both the customers and grower are happy for several reasons. Trellised trees and fairly tight hedgerows work well to control customers within picking limits. There are many do's and don'ts for conducting this type marketing procedure which can be found in my book, Modern Fruit Science (1).

Concluding Remarks

In summary, I would say that dwarfed deciduous fruit trees are certainly in the future for the USA. Much research is being done and must be done to perfect the system. We have made the most progress with apple, and now are seeking dwarfing rootstocks for other trees as cherry, peach, plum, pear, the nuts and others. If you have questions, I would be happy to correspond.

Literature Cited


SPACING

TRENDS IN HIGHER CITRUS PLANTING DENSITIES

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Abstract. There exists a worldwide trend in citrus culture toward higher density plantings encompassing a wide assortment of tree spacing combinations. The results of a survey of such trends are discussed. From 1900 to 1978, between-row spacings in Florida have not varied much, however in-row spacings have been reduced from 25 to 20 ft (7.62 to 6.10 m). At present, the highest percentage of total orange and grapefruit acreages are on 25 x 25 ft (7.62 x 7.62 m) and 25 x 30 ft (7.62 x 9.14 m) spacings, respectively. However, there are substantial acreages set at closer spacings. Reasons for such trends are discussed along with similar developments in other major citrus-growing areas.

Experience to date has shown that higher density plantings have produced earlier returns over a 10 to 15-year period without insurmountable problems. Yet to be determined are the productive life of such groves and whether early returns will be offset by the cost of future tree size control and/or tree removal. Possible modifications in pruning practices, irrigation, nutrition and other cultural practices for such plantings appear necessary, but must be defined by further research.

Introduction and History

Throughout citrus producing regions of the world, there has always been discussion regarding the proper spacing of trees in order to produce yields of high quality fruit for maximizing net returns. Decisions about the optimum citrus tree spacing have always been difficult, and usually result in a degree of compromise. Basically, those spacings with larger numbers of trees per acre result in greater early production, while wider spacings give greater production later on in the life of the grove.

Observations with respect to past tree spacing trends in Florida were made in 1960 by Dr. A. F. Camp in the publication, Citrus Industry of Florida (2). Commonly used spacings were 25 x 25 ft for oranges and 30 x 30 ft (9.14 x 9.14 m) for grapefruit. At that time these tree spacings were considered too close on deep ridge sandy soils. Older groves set 20 x 20 ft (6.10 x 6.10 m) declined in vigor due to excessive crowding, while fruit size and external quality were frequently reduced. It was also observed that spacings of 15 x 30 ft (4.57 x 9.14 m) were desirable when growers removed alternate trees somewhere between the tenth and fifteenth year. However, growers were hesitant to make this decision when the appropriate time arrived. A 20 x 20 ft spacing was another standard planting in Florida. When budded on rough lemon rootstock it was considered too close for the satisfactory operation of equipment by the twentieth year. However, when budded on other rootstocks which resulted in slower growing trees, it was sometimes satisfactory until about the twentieth year. Groves on a 25 x 25 ft spacing, popular for many years, have had to be hedged and topped to enhance cultural and harvesting operations. This was particularly true for grapefruit. The 30 x 30 ft spacing gave acceptable production between 20 and 30 years of age, but relatively low production for the first 20 years. Such plantings proved highly suited for movement of grove machinery and harvesting equipment. Plantings of 35 x 35 ft (10.67 x 10.67 m) were highly suitable for grove operations, but resulted in extremely low production in early years. It was also noted that growers who removed trees at the appropriate time, had a number of alternatives available to them. For example, a 20 x 20 ft spacing could be thinned on the diagonal at 20 to 25 years old to a 28.3 x 28.3 ft (8.63 x 8.63 m) spacing, which provided adequate spacing up to 35 years for oranges and about 30 years for grapefruit.

Data of Savage (6) from mixed groves throughout the citrus-growing area over 28 seasons (1931-59) indicated that trees of mixed citrus from 5 to 24 years of age from time of planting had maximum yields and net returns per acre where 80 to 99 trees were set per acre. After trees reached 25 years of age, spacings that resulted in fewer trees per acre gave greater production and higher net returns per acre. Tree settings of more than 80 trees per acre began to crowd at about 25-years-old, with resulting lower yields and net returns as trees attained greater age and size. Trees 40 years of age or older produced greater yields and net returns per acre with settings that placed less than 60 trees per acre of land.

