A STATISTICAL STUDY OF THE EFFECTS OF THE NUMBER OF PECANS PER POT ON THE UNIFORMITY OF THE SEEDLINGS IN SIZE

by

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ABSTRACT

Research is being conducted by Bud Antle, Inc. of California at Redrock, Arizona, on growing open-pollinated Ideal seedlings in pots in the greenhouse using gibberellic acid to increase the basal stem growth.

This experiment was conducted in two phases: (1) pre-thinning phase--from planting to thinning (47 days after planting) and (2) post-thinning phase--from thinning to 39 days after thinning.

In the pre-thinning phase we wanted to determine if the density of seed-nuts (2, 3, 4 or 5 per pot) affected seedling emergence and growth. The density of seed-nuts was shown to have no effect on percent germination, time to germination or seedling height at thinning.

At thinning, three different selection criteria were used: (1) Thin to the seedling per pot having height between 4 to 5 inches and a stem change from red to green. (2) Thin to the most vigorous seedling per pot. (3) Thin to the seedling per pot having height between 5 to 6 inches.

Results 39 days after thinning showed that Selection Criteria 2 was twice as variable as 1 or 3. There is no preference between Selection Criteria 1 or 3 if the optimal time for thinning to their selection criteria is used.

CHAPTER I

INTRODUCTION

Research is being conducted at Redrock, Arizona, by the Bud Antle Corporation on the feasibility of propagating pecan trees under greenhouse conditions. Similar research conducted on citrus propagation under greenhouse conditions led researchers to believe that pecans can be propagated very well under greenhouse conditions.

Western Schley and Ideal (Bradley) are two of several varieties being propagated under greenhouse conditions. Western Schley is the main variety being grown commercially at Bud while the Ideal variety is being propagated principally as a pollinator for the Western Schley.

According to Childers (1961, p. 454) a good commercial variety must have the following characteristics: (1) come into bearing early, (2) be a prolific and annual producer, (3) have seed-nuts of large size that crack easily with plump straw-colored kernels of good flavor and quality, (4) most of the total weight should be in the kernel of the seed-nut and (5) be resistant to diseases or at least sufficiently so that it can be sprayed economically.

Some of the characteristics of the Western Schley are: (1) 56 to 59 percent of the total weight of the

seed-nut is accumulated in the kernel; (2) it produces from 55 to 75 nuts per pound; (3) it sheds its pollen early; (4) its stigma receptivity occurs late; (5) the nuts usually ripen by midseason. Western Schley is a good commercial pecan variety except for a slight problem with self-pollination called dichogamy.

Dichogamy occurs when male and female flowers do not mature at the same time and this is why self-pollination is not very effective in some varieties. According to Chandler (1942, p. 396), most mature pecan trees normally produce large quantities of pollen which is shed from mature catkins when humidity is below 85 percent. Pecan pollen is dispersed by wind. In Western Schley pollen shed starts early, sometimes before its own pistillate flowers are receptive. Under Arizona conditions, pollen shed is over a fairly long period so that most Western Schley pistillate flowers can be self-pollinated.

According to Romberg and Smith (1946), data from experiments conducted at the USDA Pecan Field Station at Brownwood, Texas, has shown that cross-pollination is an effective means of pollination. The results further show that where cross-pollination between varieties has occurred the results show more nuts per cluster at harvest than by self-pollination and the nuts generally were larger in size and contained heavier kernels. Observations by Tate (1972)

and others have shown Ideal to be a good pollinator for Western Schley because its late pollen shedding provides pollen for late developing Western Schley pistillate flowers.

The basic reasons for propagating pecan trees under greenhouse conditions are: (1) The time to propagate trees which will be placed in the orchard is reduced compared to field nursery operations. Field nursery operations require 3 years before a tree is ready to be put into the orchard, and the nursery trees are not budded until the fall of the second year. It takes an additional year of scion top growth before the nursery trees are transplanted to the orchard. In the greenhouse, seedlings grown in pots are ready for budding in 4 to 6 months. After another 6 to 8 months of scion growth, the trees can be planted in the orchard. So the total amount of growing time in the greenhouse was 12 to 15 months or about one-half the time of the field nursery operation. (2) The cost of growing pecan seedlings in a greenhouse is about half the cost of purchasing a 3 year old tree from a nursery. (3) The greenhouse grown trees are more uniform in height and girth than 3 year old nursery trees.

The propagation of pecan seedlings in the greenhouse follows these steps: (1) the planting of the seed-nuts in pots, (2) germination, (3) thinning each pot to one seedling, (4) application of the gibberellic acid treatment, (5)

seedling growth, (6) budding, (7) scion growth and (8) transplanting to the orchard. A schematic for the greenhouse propagation of budded pecan trees is shown in Fig. 1.

The objectives of this experiment were as follows: (1) determine the amount of inherent variability of open-pollinated Ideal pecan seed-nuts planted and grown in containers under greenhouse conditions with respect to:

(a) percent germination at 47 days,

(b) time to 50%-germination,

(c) growth rates of the seedlings.

(2) Determine whether the above factors were affected by the density of seed-nuts planted per pot (2, 3, 4 or 5 seed-nuts per pot). (3) Obtain estimates of the probability that at thinning time at least one seedling per pot would be between 4 to 5 inches or between 5 to 6 inches for the various nut densities. (4) Determine the variability in the growth patterns of selected seedlings 39 days after selection for uniformity by three different selection criteria.

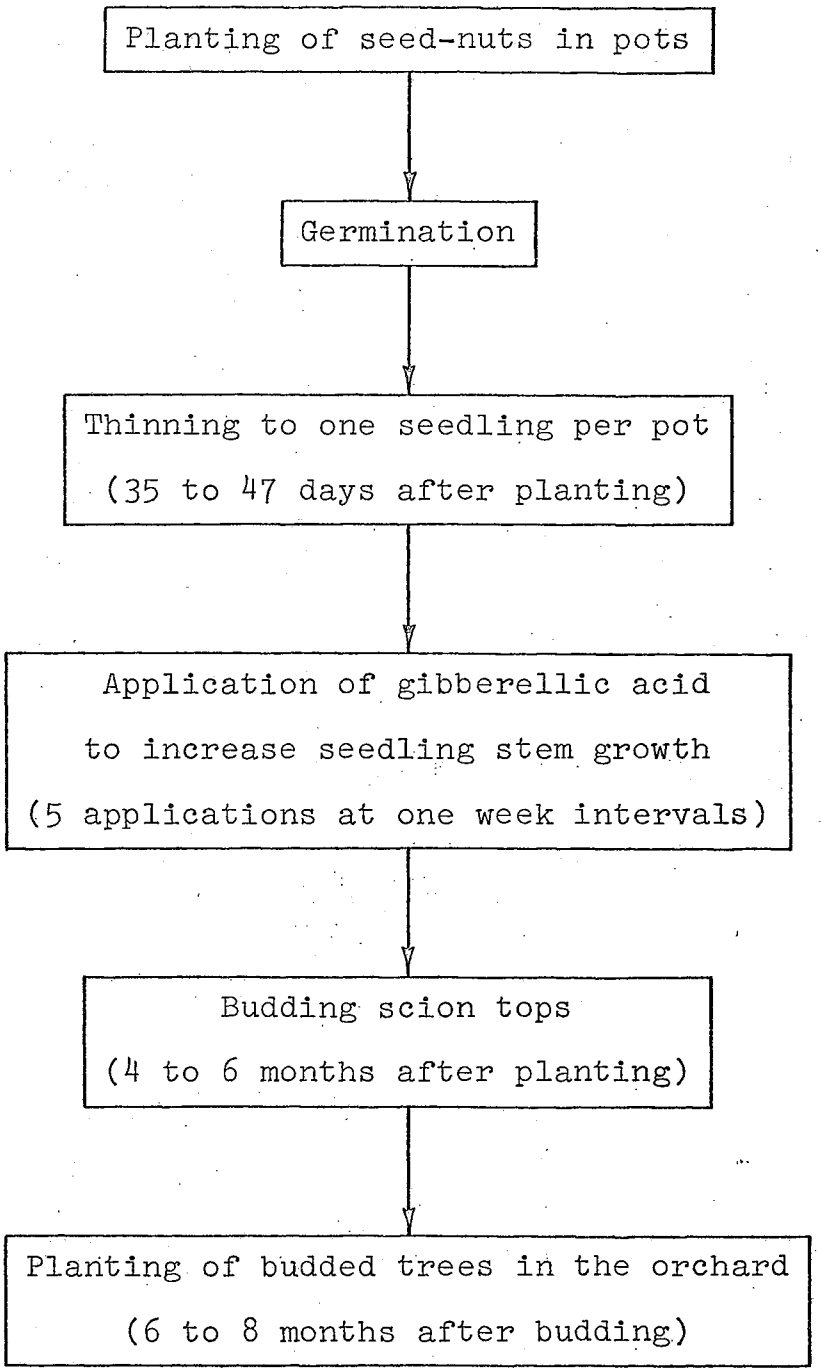

Fig. 1. Schematic of greenhouse propagation of pecan trees.

CHAPTER II

MATERIALS AND METHODS

This study was conducted at Redrock, Arizona, from January 13--time of planting of the seed-nuts--until April 15--when the last measurements were taken. All dates in the rest of this thesis will be given in terms of days from planting (January 13) or days from thinning (March 1). For example, the first measurements on height were taken 12 days after planting (January 25).

A brief description of the greenhouse will be given to acquaint the reader with the physical layout of the greenhouse and its operation. A schematic of the greenhouse is given in Fig. 2. The general dimensions of the greenhouse are 26 feet by 85 feet.

An important aspect of the greenhouse is its temperature control. The temperature ranged from 65°F to 90°F. This temperature range was maintained by a heater-cooling system. The heating system employed in the greenhouse was a relatively simple system. Warm air from the heater is forced through plastic tubing that is perforated to allow the air to escape at various places along the tubing to achieve uniform heat. The pots are placed on pallets and the tubing lies under the pallets to give a "bottom heat" effect.

