APPLE TREE ADAPTATION TO MECHANICAL HARVESTING

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

BERNARD BOND BIBLE

1969

This is to certify that the

thesis entitled

APPLE TREE ADAPTATION TO
MECHANICAL HARVESTING

presented by

Bernard Bond Bible

has been accepted towards fulfillment
of the requirements for

PhD degree in Horticulture

S. K. Ries
Major professor

Date March 3, 1968

O-169

NOT 315

DEC 0 7 2000

ABSTRACT

APPLE TREE ADAPTATION TO MECHANICAL HARVESTING

By

Bernard B. Bible

A "Lilliputian" apple production system consisting of high population densities of small trees was evaluated for two years. Trees planted in May of 1967 were used to determine the adaptability of this system to mechanized harvest. An economic study was conducted using 2,430 combinations of critical inputs.

The vegetative growth of 'East Malling IX' transplants per unit area of land was maximal at the highest plant population of 43,560 trees per acre in both 1967 and 1968. Although the trees did not flower in 1968, the effect of competition on yield was inferred from the growth data. The highest fruit yield per acre would have occurred at some population higher than 43,560 trees per acre.

The maximum plant population (10,890 trees per acre) of both 'Golden Delicious'/EM IX and 'Tydemans Red'/EM IX produced the highest yields of 720 and 119 bushels per acre respectively. Even these high populations did not produce the maximum yield per unit area of land during 1967 or 1968. 'Golden Delicious' yielded better than 'Tydemans

Red' at all tree populations tested. Both peach cultivars, 'Suncling' and 'Redhaven,' exhibited no effects of competition at tree populations up to 2,722 plants per acre based on growth and flowering observations.

'East Malling IX' trees grown on mulches had more terminal growth per plant at lower plant populations, but at the higher densities there was no response to mulching.

The economic feasibility study indicated that a "Lilliputian" system may be most dependent on: a plant population of 10,000 trees per acre, a tree cost of $.25 each, and a minimum of four harvests over a seven year period. Factors of less economic significance were harvester cost, harvester capacity, and size of planting.

The results reported here are not conclusive for all the factors concerning the practicality of a "Lilliputian" production system. It is hoped they will serve as guidelines for the development of a more efficient system for both apple production and mechanical harvesting.

APPLE TREE ADAPTATION TO MECHANICAL HARVESTING

By

Bernard Bond Bible

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

1969

ACKNOWLEDGMENTS

The author wishes to thank Dr. S. K. Ries for his assistance throughout the thesis studies, and Dr. R. F. Carlson, Dr. R. L. Carolus, Dr. A. L. Kenworthy, Dr. H. D. Foth, and Dr. C. M. Harrison who have each contributed to the worth of his graduate studies.

Appreciation is expressed to my wife and parents for their help during the course of this study.

This research was supported by a grant from the MSU-NSF "Break Through Research Program."

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Apple production for the fresh market in the United States consists of hand harvesting 27 to 800 large trees per acre. The apple industry has attempted to partially mechanize the harvest by the use of mobile picking platforms. Power operated tree shakers and vibrators have been used experimentally to harvest standard apple trees, however serious bruising of fruit usually occurred. There also has been considerable effort to alter cultural practices for mechanized harvest.

The objectives of this study were to determine the feasibility of drastically altering both the cultural and mechanical approach to apple production. A "Lilliputian" system of apple culture was considered utilizing populations as high as 43,000 trees per acre. Cultural practices tried were mulching, sprinkler irrigation, and treatments to stimulate flowering. An economic analysis was made using the different production and mechanical harvesting inputs of tree density, tree cost, harvester cost, harvester capacity, size of planting, growing expense, and number of harvests.

LITERATURE REVIEW

Trends Toward Mechanization of Tree Fruit Harvesting

Within the last twenty years horticultural production methods have progressed towards complete mechanization. This movement has been induced by higher returns for growers and forced by a growing scarcity of competent manpower.

Harvesting has been the most difficult practice for horticulturists to mechanize. The extent of harvest mechanization will depend on the relative costs of hand and machine harvest, and the creative ability of men to develop new cultivars, cultural techniques, and machines.

The fragile characteristics of the apple fruit have been the major obstacle to successful mechanical harvesting for the fresh market. Many attempts have been made to harvest apples mechanically or with picking aids. Most of these fall into two categories: the shake and catch method (80, 2, 42, 4, 40) and the mobile picking platforms (8, 12, 59, 9, 3, 41, 5).

The shake and catch system utilizes a tractor-mounted hydraulically operated, boom-type shaker to shake the fruit from the tree onto a canvas-covered collector under the tree which conveys the apples into bulk boxes (62). There are variations of this technique (80). The shake and catch method has proven feasible for apples which are processed (42), but has not been satisfactory for the fresh market crop (40). The percentage of bruised fruit from shaker harvested trees has been high, in some cases exceeding the acceptable limits for fresh market apples (40). Shakers have worked very well for harvesting of cherries and their use has become an accepted practice (28). Other systems to completely mechanize apple harvesting have been tested (80). These machines shake the fruit from the tree into decelerating devices which slow the fall of the apple.

Other innovations have been mechanical picking aids used by some growers (9, 3). They generally consist of some sort of mobile platform that moves between rows of trees with pickers harvesting from the platform, thus eliminating need for ladders and movement on foot. One obvious advantage of picking platforms is their easy convertibility to pruning platforms thus saving labor expense in that costly operation (41). Berlage et al. (12) suggested adapting orchards to picking platforms such that continuous tree walls 5 to 6 ft thick with drive rows 8 to 10 ft wide would be harvested by pickers riding on an automatic steering platform. Rollins (59) and others (41) questioned the economic feasibility of using picking platforms. The history of mechanical harvesting has recorded a trend to complete mechanization of processes and not the development of machines as accessories for human hands.

Physiology of Dwarf Apple Trees

The development of dwarf apple cultivars which come into bearing quickly may preclude the development of a straddle row mechanical harvesting technique for apples. The apple (*Malus sylvestris*) is a deciduous, woody perennial propagated asexually. Among apple tree populations there exists a certain percentage of dwarf variants, as is the case with most classes of plants (73). According to Pelton (55) the differences in size and other manifestations of dwarfism in plants are quantitative and not qualitative. Plant hormones probably play an important role in this phenomenon since they are reportedly essential to the control and timing of growth rates in many plants (76). Auxins, gibberellins, and cytokinins have been intensively studied in relation to growth. Van Overbeek (76) reported that the reduced growth rate of some single gene dwarf plants was due to their higher rates of auxin destruction. Phinney (56) found reduced concentration of endogenous gibberellin to be a factor in dwarfism. Cytokinins have proven effective as both promoters and inhibitors of cell enlargement (29, 48). Jones (36) found cytokinin-like activity in apple stem xylem sap. He (36) later applied a synthetic cytokinin (benzyl adenine) to excised apple shoots which resulted in a marked stimulation of shoot growth.

Another possibility is the presence of growth inhibitors in dwarf apple trees. Luckwill (47) detected two growth inhibitors in leaves of malus species that could inhibit shoot extension. Miller (50), using leaf extract from 'East Malling' II, VII, and IX, found that the extract inhibited growth in the same ratio as the known vigor of the rootstocks. Thus its conceivable that dwarf apple trees have higher rates of auxin destruction, lower endogenous levels of gibberellins, less production or transport of cytokinins, more growth inhibitors quantatively or qualitatively, or any and all combinations of the above.

Girdling and placing plants in a horizontal position are two methods used to bring apple trees into bearing quickly (72). Probably the most reliable way to do this has been to graft the desired scion on EM IX rootstock, consequently shortening the time to bearing (37, 71). The mechanism of action of this subtle interaction of stocks, scions, and environment has eluded researchers up to now. Dennis (24) tried chemical regulators on apple seedlings, but failed to advance the time of bearing. An attempt to induce flowering of apple seedlings in the juvenile stage by grafting onto bearing trees also failed (23). Radiation treatment in one case induced flowering of some one year seedling trees, but only one fruit set and it was seedless (70).

Referring to the development of compact beans and tomato cultivars adapted to mechanical harvesting, Tukey (73) pointed out that similar developments were theoretically possible with apples. The many generations needed and length of time involved are the critical problems that must be resolved.

Plant Population Competition

Plant growth and development is markedly affected by interplant competition. Donald (25) stated that "competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing that is below the combined demand of the organisms." He listed water, nutrients, light, oxygen, carbon dioxide, and sometimes the agents of pollination as factors over which competition between plants may occur.

Holliday (33) classified the graphical presentations of crop yield relative to number of plants/unit area into two types of curves. One, approximately parabolic in shape, typified situations where yield was some product of reproductive growth. With this type of curve a certain plant population gave a maximum yield, while higher or lower populations resulted in lower yields. The other curve was asymptotic and characterized the case where yield was a product of vegetative growth. Thus, a certain population would produce the maximum yield; however, the yield did not decrease at populations beyond this maximum. Wiggins (81) and Bleasdale (14) discovered some exceptions to this generalization.

Bleasdale (14) showed that for onions at any given plant density the yield was lower from those plants grown at rectangularities (ratio of the between-row distance to within-row distance) greater than 5:1. He concluded that equidistant spacing, or nearly so, increased plant yield. Other workers (21, 30) have reported similar results with other crops.

The experimental materials used to elucidate these principles of competition have been mainly herbaceous crops. However, there have been plant density studies dealing with woody plants. 'Golden Delicious' and 'Jonathan' cultivars grafted on EM IX gave maximum yields at the highest population density (1348 trees/acre) tested (45, 54). These high density plantings were economically feasible in Germany (77). Močalova (51) found that apple tree populations of 270 trees/acre outyielded plantings of 162 trees/acre. He also observed less damage of frost susceptible varieties at the closer spacing. Shoulders (63) worked with Loblolly and Slash pine seedlings at densities of 10, 20, 30 and 40 plants/ft^2. He found root collar diameters decreased with increased population density, but heights of seedlings were unaffected. Standard sized 'Cox' apple trees yielded more fruit at medium and high plant densities as compared to the lowest densities (57). However, this work was done with mixed populations of standard, semi-dwarf, and dwarf trees; thus, the degree of competition was hard to assess. Serafimova (61) evaluated fig trees at spacing of 6x4, 6x6 and 6x8 M. He reported that the closest spacing reduced the growing period and tree size, but yield/tree and per unit area was greater at closer spacing, and fruit ripened earlier.

Response to Mulching

The reported effects of mulching have been varied depending on the type of mulch and the conditions under which it is used. Tukey and Schaff (74), working with decomposable mulches such as straw, observed lower soil temperature, increased soil moisture and increased water infiltration rates into the soil due to the mulch treatments. The most striking effects of mulch were on the physical properties of the soil. Black polyethylene plastic mulch in most cases raised soil temperatures (31, 22, 69). Harris (31) reported that black plastic mulch increased soil moisture content; however Schales and Sheldrake (60) reported the opposite response. Clear and black plastic mulch treatments have resulted in earlier harvests for some crops (34, 49).

