly been focused on orchard culture for nut production. At present, the existing gene pools for native sweet pecan are threatened by past and present logging practices, increased development as a multi-use tree, and lack of attention from research organizations dealing with genetic improvement of timber species. Previous studies on other hardwoods have identified several methods for examining genotypic variation in growth characteristics. Provenance testing helps determine which growth variables may be useful in identifying seed sources for developing seed orchards for quality seed production.

Calvin Bey has initiated several research efforts to improve black walnut, a species similar in many respects to pecan. Both species require deep, moist, but well drained soils for optimum growth. Walnut and pecan are also similar in some physiological aspects such as flowering dates, seed ripening and dispersal dates, light tolerance and leaf characteristics. Examination of his methods and results was useful in the design and interpretation of this study.

One of the primary steps toward improvement of a tree species is the provenance test. Calvin Bey (1968) conducted a range-wide provenance study of black walnut as part of his dissertation work. He used a randomized complete block design with six blocks. The study was conducted in a nursery situation. Each block contained 480 families representing 78 stands. The seed were planted one foot apart with one foot between rows. The characters studied were leaf color, insect damage, leaf angle, total height in August, leaf length in August, date of leaf drop, total height at growth cessation, stem diameter, and number of trees with multiple stems.

During the first two years of observation, Bey (1968) noted that variation in growth related characters was associated with climatic factors specific to the site from which the seed were collected. Correlations with latitude of seed origin were not computed. However, characters were plotted against north latitude in one degree intervals. All characters studied except leaf angle showed a north-to-south trend. Trees from southern sources grew taller and larger, and leaves dropped later than trees from northern sources. Significant variation was noted for amount of red coloring in new leaves and insect damage. Degree of red coloring and amount of insect damage increased for southern seed sources. No geographic variation pattern was discernable for leaf angle. Bey also noted a significant influence of seed size on growth. He indicated that larger seed usually produced larger first-year seedlings but source did not influence seed size.

Early results of a black walnut seed source study conducted in southern Illinois suggest that to insure rapid growth seed should be collected from local or south-of-local areas (Bey, Toliver, and Roth, 1971). In this study seed from 20 sources was planted in deep, alluvial, silt loam soil, which is considered excellent soil for walnut. Weeds were controlled for two years. Data were collected on date of leaf flush and leaf fall, and height and diameter growth. Results indicated a clinal pattern of variation in a north-to-south direction. Trees from southern sources grew taller and larger than local or northern sources. Bey et al. (1971) also showed southern sources flushed earlier and leaves persisted longer than northern sources.

Bey (1973) reported similar results in a provenance test of black walnut planted in eight midwestern states. In this test, one-year-old black walnut seedlings from 15 to 25 sources were planted at each of eight locations in the Midwest. After six years, data were collected on survival, height, and diameter. At all locations tested, trees from sources south of the planting site generally performed better than trees from north of the planting site. Bey (1973) notes that there may be a genotype x location interaction which demonstrates the need for further provenance testing at many locations.

Studies of walnut by Bey (1973), and Sprague and Weir (1976) indicate that the greatest source of variation was from among stands. Sprague and Weir (1976) suggest that the greatest genetic gains could be obtained by selecting the best stands and then selecting the best trees from those stands.

The provenance test described in this thesis is the first effort for genetic improvement of pecan as a timber species in Oklahoma. A study initiated in Lousiania by Adams (1976) has provided an initial data bank on both pecan and a promising hybrid.

The first portion of the study reported by Adams (1976) evaluated the effect of seed size on seedling growth. He collected pecan seed from 35 native trees near Baton Rouge, Louisiana. Parent tree selections were made so as to give a wide range of seed sizes. A sample of the natural hybrid Carya x lecontie Little, (between sweet pecan and water hickory), was also included.

Seed from each of the 35 parent trees were checked for soundness, and length, width, and weight were measured. A total of 200 seed were randomly planted in the Baton Rouge nursery at three inch intervals in rows eight inches apart. This spacing was necessary since the seedlings remained in the nursery for two years.

Seedling height was measured at the end of the first and second growing seasons. A multiple regression was used to analyze the effect of seed size (nut length, width and weight) on first-year height growth of pecan and the hybrid. The effect was positive and significant ($P<0.01$) with R square of 0.21. The effect of seed size on second-year growth was positively correlated but nonsignificant. When the components of seed size were analyzed separately, seed weight was the only component found to have an effect on seedling growth of pecan. This influence diminished during the second year. Seed size components showed no significant effect on growth of the hybrid.

Adams (1976) suggests that even though seed size may influence seedling growth for one year, only 21 percent of the individual seedling variation was due to seed size. This influence quickly decreases after the first year. The remaining variation in seedling growth was due to other factors. Adams held nursery factors relatively constant minimizing environmental variation. This indicates the major sources of variation were due to genetic makeup. Adams (1976) notes that additional gains in growth may be possible by using both good phenotypic qualities and seed size (length, width, or weight) as guidelines during field selection.

Adams (1976) also conducted an open-pollintated progeny test of 40 families of native pecan. Four natural stands were visited and the best ten trees in each stand were selected as seed parents. Selection was made on the basis of phenotype using objective criteria including vigorous growth, position of crown (dominant or codominant), straightness of bole, pruning ability, and crown size in relation to height. Selected stands were located from one half mile to five miles apart. A general seed collection was also made from each stand to serve as a control sample.

At least 100 seed were collected from each parent tree. The seed were placed in cold dry storage (2-5 degrees C.) for 90 days. The seed were planted at two locations. Each planting was replicated. The Lumberton nursery site consisted of nuts planted one inch (2.54 cm) apart and two inches (5.08 cm) deep. There was no supplemental watering. In the Baton Rouge site, nuts were planted 5.08 centimeters deep and spaced 5.08 centimeters apart, and were watered throughout the growing season when necessary. First and second year heights were measured.

Analysis of first-year growth showed significant differences between the two nurseries. Seedlings at the Lumberton nursery grew 18 percent taller than the Baton Rouge seedlings. Adams (1976)indicates these differences may be due to a large genotype x environment interaction. Differences among families were also significant. The occurrence of a large amount of variation among families from a small study area indicates a large amount of genetic diversity in wild populations of pecan.

Interaction of genotype with environment is also indicated in a report by Sparks and Toliver (1978) on a three-year old progeny test. This study consisted of progeny from both pecan and the hybrid <u>Carya</u> x <u>lecontie</u> Little, grown on two separate sites. One planting was on an upland site with sandy loam soil of low fertility and good drainage. The second planting was on a bottomland site with heavy alluvial clay soil with high fertility and poor drainage. Sparks and Toliver (1978) reported that pecan performed better on the upland site. This increase in early growth over the bottomland site was most likely due to better root development in the lighter soil. The among stand differences at both sites were nonsignificant for diameter. Substantial variation did occur for height. The among stand variation in height indicates a closer relationship between individuals within a stand than between individuals in different stands. Sparks and Toliver (1978) suggest that even though some inbreeding does occur there is still a large amount of genetic diversity within small pecan populations.

Hybrid vigor resulting from certain crosses is another means for the forest geneticist to improve growth. The cross between sweet pecan and water hickory may be exhibiting this vigor. This hybrid has repeatedly outperformed native sweet pecan. Sparks and Toliver (1978) reported significant gains in growth by *Carya* x *lecontie* Little over native pecan on both the upland site and the bottomland site. The largest gains were on the upland site with 33 percent and 22 percent greater mean height and diameter growth, respectively, over pecan family means.

Information generated by seed source studies of various species conducted over a wide range of environments shows that significant differences in growth are detectable in early stages of seedling development. The primary objective of this limited-range study was to examine and quantify the nature and pattern of natural variation present in selected characteristics of regional native pecan. It was assumed that usable variation can be detected over a portion of the pecan range totalling only a few hundred square miles. Estimates for narrow sense family mean heritabilities were calculated for height and diameter, leaf area, leaf length, date of leaf drop, frequency of multiple stems, weighted germination rate, and germination percent. The secondary objective of this study was to provide initial selection data for identifying exceptional seed sources and individuals for the purpose of collecting seed to insure quality seedlings for regeneration. The nursery data accumulated during this study will be used to examine juvenile-mature relationships at a later date. The final objective of this provenance test was to provide an initial data bank and seedling material for developing a seedling seed orchard and further progeny testing.

Breeding programs developed by Louisiana State University indicate a well-stocked pecan stand could produce quality lumber, maintain populations of game animals and provide regular nut crops (Adams and Thielges, 1974). One of the greater accomplishments from this and future studies may be the development of pecan orchards as multi-use enterprises.

CHAPTER III

METHODS AND MATERIALS

Stand Selection

Native pecan in Oklahoma ranges from Ottawa county to Woods county across the north and from Kiowa to McCurtain county across the south. The study sample area includes this range and surrounding states (Figure 2). Stands outside Oklahoma include three from northeast Texas, one from western Louisiana, one from southwestern Arkansas, one from northcentral Missouri, and one from southern Kansas. Location of each stand was recorded, but identity of specific parent trees was not maintained in the field. Elevation over the sample area ranges from 60 meters (200 feet) above sea level in the southeast to 426 meters (1400 feet) above sea level in the southwest. The average annual rainfall over this range varies from less than 68 centimeters (27 inches) in the west to over 137 centimeters (54 inches) in the southeast (Table I).

Seed source stands in Oklahoma were systematically selected using average annual rainfall isolines as baselines over the botanical range of pecan. An alternating arrangement with either two or three points per isoline at four inch/year rainfall intervals served as a basis for locating

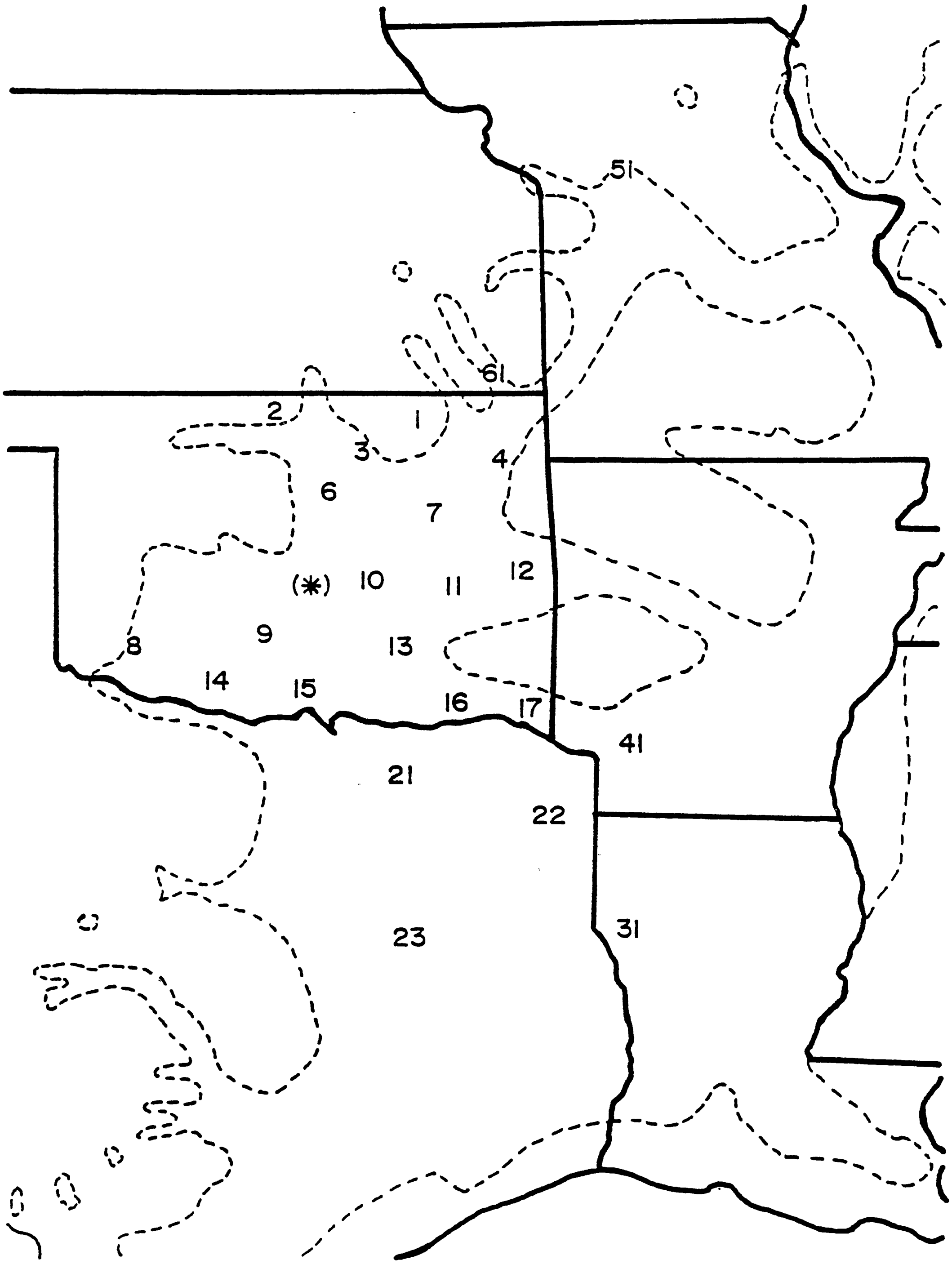

Figure 2. Location of Seed Collection Sites (numbers), Nursery Planting Site (*), and Natural Range of Pecan (--).

TABLE I

SUMMARY OF LATITUDE, LONGITUDE, ELEVATION, AND AVERAGE ANNUAL RAINFALL FOR SEED COLLECTION SITES

Stand	State	Latitude Deg.	Latitude Min.	Longitude Deg.	Longitude Min.	Elevation	Average Annual Rainfall
1	OK	36	37	96	12	800	34
2	''	36	56	97	20	1100	27
3	''	36	25	96	34	800	33
4	''	36	25	95	10	775	43
6	''	36	05	97	03	945	33
7	''	35	56	95	50	600	40
8	''	34	51	99	06	1400	27
9	''	34	52	97	36	1025	34
10	''	35	19	96	44	1000	38
11	''	35	19	95	40	820	42
12	''	35	30	94	59	300	44
13	''	34	48	96	37	950	41
14	''	34	29	98	20	1050	30
15	''	34	19	97	30	1000	38
16	''	34	02	95	42	500	44
17	OK	33	49	94	50	325	48
21	TX	33	33	96	34	700	33
22	TX	33	00	95	00	400	44
23	TX	32	03	96	26	300	40
31	LA	32	27	93	35	200	54
41	AR	33	38	93	35	250	52
51	MO	39	27	93	09	630	36
61	KS	37	11	95	09	850	40

points on a collection map. A minimum distance of 50 miles between points was maintained. A circle with a ten-mile radius was drawn around each point, the point photographed, and advertizements for help in locating native pecan stands were published in newspapers covering each collection area. All stand notifications recieved from landowner response were visited. The first stand in each collection area having an adequate number of fruitful trees was selected for the study. Stands in surrounding states were located from the road during seed collection.