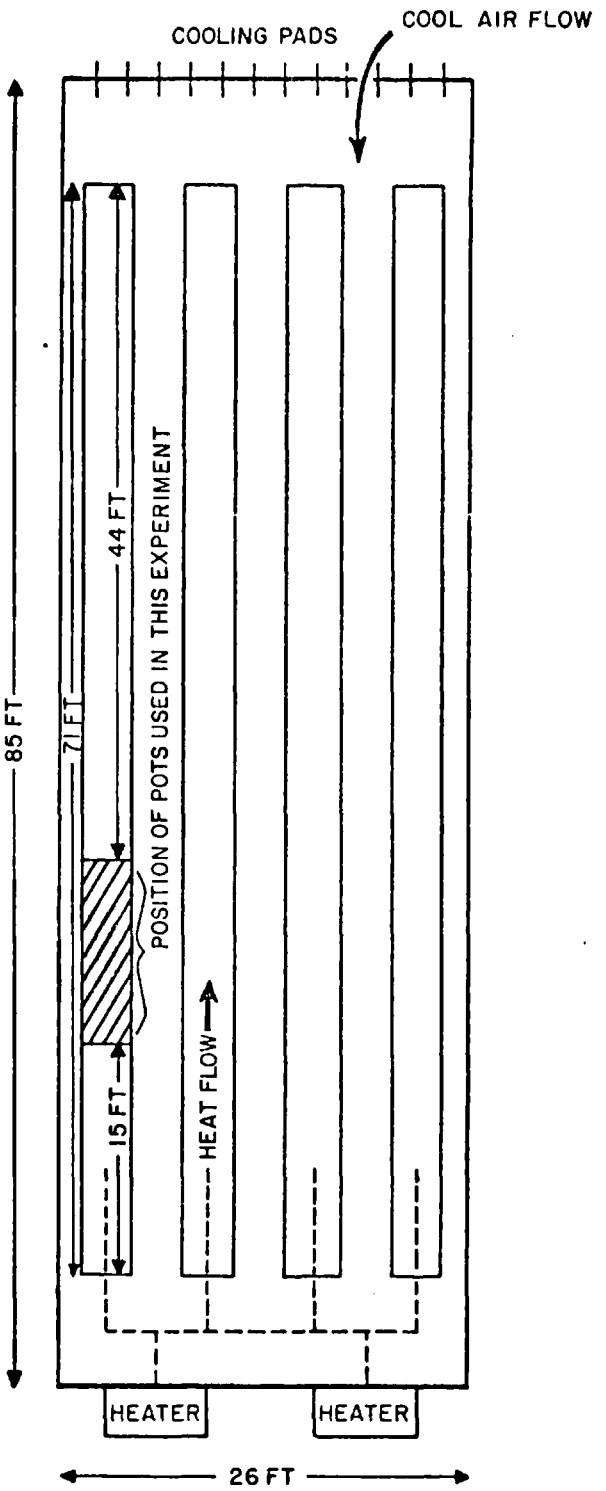

Fig. 2. Schematic of the greenhouse.

The plants in the greenhouse received sunlight from about 6 a.m. to 6 p.m. each day. The plants also received artificial light from 6 p.m. to 6 a.m. each day. This artificial light was supplied by 300-watt Sylvania light bulbs. So the plants received approximately 24 hours of light every day.

The type of pots that were used in this experiment were pistachio pots. The pots were 16 inches tall having diameters of 7 inches and 5 inches on the top and bottom, respectively. The soil that was placed in these pots was a mix: 4 parts peat moss, 4 parts sand, 2 parts soil (coarse). The fertilizer that was used in this soil was Osmocote 18-6-12. This fertilizer contained 12% soluble potash (K_2O), 6% phosphoric acid (P_2O_5) and 18% nitrogen (N). The reason for using Osmocote 18-6-12 is to produce uniform growth of the plants by providing a slow release of essential plant nutrients to the plant for up to nine months.

The seed-nuts that were used in this experiment were of the Ideal variety. These seed-nuts were obtained from Farmers Investment Corporation (FICO) at Sahuarita, Arizona, in December. They were stored outside until January 8. On January 8 they were soaked in running water until planting on January 13.

Two experimental designs were used in this experiment. A replicated 4 × 4 Latin Square design was used

in the initial phase of the experiment where we were interested in determining the number of seed-nuts to plant in each pot for efficient greenhouse operations. The number of seed-nuts per pot (2, 3, 4 and 5) were the four treatments. At thinning time it was decided to change from the Latin Square design and use a randomized block design with the three thinning procedures used as treatments. The reason for this change will be explained later.

The reason why a Latin Square design was initially used was to determine if position in the greenhouse had any effect on germination. Position in the greenhouse could possibly affect germination either because of differences in temperature throughout the greenhouse or differences in the amount of sunlight received. In all, eleven replicates of a 4 × 4 Latin Square were used. A total of 176 pots were used, 44 pots each having 2, 3, 4 or 5 seed-nuts per pot in them for a total of 616 seed-nuts planted. Each of the eleven Latin Squares was chosen randomly by the method stated in Cochran and Cox (1957). A complete diagram showing all eleven Latin Squares and how the treatments (number of seed-nuts per pot) were arranged within each square is given in Fig. 3.

A method was devised to tag each pot so upon inspection the number of the pot and the number of seed-nuts per pot could readily be observed. A color code system using different colored tape was used. The color code system was

Columns					Columns				
1	2	3	4	Rows	1	2	3	4	Rows
Number of seed-nuts/pot					Number of seed-nuts/pot				
4	3	2	5	1	5	3	4	2	25
3	4	5	2	2	4	2	5	3	26
2	5	3	4	3	2	4	3	5	27
5	2	4	3	4	3	5	2	4	28
3	5	2	4	5	3	4	5	2	29
2	4	3	5	6	4	3	2	5	30
5	3	4	2	7	5	2	4	3	31
4	2	5	3	8	2	5	3	4	32
3	4	2	5	9	5	2	3	4	33
5	3	4	2	10	3	4	5	2	34
4	2	5	3	11	4	3	2	5	35
2	5	3	4	12	2	5	4	3	36
4	5	2	3	13	4	2	3	5	37
2	3	5	4	14	2	4	5	3	38
5	4	3	2	15	3	5	2	4	39
3	2	4	5	16	5	3	4	2	40
3	5	4	2	17	2	3	4	5	41
5	2	3	4	18	4	5	2	3	42
4	3	2	5	19	5	4	3	2	43
2	4	5	3	20	3	2	5	4	44
5	3	2	4	21					
2	4	5	3	22					
4	5	3	2	23					
3	2	4	5	24					

Fig. 3. Diagram showing the 11, 4 × 4 Latin Squares and the arrangement of the seed-nuts per pot in each square.

designed to tell the observer how many seed-nuts per pot were planted in each pot. The color code used was: 2 seed-nuts per pot--blue, 3 seed-nuts per pot--red, 4 seed-nuts per pot--orange and 5 seed-nuts per pot--yellow. A magic marker was used to assign a number (1 to 176) to each pot label.

The method that was used to plant the pecan seedlings was: first all the pots having 2 seed-nuts per pot were planted, then in turn all pots with 3, 4 or 5 seed-nuts per pot were planted.

A method was devised to identify each seedling within each pot when it germinated so that growth measurements could be taken on each seedling. A colored plastic toothpick was placed next to each newly germinated seedling. Care was taken so that no two seedlings within a pot were marked with the same colored toothpick.

Heights of the seedlings were measured from the soil level to the terminal bud. The unit of measurement that was used was height to the nearest half-inch. Measurements were taken from 12 to 88 days after planting. On the 47th day the seedlings, for the most part, were of sufficient height that they could be thinned to one seedling per pot. Each pot was thinned to one seedling according to three selected criteria. The effect of crowding did not appear noticeable at this stage but would probably become apparent if no thinning was done.

The three thinning treatments that were applied were: (1) thin to a seedling having a height between 4 to 5 inches and having undergone a change in stem color from red to green, (2) thin to the most vigorous seedling in each pot and (3) thin to a seedling having a height between 5 to 6 inches. Not all pots had seedlings that satisfied the selection criteria that the pot was to receive, so the seedling nearest the selection criteria was chosen. Thinning treatments were applied before a complete analysis of the early growth distributions had been performed. However, visual inspection of other seedlings in the greenhouse appeared to show that certain rows had less growth than other rows. Plants in Rows 17 to 32 seemed to be smaller than those in Rows 1 to 16 and 33 to 44.

When it became time to thin the seedlings to one seedling per pot, the following points suggested shifting from the Latin Square design to some other statistical design for additional observations: (1) differences in seedling growth seemed to exist between areas on the bench but no discernible differences existed for the different positions within a square. (2) Since some of the pots were inadvertently damaged and we now would have to superimpose three thinning treatments on the 4×4 Latin Square, we have lost the balanced aspect of the original experimental design.

Since two different growth patterns were apparent in the experimental plants, it was decided to use a randomized block design for the three thinning treatments. Block 1 consisted of Rows 1 to 16 and Rows 33 to 44. Block 2 consisted of Rows 17 to 32. The thinning treatments (1, 2 and 3) were randomly assigned within Blocks 1 and 2. A complete list of Blocks 1 and 2 and how the three different thinning treatments were randomized within each block is shown in Fig. 4. It should be noted that throughout this thesis Thinning Treatments 1, 2 and 3 correspond to the thinning procedures stated on page 12.

In the randomized block design mentioned above, Block 1 contained 109 undamaged pots and Block 2 contained 64 pots. Block 1 had 37 pots with Thinning Treatment 1, 36 pots with Thinning Treatment 2 and 36 pots with Thinning Treatment 3. Block 2 had 21 pots with Thinning Treatment 1, 21 pots with Thinning Treatment 2 and 22 pots with Thinning Treatment 3.

Before the thinning treatments were applied, the plants were watered down fairly well. The reason for this watering was that it made it easier to pull the seedlings to be thinned out of the pots. It was necessary to make sure to get the seed-nut of the seedling out at thinning because if it remained it would start to grow again.

Fig. 4. Randomized block design showing the arrangement of the three thinning treatments in each block.

The numbers of the thinning treatments in this diagram refer to the numbering system on page 12. The x's denote pots that were inadvertantly damaged and therefore could not be used in the second phase of the experiment.

Columns				
1	2	3	4	Rows
Thinning Treatments				
2	2	1	1	1
1	3	2	2	2
x	3	3	2	3
x	2	1	1	4
2	3	1	3	5
1	1	3	2	6
2	3	3	2	7
3	3	x	1	8
2	1	2	2	9
3	3	1	1	10
3	1	2	2	11
2	1	1	3	12
1	3	1	2	13
2	1	2	2	14
1	3	1	3	15
1	1	2	3	16
1	2	2	3	17
2	3	1	1	18
2	2	3	3	19
2	1	3	1	20
1	3	2	3	21
3	1	1	1	22
3	3	2	2	23
1	1	3	3	24

Block 1

Block 2

Block 1 (Continued)

Columns				
1	2	3	4	Rows
Thinning Treatments				
2	3	2	3	25
3	2	2	1	26
1	1	3	1	27
2	1	2	1	28
3	3	1	3	29
2	2	3	1	30
2	1	3	2	31
2	1	2	3	32
2	2	3	1	33
1	3	1	3	34
3	2	2	1	35
1	3	2	3	36
1	3	2	3	37
3	3	2	1	38
2	3	1	2	39
1	3	1	2	40
2	1	3	3	41
3	2	1	2	42
2	1	3	1	43
3	3	2	1	44

Block 2 (Continued)

Fig. 4. Randomized block design showing the arrangement of the three thinning treatments in each block.