The above discussion must be tempered with the realiza-
tion that prior to the 1960's, permanent irrigation was not a major factor in central Florida citrus production. Also the widely used versatile hedging and topping equipment and modified front-end loaders for tree removal were not available.

**Planting Densities in Florida**

A survey of tree-planting services indicated that current popular spacings in Florida for oranges are 12½ × 25 ft (3.81 × 7.62 m), 15 × 25 ft (4.57 × 7.62 m) and 15 × 20 ft (4.57 × 6.10 m) while those for grapefruit are 20 × 25 ft (6.10 × 7.62 m) and 15 × 25 ft (5.49 × 7.62 m). While such spacings are typical, many variations of these are used depending on grower preference. A computer printout from the 1976 Florida Crop and Livestock Reporting Service Citrus Tree Census shows spacing trends for oranges and grapefruit from 1900 through 1976 (Fig. 1). While between-row spacings have changed little over the years, the in-row spacings have definitely been reduced.

**Yield Performance of Some Higher Density Florida Plantings**

Partial yield data of some known higher density commercial plantings in Florida are shown in Table 1. Production records of many other such blocks have not been kept separate from others, and therefore, accurate figures could not be obtained.

A tree-spacing trial was initiated in 1962 at the Lake Alfred, AREC, Davenport grove. 'Pineapple' orange trees on rough lemon rootstock were planted in a replicated experiment which included 3 spacings: 10 × 15 ft (3.05 × 4.57 m), 15 × 20 ft and 20 × 25 ft. The planting established under permanent irrigation was frozen back in the 1962 freeze but recovered satisfactorily. The performance of trees at the various spacings has been reported (4, 5). Cultural practices were identical in the 3 spacings with the following exceptions: fertilizer rates were higher in the closer spacings; trees in the 15 × 20 ft spacing were pruned during the 1976-77 season; trees on the 10 × 15 ft spacing were pruned annually since 1975; and every fifth tree in the rows removed during the 1976-77 season. For the 20 × 25 ft spacing, the average returns were realized, trees became crowded too quickly, skirts were lost, and the fruiting zone moved higher into the canopy. Closer spacings were less suitable for the more vigorous scion/rootstock combinations growing in climatic areas favoring more rapid growth. Management became more difficult and problems were encountered during the picking and hauling operations. Tree densities now vary from 100 to 150 per acre and spacings of 20 × 22 ft (6.10 × 6.71 m) to 18 × 24 ft (5.49 × 7.32 m) are now quite common. Plantings are still being established at 22 to 24 ft (6.71 to 7.32 m) between rows and 12 to 15 ft (3.66 to 4.57 m) in rows. Many of the 11 × 22 ft (3.35 × 6.71 m) hedge rows of the 1950's are now thinned to 22 × 22 ft (6.71 × 6.71 m), and the 15 × 15 ft (4.57 × 4.57 m) lemon plantings thinned to 80 × 30 ft. Response to the survey was mixed, with indications that higher density plantings would again become more prevalent, but not perhaps until dwarfed tree combinations were developed.

**Planting Densities in Other Citrus-Growing Areas**

A survey was conducted by the authors to determine recent trends in citrus planting densities in major citrus-growing areas of the U.S. and world.

**California.** The trend during the 1950's was toward higher-density plantings. However, there appears to be a move under way back to wider spacings. Although earlier returns were realized, trees became crowded too quickly, skirts were lost, and the fruiting zone moved higher into the canopy. Closer spacings were less suitable for the more vigorous scion/rootstock combinations growing in climatic areas favoring more rapid growth. Management became more difficult and problems were encountered during the picking and hauling operations. Tree densities now vary from 100 to 150 per acre and spacings of 20 × 22 ft (6.10 × 6.71 m) to 18 × 24 ft (5.49 × 7.32 m) are now quite common. Plantings are still being established at 22 to 24 ft (6.71 to 7.32 m) between rows and 12 to 15 ft (3.66 to 4.57 m) in rows. Many of the 11 × 22 ft (3.35 × 6.71 m) hedge rows of the 1950's are now thinned to 22 × 22 ft (6.71 × 6.71 m), and the 15 × 15 ft (4.57 × 4.57 m) lemon plantings thinned to 80 × 30 ft. Response to the survey was mixed, with indications that higher density plantings would again become more prevalent, but not perhaps until dwarfed tree combinations were developed.

