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A Study of Genetic Variability in Wild Populations of Pecan (Carya Illinoensis (Wangenh.) K. Koch).

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A STUDY OF GENETIC VARIABILITY IN WILD POPULATIONS OF PECAN (CARYA ILLINOENSIS (WANGENH.) K. KOCH)

A DISSERTATION

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ABSTRACT

To determine the extent and pattern of genetic variability in wild populations of sweet pecan (Carya illinoensis (Wangenh) K. Koch), a 40-parent open-pollinated progeny test was established and evaluated. Additional information on germination requirements, seed size-seedling growth relationship, and nursery effects was also obtained during the course of this study.

In 1973, seed was collected from 40 pecan trees selected for growth and form in South-central Louisiana along the Mississippi River. These seed were planted in two nursery locations; Baton Rouge, Louisiana, a conventional forest tree nursery planting, and Lumberton, Mississippi, in a field nursery similar to row cropping. First year nursery results indicated a very strong nursery effect on the growth of seedlings, especially root system development. Seedlings grown at Lumberton were found to have much larger root systems, in terms of root length and diameter, than corresponding genotypes planted at the Baton Rouge nursery. When the families were outplanted in the second year, the nursery effect was evident in survival, growth initiation, and second year height growth.

Progeny testing was done on three sites; Baton Rouge and Washington, La., and Lumberton, Miss. Results indicated a large degree of genetic diversity within populations of pecan. At the

end of the second growing season, several families were identified that were growing well on all three sites. Also, there was a high degree of variation among breeding populations, indicating that there may be inbreeding and a closer relationship among trees within these small stands. Genotype-environment interaction was determined to be highly significant between the Lumberton (hill site) and Baton Rouge (bottomland site) progeny tests. Surprisingly, the progeny test at the hill site had the best overall growth rate. Several families performed well in both bottomland and upland environments indicating a potential for selecting genotypes that survive and grow well on many sites.

Heritability estimates for height growth at the end of the second year were determined to be 0.57-0.74 for broad sense and 0.22-0.41 for narrow sense. These estimates are high enough to effectively select for this trait and enough genetic variation is available to obtain significant genetic gains.

The effect of seed size on first-year growth of seedlings was found to be highly significant, but this effect had diminished by the end of the second year. Pecan germination studies showed that moist, cold storage (stratification) for periods of 90 days produced best results.

Generally, results indicated that there is sufficient genetic diversity in pecan to justify continuation and expansion of breeding programs to best utilize the native genetic material that is presently available.

CHAPTER I

INTRODUCTION AND GENERAL LITERATURE REVIEW

Pecan (Carya illinoensis (Wangenh.) K. Koch), a component of the bottomland forest in the central United States, is presently one of the most valuable hardwood species in the mid-south. In the past 25 years pecan has increased in utility and value from an unwanted commodity to an extremely marketable material for use in the manufacture of furniture, cabinets and paneling. However, with this increase in demand for pecan products the supply of good quality forest trees will decrease as mature stands are cut. For this reason it is important to locate, select, and preserve superior mature individual pecan trees and stands. Genetic improvement programs for pecan must be established before the logger's saw removes all the best mature phenotypes, a process which has occurred with black walnut (Juglans nigra L.) and some species of oaks (Quercus spp.).

Pecan has a natural range (Figure 1) that extends from southern Indiana, Illinois, and Iowa down the Mississippi River to the lower portion of Louisiana and westward into Texas and Oklahoma with some scattered occurrences in Mexico (Flack 1970). Sites within this range are limited primarily to the first-bottom alluvial soils of relatively recent origin (Fowells 1965). Generally, the species is

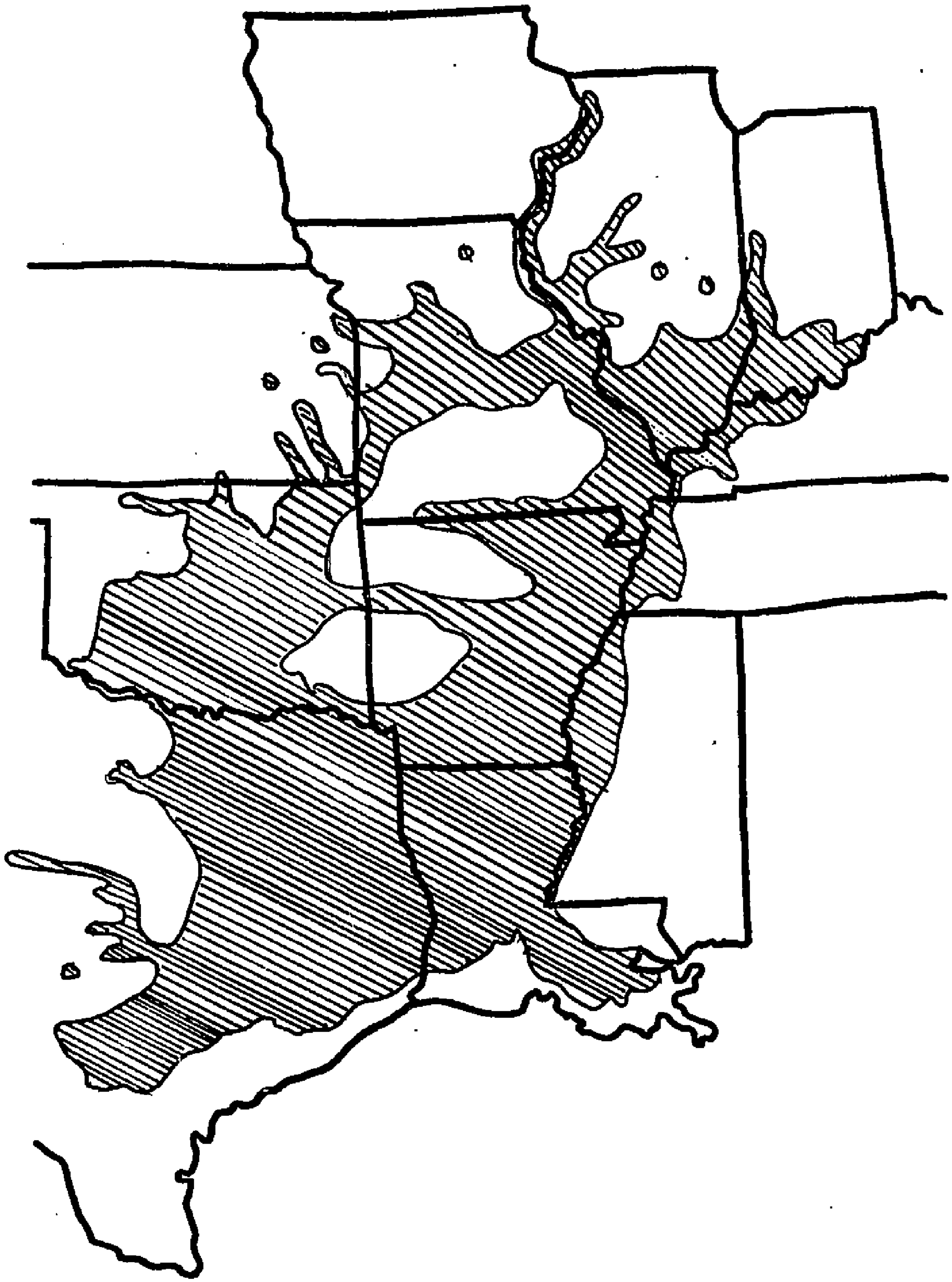

Figure 1. Native range of sweet pecan within the United States.

found growing on well-drained loam soils not subject to prolonged overflow. However, flooded conditions can be tolerated for several months in the dormant season.

The species is a major component of the Sycamore-Pecan-American Elm forest cover type and it is associated with a large number of bottomland species such as willow (*Salix nigra* Marsh.), sweetgum (*Liquidambar styraciflua* L.), various oaks, sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.) and others (Fowells 1965). Pecan is a strong intolerant or weak mid-tolerant species depending on the particular association. Competition in the first three years greatly reduces the growth rate and may contribute to mortality. However, vigorous pecan seedlings that have been overtopped by weeds will continue to survive and, when released from competition, will generally grow well.

Pecan trees are usually considered by the public as an orchard crop grown to produce edible nuts. The average person would describe a pecan tree as having many branches starting low to the ground with a large, full crown. This description applies only to orchard grown varieties which are usually grafted and cultured to produce this type of crown configuration. The forest-grown tree (Figure 2) can be a truly magnificent specimen reaching heights of 55 m and diameters of 1.8 to 2.0 m (Fowells 1965). In well-stocked stands pecan prunes well and may have three 16-foot logs before the first limb. Growth rate is relatively good, ranging from 5.0 to 6.4 cm

Figure 2. Forest-grown pecan tree representative of the phenotypic selections made in this study.

per 10-year period which, according to Fowells (1965), is average for bottomland hardwoods.

The time of flowering of pecan varies with latitude and occurs between March and May over the range. Seed dispersal is also variable beginning in September and extending through December and into January. The species is monoecious but is generally cross-pollinated. Pollen is wind disseminated and this contributes to variable seed crops. If weather conditions are warm and wet when pollen is mature, this greatly reduces the effectiveness of wind transport of the pollen. Seed crops appear to be cyclic, with a good crop every 2 to 3 years.

At the present time there are a number of excellent, almost pure stands of pecan throughout the lower Mississippi Valley. These exist as a result of past logging practices where only the species of the greatest then-current value were cut. Until very recently, bottomland harvesting practices concentrated on cutting the associates of pecan such as sweetgum and sugarberry. After several of these cutting cycles, pecan remained the predominant or, in some cases, the only species standing in certain areas (Adams and Thielges 1974). Thus, past utilization practices have left large, excellent stands of pecan which are now a valuable commodity for the forest tree breeder as well as the lumberman.

Pecan plays a rather unique role in bottomland forests, serving as an excellent timber resource and also producing a valuable nut crop. This makes pecan an ideal multiple-use species. In areas where pecans are abundant, crows, wood ducks, squirrels and turkey rely heavily on the nut for food. Human consumption of the nuts is also of importance and, even though the majority of the native pecan nuts are rather small compared to commercial "paper-shell" varieties, they have a high oil content and are very desirable for confections and bakery products. Hussein et al. (1967) found that pecans had higher nutritional value per calorie than walnut, almond, or hazelnuts. Because of the desirability of the pecan nut as food, people collect them for added income in the late fall and early winter. Thus, pecan can provide timber, wildlife food and a marketable nut crop and because of this versatility it is very compatible with the multiple-use forest management concept.

Historically, pecan has been utilized for nut production for centuries. American Indian tribes used the nut of native trees as a source of food as well as a medium for barter with other tribes before the white man came. Early European settlers quickly recognized the pecan as a valuable crop, readily available in the bottomland forests, and used wild pecan crops to supplement their incomes. Soon, pecans were shipped to various cities in the New World. As early as the latter part of the 18th century, pecan trees were being planted in areas of the Eastern United States, far from the native range. Prominent people such as George Washington and Thomas Jefferson were among those interested in cultivating the tree for nut crops (Flack 1970 and Brison 1974).

Because of the value and desirability of pecan as a food source, many early efforts were made to propagate the species. Seed from trees having a particularly desirable nut were planted only to discover that the trees did not "breed true" and seedlings were not like the parent trees in terms of nut quality. The first actual progress toward the development of today's varieties was made when trees with desirable nut quality were selected and vegetatively propagated by grafting. In the first quarter of the 20th century controlled crosses were made on selected parent trees in an effort to improve nut quality (Flack 1970). Using native selections and controlled crosses and grafting, new varieties of pecans were developed and made available for orchard planting. Horticulturists took an early interest in developing pecan varieties for nut production and there are now many research institutions involved in breeding work.

Despite this intensive research and development effort in orchard pecan breeding and culture, like most hardwood species pecan has been almost completely ignored in terms of research on the genetic potential of the species as a timber crop. However, in the last 10 years there has been a re-evaluation of the ecological and economic potential of the hardwood forest resource and many agencies are now doing research on the genetic improvement of several native hardwood species (McKnight 1975).

There are several reasons for the current interest in the genetic improvement of hardwood species and these apply particularly to the bottomland hardwood species of the South, including pecan. The first is the reduction of the total hardwood land base (i.e., good bottomland sites) due to powerline and pipeline rights-of-way, intensive agricultural use, and the encroachment of industry and housing areas. A second factor is the increased demand for and value of hardwood products. For example, pecan is in high demand for use as high quality veneer for paneling and expensive furniture. Third, there are thousands of bottomland forest acres that are producing far below their potential, primarily because of the lack of proper forest management and exploitative logging in the past. If programs are not developed to provide genetically improved hardwood planting stock for reforestation of clearcut stands, alternative land uses may be sought and these alternatives may be economically and environmentally unsound in the long run.

Of the commercially important bottomland hardwoods in the South, species such as cottonwood, ash, sycamore, sweetgum and some oaks are currently included in genetic improvement programs by one or more research organizations. However, there are no active programs for the genetic improvement of pecan. Because of the importance of pecan in natural bottomland hardwood associations, the value of its products, and the need for improved seedling stock for reforestation, a study of the genetic variability in wild populations of pecan is essential as a first step in the development of an applied selection and breeding program for this species.

The final objective of this work is to develop superior fast-growing varieties and make these varieties available to state and private seed orchards to be used in future pecan reforestation programs. Pecan is particularly desirable in future hardwood forests because of the versatility of the species. As previously noted, it provides excellent wildlife food and an interim nut crop as well as being a good timber species. Also, as the value of the wood product continues to increase the possibility for the use of pecan as a dual role tree increases, that is, an orchard tree for nut production but also a tree that may be harvested as a timber crop. This system has been used successfully for black walnut and there may be potential for using superior pecan in this manner.

The primary objective of this initial study was to determine the extent and pattern of genetic variability in selected wild pecan stands in Louisiana. A second objective was to obtain basic information on the biological requirements of the species for successful seed germination, nursery culture, and field establishment, knowledge of which is essential to future research efforts with pecan. Progeny from selected trees were grown at two different nursery locations, one considered conventional, the other a rather radical approach to producing forest tree seedlings. Progeny were outplanted at three locations to test the performance of parent trees and to evaluate genotype-environment interactions. Traits which were investigated in the first and second growing season were survival, height growth, root growth, and time of leaf initiation.

To accomplish these objectives, several experiments were designed and executed in a logical progression. Genetic variability was estimated by selecting 10 parent trees from each of four natural stands, which represented four breeding populations. Appropriate analyses of seed and seedling characteristics were made to compare parent tree progenies and breeding populations and a replicated open-pollinated progeny test was established in the field at three locations to evaluate genotype-environment interactions. Laboratory, greenhouse, and nursery experiments were conducted to evaluate the effects of seed size and pretreatment on germination, survival, and growth, and seedling stock was grown under two radically different nursery systems to determine the extent and duration of early environmental (nursery) influences on field survival and growth.

The results of these experiments are reported in separate chapters of this dissertation (Chapters II-IV). A summary discussion of genetic variability in pecan and implications for selection and breeding programs is presented in Chapter V.

CHAPTER II

SEED TREATMENT AND GERMINATION STUDIES

Introduction and Literature Review

The purpose of nursery production of tree seedlings is to supply strong, healthy seedlings that emerge from the soil quickly and uniformly. One factor influencing successful seedling production in many forest tree species is relieving seed dormancy. To overcome the problems related to seed dormancy, the specific requirements for storage, treatment, and handling of seed must be ascertained to obtain acceptable germination and seedling growth.

To produce higher and more uniform germination rates, various storage treatments and stratification methods have been developed for individual species requirements. Species such as dogwood (*Cornus florida* L.) may require 60 days exposure to a moist, warm environment, and/or immersion in concentrated sulfuric acid for 1 to 3 hours. At the other end of the spectrum is black willow which exhibits no dormancy and will readily germinate in 12 to 24 hours on moist sand or alluvium (Brinkman 1974). Between these extremes lie most tree species, and those having large seeds generally require wet stratification to preserve moisture content and enhance germination.

Krugman et al. (1974) classified seed in three groups on the basis of ability to germinate. These are (1) non-dormant, (2) physiologically dormant or (3) physically dormant. All seed fall in one or a combination of these groups, and pecan and other Carya spp. exhibit physiological or embryo dormancy which can generally be overcome by cold stratification in a moist medium at 33-40 F for a period of 30-150 days (Bonner and Maisenhelder 1974). On the other hand, some workers have found that pecan seed have no well-defined dormant period and will germinate any time after harvest (Anonymous 1960). Also, personal observations indicate that pecan seed will germinate if planted immediately after they are dispersed from the tree, but germination is poor. Amen (1968) concluded that physiological dormancy in higher plants is generally controlled by a balance of growth inhibitors and promoters. This could be an explanation of the low germinability of pecan seeds that have just matured; these seeds may be undergoing various physiological changes during the maturation process.

Another explanation of intraspecific differences in germination may be inherent variation in degree of dormancy. Kramer and Kozlowski (1960) stated that this phenomenon has been observed in Douglas fir (Pseudotsuga menziesii (Mirb) Franco), ponderosa pine (Pinus ponderosa Laws), and loblolly pine (P. taeda L.) which have evolved physiologically different geographic races in terms of seed dormancy. Nidolaeva (1967) distinguished five groups within the genus Fraxinus in terms of germination requirements; these differences were correlated with the geographic distribution of the species.

Whatever the dormancy mechanism, it is generally accepted to be biologically advantageous, and evolutionary pressures have refined the mechanisms which cause the process to occur (Villiers 1972).

Generally, large-seeded species exhibit embryo dormancy and require cold, moist stratification for optimum germination results. Vande Linde (1964) found that cold storage (35F in wet sand for 40-90 days) was an effective method of treating red and white oak seed to obtain best germination. Jones (1962) studied the seed of black walnut and red and white oak species and recommended that these be stored in a moist medium above the freezing point. Larsen (1963) subjected seed of upland and bottomland oak species to various water soaking treatments but found rather poor germination.

