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TREE TRUNK DEVELOPMENT: INFLUENCE OF SPACING AND MOVEMENT [1]

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Abstract. The spacing of container-grown *Betula verrucosa* Ehrh., *Eucalyptus sideroxylon* A. Cunn., *Dodonaea viscosa* 'Purpurea' Jacq., and *Liquidambar styraciflua* L was studied at two California locations in 1967 and 1968 As area per plant increased from can-to-can spacing, the plants grew

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1. The authors gratefully acknowledge the assistance of plants and use of facilities of Oki Nursery, Sacramento and the Saratoga Horticultural Foundation, Saratoga, California

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more in trunk caliper and taper, and in weight of roots and branches plus leaves, but less in height and weight of trunk. At the closest spacings, the lower foliage was sparse giving the trees a leggy appearance. Adequate spacing, about twice the can-to-can area, the first season gave benefits of of increased trunk caliper and fuller foliage with a minimum sacrifice in height growth

Greenhouse trials with *Liquidambar* and *Zea mays* suggest that the greater height growth of closely-spaced plants may largely be due to less movement. Height growth was reduced at least 50% by a daily, 30-second period of trunk motion

Spacing and arrangement of containers commonly used in commercial nursery production is the least area consistent with ease of providing adequate care. This usually results in placing plants can-to-can in beds of several hundred containers, particularly those in gallon cans Larger containers are usually closely spaced in 2- or 4-can rows with narrow aisles between.

Field spacing of forest (11, 12), fruit (1, 2), and vegetable (8, 9) crops has been extensively studied. Trunk diameter growth of forest and fruit trees increased as the space per plant increased. As the more closely spaced trees began to crowd, the lower foliage weakened and died (1). Tree height did not appear to be greatly affected at the spacings used (1, 11). Yield per plant, but not per acre, was increased as the space per plant increased (1, 8, 9).

Tree height and caliper growth of nursery-grown trees determines in large measure their monetary value as well as how well they will be able to stand upright in the landscape (4). Earlier observations of the lack of response of pruning treatments of close-spaced container-grown trees, raised the question of the influence of spacing on trunk development of young trees.

MATERIALS AND METHODS

The spacing study was carried out at Oki Nursery in Sacramento County and at the Saratoga Horticultural Foundation in Santa Clara County, California. Peat-pot liner seedlings of *Betula verrucosa* Ehrh., European white birch, and *Eucalyptus sideroxylon* A. Cunn., eucalyptus or mulga ironbark were supplied by Oki Nursery. *Dodonaea viscosa* 'Purpurea' Jacq., purple leaved dodonaea, and *Liquidambar styraciflua* L., liquidambar or sweetgum, were supplied by the Saratoga Horticultural Foundation.

The study was started in late June and early July of 1967. The trees were planted in gallon cans and placed in blocks having spacings of 18, 25 and 35 cm on center. These spacings gave surface areas per plant of about 300, 600 and 1200 cm^2 or area relationships of about 1 (can-to-can spacing), 2 and 4. Six plants were in a replicate at each spacing with each replicate being surrounded by guard plants at the appropriate spacing. There were 3 replicates of each treatment. If necessary, individual trees were tied loosely to a short stake that protruded about 10 cm above the soil to hold the trunk in an upright position.

In December, 1967, the plants were moved into 4-gallon (egg) cans at Sacramento and into 5-gallon cans at Saratoga (both will be referred to as 5-gallon cans). The spacings were increased to 25, 43 and 60 cm on center. These spacings gave areas of about 600, 1800 and 3600 cm^2 or area relationships of about 1 (can-to-can), 3 and 6.

To reduce the influence solar radiation might have on soil temperatures at the different can spacings, the gallon cans were surrounded with wood shavings to the can top. The 4-gallon cans had a shiny enamel finish that was considered adequate to reflect sunlight. The 5-gallon cans were painted with a white latex paint. No additional protection was given these cans. During the two growing seasons the lateral branches along the trunks were pinched several times beginning when their tips were 5-7 cm beyond the edge of the cans. Except for the lateral pinching and the elimination of staking, the plants received regular nursery care.