After the thinning treatments were applied, the first of the five gibberellic acid (GA_3) applications was made. Subsequent applications were made at weekly intervals. The effect of the gibberellic treatment according to Hanna and Storey (1972) is that it can save as much as a year in the time it takes to produce salable pecan budlings. The gibberellic treatment hastens basal stem enlargement but has relatively little effect on seedling height.

By combining the gibberellic treatment with the semi-controlled environment of the greenhouse, it is possible to produce a budded tree ready for planting in the orchard in about one-half the time required for the field nursery propagation method.

The gibberellic acid was applied in the form of a lanolin paste. The composition of the paste was as follows: 7.5 m.l. of 2% gibberellic acid (Merck and Company, or Abbott) per one pound of lanolin paste, mixed at low heat. It is applied to the base of the seedling stems $\frac{1}{2}$ to 1 inch above the soil level. When the first of the gib treatments was applied, a paper Dixie cup was placed around the treated part of the stem. The paper cup was placed around the seedling stem in order to keep the sunlight from the treated area. If the gibberellic treated area was not protected from the sun the sun-heated lanolin could damage the stem tissues.

When this experiment was originally planned, it was decided to take measurements every two days until thinning and once weekly after thinning. Heavy rainstorms occurred frequently during the experimental period and made the dirt road to the greenhouse sometimes impassible. Therefore measurements were made as close as possible to the above schedule.

CHAPTER III

RESULTS AND CONCLUSIONS

As discussed in Chapter II, this experiment can be divided into two phases. In the first, or pre-thinning phase, we have seedling emergence and growth before thinning. This phase of the experiment was set up as a replicated 4 × 4 Latin Square design with four densities of seed-nuts per pot as treatments. The second phase of the experiment, or post-thinning phase, was the study of seedling growth from thinning until the end of the test period. This phase of the experiment was set up as a randomized block experiment with two blocks and three thinning treatments.

In this section the results from each phase will be discussed separately. The discussion for each phase will be treated in two subsections. The first subsection is General Results and will include the main conclusions that can be drawn from this phase of the experiment. The second subsection will contain the tables of data and analysis of the data that led to the conclusions made in the general section plus additional conclusions.

Pre-Thinning Phase

General Results

In the pre-thinning seedling growth period, the density of seed-nuts per pot (2, 3, 4 or 5) did not significantly affect percent germination, time to germination or the seedling heights at thinning. For the Ideal seed-nuts used in this experiment, the percent germination was 86.5%. The time to 50%-germination was 25.38 days. At thinning the mean height was 4.95 inches with a standard deviation of 1.41 inches.

Seed-nuts in pots nearer the walkway had a higher percent germination than those nearer the center of the bench.

Specific Results

This section of the pre-thinning phase will be divided into three subsections: (a) percent germination, (b) time to germination and (c) height distribution data.

Percent Germination. The first topic to be discussed in this subsection will be the germination percentages for 2, 3, 4 and 5 seed-nuts per pot. Table 1 gives the proportion of seed-nuts that germinated for 2, 3, 4 and 5 seed-nuts per pot. While examining Table 1, the reader will note that for the two seed-nuts per pot data, two of the seedlings were not included. The reason for this was the pot that contained

Table 1. Percent germination of Ideal pecan seed-nuts using 2, 3, 4 and 5 seed-nuts per pot

Number of seed-nuts per pot	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Total	Percent germination
2	80	6	86*	93.0
3	116	16	132	87.9
4	147	29	176	83.5
5	188**	32	220	85.4
Total	531	83	614	86.5

$\chi^2 = 4.885$

*Two of the seed-nuts were inadvertantly damaged before germination.

**This includes five seed-nuts that germinated but were inadvertently damaged after germination but before any height measurements could be taken.

these two nuts was inadvertently damaged before it could be determined if either of the nuts would germinate.

To test whether the proportion of seed-nuts that germinated for 2, 3, 4 and 5 seed-nuts per pot were the same, a χ^2 test was used. The χ^2 test statistic is calculated according to the method described in Steel and Torrie (1960). The calculated value of χ^2 was found to be 5.676 which is not sginificant. Therefore there was no significant differences among the germination percentages of 2, 3, 4 and 5 seed-nuts per pot.

Using the overall percentage germination of 0.865, it is interesting to see how many empty pots we would expect for 2, 3, 4 or 5 seed-nuts per pot. If an experiment was conducted using 1,000 pots each for the seed-nut densities of 2, 3, 4 or 5 seed-nuts per pot we would expect: 18 empty pots out of 1,000 for 2 seed-nuts per pot, 2 empty pots out of 1,000 for 3 seed-nuts per pot and less than 1 empty pot for 4 and 5 seed-nuts per pot.

To see whether position on the bench within the greenhouse affected percent germination, analysis was done on the germination percentages of Latin Squares, rows and columns. Differences among position could be caused by a variety of environmental factors. The χ^2 values are given below Tables 2, 3 and 4. Results showed that the row and Latin Square χ^2 were not significant whereas the column χ^2

Table 2. Percent germination of seed-nuts within Latin Squares

Number of the Latin Square	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Percent germination
1	48	6*	88.8
2	44	12	78.6
3	44	12	78.6
4	48	8	85.7
5	49	7	87.5
6	51	5	91.2
7	51	5	91.1
8	46	10	82.1
9	54	2	96.4
10	46	10	82.1
11	50	6	89.3

$\chi^2 = 15.278$

*The number of seed-nuts that did not germinate does not include the two seed-nuts that were damaged before germination.

Table 3. Percent germination of seed-nuts within columns

Column	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Percent germination
1	136	16*	89.5
2	140	14	90.9
3	124	30	80.5
4	131	23	85.1

$\chi^2 = 8.693$

*The number of seed-nuts that did not germinate does not include the two seed-nuts that were damaged before germination.

Table 4. Percent germination of seed-nuts within rows

Row	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Percent germination
1	13	1	93
2	13	1	93
3	10	2*	83
4	12	2	86
5	12	2	86
6	13	1	93
7	10	4	71
8	9	5	64
9	11	3	79
10	12	2	86
11	13	1	93
12	8	6	57
13	12	2	86
14	12	2	86
15	11	3	79
16	13	1	93
17	13	1	93
18	12	2	86
19	13	1	93
20	11	3	79
21	12	2	86
22	13	1	93
23	12	2	86
24	14	0	100
25	13	1	93
26	12	2	86

Table 4, Continued

Row	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Percent germination
27	13	1	93
28	13	1	93
29	11	3	79
30	12	2	86
31	11	3	79
32	12	2	86
33	14	0	100
34	13	1	93
35	13	1	93
36	14	0	100
37	13	1	93
38	11	3	79
39	11	3	79
40	11	3	79
41	12	2	86
42	14	0	100
43	13	1	93
44	11	3	79

$\chi^2 = 41.91$

*The number of seed-nuts that did not germinate does not include the two seed-nuts that were damaged before germination.

was significant. The columns nearest the walkway had a higher percent germination than the columns nearer the center of the bench.

Time to Germination. Tables 5, 6, 7, 8 and 9 give the time to germination distributions for 2, 3, 4 and 5 seed-nuts per pot. The "time to germination" data was terminated at 47 days. This was the point at which thinning of the seedlings took place, i.e., seedlings reduced to one seedling per pot.

Below each of the above tables are given the mean ($\bar{x}$) number of days until germination (emergence of the hypocotyl above soil surface), the variance (s^2), the standard deviation (s) and the median. Since the data in these tables is given in the form of grouped data, the following calculation formulas were used for $\bar{x}$ and s^2:

$$\bar{x} = \frac{\sum x_i f_i}{\sum f_i}, \qquad s^2 = \frac{\sum f_i (x_i - \bar{x})^2}{\sum f_i - 1}$$

where f_i is the frequency of the ith class and x_i is the value of the variable in the ith class. The formula for the median is:

$$\text{median} = x_L + \frac{gI}{f}$$

where x_L = value of x at the lower limit of the class containing the median, g = order statistic number of the median minus cumulative frequency up to the upper limit of previous

Table 5. Time to germination distribution for seed-nuts in pots with 2 seed-nuts per pot

Days from planting	Frequency (number of seedlings emerged)	Cumulative frequency	Cumulative percent germination
12	0	0	0
14	0	0	0
16	9	9	10.46
18	9	18	20.93
20	15	33	38.37
22	4	37	43.02
24	5	42	48.84
26	7	49	56.98
28	4	53	61.63
31	5	58	67.44
35	9	67	77.91
42	10	77	89.53
47	3	80	93.02

Median = 24.43 days

$\bar{x}$ = 26.74 days

s^2 = 86.20

s = 9.28

Table 6. Time to germination distribution for seed-nuts in pots with 3 seed-nuts per pot

Days from planting	Frequency (number of seedlings emerged)	Cumulative frequency	Cumulative percent germination
12	0	0	0
14	3	3	2.3
16	13	16	12.1
18	15	31	23.5
20	16	47	35.6
22	8	55	41.7
24	6	61	46.2
26	11	72	54.5
28	11	83	62.9
31	6	89	67.4
35	14	103	78.0
42	12	115	87.1
47	1	116	87.9

Median = 25.00 days

$\bar{x}$ = 25.70 days

s^2 = 71.74

s = 8.47

Table 7. Time to germination distribution for seed-nuts in pots with 4 seed-nuts per pot

Days from planting	Frequency (number of seedlings emerged)	Cumulative frequency	Cumulative percent germination
12	0	0	0
14	6	6	3.4
16	33	39	22.2
18	15	54	30.7
20	14	68	38.6
22	6	74	42.0
24	6	80	45.4
26	11	91	51.7
28	14	105	59.6
31	10	115	65.3
35	13	128	72.7
42	12	140	79.5
47	7	147	83.5

Median = 25.55 days

$\bar{x}$ = 25.26 days

s^2 = 90.32

s = 9.5

Table 8. Time to germination distribution for seed-nuts in pots with 5 seed-nuts per pot

Days from planting	Frequency (number of seedlings emerged)	Cumulative frequency	Cumulative percent germination
12	3	3	1.4
14	4	7	3.2
16	19	26	11.8
18	26	52	23.6
20	19	71	32.3
22	16	87	39.5
24	10	97	44.1
26	11	108	49.1
28	8	116	52.7
31	18	134	60.9
35	15	149	67.7
42	26	175	79.5
47	13	188	85.4

Median = 26.63 days

$\bar{x}$ = 27.30 days

s^2 = 104.16

s = 10.21

Table 9. Time to germination distribution for all seed-nuts planting densities

Days from planting	Frequency (number of seedlings emerged)	Cumulative frequency	Cumulative percent germination
12	3	3	0.5
14	13	16	2.6
16	74	90	14.6
18	65	155	25.2
20	64	219	35.7
22	34	253	41.2
24	27	280	45.6
26	40	320	52.1
28	37	357	58.1
31	39	396	64.5
35	51	447	72.8
42	60	507	82.6
47	24	531	86.5

Median = 25.38

$\bar{x}$ = 26.30

s^2 = 90.80

s = 9.53

class, I = class interval and f = frequency in class containing the median.