Several papers that dealt with mulching of apple trees explored its value as a substitute for nitrogen fertilizer (1, 35, 15, 43) and only incidentally mentioned the possibility of better soil moisture conditions under mulch. Lavee (44) found that EM II apple rootstock responded with more vigorous growth to a mulching treatment of wood shavings. Buller and Gibbs (17) noted more vigorous growth and less fatalities of pine trees grown on mulched soil. Other researchers (82, 10) observed that mulched apple trees had a very shallow lateral root development. The spacial distribution of roots was altered, but the number of roots/plant was not affected (10). Citrus responded differentially to black plastic mulching, depending on the rootstock and location (18).

Determining the Economic Feasibility of Proposed Mechanical Harvesting Systems

Development of mechanical harvesting systems for cherries, prunes, and blueberries has stimulated work toward developing a mechanical harvester for apples. LaBelle (39) stated that there is potentially less economic advantage in harvesting the larger fruits (e.g., apples), where hand labor is more efficient. Rollins (59) pointed out that apple harvesting costs represented less than 25 per cent of the value of the crop, whereas cherry harvesting cost represented 75 per cent of the value of the crop. However, Fridley and Adrian (26) indicated that while a high percentage of the grower's return was for hand harvest of cherries, only a low percentage for lettuce harvest, this has not diminished the interest in a mechanical lettuce harvester. LaBelle (39) speculated that even small economic advantages will eventually be exploited in this highly competitive field.

A mechanical harvesting system must be economically sound in order to be useful. Fridley and Adrian (26) stated that the economic soundness of a mechanical harvesting system depended on three factors: amount of fruit lost in excess of hand harvesting losses, degree of mechanization achieved (equipment use per season), and the rate of harvest. Thus, before the actual development of a mechanical harvester and its components can be accomplished, the economic feasibility of the harvest system should be analysed. Stout et al. (66) undertook a study of the feasibility of a once over mechanical harvester for pickling cucumbers. They determined that once-over harvest was generally not feasible, and concluded that the success of a once-over harvest for cucumbers depended on the development of a good quality small vined cucumber.

Stout (67), using a computer technique to analyze over 800 combinations of variables, determined the economic feasibility of asparagus mechanical harvesting systems. Fridley and Adrian (26) constructed nomograms to evaluate and compare the feasibility of mechanizing crop harvest for several fruits and vegetables.

Stout (68) extended his computer routine to include a further study of asparagus harvesting systems and mechanical harvesting systems of cucumbers and tomatoes.

He concluded that mathematical models of harvesting economics can provide useful guide lines for predicting economic feasibility.

FIELD EXPERIMENTATION

Materials and Methods

General Procedures

Experiments were conducted at East Lansing, Michigan on a Miami loam soil. The previous year the land had been planted to rye. The soil was disked and prepared for planting by May 4, 1967. Soil analysis (conducted by the Michigan State Soil Testing Laboratory) for the plots indicated that pH ranged from 5.0 to 5.5 and the levels of P, K, Ca, and Mg were adequate for fruit trees.

Three thousand rooted (mound layered) EM IX trees were hand planted May 5 to May 16, 1967 for various experiments. The transplants, approximately 18 inches long and 3/8 inch diameter, were planted 6 inches deep and pruned to 8 inches above ground level. Three hundred, 1/2 inch diameter 'Golden Delicious'/EM IX and 100 'Tydemans Red'/ EM IX of the same size were hand planted on May 5, 1967.

A tractor mounted boom-type sprayer was used on May 22 to apply the herbicide simazine at 2 lb/acre to all plantings of EM IX. The plantings of the larger 'Golden Delicious'/EM IX and 'Tydemans Red'/EM IX trees were sprayed at the same rate of simazine with 2 1/2 gallon knapsack sprayer. Standard pesticides were sprayed on all apple trees throughout the experiment to control insects and diseases. Apple trees were treated with Arasan 42-S deer and rodent repellent on July 12 and December 4, 1967 and July 8, 1968.

Ammonium nitrate was applied twice (July 11, 1967 and May 24, 1968) to all apple trees at a rate of 1/8 lb/tree.

Overhead sprinkler irrigation adjusted to apply approximately 1 inch/hr was used to provide moisture to all plots when rainfall was inadequate.

Analysis of variance was used on all designs except the systematic spacing designs. Mean differences were compared by Duncan's multiple range test where applicable.

Plant Population Studies

A systematic spacing design was used to study apple tree response to population density. These types of designs, in which plant density changes gradually over the block, are non-random. The advantages of this systematic approach were uniform block size and only a small proportion of the plants were needed for guard rows. Nelder (53) indicated that when the major source of error variance was plant variation rather than soil variation systematic designs were valid. The design is best described by mutually perpendicular horizontal and vertical axes which divide a plot into 4 quadrants or replications. Starting from the point of axes intersection, points were designated at one ft intervals over a range of 1 to 5 ft in both directions on both axes. If straight lines are drawn through all points on the axes a grid was formed, and at each point of intersection on the grid a tree was located. Guard rows were placed only on the outside edge of the planting. Four blocks of EM IX trees consisting of four replications each were measured October 1967 for terminal growth/plant and checked for number of branches/plant. During October of 1968, trees in eight replications of this experiment were measured for terminal growth/plant and stem diameter at 1 inch from ground level.

The 'Golden Delicious'/EM IX and 'Tydemans Red'/EM IX trees were set out in the systematic design described above. The only difference was that the foot increments increased over a range from 2 to 5 ft. Three blocks (12 replications) were planted to 'Golden Delicious'/EM IX and one block (four replications) was planted to 'Tydemans Red'/EM IX trees. During October of 1967, these trees were measured and counted. The total number of flowers and flower clusters/tree were counted on May 11, 1968. In late October 1968, the fruit from each tree was harvested, counted, weighted and graded into the following categories on the basis of size and defects: (1) 3 inch diameter or larger, (2) 2 1/2 to 3 inch, (3) 2 to 2 1/4 inch, (4) 1 1/2 to 2 inch and (5) less than 1 1/2 inch. Any fruit with a skin defect area of 1/2 inch or more in diameter was placed in category (5). After the fruit were harvested the total terminal growth/tree and the stem diameter 2 inches above the graft union were measured.

Four hundred peach trees (3/4-inch stem diameter) half of them 'Redhaven'/Seedling and the other half 'Suncling'/Seedling were planted in a systematic spacing design on May 16, 1967. The same design was used as before except the range of points on the axes was 4 to 7 ft and there were eight replications of each cultivar. On July 11, 1967 and June 21, 1968 NH_4NO_3 at approximately 1/8 lb/tree was applied to all peach trees. The contact herbicide paraquat was used at 2 lb/acre during the growing seasons of 1967 and 1968 to control weeds. The number of flowers/tree was counted on April 21, 1968 and the stem diameter at 8 inches from ground level measured on October 10, 1968.

Data from systematic spacing designs were evaluated by the least squares analysis, with a CDC 3600 computer.[1] The data for growth and yield/tree, and growth and yield/ ft^2 of land were fitted to linear and curvilinear equations of the general forms:

---

[1]Control Data Corporation model 3600 computer.

$$Y = a + bX \quad \text{(Linear)}$$

$$Y = a + b_1X_1 + b_2X_2 \quad \text{(Quadratic)}$$

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 \quad \text{(Cubic)}$$

$$\text{Log } Y = \text{Log } a + b \text{ Log } X \quad \text{(Curvilinear)}$$

$$\text{Log } Y = \text{Log } a + (\text{Log } b)\ X \quad \text{(Curvilinear)}$$

$$\text{Log } Y = a + b_1X_1 + b_2X_2 \quad \text{(Curvilinear)}$$

$$\text{Log } Y = a + b_1X_1 + b_2X_2 + b_3X_3 \quad \text{(Curvilinear)}$$

where Y equals growth or yield parameter: X_1 equals plant population / 1000; and $X_2 = X_1^2$, and $X_3 = X_1^3$. The equation that gave the best fit was selected in all cases. If none of the general equations were significant for a given dependent variable, that variable was considered not correlated with plant population.

Treatments to Increase Flower Initiation

Three methods of promoting flower initiation and increasing number of flowers/tree were studied using the EM IX transplants set at 3 ft intervals in rows 5 ft wide and 21 ft long. Treatments consisted of transplanting (on May 5, 1967) at an angle of 45°, foliar sprays of 2, 3, 5-triiodobenzoic acid (TIBA) at 25 ppm in the early summer, and scoring of transplants. The plants were sprayed with TIBA on the evenings of July 7 in 1967 and June 7 in 1968. All other non TIBA treated trees were sprayed with tap water at the same time. The scoring was done, on July 7, 1967 and June 7, 1968, with a small knife by cutting a ring completely around the stem 1 inch above ground level. The cut was intended to temporarily interfere with phloem transport. The three treatments and a control were arranged in a randomized block design with 12 replications. Each treatment in each block had seven trees. The terminal growth was measured and number of branches counted during October, 1967. The following year the terminal growth and stem diameter were measured.

Mulch Treatments

The treatments tested were black polyethylene plastic mulch, straw mulch, straw spread on top of black polyethylene and clean cultivation (control). The spacings used were 1, 2, 3, and 4 ft in rows 4 and 5 ft between rows. The black plastic, 3 ft wide and 1 1/2 mils thick, was perforated and placed down around the base of the transplants three weeks after they were planted. The straw was placed around the transplants, forming a 3 ft wide, 2-3 inch deep cover over the soil or the black plastic, depending on the treatment. A modified split plot design was used in which between row spacing treatments were main plots with mulch treatments as subplots, while the sub-subplots (in-row spacings) were arranged in strips across each replication of the subplots. Main plots were replicated four times. The same counts and measurements were made as for the experiment on flower bud initiation.

Mist Irrigation Treatment

'East Malling IX' trees were transplanted 1, 3 and 5 ft apart in rows 3 ft wide. These spacings were compared under a mist irrigation of .10 to .15 inches/day and no mist irrigation. Mist irrigation was applied with rotary sprinklers fitted with 1/16-inch nozzles adjusted to apply .05 inches of water/hr between 11:30 AM and 2:00 PM when the air temperature was above 85 F with clear skies. Mist was applied 13 days in 1967 and 11 days in 1968 from June to August. Supplemental irrigation was used in both the control and mist plots when rainfall was inadequate. A split plot design was used with mist treatments not replicated, while the in-row spacings were replicated twice in each main plot. The same measurements and counts were made as for the experiment on flower bud initiation.