**Arizona.** Acreage planted 15 to 20 years ago was mostly developed for sale to investors and was planted 180 to 360 trees per acre. Trees were later thinned to 90, but some acreage left at 180 trees per acre. Some uncertainty about the most profitable varieties for future markets resulted in mixed double plantings, which it was felt could be thinned later when it was decided which variety would be in demand. The trend now seems back to spacings of 20 × 20 ft to 20 × 22 ft for oranges and 25 × 25 ft for lemons.

**Texas.** Planting densities changed markedly following the 1962 freeze. Orange spacings changed from 18 × 25 ft to 12 or 14 × 25 ft, while grapefruit changed from 20 × 30 ft (6.10 × 9.14 m) to 15 × 25 ft. An influx into the Texas citrus industry of management-oriented retired military personnel, willing to adopt and develop new management practices, has stimulated an increase in higher density plantings. Predictions are for more such plantings of 125 to 150 trees per acre with tree and row spacings of 10 to 16 ft.
Table 1. Yield performance of some higher density commercial citrus plantings.

<table>
<thead>
<tr>
<th>Scion/Rootstock</th>
<th>Area</th>
<th>Spacing (ft)</th>
<th>Yield (boxes/acre) for age group (yr)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>6-8</td>
</tr>
<tr>
<td>Marsh/Carrizo</td>
<td>Ridge</td>
<td>10 x 20</td>
<td>700</td>
</tr>
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<td></td>
<td></td>
<td>20 x 23</td>
<td>300</td>
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<tr>
<td>Bearss Lemon/RL</td>
<td>Flatwoods</td>
<td>10 x 23</td>
<td>300</td>
</tr>
<tr>
<td>Pa/Cleo, SO</td>
<td>Flatwoods</td>
<td>12½ x 30</td>
<td>180</td>
</tr>
<tr>
<td>Val/RL</td>
<td>Ridge</td>
<td>10 x 20</td>
<td>500</td>
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<tr>
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<td>Ridge</td>
<td>15 x 25</td>
<td>248</td>
</tr>
<tr>
<td>Pa/RL</td>
<td>Ridge</td>
<td>15 x 20</td>
<td>250</td>
</tr>
<tr>
<td>Pa/RL</td>
<td>Ridge</td>
<td>20 x 25</td>
<td>350</td>
</tr>
<tr>
<td>Ha/Cleo</td>
<td>Ridge</td>
<td>12 x 20</td>
<td>620</td>
</tr>
<tr>
<td>Val/RL</td>
<td>Flatwoods</td>
<td>18 x 14½</td>
<td>411</td>
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<tr>
<td>Cleo, SO,</td>
<td>(3-row bed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trifoliate</td>
<td>18 x 29</td>
<td>(Thinned, 2-row bed)</td>
<td></td>
</tr>
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<td>Flatwoods</td>
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<tr>
<td>Cleo, SO,</td>
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</tr>
<tr>
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<td>(Thinned)</td>
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<tr>
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<tr>
<td>Pa/SO, Cleo</td>
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<td>365</td>
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<td>(Thinned)</td>
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<tr>
<td>Queen/RL</td>
<td>Ridge</td>
<td>15 x 30</td>
<td>600</td>
</tr>
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</table>

(3.05 to 4.88 m) and 25 to 28 ft (7.62 to 8.53 m), respectively. Future disastrous freezes might accelerate this trend.

Japan. Japanese plantings have historically been of high density due to their smaller trees, limited land areas, and cooler growing conditions. Spacing has varied markedly depending on variety, terrain and soil type. From the mid-1980's, spacings changed from 12 x 12 ft (3.66 x 3.66 m) to 18 x 18 ft (5.49 x 5.49 m), and then back to 6 x 6 ft (1.83 x 1.83 m) during the post-war period. A common spacing is currently 9 x 9 ft (2.74 x 2.74 m), which may then be thinned to 18 x 18 ft when crowding occurs. The Japanese plant their groves with the intention of thinning to permanent trees later on in the life of the planting. The following is an example of how a grove might be managed with respect to thinning. A grove with about 1000 trees per acre for the first 10 years might be thinned to 500 trees for the 10 to 20-year period, to 250 trees during the 20 to 30-year period and finally to 125 trees after 30 years.