Seed Aquisition

Native sweet pecan seed was collected from five parent trees in each of sixteen natural stands, scattered throughout its range in Oklahoma, and seven stands in surrounding states. Parent trees were randomly selected and flagged before nut fall for stands where landowners cooperated in nut collection. For all remaining stands, parent trees were selected during nut collection. A distance of at least 200 feet between parent trees was maintained. The author collected seed from 12 of the 23 stands. The remaining stands were collected by private landowners, including one stand collected by Missouri Department of Conservation personnel. Seed collection began in October, 1981, and continued through December, 1981. An effort was made to collect at least 200 nuts from each parent tree.

Seed was collected from natural stands only. In all cases, parent trees were in pure stands or stands where all other species had been removed (Figure 3). Selection of mature trees in natural stands comes closest to assuring selection of trees possessing climatic adaptation (Funk, 1969). It is hoped that this adaptation is genetically controlled and transmitted to offspring.

One family, was presumed to be the hybrid *Carya* x *lecontie* Little because of intermediate nut characteristics. This sample was collected from the stand in southwestern Arkansas. It was analyzed as part of the total collection.

Seed Handling and Nursery Treatment

Seed was kept in cold dry storage (1.6 degrees C.) until all seed was collected. Three random samples of 25 seed from each mother tree were cleaned (hulled if needed) and weighed to the nearest 0.1 gram. A random sample of 20 cleaned nuts from each mother tree was also taken after replacement of nuts used in weighing. Length and diameter were measured to the nearest 0.001 centimeter using a vernier caliper. Figure 4 shows a sample of the observed variation in nut size and shape. The top two nuts in the lower right hand corner are from the putative hybrid. The nut weights, lengths, and diameters were averaged and used to examine the influence of seed size on seedling size after one growing season. The seed was returned to cold storage

Figure 3. Example of a Typical Seed Collection Stand.

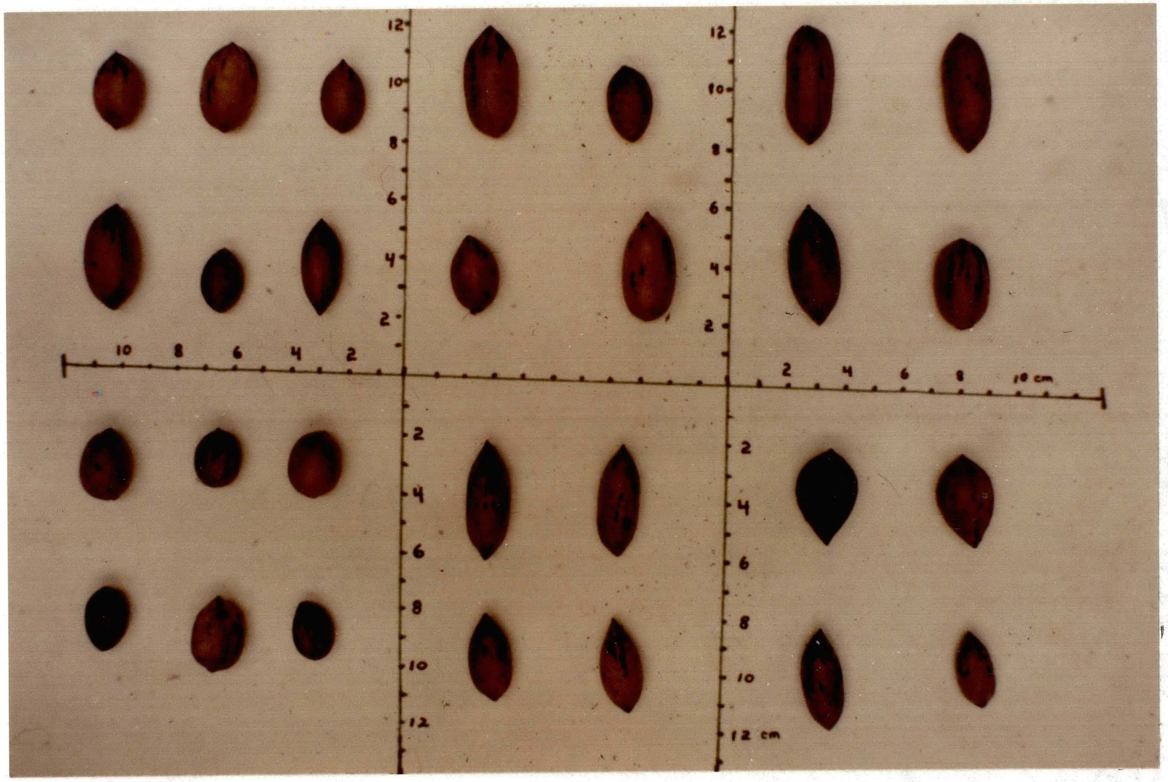

Figure 4. Observed Variation in Pecan Nut Size and Shape Found Across Collection Area.

until planting.

The Oklahoma State Forestry Division nursery south of Norman, Oklahoma, was the planting site used for this study. The nursery is not over 322 kilometers (200 miles) from any seed source in Oklahoma, and less than 644 kilometers (400 miles) from any source in surrounding states (Refer to Figure 2). This location helped minimize extreme environmental effects that may influence growth response of seed planted too far from its origin. The nursery has easy access, and facilities available for site preparation, irrigation, and pest control. The soil at the nursery is a fine, sandy loam.

Seed beds were four feet wide by several hundred feet long. The beds were oriented in an east-west direction. The seed were planted 20.3 centimeters (8 inches) apart with 20.3 centimeters between rows, and approximately 10 centimeters (4 inches) deep. Figure 5 shows the seed beds after planting. The bed to the far right is replicate one which extends the full length of the bed. The irrigation pipe was positioned beside replicate one. Each subsequent replicate was planted parallel to replicate one with some overlap onto adjoining beds. Figure 6 shows how the seedling spacing looked after one growing season. The nuts were planted by Oklahoma State University forestry personnel on December 16, 1981.

Cultivation and weed control were applied prior to planting. Weed control and irrigation, when necessary, continued

Figure 5. The Planting Site.

Figure 6. Seedling Spacing at the Planting Site.

throughout the study. Weed control prior to germination was obtained by application of .9 kilograms (2 pounds) per acre active Devernol herbicide. Roundup herbicide at 23.46 milliliters per liter (three ounces per gallon) of water was also applied prior to planting to kill rye grass ground cover. Good control was obtained.

Experimental Design

A randomized complete block design was used in the nursery planting. The 200 nuts from each parent tree were randomly divided into four 48-seed lots. Extra seed were planted as border on each end of the planting beds. A replicate consists of 48 seed from each family (parent tree). A high occurrence of pecan weevil in northwestern Oklahoma lowered the number of trees producing adequate amounts of sound seed in stand number two to three instead of five. There were 113 families including one family of the putative hybrid randomly located within each replicate, and there were four replicates. For individual progeny measurements, the rows along the outside edge of each seed bed were considered border rows. For plot mean data all 48 seed positions were included.

Data Collection

Seed size information was collected as discussed in the seed handling and nursery treatment section of this chapter. Growth data were recorded during and at the end of the first growing season. Data collection was divided into two categories. The first consisted of whole plot counts using all available seedlings in each 48 seed plot. The plot data includes variables 1-4 listed below. The second category was individual progeny measurments. This category includes variables 5-9. Five seedlings in each plot were chosen using a computer generated table of random numbers from one-to-thirty-two representing each position in a family plot excluding border. A set of 32 random numbers was printed for each family. Starting with the first number, the corresponding position was checked for a live seedling. If alive, the seedling was tagged. If dead or missing, the next random number was checked and the same procedure applied. This process continued until five live seedlings were tagged in each family plot.

The following variables were measured:

1. Germination rate
2. Germination percent
3. Frequency of multiple stems
4. Frequency of albino plants
5. Total leaf length of the longest simple and/or compound leaf (cm.)

6. Total leaf area of the longest simple and/or compound leaf (cm2.)
7. Date of leaf drop (days after Oct. 20)
8. Total seedling height (cm.)
9. Stem diameter (cm.)

The number of seed germinated for each 48 seed plot (family plot) was recorded on April 23, May 4, May 27, and August 16, 1982. Each count was cumulative. The August count was first taken as survival. Visual observation of the data indicated almost all plots either remained the same or increased in number germinated since the May 27th count. The August count was thus more useful for germination rate than survival. The day-of-year corresponding to the germination count date was recorded for each of the four counts. The day recorded for April 23, May 4, May 27, and August 16 was 128, 139, 162, and 243, respectively. The actual number germinated for each date was weighted by multiplying each count by its respective day-of-year. These four products were summed and the total divided by the August germination count to give a weighted germination rate for each family. Early germination was indicated by a lower weighted germination value. A germination percent was calculated using the August germination count.

The number of seedlings with multiple stems was recorded for each family plot in August. The August germination count was used as the denominator to calculate a percent of multiple stems for each plot.

During germination counts certain plots were observed having a high frequency of albino seedlings (Figure 7). The number of albino plants per plot was counted in June, 1982. The albino seedlings died soon after the count was taken and are largely responsible for the decrease in August germination counts for some plots. The presence of albino plants may be useful in isolating marker genes at a later date. High frequency of albino plants also indicates possible inbreeding within the local population, which may explain poor form or below average performance.

Leaf measurements were taken to examine their relationship to height and diameter growth. The stage of seedling development varied between families. Some seedlings had only simple leaves, others had only compound leaves, and some seedlings had both. Leaf samples were taken from each of the five tagged progeny in each plot on August 19,1982. Samples of the longest simple and/or compound leaf were taken from the field to the lab. The longest leaf was chosen to standardize the measurement procedure. The samples were sealed in plastic bags and kept refrigerated in the lab until measured. Leaf measurements were taken on August 24-28, 1982. A sample of the variation observed in leaf size and shape is shown in Figure 8. Leaf lengths were measured to the nearest 0.1 centimeter. Total leaf area was measured to the nearest 0.01 square centimeter using a Li-Cor 3000 portable leaf area meter (Figure 9).

After heavy spring rains minimized the effectiveness of

Figure 7. Example of Albino Plants.

Figure 8. Observed Variation in Size and Shape of the Longest Leaf Collected from Sample Seedlings.

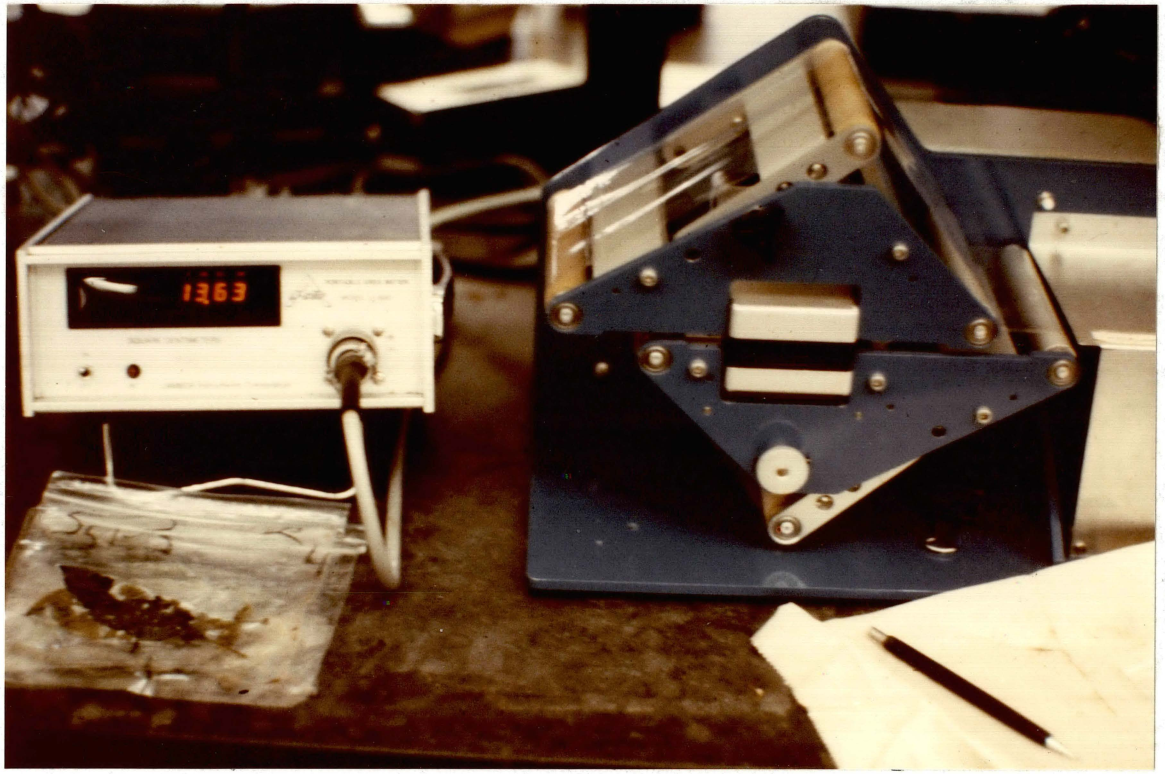

Figure 9. The Li-Cor 3000 Leaf Area Meter.

pre-emergent herbicides, plots were retreated in July with 1.1 kilograms per hectare (one pound/acre) active treflan. A three percent mixture of Roundup was applied to tall grasses. Overspray or dripping onto seedlings occurred causing varying leaf damage. Only a few seedlings were killed, but leaf damage ranged from light spotting to total drop. When leaf area data were recorded a correction factor was calculated to estimate the amount of area lost. Any loss due to insects was also included in the correction. Loss estimates were made using a 64 dot/inch grid and recorded to nearest 0.1 square centimeter. The correction factor and the leaf area measurements were summed to estimate total leaf area.

Date of leaf drop was recorded for each of the five tagged seedlings in each plot. The date of leaf drop was recorded as the date on which the seedling had lost at least all but one leaf. Plots were checked once a week until drop for the first seedling had occurred. This date was October 20, 1982. Starting on this date, plots were checked twice weekly. Leaf drop was taken as the number of days past October 20.

Total height and stem diameter were also measured on each of the five tagged progeny in November. Height was measured to the nearest 0.1 centimeter. Diameter was measured 2.5 centimeters above the ground line with a vernier caliper to the nearest 0.01 centimeter.

Statistical Analysis

The data were analyzed using the general linear model (GLM) procedure as described in the Statistical Analysis Systems(SAS) Manual, 1979 edition. The expected mean squares and estimates of components of variance were derived from a random effects model. To test for significance among sources of variation the 'F' test (i.e., $Ho: \sigma^2 = 0$) described by Snedecor and Cochran (1967) was computed. Significance was declared at the 0.05 probability level. It was necessary to use two forms of analysis of variance since the variables germination rate, germination percent, frequency of multiple stems, frequency of albino plants, and nut weight were based on plot means. These variables were tested using the form of analysis of variance shown in Table II. The variables seedling height, seedling diameter, leaf area, leaf length, and date of leaf drop were analyzed with an individual progeny component. These variables used the form of analysis of variance shown in Table III.