Many methods have been tried, both storage and chemical pretreatment, to enhance the germination of pecan seed. Seporteu and Lebedinets (1965) subjected pecan seeds to various levels of ultrasonic waves and found that each treatment increased field germination and also promoted earlier and more uniform seedling emergence. Lebedinets (1971) irradiated seed with doses of rays ranging from 555-6000 R. In this range, he found that exposures of from 1000-3500 R improved both germination and the development of the plant. However, he also found somatic mutants in some of the two-year-old seedlings. McHutton and Woodroof (1926) soaked pecan seeds in sulfuric acid (20 sec), ammonium hydroxide (1-10 min), cold water, and hot water. Their results showed negative effects with sulfuric acid and hot water treatments and no effects with ammonium hydroxide or cold water soaks. Bilan and Foster (1970) applied five different chemical treatments and found no significant increase in germination over seed treated with distilled water. However, stratification for various lengths of time significantly increased the germination of pecan and they suggested that stratifying seed could reduce germination time by one-half.

Chase (1947) found that black walnut could either be planted in the fall or held in cold moist storage until spring. He also found that the germination rate was lower in seeds that were held over winter in artificial cold storage and suggested that if stratification was to be done, moist sand in the outdoors was most effective. Wahlenberg (1924) referred to this method as being a common practice among nurserymen and foresters which Baldwin (1942) described as "nature's way of bringing after-ripening" (breaking embryo dormancy). Croker and Barton (1953) were in disagreement, maintaining that stratification under controlled conditions (such as a refrigerator) is superior to outdoor treatments.

Bonner and Maisenhelder (1974) recommended cold, moist storage in a medium such as sand for the genus <u>Carya</u> and other large-seeded species. Sparks et al. (1974) used several stratification periods to determine the effect of time of stratification on germination of the first seed, uniformity of germination, and percentage germination of Stuart pecans (a common southern commerical variety). Seeds were stratified in sand at a temperature of 34-35F for 0, 1, 2, 4, 6, 8, and 10 weeks. Their results show that pecan seed germination can be enhanced and more uniform seedlings can be produced with longer periods of stratification.

Madden and Tisdale (1975) compared the effects of chilling seeds in moist peat moss with storing seeds in dry cold storage followed by a 3-day water soak. They found that chilling alone had the same general effect as stratification. They concluded that the positive effects of stratification and cold storage-water soak were more pronounced as periods of treatment increased from 0-12 weeks.

Because the published results of studies applying various treatments to pecan seeds have been rather inconclusive and, in some cases contradictory, an experiment was initiated to evaluate a variety of treatments on a uniform sample of seed. This experiment also tested the hypothesis that a southerly seed source may not have embryo dormancy and therefore stratification treatments are ineffectual.

Methods and Procedures

The germination study was conducted as two separate experiments which are designated as Experiments A and B. All pecan seeds were collected from the ground and no discolored or damaged seeds or seeds remaining in the husk were included in the collections.

Experiment A. Seeds were collected in November 1973 from wild pecan trees located on Raccourci Island in south-central Louisiana (Figure 3). Collection trees were selected at random and 50-75 seeds were taken from each of 30 trees. These seeds were bulked and mixed to obtain one large homogeneous sample of pecans. The seeds were then divided into lots of 100, placed in paper bags, and stored at normal room temperature.

Stratification or storage treatments applied were:

Wet sand (2-5C) for 30, 60, and 90 days;

Dry storage (2-5C) for 30, 60, and 90 days;

Cold water soak (2-5C) for 5, 10, and 15 days;

Room temperature (24C) water soak for 5, 10, and 15 days;

Acid (H_2SO_4) soak for 10, 20, and 30 minutes;

Dry storage (2-5C) for 60 days with water soak for 10 days;

Control (untreated-room temperature).

The target date for planting was 1 April 1974, and at appropriate intervals (i.e., beginning 90 days before 1 April), seeds to be stratified were placed in the particular medium of stratification. Four mil polyethylene bags were used to contain the sand stratification and dry storage treatments and laboratory beakers were used for the soak treatments. Distilled water was used and all sand was heat-sterilized at 180C for 12 hours.

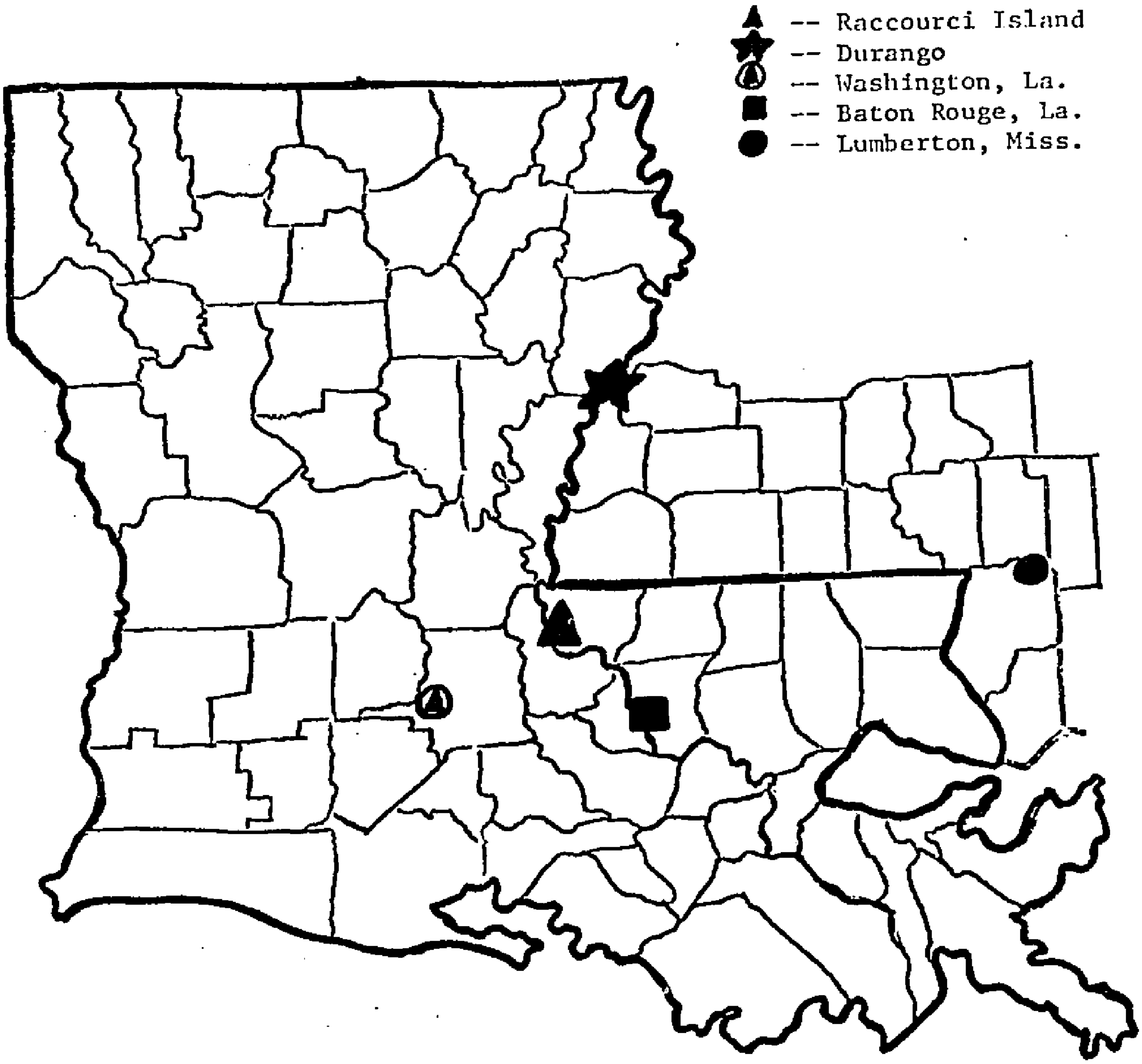

Figure 3. Location of pecan seed collection areas, nurseries, and outplanting sites.

Seeds were planted 1 April 1974 in plastic germinating trays filled with vermiculite. Seeds were planted 1 inch below the surface, 100 seeds per tray. Trays were placed in a greenhouse and arranged in a completely random manner. No artificial heat was used. Water was applied when the top 1 inch of vermiculite became dry, and the medium surrounding the seed was kept continually moist.

Experiment B. Seeds were collected in 1974, from wild pecan trees located at Durango, southwest of Natchez, Mississippi, in the Mississippi River flood plain (Figure 3), or about 60 miles north of the collections in Experiment A. The same storage and stratification treatments were applied, with the exception of the acid soak and 60-day cold dry storage with 10 day water soak. All seeds were planted on 1 April 1975.

In both experiments, trays were checked at 5-day intervals for germination and, once the seeds began to germinate, a count was made every three days. A seed was considered germinated when the plumule was first observed. This procedure was followed for 60 days at which time the study was terminated.

The results of these experiments were evaluated by using a formula developed by Czabator (1962) which quantifies germinative energy by combining speed and completeness of germination. Combining both speed and completeness of germination into a composite score, termed "germinative value", eliminates the need of subjective interpretation of germination tests. In order to obtain the germinative value (GV), the formula, $GV = MDG \times PV$ was used where:

MDG = percentage of full seed at end of test, divided by the number of days to the end of the test;

and PV = the mean daily germination of the most vigorous component of the seed lot, a mathematical expression of the break of the sigmoid curve representing a typical course of germination (Figure 4).

Results and Discussion

Germination response varied from treatment to treatment and from year to year (Tables 1 and 2). In both studies, three seed treatments were consistently higher in germinative value. These were, in order of best performance: Wet sand (2-5C) for 90 days, wet sand (2-5C) for 60 days, and water soak (24C) for 10 days. In both experiments, the wet sand (60 and 90 days) and the water soak (10 days) were consistently highest in ranking. The cold water soak (10 days) varied between years, being very effective in Experiment B but considerably less effective (though still superior to the control) in Experiment A.

The remaining treatments showed variable results. In Experiment A, all treatments except the acid were superior to the control with some samples having relatively high germinative values compared to the control. This was not true in Experiment B the following year, when the control performed as well or better than some of the average treatments, although between the control and the next three treatments there was little difference in germinative value or percent germination, indicating little effect of these treatments.

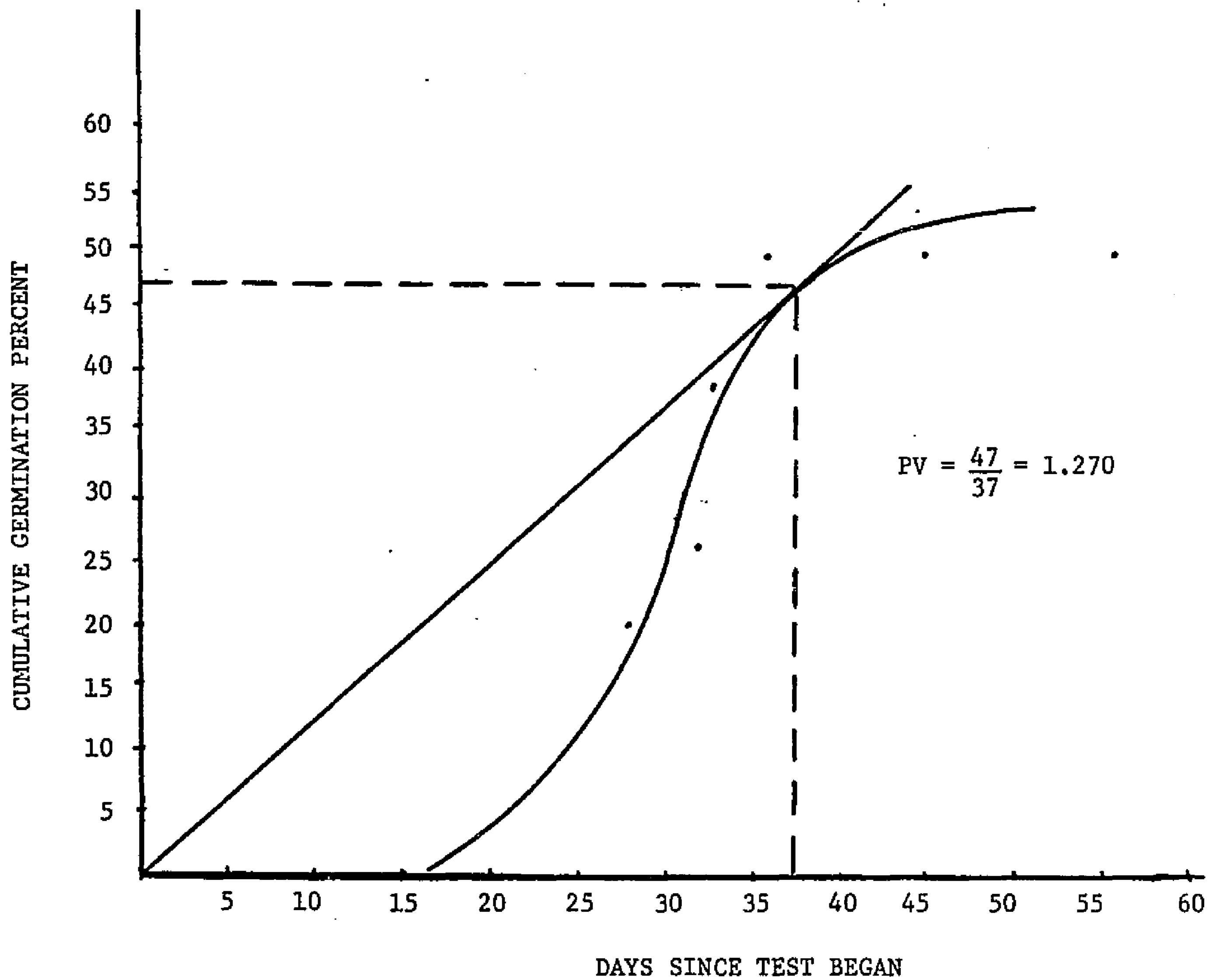

Figure 4. A typical germination curve illustrating peak value determination for a cold wet sand (60 days) treatment of pecan seed.

Table 1. Results of stratifications and seed treatments on pecan seed collected in the fall of 1973 (Experiment A).

Treatment	Mean Daily Germination	Peak Value	Percent Germination	Germinative Value
Wet sand (2-5C) - 90 days	1.03	2.46	62.0	2.53
Wet sand (2-5C) - 60 days	1.10	1.70	70.9	1.87
H_2O soak (24C) - 10 days	1.20	1.48	72.0	1.78
H_2O soak (24C) - 15 days	1.03	1.68	62.0	1.73
Dry storage (2-5C) - 60 days with H_2O soak (24C) - 10 days	0.88	1.29	53.0	1.14
Wet sand (2-5C) - 30 days	1.25	0.86	48.4	1.07
H_2O soak (2-5C) - 15 days	0.83	0.86	54.3	0.71
Dry storage (2-5C) - 30 days	0.77	0.83	54.7	0.64
Dry storage (24C) - 60 days	0.73	0.74	46.3	0.54
H_2O soak (24C) - 5 days	0.63	0.55	48.7	0.35
Dry storage (2-5C) - 90 days	0.63	0.56	42.6	0.35
H_2O soak (2-5C) - 10 days	0.65	0.53	47.5	0.34
H_2O soak (2-5C) - 5 days	0.60	0.51	66.6	0.31
Control (no treatment)	0.62	0.45	46.8	0.28
H_2SO_4 treatment (10 min)	0.23	0.05	13.0	0.05
H_2SO_4 treatment (20 min)	1.13	0.38	8.0	0.05
H_2SO_4 treatment (30 min)	0.08	0.14	4.7	0.01

Table 2. Results of stratifications and seed treatments on pecan seed collected in the fall of 1974 (Experiment B).

Treatment	Mean Daily Germination	Peak Value	Percent Germination	Germinative Value
Wet sand (2-5C) - 90 days	1.61	2.25	90	3.62
Wet sand (2-5C) - 60 days	0.88	1.27	49	1.11
H_2O soak (2-5C) - 10 days	0.98	1.02	55	1.00
H_2O soak (24C) - 10 days	0.80	1.00	45	0.80
Control (no treatment)	0.82	0.93	46	0.76
Dry storage (2-5C) - 60 days	0.82	0.93	46	0.75
Dry storage (2-5C) - 90 days	0.84	0.87	47	0.73
H_2O soak (2-5C) - 15 days	0.73	0.88	41	0.64
H_2O soak (24C) - 15 days	0.80	0.71	45	0.57
Dry storage (2-5C) - 30 days	0.71	0.77	40	0.55
H_2O soak (24C) - 5 days	0.64	0.68	36	0.44
H_2O soak (2-5C) - 5 days	0.61	0.68	34	0.41
Wet sand (2-5C) - 30 days	0.57	0.57	32	0.33

Experiment A contained three treatments with sulfuric acid which had a negative effect on germination. Total germination for the best acid treatment (10 minutes) was only 13 percent, far below all the other treatments. Apparently, the acid penetrated the seed coat and damaged the embryos. For this reason acid treatments were not included in Experiment B.

In nursery practice, the desired result is a uniform, rapidly germinating, vigorous group of seedlings, and the germinative value is the key to determining the most effective method of treating pecan seed to achieve these results. In several cases (Tables 1 and 2) there were treatments having high percentage germination but these were rated lower because of the lower germinative value in comparison to other treatments. For example, in Experiment A, cold wet sand (90 days) had a germination percent of 62.0 and cold water soak (5 days) had a germination percentage of 66.6. However, when ranked according to the germinative value, the wet sand stratification was the best treatment with a germinative value of 2.53, while the cold water soak was ranked 14th with a germinative value of 0.31. The use of germination percentage alone as the basis for selecting the best treatment method would have placed a far inferior treatment ahead of the one that actually produced the best results from a practical nursery production standpoint.