At the beginning of the experiments, after the first growing season and at their conclusion the second year, the trees were measured for height and for caliper at 5 and either 105 or 155 cm above the soil line. Since plants at the different 5-gallon spacings were different in caliper at the start because of their previous spacing, trunk growth is expressed on an area-increase basis. Taper, decrease in caliper with height, was determined by dividing the difference in trunk diameters by the difference in the heights at which the diameters were measured and expressed as mm / m. At the end of the experiment at Sacramento and Saratoga, the height of each node was recorded. The birch, dodonaea and liquidambar grown at Sacramento were sacrificed and partitioned into three portions; roots, trunk and laterals plus leaves. The fresh weight of each was determined.

The birch and eucalyptus trees were ready for sale or moving to larger containers at both locations in late June, 1968. These species were measured at that time and removed from the experiments. The dodonaea and liquidambar at Sacramento were removed in early July while these two species at Saratoga remained in the experiment until the end of the 1968 growing season.

RESULTS AND DISCUSSION

Height and trunk area growth was 15 to 20% greater at Sacramento than at Saratoga for the four species at the widest spacings. These differences were probably due to the high rates of fertilization and warm, sunny spring weather at Sacramento compared to that at Saratoga. The species responded similarly to the spacing treatments at the two locations. Liquidambar was the only exception as noted later.

As spacing increased, the plants increased in caliper (trunk area) and taper, improved in appearance, but made less height growth, Figs. 1 and 2. At the closest spacing, the lower foliage was heavily shaded and much of it dropped off. These trees were not as attractive as those given more space. This is shown in Fig. 2.