Results and Discussion

Plant Population Studies

In 1967 the terminal growth and number of branches/ EM IX transplant were not correlated with population (from 1,742 to 43,560 trees/acre). The same trees in 1968 had reduced terminal growth and stem diameter/plant with population increases (Figure 1). Terminal growth/ft^2 in 1967 and stem diameter/ft^2 in 1968 increased

Fig. 1.--The relationships between EM IX population and growth parameters.

A. Terminal growth per plant and per square foot of land relative to plant population. (Plant population/1000 = X.)

1. 1967 Growth/ft^2

$$\hat{Y} = .182 + .612X, \ r = .83^{***}$$

2. 1968 Growth/plant

$$\hat{Y} = 251.5X^{-.1809}, \ r = -.44^{***}$$

3. 1968 Growth/ft^2

$$\hat{Y} = 5.77X^{.8191}, \ r = .91^{***}$$

B. Stem diameter per plant and per square foot of land relative to plant population in 1968. (Plant population/1000 = X.)

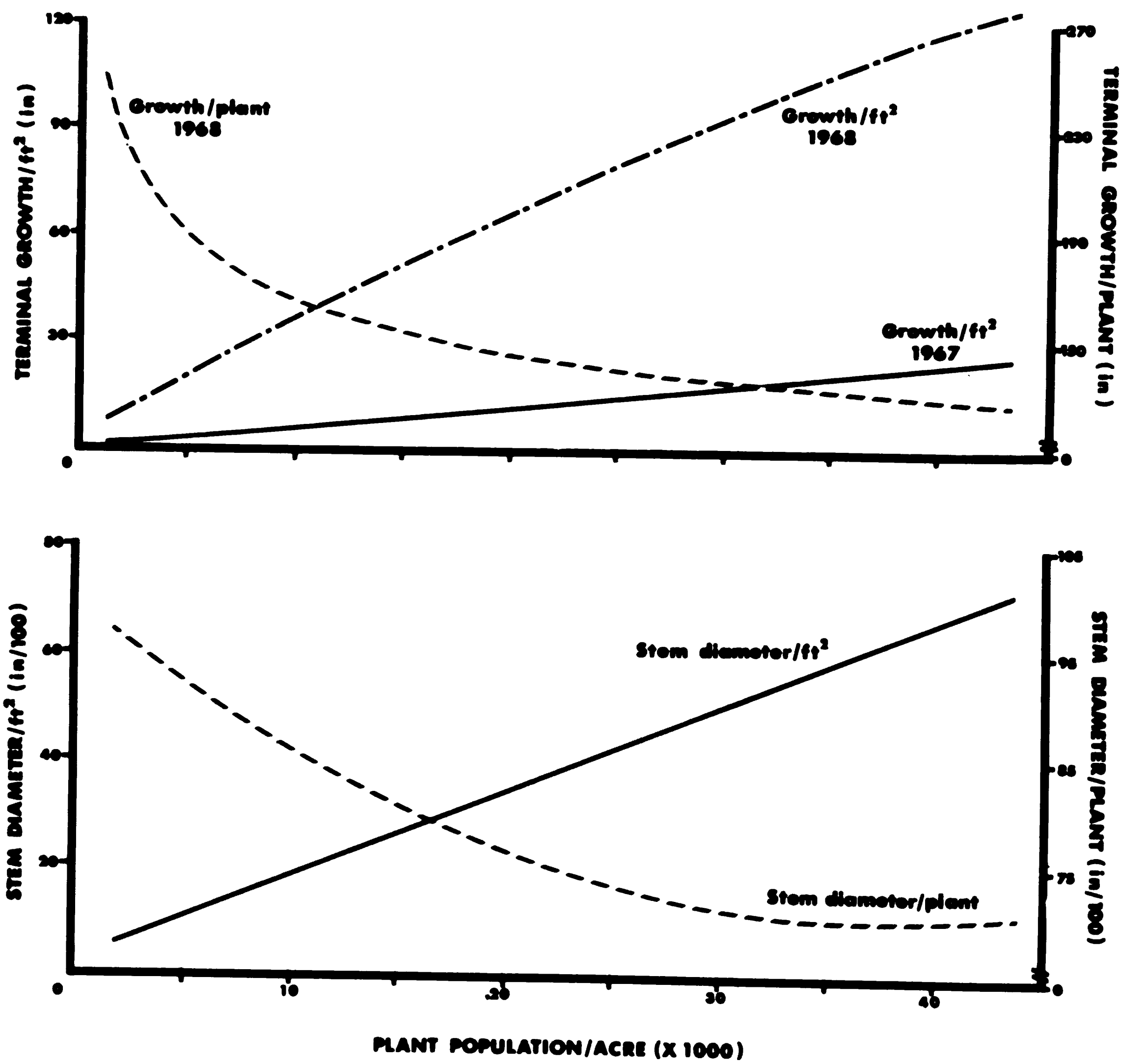
1. Stem diameter/plant

$$\hat{Y} = .998 - .0158X + .000212X^2, \ R^2 = .50^{***}$$

2. Stem diameter/ft^2

$$\hat{Y} = .0254 + .01605X, \ r = .979^{***}$$

MALLING IX


TERMINAL GROWTH/ft² (in)
TERMINAL GROWTH/PLANT (in)
Growth/plant
1968
Growth/ft²
1968
Growth/ft²
1967
STEM DIAMETER/ft² (in/100)
STEM DIAMETER/PLANT (in/100)
Stem diameter/ft²
Stem diameter/plant
PLANT POPULATION/ACRE (X 1000)

linearly with increasing population. During 1968 increase in population increased terminal growth/ft^2, but at a decreasing rate.

Competition occurred among EM IX trees in 1968 but not in 1967. The response of the trees in 1968 to competition conformed to the general formula proposed by Kira (38) of $wd^a = K$ where w is yield/plant, d is density, and K and a are constants. The terminal growth/unit area increased at a decreasing rate with population indicating competition.

Donald (25) suggested that the minimum plant population that produced the ceiling yield of dry forage/acre was equivalent to the population that would produce the maximum grain yield.

If terminal growth/ft^2 in 1967 or 1968 was substituted for dry forage/acre, the minimum tree population that resulted in the maximum yield/acre of apples would have been greater than 43,560.

Two year old 'Golden Delicious'/EM IX and 'Tydemans Red'/EM IX trees did not respond similarly to plant population stress. Terminal growth and branch number/tree in 1967 and terminal growth, stem diameter, flower number, fruit number and fruit weight/tree in 1968 were not correlated with number of 'Golden Delicious' trees/acre. During 1968 the terminal growth, stem diameter, flower number, fruit number and fruit weight/ft^2 of 'Golden

Delicious' increased linearly with increasing population (Figure 2). The terminal growth/ft^2 in 1967 increased at an increasing rate as the population increased. The fruit size and quality of 'Golden Delicious' were not consistently influenced by population, but at the highest population (10,890 trees/acre) the percentage of large fruits was reduced (Table 1).

TABLE 1.--The relationship of 'Golden Delicious'/EM IX population with fruit size and quality in 1968.[a]

Square feet per plant	Trees per acre	Number of fruit per tree	Per cent of fruit in each category — Fruit Quality Ratings				
			1	2	3	4	5
20.25	2141	10.7	8	35	38	15	3
15.75	2766	9.0	9	32	37	18	4
12.25	2556	11.7	14	32	42	10	2
11.25	3872	11.8	7	35	36	16	2
9.00	4729	12.2	7	29	41	20	2
8.75	4978	10.0	15	37	27	16	5
7.00	6223	11.5	10	37	39	13	1
6.25	6969	11.4	9	17	35	39	0
5.00	8712	7.9	10	27	47	13	4
4.00	10890	9.1	1	26	48	18	5
AVERAGE		10.5	9	31	39	18	3

[a]Each line of observations is mean of eight replications.

Fig. 2.--The relationships between 'Golden Delicious'/ EM IX population and growth, number of flowers, and yield of fruit.

A. Terminal growth and stem diameter per square foot of land relative to plant population. (Plant population/1000 = X.)

1. 1967 Growth/ft^2

$$\hat{Y} = .915X^{1.1035}, \ r = .76^{***}$$

2. 1968 Growth/ft^2

$$\hat{Y} = 5.02X - 1.29, \ r = .86^{***}$$

3. 1968 Stem diameter/ft^2

$$\hat{Y} = .0179X - .00149, \ r = .98^{***}$$

B. Number of flowers, number of fruit, and fruit weight per square foot of land relative to plant population in 1968. (Plant population/1000 = X.)