In both experiments, it was evident that cold wet sand stratification for 90 days was the superior treatment. Seed treated in this manner germinated earlier, and complete germination was obtained in a shorter span of time. In some of the less effective treatments, seeds were still germinating when the study was terminated. In practice, seeds planted with no stratification or with one of the less effective treatments might result in greatly delayed and irregular germination, thus exposing the seed to a longer period of time during which damage might occur and producing a very non-uniform stand of seedlings. Seedlings which germinate a month or more later than others will be smaller and physiologically inferior at lifting time.

Stratification in cold wet sand for 60 days was the next most effective treatment. There is no real advantage, however, to shorten this treatment because the additional gain in germinative value of an additional 30-day stratification period would more than justify the extra storage time, once the seeds are prepared for stratification.

The two treatments, cold and room temperature water soaks (10 days), were more effective than the control but very inferior to the cold sand stratification. An increase in both speed and completeness of germination can be obtained using these treatments, and storage space required and weight of dry stored pecans is much less than that of seed stored in wet sand. Because of this, the nurseryman storing large numbers of seed with limited space could use the water soak methods to increase germinative value of the seed. Apparently, by soaking the seed, enough water is imbibed to stimulate germination, which probably is why this treatment was more effective than the control where the seed begins to imbibe water from the soil only after planting.

When the pecan seed "ripens" or matures on the tree, a drying process takes place resulting in separation of the husk followed by the fall of the seed (nut) from the tree. This drying or maturation of the seed apparently triggers dormancy as a result of changing the activities of various growth inhibitors and promoters (Amen 1968). Normally, these seeds will be subjected to natural stratification in the moist litter on the forest floor for periods of up to 150 days. Ecologically, this is an effective system because seeds that disseminate early in the fall, unless they are dormant, might germinate when temperature and moisture conditions are adequate, only to be subjected to harsh winter weather conditions at a very tender seedling stage. Thus, because of dormancy, pecan seeds germinate in the spring and are able to grow under more advantageous conditions.

The ability of pecan to germinate is apparently closely related to the moisture content of the seed and the seed will not germinate until adequate moisture content is achieved. Cold storage alone will not increase germination; there must be moisture in addition to chilling to activate the metabolic processes of growth initiation. This is demonstrated very well in Tables 1 and 2 where the cold dry storage samples performed poorly and generally not as well as the control. The water soaks, both cold and normal temperature, were more effective.

In these germination experiments, the cold wet sand stratification treatments closely duplicate the natural conditions during the winter. Temperature and the number of days that the seeds will be subjected to the treatment can be controlled. This is a good, feasible treatment for the commercial nurseryman.

In summary, time of stratification and maintenance of a moist medium are apparently the keys to optimal germination. If adequate facilities are available and time permits, the most effective storage/stratification method would be cold wet sand for 90 days or perhaps longer. If time or storage space is a problem, then cold dry and soaking the seeds in water prior to planting will produce better results than no treatment.

Also, it is apparent that pecan seeds from southern origins are characterized by some degree of embryo dormancy. This dormancy can be relieved through application of the above treatments.

CHAPTER III

SEED SIZE AND NURSERY TREATMENT EFFECTS ON SURVIVAL AND GROWTH

Introduction and Literature Review

Most southern hardwood planting stock is one-year-old, bare-rooted nursery grown seedlings (Turner 1970), and these seedlings must be able to withstand the competitive pressure of weeds, grasses, and other volunteer tree seedlings. The first two years are generally the most critical period. For this reason, the larger, more vigorous the seedlings, both in shoot and root growth, the greater are the chances for survival and subsequent growth.

There are several factors that greatly influence the successful production of large, healthy seedlings. These can be classed into three general groups: (1) environmental influences, (2) genetic influences and (3) cultural influences. Two factors of particular interest in this study are the effect of seed size, which is dependent on the genotype as influenced by environment, and the effect of cultural practices in two different nursery locations on pecan seedling size and field performance.

Much work has been done on the effect of seed size on subsequent seedling growth for many species. Oexemann (1942) found that the importance of seed weight is greatest during the early stages of plant growth. In his work with tomatoes, cucumbers, and soybeans he found that plants resulting from lighter seed had slower initial growth. Kaufmann and McFadden (1963) found that barley from large seed produced better grain than that resulting from small seed. Bremmer et al. (1963) found that embryo size in wheat had a negligible effect on growth while endosperm size had a considerable effect. They suggested that the relationship between seed size and plant size is governed by the amount of reserve food material present in the seed.

In forestry research, Spurr (1944) found that heavier seed of eastern white pine (P. strobus L.) germinated earlier and that seedlings from heavier seed survived in greater proportion than those from lighter seed. He also noted variation due to geographic origin of seed and that the effect of seed weight diminished but was still significant after three years. Righter (1945) found that seed weight of various pines was positively correlated with seedling size but not with inherent vigor and that the effect of seed size was not lasting regardless of the size. He also concluded that selection on the basis of seed size is genetically ineffectual. Shoulders (1961) found that, in general, large slash pine seeds germinated faster and more completely than small seeds and produced seedlings whose initial growth was greater. Small, medium, and large seeds were found to germinate equally. Somewhat surprisingly, he found medium seed produced the larger, better seedlings. Seed size was found to have no lasting effect on south Florida slash pine seedlings (Bethune and Langdon 1966).

Korstian (1927) did some early work with seed-size relationships in oaks and he found heavy acorns possessed greater germinative capacity and that the resulting seedlings showed greater resistance to injurious environmental influences. He related this to the greater quantity of reserve food materials contained in the acorn. In 1933, Perry and Coover concluded that size of fruit in white ash (Fraxinus americana L.) and yellow poplar (Liriodendron tulipifera L.) was a poor index of quality but that weight is roughly proportional to germinative energy and seedling vigor. McComb (1934) found that variation in seedling size of chestnut oak (Quercus prinus L.) showed a close correlation with acorn weight.

Jarvis (1963), in his work with sessile oak (Q. sessiliflora Salisb.), found that the relative growth rates of the seedlings were independent of acorn size and origin but the size of the seedlings at time of lifting was linearly related to acorn size, thus indicating the great importance of acorn size on first season's growth. All the cotyledons were exhausted after one season's growth in this study. Madden (1975) indicated that weight had no influence on germination or seedling vigor in improved varieties of pecan.

Most of the previous work indicates that seed size has a positive effect on growth, but this positive effect is limited to the first year, primarily due to exhaustion of food reserves in the seed.

The effects of environment and cultural practices on the production of nursery seedlings has been investigated primarily from the standpoint of fertilization levels, maintenance of good soil texture, and stocking levels. Generally, forest tree nursery sites are chosen using established recommendations such as those outlined by Wakeley (1954), and most research has been conducted on various levels of seedling production within one nursery area. Abbott and Eliason (1968) sampled 129 forest nurseries and found that maintenance of pH, fertility, and controlling compaction were the major concerns in seedling production.

Armson et al. (1963) found that red pine (P. resinosa Ait.), white pine, black spruce (Picea mariana Miller) and white spruce (P. glauca (Moench) Voss) all responded favorably when different fertilizer applications were made in the nursery. They found that the earliest application had the greatest positive seedling response. Switzer and Nelson (1963) used various levels of sowing density and fertilizer application in the nursery and checked performance of loblolly pine seedlings for three years after outplanting. They found that total height at the end of three years increased with increasing fertility and decreasing density. They also noted that total height growth was related to such seedling characters as size and nitrogen content at the time of lifting. Voigt and Wilde (1963) raised jack pine (P. banksiana Lamb.) and white spruce in soils treated with various chemicals, mineral fertilizers, and layers of humus from hardwood/hemlock stands. After four years of observations they concluded that there was no clear relationship between seedbed treatments and field performance in the early growth of trees being studied.

Switzer and Nelson (1967) did a quite extensive study on nursery soil management in Mississippi and the influence on pine seedling production. They found fertility important to seedling production, especially production of a high percentage of number one grade seedlings. Residual effects of the nursery were found for root and height growth in the field and were correlated with levels of application of nitrogen in the nursery. However, survival of outplanted seedlings could not be related to nursery practices.

For successful outplanting of pecan in the river flood plains, it is essential to produce large vigorous seedlings that will be able to successfully compete with other vegetation. If the seedlings cannot compete, survive, and grow, much time and expense is wasted and a year's growth is lost. The following experiments were initiated to determine the effect of seed size and the effect of two rather different nursery practices on the production of vigorous pecan seedlings. Each experiment is reported separately below. The results of both experiments are discussed in a summary of their implications for the production of vigorous pecan nursery stock for reforestation.

Methods and Procedures

For this study, pecan seeds of various sizes were collected from 35 native pecan trees within a 50-mile radius of Baton Rouge.

No more than five pecans (nuts) from a single tree were used and considerable variation in seed size existed among trees. Also included in the study were samples of 15 seeds from each of two trees identified as the hybrid C. x lecontei Little. These hybrid seed, identified by their intermediate shell characteristics (Rousseau 1976), were larger than the pecan seed and were included in the study to obtain further information on this hybrid.

A total of 200 seeds were visually checked for soundness, and determinations of length, width, and weight were made. Seeds were weighed on a Mettler balance to 0.01 gm. Length and width were determined with vernier calipers to 0.01 cm and measurements were taken at the longest and widest points on the pecan seed. Each nut was numbered as it was measured and all were placed in cold dry storage (2-5C) for 120 days.

The seeds were randomly planted in the Baton Rouge nursery the first week in May 1974, at 3 in intervals in rows 8 in apart. Individual seed location was mapped to identify seeds for future seed size - seedling growth evaluations. These seed beds received the normal nursery schedule of weeding and watering.

At the end of the growing season (November 1974) heights of all seedlings were measured with a standard meter stick to the nearest 0.5 cm. The seedlings were allowed to grow for another year in the nursery beds (second growing season). In November 1975, height was again measured.

A multiple regression analysis was used to determine the effect of length, width, and weight of seed on seedling growth the first year and to determine if there was a residual effect into the second year.

Results and Discussion

The relationship between seed size and seedling height. These data were statistically analyzed by combining data for both pecans and hybrid seed and also by analyzing each set of data separately.

The effect of seed size on first-year height growth of pecans and hybrids was positive and highly significant ($P < 0.01$) with an R^2 value of 0.21. The effect of seed size on second-year height growth was positively correlated but non-significant with an R^2 of 0.08. When each of the three components of size (length, width, and weight) were analyzed, only weight was found to have a significant effect ($P < 0.05$) on first-year height growth, and for second-year height growth no seed size component was found to be significant.

The effect of size of seed on first-year height growth of hybrids (analyzed separately) was positive ($R^2 = 0.14$) but non-significant. The effect of seed size on second-year growth of hybrids was also non-significant ($R^2 = 0.21$). When size components were separately analyzed, no significant effect was found for length, width, or weight on first-year or second-year growth of the hybrid seedlings.

The effect of seed size on first-year height growth of pecans (analyzed separately) was positive ($R^2 = 0.09$) and significant ($P < 0.05$). Again, the effect of seed size on second-year height growth was positive but non-significant ($R^2 = 0.03$). When size components were evaluated, length and weight were found to have a significant effect ($P < 0.05$) on the height growth of pecan seedlings in the first growing season. The effect of seed size components on second-year growth was again found to be non-significant.

The overall results of this experiment indicate that it is possible to grow larger one-year-old seedlings in the nursery by selection for larger seed, but that the positive effects of seed size are non-significant by the end of the second year. This held true for both hybrids and pecans. Apparently, seedlings from smaller seeds are able to grow well in the nursery once they have become established.

Although the size of the pecan was significantly related ($P < 0.05$) to height growth the first year, the R^2 values were low. The R^2 value is an indication of the strength of the relationship between dependent variable Y (height growth) and independent variable X (seed size) and gives a good estimate of the variation in Y explained by the regression of the variable Y on X. In the study with both pecans and hybrids an R^2 value of 0.21 was obtained. This indicates that 21 percent of the variation in seedling height growth was due to the size of the seed. The remaining variation

(79 percent) should be due to other genetic and environmental variation and experimental error.

In this study, the environment was very uniform and only a small portion of one homogenous nursery bed was used. Seed and germinated seedlings were spaced uniformly and treated in the same manner, thus the portion of the remaining variation (79 percent) due to environmental influences should have been rather small. This suggests that the genetic makeup of each individual seedling accounted for much of the remaining height growth variation encountered in the experiment.

Since seed size accounted for only a small percentage of the total variation and other genetic factors apparently account for a large part, the selection of superior trees which also have large seed could produce optimal growth in the first year due to the effect of both seed size and other inherent traits of the parent influencing seedling growth. In practice, therefore, the selection of a parent pecan tree on the basis of phenotype and also with consideration of seed size should enable the nurseryman to produce larger seedlings.

The relationships between seed size and seedling growth of the hybrid _C_. x _lecontei_ seedlings suggest that these progenies possess hetorosis or hybrid vigor for early growth. As already discussed, analysis of the hybrid data showed no significant correlation of seedling size with seed weight. Hybrid seedling height growth in both the first and second year was much better than that of pecan seedlings (Table 3). Hybrid seed size is relatively uniform and the seed is larger than that of pecan, but the comparative height growth is of interest.

In the first year, mean height of the hybrid seedlings was 22.89 cm compared to 14.18 cm for pecan seedlings, a difference of 8.71 cm (60 percent) in height growth in the first year. This can partly be explained by the size of the hybrid seed which were much larger than the pecan seed (Table 3). Means for second year height growth were 38.41 cm for the hybrids and 24.27 cm for pecan, a 14.14 cm difference (58 percent). For second year height growth there was no significant correlation between seed size and height growth of hybrid seedlings. This suggests that the superior height growth of the hybrids was not due to seed size (especially in the second year) but was due to other genetic factors, since the environment in the nursery bed was relatively uniform. If the pecan and the hybrid seedling growth data are compared, an increase in mean height growth at the end of the second growing season of 15.52 cm for the hybrids and 10.09 cm for the pecans is noted. If growth from the first year to the end of the second growing season is primarily genetically controlled, then the hybrid seedlings are outperforming the pecan seedlings and there may be hybrid vigor involved (Figures 5 and 6).

If this is true, then there is potential in the use of these hybrids for reforestation and as grafting root stock for commercial pecan nurseries. However, much more research must be done on the

Table 3. Mean length, width and weight of seed and mean seedling heights for pecans, hybrids, and pecan and hybrids for first and second year growth.

	Mean Length	Mean Width	Mean Weight	Mean Height Year 1	Mean Height Year 2
	cm	cm	cm	cm	cm
Pecans and Hybrids	2.96	1.59	3.09	15.55	26.50
Hybrids	3.41	2.18	4.74	22.89	38.41
Pecans	2.88	1.48	2.78	14.18	24.27

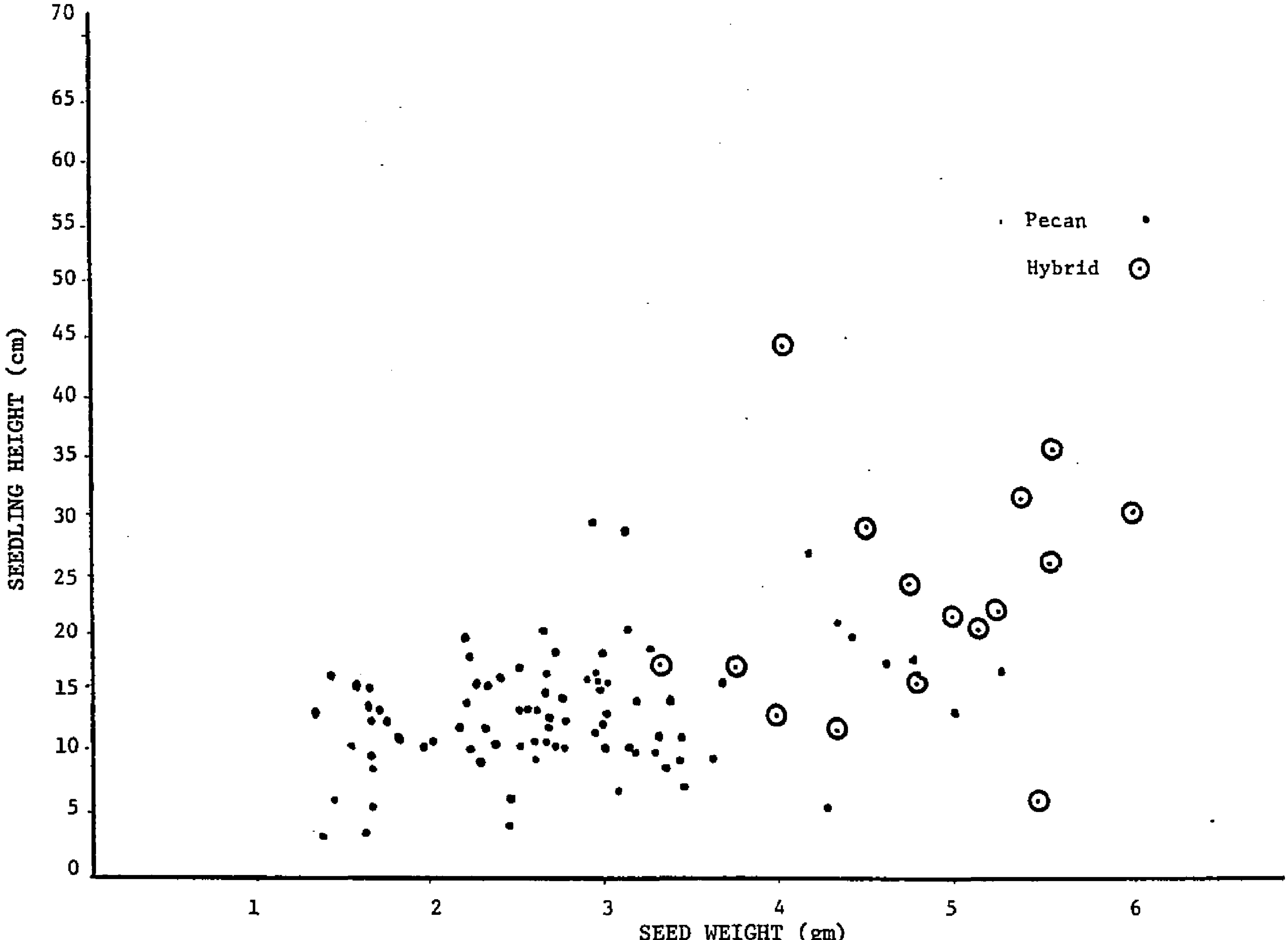

Figure 5. Scatter diagram of first-year height growth over seed weight of pecans and hybrids.