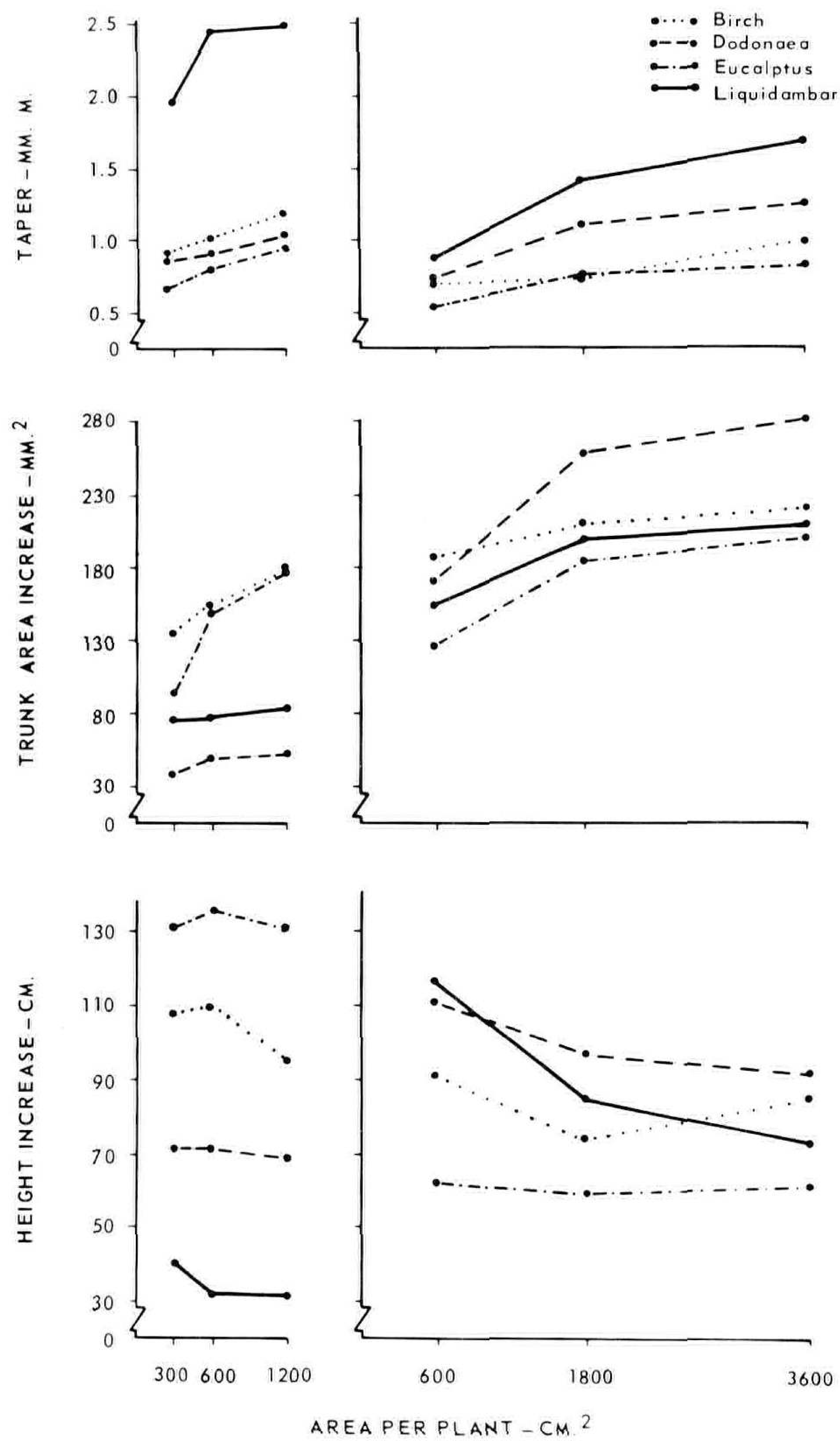

Fig. 1. **Influence of area per plant on trunk-area and height increases and the taper of four species of trees in 1-gallon (1967) and 5-gallon (1968) containers at Sacramento and Saratoga, California.**

Increasing the area per plant had less effect on the height of the trees the first season in the gallon cans than it did the second year when they were in 5-gallon cans. However, trunk area was increased on the average 30% both years when the can-to-can area per plant was increased to the intermediate spacing. Since taper is a height-caliper relation it, therefore, was more greatly influenced during the 5-gallon than during the 1-gallon stage.

The effect on height and trunk-area growth and taper was greater between the intermediate versus can-to-can spacing than was the effect between the maximum and the intermediate spacing, Fig. 1.

Fig. 2. Influence of area per plant on liquidambar at Sacramento, (left to right): 3600, 1800 and 600 cm^2 per plant, 1968.

Of the four species, liquidambar was most affected in height growth and taper by increasing area per plant. Eucalyptus and dodonaea were most affected in trunk-area growth. In the 5-gallon can, dodonaea also was markedly influenced in the degree of taper by the amount of area per plant.

Increasing the space per plant increased the weight of roots and branches plus leaves, but decreased the weight of the trunk slightly, particularly of dodonaea and liquidambar, Fig. 3. Apparently a higher proportion of tissue formed in the roots and branches of trees with greater space, while the closest-spaced trees grew taller and had less taper. This resulted in a greater volume of wood which caused the trunks of the closest-spaced trees to weigh more than the trunks of the trees grown with greater spacing.