Although the data indicated that the number of seed-nuts per pot did not affect percent germination we wanted to determine if the seed-nut density affected time to germination. To test whether the average time to germination was the same for 2, 3, 4 and 5 seed-nuts per pot, the standard procedure would be to use analysis of variance. However, before applying analysis of variance it is necessary to test for normality of the data. A test for normality is the χ^2 goodness of fit test which is discussed in Snedecor and Cochran (1967). Tables 10 to 14 give the χ^2 test for normality for 2, 3, 4 and 5 seed-nuts per pot and for the overall time to germination data. In each table the standard normal variate was partitioned into ten equally probable classes. The ten classes that were used were: $(-\infty,-1.28)$, $[-1.28,-0.841)$, $[-0.841,-0.524)$, $[-0.524,-0.253)$, $[-0.253,0)$, $[0,0.253)$, $[0.253,0.524)$, $[0.524,0.841)$, $[0.841,1.28)$, $[1.28,\infty)$. In Tables 10 to 14, the equi-probable intervals are given in terms of days from planting instead of the standard normal variate (z). To change from the standard normal variate to days from planting, the transformation $x = zs + \bar{x}$ was used, where z was the standard normal variate value of the upper or lower limit of the above intervals, $\bar{x}$ was the mean time to germination for 2, 3, 4 or 5 seed-nuts

Table 10. Calculation of the χ^2 goodness of fit test for normality for the time to germination data from pots having 2 seed-nuts per pot

Equi-probable intervals in terms of days	Observed frequency (O) (number of seedlings emerged)	Expected frequency (E)	$\frac{(O-E)^2}{E}$
0 - 15	0	8	8
16 - 19	18	8	12.5
20 - 21	15	8	6.12
22 - 24	9	8	0.12
25 - 27	7	8	0.12
28 - 29	4	8	2
30 - 32	5	8	1.12
33 - 35	0	8	8
36 - 39	9	8	0.12
40 - 47	13	8	3.12

$\chi^2 = 41.22$

Table 11. Calculation of the χ^2 goodness of fit test for normality for the time to germination data from pots having 3 seed-nuts per pot

Equi-probable intervals in terms of days	Observed frequency (O) (number of seedlings emerged)	Expected frequency (E)	$\frac{(O-E)^2}{E}$
0 - 15	3	11.6	6.38
16 - 19	28	11.6	23.19
20 - 21	16	11.6	1.67
22 - 24	8	11.6	1.12
25 - 26	6	11.6	2.70
27 - 28	11	11.6	0.03
29 - 30	11	11.6	0.03
31 - 33	6	11.6	2.70
34 - 37	14	11.6	0.50
38 - 47	13	11.6	0.17

$\chi^2 = 38.49$

Table 12. Calculation of the χ^2 goodness of fit test for normality for the time to germination data from pots having 4 seed-nuts per pot

Equi-probable intervals in terms of days	Observed frequency (O) (number of seedlings emerged)	Expected frequency (E)	$\frac{(O-E)^2}{E}$
0 - 13	0	14.7	14.76
14 - 17	39	14.7	40.17
18 - 20	29	14.7	13.91
21 - 23	6	14.7	5.15
24 - 26	6	14.7	5.15
27 - 28	11	14.7	0.93
29 - 30	14	14.7	0.03
31 - 33	10	14.7	1.50
34 - 37	13	14.7	0.20
38 - 47	19	14.7	1.26

$\chi^2 = 83.06$

Table 13. Calculation of the χ^2 goodness of fit test for normality for the time to germination data from pots having 5 seed-nuts per pot

Equi-probable intervals in terms of days	Observed frequency (O) (number of seedlings emerged)	Expected frequency (E)	$\frac{(O-E)^2}{E}$
0 - 14	7	18.8	7.41
15 - 19	45	18.8	36.51
20 - 22	19	18.8	0.00
23 - 25	26	18.8	2.76
26 - 27	11	18.8	3.24
28 - 30	8	18.8	6.20
31 - 33	18	18.8	0.03
34 - 36	15	18.8	0.77
37 - 40	0	18.8	18.8
41 - 47	39	18.8	21.70

$\chi^2 = 97.42$

Table 14. Calculation of the χ^2 goodness of fit test for normality for the time to germination data from pots having 2 seed-nuts per pot

Equi-probable intervals in terms of days	Observed frequency (O) (number of seedlings emerged)	Expected frequency (E)	$\frac{(O-E)}{E}$
0 - 14	16	53.1	25.92
15 - 18	139	53.1	138.96
19 - 21	64	53.1	2.24
22 - 24	61	53.1	1.18
25 - 26	40	53.1	3.23
27 - 29	37	53.1	4.88
30 - 31	39	53.1	3.74
32 - 34	0	53.1	53.1
35 - 39	51	53.1	0.08
40 - 47	84	53.1	17.98

$\chi^2 = 251.31$

per pot and for the overall data. The data (Tables 5 to 9) did not follow normal distributions. The data indicated that the period from about 15 days to 19 days had more seedlings germinate than would be expected assuming a normal distribution. Another indication of nonnormality is the fact that the frequency distributions are bimodal with one mode around 16 days and the other mode around 42 days. This bimodal effect could be caused by two sources of seed-nuts for this experiment; possibly nuts from two trees or self- and cross-pollinated nuts.

Since standard methods of statistical analysis cannot be applied, an alternate method had to be found to compare the time to germination distribution for 2, 3, 4 and 5 seed-nuts per pot. The test that was used to compare the distributions was Kiefer's test (1959). The Kiefer test statistic is:

$$\underset{x}{\text{SUP}}\ T(x) = \underset{x}{\text{SUP}} \sum_{i=1}^{K} n_i [S_{n_i}(x) - \bar{S}(x)]^2$$

where $\bar{S}(x)$ is the sample CDF (cumulative distribution function) for the combined observations. S_{n_i}'s are the sample CDF's for 2, 3, 4 or 5 seed-nuts per pot. Table 15 shows the calculation of T(x). In Table 15 $S_{n_i}(x)$, i = 1 to 4, are CDF's for 2, 3, 4 and 5 seed-nuts per pot, respectively. The last column shows the calculation of T(x) for each individual day. At the bottom of Table 15 is shown the maximum

Table 15. Calculation of the Kiefer test statistic for the time to germination distributions for 2, 3, 4 and 5 seed-nuts per pot

Days after planting	$\bar{S}(x)$	$S_{n_1}(x)$	$S_{n_2}(x)$	$S_{n_3}(x)$	$S_{n_4}(x)$	$T(x) = \sum_i n_i[S_{n_i}(x) - \bar{S}(x)]^2$
12	0.005	0	0	0	0.014	0.0152
14	0.026	0	0.023	0.034	0.032	0.0714
16	0.147	0.105	0.121	0.222	0.118	1.204
18	0.252	0.209	0.235	0.307	0.236	0.6742
20	0.357	0.384	0.356	0.386	0.323	0.3993
22	0.412	0.430	0.417	0.420	0.395	0.0925
24	0.456	0.488	0.462	0.454	0.441	0.2016
26	0.521	0.570	0.545	0.517	0.491	0.4420
28	0.581	0.616	0.629	0.596	0.527	0.9992
31	0.645	0.674	0.674	0.653	0.609	0.4179
35	0.728	0.779	0.780	0.727	0.677	1.011
42	0.826	0.895	0.871	0.795	0.795	0.9383
47	0.865	0.930	0.879	0.835	0.854	0.5146

Maximum $T(x) = 1.204$

value it takes on (1.204). According to tables derived by Kiefer (1959), the value (1.204) is found not to be significant. Therefore there are no significant differences among the time to germination distributions of 2, 3, 4 and 5 seed-nuts per pot.

To answer the question whether the density of seed-nuts affects the average time to germination, I investigated whether they had the same time to 50%-germination The times to 50%-germination (median germination time) are: 24.43 days for 2 seed-nuts per pot, 25 days for 3 seed-nuts per pot, 25.55 days for 4 seed-nuts per pot and 26.63 days for 5 seed-nuts per pot. To see if the time to 50%-germination is the same for 2, 3, 4 and 5 seed-nuts per pot, the median test (Siegel, 1956) was used. The calculated value of χ^2 (0.27), in Table 16, is not significant. Therefore no significant differences exist among the times to 50%-germination for 2, 3, 4 and 5 seed-nuts per pot. The median time to germination for all seed-nuts was 25.38 days.

Height Distribution Data. Table 17 gives the overall height distribution for 26, 28, 31, 35, 42 and 47 days after planting. The height intervals are divided into half-inch intervals since the measurements in this experiment were tabulated in terms of half-inches. Below each of the above tables are given the mean height ($\bar{x}$) for that day, the variance (s^2) and the standard deviation (s).