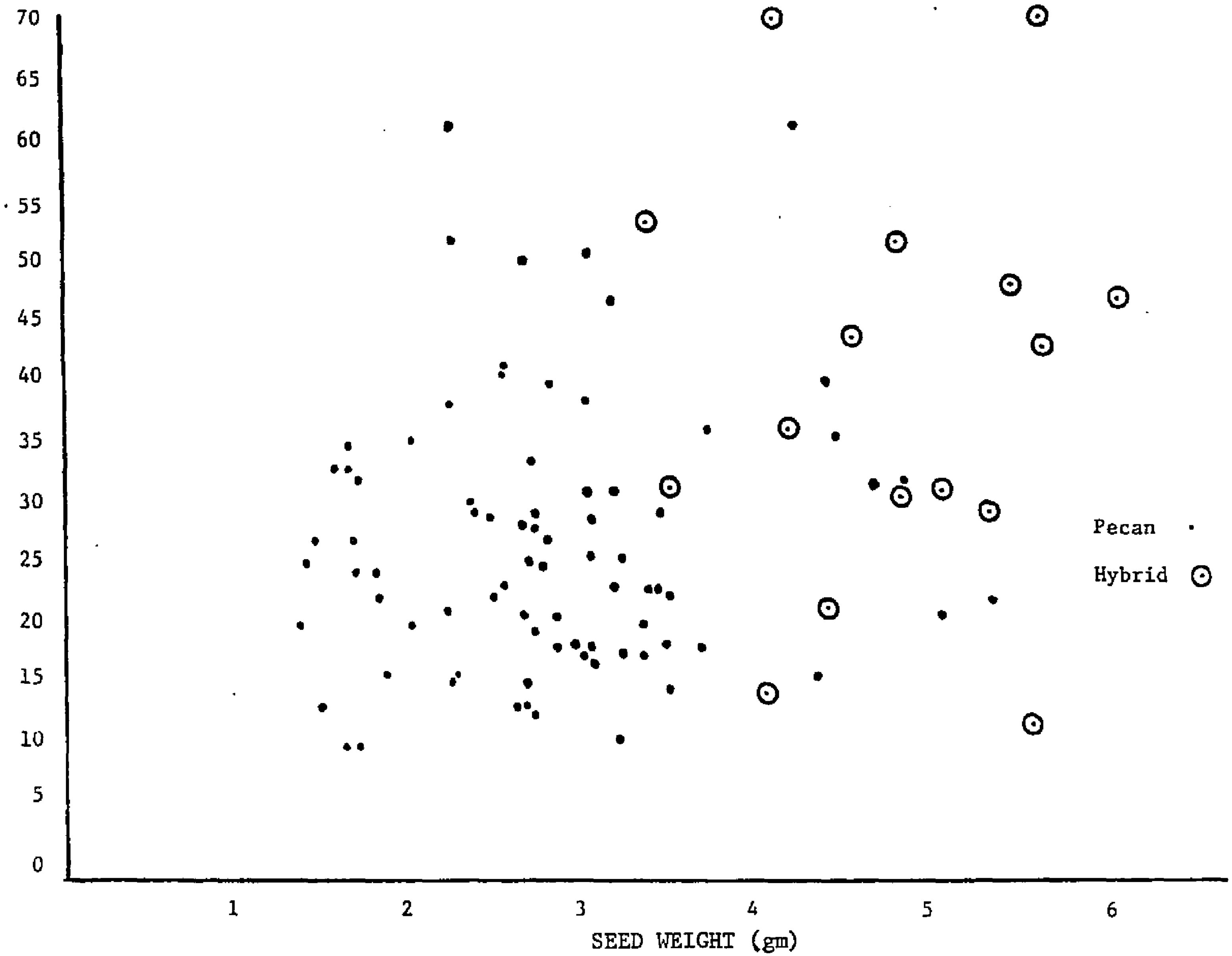

Figure 6. Scatter diagram of second-year height growth over seed weight of pecans and hybrids.

grafting compatibility and wood properties of the C. x lecontei hybrid. Also, there may be a problem of partial inviability in the hybrid because only a small percentage of the planted hybrid seed germinated.

From the results of seed size-seedling growth regressions, can a meaningful value of (Y) be predicted? Because of the low R^2 value for each analysis, the use of a value predicted on the basis of these results would not be a good estimate. From these results the most accurate prediction would only account for 21 percent of the variation. If a random group of seed from different genetic sources were weighed, measured and a prediction of their height growth in the first year was made, the results would probably be of little value. The inherent qualities of the seedlings and the environment would have the greatest effect, making the predicted value almost useless.

The production of seedlings that are both large and vigorous is important both to the forester who will outplant at the end of the first growing season and to the horticulturist who intends to graft a commercial nut variety on native root stock. Size of the seedlings is critical from the standpoint of survival and the ability to withstand competition from other seedlings, grasses, and weeds. Unless the pecan seedlings are vigorous, they will eventually succumb to competition. In horticulture, the motive for production of large, vigorous seedlings is to facilitate earlier grafting. If seedlings could be grown large enough to graft in the first year, about two years could be gained and much weeding and additional care and expense required to keep seedlings for 3-4 years could be eliminated.

However, the most important fact in the seed size-seedling growth relationship found in this experiment is that there is a measurable and significant increase in mean first-year seedling height growth associated with an increase in mean seed size (especially weight). Again, this increase accounts for only a small percentage of the total variation and genetic selection and progeny testing should result in further genetic gain in juvenile growth.

Nursery Methods and Procedures

Two locations were selected for the nursery planting experiment. One was the School of Forestry nursery on the Louisiana State University campus, Baton Rouge, Louisiana, and the other was the Bass Pecan Company nursery, Lumberton, Mississippi (Figure 3, p. 17).

The Baton Rouge nursery was the more conventional approach, using constructed 5-foot-wide beds containing 5 rows per bed. Soil prepartion consisted of tilling the beds to a depth of 8 inches with a rototiller. Application of methyl bromide fumigant was done at recommended rates to control weeds. Seeds were planted at a depth of 1 inch, and spaced 2 inches apart. Watering and weeding were done by hand as required. No fertilizers were applied before or after planting.

The Bass Pecan nursery at Lumberton, Mississippi, was a departure from conventional forestry nursery practices. Bass Pecan Company's nursery objective is to produce quantities of pecan seedlings that can be used as grafting rootstock in 2 to 3 years. Since their emphasis is on supplying orchards with commercial nut varieties, their seedling nursery of wild pecan serves as root stock only. Planting preparation and procedure consisted of discing the planting area and then furrowing long rows 6 feet apart with a mule-drawn plow. As each furrow was opened, seeds were planted approximately two inches apart and covered with about an inch of soil. Cultural practices consisted of hand weeding and cultivation both with mule- and tractor-pulled implements. No supplemental fertilizer or water was added. This method closely resembles conventional agricultural row cropping except that the rows are 6 feet apart.

Soils at the two nursery sites are quite different. The Baton Rouge nursery is a silt loam topsoil (10-12 inches) in the beds, but the beds had been built over an old building site resulting in a subsoil (12-24 inches) containing various foreign materials such as rock, bricks, and concrete mixed with red clay. All of this overlaid the heavy clay soils that are typical of the Mississippi River flood plain. Soil nutrient levels, pH, and organic percent were adequate for good seedling growth (Table 4).

The Lumberton nursery was established on an old field site in an area of rolling hills. The site has a shallow (4 to 8 inch)

Table 4. Nutrient levels, pH and organic matter content of top-soil and subsoil at the nursery locations at Baton Rouge and Lumberton.

Sample	Block	Depth	Extractable P	K	Ca	Mg	pH	Organic Matter
		In	PPM					Percent
Baton Rouge	1	0-8	143	26	590	46	6.2	1.20
"	2	"	143	50	580	67	7.0	1.01
"	1	18-24	67	368	1300	294	6.8	0.62
"	2	"	57	420	1470	225	7.2	0.62
Lumberton	1	0-8	24	35	670	176	6.9	0.73
"	2	"	48	30	69	172	6.9	1.40
"	1	18-24	5	27	360	85	5.8	0.73
"	2	"	5	26	410	158	5.8	0.36

sandy loam soil with a red sandy clay B horizon. Nutrient levels were low compared with the Baton Rouge site, but pH and percentage of organic matter were adequate for good growth. The main differences between the two nursery locations were in nutrient levels and type of subsoil. The Lumberton nursery has good internal drainage whereas the drainage at the Baton Rouge nursery is variable because of the variety of materials and soils found under the beds.

To determine differences in survival and growth due to nursery conditions, seeds of the same genotypes (same parent tree) were planted at both locations. Seeds from 40 parent trees selected for progeny testing were used and 100 seeds from each tree were planted at each nursery as described above. The seed were planted at the Lumberton nursery on 30 April 1974 in a long continuous row on the Bass Pecan nursery area. The Baton Rouge nursery was planted 18 April 1974 in two beds. The planting at each nursery site was replicated twice to account for soil differences.

First year height growth measurements were made in December 1974 at both nurseries. Measurements were taken from the ground to the tip of the terminal bud to the nearest 0.5 cm with a meter stick. The experimental design was a randomized block with factorial arrangement of open-pollinated progenies, and analysis of variance was used to determine differences in progeny performance between the two nursery locations.

Root diameter measurements were made at lifting time on 30 families at the Baton Rouge nursery and on the same 30 progenies at Lumberton. Ten seedlings per family were measured with a vernier caliper to the nearest 0.01 cm. All measurements were made 2.0 cm below the root collar. The same statistical analysis was done on root diameters as on first-year height measurements.

After lifting from both nurseries, seedlings representing each nursery location were outplanted at Baton Rouge. The site was prepared by discing, and all seedlings were planted with a standard dibble at a 10 X 10 foot spacing. Four replications were used to minimize the error associated with non-uniform field conditions. Each open-pollinated family was represented in a single replication by a five-tree line plot of seedlings grown at each nursery, a total of ten seedlings from each female parent. The five-tree line plots from each nursery were planted together in parallel rows.

Variation in leaf initiation was determined by using a numerical score for different degrees of leaf flush:

0 = no leafing visible (Figure 7);

1 = single embryonic leaves just emerging;

2 = small compound leaves (Figure 8);

3 = leafing becoming full with several leaves present;

4 - leafing full with several larger leaves present (Figure 9).

Each seedling in a five-tree progeny group was evaluated and the group mean for each block was computed. This numerical rating was made three times during the spring: April 17 and 27, and May 15, 1975. The design of this experiment was a randomized block with a

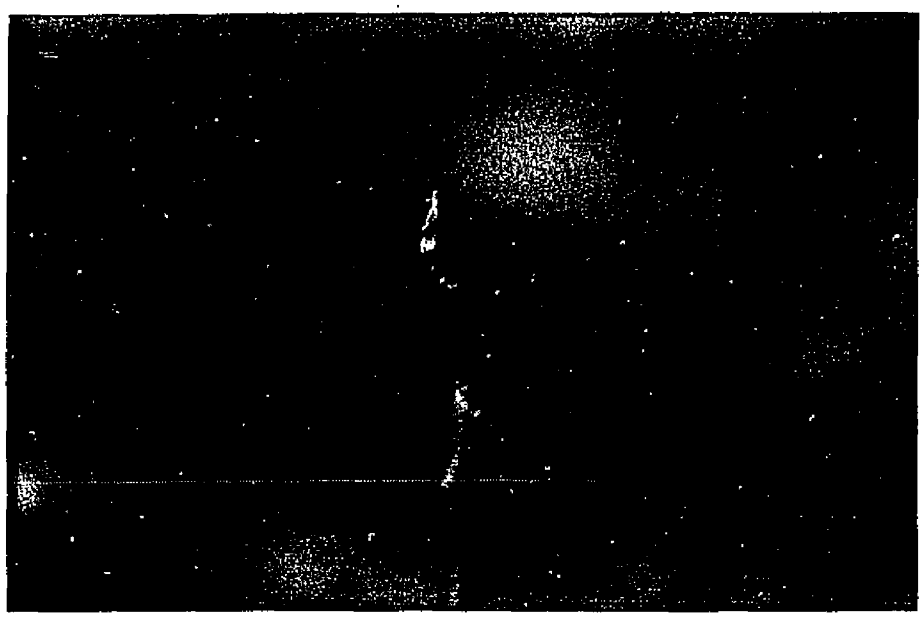

Figure 7. Pecan seedling with no leafing visible (Rating 0).

Figure 8. Pecan seedling with several small, compound leaves developing (Rating 2).

Figure 9. Pecan seedling in full leaf with many compound leaves in full development (Rating 4).

split-plot. A statistical analysis was done for each of the three time periods and for all time periods combined.

Second-year height growth was measured in November 1975. Measurements were made with a meter stick to the nearest 0.5 centimeter. Design and analysis was the same as for the leafing study, above.

Results and Discussion

Nursery effects on first year survival, height growth and root diameter. Survival percentage of the seedlings planted at the two nursery locations was the same. There was less than one percent difference in first year survival between the two nurseries. The Lumberton nursery had a 54.7 percent survival and the Baton Rouge nursery had a 55.6 percent survival. The mean germination percentage for both nurseries was 55.2. This percent germination is rather low compared to other reports (Bilan & Foster 1970, Sparks et al. 1974) where germination percentage was considerably higher for pecans. However, in the year preceding and the year following this experiment native pecan seed of various origins were planted with total germination success very close to the same results as the current study. These results indicate that for large scale pecan seedling production from native seed, allowances must be made for the high number of non-germinating seed and for mortality in the first year. Of course, germination results are also dependent upon weather conditions when the seed are maturing and condition of the seed when planted.

Analysis of variance for height growth of the seedlings grown at both nurseries showed no significant differences between nurseries, although the Lumberton seedlings were about 18 percent taller. Mean seedling height in the Lumberton nursery was 18.38 cm and in the Baton Rouge nursery 15.52 cm, a difference of 2.86 cm. Although there were highly significant differences ($P < 0.01$) among individual families at the two locations (Chapter IV), there is apparently little significant nursery effect on the initial height growth of pecan seedlings (Table 5).

Though overall differences in height growth between the two nurseries were not significant an obvious difference in root size, both diameter and total length, was observed. The total length of the tap root could not be measured as the Lumberton nursery seedlings were root pruned in order to remove them from the bed. However, diameter measurements were made and the analysis of variance showed highly significant ($P < 0.01$) nursery effects (Table 6). Mean root diameter at the Lumberton nursery was 0.81 cm and the mean at the Baton Rouge nursery was 0.66 cm, which is a 23 percent difference in seedling root diameter.

Since the two nursery locations differed greatly in soil type, depths of topsoil and subsoil, and fertility levels, differences were expected. However, the more uniform seedling heights indicate that total first-year height growth is more dependent on food reserves in the seed than on environmental differences in climate, soil fertility, drainage, etc.

Table 5. Analysis of variance for first year height growth of sweet pecan families grown at two nursery locations.

Source	D.F.	Sum of Squares	Mean Squares	F
Location	1	9127.78	9127.78	12.50
Block/Location	2	1460.00	730.00	1.49
Stand	3	11208.89	3736.30	7.65**
Family/Stand	35	17103.13	488.66	28.49**
Location X Stand	3	801.49	267.16	15.58**
Location X Family/Stand	26	4090.88	157.34	9.17**
Block/Location X Stand	6	439.36	73.23	4.25**
(Block/Location) X (Family/ Stand)	62	3546.67	57.20	3.34**
Error	4330	74274.65	17.15	
Total	4468			

**Significant at the 0.01 level of probability.

Table 6. Analysis of variance for root diameter differences in sweet pecan families grown at two nursery locations.

Source	D.F.	Sum of Squares	Mean Squares	F
Location	1	3.224	3.224	30.705**
Stand	3	0.580	0.193	1.838**
Family/Stand	34	3.572	0.105	2.625**
Location X Stand	3	1.029	0.343	8.575**
Location X (Family/Stand)	20	1.966	0.098	2.450**
Error	568	22.145	0.040	
Total	629	32.517		

**Significant on the 0.01 level of probability.

Germination of pecan, like other members of the genus *Carya*, is hypogeal with the seed remaining underground as a source of stored food for initial seedling growth. Pecan seedlings are also slow to emerge above ground, developing a large, strong root system before the epicotyl emerges from the soil. Young pecan seedlings apparently channel more growing energy into root development and, generally, the height growth attained 30 days after germination was a close approximation of total height growth in the first season in this study.