1. Flowers/ft^2

$$\hat{Y} = 2.22X - .042, \ r = .64^{***}$$

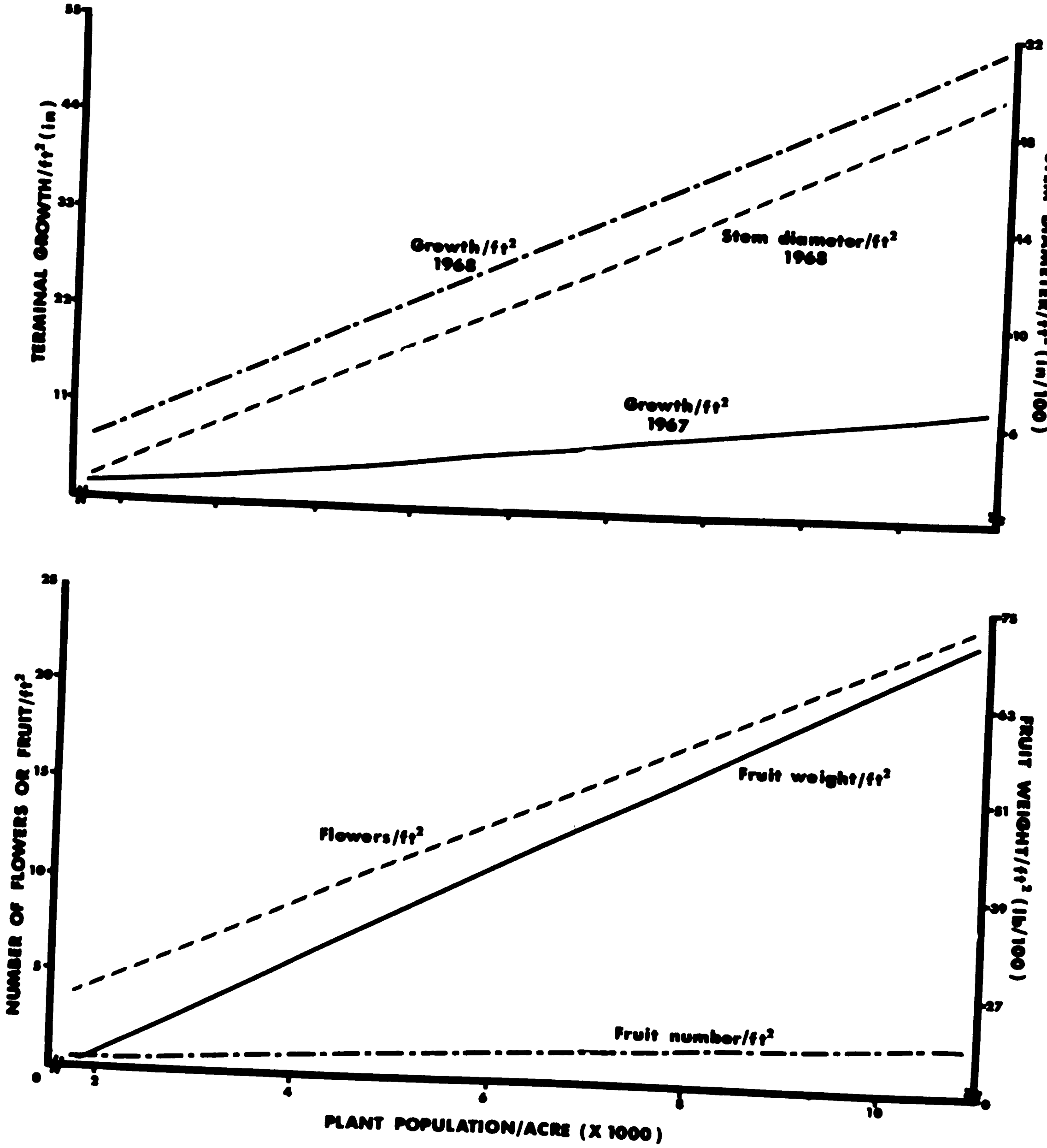
2. Fruit number/ft^2

$$\hat{Y} = .124 + .222X, \ r = .60^{***}$$

3. Fruit weight/ft^2

$$\hat{Y} = .052 + .060X, \ r = .62.^{***}$$

GOLDEN DELICIOUS/M IX



The terminal growth/tree and per ft^2 of land in 1967 and the stem diameter/ft^2 in 1968 increased linearly as the population of 'Tydemans Red' trees increased (Figure 3). However, other expressions of vegetative growth in 1968 exhibited peculiar responses to various plant densities. These growth measurements were related to population by the cubic regression equation of the general form $Y = a + b_1X_1 + b_2X_2 + b_3X_3$ where y equals the growth measurement in inches; X_1 equals plant population/1000; and $X_2 = X_1^2$, and $X_3 = X_1^3$. The final equations, which explained more of the variation than any other of the general equations tested, were the following: For terminal growth/plant:

$$\text{Log } \hat{Y} = .389 + .39X - .067X^2 + .00337X^3, \; R^2 = .54^{***}$$

For terminal growth/ft^2:

$$\text{Log } \hat{Y} = .156 + .227X - .0312X^2 + .00144X^3, \; R^2 = .69^{***}$$

For stem diameter/plant:

$$\hat{Y} = .322 + .317X - .0545X^2 + .00274X^3, \; R^2 = .34^{***}$$

In 1968 there was no relationship between number of flowers and fruit or fruit weight/'Tydemans Red' tree and plant population. Fruit number and fruit weight/ft^2 increased curvilinearly with population increases.

Fig. 3.--The relationships between 'Tydemans Red'/ EM IX population and tree growth and yield.

A. Terminal growth per plant and per square foot of land, and stem diameter per foot square relative to plant population. (Plant population/1000 = X.)

1. 1967 Growth/plant

$$\hat{Y} = 26.39 + 3.06X, \; r = .39^{***}$$

2. 1967 Growth/ft^2

$$\hat{Y} = 1.44X - 1.252, \; r = .81^{***}$$

3. 1968 Stem diameter/ft^2

$$\hat{Y} = .00425 + .0186X, \; r = .96^{***}$$

B. Number of fruit and fruit weight per square foot of land relative to plant population in 1968. (Plant population/1000 = X.)

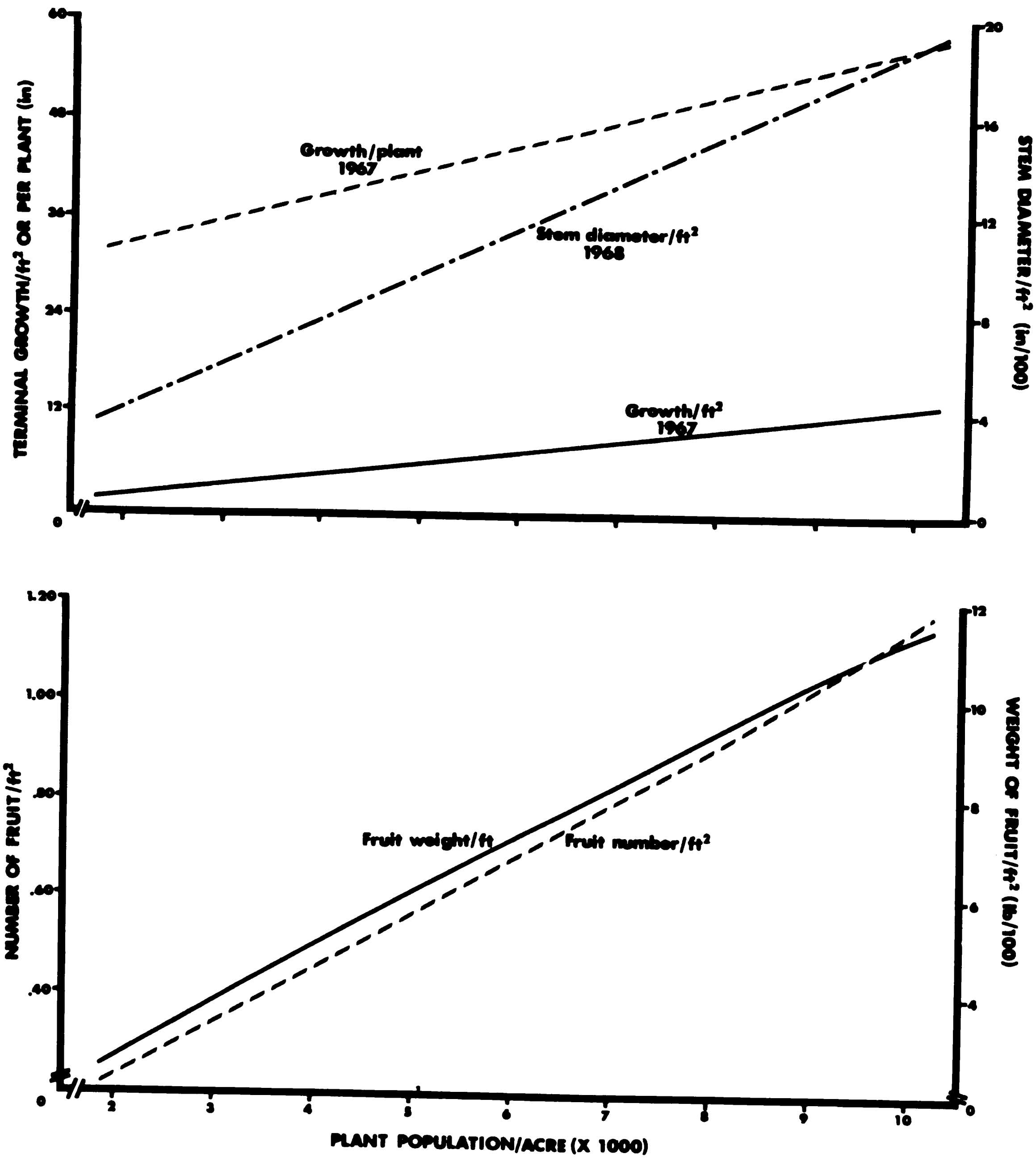
1. Fruit number/ft^2

$$\hat{Y} = .1106X^{1.0133}, \; r = .63^{***}$$

2. Fruit weight/ft^2

$$\hat{Y} = 2.65X^{.879}, \; r = .56^{***}$$

TYDEMANS RED/M IX



Two peach cultivars ('Suncling' and 'Redhaven') responded similarly at the various tree densities in 1968. The stem diameter and number of flowers/ft^2 increased linearly with population (Figure 4). Both cultivars flowered in 1968 but frost damage prevented fruit set.

Donald (25) proposed that it was the community of suppressed plants which gave the greatest yield/acre. Thus at the plant populations necessary for maximum yield the intense competition resulted in quantitatively subnormal plants. Since none of the populations tested caused reduced growth, flowering, or fruit/plant of 'Golden Delicious' trees; the maximum yield/acre was not attained. The increased growth/tree in 1967 with increasing competition of 'Tydemans Red' may be analogous to the increased height/plant of wheat caused by competition for light (78).

There was an obvious interaction of plant population and cultivar considering the response of 'Golden Delicious' and 'Tydemans Red'. The more extensively branched and compact 'Golden Delicious' trees were better adapted to production at high plant populations than 'Tydemans Red'. No such interaction was apparent for the two peach cultivars. Neither the maximum growth nor number of flowers/unit area was attained at the range of populations tested.

Fig. 4.--The relationships between peach tree population, stem diameter and flowering in 1968.