When analyzing data based on proportions, frequently the distibution is skewed causing a loss of efficiency in the analysis. Normally when this occurs, a data transformation is used and as a result, variances are stabilized. Transformation was needed for the variables frequency of multiple stems and frequency of albino plants. Angle (arcsine) transformation was computed using the equation given below:

TABLE II

FORM OF ANALYSIS OF VARIANCE FOR WEIGHTED GERMINATION RATE, GERMINATION PERCENT, FREQUENCY OF MULTIPLE STEMS, AND FREQUENCY OF ALBINO PLANTS

Source of Variation	df	(E) Mean Squares
Replication	r-1	$\sigma^2 r*t(s) + t\sigma^2 r*s + st\sigma^2 r$
Stand	s-1	$\sigma^2 r*t(s) + t\sigma^2 r*s + r\sigma^2 t(s) + rt\sigma^2 s$
Parent trees in stands	s(t-1)	$\sigma^2 r*t(s) + r\sigma^2 t(s)$
Error		
Rep x stand	(r-1)(s-1)	$\sigma^2 r*t(s) + t\sigma^2 r*s$
Parent trees x rep in stands	s(r-1)(t-1)	$\sigma^2 r*t(s)$
Total	rst-1	

$\sigma^2 s$ -- variance due to differences among stands.
$\sigma^2 r$ -- variance due to differences among replications.
$\sigma^2 t(s)$ -- variance due to differences among families.
$\sigma^2 r*t(s)$ -- variance due to differences in performance in each replication of progeny from a parent tree, pooled across stands.
$\sigma^2 r*s$ -- variance due to differences in performance in each replication of progeny from a stand.

TABLE III

FORM OF ANALYSIS OF VARIANCE FOR LEAF DROP DATE, SEEDLING HEIGHT, SEEDLING DIAMETER, COMPOUND LEAF LENGTH, AND COMPOUND LEAF AREA

Source of Variation	df	(E) Mean Squares
Replication	r-1	$\sigma^2 p + p\sigma^2 r*t(s) + tp\sigma^2 r*s + stp\sigma^2 r$
Stand	s-1	$\sigma^2 p + p\sigma^2 r*t(s) + tp\sigma^2 r*s + rp\sigma^2 t(s) + rtp\sigma^2 s$
Rep x Stand	(r-1)(s-1)	$\sigma^2 p + p\sigma^2 r*t(s) + tp\sigma^2 r*s$
Parent trees in stands	s(t-1)	$\sigma^2 p + p\sigma^2 r*t(s) + rp\sigma^2 t(s)$
Error		
Parent trees x reps in stands	s(r-1)(t-1)	$\sigma^2 p + p\sigma^2 r*t(s)$
Progeny in parent trees in reps in stands	rst(p-1)	$\sigma^2 p$
Total	rstp-1	

$\sigma^2 r$ -- variance due to differences among replicates.
$\sigma^2 s$ -- variance due to differences among stands.
$\sigma^2 p$ -- variance due to differences among families.
$\sigma^2 r*s$ -- variance due to differences in performance in each replication of progeny from a stand.
$\sigma^2 t(s)$ -- variance due to differences among families pooled across stands.
$\sigma^2 r*t(s)$-- variance due to differences in performance in each replication of progeny from a parent tree, pooled across stands.

$$\text{Angle}=\text{Arcsine}\sqrt{\text{Percentage}} \qquad (1)$$

After transformation, the analysis of variance was performed using the form shown in Table II.

Simple correlations were computed for all possible combinations of study traits and selected environmental factors of each stand. Data were plotted for selected combinations having significant correlation coefficients. The possibility of clinal trends was evaluated using the plotted relationships.

Variance components were estimated by solving the equation for expected mean squares shown in Tables II and III. These components were used to estimate family mean heritabilities for selected study traits. Heritability is defined as the fraction of the total variance for any trait in a population which is due to genetic effects. The narrow sense heritability of a trait is the fraction of the total variance due to additive genetic effects. Narrow sense family mean heritability was computed for seedling height, seedling diameter, leaf drop date, leaf length, and leaf area using equation 2:

$$h^2 = \frac{\sigma^2 t(s)}{\sigma^2 t(s) + \sigma^2 p/rp + \sigma^2\ r{*}t(s)/r} \qquad (2)$$

Narrow sense heritability was computed for germination rate, germination percent, frequency of multiple stems, and frequency of albino plants on a plot mean basis using equation 3:

$$h^2 = \frac{\sigma^2 t(s)}{\sigma^2 t(s) + \sigma^2\ r{*}t(s)/r} \qquad (3)$$

Equation three is essentially the same as two. The difference is that the individual progeny component ($\sigma^2 p$) is not present in equation three. A high heritability indicates that the trait is under a high degree of genetic control. Increases in environmental effects will act to decrease heritability estimates.

Standard error estimates were calculated using equation four:

$$Se = \sqrt{\frac{\sigma^2 error}{\sigma^2 t(s)}\ Var(F)} \qquad (4)$$

where: $$Var(F) = \frac{2\{t(s)\ df\}^2 \{t(s)\ df + error\ df - 2\}}{error\ df\{t(s)\ df - 2\}^2 \{t(s)\ df - 4\}}$$

CHAPTER IV

RESULTS AND DISCUSSION

Patterns of Variation

The analysis of variance examined four sources of variation for all study characters. The first source was variation among replications. Variation of this type indicates differences in nursery treatment and nursery environment across the planting. The second was variation among the stands. Significant differences at this level suggest geographic and possible clinal variations exist among the 23 stands tested. The third source of variation was among trees within a stand. Significance at both the second and third levels suggest genetic differences which may be important in designing selection programs. The fourth source is error. Experimental error and nonsignificant interactions were combined in the analysis of variance for this study. The variance components associated with nonsignificant interactions were assumed to be near zero and thus were pooled with error. The replication x stand interaction was nonsignificant for the traits germination percent, frequency of multiple stems, frequency of albino plants, and simple leaf length and area. For variables height, diameter, leaf drop date, compound and simple leaf length, and compound and simple leaf area the individual progeny component was included in the error term of the analysis. Family means were used instead of the individual progeny component when analyzing the traits germination rate, germination percent, frequency of multiple stems, frequency of albino plants, and nut size components.

Significant differences were found among stands and among families in stands for all traits except frequency of multiple stems. Frequency of multiple stems showed significance for replication only. Tables IV and V show the percent of the total variation resulting from each source of variation for each study trait. Table IV shows that 62 percent of the total variation in frequency of multiple stems was due to replicates. Differences in frequency of multiple stems were apparently due mostly to damage received from herbicide overspray early in the growing season.

Weighted germination rate also showed high variation across replicates, accounting for 71 percent of the total variation (Table V). Nursery treatment differences across replicates did occur. The irrigation layout may have been the major cause of these differences. All replicates paralleled the irrigation pipe. Replicate one received adequate supplemental water. Replicate two received slightly less than replicate one. Replicates three and four received little or no supplemental water. This difference in watering may have slowed germination rate and decreased mean stem diameter across replicates as amount of water decreased.

TABLE IV

ANALYSIS OF VARIANCE FOR WEIGHTED GERMINATION RATE, GERMINATION PERCENT, FREQUENCY OF MULTIPLE STEMS, AND FREQUENCY OF ALBINO PLANTS

Source of Variation	df	Germination Rate Mean Square	Germination Rate Variance Component (%)	Germination Percent Mean Square	Germination Percent Variance Component (%)
Replication	3	3903.85*	71.5	.0074	6.4
Stand	22	1122.22*	20.5	.0549*	47.1
Tree(Stand)	90	283.17*	5.2	.0435*	37.4
Error	336	153.76	2.8	.0106	9.1

Source of Variance	df	Frequency of Multiple Stems Mean Square	Frequency of Multiple Stems Variance Component (%)	Frequency of Albino Plants Mean Square	Frequency of Albino Plants Variance Component (%)
Replication	3	.0690*	61.9	.0011	3.3
Stand	22	.0081	7.3	.0236*	70.2
Tree(Stand)	90	.0118	10.6	.0053*	15.8
Error	336	.0225	20.2	.0036	10.7

* Significant at the 0.05 probability level.

TABLE V

ANALYSIS OF VARIANCE FOR LEAF DROP DATE, SEEDLING HEIGHT, SEEDLING DIAMETER, COMPOUND LEAF LENGTH, AND COMPOUND LEAF AREA

Source of Variance	df	Leaf Drop Date Mean Square	Leaf Drop Date Variance Component (%)	Seedling Height Mean Square	Seedling Height Variance Comp. (%)	Seedling Diameter Mean Square	Seedling Diameter Variance Comp. (%)
Replication	3	601.26*	26.6	126.39*	28.5	.2354*	66.2
Stand	22	1093.31*	48.4	200.94*	45.3	.0625*	18.3
Tree(Stand)	90	295.84*	13.2	83.09*	18.7	.0350*	9.8
Rep*Stand	66	183.99*	8.1	19.65*	4.4	.0124*	3.5
Error	(1)	84.49	3.7	13.46	3.1	.0075	2.2

Source of Variance	df	Compound leaf Length Mean Square	Compound leaf Length Variance Component (%)	Compound leaf Area Mean Square	Compound leaf Area Variance Comp. (%)
Replication	3	189.36*	53.5	15002.27*	57.5
Stand	22	84.68*	23.9	5773.27*	22.2
Tree(Stand)	90	51.33*	14.5	3191.78*	12.2
Rep*Stand	66	18.71*	5.3	1374.67*	5.3
Error	(1)	10.13	2.8	730.52	2.8

(1) The error degrees of freedom for leaf drop date, height, diameter,compound leaf length, and compound leaf area are 2078, 2045, 2073, 1923, and 1923, respectively.

(*) Significant at the 0.05 probability level.

Significant stand differences in weighted germination rate are probably due mostly to geographic adaptation within each collection locality as no clinal trends were apparent. Within stand (family) differences were small, but significant. The significant within stand differences suggest genetic variation exists within relatively small pecan populations.

Germination percent was not affected by differences in nursery watering. Germination percent and frequency of albino plants both show a high percent of variation due to stand (Table IV). Table VI lists the germination percents and number of albino plants by stand. Differences in germination percent are probably due in part to climatic and biotic factors specific to that stand during the nut production year. Significant variation both among and within stands may also be due in part to inherent factors affecting both seed dormancy and viability. Germination percent showed no significant correlations with geographic location of the stand.

There were five stands where albino plants occurred. Random recombinations of genes will produce an occasional albino. Geographic barriers can reduce the gene pool from which gene combinations are drawn. One result is increased inbreeding. Increase in inbreeding will increase the chance for the albino combination to occur. For example, stand 8 was a somewhat isolated stand and had an unusually high frequency of albino plants. Stand 8 was 10-15 miles from any

TABLE VI

SUMMARY OF STAND MEANS FOR LEAF DROP DATE, WEIGHTED GERMINATION RATE, GERMINATION PERCENT, COMPOUND LEAF LENGTH, AND COMPOUND LEAF AREA

Stand	Leaf Drop Date(1)	Weighted Germination Rate(*)	Germination Percent	Compound Length (cm)	Leaf Area (cm2)	Number of Albino Plants
1	25.4	160.6	84	13.9	45.5	0
2	21.9	162.9	77	13.0	40.6	0
3	23.8	146.5	91	15.4	56.8	0
4	26.2	171.0	77	13.9	47.0	0
6	23.2	153.3	84	14.6	53.1	0
7	26.3	154.1	87	15.1	54.8	0
8	25.4	142.3	85	14.4	49.9	32
9	24.2	146.7	85	14.4	49.0	0
10	26.3	160.1	84	13.6	45.0	0
11	26.4	147.1	66	15.5	56.8	10
12	25.9	151.6	88	15.2	53.8	0
13	28.4	150.9	76	13.9	48.1	0
14	25.8	155.0	86	14.6	60.7	0
15	26.1	144.6	85	15.8	62.5	6
16	29.0	154.7	78	14.4	51.4	0
17	29.0	157.9	85	14.9	55.6	0
21	30.4	149.3	77	15.5	60.2	0
22	33.0	142.0	82	17.6	79.9	0
23	31.6	142.5	82	13.6	47.9	9
31	32.6	164.4	82	14.5	53.6	0
41	30.1	155.9	78	13.9	47.7	14
51	19.8	155.1	85	15.4	55.9	0
61	23.4	149.0	88	15.3	55.7	0
Range	9.0-52.0	131.2-205.4	0-100	2.1-29.1	4.6-244.0	
Mean	26.7	152.9	82	14.7	53.5	

(1) Number of days after October 20.
(*) Smaller values correspond to earlier seedling emergence.

other native pecan stand. Stand 8 was among the three stands with early germination time and was exceeded by only one stand in average nut size, but only achieved average height growth. Inbreeding may account for some of this loss in growth since for the study in general large nuts produced taller first year seedlings.

Significant differences among stands and among trees in stands occurred for height and diameter. There were differences within families as shown in Figure 10, but they were nonsignificant. The among stand variation accounted for 45 percent of the total variation in height growth (Refer to Table V). Diameter growth was affected most by nursery treatment with 66 percent of the variation observed due to replicate, again no doubt due to watering differences. General geographic variability or clinal variation more subtle than we can detect by this test may account for most of the interstand diversity. The total amount of intrastand genetic variation is less than interstand variation but is significant. The existence of detectable variation at the family level helps quantify the genetic potential of pecan stands.

The putative hybrid (stand 41, tree 3) performed very well compared to sweet pecan. As shown in Appendix A, the putative hybrid showed greater mean height growth than all other pecan families, except one (stand 22, tree 5). The height growth is of note since 41-3 was matched or exceeded by 23 percent of the pecan families for diameter and 25 per-

Figure 10. Example of Variation in Height Growth Observed Within an Open-Pollinated Family.

cent for nut weight. Length of the growing period may have contributed some toward the hybrid's height, with a leaf drop date of 33.0 being later than 90 percent of the pecan families. The hybrid germination rate remained close to the plantation average at 152.95. Germination percent was below the average pecan family. Seed viability for the hybrid is not a problem with 72 percent germinating.

Compound leaf length and compound leaf area showed significant differences among stands and among trees within stands. Since there were no apparent geographic trends, these differences may be partly due to random geographic variation. Nursery treatment (mainly watering differences) influenced leaf size most with 54 percent and 58 percent of the total variation for leaf length and leaf area, respectively, occurring across replicates.

Correlations Between Characters

Simple correlations between all possible combinations of traits measured and selected geographic components for each stand were computed using stand mean data (Tables VII and VIII). Selected significant correlations were plotted and linear regression computed for trend analysis. There were other significant relationships, which are not presented as the trends were not visually apparent. All relationships plotted were significant at the 0.05 probability level.