The root system of pecan apparently continues to grow during the first year, provided conditions are favorable for root development. The most apparent differences between the two nurseries from the standpoint of its effect on root development was the subsoil texture and drainage characteristics of the nursery beds. Whereas the Baton Rouge beds had poor drainage and various materials underlying the beds, the Lumberton nursery beds had a deep subsoil of sandy clay composition which was well-drained but retained enough moisture for good plant growth. Since fertility level (Table 4) was higher at the Baton Rouge nursery and the same genotypes were planted at both nurseries, the only explanation for the increased root growth was that the zone of root development was more favorable in the Lumberton nursery. Although no measurements were taken, the length of the tap root was observed to be much larger and generally, the smallest root system measured at the Lumberton nursery exceeded the largest root system measured at the Baton Rouge nursery.

Apparently, environmental influences of the nursery soil type and structure had an important effect on root development and, in the case of the Baton Rouge nursery, this was a limiting factor. Another factor that must be considered in comparing the seedlings produced in the two nurseries is the density at which the seeds were planted. The Baton Rouge nursery was sown at a density of about 18-20 seeds per square foot whereas the Lumberton nursery was sown with only six to eight seed per linear foot, with no competition developing from the sides as the seedlings grew. This density or competition may account for a portion of the differences in the root size of the seedlings at the two nurseries.

To summarize, the most striking difference in first-year growth between the seedlings grown at the different nurseries was the root size; both the diameter of the tap root and the overall size of the root system were much larger on seedlings grown at Lumberton.

Nursery effects on survival, growth initiation, and height growth after field planting. Analysis of variance for growth initiation of pecan seedlings in the spring following outplanting (second season) showed highly significant ($P < 0.01$) differences among times of measurement and among the seedlings from the Lumberton nursery and those from the Baton Rouge nursery. No significant differences were detected among families or among replications.

Time period was highly significant as the seedlings began their leaf flush and progressed over the three periods of measurement.

When the analysis was done separately for each time period, the same basic trend is apparent, and no significance was found between families for any of the three time periods. Also, for Times 1 and 2, there were highly significant ($P < 0.01$) nursery effects and for Time 3 a significant ($P < 0.05$) nursery effect was noted.

The two nursery locations at which the seedlings were grown had significant effect upon the time of growth initiation the following year. This is very evident when comparing the mean leafing values of the seedlings from the two nursery origins (Table 7).

As previously discussed, root diameters were much larger on seedlings grown in the Lumberton nursery. There is some evidence that time of leafing in the spring is related to the level of metabolic activity in the root system, particularly the synthesis and export of growth-promoting compounds from the root system to the vegetative buds (Lavender et al. 1973, Thielges and Beck 1976). Since climatic conditions were very similar at both nursery sites, it is possible that the accelerated growth initiation of the seedlings grown at Lumberton was due to their much larger root systems.

It also seems likely that the Lumberton seedlings would have an advantage in field survival and growth because of the size and vigor of their root systems. The root systems of seedlings from the Lumberton nursery were so large that they were pruned in order to plant them. This pruning may have stimulated the formation of lateral roots which would increase the seedlings' ability to absorb

Table 7. Comparisons of mean leafing rates for three time periods of pecan seedlings grown at two nurseries and outplanted at Baton Rouge.

Time	Baton Rouge Nursery	Lumberton Nursery
17 April 1975	0.740	0.960
27 April 1975	1.248	1.487
15 May 1975	2.040	2.289

water and nutrients following planting. Clark (1965) found indications that root pruning black walnut resulted in a more fibrous root system which enabled seedlings to grow faster than unpruned seedlings. Thus, the seedlings grown at the Lumberton nursery had an initial advantage of larger roots and the added effect of pruning which should have resulted in better root system development after planting in the field.

Since the nursery effect had such a great influence on growth initiation, a similar analysis was done on survival and total height growth of the families at the end of the first year in the outplanting site. The parallel family plots from different nurseries offered an excellent opportunity to determine how long the effect of the nursery environment continued in an outplanting of this species.

Analysis of variance of survival showed highly significant ($P < 0.01$) differences between the seedlings grown at the two nurseries. Survival in the field is dependent upon the seedling becoming established, initiating growth, and growing at a rate competitive with other vegetation. Survival for the seedlings grown at the Lumberton nursery was 87 percent and for those grown at the Baton Rouge nursery, 80 percent. Since there were no differences in survival among families and the environmental conditions at the outplanting site were uniform within replications, the differences in survival between nurseries apparently resulted from variation in seedling size, especially the size of the root system.

Generally, the same is true for height growth. The mean height growth during the season following outplanting for the Lumberton nursery seedlings was 20.4 cm and for the Baton Rouge seedlings 17.4 cm. As discussed in the previous section, height growth differences were not significant between the two nursery locations in the first year. However, root size differences were highly significant. At the end of the growing season after outplanting, however, height growth differences become highly significant, indicating that the seedlings from the Lumberton nursery were performing better than those from the Baton Rouge nursery. The only significant difference between the seedlings from the two nurseries at time of outplanting was in root size, and this appears to have an important effect on the performance of the seedlings in the following year.

Possibly, the larger initial root system, through its influences on early growth initiation, increased absorption of water and nutrients, and more stored food reserves, had an overall effect on growth acceleration in the second year. Further evalutations should be made to determine the duration of this effect on growth.

Obviously, the ability of the root system of the field-planted seedling to establish itself and produce new lateral roots to provide the plant with nutrients and water is essential to survival and growth. Again, the seedlings grown in the Lumberton nursery had the advantage of larger root systems; they began growth earlier and had a larger absorptive surface, which was reflected in better survival and greater rates of growth in the second year. These results indicate that production of pecan nursery stock that have large, well-developed root systems should be one of the priorities of the nurseryman.

In summary, when survival, rate of growth initiation, and height growth of pecan seedlings grown at two different nurseries were compared, obvious differences were noted. Apparently, the large root systems developed by the seedlings grown in the Lumberton nursery provided an accelerative effect for initiation and rate of growth. This effect was also noted among families within each nursery location; the tendency is for the families with the larger root systems to also initiate growth earlier. This provides an obvious advantage to field survival and early growth. Seedlings that begin growth earliest are less susceptible to effects of competition and thus have a much better chance for survival and growth during the critical first season in the field.

CHAPTER IV

PARENT TREE SELECTION AND PROGENY TESTING

Introduction and Literature Review

The genetic worth of individual parent tree selections must be evaluated to eliminate inferior parents and to retain only the best or most promising individuals for further breeding work. Regardless of the final objectives of an improvement program, knowledge other than phenotypic relationships must be obtained in order to accurately utilize available genetic diversity and to obtain the best parent tree base for subsequent generations. The field testing of progeny from different parent trees is the best method available to determine the inherent value of the tree for future generations. Strictly phenotypic evaluations are misleading and may result in the inclusion of undesirable parent trees into a seed orchard. Unless a parent tree selected as superior on the basis of phenotypic evaluations is backed by evidence of genotypic superiority from progeny testing, the tree is of no use in tree improvement work (Mergen 1960).

Data from properly designed and executed experiments can yield useful information on many traits: their heritability, their frequency, and the probability of genetic gain through the use of certain genotypes (Wright 1970, van Buijtenen et al. 1971). The practical use of the progeny test can be divided into two objectives. One would be to evaluate the family line or the performance of the selected trees for the purpose of elimination or retention of parents in the improvement program. The other objective would be to establish an orchard of the progeny from selected trees and the future evaluation of these trees for second generation selections (van Buijtenen et al. 1971).

Extensive progeny testing has been done with coniferous species especially the Genus Pinus, and these tests have yielded much information on a large number of traits (Stephenson and Snyder 1969). In fact, tree improvement work has advanced until information is now available on the genetic control of traits such as the inheritance of wood properties in Virginia pine (P. virginiana Mill.) (Rink and Thor 1973), inheritance of rust resistance in Mississippi loblolly pine (Wells and Switzer 1971), or even the grafting compatability of known genetic rootstock material of loblolly pine (McKinley 1975). Pine improvement has also advanced to the point where work is being done with advanced generation selections (van Buijtenen 1975, Squillace 1973).

In contrast with this level of knowledge of southern pine genetics, hardwood research is just now reaching some degree of intensity. Generally, hardwood species have presented complex problems that have impeded progress. Exceptions are eastern cottonwood and black walnut, where interest in genetic improvement came early because of the fast growth rate of cottonwood and the price commanded by walnut products. However, at the present time, work has been initiated on a number of other hardwood species (McKnight 1975).

Through these investigations, the genetic control of various traits and the breeding potential of many species have been determined. Wilcox (1970) found strong genetic control of foliation, branch angle, tree form and height growth in sweetgum. John and Schmitt (1973) found moderate heritability for height and diameter growth rate in the early development of open pollinated sweetgum progenies. Cooper and Randall (1973), working with advanced generation cottonwood, found clones from controlled crosses were performing better than first generation clones from selections. They concluded that "genetic superiority due to additive genetic variance can be accumulated through repeated cycles of selection and intermating."

Randall (1973), in studies with cherrybark oak (Q. falcata var. pagodaefolia Ell.), found that progenies from phenotypically selected parents were significantly larger than those from randomly selected parents. Also, enough genetic variability was evident in the progenies to justify further improvement work with this species. Other studies with red oak (Q. rubra L.) have indicated a considerable degree of genetic variability for various traits (Kriebel 1965, McGee 1970), especially for different geographic origins.

One species of hardwood in which a great deal of interest has been generated is black walnut. Early results indicate that appreciable genetic gain can be obtained by selection of superior parent trees and progeny testing. Bey (1970) estimated heritabilities for leaf color (0.45), leaf angle (0.32), adjusted stem height growth rate (0.44), and adjusted stem diameter growth rate (0.49). In another study, Bey et al. (1971) reported that heritabilities for height (0.45) and diameter (0.40) growth rate were moderate for walnut. Beinike and Masters (1973) reported heritabilities in walnut comparable to those reported by Bey.

Though work is progressing, very little is known about the genetics of hardwoods. The level of genetic diversity and the genetic control of traits has only been investigated in a superficial manner for a few species. Much of the present knowledge is based on results of only a few years' growth in plantations. Though this information is valuable, much more work must be done to obtain a clear understanding on which we can base future selections, breeding programs, and total hardwood reforestation concepts.

Unlike the southern pines which are rather homogeneous in terms of site, flowering, and other characteristics, hardwoods present a much more complex problem which requires much thought and planning. Land (1975) described in detail the unique problems involved in hardwood genetic improvement, economics, and silvicultural practices. Among several factors contributing to the complexity of hardwood research is diverse speciation, site sensitivity, uneven-aged stand composition, and general lack of biological knowledge of of most hardwood species. Because of these problems, hardwoods must be researched on an individual species basis and cannot be considered as a group as are southern pines.

If hardwoods in general have been ignored, pecan as a timber species has been completely neglected from a tree improvement standpoint. The value of the pecan nut has resulted in horticultural research on improving nut size and quality, but the species was almost forgotten as an important hardwood timber crop. Like other hardwood species the reproductive biology, the nature of genetic control of various traits, and the degree of genetic diversity throughout the range must be known in order to breed for improvement of this species. Questions such as the degree of inbreeding in natural stands and the best selection and breeding systems for the species must be answered. If pecan stands are inbred, there will be a closer relationship between trees in a stand than between trees located further distances apart. The trees within a stand would thus carry the same or common genes and the differences between the trees within the stand would be more due to environmental influences than genetic variability (Thielges 1971). If this were true, then there would be little advantage to single-tree selection.

To obtain basic information on the genetic diversity in wild populations of pecan, a program of stand and individual tree selection and progeny testing was initiated. Analyses of seedling characteristics were made to compare the parent tree progenies and breeding populations, and a replicated, open-pollinated progeny test was established in the field at three locations to evaluate genotype-environment interactions. The program was also designed to compare the efficiency of stand versus individual tree selections by also including in the test progenies derived from random seed collections.

Methods and Procedures

Parent trees were selected in the summer of 1972 from Raccourci Island in West Feliciana Parish, Louisiana (Figure 3, p. 17). This land area is bounded on one side by the Mississippi River and on three sides by an old river bed called Old River Lake. This "island" was formed in 1848 when the Mississippi River changed course. Soils are typical Mississippi River bottomland types consisting of azonal heavy clay (gumbo) deposits. The island is laced with ridges, sloughs and lakes and is subject to frequent overflow because it is not protected by a levee system.

Species composition on the "island" and common pecan associates are sugarberry, green ash, sweetgum, cottonwood, sycamore (*Platanus occidentalis* L.) and several species of oak. Pecan is found growing throughout the area and stand associations are generally the result of past selective logging practices and the relative tolerance of the various species to water and competition.

Total land area on Raccourci Island is approximately 25,000 acres and from this area four stands (Figure 10) were chosen on land owned by the Roy O. Martin Lumber Company, Alexandria, Louisiana.

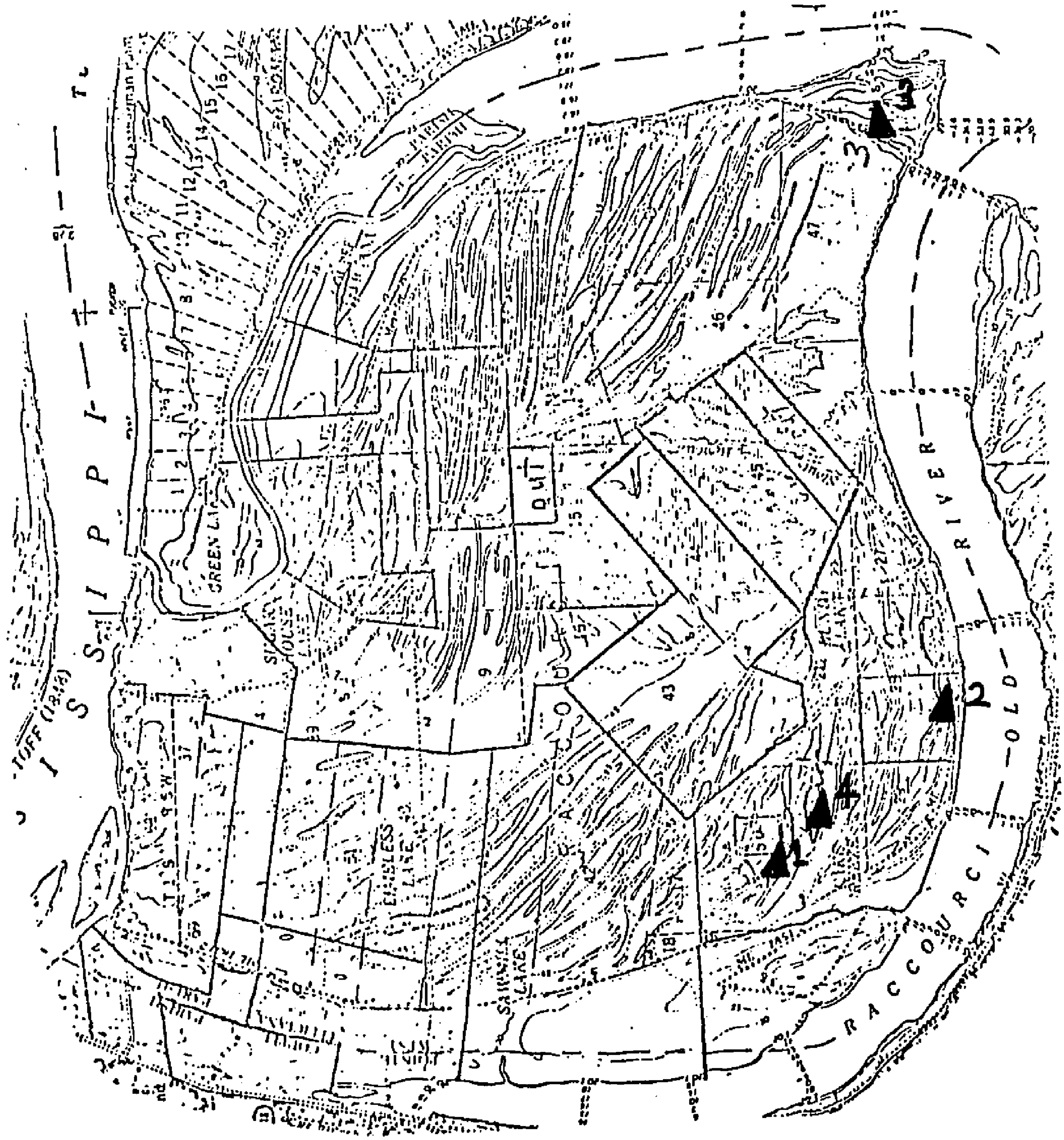

Figure 10. Approximate pecan stand locations on Raccourci Island, La.

Within these four stands, ten of the best pecan trees were selected as seed parents on the basis of their phenotypes. Selection criteria included vigorous growth, position of the crown (dominant or co-dominant), straightness of bole, absence of limbs for at least 10-15 meters of bole length, and a full crown one-third of the total height of the tree. These phenotypic selections were made by visual estimate in relation to neighboring trees in the stand. No attempt was made to apply a quantitative grading system. The stand areas from which the selections were made were about 2 acres (0.8 hectare) or less. Selected stands were located from 0.5 to 5 miles (0.8 to 8 km) apart.

All trees were marked and tagged, and diameter (breast height), total height, and merchantable height were measured (Table 8).

In the fall of 1973, an abundant crop of pecan seed was available and collections were made from the 40 parent trees previously selected. A general seed collection was also made in each stand from trees that had not been selected. These collections were represented by many parent trees of variable quality. Their purpose was to serve as a control sample for comparisons with selected tree performance to estimate the effectiveness of individual tree selections.

At least 100 seeds were collected from each tree and placed in polyethylene bags (4-mil). Seeds were then placed in dry cold storage (2-5C) for 90 days. After the 90 day storage period, seeds were soaked in water for 48 hours and planted. One hundred seeds

Table 8. Total height, merchantable height and diameter breast height for 40 selected parent trees located on Raccourci Island, La.