Australia. Relatively cool growing conditions result in slower tree growth in Australia compared to Florida. Many plantings are now set 22 x 22 ft although it is not uncommon to find those of 11 x 22 ft. Production during the early life of groves is low as it is in Japan. The development of small trees by the introduction of a dwarfing virus has resulted in trees being planted at densities of 400 per acre, which have not had to be thinned during the first 10 years.

Israel. Several changes in tree spacings have occurred in Israel since the 1930's when spacings of 13 x 13 ft (3.96 x 3.96 m) and 11 x 11 ft (3.35 x 3.35 m) were quite common. The original dense plantings of the 1930's have now almost all been thinned to 13 x 26 ft (3.96 x 7.92 m). During the 1950's more commonly used spacings were 13 x 20 ft (3.96 x 6.10 m), while for more vigorous combinations, spacings of 16 x 25 ft (4.88 x 7.62 m) were more common. Desert lemons planted 10 x 20 ft (3.05 x 6.10 m) were eventually thinned to 10 x 40 ft (3.05 x 12.19 m). Current trends are again towards closer spacings; however, this is dependent on tree vigor. Viral dwarfed trees are spaced 10 x 13 ft (3.05 x 3.96 m). The idea is to adapt spacing to tree growth habit and not vice versa. At present the final size of such dwarf trees and the age at which such a size will be reached cannot be assessed.

South Africa. There has been little change in tree spacings in South Africa over the past 20 years. In the cooler growing areas, spacings of 10 x 20 ft are used as opposed to 11.5 x 23 ft (3.51 x 7.01 m) in warmer areas where trees grow more vigorously. Grapefruit spacings are reported to be about 26 x 26 ft (7.92 x 7.92 m), and may...
sometimes be double planted. They are also looking experimentally at rootstocks planted at 45° angles and budded in place in the hope of producing semi-dwarfed trees. Planting distances are approx 3.3 x 5 ft (1.01 x 1.52 m) with the possibility of keeping the tree height to about 5 ft. With their production geared totally toward the fresh fruit export market, external fruit appearance and color are of primary concern. Therefore, crowding, which may reduce these qualities, is not acceptable.

_Brazil._ Commonly used spacing in citrus groves over the past 10 years has been about 23 x 23 ft (7.01 x 7.01 m). There is, however, a trend toward closer spacings for higher tree densities. Experimental results in Brazil indicate that spacings of 11.5 x 24 ft (3.51 x 7.32 m) would be suitable for greater and earlier production.

_Mexico._ New plantings established after the 1962 freeze were spaced 26 x 26 ft (7.92 x 7.92 m). On the flatland areas, this spacing is more predominant, with closer spacings on the hillsides and in mountainous areas. In some areas the 13 x 26 ft (3.96 x 7.92 m) spacing is used and some older groves set 26 x 26 ft (7.92 x 7.92 m). Indications are that 26 x 26 ft is appropriate for grapefruit with closer spacings for oranges and tangerines. As in some other areas, spacings vary with the climate, with less vigorous growing trees in cooler areas spaced more closely.

_Spain._ A commonly used spacing for Spanish citrus 10 to 15 years ago was 18 x 18 ft (5.49 x 5.49 m). Current tree spacings vary with variety planted, with 10 x 16 (3.05 x 4.88 m) and 13 x 13 ft (3.96 x 3.96 m) for Satsuma mandarins, 18 x 16 ft (3.96 x 4.88 m) for tangerine varieties such as 'Clementine' and 13 x 20 ft (3.96 x 6.10 m) or 18 x 18 ft for oranges. Indications are that increased acreages of closer set plantings will continue to be planted in Spain where suitable land for citrus culture is scarce and costly.