A. Stem diameter per square foot of land relative to plant population. (Plant population/1000 = X.)

1. Suncling stem diameter/ft^2

$$\hat{Y} = 3.657X - .392, \ r = .91^{***}$$

2. Redhaven stem diameter/ft^2

$$\hat{Y} = .171 + 3.14X, \ r = .95^{***}$$

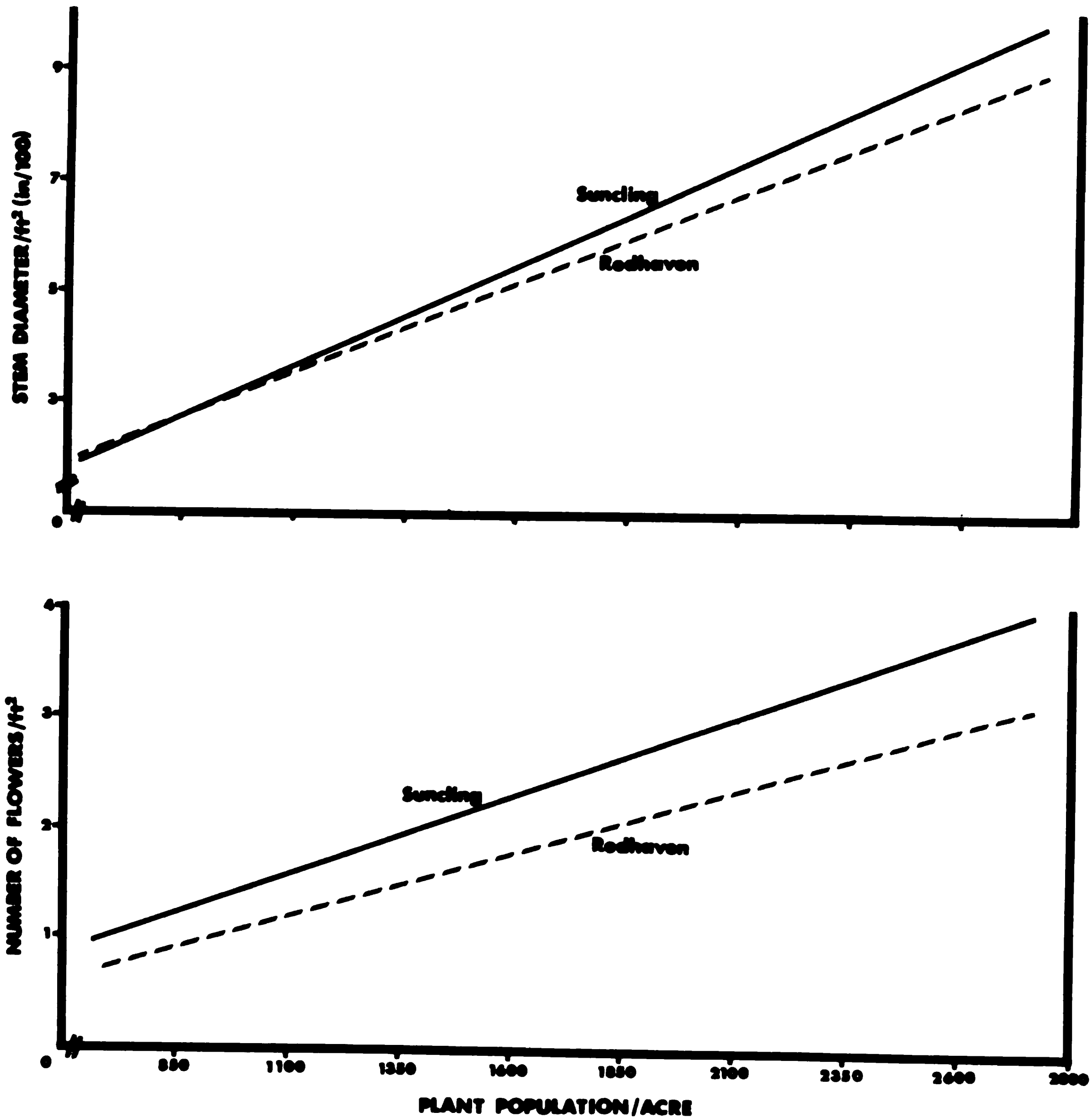
B. Number of flowers per square foot of land relative to plant population. (Plant population/1000 = X.)

1. Suncling flowers/ft^2

$$\hat{Y} = 1.424X - .0016, \ r = .45^{***}$$

2. Redhaven flowers/ft^2

$$\hat{Y} = .052 + 1.13X, \ r = .47^{***}$$



STEM DIAMETER/ft² (in/100)
9
7
5
3
0
Suncling
Redhaven
NUMBER OF FLOWERS/ft²
4
3
2
1
0
Suncling
Redhaven
850
1100
1350
1600
1850
2100
2350
2600
2850
PLANT POPULATION/ACRE

Modifying Flower Bud Initiation

Treatment with TIBA in 1967 increased the number of branches/tree, but planting at a 45° angle decreased the branches/tree of EM IX transplants (Table 2).

TABLE 2.--Terminal growth, branch number, and stem diameter per EM IX tree in relation to flower bud initiation treatments.

	Growth (inches)		Branches (no.)		Stem[1] diameter (inches)
	1967	1968	1967	1968	1968
Control	22 ab[2]	126	5.5 b	20	.86
TIBA (25 ppm)	26 a	144	6.4 a	20	.81
Planting (45° angle)	20 b	120	4.5 c	17	.84
Scoring	23 a	137	6.3 ab	19	.84

[1]At one inch above ground level.

[2]Values followed by uncommon letters are significantly different at the 5% level.

Both TIBA and scoring treatments caused more terminal growth/tree than did planting at a 45° angle. Reapplication of these treatments in 1968 did not alter the number of branches, terminal growth, or stem diameter of EM IX trees. None of these treatments affected flower bud initiation, in fact, none of the EM IX trees flowered in 1968.

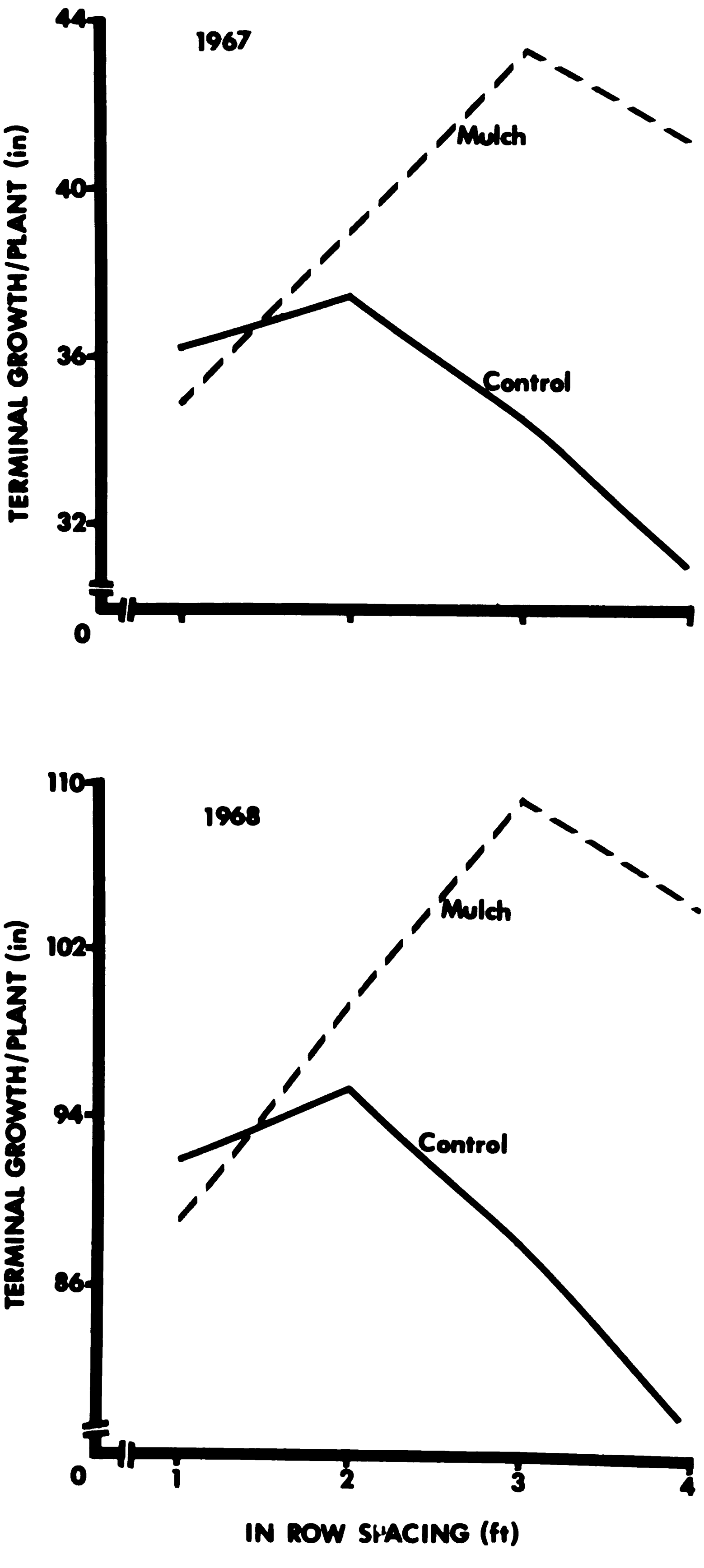
The failure of these treatments to promote flower initiation after only one year of growth was not unexpected (46, 52). The reported modifications of tree form and flowering may not occur until after the second or third year of growth (16).

The increased number of branches/plant caused by TIBA was consistent with other results which indicated disruption of apical dominance by TIBA (27). The increased terminal growth of TIBA treated trees was due to the extra branches/tree and not to more elongation/branch. Carlson (19) reported that apple trees grown in an inverted position had fewer "bud breaks," however Tukey (73) indicated that apple trees planted at an angle of 45° had increased "bud breaks." The decreased number of branches/plant of the trees planted at a 45° angle supported the findings of Carlson. Although in planting the trees at a 45° angle, they may have inadvertently been set deeper thus more buds were beneath the soil line than for the upright trees. This also would have resulted in fewer branches/plant. The lack of response to TIBA in 1968 may have been due to the lateness of application.

Mulch Treatments

In both years (1967 and 1968) mulching and in-row spacing affected the terminal growth/plant of EM IX trees (Figure 5). The mulches did not affect growth at

Fig. 5.--The effect of in-row spacing and mulching on the growth/plant of EM IX trees during 1967 and 1968.


1967
TERMINAL GROWTH/PLANT (in)
44
40
36
32
0
Mulch
Control
1968
TERMINAL GROWTH/PLANT (in)
110
102
94
86
0
Mulch
Control
1
2
3
4
IN ROW SPACING (ft)

1- and 2-ft in-row spacing, but at wider spacings (3- and 4-ft) mulching increased growth.

Possibly at the closer spacings competition for light limited growth; however at the wider spacings the increased growth was due to the benefits derived from mulch, which promote root growth, water absorption, and soil moisture conservation (20, 32).

Mist Irrigation Study

Mist irrigation did not alter the growth of EM IX trees, but in 1968 at 1-ft in-row spacing the terminal growth and diameter were reduced compared to the 2- and 3-ft spacings (Table 3).

TABLE 3.--Terminal growth, branch number, and stem diameter per EM IX tree in relation to irrigation and spacing.[1]

In Row Spacing		1967		1968	
		Growth (inches)	Branches (no.)	Growth (inches)	Stem diameter (inches)
1	1-ft	46	7.2	128 b	.83 b
2	2-ft	51	7.2	210 a	.98 a
3	3-ft	47	7.5	161 ab	.98 a

[1]Values followed by uncommon letters are significantly different at the 5% level.

Mist irrigation applied when air temperature was above 80 F at rates of .25 to .35 inches/day increased yields of certain vegetable crops (13). Either EM IX trees were not responsive to misting, or it was not applied as often or as extensively as needed.

ECONOMIC FEASIBILITY ANALYSIS

Materials and Methods

An economic analysis was made of "Lilliputian" apple culture and mechanical harvesting costs. The technique developed by Stout and Kline (68) to determine economic feasibility of mechanical harvesting systems was used with slight modifications.