Stand/Tree	Total Height		Merchantable Height		D.B.H.	
	ft	m	ft	m	in	cm
1-1	130.0	39.6	52.0	15.8	24.0	60.9
1-2	108.0	32.9	60.0	18.3	18.0	45.7
1-3	125.0	38.1	59.0	17.9	20.3	51.6
1-4	110.0	33.5	54.0	16.5	19.0	48.3
1-5	126.0	38.4	64.0	19.5	22.0	55.9
1-6	98.0	24.9	50.0	15.2	15.7	39.9
1-7	127.0	38.7	68.0	20.7	23.0	58.4
1-8	127.0	38.7	60.0	18.3	22.8	57.9
1-9	114.0	34.8	54.0	16.5	20.0	50.8
1-10	114.0	34.8	59.0	17.9	19.0	48.3
2-1	134.0	40.8	61.0	18.6	26.4	67.1
2-2	131.0	39.9	74.0	22.6	25.8	66.5
2-3	115.0	35.0	68.0	20.7	33.3	84.6
2-4	134.0	40.8	71.0	21.6	32.8	83.3
2-5	120.0	36.6	60.0	18.3	21.0	53.3
2-6	116.0	35.4	63.0	19.2	21.9	55.6
2-7	96.0	29.3	55.0	16.8	20.1	51.1
2-8	101.0	30.8	46.0	14.0	20.8	52.8
2-9	121.0	36.9	67.0	20.4	25.5	64.8
2-10	115.0	35.0	65.0	19.8	26.0	66.0
3-1	118.0	35.9	55.0	16.8	18.0	45.7
3-2	119.0	36.3	70.0	21.3	17.0	43.2
3-3	135.0	41.2	58.0	17.7	28.9	73.4
3-4	136.0	41.4	52.0	15.8	19.5	49.5
3-5	131.0	39.9	64.0	19.5	24.1	61.2
3-6	130.0	39.6	52.0	15.8	24.9	63.2
3-7	126.0	38.4	52.0	15.8	22.0	55.9
3-8	154.0	46.9	60.0	18.3	32.8	83.3
3-9	122.0	37.2	72.0	21.9	22.8	57.9
3-10	120.0	36.6	60.0	18.9	21.0	53.3
4-1	120.0	36.6	66.0	20.1	19.0	48.3
4-2	113.0	34.4	59.0	17.9	22.2	56.4
4-3	120.0	36.6	53.0	16.2	24.3	61.7
4-4	119.0	36.3	60.0	18.3	24.0	61.0
4-5	115.0	35.0	57.0	17.4	19.8	50.3
4-6	123.0	37.5	59.0	17.9	24.9	63.2
4-7	119.0	36.3	63.0	19.2	20.6	53.3
4-8	118.0	35.9	68.0	20.7	30.0	76.2
4-9	119.0	36.3	50.0	15.2	23.8	60.4
4-10	114.0	34.8	52.0	15.8	21.9	55.6

per selected parent tree were planted at the Bass Pecan Company nursery, Lumberton, Mississippi, and the School of Forestry nursery, Louisiana State University, Baton Rouge, Louisiana (Figure 3, p. 17). In four of the families, there was only enough seed to plant at one location and these seed lots were represented only at the Lumberton nursery. Each nursery planting was replicated (blocked) to account for any soil differences within the Lumberton field and between the Baton Rouge beds.

The Lumberton nursery was planted 30 April 1974 in a long, continuous row in the Bass Pecan Company's nursery area. They were planted by hand, and nuts were placed approximately 1 inch apart. The rows were covered with about 2 inches of soil by a small, tractor-pulled plow. Germinated seedlings received the standard cultural treatments for Bass Pecan Company stock. There was no supplemental watering, and weeding was done by hand or by mechanical equipment throughout the growing season.

The Baton Rouge nursery was planted 18 April 1974 in two 5-foot-wide nursery beds. Seeds were planted 2 inches apart in 5 rows. Water was added when the top 2 inches of soil became dry, and the beds were weeded by hand. The effects of the different nursery practices on survival and growth were extremely great and have been discussed in detail in the preceding chapter.

First-year height measurements were made in December 1974 at both nursery locations. Total height of the seedlings was measured to the nearest 0.5 cm from the ground to the tip of the terminal bud.

In February 1975 seedlings were lifted from the nursery beds, packed in moist peat moss, and wrapped in burlap to protect the root systems. When root systems were excessively long and presented handling problems, they were pruned. This process was limited to the seedlings grown at the Lumberton site as the Baton Rouge stock did not require pruning.

Root diameter measurements were taken shortly after lifting on 30 families from the Baton Rouge nursery and 30 families from the Lumberton nursery. Ten seedlings per family were measured using a vernier caliper to obtain root diameter to the nearest 0.01 cm. All measurements were taken 2.0 cm below the root collar.

Statistical analysis of the data for nursery height and root growth revealed that there were highly significant differences in root diameter between the two nursery treatments. In addition, regression analysis of seedling height growth on seed size indicated a significant positive correlation. These influences have been discussed in Chapter III.

Because of these influences, comparisons of first-year growth results were limited to family differences within each nursery planting and these were subject to the influence of seed size. Seed size effects were not apparent for second-year height growth and the field plantings of the progeny test were designed to compensate for the nursery effect. Seedling stock grown at Lumberton was planted at Lumberton and at Baton Rouge to provide replication to test for genotype-environment interactions. Seedling stock grown at Baton Rouge was outplanted at Baton Rouge and at Washington (Figure 11).

Accordingly, major emphasis has been placed on field survival and second-year growth in the following discussion of progeny test results. The design of the replicated field plantings also provided for analysis of genotype-environment interactions by comparing the results at the planting sites.

All three outplanting sites were located at approximately the same latitude and climatic conditions were similar. The Washington, La., planting was located approximately 4 miles north of the town on the Thistlethwaite Wildlife Management area. The Lumberton, Miss., planting was located about 5 miles northeast of the town and was planted on the Bass Pecan Company land. The Baton Rouge, La., site was located south of the city on the Louisiana State University, Ben Hur Farm (Figure 3, p. 17).

All three sites had been or were in agricultural production. They vary in soil type, fertility, pH and organic matter content (Table 9). The Lumberton site was more acidic, lower in organic matter and in K, Ca, Mg. The Baton Rouge and Lumberton sites were disced prior to planting. The Washington site was not disced and seedlings were planted in old soybean stubble on elevated rows.

All sites were planted in late February and early March 1975. Seedlings were planted with a standard dibble at a 10 x 10-foot spacing. Each open-pollinated family was represented by a five-tree

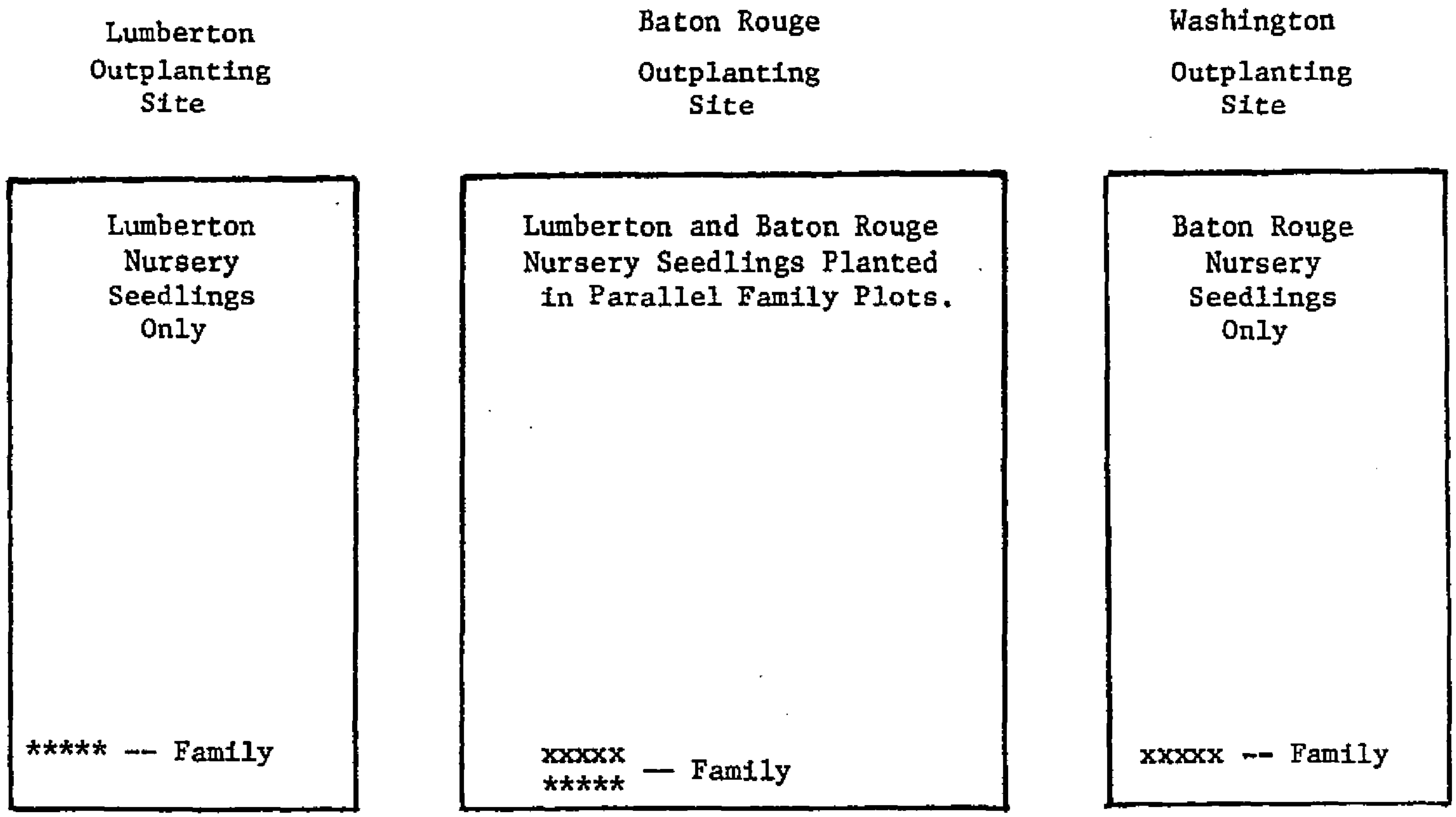

Figure 11. Planting scheme for the Lumberton, Washington, and Baton Rouge planting sites.

Table 9. Nutrient levels, pH and organic matter content of topsoil and subsoil at Washington, Lumberton and Baton Rouge planting sites.

Site	Block	Depth	Extractable Nutrients P	K	Ca	Mg	pH	Organic Matter
		In	PPM					Percent
Washington	1	0-8	7	117	1990	862	6.3	2.29
"	2	"	5	145	1700	656	6.0	2.52
"	3	"	5	139	1680	774	6.0	2.50
"	4	"	5	144	1380	606	5.9	1.77
"	1	18-24	5	216	2400	1000	6.0	0.73
"	2	"	5	208	2460	1000	5.8	0.68
"	3	"	7	175	1930	1000	6.1	0.52
"	4	"	5	75	780	372	6.0	0.36
Baton Rouge	1	0-8	48	270	2690	727	6.2	1.35
"	2	"	72	231	3200	914	6.5	1.77
"	3	"	110	234	3170	939	6.7	1.72
"	4	"	57	205	2840	809	6.4	1.14
"	1	18-24	86	134	2440	1000	6.5	0.62
"	2	"	86	170	3060	1000	7.0	0.62
"	3	"	124	187	3160	1000	6.9	0.99
"	4	"	76	159	2530	848	6.7	0.31
Lumberton	1	0-8	24	62	240	54	5.8	0.78
"	2	"	24	61	310	83	5.8	0.62
"	3	"	31	84	310	88	5.8	0.73
"	4	"	53	73	280	79	6.0	0.55
"	1	18-24	5	30	310	108	5.9	0.08
"	2	"	5	27	430	187	5.7	0.36
"	3	"	7	19	260	89	5.8	0.13
"	4	"	5	33	230	69	5.9	0.21

line plot. Each test was replicated four times to account for any variation within the sites.

Measurements of height growth at the end of the first year after outplanting (second-year growth) were made in November 1975. Heights were measured with a meter stick to the nearest 0.5 cm. The statistical design was a randomized block with a factorial arrangement. In effect, three different analyses were conducted. One was on the parallel family plots at the Baton Rouge outplanting site to determine second-year nursery effects which were discussed in the preceding chapter. The second analysis compared families grown at the Lumberton nursery in terms of field performance at Baton Rouge and Lumberton. The third analysis compared the families grown at the Baton Rouge nursery in terms of field performance at Baton Rouge and Washington.

Results and Discussion

First year growth. The analysis of variance for height and root diameter growth in the nurseries are presented in Tables 5 and 6 (p. 51 and 52). The outstanding relationships found in both analyses were the highly significant differences between nurseries. Seedlings grown at the Lumberton nursery were 18 percent taller and had root diameters 22 percent larger than those grown at Baton Rouge. This nursery effect was discussed in Chapter III. Major nursery site differences were also reflected by highly significant values for genotype-environment interactions. The effect on individual family means can be compared in Table 10.

Table 10. Family means for first-year root diameter and top growth of 40 open-pollinated pecan families. Families exceeding overall nursery mean underlined.

Family	Mean Root Diameter		Mean Seedling Height	
	Lumberton Nursery	Baton Rouge Nursery	Lumberton Nursery	Baton Rouge Nursery
	cm	cm	cm	cm
Overall Nursery Mean	0.81	0.66	18.38	15.53
1-1	0.90	0.60	14.93	13.66
1-2	0.79	0.60	15.62	13.83
1-3	1.07	0.50	15.20	15.07
1-4	0.63	—[a]	17.92	—
1-5	0.71	0.61	16.32	13.47
1-6	0.85	0.45	14.47	10.62
1-7	0.88	0.54	16.99	14.03
1-8	0.70	0.44	15.35	13.29
1-9	0.93	0.59	18.94	15.53
1-10	0.83	0.72	20.15	16.73
2-1	0.85	0.66	21.06	14.55
2-2	0.73	0.84	20.46	16.27
2-3	0.66	0.72	19.19	14.26
2-4	0.57	0.70	16.48	14.44
2-5	0.82	0.71	17.66	16.54
2-6	0.70	0.63	15.09	14.59
2-7	0.81	—	18.96	—
2-8	0.78	—	14.68	—
2-9	—	—	—	—
2-10	0.89	0.72	20.07	17.80
3-1	0.84	0.70	17.49	14.17
3-2	—	—	21.15	12.53
3-3	0.99	0.65	16.68	14.79
3-4	0.74	—	14.46	12.78
3-5	0.83	—	14.92	12.14
3-6	0.69	—	13.45	13.32
3-7	0.95	0.60	19.24	14.99
3-8	0.88	0.83	21.84	18.50
3-9	0.67	—	17.14	15.10
3-10	0.84	0.56	18.06	13.15

Table 10. Cont.

Family	Mean Root Diameter: Lumberton Nursery	Mean Root Diameter: Baton Rouge Nursery	Mean Seedling Height: Lumberton Nursery	Mean Seedling Height: Baton Rouge Nursery
	cm	cm	cm	cm
4-1	1.00	0.70	25.45	21.94
4-2	0.88	0.83	20.59	21.22
4-3	0.74	———	22.11	19.56
4-4	0.81	0.98	18.69	19.29
4-5	0.58	0.54	16.54	14.80
4-6	0.91	0.70	24.89	16.63
4-7	0.91	0.63	18.68	14.47
4-8	0.85	0.63	20.92	16.49
4-9	0.80	0.82	23.25	17.59
4-10	0.72	0.56	17.56	15.91
U-1[b]	0.68	0.56	15.99	17.31
U-2	0.89	0.61	21.11	16.53
U-3	0.72	0.57	19.83	16.74
U-4	1.08	———	20.05	15.39

[a]Seedlings not available due to lack of seed or mortality.

[b]Unselected collection and stand area from which collected.

Differences in family performances for height and root diameter growth at the end of the first growing season were also highly significant ($P < 0.01$). This large degree of individual parent-tree or family variation was found among the progenies of parent trees selected from one local source, Raccourci Island. The presence of this large degree of genetic variation within a small study area is a strong indication of the genetic diversity found in wild populations of pecan.

To further evaluate this variation and the relative performance of the families of the 40 selected parent trees, mean values for height and root diameters were compared. Family means for root diameter and height growth for both nursery locations are presented in Table 10 with families exhibiting performance above the location mean indicated by underlining. An examination of these family means shows that only 7 families of the 40 parent trees originally selected were performing above the average for both height and root diameter growth at both nursery locations. Families exhibiting superior performance were Families 1-10, 2-10, 3-8, 4-1, 4-2, 4-4, and 4-6.

The four unselected stand collections (unselected trees throughout each stand) performed well when compared to selected families. For height, three of the four unselected stand collections exceeded the location mean at both nurseries (Table 10), whereas only 7 of the 40 selected families performed this well. However, results of this type were not found for root diameter growth rate where the location mean was exceeded by only two unselected stand collections at one nursery location. By looking at only first-year nursery performance for height growth, one might conclude that unselected stand collections were just as effective as individual tree selection.

However, when comparing the results of individual parent tree selection to unselected stand collection for each area, the results are variable. A comparison of the mean performance of selected families to that of the unselected collection in Stands 2 and 3 indicate that parent tree selection was ineffective for increased seedling height in these stands; for example, none of the selected families grown at Lumberton exceeded the unselected collection means for this trait in Stand 2 and only one family (3-8) exceeded the unselected means in Stand 3. Stand 1 was somewhat intermediate with 5 families exceeding the unselected stand mean for height growth. On the other hand, individual selection in Stand 4 appeared quite effective for seedling height; in the Lumberton nursery, 6 selected families exceeded the unselected mean while 8 did so in the Baton Rouge nursery.