Date of leaf drop was the only trait measured with a sig-

TABLE VII

SIMPLE CORRELATION COEFFICIENTS AMONG SEEDLING GROWTH VARIABLES ON A STAND MEAN BASIS

	Leaf Drop Date	Seedling Height	Seedling Diameter	Nut Length	Nut Diameter	Nut Weight	Compound Leaf Length	Compound Leaf Area	Simple Leaf Length	Simple Leaf Area	Freq. of Multiple Stems	Germination Rate	Germination Percent
Leaf Drop Date													
Seedling Height	.26												
Seedling Diameter	.24	.76*											
Nut Length	.24	-.03	.20										
Nut Diameter	.09	.60*	.56*	-.01									
Nut Weight	.16	.61*	.60*	.35	.87*								
Compound Leaf Length	.17	.35	.71*	.25	.05	.14							
Compound Leaf Area	.31	.42*	.70*	.20	.15	.22	.95*						
Simple Leaf Length	.08	-.13	.08	.45*	-.27	.05	.35	.25					
Simple Leaf Area	-.11	-.03	.19	.46*	-.09	.22	.36	.29	.86*				
Freq. of Multiple Stems	.10	-.04	.02	-.001	.004	-.13	.09	.13	-.43*	-.37			
Germination Rate	-.11	-.41*	-.63*	-.09	-.41*	-.28	-.53*	-.49*	.22	.22	-.27		
Germination Percent	-.29	.28	.30	.21	.20	.29	.15	.13	.16	.15	-.07	-.14	

* Significance at the 0.05 level

TABLE VIII

SIMPLE CORRELATIONS OF SEEDLING GROWTH VARIABLES WITH GEOGRAPHIC VARIABLES OF SEED COLLECTION SITES, ON A STAND MEAN BASIS

	Latitude	Longitude	Elevation	Average Annual Rainfall	January Minimum Temperature	July Maximum Temperature	Number of Frost Free Days
Leaf Drop Date	-.91*	-.24	-.60*	.63*	.88*	.29	.86*
Seedling Height	-.38	.23	-.01	-.05	.42*	.37	.45*
Seedling Diameter	-.24	.07	-.02	-.03	.21	.10	.31
Nut Length	-.25	-.10	-.18	.24	.15	-.02	.19
Nut Diameter	-.25	.58*	.43*	-.34	.22	.49	.17
Nut Weight	-.29	.39	.19	-.17	.27	.48	.26
Compound Leaf Length	-.07	-.21	-.21	.15	.07	-.21	.08
Compound Leaf Area	-.25	-.13	-.21	.14	.23	-.14	.23
Simple Leaf Length	.23	-.41*	-.29	.25	-.19	-.35	-.16
Simple Leaf Area	.24	-.45*	-.24	.24	-.24	-.36	-.14
Freq. of Multiple Stems	-.19	.17	.03	-.19	.10	.06	-.09
Germination Rate	.26	-.34	-.13	.23	-.17	-.13	-.15
Germination Percent	.21	.11	.03	-.20	-.22	-.22	-.12

* Significant at the 0.05 level.

nificant north-south trend. Date of leaf drop is apparently influenced in part by several environmental factors specific to seed origin, as it is significantly negatively correlated with latitude and elevation. The relationship between leaf drop date and latitude showed the most significant trend with R square of .82 (Figure 11).

Stand 51 from north central Missouri is geographically separated from the other stands. This separation is indicated on three of the five graphs (Figure 11-15), but when the linear regression was applied, stand 51 fit the north-south trend.

Leaf drop date was also positively and significantly correlated with average annual rainfall, average annual minimum temperature, and average number of frost free days (Refer to Appendix C for stand means on average maximum annual temperature, average annual minimum temperature, and average number of frost free days). Most of the trends plotted were expected due to the high correlations among stand geographic factors (Appendix D). For example, as north latitude increases, the number of frost free days and average annual minimum temperature decreases. Figure 12 and 13 show the effect of number of frost free days (R^2=.74) and average annual minimum temperature (R^2=.78) on leaf drop data. Elevation was significantly correlated with longitude, but still affects leaf drop date in a north-south direction (Figure 14). Average annual rainfall was also correlated with longitude. The effect of rainfall on leaf drop date (R^2

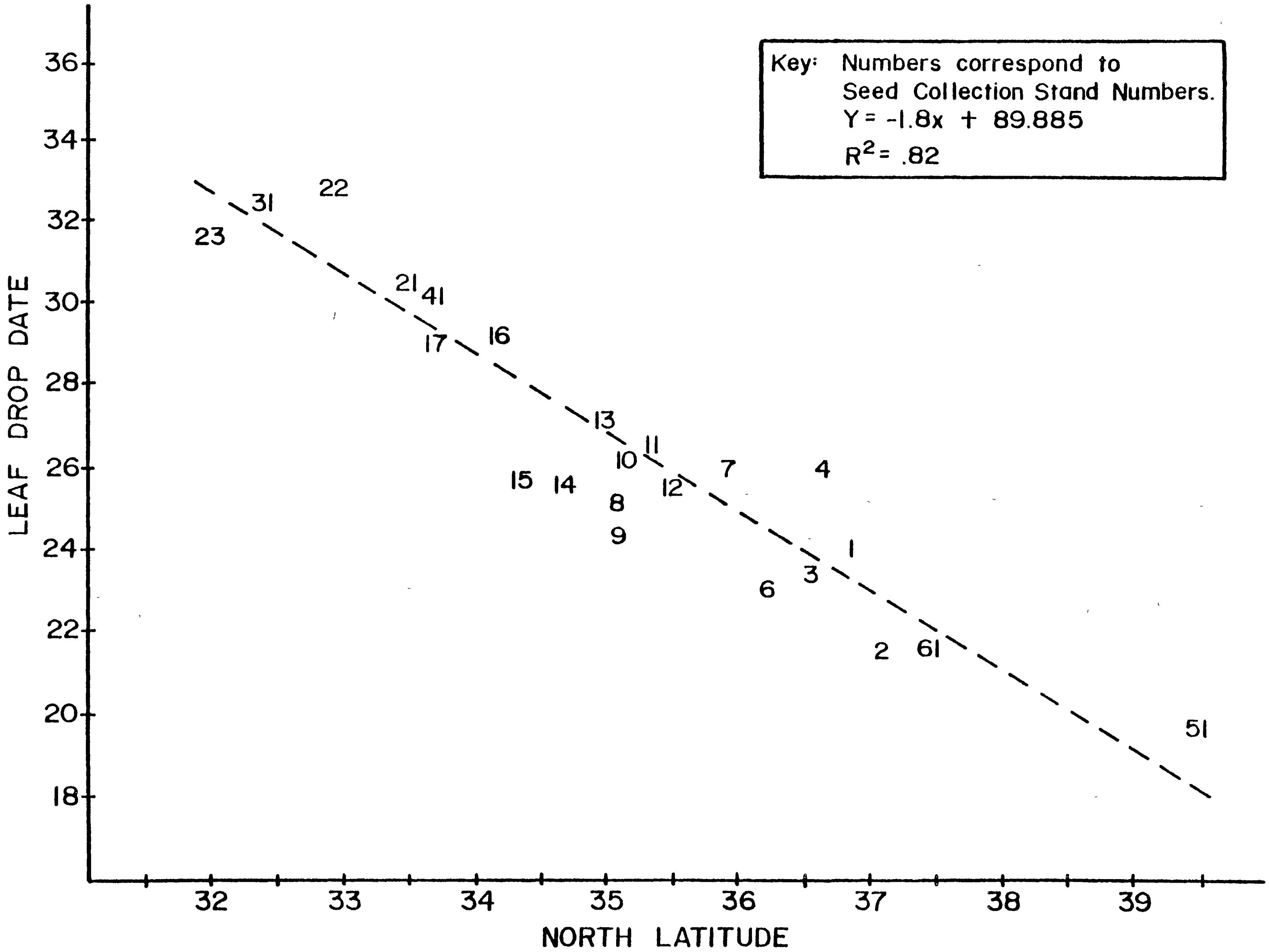

Figure 11. Relationship of Mean Leaf Drop Date with Latitude.

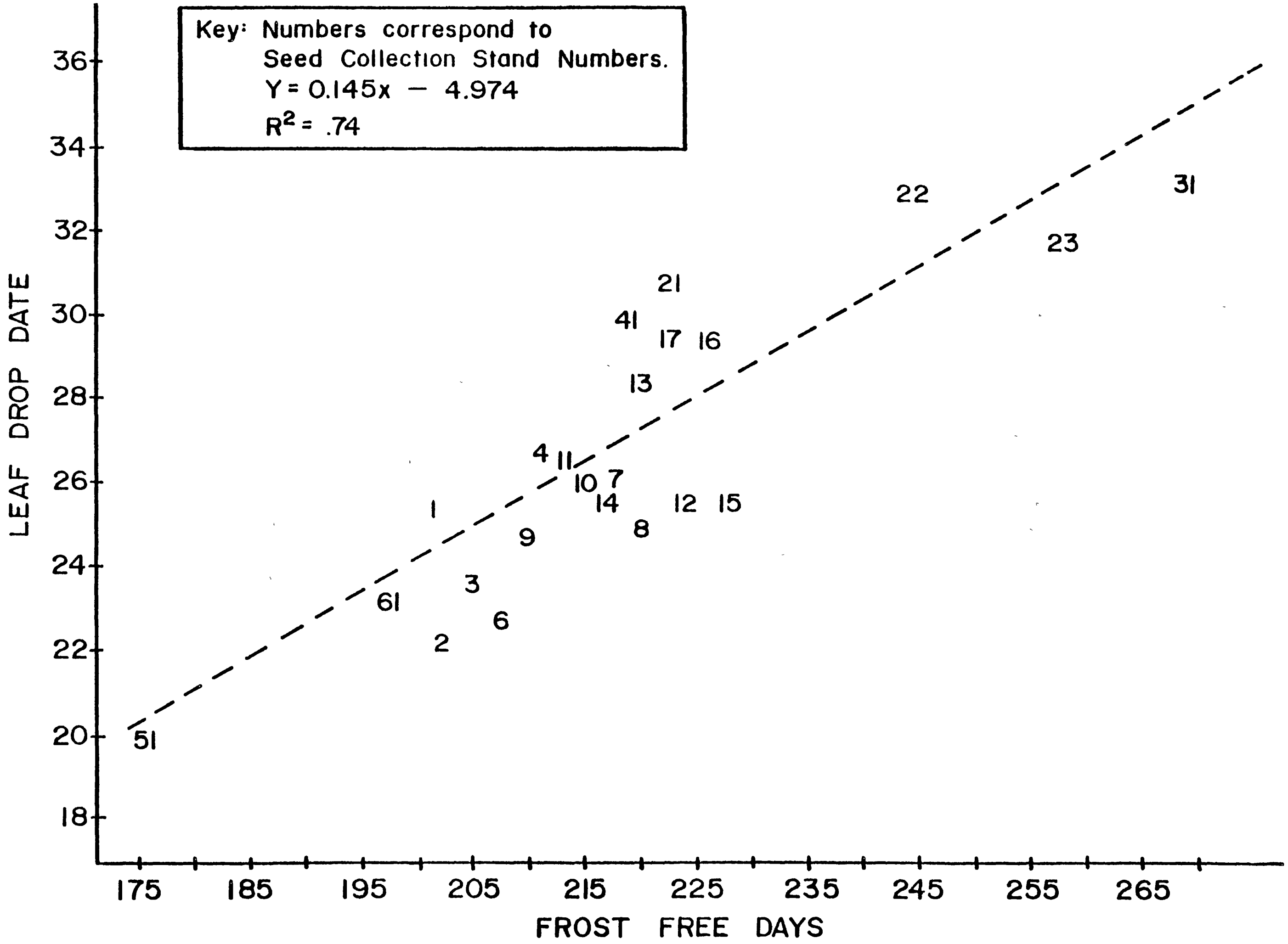

Figure 12. Relationship of Mean Leaf Drop Date with Average Number of Frost Free Days.

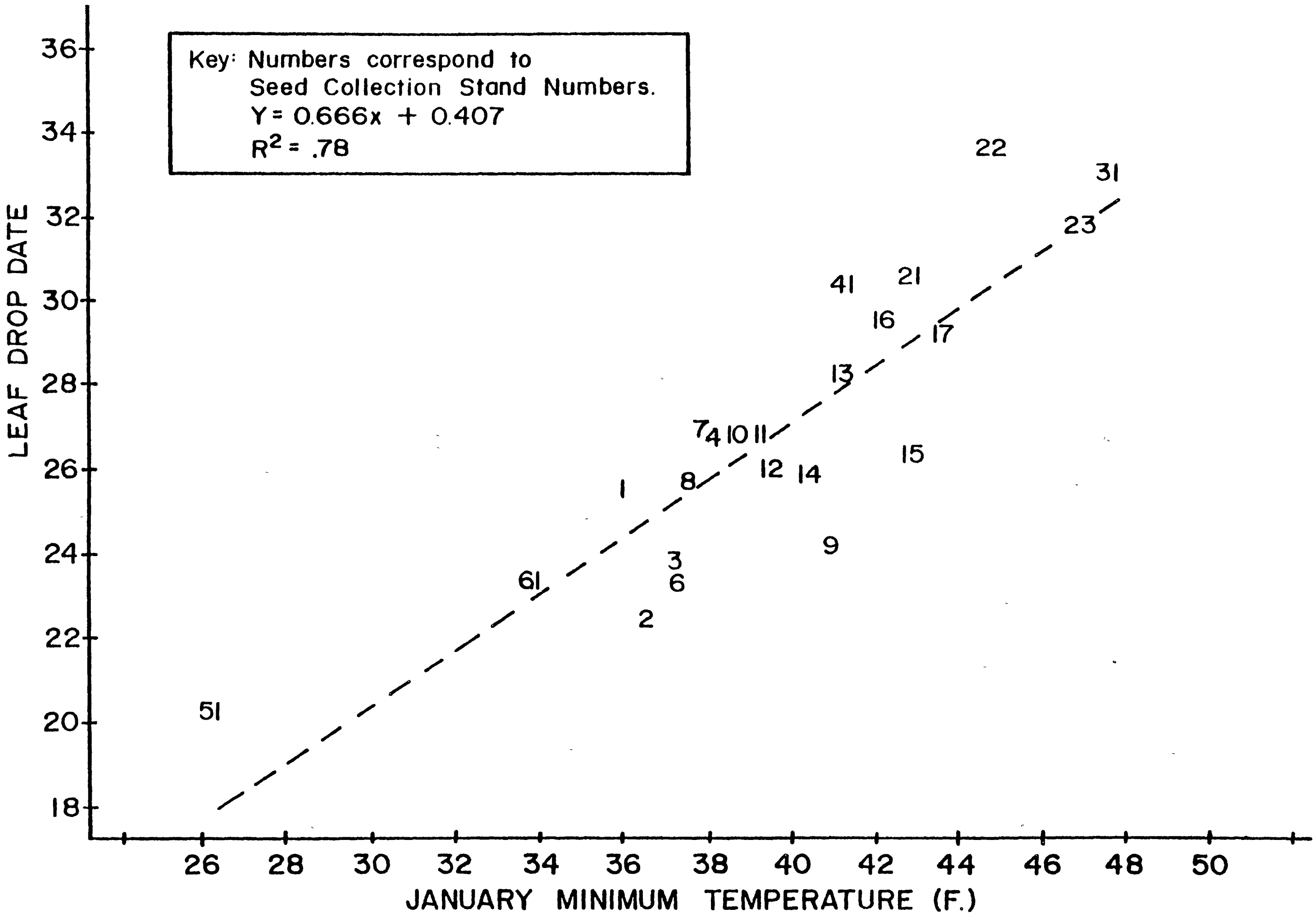

Figure 13. Relationship of Mean Leaf Drop Date with Average (January) Minimum Temperature.