Cost items that could be predicted with reasonable certainty were given specific values (Table 4). Uncertain items such as tree cost, acreage, tree population, harvester capacity, harvester cost, growing costs, and the number of harvesting years out of seven were assigned ranges of values (Table 5). The cost values for production and harvesting variables were assembled from numerous studies (68, 12, 58, 73). A series of equations was used to calculate total costs for a seven year period (Table 6). The seven years assumed one year for transplanting the trees and six years as the approximate life expectancy of a mechanical harvester. A CDC 3600 computer was used to solve the equations for all the possible solutions of the 2,430 combinations of variables. The total cost values for the seven year period were transformed to break-even yields computed in dollars per acre.

TABLE 4.--Specific variables for economic feasibility program.

Symbol	Description	Value
	Planting Costs	
PL	Land preparation (including cover crop, fertilizer, and working soil, $/acre)	60
TP	Transplanting costs ($/acre)	25
	Harvester System	
AT	Annual use of tractor (hr/yr)	600
CIT	Initial cost of tractor ($)	4000
CLH	Cost of labor to operate harvestor ($/hr)	4
CLT	Cost of labor to operate tractor ($/hr)	2.50
FC	Cost of fuel ($/gal)	.17
HP	Horse power of tractor	15
R	Interest rate (per cent)	6
RMH	Repairs, maintenance, lubrication on harvester (per cent of initial cost/yr)	4
SFC	Specific fuel consumption (horse power-hr/gal)	8.5
SLH	Service life of harvester (yr)	6
SLT	Service life of tractor (yr)	10
SVH	Salvage value of harvester (per cent of initial cost)	5
SVT	Salvage value of tractor (per cent of initial cost)	10
TS	Taxes, insurance, shelter (per cent of initial cost/yr)	1.5

TABLE 5.--Non-specific variables for economic feasibility program.

Symbol	Description	Range of Values
A	Size of planting (acres)	50 - 150 - 250
AH	Harvest rate (acres/hr)	.2 - .4 - .6
CIH	Initial cost of harvester ($)	15,000-25,000-35,000
GC	Cost of growing trees, including pest control, property tax, cost of fertilizing, and cost of operating equipment and buildings ($/acre/yr)	135 - 200
PP	Plant population (trees/acre)	7,400-12,500-37,000
TC	Initial cost of trees ($/tree)	.01-.09-.17-.25-.33
R (L-M-H)	Number of years trees will have fruit to harvest over a 7 year period (yr)	2 - 4 - 6

TABLE 6.--Equations utilizing specific and non-specific variables for economic feasibility program.

Symbol	Description (Expressed in dollars)	Equation
CFL	Cost of fuel and lubricants (yr)	$CFL = \frac{(1.03)(FC)(HP)(A)}{(AH)(SFC)}$
COH	Cost of harvester overhead (per yr)	$COH = \frac{CIH - (SVH/100)(CIH)}{SLH} + \frac{R}{100}(\frac{CIH+(SVH/100)(CIH)}{2}) + \frac{(TS)(CIH)}{100} + \frac{(RMH)(CIH)}{100}$
COT	Cost of tractor overhead (per yr)	$COT = \frac{(A)}{(AH)(AT)}((\frac{CIT-(SVT/100)(CIT)}{SLT}) + \frac{R}{100}(\frac{CIT + (SVT/100)(CIT)}{2}) + \frac{(RMT)(CIT)}{100} + \frac{(TS)(CIT)}{100})$
COL	Cost of labor to operate tractor and harvester (per yr)	$COL = \frac{(A)(CLT + CLH)}{AH}$
CMH	Cost of mechanized harvesting (per yr)	$CMH = CFL + COH + COT + COL$
GCI	Growing cost plus interest on investment for tree cost (per yr)	$GCI = (A)(GC) + ((6)(A)(PP)(TC))/100$
PY	Planting year total cost (per yr)	$PY = (A)(PP)(TC) + GCI$
HY	Harvesting year total cost (per yr)	$HY = CMH + GCI$
RL	Two harvests in 7 years (total cost for 7 years)	$RL = PY + 4GCI + 2HY$
RM	Four harvests in 7 years (total cost for 7 years)	$RM = PY + 2GCI + 4HY$
RH	Six harvests in 7 years (total cost for 7 years)	$RH = PY + 6HY$

Results and Discussion

To aid interpretation of the economic analysis results the approximate value of the yield from 'Golden Delicious' trees was used. At 10,890 trees/acre the yield was .695 lb. of fruit/ft^2 (Figure 2), this was transformed to gross return as follows:

$$(.695 \text{ lb/ft}^2) \times (43{,}560 \text{ ft}^2\text{/acre}) \div (42 \text{ lb/bu})$$

$$= 720 \text{ bu/acre}$$

$$(720 \text{ bu/acre}) \times (\$2.00\text{/bu}) = \$1{,}440\text{/acre gross return/acre.}$$

The gross return value of $1,440/acre was used to test the economic soundness of the various combinations of variables.

The break-even yields in dollars/acre per year for "Lilliputian" production and mechanical harvesting costs are presented in Figure 6. The assumptions were a planting of 150 acres, a $25,000 harvester, harvester capacity of .6 acres/hr, and four harvesting years out of seven. The tree population/acre, cost/tree, and growing costs/acre per year were assigned ranges of values. Using the $1,440/ acre value as a standard, the desirability of having not more than 10,000 trees/acre and trees costing $.25 each or less can be seen. The higher growing costs increased the break-even yield/acre about $120.

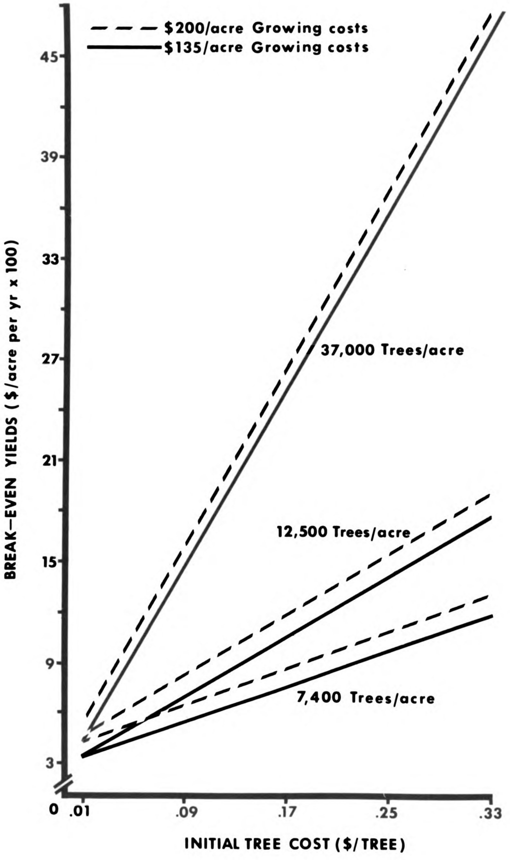
Fig. 6.--Break-even yields for "Lilliputian" production and mechanical harvest with 7,400; 12,500; 37,000 trees/acre and $135 or $200 growing costs.

Assuming the following:

Harvester cost of $25,000

Planting of 150 acres

Four harvests out of seven years


$200/acre Growing costs
$135/acre Growing costs
BREAK—EVEN YIELDS ($/acre per yr x 100)
45
39
33
27
21
15
9
3
0
.01
.09
.17
.25
.33
37,000 Trees/acre
12,500 Trees/acre
7,400 Trees/acre
INITIAL TREE COST ($/TREE)

Break-even yields are shown for 2, 4, or 6 harvesting years out of a seven year period, and 7,400 or 12,500 trees/acre in Figure 7. A harvester cost of $25,000, 150 acre planting, $200/acre growing costs, and .4 acre/hr harvester capacity were assumed. The economic benefit of having four harvesting years in seven years to at least break-even can be seen.

The rate of harvest was not an important economic factor, but it determines the physical limitations of a harvester. For example, a harvester with a capacity of .2 acres/hr working 20 hr/day would take 37 1/2 days to harvest 150 acres. This indicates that certain points on the figures may be physically impossible or impractical.

The effect of a range of harvester costs and size of plantings on break-even yields can be seen in Figure 8. A harvester capacity of .4 acres/hr, tree population of 12,500/acre, $200/acre growing costs, and a tree cost of $.17 each were assumed. The initial cost of the harvester becomes increasingly important as the size of the planting decreases, although given the assumptions listed the harvester cost would not preclude economic success.

These graphs represented only a few of the possible combinations of variables used in this study. These particular combinations were chosen because they dramatize the importance of tree population, cost/tree, and number of harvesting years on the economic soundness of "Lilliputian" apple culture and mechanical harvest.

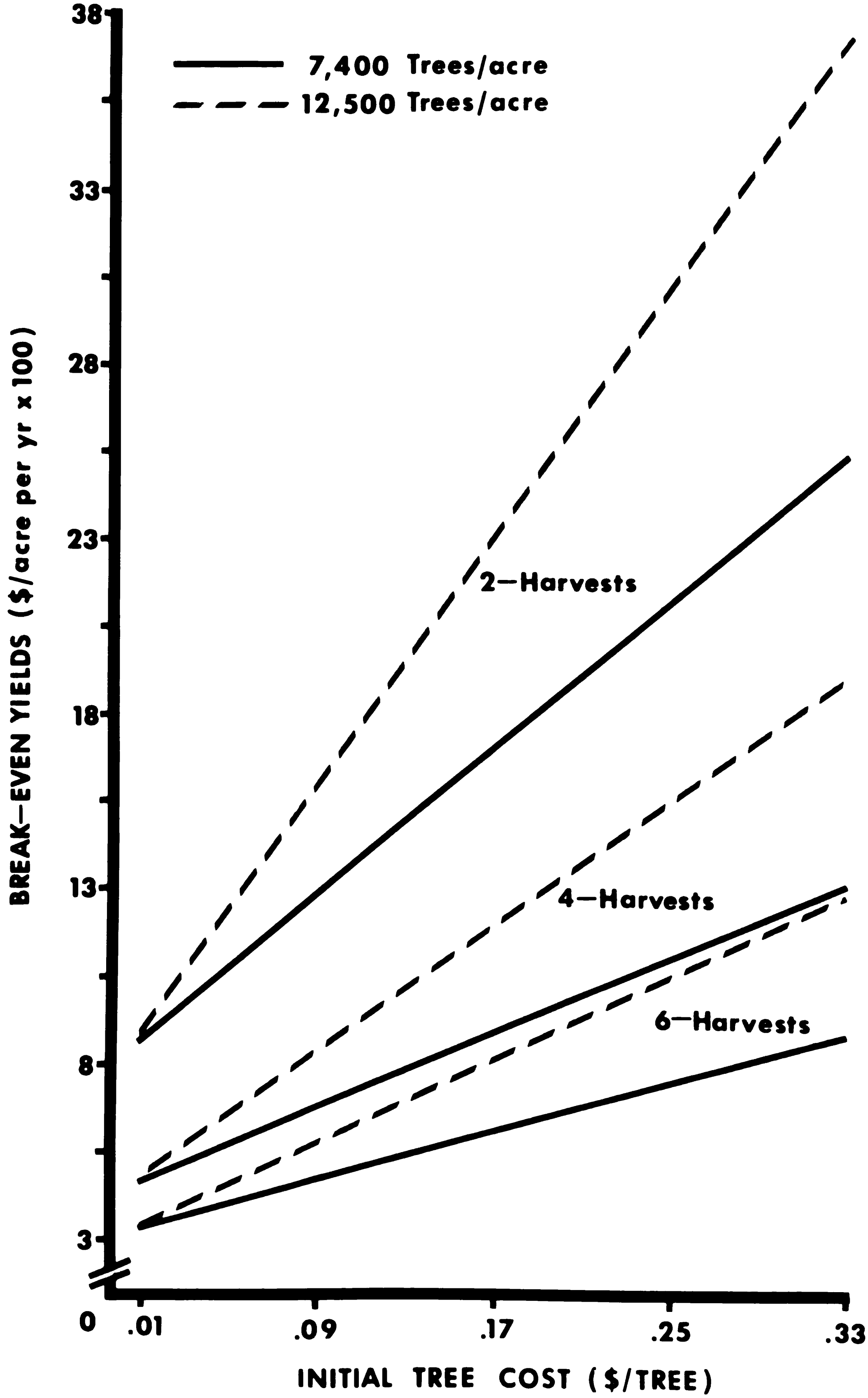
Fig. 7.--Break-even yields for "Lilliputian" production and mechanical harvest with 2, 4, or 6 harvesting years out of seven and 7,400 or 12,500 trees/acre.