For root diameter growth, individual tree selection appeared highly effective in Stand 1 and moderately effective in Stands 2 and 3. Surprisingly, root diameters of selected family seedlings in Stand 4 were generally smaller than those of unselected seedlings. It might be concluded, therefore, that individual tree selection is not effective in pecan.

To determine if there was a significant relationship between seed weight and height growth of all families for the first and second year, a regression analysis was done. The results of this investigation showed that there was a highly significant ($P < 0.01$) seed size ($r^2 = 0.12$) effect on height growth in the first year but that this effect was not significant by the end of the second year.

Because of the seed-size effect, the results presented in this section on first year growth must be viewed with this in mind. Also, many of the families found exceeding the mean growth for height and root diameter were also from larger size seed lots and the effect of seed size has probably been expressed in these early growth results.

Second year height growth. The objective of the analysis of second year height growth was to obtain information on the genetic variation among the four selected stands, the genetic variation and field performance of the 40 selected families, and environment-genotype interactions that might have occurred between planting sites. In the preceding section, concern was noted pertaining to the effect of seed size on initial (first-year) growth, but analysis indicated that there was no effect of seed size on seedling growth after the first growing season. Therefore, this second-year data should be more useful in determining genetic differences among seedling families.

1. Stand variation and field performance: The purpose of selection of pecan trees within small stand areas and evaluation of stand variability was to provide some information on the degree of relationship among parent trees within stands of this monoecious, wind-pollinated species.

In the analyses of second-year height growth at all planting sites, there was highly significant ($P < 0.01$) variation among stands. This indicates that in addition to individual tree variation, there is also detectable variation for certain traits (in this case, height growth) between stands or small breeding groups within local populations of pecan. If there is inbreeding within stands, there may be a tendency for stands within populations to develop some degree of homozygosity, and therefore a closer genotypic-phenotypic relationship among trees within the individual stands.

This would be possible in natural pecan stands because the majority of the pollen disseminated is probably intercepted by trees in the immediate area of the pollen parent. With little inclusion of new genetic material from outside stands, the trees involved could develop a pattern for expression of certain traits which would be different from a stand of pecan located a short distance away which had evolved in a divergent manner. Thus, individual trees remain highly variable but trees within stands may exhibit a closer degree of relationship to their neighbors than to distant pecan trees.

The stands from Raccourci Island had statistically significant differences in height growth but no logical pattern could be determined for this variation. Generally, the order of mean second-year height growth remained the same as first year growth (stand order was 4, 2, 1, and 3), with the exception of the results at the Lumberton site (Table 11). Also, the stand considered to have been the poorest (Stand 4) in terms of parental phenotypes selected, is the one that has the best progeny in the Lumberton planting and it also contains the majority of the families exhibiting above average performance in root diameter and height growth the first year and height growth the second year. Apparently, prediction of the performance of a given stand of pecan by parental phenotypes alone is not possible and these results emphasize the importance of progeny testing.

2. Family variation and field performance: Family variation in survival and second-year height growth was found to be highly significant for all planting sites. This supports the theory of a large degree of genetic diversity in wild populations of pecan. These pecan families are the progeny of open-pollinated female parent trees selected on the basis of their excellent phenotypes. Although only the best parents were selected in each stand and most parent trees were phenotypically similar, there is still tremendous variation among the individual open-pollinated families.

This genetic diversity is ideal for the forest tree breeder as it provides a large genetic base from which material can be

Table 11. Stand means for second year height growth of families from two nurseries planted at Lumberton, Baton Rouge, and Washington.

Nursery	Outplanting Location	Stand	Mean Height
			cm
Lumberton	Lumberton	2	30.86
"	"	4	29.68
"	"	3	29.01
"	"	1	28.92
"	Baton Rouge	4	21.20
"	"	2	20.73
"	"	1	20.39
"	"	3	19.42
Baton Rouge	Washington	4	16.63
"	"	2	16.63
"	"	1	15.48
"	"	3	15.19
"	Baton Rouge	4	18.93
"	"	2	18.18
"	"	1	16.40
"	"	3	16.07

obtained when needed for improvement programs. If no phenotypic selection had been practiced and parent trees chosen at random, the genetic diversity would probably have been even greater.

An extreme example of between-family height growth variation is exhibited by two families grown at the Baton Rouge site (Lumberton nursery seedlings). These are the open-pollinated progenies of Family 3-4 (Table 12) which had a mean second-year height of 15.95 cm and Family 4-1 which had a mean second-year height of 25.95 cm. This is 39 percent difference between seedling families of parent trees which were the result of phenotypic selections. The same pattern of large differences in growth rate was also noted between families at the other two outplanting sites, though the extremes were not as great.

The mean values for second-year height growth of all families planted at the Lumberton/Baton Rouge and Washington/Baton Rouge sites are presented in Table 12. By determining the families exceeding mean second-year height growth at each planting site (underlined) and comparing these results with the mean values for first-year growth (Table 10), some families are found to be growing well at all locations. These are Family 2-10, 3-8, 4-1, 4-2, and 4-4. Thus, by the end of the second year of growth, only five families grew better than the plantation average at all locations for both years. These results are based on only two years of growth. Many of the families grew well in one location but not the other.

Table 12. Second-year height growth mean values with pecan families exceeding overall location mean underlined.

Family	Lumberton nursery stock: Lumberton Outplanting	Lumberton nursery stock: Baton Rouge Outplanting	Baton Rouge nursery stock: Washington Outplanting	Baton Rouge nursery stock: Baton Rouge Outplanting
	cm	cm	cm	cm
Overall Location Mean	29.66	20.41	15.91	17.39
1-1	26.17	17.54	15.12	14.38
1-2	22.77	17.34	13.55	17.68
1-3	32.71	24.70	15.69	16.17
1-4	25.80	19.97	—[a]	—
1-5	30.94	17.18	14.33	16.26
1-6	31.00	15.75	10.50	15.88
1-7	30.53	23.27	14.21	14.12
1-8	29.63	19.16	9.75	15.43
1-9	30.28	22.30	20.73	16.86
1-10	27.45	24.94	19.68	20.25
Stand Mean	28.92	20.39	15.48	16.40
2-1	33.00	22.83	16.35	18.83
2-2	30.58	20.42	15.09	16.65
2-3		21.67	12.58	17.76
2-4	32.12	23.67	13.60	16.44
2-5	28.17	17.62	20.83	16.57
2-6	33.85	19.50	14.47	18.28
2-7	27.10	18.67	—	21.00
2-8	26.18	18.36	—	—
2-9	—	—	—	—
2-10	35.78	23.00	19.21	22.29
Stand Mean	30.86	20.73	16.63	18.18
3-1	22.57	19.31	17.10	15.50
3-2	32.00	20.15	—	11.31
3-3	28.70	21.09	15.20	17.47
3-4	—	15.95	12.88	16.11
3-5	—	17.43	—	13.23
3-6	—	17.24	17.12	14.66
3-7	31.28	19.55	14.17	18.34
3-8	30.50	22.53	19.40	20.28
3-9	29.68	19.31	14.90	16.37
3-10	29.38	22.06	14.64	14.18
Stand Mean	29.01	19.42	15.19	16.07

Table 12. Cont.

Family	Lumberton nursery stock: Lumberton Outplanting	Lumberton nursery stock: Baton Rouge Outplanting	Baton Rouge nursery stock: Washington Outplanting	Baton Rouge nursery stock: Baton Rouge Outplanting
	cm	cm	cm	cm
4-1	31.36	25.95	18.28	20.10
4-2	26.26	23.78	20.67	19.74
4-3	31.76	18.18	18.00	19.95
4-4	34.24	20.00		21.92
4-5	24.47	20.59	14.71	17.25
4-6	29.26	21.15	13.58	17.84
4-7	29.76	20.43	15.38	14.54
4-8	28.13	19.57	14.50	16.35
4-9	33.28	24.75	15.41	17.09
4-10	30.05	17.61	18.00	24.68
Stand Mean	29.68	21.20	16.63	18.93
U-1[b]	26.86	12.32	16.41	15.22
U-2	30.95	23.70	19.06	25.05
U-3	26.05	20.86	17.00	19.39
U-4	32.60	26.92	16.00	14.56

[a]Seedling not available due to lack of seed as mortality.

[b]Unselected collection and stand area from which collected.

In most of the cases, progeny performance was better in plantings that were from the Lumberton nursery which indicates that the effects of the nursery environment may be extremely important not only in production of 1-0 seedlings but in the years following outplanting.

As in the first-year growth analysis, general stand collections were included in the progeny test to determine how an unselected group of seedlings compared to the selected families discussed above. The general collections were growing well at the end of the first year in the nursery and analysis of second-year height growth showed that two of the stand collections were still performing above average at both the Lumberton/Baton Rouge and Washington/Baton Rouge sites (Table 12). However, only Stand 2 is above the plantation average for height growth at all planting sites. This stand collection was also above average for height growth at both nursery locations.

Again, as with the results [illegible] the first-year height growth, a comparison of select-tree progeny performance to that of seedlings in the unselected stand collections yielded variable results. For example, individual tree selection was apparently effective in Stand 1 where selected families outgrew the unselected stand collection at two of the three locations. At the other extreme, selected families of Stand 2 grew poorly when compared to the means for the unselected seedlings at each planting site. When means for selected stands (Table 11) are compared with general collection means (Table 12), there is a trend for the selected family means to be higher on the better of the two sites (Lumberton site over the Baton Rouge, Baton Rouge over Washington). This trend should be observed in subsequent measurements to see if it is maintained as the trees get older.

In summary, only one unselected stand collection and five selected families of 40 have exhibited superior growth throughout this study. This is an indication that some families grow well (above average) on all sites. However, many families varied greatly in their growth at the different sites indicating that there was some degree of interaction between genotypes and planting sites.

3. Genotype-environment interactions: The Baton Rouge/ Lumberton planting sites (established with seedling grown at the Lumberton nursery) were very different from each other in terms of soil type, depth of the top soil, fertility levels and growth of unwanted vegetation. The Baton Rouge site was the most fertile (Table 9, p. 73), but consisted of heavy (gumbo) clay soils and supported heavy weed growth.

The Washington/Baton Rouge sites (established with seedlings grown at the Baton Rouge nursery) were more similar to each other in terms of soil fertility, texture and weed growth. Both were essentially typical bottomland sites.

The analysis of variance for second-year height growth at the Washington/Baton Rouge sites revealed no genotype-environment interaction. This is not too surprising because of the similarity of the two sites in terms of climate and soils. This similarity is reflected in the overall second-year height growth means where the seedlings growing at Washington had a mean height growth of 15.9 cm and the seedlings grown at Baton Rouge had a mean height growth of 17.4 cm, or only a 1.5 cm mean difference.

Growth was not similar between the Lumberton and Baton Rouge planting sites, and analysis of variance for second-year height growth revealed highly significant ($P < 0.01$) genotype-environment interactions between the two sites. These interactions are illustrated in the comparison of family means for Lumberton and Baton Rouge in Table 12, where the relative ranking of family performance is significantly different at each location. A specific example of the effect of the different environments on particular genotypes is provided by Stand 4. The families ranked 1, 2, 3, 4, 5 (Families 4-1, 4-9, 4-2, 4-6, and 4-4) in terms of second year height growth at Baton Rouge ranked 4, 2, 9, 7, and 10, respectively, in the Lumberton planting.

The environment not only affected the relative ranking of families but altered the mean height growth by a considerable margin between the two different sites of Baton Rouge and Lumberton. Two examples of excellent family growth at Lumberton and poor growth at the Baton Rouge site were Families 1-5 and 1-6 which had mean height growth of 30.94 cm and 31.00 cm at Lumberton and 17.18 cm and 15.75 cm at Baton Rouge, respectively. This is an increase in growth of 44 and 49 percent from one site to the other and this also affected the ranking of these families. In fact, Families 1-5 and 1-6 are ranked 3 and 2 at Lumberton and 9 and 10 at Baton Rouge.

This large effect of the environment on some of the genotypes is very evident. In all families there was some evidence of genotype-environment interaction between the Lumberton and Baton Rouge sites. However, there was a considerable range in growth performance of these families with some showing extreme changes in growth and ranking while other families were not affected to this magnitude. This change in ranking and individual performance due to genotype-environment interaction is graphically shown in Figures 12-15.

The large range in height growth of families at the two sites indicates that selection of genotypes to match the particular environment may be feasible. In this study there were families that did well regardless of where they were planted. Some did well on one site but poorly on the other. Thus, much consideration should be given to matching genotypes to the environments in which they may be planted. If individual families that will perform well over a range of environments can be determined, then reduced growth that may result from the incompatability of a genotype with a particular site can be avoided.

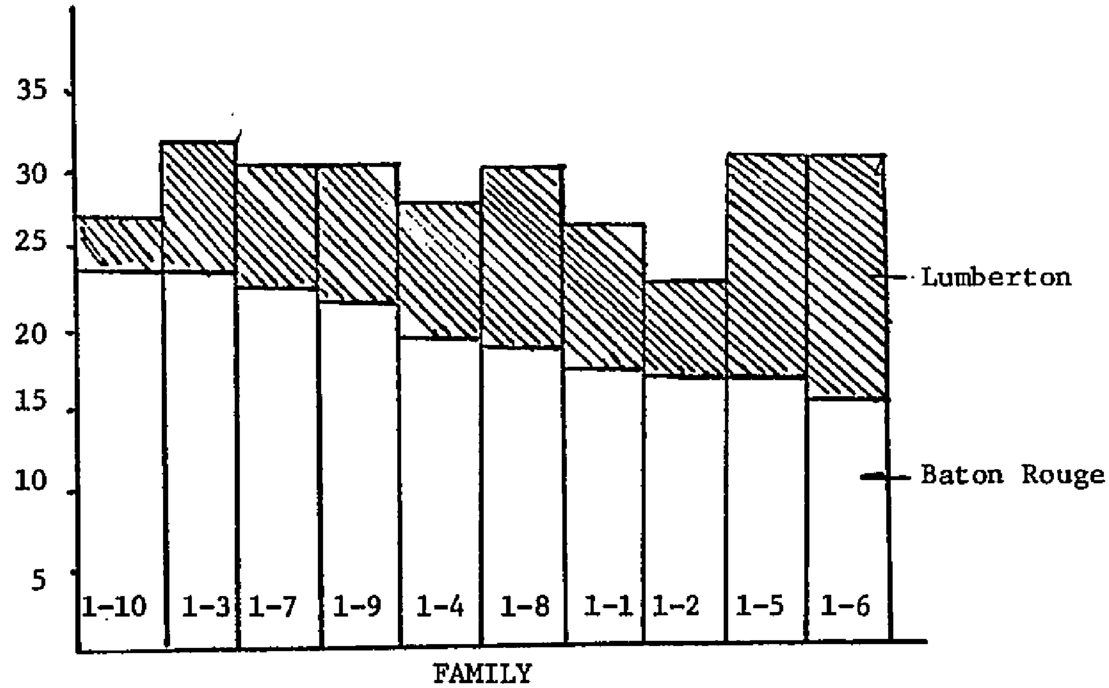

Figure 12. Mean total height growth of Stand 1 families planted at Baton Rouge and Lumberton.

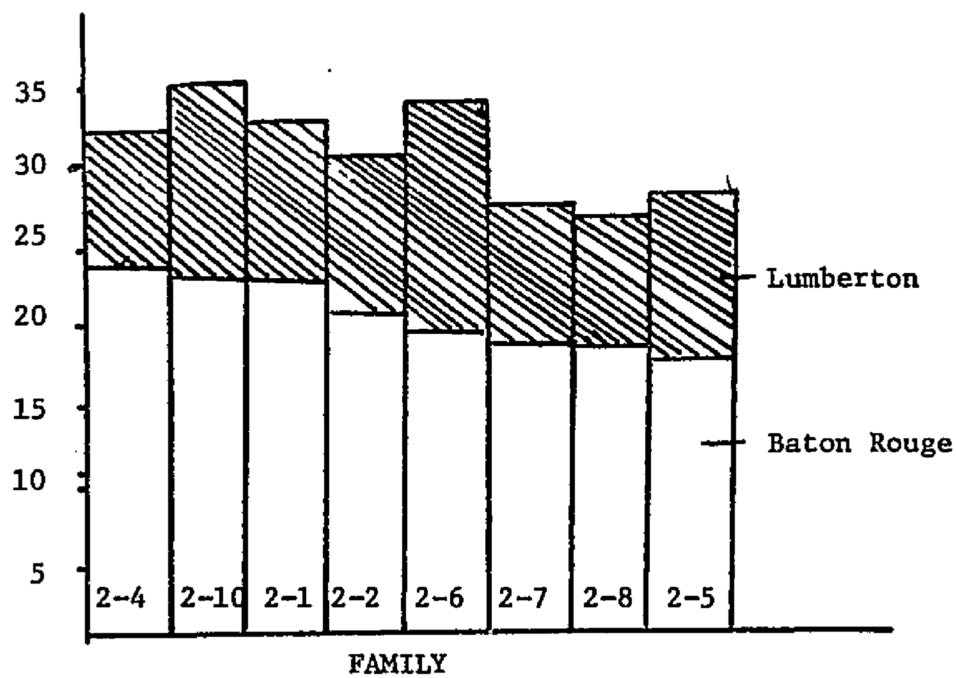

Figure 13. Mean total height growth of Stand 2 families planted at Baton Rouge and Lumberton.