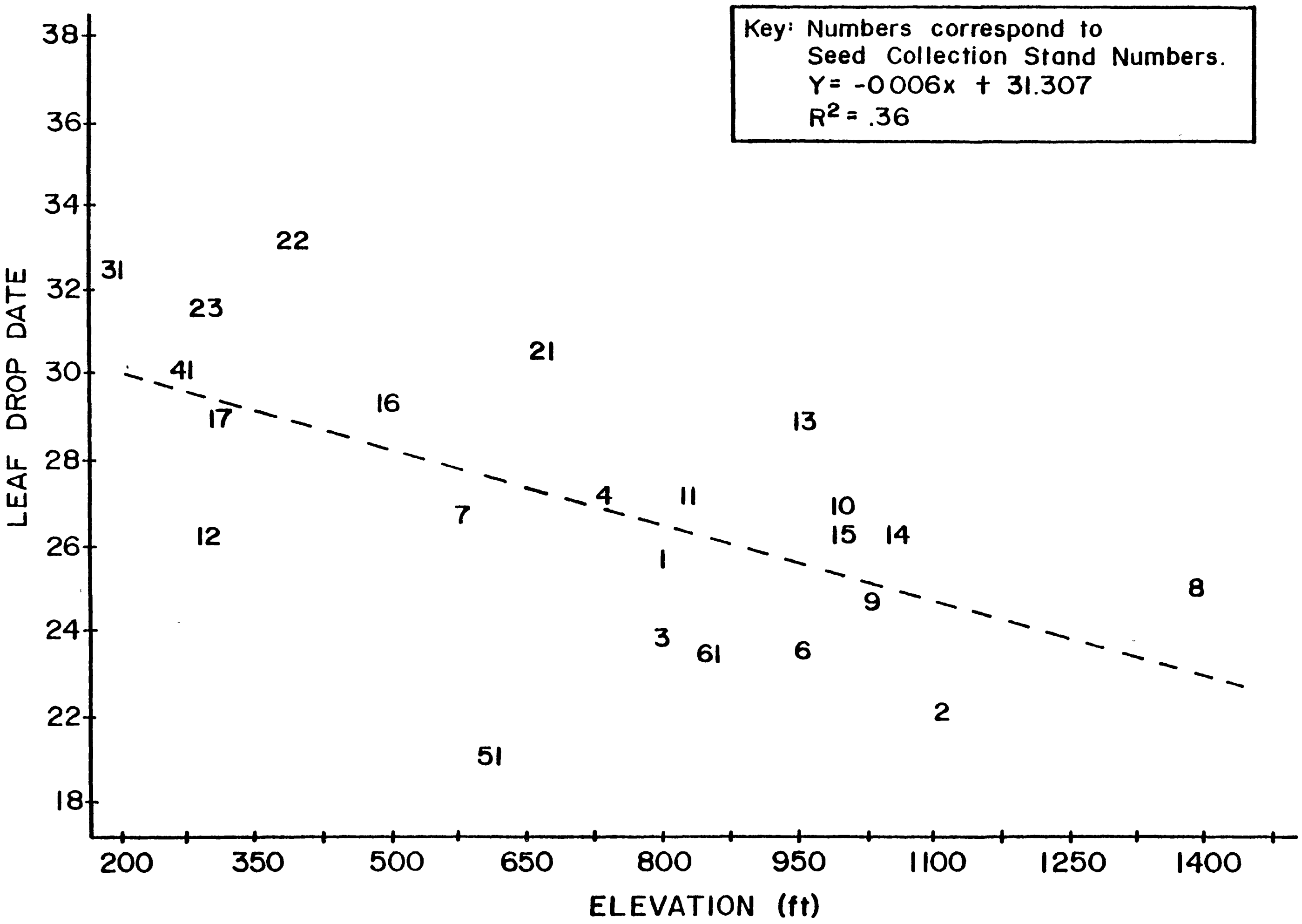

Figure 14. Relationship of Mean Leaf Drop Date with Elevation.

=.39) is shown in Figure 15. Leaf drop date may be useful in producing pecan with an extended growing period especially if coupled with early germination or leaf flush.

Seedling height showed a significant positive correlation with seedling diameter (Figure 16), nut diameter, and nut weight and a negative correlation with weighted germination rate. Table IX lists stand means for seedling height, seedling diameter, and nut size components. Nut size components (weight and diameter) had significant positive effects on both seedling height and diameter. Increased first year seedling size might be achieved by utilizing the positive correlation between seedling height and average nut weight (Figure 17). Nut length showed no significant effect on seedling growth. Early germination also tends to increase first year height as shown in Figure 18. Note that a decrease in the germination rate value indicates early seedling emergence. Nursery production of larger pecan seedlings increases the chance for survival and seedling establishment after outplanting.

Seedling diameter was positively correlated with compound leaf length and leaf area, nut diameter, and nut weight. Seedling diameter was negatively correlated with weighted germination rate. Figure 19 and 20 show the relationship between seedling diameter and compound leaf length and compound leaf area. Increase in leaf area should increase the plants photosynthetic capacity. However, photosynthetic efficiency may not be affected. This increase in food pro-

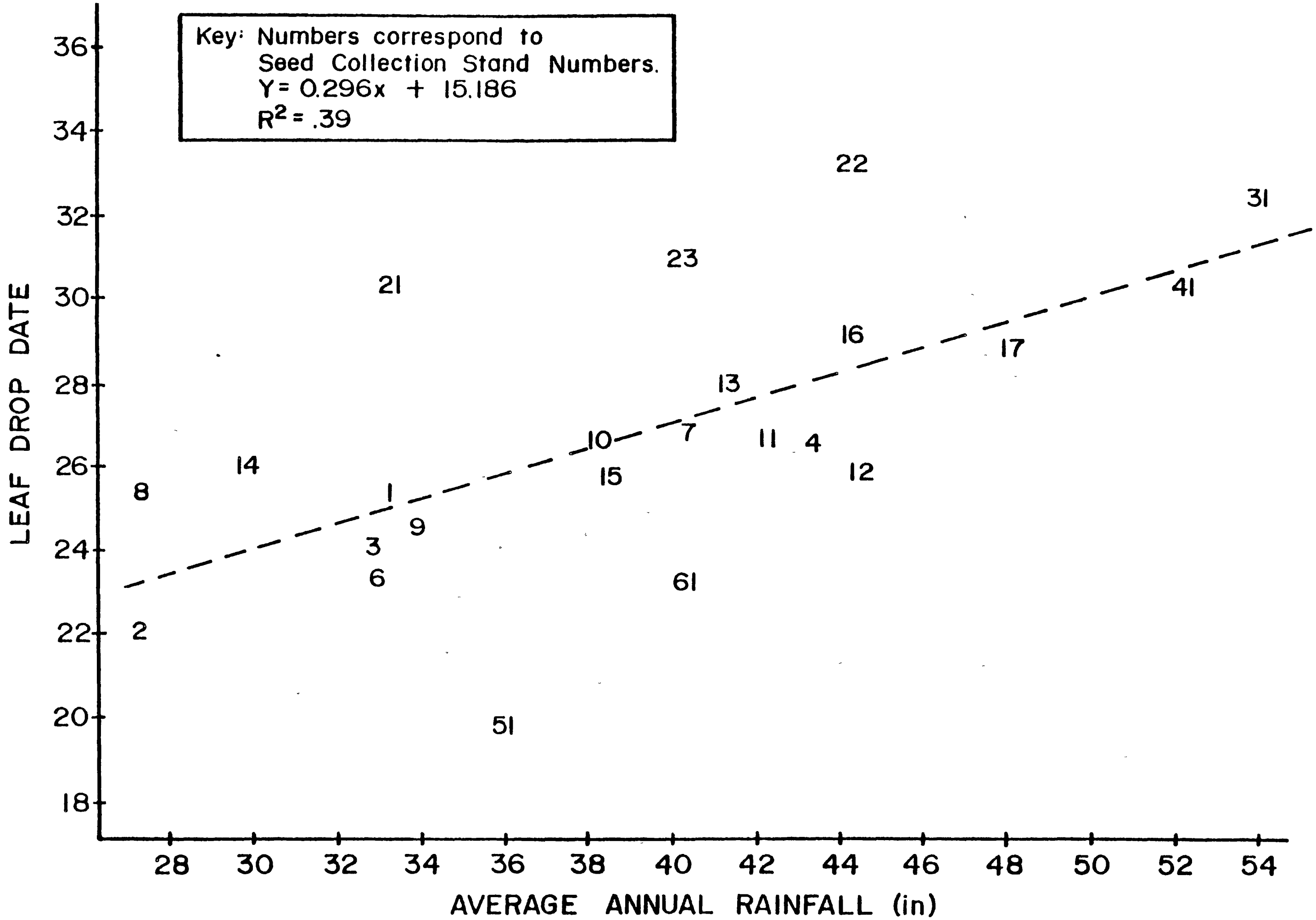

Figure 15. Relationship of Mean Leaf Drop Date with Average Annual Rainfall.

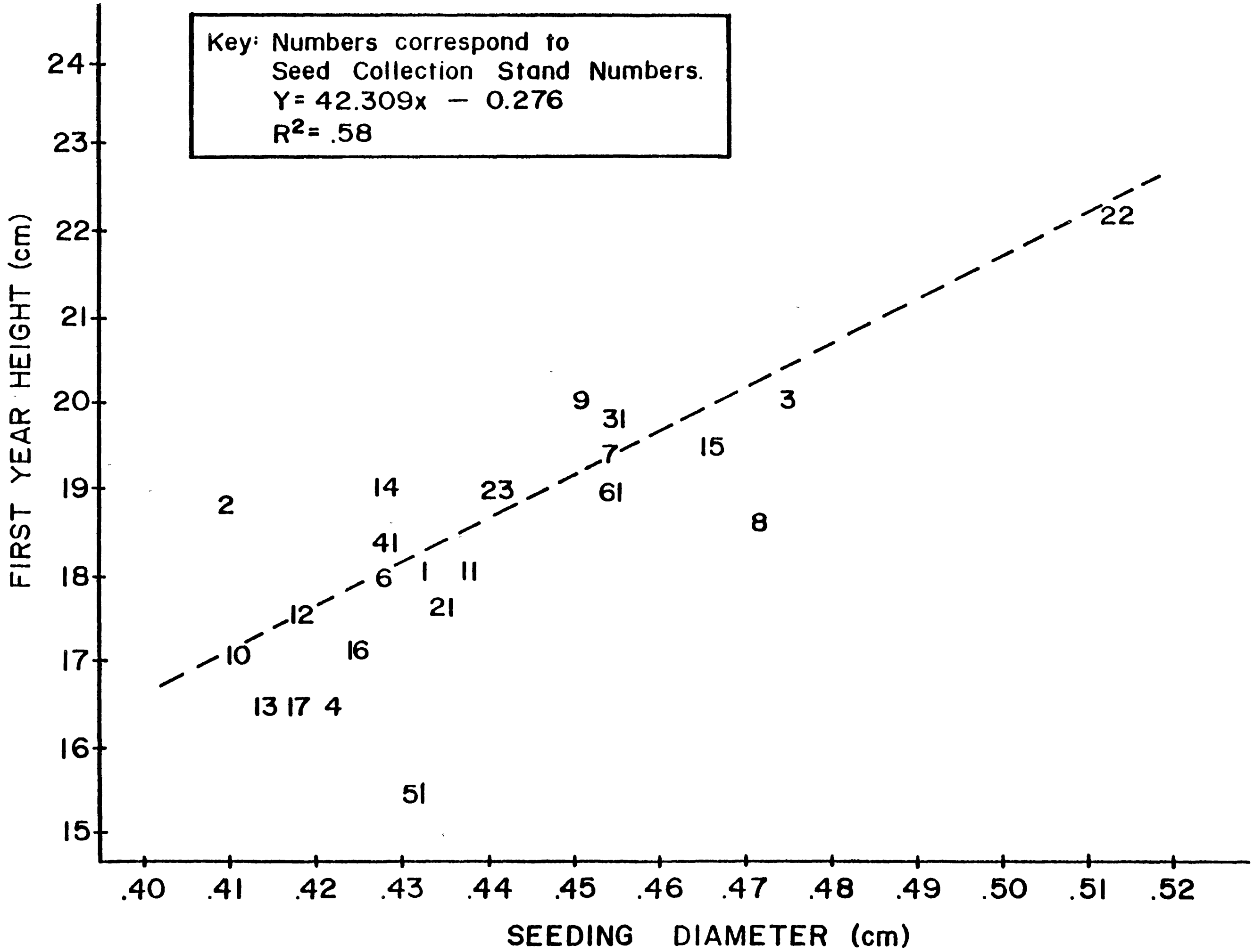

Figure 16. Relationship of First Year Height with Seedling Diameter.