Assuming the following:

Harvester cost of $25,000

Planting of 150 acres

Growing costs of $200/acre per yr



7,400 Trees/acre
12,500 Trees/acre
2—Harvests
4—Harvests
6—Harvests
BREAK—EVEN YIELDS ($/acre per yr x 100)
38
33
28
23
18
13
8
3
0
.01
.09
.17
.25
.33
INITIAL TREE COST ($/TREE)

Fig. 8.--Break-even yields for "Lilliputian" production and mechanical harvest with $15,000; $25,000; or $35,000 harvester.

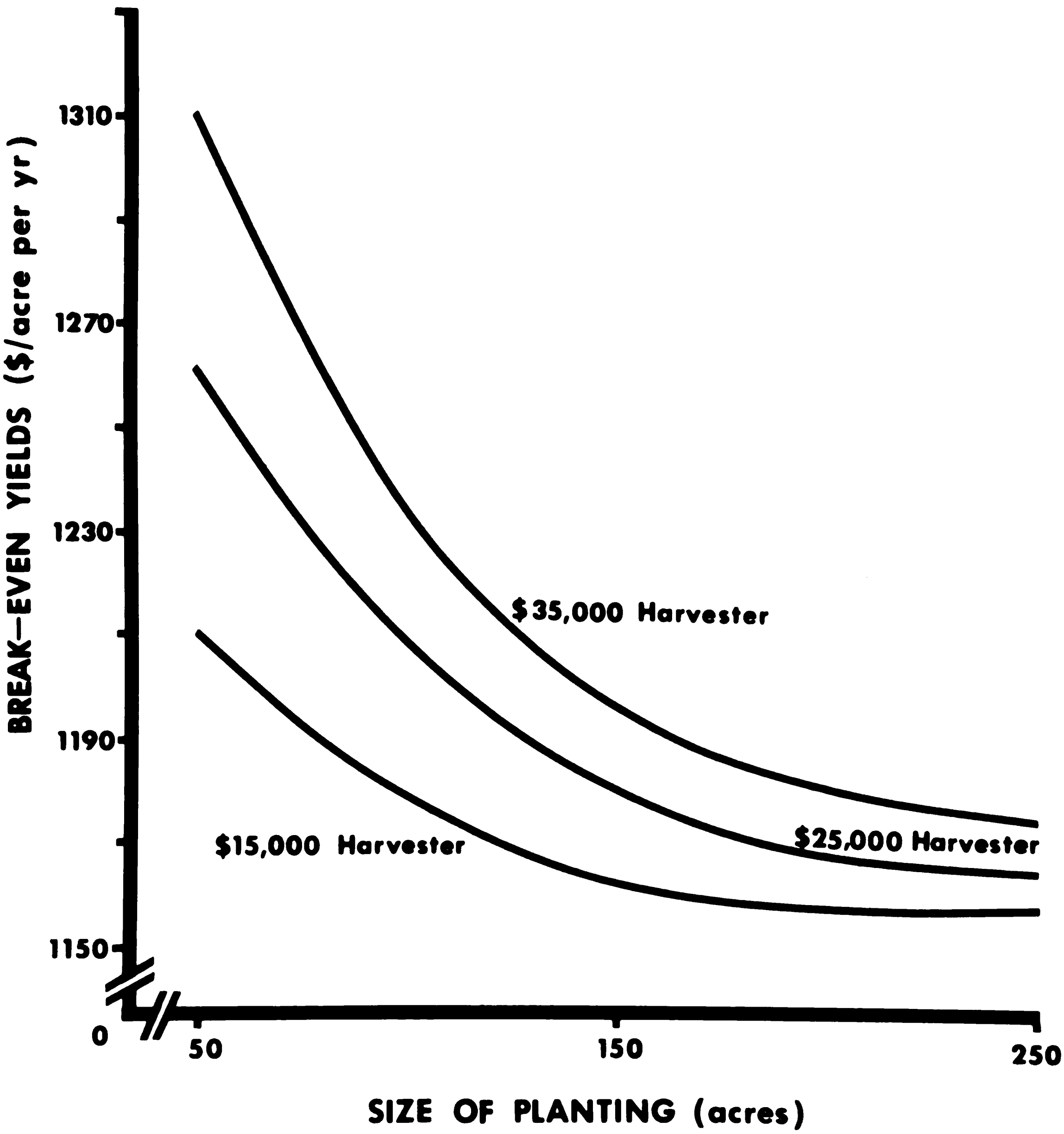
Assuming the following:

Tree cost of $.17/tree

Trees/acre equal to 12,500

Growing costs of $200/acre

Four harvests out of seven years


BREAK—EVEN YIELDS ($/acre per yr)
1310
1270
1230
1190
1150
0
50
150
250
SIZE OF PLANTING (acres)
$35,000 Harvester
$25,000 Harvester
$15,000 Harvester

SUMMARY

Tree density and cultural practices were tested using three apple cultivars, EM IX, 'Golden Delicious,' 'Tydemans Red', and two peach cultivars 'Suncling' and 'Redhaven'. The economic feasibility of "Lilliputian" apple production and mechanical harvest was considered using various combinations of costs.

During 1967 EM IX trees were not affected by high tree populations, but in 1968 modified vegetative growth indicated competition. The terminal growth/ft^2 of land increased with tree population during 1967 and 1968. This suggested that the maximum fruit yield/acre would have occurred at some population higher than 43,560 trees/acre.

The growth, flowering, and fruiting/tree of 'Golden Delicious' were not altered over the range of tree populations from 1,742 to 10,890/acre. Thus the maximum fruit yield/acre was not attained in 1968. At the highest tree population the percentage of large size 'Golden Delicious' fruit was reduced. 'Tydemans Red' trees grew taller with increasing competition in 1967. 'Tydemans Red' growth measurements in 1968 were related to plant population by cubic equations. 'Golden Delicious'

out yielded 'Tydemans Red' at all populations tested in 1968. The growth and flowering of the two peach cultivars were not altered by tree population from 600 to 2,722 trees/acre.

Attempts to modify flower bud initiation of EM IX transplants were unsuccessful. Planting at a 45° angle reduced the branch number/tree in 1967, but TIBA increased it. None of the treatments altered growth in 1968.

Three mulches were compared to clean cultivation at various in-row and between-row spacings in 1967 and 1968. The trees grew taller on mulch when spaced 3 and 4 ft apart in the row compared to the 1- and 2-ft spacing.

Certain combinations of cost variables indicated the economic soundness of "Lilliputian" production and mechanical harvesting. The results indicated a need for: a population of less than 10,000 trees/acre, a tree cost of less than $.25 each, and at least four harvesting years over a seven year period. Factors of less importance were harvester cost, harvester capacity, and size of planting.

The results of this study established certain guidelines that could be used to adapt apple production to mechanized harvest. Development of apple cultivars that could be propagated inexpensively or better control of growth and flowering of apple trees would make "Lilliputian" production feasible.

LITERATURE CITED

LITERATURE CITED

1. Anonymous. 1951. Hay mulch of value in apple orchard. Organic Gardening 18(1):55.

2. ______. 1966. Mechanical harvesting making big strides. Amer. Fruit Grower. 86(11):20.

3. ______. 1966. Five men + one machine = a thorough apple harvest. Amer. Fruit Grower. 86(12):14.

4. ______. 1967. The latest in shockers and shakers. Amer. Fruit Grower. 87(9):8-9.

5. ______. 1967. Platforms to success--special report. Amer. Fruit Grower. 87:(11):11-13.

6. ______. 1967. Zijn zeer dichte beplantinger redabel. Fruitteelt. 57:1294-1295.

7. ______. 1968. They've mechanically harvested apples for the fresh market. Amer. Fruit Grower. 88(3):34.

8. ______. 1968. They ride while they pick tree walls of fruit. Amer. Fruit Grower. 88(6):11.

9. Barney, A. 1968. The picking platform. Eastern Fruit Grower. 31:12.

10. Bechenbach, H and J. H. Gourly. 1932. Some effects of different cultural methods upon root distribution of apple trees. Proc. Amer. Soc. Hort. Sci. 29:202-204.

11. Berlage, A. G., R. B. Tukey and G. E. Yost. 1967. Modifying tree fruit culture to engineering needs. Paper presented at 1967 annual meetings of Pacific Northwest Region ASAE.

12. ______, and G. E. Yost. 1968. Tree walls for the tree fruit industry. Agr. Eng. 49(4):198.

13. Bible, B. B., R. L. Cuthbert, and R. L. Carolus. 1968. Response of some vegetable crops to atmospheric modifications under field conditions. Proc. Amer. Soc. Hort. Sci. 92:590-594.

14. Bleasdale, J. K. A. 1966. The effects of plant spacing on the yield of bulb onions (Allim cepa L.) grown from seed. Jour. Hort. Sci. 41:145-153.

15. Boynton, D. and L. C. Anderson. 1956. Some effects of mulching, nitrogen fertilization, and liming on McIntosh apple trees, and the soil under them. Proc. Amer. Soc. Hort. Sci. 67:26-36.