_Italy._ In the past, very high density plantings were common. However, new government regulations tied to grower financial aid stipulate planting distances of 20 x 20 ft or 16 x 23 ft (4.88 x 7.01 m) for lemons, and 16 x 16 ft (4.88 x 4.88 m) or 13 x 20 ft for mandarins and oranges. Many new groves are, therefore, now planted at these spacings. Experimental work is also in progress using rootstocks planted at various angles and budded in place, with the objective of obtaining higher densities of smaller trees.

**Comments on Higher Density Plantings**

Those responding to the survey shared a number of personal observations on higher density plantings.

1. Earlier production and net returns per acre are initially realized. This was especially true during the first 10 to 15 years of grove life.

2. Increasing land values, higher property taxes and their relationship to the land's future use in an urbanizing economy influence decisions on tree spacing. Higher density plantings appear more attractive if the normal producing life of the grove is expected to be shortened due to factors outside of commercial agriculture.

3. Initial capital investment is higher due to the greater number of trees, and higher costs for planting and early grove care.

4. Decisions on planting densities should also be made in relation to (a) vigor of tree (particular scion/rootstock combination); (b) climate as it relates to vigor of growth; (c) soil fertility and drainage; (d) water availability; and (e) market outlet—fresh or processed.

5. Higher density plantings should be considered in the flatwoods as fewer trees can be planted per gross acre due to land area lost for construction of canals, ditches and swales, etc. Therefore, the number of trees per planted acre should be increased. Closer in-row and between-row spacings would be preferable to planting areas along ditchbanks which lead to serious management problems.

6. Smaller and perhaps less expensive equipment can be developed for production and harvesting in such plantings. When planting a new grove and purchasing equipment, tractor size, disk, chopper, and mower widths should be compatible with grove spacing to minimize horsepower requirements. While equipment of too narrow width will require extra passes between rows, excessively wide equipment will require more horsepower.

7. More efficient use of fertilizer and water is expected due to the greater root densities per ground area. Water management is certainly an important factor as tree consumption is greater per land area under higher density plantings. Higher frequency irrigation schedules may be necessary.

8. More efficient pesticidal application may be obtained due to the greater degree of spray interception. Conversely as thick hedge rows are formed, spray coverage of inside wood becomes less efficient. As higher density groves shade out the ground area more rapidly, weed control becomes less of a factor. On the other hand, when such plantings are thinned, increased sunlight penetration and the soil disturbance results in explosive weed growth which is difficult to control.

9. It has been reported that colder temperatures have been recorded in higher density plantings due to reduced air movement. This was observed when wind machines were in operation under temperature inversion conditions (1).

10. Higher density plantings have distinct advantages where future substantial early tree loss is expected from disorders such as blight. The development of widely spaced groves with such predictable tree loss in mind is questionable. There are certain problems associated with tree removal in close plantings such as damage to adjoining trees, disruption of certain permanently installed irrigation systems, control of sprouts arising from root systems and the possible movement of nematodes if trees are being removed for transplanting to other locations.

11. If maintenance hedging is not initiated prior to crowding, later continuous heavy pruning to maintain suitable drive rows results in the removal of fruiting wood and excessive vegetative growth. This, combined with reduced light access to lower tree skirt areas results in the redistribution of the fruit-bearing surface to the upper canopy areas and loss of lower tree skirts. Some have noted that fruit color and external fruit quality or cosmetic appearance has been a problem where the fresh fruit export market is of prime importance.

12. Florida growers with high density blocks have observed unfavorable picker attitudes toward continuous hedge rows because of lack of access between rows for the individuals and their ladders. Difficulties have been encountered with picking container placement and loading, associated with which are tree limb damage and some hazard to pickers due to poor visibility on the part of the latter and vehicle operators.

13. As such blocks reach a plateau in their production and prior to the start of crowding, serious management decisions must be made and effected with respect to pruning and/or tree thinning. Such drastic decisions frequently are difficult for individuals to make, especially in years of high fruit prices.

14. To the grower selling fruit for processing, net returns on pounds of solids per acre largely reflects his management ability. Pick and haul costs substantially influence net returns. If the grove layout with respect to tree density

creates higher than normally incurred picking and road-siding costs, then net returns will be proportionally reduced.