Table 16. Calculation of χ^2 for the median test for the time to germination distribution for 2, 3, 4 and 5 seed-nuts per pot

	Number of seed-nuts per pot				
	2	3	4	5	Total
Number of seed-nuts whose germination was less than the common median germination	42	61	80	97	280
Number of seed-nuts whose germination was greater than the common median germination	38	55	67	91	251
Total	80	116	147	188	531

$\chi^2 = 0.27$

Table 17. Overall height distribution of seedlings for 26, 28, 31, 35, 42 and 47 days after planting

Height in inches	Frequency for 26 days	Frequency for 28 days	Frequency for 31 days	Frequency for 35 days	Frequency for 42 days	Frequency for 47 days
0 - 0.5	19	26	15	12	2	5
0.5 - 1.0	26	30	30	25	10	5
1.0 - 1.5	17	15	28	26	13	7
1.5 - 2.0	15	16	22	20	17	3
2.0 - 2.5	18	17	19	25	18	13
2.5 - 3.0	31	21	19	30	25	12
3.0 - 3.5	40	37	30	30	31	22
3.5 - 4.0	36	47	46	40	51	45
4.0 - 4.5	53	57	54	52	50	52
4.5 - 5.0	34	48	58	70	78	77
5.0 - 5.5	9	14	38	54	96	89
5.5 - 6.0	10	7	18	30	56	77
6.0 - 6.5	4	7	7	12	30	64
6.5 - 7.0	2	3	5	9	14	37
7.0 - 7.5	1	6	1	4	7	9
7.5 - 8.0	0	1	1	0	2	4
8.0 - 8.5	0	0	0	2	1	4
8.5 - 9.0	0	0	0	1	1	0
9.0 - 9.5	0	0	0	0	0	0
9.5 - 10.0	0	0	0	0	0	1
$\bar{x}$	3.17	3.32	3.49	3.79	4.44	4.95
s^2	2.46	2.94	2.82	2.95	2.20	1.99
s	1.57	1.71	1.68	1.72	1.48	1.41

Table 18 gives the individual height distributions at thinning (47 days after planting) for 2, 3, 4 and 5 seed-nuts per pot. We were interested in seeing whether there were differences in the height distributions at thinning. Since the time to germination distributions were not normally distributed, the height distributions at thinning would not be expected to be normally distributed. Therefore the Kiefer test was used to test if the height distributions for 2, 3, 4 and 5 seed-nuts per pot were the same. Table 19 gives the calculation of the Kiefer test statistic. The calculated value (1.571) is not significant. Therefore we can conclude that no significant differences exist for the height distributions of 2, 3, 4 and 5 seed-nuts per pot 47 days after planting.

To test whether the average value for the height distributions of 2, 3, 4 and 5 seed-nuts were the same, the median test was used. Table 20 shows the calculated χ^2 value (5.51) is not significant so no significant differences exist among the medians of 2, 3, 4 and 5 nuts per pot for 47 days after planting. The median height at 47 days was 5.36 inches.

Post-Thinning Phase

General Results

Although there appeared to be different seedling heights of the two blocks at thinning, no difference was

Table 18. Height distributions of seedlings from pots with 2, 3, 4 and 5 seed-nuts per pot 47 days after planting

Height in inches	Frequency of 2 seed-nuts per pot	Frequency of 3 seed-nuts per pot	Frequency of 4 seed-nuts per pot	Frequency of 5 seed-nuts per pot
0 - 0.5	0	1	0	4
0.5 - 1.0	1	1	1	2
1.0 - 1.5	2	2	2	1
1.5 - 2.0	0	2	0	1
2.0 - 2.5	1	2	4	6
2.5 - 3.0	1	0	8	3
3.0 - 3.5	2	2	8	10
3.5 - 4.0	7	9	11	18
4.0 - 4.5	6	13	10	23
4.5 - 5.0	11	18	20	28
5.0 - 5.5	22	18	19	30
5.5 - 6.0	10	20	30	17
6.0 - 6.5	13	19	13	19
6.5 - 7.0	4	7	13	13
7.0 - 7.5	0	1	2	6
7.5 - 8.0	0	1	2	1
8.0 - 8.5	0	0	3	1
8.5 - 9.0	0	0	0	0
9.0 - 9.5	0	0	0	0
9.5 - 10.0	0	0	1	0
$\bar{x}$	5.00	5.03	5.07	4.80
s^2	1.51	1.82	2.21	2.24
s	1.23	1.35	1.49	1.50
Median	5.43	5.44	5.50	4.94

Table 19. Calculation of the Kiefer test statistic for the height distributions of 2, 3, 4 and 5 seed-nuts per pot 47 days after planting

Height in inches	$\bar{S}(x)$	$S_{n_1}(x)$	$S_{n_2}(x)$	$S_{n_3}(x)$	$S_{n_4}(x)$	$T(x) = \sum_i n_i[S_{n_i}(x) - \bar{S}(x)]^2$
0 - 0.5	0.010	0	0.009	0	0.022	0.142
0.5 - 1.0	0.019	0.013	0.017	0.007	0.033	1.769
1.0 - 1.5	0.032	0.038	0.035	0.020	0.038	0.051
1.5 - 2.0	0.038	0.038	0.052	0.020	0.044	0.076
2.0 - 2.5	0.063	0.050	0.069	0.048	0.076	0.081
2.5 - 3.0	0.086	0.063	0.069	0.102	0.093	0.122
3.0 - 3.5	0.127	0.088	0.086	0.156	0.147	0.448
3.5 - 4.0	0.213	0.175	0.163	0.231	0.246	0.745
4.0 - 4.5	0.312	0.250	0.276	0.299	0.371	1.120
4.5 - 5.0	0.458	0.388	0.431	0.435	0.525	1.374
5.0 - 5.5	0.627	0.663	0.586	0.564	0.688	1.571
5.5 - 6.0	0.774	0.787	0.758	0.769	0.781	0.063
6.0 - 6.5	0.895	0.950	0.922	0.857	0.885	0.544
6.5 - 7.0	0.965	1.000	0.982	0.946	0.956	0.195
7.0 - 7.5	0.982	1.000	0.991	0.959	0.989	0.122
7.5 - 8.0	0.990	1.000	1.000	0.973	0.994	0.062
8.0 - 8.5	0.998	1.000	1.000	0.993	1.000	0.006
8.5 - 9.0	0.998	1.000	1.000	0.993	1.000	0.006
9.0 - 9.5	0.998	1.000	1.000	0.993	1.000	0.006
9.5 - 10.0	1.000	1.000	1.000	1.000	1.000	0

Maximum $T(x) = 1.571$

Table 20. The median test for the height distributions of 2, 3, 4 and 5 seed-nuts per pot 47 days after planting

	Number of seed-nuts per pot			
	2	3	4	5
Number of observations of seedling height below the median	31	50	64	96
Number of observations of seedling height above the median	49	66	83	87

$\chi^2 = 5.51$

found for the median seedling height or for the height distributions. Moreover, no difference between germination percentages, time to 50%-germination or time to germination distribution was detected.

Around 80% of the pots will have at least one seedling in the height range chosen if the correct time for thinning is used. The data indicated that around 42 to 47 days was the best for thinning to 5 to 6 inches whereas around 35 days was best for thinning to 4 to 5 inches.

Thinning to most vigorous seedling is shown to be twice as variable as thinning to either height range. The height distribution data did not indicate any preference between the two thinning to height ranges or among the different seed-nut densities.

Specific Results

In this section the data will be divided into four subsections: (a) germination results, (b) selection criteria data, (c) height distribution data and (d) average growth rate.

Germination Results. For reasons stated in Chapter II, a randomized block design was used at thinning. Block 1 consisted of Rows 1 - 16 and 33 - 44 and Block 2 consisted of Rows 17 - 32. Table 21 gives the seedling height distribution for Blocks 1 and 2 on the 47th day prior to thinning.

Table 21. Seedling height distributions for Blocks 1 and 2, 47 days after planting and prior to thinning*

Height in inches	Frequency for Block 1	Frequency for Block 2
0 - 0.5	4	1
0.5 - 1.0	4	1
1.0 - 1.5	3	4
1.5 - 2.0	2	1
2.0 - 2.5	9	4
2.5 - 3.0	7	5
3.0 - 3.5	10	12
3.5 - 4.0	27	18
4.0 - 4.5	35	17
4.5 - 5.0	52	25
5.0 - 5.5	48	41
5.5 - 6.0	43	34
6.0 - 6.5	46	18
6.5 - 7.0	26	11
7.0 - 7.5	6	3
7.5 - 8.0	4	0
8.0 - 8.5	2	2
8.5 - 9.0	0	0
9.0 - 9.5	0	0
9.5 - 10.0	1	0

*The five seed-nuts that germinated but were inadvertently damaged before height measurements could be taken are not included in the frequency distribution of Block 1.

To examine whether or not actual differences did exist between seedling heights in Blocks 1 and 2, a median test was performed on the data in Table 21. Table 22 shows the calculated χ^2 value (0.17) for the median test. The calculated χ^2 value (0.17) is found not to be significant so that no significant differences existed between median seedling heights in Blocks 1 and 2. The median height for Block 1 was 5.42 inches and for Block 2 was 5.30 inches.

The results of Table 22 show that the environmental factors are found not to affect the median seedling heights of the blocks. Table 23 gives the percent germination for Blocks 1 and 2 which are 85.6 and 87.9 percent, respectively. A χ^2 test was used to determine whether these percents differed significantly. The calculated χ^2 value (0.65) showed that no significant difference existed between the germination percentages of Blocks 1 and 2.

Table 24 gives the time to germination distributions for Blocks 1 and 2. To test whether the time to germination distributions for Blocks 1 and 2 were identical, the Kolmogorov-Smirnov test was used. The Kolmogorov-Smirnov test is discussed in Bradley (1968). Table 25 shows the calculation of the test statistic which is $D = \text{Maximum } |S_{n_1}(x) - S_{n_2}(x)|$ where $S_{n_1}(x)$ and $S_{n_2}(x)$ are the CDF's (cumulative distribution functions) for Blocks 1 and 2.

Table 22. The median test for the seedling height distributions of Blocks 1 and 2, 47 days after planting and prior to thinning

	Block 1*	Block 2
Number of seedlings less than the median	153	88
Number of seedlings that are above the median	176	109

$\chi^2 = 0.17$

*The five seed-nuts that germinated but were inadvertently damaged before height measurements could be taken are not included in Block 1.

Table 23. Percent germination within blocks

Block	Number of seed-nuts that germinated	Number of seed-nuts that did not germinate	Percent germination
1	334	56	85.6
2	197	27	87.9
Total	531	83	86.5

$\chi^2 = 0.65$

Table 24. Time to germination distributions for seed-nuts within Blocks 1 and 2

Days after planting	Frequency for Block 1	Frequency for Block 2
12	2	1
14	10	3
16	40	34
18	43	22
20	39	25
22	21	13
24	16	11
26	25	15
28	25	12
31	23	16
35	33	18
42	42	18
47	15	9
$\bar{x}$	26.62	25.76
s^2	93.02	87.04
s	9.64	9.32

Table 25. The Kolmogorov-Smirnov test of the time to germination distributions for seed-nuts within Blocks 1 and 2

Days after planting	$S_{n_1}(x)$	$S_{n_2}(x)$	$\lvert S_{n_1}(x) - S_{n_2}(x) \rvert$
12	0.005	0.045	0.040
14	0.031	0.018	0.013
16	0.133	0.170	0.037
18	0.244	0.268	0.024
20	0.344	0.379	0.035
22	0.397	0.438	0.041
24	0.438	0.487	0.049
26	0.503	0.554	0.051
28	0.567	0.607	0.040
31	0.626	0.679	0.053
35	0.710	0.759	0.049
42	0.818	0.839	0.021
47	0.856	0.879	0.023

$D = 0.0530$

The last column shows the calculation of all values of $|S_{n_1}(x) - S_{n_2}(x)|$. Since the calculated value of D (0.053) is not significant, no significant differences exist between the time to germination distributions of Blocks 1 and 2.