TABLE IX

SUMMARY OF STAND MEANS FOR SEEDLING HEIGHT, SEEDLING DIAMETER, NUT LENGTH, NUT DIAMETER, AND NUT WEIGHT

Stand	Height (cm)	Diameter (cm)	Nut Length (cm)	Nut Diameter (cm)	Nut Weight (grams)
1	18.2	.43	2.79	1.66	3.16
2	18.8	.41	2.72	1.65	3.39
3	20.1	.48	3.05	1.76	3.90
4	16.7	.42	3.05	1.76	4.03
6	18.0	.43	2.93	1.71	3.69
7	19.6	.45	3.09	1.72	3.91
8	18.5	.47	3.42	1.89	4.43
9	20.1	.45	2.97	1.89	4.32
10	17.0	.41	3.11	1.71	3.64
11	17.7	.43	2.98	1.58	2.96
12	17.5	.42	3.07	1.50	2.86
13	16.7	.41	2.67	1.68	2.81
14	19.0	.43	2.96	1.76	3.74
15	19.3	.46	2.95	1.79	3.71
16	17.2	.42	3.31	1.66	3.96
17	16.7	.42	3.35	1.55	3.39
21	17.4	.43	3.16	1.60	3.15
22	21.5	.52	3.02	1.88	4.50
23	19.1	.44	2.91	1.79	3.96
31	20.0	.45	3.17	1.60	3.43
41	18.2	.43	3.04	1.68	3.42
51	15.4	.43	2.95	1.53	2.83
61	19.0	.45	3.18	1.66	3.63
Range	5.6-43.0	.14-.88	1.1-4.8	1.2-2.3	2.0-6.3
Means	18.3	.44	3.04	1.69	3.60

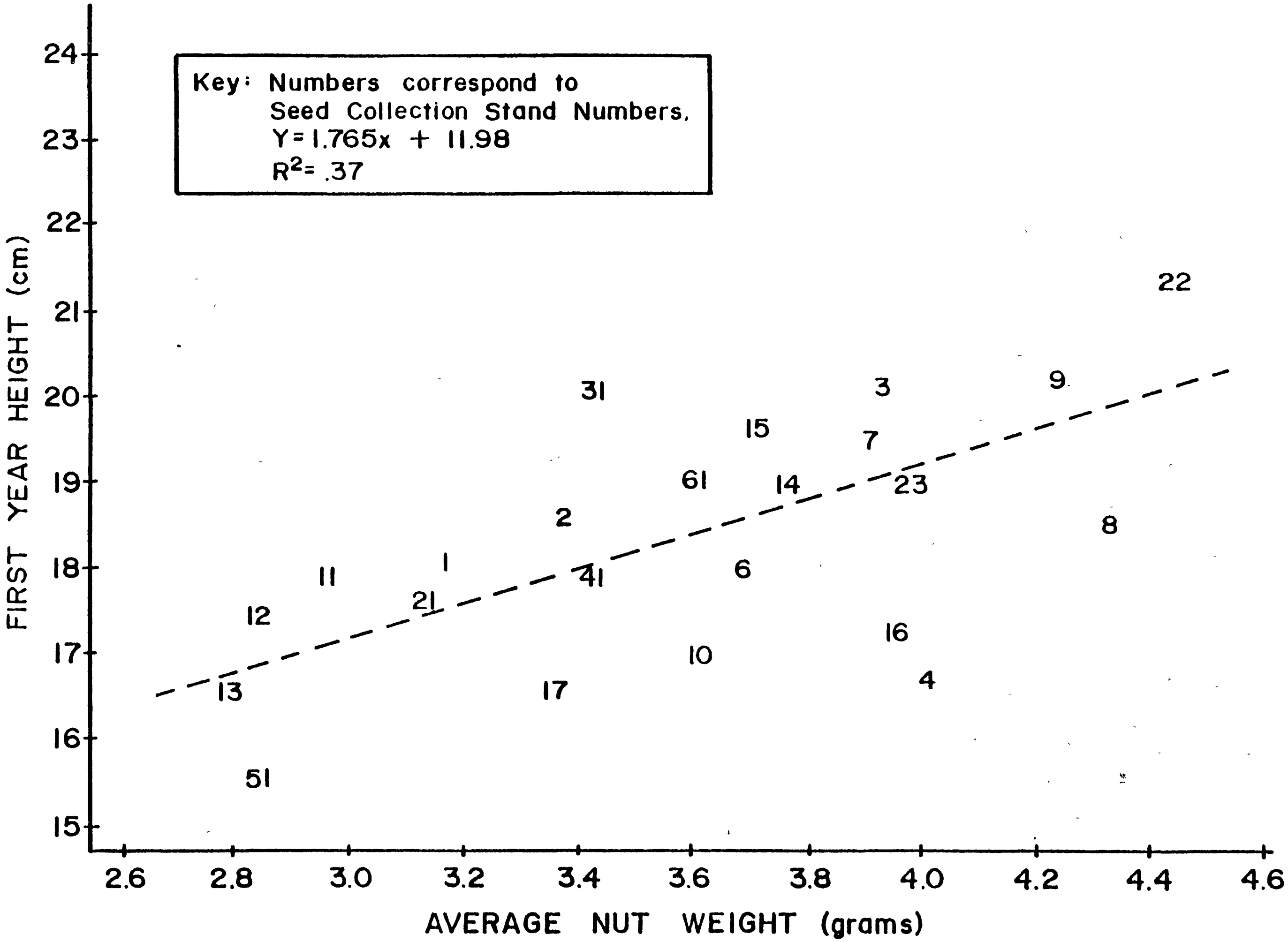

Figure 17. Relationship of First Year Height with Average Nut Weight.

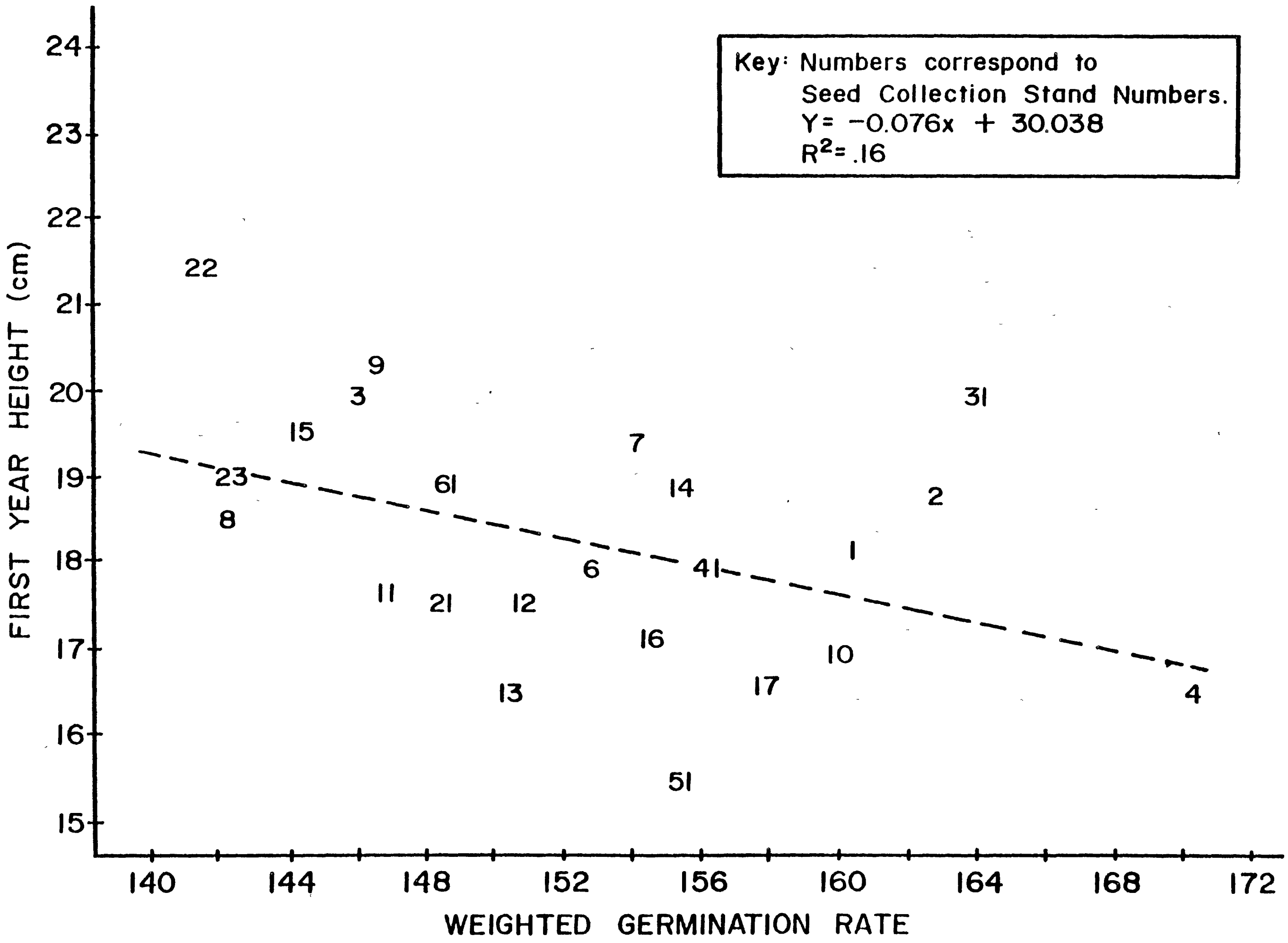

Figure 18. Relationship of First Year Height with Weighted Germination Rate.

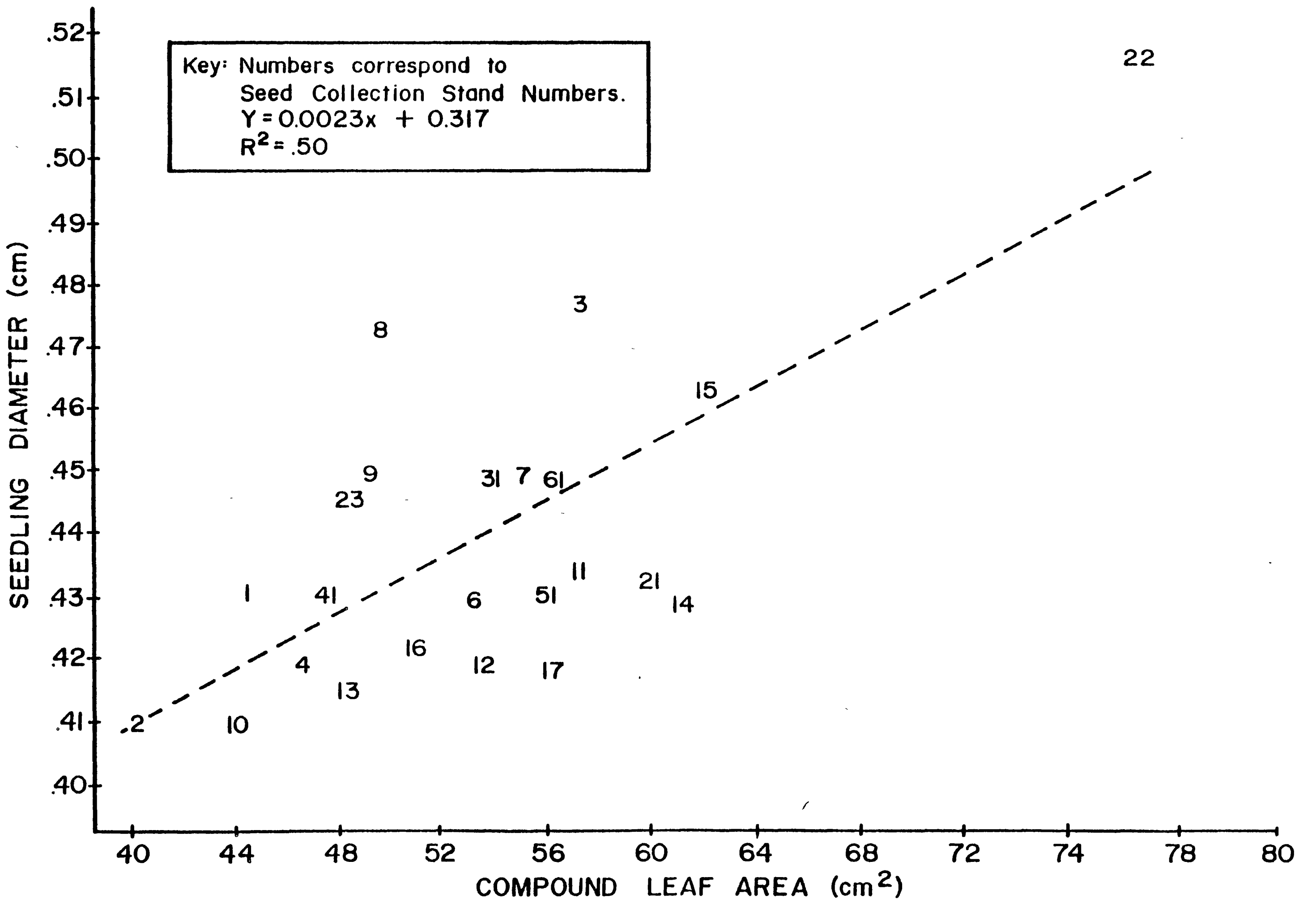

Figure 19. Relationship of Seedling Diameter with Total Leaf Area of the Longest Compound Leaf.

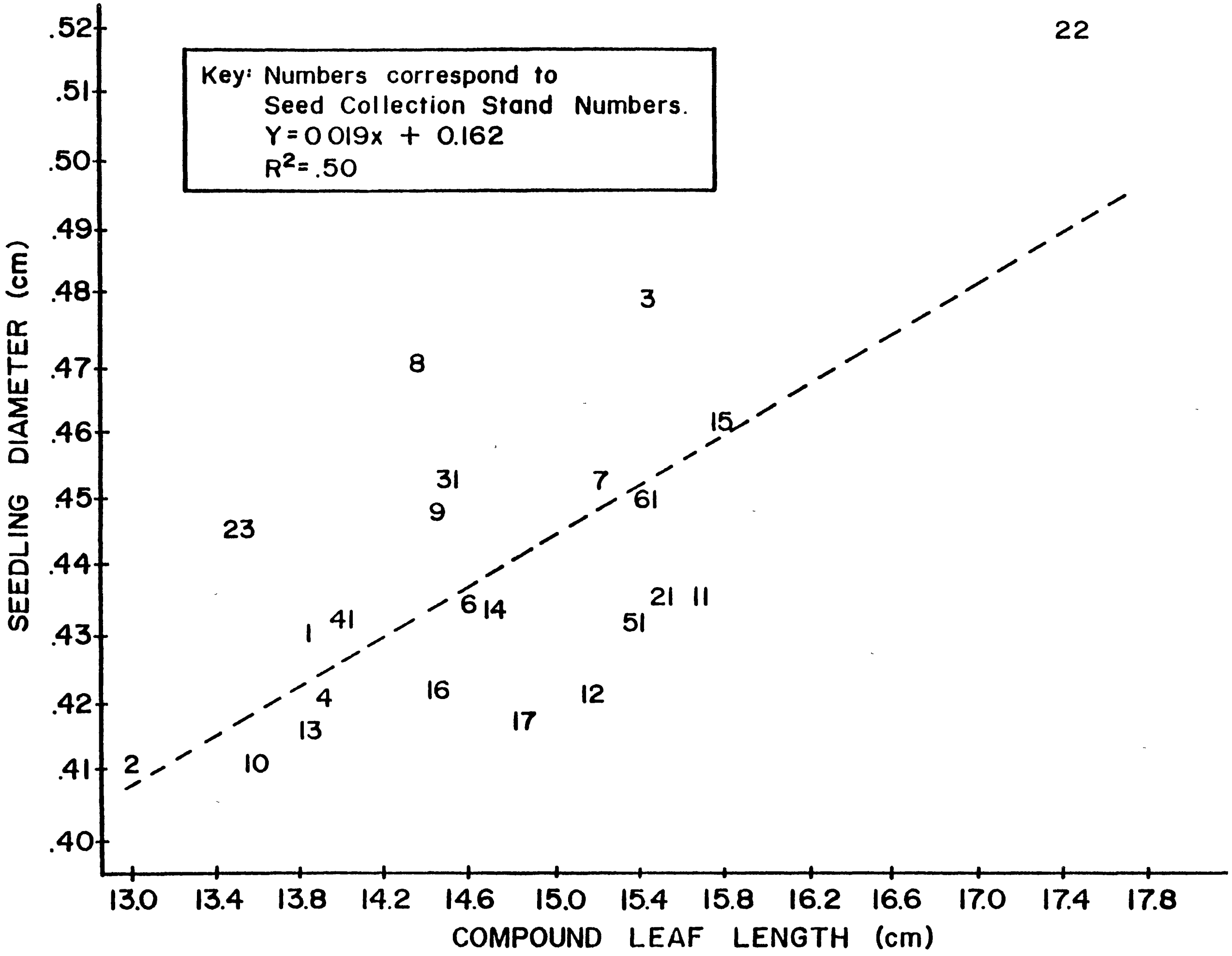

Figure 20. Relationship of Seedling Diameter with Total Leaf Length of the Longest Compound Leaf.

ducing area may account in part for an increase in growth. Nut weight and early germination time also affect stem diameter for the first year (Figure 21 and 22). Increased growth from larger nut size is no doubt partly due to the larger amount of stored nutrients. Early germination may take advantage of more optimum growing conditions associated with the spring season, and a longer growing period, resulting in increased growth.