Summary and Conclusion

Many survey respondents indicated a shortage of accurate research data on the performance of higher density plantings on which to base decisions. More experience is needed with respect to the management of such blocks as it is expected that they will have to be managed more intensively with more flexibility in present thinking. Most respondents agreed that closely-spaced groves are a move toward optimal use of natural resources such as land and water.

Information gathered from experimental and commercial and higher density plantings in Florida would indicate that in-row and between-row spacings of 10 to 15 ft and 20 to 25 ft should be considered for oranges with wider spacings for grapefruit and lemons. Such decisions will, of course, be tempered by the vigor of the scion/rootstock combination, soil fertility, climatic conditions influencing growth, and the expected life of the planting as a commercial venture.

In conclusion, note this quote from a popular article written in 1950: “As most of us live for very few 20-year periods, the average grove should be planted on a somewhat crowded basis” (3).

Literature Cited


COMPARISON OF TWO 'WASHINGTON' NAVEL PLANTINGS AT SEVERAL DENSITIES: A VIGOROUS SCION-ROOTSTOCK COMBINATION VS. A LESS VIGOROUS COMBINATION

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Additional index words. yields, fruit quality, growth rate, frost protection.

Abstract. A planting at several tree spacings of a vigorous (standard) 'Washington' navel sweet orange [Citrus sinensis (L.) Osbeck] on Troyer citrange [Poncirus trifoliata (L.) Raf. x Citrus sinensis (L.) Osbeck] was compared with a planting of less vigorous (sub-standard) scion-rootstock combination old-line 'Atwood' navel sweet orange [Citrus sinensis (L.) Osbeck] on Rubidoux trifoliata orange [Poncirus trifoliata (L.) Raf.]. Growth rates of trees of both combinations were fastest in widely spaced trees and slowest in closely spaced trees. Per tree yields were in inversely correlated with planting density in both plantings. In the standard combination, fruit color-break in the closely planted trees was as much as 10 days to 2 weeks later than in wider spaced trees. Through the eighth year there has been no effect on color-break in the standard combination. After 6 production years, the standard trees produced less than the standard trees at identical spacing.

California citrus growers have been interested in tree density since the early 1930's (7) LaRue and Rounds (8) reported that “In most orchards with standard plantings, the trees are set at the corners of squares or rectangles of such size to accommodate the trees when fully grown. The full distance allowed from tree to tree will not normally be required by the trees for 10 to 15 years, and in the meantime interplanting can often be done to advantage.” The size of a mature citrus tree in California depends upon climate, soil fertility, rootstock, scion, water quality, density, pruning and cultural practices. Citrus is grown in 4 general climatic areas of California: (a) Coastal, Santa Barbara to San Diego with relatively high humidity, cool summers and warm winters, (b) Intermediate, Riverside area with medium humidity, medium hot summers and cold winters, (c) Central Valley, Orland, Oroville and Madera to Bakersfield with medium humidity, medium hot summers and cold foggy winters, (d) Desert, Indio, Brawley and Blythe with hot summers and warm winters with long growing season. All California citrus growing sections are subject to frost damage. Frost protection equipment, consisting of wind machines and oil burning heaters, guards nearly half of California's citrus orchards.

A vigorous lemon scion and rootstock planted on the coastal area may have ample space at maturity planted 20 x 22 ft while this same combination planted in the desert would begin to crowd at 8 to 10 years. Planting distances in California citrus orchards have undergone a marked change since 1945. Earlier, planting distances averaged 22 x 22 ft. The orchards planted in 1950's or early 1960's most likely were spaced 11 x 22 ft; some orchards are more closely planted. These changes came about because growers found that steadily decreasing profit margins have made it necessary to raise net income by more efficient methods of management and production. One way to improve early returns is to plant more trees per acre, hopefully to increase production, particularly during the early years of the orchard's life when bearing volume of each tree is smaller (4, 6, 7, 10, 11, 12).

Until the last 10 years, most double set orchards presented no special problem in management. Since that time, however, many growers have had to make hard decisions on what to do about overcrowding. For some, it is too late to remove excess trees or to prune filler trees without suffering considerable loss in production while the permanent trees produce new skirt growth. One reason why so many orchards were left to crowd was the hope that hedge rows could be fitted for some kind of mechanical harvesting. Thus far,

Conversion factor, 1 ft = 0.3048 m.