Therefore environmental factors do not cause blocks to differ significantly in height, percent germination or time to germination.

Selection Criteria Data. Before I discuss the results of this subsection I would like to restate the three thinning procedures that were applied 47 days after planting: (1) thin to a seedling having height between 4 to 5 inches and having undergone a stem change from red to green, (2) thin to the most vigorous seedling and (3) thin to a seedling having height between 5 to 6 inches. In all subsequent tables the thinning treatments will be identified by the above numbering system.

It is of interest to the grower to obtain an idea of how efficient his selection criteria (thinning procedures) are. Tables 26 to 28 show the estimated probabilities that at least one seedling per pot fits the selection criteria of Thinning Treatments 1 and 3 if thinning took place 47, 35 or 42 days after planting. The probabilities in Table 26 were calculated in the following way: (a) separate the pots into two selection criteria, (b) separate those into various densities, (c) for each density and selection criteria class

Tables 26. Estimated probabilities that at least one seedling per pot fits the selection criteria for Thinning Treatments 1 and 3 when thinning actually took place (47 days after planting)

Original seed density (seed-nuts per pot)	Number of pots of each density to which Thinning Treatments 1 and 3 were applied		Number of pots having one seedling per pot fitting criteria at 47 days		Percent of pots fulfilling the selection criteria of Thinning Treatments 1 and 3	
	Thinning Treatment 1	Thinning Treatment 3	Thinning Treatment 1	Thinning Treatment 3	Thinning Treatment 1	Thinning Treatment 3
2	14	13	5	11	0.36	0.85
3	16	13	7	11	0.44	0.85
4	15	19	5	15	0.33	0.79
5	13	13	7	9	0.54	0.69

Table 27. Estimated probabilities that at least one seedling per pot fits the selection criteria for Thinning Treatments 1 and 3 if thinning took place 35 days after planting

	Number of seed-nuts per pot			
	2	3	4	5
Thinning Treatment 1	0.47	0.71	0.87	0.83
Thinning Treatment 3	0.33	0.46	0.62	0.85

Table 28. Estimated probabilities that at least one seedling per pot fits the selection criteria for Thinning Treatments 1 and 3 if thinning took place 42 days after planting

	Number of seed-nuts per pot			
	2	3	4	5
Thinning Treatment 1	0.43	0.64	0.50	0.58
Thinning Treatment 3	0.67	0.80	0.75	1.00

find the number that satisfy its own selection criteria and (d) for each density-selection criteria class divide the number that satisfy the selection criteria by the total number in the density-selection criteria class.

For 35 and 42 days after planting, there is a major problem in calculating estimates for the probabilities that pots have at least one seedling satisfying Selection Criteria 1. This occurs because no record was kept on stem change. Although we know the height of each seedling, we do not know whether there was a stem change. Estimates for these days were calculated assuming that stem change had occurred for all seedlings 4 to 5 inches. This assumption leads to estimates slightly on the high side. This assumption could lead to poor estimates if crowding had some affect upon whether stem change occurred.

Keeping this modification of Thinning Treatment 1 in mind, the estimated probabilities in Tables 27 and 28 for 35 and 42 days were calculated in the same way as they were calculated for 47 days when thinning actually took place. The same steps were followed (a to d) as for 47 days except that we would assume thinning took place at 35 or 42 days after planting. To get comparable probability estimates at 35 and 42 days to those at 47 days, only those pots thinned to a particular selection criteria at 47 days were considered to be thinned to that same selection criteria at 35 and 42 days.

The results in Table 26, 47 days after planting, show that for Thinning Treatment 3, approximately an 80% level is attained for 2, 3 and 4 seed-nuts per pot. Results on Thinning Treatment 1 show that all probabilities are very low tending to indicate that the optimal time to apply this thinning treatment had passed.

If crowding has no effect, we would have an increase in probability as the number of seed-nuts per pot increases. Since the estimated probabilities in Table 26 do not indicate this increase, we either have poor estimates or we have some indication of a crowding effect. The estimates in Table 27 are nearer to what one would expect. The estimated probabilities for Thinning Treatment 1 in Table 28 may again be an indication of some crowding effect.

Table 27 gives the estimated probabilities that pots satisfied the selection criteria 35 days after planting. Approximately 80% of the pots satisfy Selection Criteria 1 if 3, 4 or 5 seed-nuts per pot is chosen. The estimated probabilities for Selection Criteria 3 were lower than those 47 days after planting.

Table 28 gives the estimated probabilities that the pots satisfy the selection criteria 42 days after planting. The results for Selection Criteria 1 show that all probabilities are below the 80% level which again gives an indication that the optimal time for thinning to Selection

Criteria 1 had passed. For Selection Criteria 3 with 3 seed-nuts or more per pot we have 80% efficiency. This gives an indication that we are around the optimum time for thinning to Selection Criteria 3.

Height Distribution Data. In this subsection, all height distribution data collected after thinning will be discussed. Table 29 gives the overall height distributions at thinning and for 2, 5, 16, 23, 34 and 39 days after thinning. Below each of the above distributions is given the mean height ($\bar{x}$) per day, the variance (s^2) and the standard deviation (s). Tables 30 to 36 give the seedling height distributions for the three thinning treatments at thinning and for 2, 5, 16, 23, 34 and 39 days after thinning.

To analyze the data in this section, non-parametric techniques (median test, Kolmogorov-Smirnov test and Kiefer's test) were used.

To examine whether the height distributions at 39 days after thinning for Selection Criteria 1, 2 and 3 were identical, Kiefer's test was used. Table 37 shows the calculation of Kiefer's test statistic. The calculated value (1.894) is found to be significant. Table 37 shows that the cumulative distribution function (CDF) for Thinning Treatment 2 [$S_{n_2}(x)$] is accumulating slower than the CDF's for Thinning Treatments 1 and 3 [$S_{n_1}(x)$ and $S_{n_3}(x)$]. There are more larger plants for Thinning Treatment 2.

Table 29. Overall height distributions at thinning and for 2, 5, 16, 23, 34 and 39 days after thinning

Height in inches	Frequency at thinning	Frequency 2 days after	Frequency 5 days after	Frequency 16 days after	Frequency 23 days after	Frequency 34 days after	Frequency 39 days after
3.5 - 4.0	8	3	1	1	1	0	0
4.0 - 4.5	18	7	5	1	1	2	1
4.5 - 5.0	30	22	15	7	4	2	2
5.0 - 5.5	50	31	24	16	10	8	2
5.5 - 6.0	26	48	41	24	20	13	9
6.0 - 6.5	24	22	30	31	20	12	12
6.5 - 7.0	10	24	31	29	38	25	17
7.0 - 7.5	4	11	15	29	27	27	27
7.5 - 8.0	2	4	5	16	26	29	12
8.0 - 8.5	0	0	4	8	10	17	25
8.5 - 9.0	0	0	0	6	7	16	15
9.0 - 9.5	1	1	1	4	5	11	16
9.5 - 10.0	0	0	1	0	3	6	17
10.0 - 10.5	0	0	0	1	1	2	7
10.5 - 11.0	0	0	0	0	0	1	3
11.0 - 11.5	0	0	0	0	0	1	3
11.5 - 12.0	0	0	0	0	0	1	2
12.0 - 12.5	0	0	0	0	0	0	0
12.5 - 13.0	0	0	0	0	0	0	0
13.0 - 13.5	0	0	0	0	0	0	2
13.5 - 14.0	0	0	0	0	0	0	1
$\bar{x}$	5.39	5.80	6.09	6.67	6.95	7.48	8.13
s^2	0.80	0.81	0.94	1.23	1.31	1.80	2.70
s	0.89	0.90	0.97	1.11	1.14	1.34	1.65

Table 30. Height distributions at thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
3.5 - 4.0	2	2	4
4.0 - 4.5	11	4	3
4.5 - 5.0	10	5	15
5.0 - 5.5	20	9	21
5.5 - 6.0	9	7	10
6.0 - 6.5	4	16	4
6.5 - 7.0	1	8	1
7.0 - 7.5	1	3	0
7.5 - 8.0	0	2	0
8.0 - 8.5	0	0	0
8.5 - 9.0	0	0	0
9.0 - 9.5	0	1	0
$\bar{x}$	5.13	5.90	5.15
s^2	0.52	1.11	0.42
s	0.72	1.05	0.65

Table 31. Height distributions 2 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
3.5 - 4.0	0	1	2
4.0 - 4.5	4	1	2
4.5 - 5.0	8	6	8
5.0 - 5.5	12	5	14
5.5 - 6.0	20	12	16
6.0 - 6.5	7	9	6
6.5 - 7.0	4	12	8
7.0 - 7.5	3	6	2
7.5 - 8.0	0	4	0
8.0 - 8.5	0	0	0
8.5 - 9.0	0	0	0
9.0 - 9.5	0	1	0
$\bar{x}$	5.61	6.19	5.61
s^2	0.55	1.05	0.65
s	0.74	1.02	0.80

Table 32. Height distributions 5 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
3.5 - 4.0	0	0	1
4.0 - 4.5	1	1	3
4.5 - 5.0	6	3	6
5.0 - 5.5	13	6	5
5.5 - 6.0	14	8	19
6.0 - 6.5	12	9	9
6.5 - 7.0	8	13	10
7.0 - 7.5	3	7	5
7.5 - 8.0	1	4	0
8.0 - 8.5	0	4	0
8.5 - 9.0	0	0	0
9.0 - 9.5	0	1	0
9.5 - 10.0	0	1	0
$\bar{x}$	5.86	6.56	5.87
s^2	0.57	1.25	0.71
s	0.76	1.12	0.84

Table 33. Height distributions 16 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
3.5 - 4.0	0	0	1
4.0 - 4.5	1	0	0
4.5 - 5.0	1	1	5
5.0 - 5.5	6	5	5
5.5 - 6.0	9	8	7
6.0 - 6.5	12	5	14
6.5 - 7.0	17	5	7
7.0 - 7.5	7	10	12
7.5 - 8.0	3	8	5
8.0 - 8.5	1	5	2
8.5 - 9.0	1	5	0
9.0 - 9.5	0	4	0
9.5 - 10.0	0	0	0
10.0 - 10.5	0	1	0
$\bar{x}$	6.43	7.17	6.39
s^2	0.72	1.67	0.98
s	0.85	1.29	0.99