Nut diameter and nut weight were highly correlated (.87) with each other. Nut diameter and nut weight were positively correlated with all the same variables except longitude and elevation (Tables VII and VIII). Nut diameter showed a moderate correlation (.58) with longitude and elevation (.43). Nut diameter was negatively correlated (-.41) with weighted germination rate. By using either nut weight or nut diameter, expected seedling growth for first year nursery stock could be estimated for selected pecan families.

Frequency of multiple stems, germination percent, and nut length showed no significant relationships.

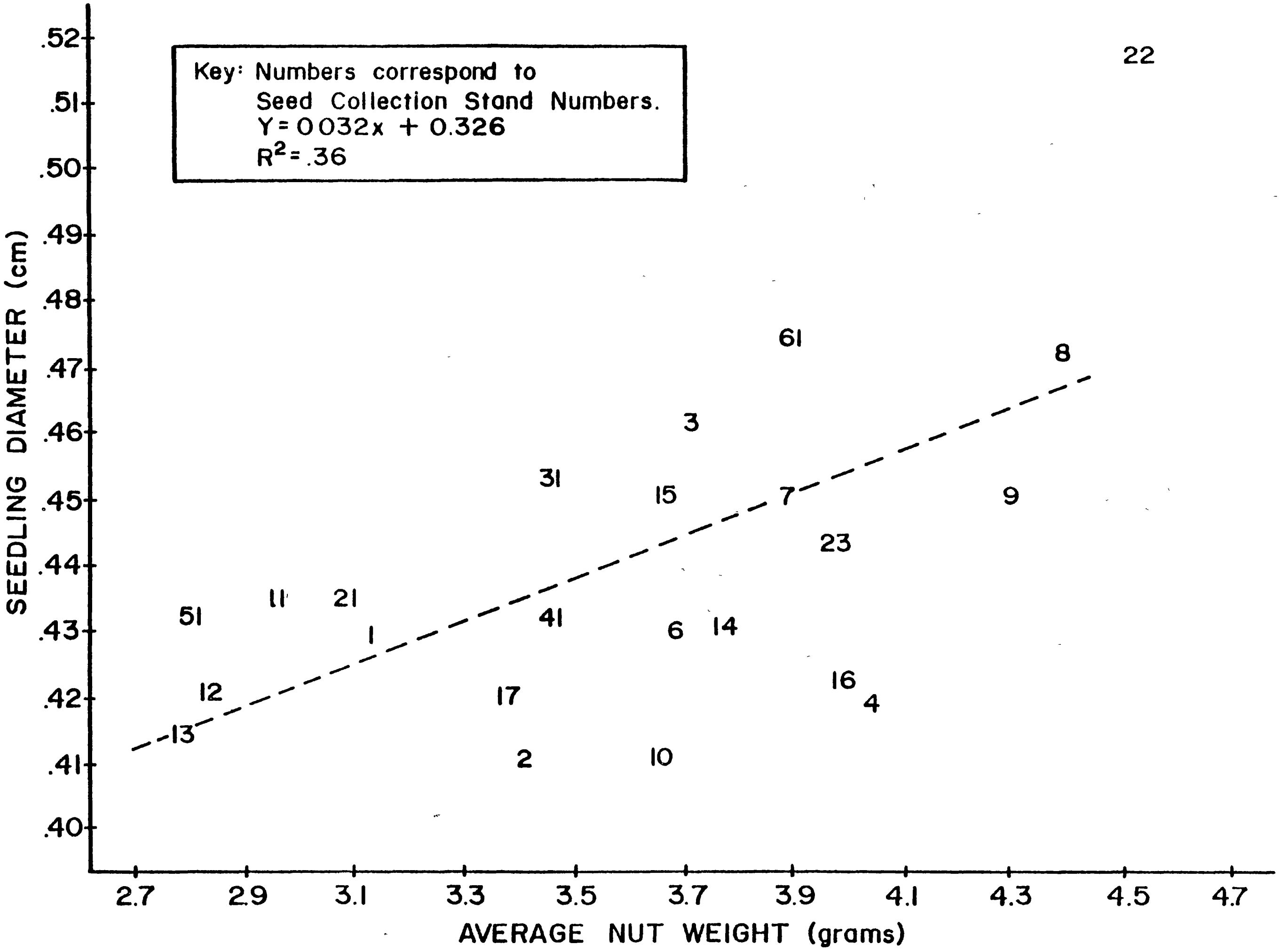

Figure 21. Relationship of Seedling Diameter with Average Nut Weight.

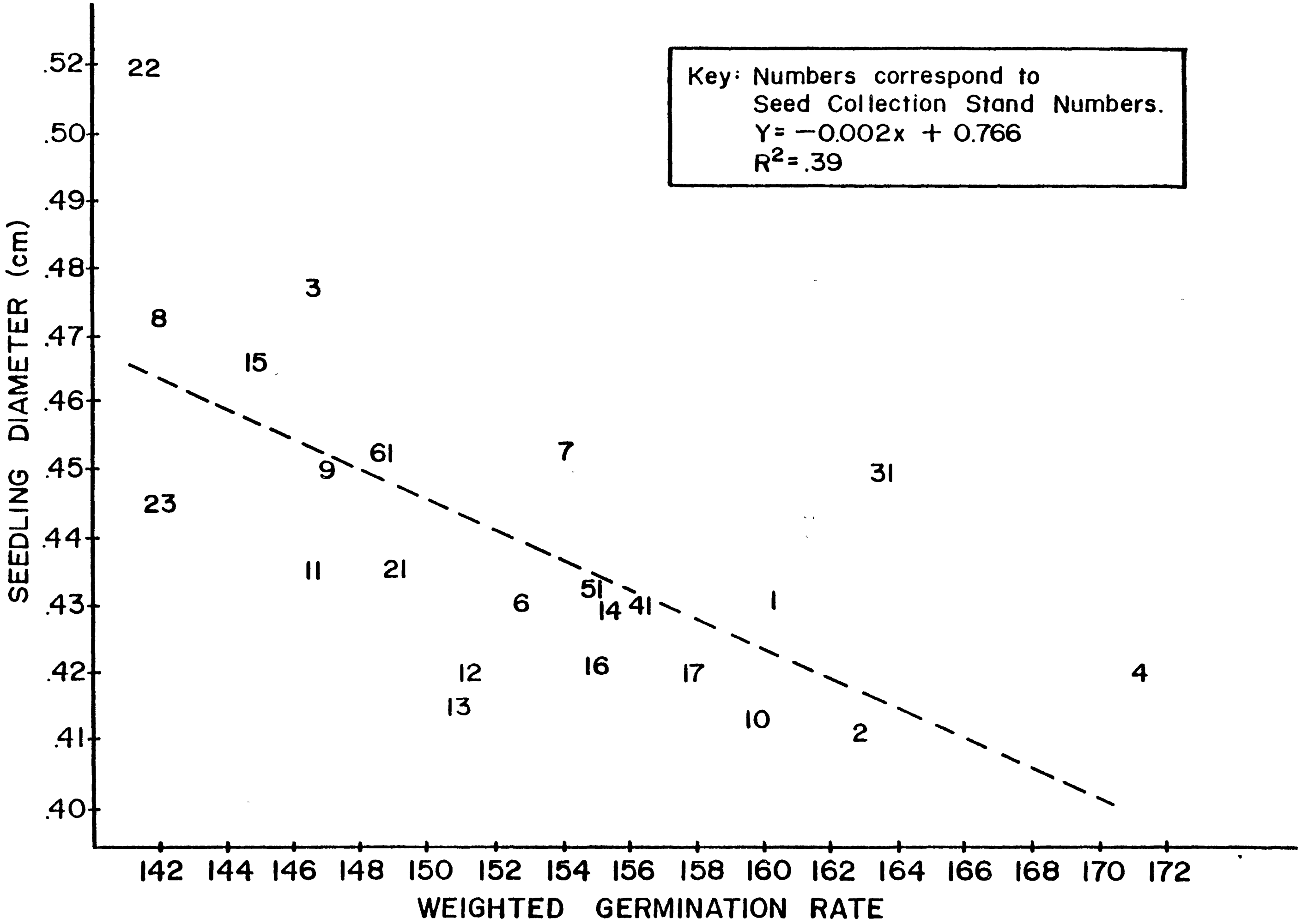

Figure 22. Relationship of Seedling Diameter with Weighted Germination Rate

Estimates of Heritability

Heritability estimates were calculated for leaf drop date, seedling height and diameter, compound leaf length and area, weighted germination rate, germination percent, frequency of multiple stems, and frequency of albino plants (Table X). The precision of these estimates is confounded by environment. Heritability estimates for seedling height (.60) and diameter (.46) are slightly higher than estimates calculated using data from older individuals. The positive correlation of seed size with seedling size for the first year may have attributed in part to this increase. Selection of pecan for improved seedling height and diameter growth should still prove successful as heritability estimates are quite high. It is hoped that this improvement will be maintained through to tree maturity. A high heritability for a specific trait suggests that progeny from trees selected for that trait should perform better than progeny from the average tree. Controlled crosses between superior individuals of diverse origins may yield further gains due to heterosis. Compound leaf length and area showed high heritibilities (.79 and .43). The high correlation between leaf length and leaf area and their relationship to seedling diameter suggest either leaf trait might be used for early selection. Germination rate is also highly correlated with seedling growth and had a heritibility of .78. Early selection may be possible using nut weight, nut

TABLE X

HERITABILITY ESTIMATES AND STANDARD ERRORS FOR SELECTED STUDY VARIABLES ON A FAMILY MEAN BASIS

Variable	Heritability Estimates	Standard Error
Leaf Drop Date	.23	.0468
Seedling Height	.60	.0637
Seedling Diameter	.46	.0855
Compound Leaf Length	.79	.0333
Compound Leaf Area	.43	.0910
Germination Rate	.78	.0396
Germination Percent	.87	.0220
Frequency of Multiple Stems	.07	.1700

diameter, germination rate, compound leaf length, and/or compound leaf area. All five variables influence growth in a positive manner.

Germination percent indicates a high degree of genetic control with a heritability estimate of .87. Germination percent is affected by inherent seed characteristics and by environmental factors occurring during seed formation. Germination percent may also be affected by the site conditions on which the seed is planted. Sound silivicultural practices may be necessary to help minimize the environmental effect during a breeding program.

A high heritability for albino plants would be expected since the environmental effect is near zero and certain genetic combinations of recessive alleles are necessary for the trait to occur. Selection against albinism is natural since the trait is lethal.

CHAPTER V

SUMMARY AND CONCLUSIONS

Research into the genetic variation present in native sweet pecan is the primary step toward improvement of the species for timber production. The high value annual nut crop has diverted previous attention from tree improvement to improveing commercial nut varieties. The increase in demand for and value of pecan lumber has initiated new efforts in development and regeneration of high quality genetic stock.

Successful breeding programs have been developed for black walnut and other hardwood species. Provenance tests and progeny tests have generated useful information about the natural diversity within the range of these species. Use of this natural variation has provided significant gains in growth and form for lumber production.

The major objective of this study was to determine if significant genetic variation is detectable over a portion of the pecan range. If considerable diversity exists, substantial gains are possible through selection and breeding. The 23 stands sampled provided a cross section of the natural population available in this area. Results from this nursery study showed considerable variation among open-pollinated families in different stands. Significant variation was also detectable among individuals within stands of pecan. Native pecan stands of sufficient size still remain from which superior tree selections can be made. Another objective of this study was to generate early growth data to evaluate juvenile-mature relationships at a later date. There are indications that seed size may cause increases in hertibility estimates using first year seedlings over estimates from older material. Heritability estimates obtained in this study were not adjusted for the influence of seed size or environment. Seed size does affect first year growth (Adams, 1976). This influence is positive and could be advantageous to nursery production of pecan regeneration material. Estimates should be calculated using data from more mature progeny tests planted at several locations.

Hybridization has already proven successful in improving height and diameter growth over native pecan (Sparks and Toliver, 1978). For example, Carya x lecontie Little, a cross between native pecan and water hickory, exhibited greater height and diameter growth than pecan trees in the same stand. The putative hybrid included in this study also outperformed the native pecan trees from the same stand. It was matched in mean height growth by only one of the 113 pecan families evaluated. Hybrids may provide substantial gains over pecan in timber production. Further progeny testing is needed to test other characteristics, both growth and form related, as well as wood characteristics.

An important element identified in this study was the affect of nursery practices on first year growth. Germination rate and seedling diameter were both influenced by differential watering across the planting. The genotype x environment interaction must be evaluated further to insure success of nursery efforts to produce larger seedling stock for future plantation establishment.

Progeny tests at three locations in Oklahoma will be established from the seedling material grown during this study. These tests will help identify families which exhibit superior growth on a variety of sites. Identification of such trees, if they exist, will aid in producing pecan trees suitable for a variety of planting sites.

Future studies need to evaluate the effectiveness of selecting individuals with superior phenotypes from stands identified as having the gene pool necessary to produce such individuals. With the apparent large amount of variation existing throughout the native range of pecan, selection of this type should be productive.