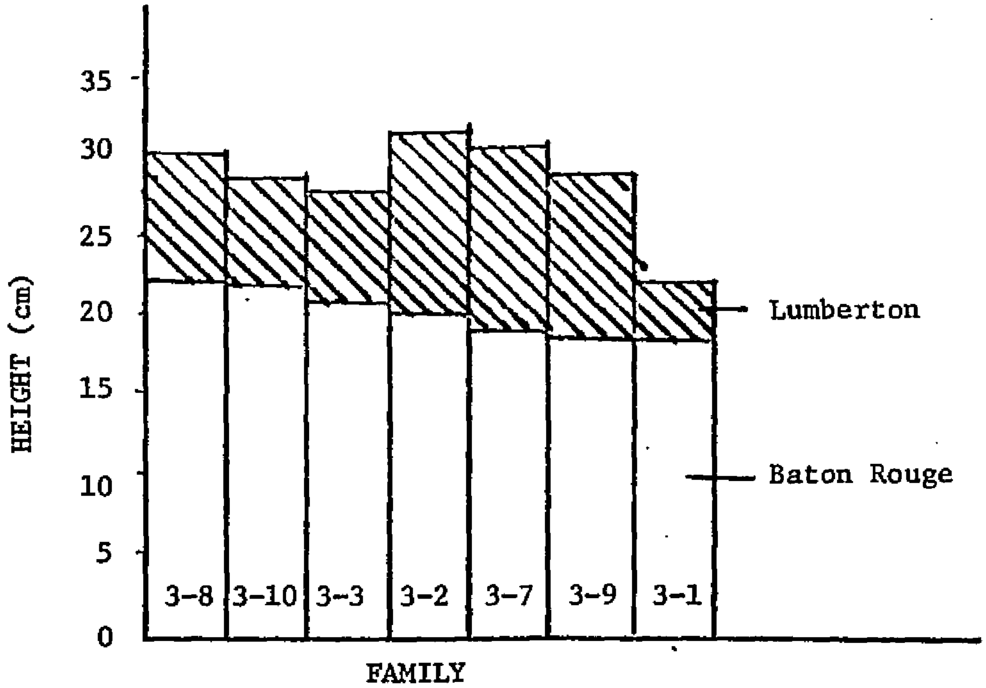

Figure 14. Mean total height growth of Stand 3 families planted at Baton Rouge and Lumberton

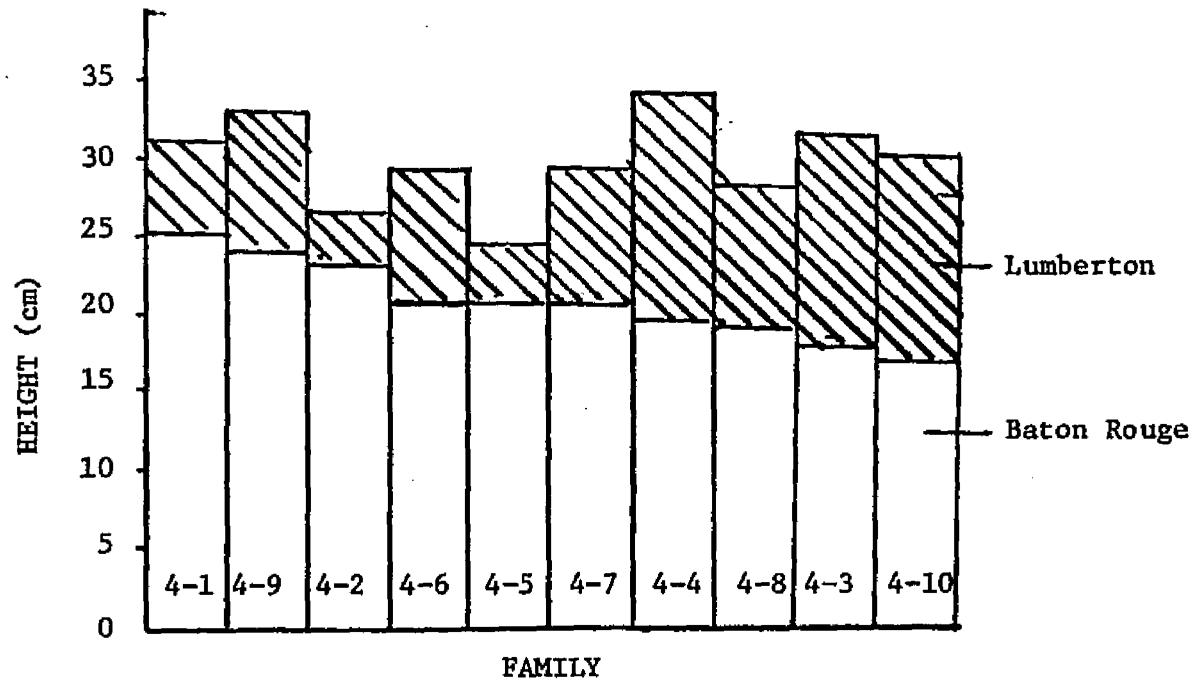

Figure 15. Mean total height growth of Stand 4 families planted at Baton Rouge and Lumberton.

Pecan is site-specific, and improvement work must either match genotypes to the environment or find genotypes that are capable of growing over a large range of environments. With pecan, the genetic diversity is apparently available and from this study indications are that either method could be utilized to provide pecan seedlings suitable for many different sites.

4. Summary of second-year growth results: Second-year growth, like results of the first year, indicated a considerable degree of genetic variation for height growth among the 40 open-pollinated selected families. Several families were found to be performing above average on all three sites and other families were above average on at least one site. Genotype-environment interactions were detected between the Lumberton and Baton Rouge sites which resulted in changes in height growth of families grown at these locations. In some cases the relative rankings were radically changed while a few families remained consistent regardless of site.

Comparisons between selection methods (unselected stand versus individual tree selections) indicated that seedlings from stands containing good phenotypes were performing in a satisfactory manner and were in some cases growing better than the progenies of phenotypically selected parents. However, no clearcut conclusions could be made other than that general collections and selected progenies were very similar in mean second-year height growth rate.

Heritability estimates. Components of variance and heritabilities for second-year height growth of pecan are estimated using the following mean square components:

Source of Variation	Expected Mean Square
Site	$V_e + NV_{fb} + NBV_{fs} + NFV_b + NFBV_s$
Block/Site	$V_e + NV_{fb} + NFV_b$
Tree (family)	$V_e + NV_{fb} + NBV_{fs} + NBSV_f$
Tree x Site	$V_e + NV_{fb} + NBV_{fs}$
Tree x Block/Site	$V_e + NV_{fb}$
Error	V_e

Where: F,B,S, and N represent the numbers of trees, blocks per site, sites, and trees per plot, respectively; V_e, V_{fb}, V_{fs}, V_f. V_b, and V_s are variances due to tree-within plot, tree x block-within-site, tree x site, tree, block/site and site, respectively.

The expected mean square estimated and the following estimates for family (broad sense) and single tree (narrow sense) heritabilities closely follow Wright's (1976) variance analysis for a replicated half-sib progeny test.

The procedures used to estimate heritabilities are as follows:

$$\text{Family heritabilities} = \frac{V_f}{V_e/NBS + V_{fb}/BS + V_{fs}/S + V_f}$$

and

$$\text{Single tree heritabilities} = \frac{4\ V_f}{V_e + V_{fb} + V_{fs} + V_f}$$

For the purpose of this study, no nursery heritability estimates were made because of the effect of seed size on family performance in the first-year growth of pecan progenies. Gall and Taft (1973) found this seed-size effect in red oak progenies and they suggested that seed-size effect may bias any heritability estimate based on first year nursery growth. Data from these pecan studies strongly support their observations. However, the seed-size effect was diminished by the end of the second-year in the present study and, therefore, heritability estimates for second-year height growth should be valid.

The heritability estimates for second year height growth of pecan (Table 13) are in the range of those reported by Bey (1970) and Bey et al. (1971) for height growth of black walnut. There were considerable differences in the heritability estimates calculated for the Lumberton/Baton Rouge planting and those for the Washington/Baton Rouge planting. The values for the latter were higher and this is partly due to genotype-environment interaction between the Lumberton and Baton Rouge sites and the absence of interaction between the other two sites. In the estimating equations the more uniform environment between the Baton Rouge and Washington planting sites is reflected in the variance for tree (V_f) and tree x site (v_{fs}).

Heritability estimates express the relationship between phenotypic and genotypic values for a specific trait. They also

Table 13. Estimated variance components and heritabilities for second year height growth.

Planting Sites	V_f	V_{fb}	V_{fs}	V_e	Broad h^2	Narrow h^2
Lumberton and Baton Rouge	306.08	444.04	110.71	4792.54	0.57	0.22
Washington and Baton Rouge	380.01	406.74	0.0	2921.24	0.74	0.41

determine the relative effectiveness of selection; the higher the heritability, the more successful the selection process and the greater the genetic gains will be. A trait exhibiting a high heritability can be selected for with confidence that genetic gains will be obtained from this selection, provided that there is adequate genetic variation to provide for an effective selection differential.

The narrow sense heritabilities for second-year height in this study were 0.22 for the Lumberton/Baton Rouge planting and 0.41 for the Washington/Baton Rouge planting. These estimates are moderate to high and selection of pecan for superior height growth should result in early genetic gain. The pecan tree breeder can, with a degree of accuracy, know that progeny from parents selected for superior height will also exhibit this characteristic.

In summary, the large degree of genetic variation among families and the range of heritability estimates from this study indicate that selection of pecan for superior height growth should be successful. The estimates varied between the planting sites, reflecting the site-specificity of pecan and the presence of genotype-environment interactions. These two factors must be considered as they will have considerable effect on the overall success of a tree improvement-reforestation program for pecan.

CHAPTER V

GENETIC VARIATION IN PECAN (A SUMMARY)

The evaluation of genetic diversity in wild populations of pecan is essential for an improvement program to progress with any degree of success. Though much work has been done on the horticultural possibilities (nut production), little is known of the potential for improvement of this species for timber production. Recently, increased value of pecan wood products has revived interest in the species, and emphasis must be placed on the preservation and utilization of the genetic material now available to insure high quality trees for the future.

Black walnut, a relative of pecan, has been in great demand for nut and wood products for many years and improvement programs investigating the variability in natural stands and the use of this variability in breeding programs to provide walnut wood and nut products have been successful. If pecan exhibits adequate variation not only in local populations but throughout its large native range, there is no reason a program of genetic improvement by selection, progeny and provenance testing, and breeding work cannot improve this bottomland hardwood species, much in the same manner as black walnut.

Currently, excellent populations of pecan are available so that superior phenotypes can be located without great difficulty. However, as time progresses and these mature stands are harvested, many trees that are potentially valuable, genetically, may be lost. Thus, this excellent and abundant pecan gene pool must be utilized now.

The initial phase of the pecan improvement program is a progeny test of 40 phenotypically selected parent trees. The parent tree selections were made in the Mississippi River flood plain of southern Louisiana. Within this area, four stands were selected and, within these, the 10 best trees were chosen as seed parents. The objective of this method of selection was to obtain information on the genetic variation in small breeding groups as well as on individual tree variation in native pecan populations.

The results of the progeny test are based on two years' growth and provide some interesting information upon which other aspects of research with this species can be based.

Evaluation of height and root growth showed considerable variation among open-pollinated families. This variation is an important element in future improvement work because it identifies a variable gene pool for future selection and breeding. The presence of this genetic diversity should enable genetic gains in height growth and, perhaps, in other traits to be investigated in the future.

Several families have been identified that are growing well on all three planting sites in this study. Two of the sites are typical bottomland hardwood areas (Washington and Baton Rouge, La.), while the third is a more typical upland pine-type site (Lumberton, Miss.). There was no genotype-environment interaction detected between the two bottomland sites, but there was a significant genotype-environment interaction between the bottomland and upland sites. Somewhat surprisingly, the best growth was recorded on the upland site. Apparently, this can be attributed primarily to the better drainage on the upland site which promoted better root development, survival, and growth.

Families that performed well at all locations indicate some genetic plasticity or adaptability to different sites. However, many families grew well on only one or two of the sites and genotype-environment interactions were found when comparing upland versus bottomland sites. For more accurate information on general or specific performance, larger scale studies must be conducted on additional sites, perhaps including some of the open-pollinated families from this study.

Pecan, like many hardwood species, is monoecious and wind-pollinated and the degree to which small stands or breeding populations are related or inbred is not known. This study included stand selection to test the variability found between the stands. As already noted, there was a large degree of variation among open-pollinated families but also a significant degree of variability among stands. This indicates that the trees growing within stands (that is, in the same breeding population), though genetically variable individually, exhibit a closer relationship to other trees in that stand than to those trees located in other stands in the same general area. A low rate of migration and evolution along divergent lines could account for the differences among stands.

When the collections of seed for this study were made, a general seed collection was taken from unselected trees chosen at random throughout each stand. This was done to determine the effectiveness of individual tree selections. When compared with the overall means of selected families the mean height growth of the unselected progenies compared favorably, but unselected progeny means were generally exceeded by one or more individual family means. These results were highly variable and no real pattern could be detected. Of the general collections, the one from Stand 2 was generally the best, whereas the majority of the selected families performing above average came from Stand 4. It should be noted, however, that unselected trees from which the general collections were taken were relatively good phenotypes and this may account for the performance of their progeny. Also, if the hypothesis of stand inbreeding is valid, then all trees in the same stand may have relatively similar genetic makeup and phenotypic differences may be due more to environmental factors.

Perhaps the most important finding of this study was the major effect that nursery procedures and nursery site had on the growth of seedlings in the first and second years. All seedlings grown at Lumberton, Mississippi, developed much larger root systems in the nursery bed and, when outplanted they had better survival, initiated growth sooner, and grew faster than those seedlings grown in the Baton Rouge nursery.

Different nursery soil conditions, water regimes, and cultural practices were the causative factors for the differential growth rates of the seedlings, and apparently, nursery soils and practices should be designed to encourage vigorous root growth. The production of large, vigorous seedlings would greatly increase early survival and growth and this positive nursery effect may persist for several years.

No attempt was made to estimate the heritability of first-year growth because of a positive seed size-seedling growth relationship. Investigations showed that the larger-seeded families had greater initial seedling height growth and thus performance in the first year may be due, in part, to the effect of seed size. This seed size to seedling growth relationship may perhaps contribute to the production of larger seedlings through selecting parent trees on the basis of seed size as well as favorable economic traits such as growth rate, form or pest resistance.

Seed size did not influence second-year growth and heritability estimates were calculated for height growth. These estimates ranged from 0.57 to 0.74 for broad sense and from 0.22 to 0.41 for narrow sense. The heritability estimates are close to those calculated for other large-seeded hardwood species and they indicate that there should be excellent opportunity to effect genetic gain for height growth in pecan by selection and breeding.

These heritability estimates are based on second-year growth results, however, and they should be re-calculated as the progeny tests mature. Heritability estimates are not absolute and they vary according to age, genotype and environment. These heritability estimates apply only to the conditions of this study and are not a broad estimate of heritability of growth rate in pecan.

With an indication of the heritability of growth rate, the degree of variation among parent trees, and other results from this study, what methods can be used to most effectively obtain genetic gain in pecan? There are two possibilities for selection--single-tree or stand selections. The single-tree method requires more time in selecting parent trees and collecting seed but may prove to be more efficient for the detection of superior genotypes. However, evidence points to inbreeding within stands and a degree of homozygosity among parent trees within stands. Thus, superior stand selection may prove to be more effective than originally believed and, though only four stands were sampled in this study, the unselected progeny performed well through age two.

Stand selection would require guidelines to locate stands containing a majority of good phenotypes and a knowledge of past stand conditions (high-grading may be critical). Progenies from these stands should produce good seedlings and these should be retained for future selection and breeding. Using this method of progeny testing, a large number of seedlings would be grown and only the best of these would be included in seed orchards.

The individual-tree selection method would consist of establishing grafted clonal seed orchards and standard progeny testing. Inferior clones would be rogued on the basis of progeny test results.

Which method may prove the most efficient remains to be answered. The use of individual tree selections employing very rigid selection criteria would probably provide a few families that are excellent for the trait in question. The use of stand selection (modified mass selection) would probably give the quickest results and provide a larger genetic base to work with in future generations. Thus, individual-tree selection versus stand selection may result in either a few clones of outstanding quality or a large number of trees of excellent quality but not quite as good as the individual selections. Studies on combining abilities and time to reach sexual maturity may further influence the breeding strategy.

Future Work

This study was the initial investigation of the genetic variability of pecan and the prospects for improving the timber production of the species through selection and breeding. Selection and breeding for growth rate should be effective but there is much more research information needed to arrive at an efficient breeding system. Future studies should include:

1. Continued evaluation of this progeny test for growth, survival, and nursery effect;

2. Recalculation of heritabilities for growth and evaluation of form, pest resistance, and wood properties as the trees mature;

3. Additional progeny testing of families selected from various locations replicated on a number of sites;

4. A more comprehensive study of mass or stand selection as a method to improve pecan;

5. Provenance test (currently under study) to evaluate the genetic variability throughout the range of pecan;

6. Investigations into vegetative propagation methods available for use with this species for future clonal seed orchards;

7. Studies to develop techniques for control-pollinating forest grown pecan for use in full-sib progeny test;

8. Investigations into the silvicultural aspects of planting, spacing, and thinning requirements of the species;

9. Investigations into the most efficient methods of producing large seedlings, including container-grown seedlings;

10. Investigations into the potential of the hybrid C. x lecontei in breeding for timber production and possibly root stock production for horticultural use.

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VITA

John Clyde Adams was born December 11, 1947, in Angie, Louisiana. He attended public school in Angie and graduated from Angie High School in May 1965.

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EXAMINATION AND THESIS REPORT

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Major Field: Forestry

Title of Thesis: A study of genetic variability in wild populations of pecan (Carya illinoensis (Wangenh.) K. Koch)

Approved:

Bart A. Thielges
Major Professor and Chairman

James G. Traynham
Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:

June 28, 1976