Table 34. Height distributions 23 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
3.5 - 4.0	0	0	1
4.0 - 4.5	1	0	0
4.5 - 5.0	1	1	2
5.0 - 5.5	3	3	4
5.5 - 6.0	8	6	6
6.0 - 6.5	8	6	6
6.5 - 7.0	17	8	13
7.0 - 7.5	6	10	11
7.5 - 8.0	6	10	10
8.0 - 8.5	3	4	3
8.5 - 9.0	5	1	1
9.0 - 9.5	0	5	0
9.5 - 10.0	0	2	1
10.0 - 10.5	0	1	0
$\bar{x}$	6.79	7.27	6.80
s^2	1.08	1.60	1.16
s	1.04	1.27	1.07

Table 35. Height distributions 34 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
4.0 - 4.5	1	0	1
4.5 - 5.0	1	0	1
5.0 - 5.5	1	2	5
5.5 - 6.0	4	6	3
6.0 - 6.5	6	3	3
6.5 - 7.0	9	6	10
7.0 - 7.5	12	5	10
7.5 - 8.0	10	7	12
8.0 - 8.5	5	8	4
8.5 - 9.0	5	8	3
9.0 - 9.5	2	5	4
9.5 - 10.0	2	2	2
10.0 - 10.5	0	2	0
10.5 - 11.0	0	1	0
11.0 - 11.5	0	1	0
11.5 - 12.0	0	1	0
$\bar{x}$	7.29	7.91	7.24
s^2	1.33	2.29	1.57
s	1.15	1.51	1.25

Table 36. Height distributions 39 days after thinning of seedlings having Thinning Treatments 1, 2 and 3

Height in inches	Frequency for Thinning Treatment 1	Frequency for Thinning Treatment 2	Frequency for Thinning Treatment 3
4.0 - 4.5	1	0	0
4.5 - 5.0	1	0	1
5.0 - 5.5	0	1	1
5.5 - 6.0	2	3	4
6.0 - 6.5	3	5	4
6.5 - 7.0	6	4	7
7.0 - 7.5	14	5	8
7.5 - 8.0	5	3	4
8.0 - 8.5	7	8	10
8.5 - 9.0	4	3	8
9.0 - 9.5	4	9	3
9.5 - 10.0	5	6	6
10.0 - 10.5	3	3	1
10.5 - 11.0	3	0	0
11.0 - 11.5	0	2	1
11.5 - 12.0	0	2	0
12.0 - 12.5	0	0	0
12.5 - 13.0	0	0	0
13.0 - 13.5	0	2	0
13.5 - 14.0	0	1	0
$\bar{x}$	7.96	8.62	7.84
s^2	2.17	3.80	1.90
s	1.47	1.95	1.38

Table 37. Calculation of the Kiefer test statistic for the Thinning Treatments 1, 2 and 3 height distributions 39 days after thinning

Height in inches	$\bar{S}(x)$	$S_{n_1}(x)$	$S_{n_2}(x)$	$S_{n_3}(x)$	$T(x) = \sum_i n_i[S_{n_i} - \bar{S}(x)]^2$
4.0 - 4.5	0.006	0.017	0	0	0.011
4.5 - 5.0	0.017	0.034	0	0.017	0.033
5.0 - 5.5	0.029	0.034	0.018	0.035	0.023
5.5 - 6.0	0.089	0.069	0.070	0.103	0.054
6.0 - 6.5	0.150	0.121	0.157	0.173	0.083
6.5 - 7.0	0.249	0.224	0.228	0.293	0.174
7.0 - 7.5	0.405	0.466	0.316	0.431	0.706
7.5 - 8.0	0.474	0.552	0.368	0.500	1.032
8.0 - 8.5	0.618	0.672	0.509	0.672	1.015
8.5 - 9.0	0.705	0.741	0.561	0.810	1.894
9.0 - 9.5	0.798	0.810	0.719	0.860	0.588
9.5 - 10.0	0.896	0.897	0.825	0.965	0.563
10.0 - 10.5	0.936	0.948	0.877	0.983	0.374
10.5 - 11.0	0.954	1.000	0.877	0.983	0.558
11.0 - 11.5	0.971	1.000	0.913	1.000	0.298
11.5 - 12.0	0.983	1.000	0.947	1.000	0.108
12.0 - 12.5	0.983	1.000	0.947	1.000	0.108
12.5 - 13.0	0.983	1.000	0.947	1.000	0.108
13.0 - 13.5	0.994	1.000	0.984	1.000	0.108
13.5 - 14.0	1.000	1.000	1.000	1.000	0

Maximum $T(x) = 1.894$

To examine if the average values of Thinning Treatments 1, 2 and 3 are the same 39 days after thinning, the median test was used. Analysis of variance cannot be used because one of its assumptions, that variances are equal, is not satisfied (Table 38). Table 39 shows the calculation of the test statistic for the median test. The calculated value (4.11) is not significant, therefore no significant differences existed among the medians for Thinning Treatments 1, 2 and 3.

Up to now, all analysis of Thinning Treatments 1 and 3 have been based on all observations (58 each) within each thinning treatment. However, results from Table 26 show that for Thinning Treatments 1 and 3 not all data satisfied the selection criteria. In fact, for Thinning Treatment 1, only 21 out of 58 observations satisfied the selection criteria whereas, for Thinning Treatment 3, 48 out of 58 satisfied the criteria. In order to make some of the above analyses more meaningful and to avoid bias in analysis, only the seedlings that fell within the selection criteria of Thinning Treatments 1 and 3 were studied.

Tables 40 and 41 show the height distributions of Thinning Treatments 1 and 3 at 39 days after thinning using only those seedlings that satisfy the selection criteria for 1 and 3 at thinning.

Table 38. Bartlett's test for the homogeneity of variance for Thinning Treatments 1, 2 and 3 for 39 days after thinning

Class	df	Σx^2	Log s^2	(n - 1) Log s^2	1/(n - 1)
Tmt 1	57	123.69	0.336	19.15	0.01754
Tmt 2	56	212.80	0.579	32.42	0.01785
Tmt 3	57	111.15	0.290	16.53	0.01754
Total	170	447.64		68.10	0.0529

$\chi^2 = 7.45$

Table 39. The median test for the height distributions 39 days after thinning for Thinning Treatments 1, 2 and 3

	Thinning Treatment 1	Thinning Treatment 2	Thinning Treatment 3
Number of observations that were less than the median	32	21	29
Number of observations that were greater than the median	26	36	29

$\chi^2 = 4.11$

Table 40. The height distribution of Thinning Treatment 1 at 39 days after thinning using only those seedlings that satisfied the selection criteria at thinning

Height in inches	Frequency	Cumulative Frequency
4.5 - 5.0	1	0.05
5.0 - 5.5	0	0.05
5.5 - 6.0	0	0.05
6.0 - 6.5	0	0.05
6.5 - 7.0	1	0.10
7.0 - 7.5	3	0.24
7.5 - 8.0	3	0.38
8.0 - 8.5	4	0.57
8.5 - 9.0	2	0.67
9.0 - 9.5	0	0.67
9.5 - 10.0	2	0.76
10.0 - 10.5	3	0.90
10.5 - 11.0	1	0.95
11.0 - 11.5	0	0.95
11.5 - 12.0	0	0.95
12.0 - 12.5	0	0.95
12.5 - 13.0	1	1.00
Median	8.38	
$\bar{x}$	8.61	
s^2	2.95	
s	1.72	

Table 41. The height distribution of Thinning Treatment 3 at 39 days after thinning using only those seedlings that satisfied the selection criteria at thinning

Height in inches	Frequency	Cumulative Frequency
6.0 - 6.5	2	0.04
6.5 - 7.0	2	0.08
7.0 - 7.5	6	0.21
7.5 - 8.0	4	0.29
8.0 - 8.5	3	0.35
8.5 - 9.0	9	0.54
9.0 - 9.5	3	0.60
9.5 - 10.0	5	0.71
10.0 - 10.5	6	0.83
10.5 - 11.0	0	0.83
11.0 - 11.5	3	0.90
11.5 - 12.0	0	0.90
12.0 - 12.5	1	0.92
12.5 - 13.0	3	0.98
13.0 - 13.5	0	0.98
13.5 - 14.0	0	0.98
14.0 - 14.5	1	1.00
Median	8.90	
$\bar{x}$	9.18	
s^2	3.37	
s	1.84	

Tables 42 and 43 show the distributions of the growth between thinning and 39 days after thinning for only those seedlings that satisfied the selection criteria.

To test whether the distributions of Thinning Treatments 1 and 3 are the same for 39 days after thinning, and for the growth between 39 days after thinning and thinning the Kolmogorov-Smirnov test was used. It is discussed in Bradley (1968). Tables 44 and 45 show the Kolmogorov-Smirnov tests for 39 days after thinning and for the differences between 39 days after thinning and thinning for Treatments 1 and 3. In Tables 44 and 45, $S_1(x)$ and $S_2(x)$ are the CDF's for Thinning Treatments 1 and 3, respectively. The test statistic for the Kolmogorov-Smirnov test is Maximum D = $|S_1(x) - S_2(x)|$. The calculated values for the Maximum D values 0.22 (Table 44) and 0.18 (Table 45) are not significant. Therefore no significant differences in the distributions exist for Thinning Treatments 1 and 3 at 39 days after thinning or for the differences in growth between thinning and 39 days after thinning.