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APPENDIX A

SUMMARY OF FAMILY MEANS FOR NUT LENGTH, NUT DIAMETER, NUT WEIGHT, SEEDLING HEIGHT, AND SEEDLING DIAMETER

Family		Pecan nut			Seedling	
Stand	Tree	Length (cm)	Diameter (cm)	Weight (grams)	Height (cm)	Diameter (cm)
1	1	3.21	1.69	3.45	15.86	.43
	2	2.35	1.68	2.77	17.70	.43
	3	3.23	1.61	3.33	18.48	.42
	4	2.84	1.75	3.66	16.75	.39
	5	2.32	1.56	2.59	22.44	.49
2	1	2.52	1.59	2.81	17.31	.38
	2	2.70	1.71	3.65	19.80	.41
	3	2.92	1.64	3.71	19.32	.43
3	1	3.04	1.83	4.19	22.51	.53
	2	3.36	1.62	3.08	19.91	.44
	3	3.18	1.91	4.84	17.98	.44
	4	3.02	1.71	3.81	21.29	.49
	5	2.65	1.72	3.61	18.34	.48
4	1	2.88	1.91	4.21	14.98	.39
	2	3.51	1.77	4.04	15.64	.40
	3	2.98	1.72	4.12	18.38	.43
	4	2.44	1.64	3.06	15.13	.36
	5	3.43	1.79	4.71	19.26	.50
6	1	2.77	1.69	3.33	15.22	.40
	2	3.05	1.68	3.69	19.95	.45
	3	3.48	1.84	4.76	18.38	.45
	4	2.77	1.62	3.27	17.81	.43
	5	2.57	1.70	3.43	18.28	.41
7	1	2.84	1.68	3.63	17.85	.45
	2	3.28	1.65	3.82	19.70	.45
	3	3.24	1.83	4.46	18.05	.41
	4	2.99	1.72	3.78	22.19	.48
	5	3.10	1.72	3.85	19.89	.48
8	1	3.41	2.14	6.04	18.54	.50
	2	3.56	1.83	4.29	18.78	.45
	3	2.93	1.75	3.24	16.79	.45
	4	3.64	1.92	3.99	18.66	.48
	5	3.56	1.79	4.57	19.92	.49

APPENDIX A (Continued)

9	1	3.09	1.91	4.93	20.14	.47
	2	3.13	2.12	4.27	18.75	.44
	3	3.31	1.65	4.16	20.92	.46
	4	2.46	1.87	3.88	19.18	.42
	5	2.87	2.89	4.37	21.80	.46
10	1	3.54	1.71	3.71	18.80	.45
	2	2.79	1.72	3.61	16.63	.39
	3	2.96	1.83	3.90	18.61	.48
	4	3.02	1.63	3.77	16.79	.38
	5	3.26	1.66	3.19	14.09	.36
11	1	3.22	1.74	3.79	18.18	.50
	2	3.13	1.64	3.27	20.73	.50
	3	2.39	1.50	2.13	16.33	.38
	4	3.22	1.39	2.38	14.34	.38
	5	2.92	1.61	3.23	18.88	.41
12	1	2.88	1.53	3.04	19.00	.40
	2	3.06	1.53	2.86	17.01	.43
	3	3.16	1.51	2.94	17.09	.43
	4	2.68	1.53	2.45	16.95	.39
	5	3.57	1.42	3.02	17.35	.44
13	1	2.59	1.56	2.51	15.94	.38
	2	2.19	1.93	3.08	15.49	.40
	3	3.09	1.81	3.51	20.58	.45
	4	2.74	1.54	2.50	15.92	.44
	5	2.72	1.56	2.46	15.46	.40
14	1	2.77	1.63	2.98	15.02	.32
	2	2.14	1.65	2.66	18.33	.42
	3	3.42	1.56	3.38	19.73	.43
	4	3.24	1.96	4.61	20.58	.46
	5	3.23	1.97	5.08	21.49	.53
15	1	3.11	1.75	3.72	17.38	.43
	2	3.05	1.81	3.92	19.78	.51
	3	2.77	1.88	3.71	17.14	.43
	4	2.74	1.80	3.43	23.26	.51
	5	3.08	1.69	3.79	19.16	.44
16	1	4.17	1.78	6.05	19.57	.48
	2	2.97	1.59	3.23	16.23	.36
	3	3.53	1.61	4.33	17.19	.44
	4	3.24	1.74	3.19	16.97	.41
	5	2.64	1.60	3.01	16.05	.41
17	1	3.63	1.55	3.73	16.09	.41
	2	3.09	1.56	3.08	17.24	.43
	3	3.27	1.53	3.12	17.24	.38
	4	3.31	1.54	3.48	15.66	.39
	5	3.44	1.58	3.52	17.00	.46

APPENDIX A (Continued)

21	1	3.48	1.71	3.68	19.36	.47
	2	2.84	1.74	2.76	16.61	.41
	3	3.21	1.59	3.63	16.20	.42
	4	3.16	1.69	3.64	20.32	.50
	5	3.14	1.27	2.02	14.76	.37
22	1	2.70	1.86	3.79	16.56	.46
	2	3.21	1.91	4.48	22.37	.50
	3	3.53	1.89	5.29	22.45	.51
	4	2.64	1.90	4.22	21.19	.51
	5	3.04	1.82	4.76	25.06	.62
23	1	2.70	1.88	4.28	20.54	.51
	2	3.02	1.74	3.87	21.09	.48
	3	2.97	1.75	3.42	16.48	.41
	4	2.88	1.88	4.33	18.94	.43
	5	2.99	1.69	3.88	18.26	.40
31	1	3.15	1.52	3.27	19.94	.45
	2	2.64	1.66	3.14	19.86	.43
	3	3.29	1.68	4.07	21.97	.47
	4	3.11	1.49	2.57	19.25	.46
	5	3.64	1.64	4.09	18.92	.44
41	1	2.51	1.59	2.87	14.83	.39
	2	3.33	1.83	4.27	21.10	.49
	3	3.41	2.16	4.08	24.16	.48
	4	3.02	1.37	2.45	14.36	.38
	5	2.91	1.43	2.97	17.01	.41
51	1	2.73	1.48	2.36	15.18	.43
	2	2.83	1.62	3.32	15.33	.42
	3	3.20	1.65	3.27	16.31	.44
	4	2.86	1.55	2.93	17.11	.47
	5	3.14	1.39	2.29	13.26	.39
61	1	2.74	1.68	3.27	18.85	.46
	2	3.66	1.76	4.57	20.28	.49
	3	3.39	1.65	4.22	18.78	.47
	4	2.92	1.61	2.98	17.33	.42
	5	3.19	1.59	3.13	19.54	.41

APPENDIX B

SUMMARY OF FAMILY MEANS FOR LEAF DROP DATE, WEIGHTED GERMINATION RATE, GERMINATION PERCENT, COMPOUND LEAF LENGTH, COMPOUND LEAF AREA, AND NUMBER OF ALBINO PLANTS

Family Stand	Family Tree	Leaf Drop (1)	Germination Rate (*)	Germination Percent	Compound Leaf Length (cm)	Compound Leaf Area (cm2)	Number of Albino Plants
1	1	24.35	166.23	79	13.10	41.66	
	2	28.15	158.03	92	14.53	53.84	
	3	21.65	150.40	83	13.72	43.90	
	4	25.55	168.72	93	13.23	39.20	
	5	27.25	159.85	72	14.80	50.16	
2	1	21.00	170.43	56	12.06	31.30	
	2	22.70	159.12	83	13.56	42.00	
	3	22.10	159.44	94	13.42	48.03	
3	1	21.05	143.38	91	17.79	74.41	
	2	26.70	141.47	92	16.06	63.24	
	3	22.10	146.71	87	13.96	42.39	
	4	20.90	148.20	94	14.59	52.72	
	5	28.05	152.99	89	14.52	50.52	
4	1	27.50	175.18	64	12.62	44.52	
	2	30.85	182.42	68	12.06	32.79	
	3	29.85	162.06	83	13.87	46.76	
	4	18.85	175.73	89	12.46	35.41	
	5	24.10	159.72	82	17.94	72.58	
6	1	21.40	150.50	69	14.90	49.58	
	2	23.00	151.18	84	14.09	47.97	
	3	25.15	152.44	88	16.20	68.21	
	4	27.75	156.67	89	15.66	64.50	
	5	18.75	155.72	90	12.14	32.95	
7	1	21.15	147.82	92	15.69	63.09	
	2	29.00	165.47	88	13.32	41.79	
	3	23.50	159.14	88	13.30	41.68	
	4	24.90	146.13	83	17.08	67.31	
	5	32.75	152.08	85	16.33	61.37	
8	1	23.90	141.09	88	15.15	57.64	3
	2	25.60	142.11	89	15.54	62.42	4
	3	23.10	135.21	83	13.61	41.04	7
	4	23.05	147.65	83	13.70	41.54	
	5	31.20	145.26	81	13.97	45.87	18

APPENDIX B (Continued)

9	1	19.30	143.28	87	16.72	60.93	
	2	24.95	138.57	80	14.03	47.13	
	3	23.40	147.63	87	15.66	61.93	
	4	30.45	146.68	89	12.17	30.76	
	5	22.85	157.51	80	13.84	46.15	
10	1	32.10	157.79	90	15.11	55.12	
	2	28.70	157.84	89	11.93	34.91	
	3	22.30	145.21	88	14.72	57.72	
	4	19.35	147.83	96	13.04	35.39	
	5	29.25	191.62	55	13.14	40.03	
11	1	27.05	143.34	67	16.72	67.34	10
	2	25.00	139.47	70	19.30	83.29	
	3	25.65	155.71	66	13.29	41.44	
	4	27.30	152.77	59	13.29	40.71	
	5	26.75	144.19	69	14.40	45.94	
12	1	26.55	148.91	82	14.82	52.14	
	2	27.25	150.10	83	16.29	60.19	
	3	28.90	147.81	93	14.45	49.56	
	4	20.60	153.36	88	14.87	51.66	
	5	26.30	157.79	93	15.43	55.54	
13	1	26.65	159.76	89	12.55	37.28	
	2	23.95	155.26	83	12.80	38.02	
	3	32.40	146.93	67	16.20	62.75	
	4	31.50	143.53	67	14.61	55.79	
	5	27.60	149.22	76	13.08	44.98	
14	1	23.75	164.28	88	12.19	60.01	
	2	27.85	152.26	84	14.98	56.90	
	3	20.15	155.41	91	14.77	55.70	
	4	32.70	167.16	83	13.26	50.02	
	5	24.80	135.99	84	17.50	79.65	
15	1	33.75	151.78	88	15.29	56.96	
	2	22.70	134.44	72	17.21	75.68	
	3	27.50	149.30	91	13.98	47.75	
	4	26.50	143.77	89	17.81	81.81	2
	5	20.05	143.96	85	14.51	49.93	4
16	1	23.25	155.80	82	16.58	70.47	
	2	31.90	168.81	94	11.96	32.20	
	3	30.85	152.57	86	16.69	69.46	
	4	28.90	153.81	37	14.02	46.23	
	5	30.00	153.55	88	12.97	38.19	
17	1	30.25	163.01	77	14.36	52.20	
	2	27.55	149.01	87	15.98	59.95	
	3	32.40	167.44	83	13.58	46.23	
	4	23.85	155.82	92	13.76	48.39	
	5	31.15	154.31	86	17.32	74.48	

APPENDIX B (Continued)

21	1	35.90	140.20	81	13.10	57.88	
	2	26.30	144.86	56	15.65	59.41	
	3	24.40	146.33	90	16.71	64.98	
	4	29.40	152.40	81	17.05	70.78	
	5	35.75	162.66	76	13.73	46.58	
22	1	29.20	143.17	89	16.18	63.95	
	2	34.45	141.68	76	17.21	70.83	
	3	37.80	139.91	90	15.43	59.41	
	4	29.55	141.67	89	18.24	85.76	
	5	34.00	143.68	67	20.99	119.59	
23	1	29.50	148.23	89	15.72	65.47	
	2	36.55	133.45	84	14.92	56.35	
	3	28.65	147.09	89	12.97	41.89	
	4	32.75	142.59	62	12.63	40.61	9
	5	30.70	140.95	85	11.70	34.51	
31	1	29.05	164.94	91	14.80	51.45	
	2	35.45	169.95	80	12.22	39.61	
	3	32.65	151.82	91	15.52	64.29	
	4	34.60	164.83	56	14.10	48.35	
	5	31.10	170.22	90	15.82	63.05	
41	1	29.65	155.50	80	12.33	36.13	3
	2	28.75	142.39	88	15.88	62.02	
	3	33.00	154.76	72	14.26	50.84	11
	4	23.35	167.38	68	13.81	42.58	
	5	35.50	159.91	84	13.51	45.15	
51	1	17.60	145.88	89	15.89	58.56	
	2	16.55	145.96	95	15.61	53.29	
	3	17.90	146.69	85	16.85	63.02	
	4	24.85	156.83	93	15.36	63.19	
	5	22.35	179.94	63	13.17	41.78	
61	1	21.95	156.17	82	16.03	58.59	
	2	19.35	148.03	82	16.32	59.76	
	3	28.85	146.19	95	16.34	70.18	
	4	25.35	144.04	88	14.05	45.61	
	5	21.75	150.71	94	13.60	41.58	

(1) Number of days after October 20.
(*) Smaller values correspond to earlier seedling emergence.

APPENDIX C

SUMMARY OF STAND MEANS FOR ANNUAL MINIMUM TEMPERATURE, ANNUAL MAXIMUM TEMPERATURE, AND NUMBER OF FROST FREE DAYS *

Stand	State	Average Annual Minimum Temperature	Average Annual Maximum Temperature	Average Number of Frost Free Days
1	OK	35.7	81.3	200
2	''	36.5	84.8	203
3	''	37.2	83.9	206
4	''	38.1	84.0	210
6	''	37.1	81.8	207
7	''	37.5	83.2	216
8	''	37.3	83.2	219
9	''	40.4	86.2	209
10	''	38.3	84.2	214
11	''	38.9	83.1	211
12	''	39.2	81.5	223
13	''	40.9	82.6	220
14	''	39.7	82.0	215
15	''	42.7	84.4	227
16	''	41.8	84.8	223
17	OK	43.2	81.9	222
21	TX	42.5	84.2	222
22	TX	45.0	82.9	245
23	TX	47.0	85.3	260
31	LA	47.2	83.2	272
41	AR	40.9	80.4	219
51	MO	26.4	77.9	175
61	KS	34.0	79.5	198

* The annual minimum temperature occurred in January.
  The annual maximum temperature occurred in July.

APPENDIX D

SIMPLE CORRELATIONS AMONG GEOGRAPHIC VARIABLES OF SEED COLLECTION SITES

	Latitude	Longitude	Elevation	Average Annual Rainfall	Average January Minumum Temperature	Average July Maximum Temperature
Longitude	-.06					
Elevation	.41*	.80*				
Average Annual Rainfall	-.43*	-.78*	-.81*			
Average January Minimum Temperature	-.96*	.05	-.42*	.46*		
Average July Maximum Temperature	-.48*	.53*	.20	-.18	.58*	
Average Number of Frost Free Days	-.90*	-.08	-.50*	.50*	.91*	.44*

* Significant at the 0.05 probability level.

VITA

Keith David Harris

Candidate for the Degree of

Master of Science

Thesis: A LIMITED-RANGE PROVENANCE TEST OF OPEN-POLLINATED PROGENY OF CARYA ILLINOENSIS (WANGENH.) K. KOCH IN OKLAHOMA

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