16. Bukovac, M. J. 1968. TIBA promotes flowering and wide branch angles. Amer. Fruit Grower. 88(5):18.

17. Buller, G. B. and J. A. Gibbs. 1952. Planted Loblolly pines respond to mulching. Jour. of Forestry. 50:317.

18. Cahoon, G. A., E. S. Morton, B. W. Lee and G. E. Goodall. 1963. The use of plastic ground covers in citrus nurseries. Proc. Amer. Soc. Hort. Sci. 83: 309-315.

19. Carlson, R. F. 1962. Growth responses of young fruit trees grown in inverted position. Mich. Agr. Exp. Sta. Quart. Bul. 45(2):356-362.

20. Carolus, R. L. 1959. Now northern growers can grow vine crops at a profit. Amer. Veg. Grower. 7(3):13.

21. Chaplin, J. F., Z. T. Ford, J. B. Pitner and R. E. Currin. 1968. Effect of row and within-row spacing on yield and quality of flue-cured tobacco. Agron. Jour. 60:314-316.

22. Courter, J. W. and N. F. Oebker. 1964. Comparisons of paper and polyethylene mulching on yields of certain vegetable crops. Proc. Amer. Soc. Hort. Sci. 85:526-531.

23. Curtis, O. F. 1966. Juvenility in apple clones. Proc. 17th Int. Hort. Congr. Md. 1966.

24. Dennis, F. G. 1966. Effects of growth retardants on juvenile apple seedlings. Proc. 17th Int. Hort. Congr. Md. 1966.

25. Donald, C. M. 1963. Competition among crop and pasture plants. Adv. Agron. 15:1-118.

26. Fridley, R. B. and P. A. Adrian. 1968. Evaluating the feasibility of mechanizing crop harvest. Transactions of the ASAE. 11:350-352.

27. Galston, A. W. 1947. The effect of 2,3,5-Triiodobenzoic acid on the growth and flowering of soybeans. Amer. Jour. Bot. 34:356-360.

28. Gaston, H. P., R. T. Whittenberger and J. H. Levin. 1968. Report on machine harvesting of cherries in Michigan. The Great Lakes Fruit Growers News. April, 1968.

29. Glasziou, K. T. 1957. Respiration and levels of phosphate esters during kinetin-induced cell division in tobacco pith-sections. Nature. 179:1083-1084.

30. Gritton, E. T. and J. A. Eastin. 1968. Response of peas (Pisum sativum L.) to plant population and spacing. Agron. Jour. 60:482-485.

31. Harris, R. E. 1965. Polyethylene covers and mulches for corn and bean production in northern regions. Proc. Amer. Soc. Hort. Sci. 87:288-294.

32. Helslip, R. P. 1959. The influence of mulching on several vegetable crops with special reference to black polyethylene. Unpublished M.S. thesis, Michigan State University.

33. Holliday, R. 1960. Plant population and crop yield. Nature. 186:22-24.

34. Hopen, H. J. 1965. Effects of black and transparent polyethylene mulches on soil temperature, sweet corn growth and maturity in a cool growing season. Proc. Amer. Soc. Hort. Sci. 86:415-420.

35. Johnson, M. R. 1952. How to get the best from your apple trees. Organic Gardening. 20(9):16-17.

36. Jones. O. P. 1964. Observations on the growth effects of xylem sap from apple trees. Rep. E. Malling Res. Sta. for 1964, 119-122.

37. Karnatz, A. 1965. Zur Frage Des Beginnes der generativen Phase bei Apfelsamlingen, I. Erstblute. Gartenbauwiss. 30:527-540. (Hort. Abst. 37:56).

38. Kira, T. O. H., and N. Sakazaki. 1953. J. Inst. Poly. Osake City Univ. 4, 1-16. (Adv. Agron 15:1-118).

39. LaBelle, R. L., E. D. Markwardt and R. W. Guest. 1965. Improving the processing quality of mechanically harvested apples. Transactions of the ASAE. 8(2):277-280.

40. La Mont, G. F. 1967. Our experience in mechanically harvesting apples. Eastern Fruit Grower. 30(1):12.

41. Larsen, P. 1967. Mechanical lifts and platforms--do they pay? Amer. Fruit Grower. 87(4):34.

42. ______. 1967. Mechanical harvesting has arrived. Amer. Fruit Grower. 87(6):20-27.

43. Latimer, L. P. and G. P. Percival. 1947. Comparative value of sawdust, hay, and seaweed as mulch for apple trees. Proc. Amer. Soc. Hort. Sci. 50:23-30.

44. Lavee, S. 1963. The effect of mulch on the resistance of E.M.-II apple stock to Sclerotium rolfsii (Sacc.). Proc. Amer. Soc. Hort. Sci. 82:25-34.

45. Lemmens, J. 1967. Zwemmen of ver... Fruitteelt. 57: 914-915. (Hort. Abst. 38:39.)

46. Longman, K. A., T. A. A. Nasr, and P. F. Wareing. 1965. Gravimorphism in trees. 4. The effect of gravity on flowering. Ann. Bot. Lond. 29:459-473.

47. Luckwill, L. C. 1957. Studies of fruit development in relation to plant hormones. Jour. Hort. Sci. 32: 18-33.

48. Miller, C. O. 1956. Similarity of some kinetin and red light effects. Plant Physiol. 31:318-319.

49. Miller, D. E. 1968. Emergence and development of sweet corn as influenced by various soil mulches. Agron. Jour. 60:369-371.

50. Miller, S. R. 1965. Growth inhibition produced by leaf extracts from size-controlling apple rootstocks. Canadian Jour. Plant Sci. 45(6):519-524.

51. Močalova, T. Ja. 1966. Closer spacing of reinettes. Sadovodstvo. No. 10:12-13. (Hort. Abst. 37:282.)

52. Mullins, M. G. 1965. The gravitational responses of young apple trees. Jour. Hort. Sci. 40:237-247.

53. Nelder, J. A. 1962. New kinds of systematic designs for spacing experiments. Biometrics 18:283-307.

54. Peerbooms, H. 1967. Boomvormen-en plant-afstnaden-froef op zandgrond. Fruitteelt. 57:940-941. (Hort. Abst. 38:40.)

55. Pelton, J. S. 1964. Angiosperm single-gene dwarfs. Botanical Rev. 30:479-511.

56. Phinney, B. O. 1956. Biochemical mutants in maize. Dwarfism and its reversal with gibberellins. Plant Physiol. 31 (suppl).

57. Preston, A. P. 1959. Effect of tree density in an exposed apple orchard. Rep. E. Malling Res. Sta. for 1959, 52-66.

58. Ricks, D. J., R. P. Larsen, and R. G. Wheeler. 1961. Inputs and relative yields for young orchards. Mich. Ag. Ext. Fact Sheet No. 1055.

59. Rollins, H. A. 1967. New techniques and challenges. Eastern Fruit Grower. 30(3):6.

60. Schales, F. D. and R. Sheldrake, Jr. 1966. Mulch effects on soil conditions and muskmelon response. Proc. Amer. Soc. Hort. Sci. 83:425-430.

61. Serafimova, R. 1965. The effect of close spacing on the yield and cold resistance of figs. Grod. Lozar. Nauka. 2:705-712. (Hort. Abst. 36:473.)

62. Selders, A. W., R. W. Kleis, K. M. Hayes and W. J. Lord. 1967. Mechanical harvesting and handling of processing apples. Transactions of The ASAE. 10:43-44.

63. Shoulders, E. 1961. Effect of nursery bed density on Loblolly and Slash pine seedlings. Jour. of Forestry. 58(8):576-579.

64. Simons, R. K. 1966. Soil management for apple tree response to varied mulching systems. Trans. Ill. St. Hort. Soc. 100:148-153.

65. Snyder, D. P. 1968. An economic study of apple production on size-controlled trees. Cornell Univ. Ag. Exp. Sta. Ag. Econ. Res. 233.

66. Stout, B. A., S. K. Ries, and A. R. Putnam. 1963. The feasibility of a once-over mechanical harvester for picking cucumbers. Mich. Agr. Exp. Sta. Quart. Bul. 45(3):407-416.

67. ______, C. K. Kline and C. R. Hoglund. Economics of mechanical asparagus harvesting systems. Mich. State Univ. Res. Report. 64.

68. ______. 1968. Predicting the economic feasibility of mechanical harvesting systems. Transactions of The ASAE. 11:353-355.

69. Takatori, F. H., L. F. Lippert, and F. L. Whiting. 1964. The effect of petroleum mulch and polyethylene films on soil temperature and plant growth. Proc. Amer. Soc. Hort. Sci. 85:532-539.

70. Thakur, D. R. and Verma, B. R. 1967. Some observations on the effect of chronic gamma radiation on young apple trees. Sci. and Cult. 33-76-77. (Hort. Abst. 37:747.)

71. Tydeman, H. M. and F. H. Alston. 1964. The influence of dwarfing rootstocks in shortening the juvenile phase of apple seedlings. Rep. E. Malling Res. Sta. for 1964, 97-98.

72. Tromp, J. 1967. Fruit-bud formation and shoot-growth in apple in relation to gravity. Naturwissenschaften. 54:95.

73. Tukey, H. B. 1964. Dwarfed Fruit Trees. 77. The MacMillan Co., New York.

74. Tukey, R. B. and E. L. Schoff. 1963. Influence of different mulching materials upon the soil environment. Proc. Amer. Soc. Hort. Sci. 82:68-76.

75. Upshall, W. H. 1935. Malling stocks and French crab seedlings as stocks for five varieties of apples. Sci. Agr. 15(8):535-541.

76. Van Overbeek, J. 1966. Plant growth and regulators. Science. 152:721-731.

77. Verkey, E. W. M. and H. C. P. DeVries. 1966. Welke mogelijkheden biedt fruitteelt op bedden? Meded. Dir. Tuinb. 29:338-343.

78. Wassermann, V. D. 1963. Thesis, Dept. of Agron. Univ. of Adelaide, Adelaide, Australia. (Adv. Agron. 15:1-118.)

79. White, G. C. and R. I. C. Holloway. 1967. The influence of simazine or a straw mulch on the establishment of apple trees in grassed down or cultivated soil. Jour. Hort. Sci. 42:377-789.

80. Whitney, J. D., N. Mohsenin and L. D. Tukey. 1963. An elevating mechanical harvester for apple trees trained to the plateau system. Proc. Amer. Soc. Hort. Sci. 83:175-184.

81. Wiggins, R. G. 1939. The influence of space and arrangement on the production of soybean plants. Jour. Amer. Soc. Agron. 31:314-321.

82. Yocum, W. W. 1937. Root development of young Delicious apple trees as effected by soil and cultural treatments. Univ. Neb. Agr. Exp. Sta. Res. Bull. no. 95.