To test whether the medians of Thinning Treatments 1 and 3 were the same at 39 days after thinning and for the differences in growth between thinning and 39 days after thinning the median test was used. Tables 46 and 47 show the results for these median tests. The results show that

Table 42. The height distribution of Thinning Treatment 1 for the growth between thinning and 39 days after thinning using only those seedlings that satisfied the selection criteria at thinning

Height in inches	Frequency	Cumulative frequency
0 - 0.5	1	0.05
0.5 - 1.0	0	0.05
1.0 - 1.5	0	0.05
1.5 - 2.0	0	0.05
2.0 - 2.5	3	0.19
2.5 - 3.0	3	0.33
3.0 - 3.5	3	0.48
3.5 - 4.0	2	0.57
4.0 - 4.5	1	0.62
4.5 - 5.0	2	0.71
5.0 - 5.5	1	0.76
5.5 - 6.0	1	0.81
6.0 - 6.5	3	0.95
6.5 - 7.0	0	0.95
7.0 - 7.5	1	1.00
Median	3.75	
$\bar{x}$	3.96	
s^2	3.06	
s	1.75	

Table 43. The height distribution of Thinning Treatment 3 for the growth between thinning and 39 days after thinning using only those seedlings that satisfied the selection criteria at thinning

Height in inches	Frequency	Cumulative frequency
1.0 - 1.5	5	0.10
1.5 - 2.0	6	0.23
2.0 - 2.5	5	0.33
2.5 - 3.0	3	0.40
3.0 - 3.5	5	0.50
3.5 - 4.0	7	0.65
4.0 - 4.5	2	0.69
4.5 - 5.0	5	0.79
5.0 - 5.5	2	0.83
5.5 - 6.0	2	0.88
6.0 - 6.5	1	0.90
6.5 - 7.0	1	0.92
7.0 - 7.5	2	0.96
7.5 - 8.0	2	1.00
Median	3.50	
$\bar{x}$	3.67	
s^2	3.41	
s	1.85	

Table 44. The Kolmogorov-Smirnov test for Thinning Treatments 1 and 3 for the data in Tables 40 and 41

Height in inches	$S_1(x)$	$S_2(x)$	$D = \|S_1(x) - S_2(x)\|$
4.5 - 5.0	0.05	0	0.05
5.0 - 5.5	0.05	0	0.05
5.5 - 6.0	0.05	0	0.05
6.0 - 6.5	0.05	0.04	0
6.5 - 7.0	0.10	0.08	0.02
7.0 - 7.5	0.24	0.21	0.03
7.5 - 8.0	0.38	0.29	0.07
8.0 - 8.5	0.57	0.35	0.22
8.5 - 9.0	0.67	0.54	0.13
9.0 - 9.5	0.67	0.60	0.07
9.5 - 10.0	0.76	0.71	0.05
10.0 - 10.5	0.90	0.83	0.07
10.5 - 11.0	0.95	0.83	0.12
11.0 - 11.5	0.95	0.90	0.05
11.5 - 12.0	0.95	0.90	0.05
12.0 - 12.5	0.95	0.92	0.03
12.5 - 13.0	1.00	0.98	0.02
13.0 - 13.5	1.00	0.98	0.02
13.5 - 14.0	1.00	0.98	0.02
14.0 - 14.5	1.00	1.00	0

Maximum D = 0.22

Table 45. The Kolmogorov-Smirnov test for Thinning Treatments 1 and 3 for the data in Tables 42 and 43

Height in inches	$S_1(x)$	$S_2(x)$	$D = \|S_1(x) - S_2(x)\|$
0 - 0.5	0.05	0	0.05
0.5 - 1.0	0.05	0	0.05
1.0 - 1.5	0.05	0.10	0.05
1.5 - 2.0	0.05	0.23	0.18
2.0 - 2.5	0.19	0.33	0.14
2.5 - 3.0	0.33	0.40	0.07
3.0 - 3.5	0.48	0.50	0.02
3.5 - 4.0	0.57	0.65	0.08
4.0 - 4.5	0.62	0.69	0.07
4.5 - 5.0	0.71	0.79	0.08
5.0 - 5.5	0.76	0.83	0.07
5.5 - 6.0	0.81	0.88	0.07
6.0 - 6.5	0.95	0.90	0.05
6.5 - 7.0	0.95	0.92	0.03
7.0 - 7.5	1.00	0.96	0.04
7.5 - 8.0	1.00	1.00	0

Maximum D = 0.18

Table 46. The median test for Thinning Treatments 1 and 3 for the data in Tables 40 and 41

	Thinning Treatment 1	Thinning Treatment 3
Number of observations that are below the median	12	17
Number of observations that are above the median	9	31

$\chi^2 = 2.83$

Table 47. The median test for Thinning Treatments 1 and 3 for the data in Tables 42 and 43

	Thinning Treatment 1	Thinning Treatment 3
Number of observations that are below the median	10	24
Number of observations that are above the median	11	24

$\chi^2 = 0.03$

the calculated χ^2 value (2.83) at 39 days after thinning is not significant and the χ^2 value (0.03) for the difference between 39 days after thinning and thinning is not significant.

These tests indicate that the seedlings under both selection criteria had similar growth after thinning. Those seedlings under Thinning Treatment 3 had on the average larger height at the end of the test than did those of Thinning Treatment 1, but this is what would be expected since the seedlings under Thinning Treatment 3 were larger than those of Thinning Treatment 1 at thinning. Although the heights of seedlings under Selection Criteria 3 were more variable than those under Selection Criteria 1, i.e., variances of 3.37 and 2.95, respectively, no importance should be given to this difference since variance tended to increase with average height as indicated in Table 29.

Average Growth Rate. To give the grower an idea of the rate of seedling growth over time, the average growth rate was examined. If pecans were uniformly germinating over the period of experimentation and their growth rates were fairly uniform over time, then the mean heights could be used to give an indication of growth rate. Unfortunately, the above assumptions are not true. Since germination was not uniform, this implied that during the same time period

some seedlings were just germinating while others have been growing for a while. So any method that is used for determining an average growth rate must take this "time lag" into account. Since some of the seedlings were discarded because of thinning it was not felt justifiable to use those seedlings thinned out to determine growth rates. It was decided to use only the 173 pecan seedlings that were left after thinning. The method that was used to determine the average growth was the following: to look at each of 173 seedlings in one week intervals from the time of germination until the end of the experiment. By looking at each seedling on a week by week basis it was possible to determine the average growth rate per day for a specified week of seedling growth. By getting the average growth per day for a specified week of seedling growth, it was possible to compare the individual distributions even though the seedlings did not germinate at the same time by comparing the growth rates for different weeks of growth. Table 48 shows the average growth rate for the individual distributions by comparing the average growth rates. We would expect that the higher densities of seed-nuts per pot would have a lower growth rate than the lower densities if there was an effect from crowding. However, upon examination of Table 48 we see that the above statement is incorrect. In fact, no discernible pattern can be seen from the average growth rate.

Table 48. Average growth rate per day per week of seedling growth for seedlings in pots thinned from 2, 3, 4 and 5 seed-nuts per pot

Measurements are given in inches per day

Nuts per pot	Week											
	1	2	3	4	5	6	7	8	9	10	11	12
2	0.762	0.554	0.207	0.107	0.179	0.176	0.184	0.170	0.187	0.226	0.280	0.118
3	0.854	0.532	0.237	0.189	0.183	0.231	0.196	0.171	0.139	0.129	0.169	0.339
4	0.745	0.537	0.244	0.123	0.184	0.193	0.175	0.141	0.202	0.169	0.337	0.335
5	0.749	0.572	0.194	0.166	0.157	0.224	0.174	0.131	0.214	0.210	0.339	0.296
Overall	0.778	0.558	0.218	0.135	0.176	0.203	0.181	0.152	0.187	0.195	0.246	0.287

CHAPTER IV

SUMMARY

The density of seed-nuts per pot (2, 3, 4 or 5) did not affect the percent germination, time to germination and the seedling height at thinning.

The overall percent germination was 86.5%, the time to 50%-germination was 25.38 days. The median height at thinning was 5.28 inches.

Around 80% of the pots will have at least one seedling in the height range chosen if the correct time for thinning is chosen. The data indicated that 42 to 47 days was the best for thinning to 5 to 6 inches (Thinning Treatment 3) whereas around 35 days was best for thinning to 4 to 5 inches (Thinning Treatment 1).

Results showed that the seedlings under both selection criteria had similar growth after thinning. Seedlings under Thinning Treatment 3 had on the average larger heights 39 days after thinning than did those of Thinning Treatment 1. But this is what would be expected since the seedlings under Thinning Treatment 3 were larger than those of Thinning Treatment 1 at thinning.

Although the height of seedlings under Selection Criteria 3 were more variable than those under Selection Criteria 1, i.e., variances of 3.37 and 2.95, respectively, no importance should be given to this difference since the variance tended to increase with average height.

Thinning to the most vigorous seedling (Thinning Treatment 2) is twice as variable as Thinning Treatments 1 or 3. The height distribution data did not indicate any preference between Thinning Treatments 1 or 3 or among the different seed-nut densities.

Based upon the results of this experiment, I would make the following suggestions to the grower: (1) he should plant 3 seed-nuts per pot. Planting 3 seed-nuts per pot, he would expect 2 empty pots out of 1000 because of failure of seed-nuts to germinate whereas planting 2 seed-nuts per pot he would expect 18 empty pots out of 1000. This experiment has not shown any economic advantage for planting four or five seed-nuts per pot instead of three seed-nuts per pot. In order to determine the optimal density of seed-nuts per pot to plant, a cost analysis study should be conducted on all operations involving the density of seed-nuts per pot. (2) Using either Selection Criteria 1 or 3, the grower would achieve the same level of efficiency in his results. However, using Selection Criteria 1, he would be able to thin one to one-and-a-half weeks earlier than Selection Criteria

3. (3) Results on the germination percentages of columns suggested that the temperature throughout the greenhouse may not be uniform. To investigate this possibility, he should place thermometers in pots throughout the greenhouse. (4) To determine more accurately the optimal time for thinning to either Selection Criteria 1 or 3, the time period from 30 to 50 days after planting should be studied in more detail. I would suggest that measurements be taken at least once every two days within this time period of 30 to 50 days after planting.

REFERENCES CITED

Bradley, J. V. Distribution-Free Statistical Tests. Englewood Cliffs: Prentice-Hall, Inc., 1968.

Chandler, H. W. Deciduous Orchards. Philadelphia: Lea and Febiger, 1942.

Childers, N. F. Modern Fruit Science. New Brunswick: Horticultural Publications, 1961.

Cochran, W. G. and G. M. Cox. Experimental Designs. New York: John Wiley and Sons, Inc., 1957.

Hanna, J. D. and J. B. Storey. "GA_3 Applications Hasten Pecan Basal Stem Enlargement," The Pecan Quarterly, Vol. 6: 25. 1972.

Kiefer, J. "K-Sample Analogues of the Kolmogorov-Smirnov and Cramér-V. Mises Test," Annuals of Mathematical Statistics, Vol. 30: 420-447. 1959.

Romberg, L. D. and C. L. Smith. "Effects of Cross-Pollination, Self-Pollination, and Sib-Pollination on the Dropping, the Volume and the Kernel Development of Pecan Nuts on the Vigor of the Seedlings," Proceedings of the American Society of Horticultural Science, Vol. 47: 130-138. 1946.

Siegel, S. Non-Parametric Statistics for the Behavioral Sciences. New York: McGraw-Hill Book Company, Inc., 1956.

Snedecor, G. W. and W. G. Cochran. Statistical Methods. Ames: Iowa State University Press, 1967.

Steel, R. G. and J. H. Torrie. Principles and Procedures of Statistics. New York: McGraw-Hill Book Company, Inc., 1960.

Tate, H. F. "Pecans in Arizona," Cooperative Extension Service and the Agricultural Experiment Station of The University of Arizona, Bulletin A-63. 1972.