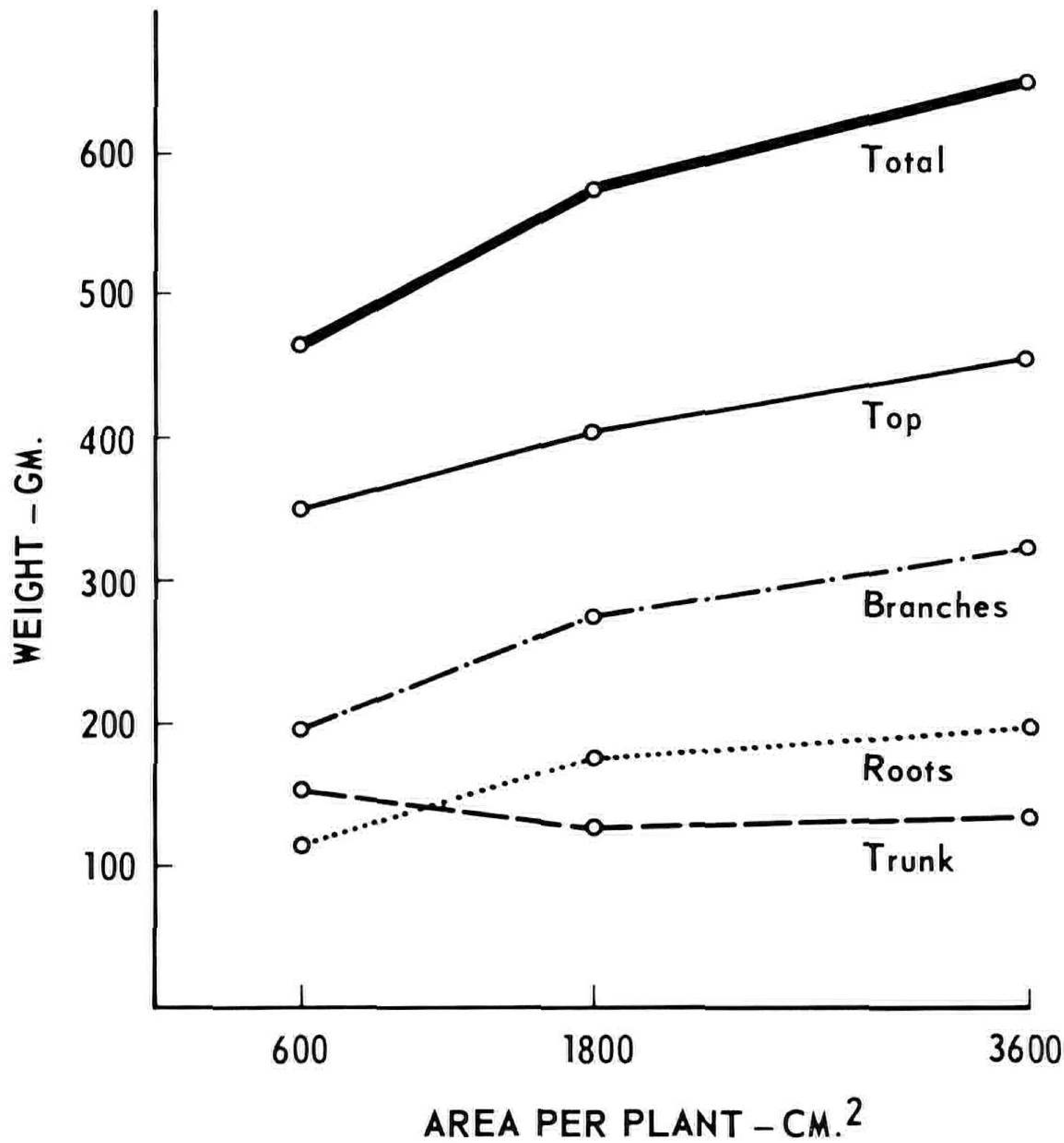

Fig. 3. Influence of area per plant on the fresh weight of different parts of liquidambar at Sacramento, 1968.

Internode length of the 1-gallon-size plants was little affected by spacing. With 5-gallon-can plants internode length of birch, dodonaea and eucalyptus was increased at the closest spacing, though not significantly. However, the closest-spaced liquidambar plants formed significantly more nodes and had longer internodes, Fig. 4.

At Saratoga, the internodes of the closest-spaced liquidambars began to be longer than those of plants with greater spacing after 6 nodes had formed in 11 cm of new growth (total tree height of 68 cm), Fig. 4. The intermediate spacing began to have an apparent effect on

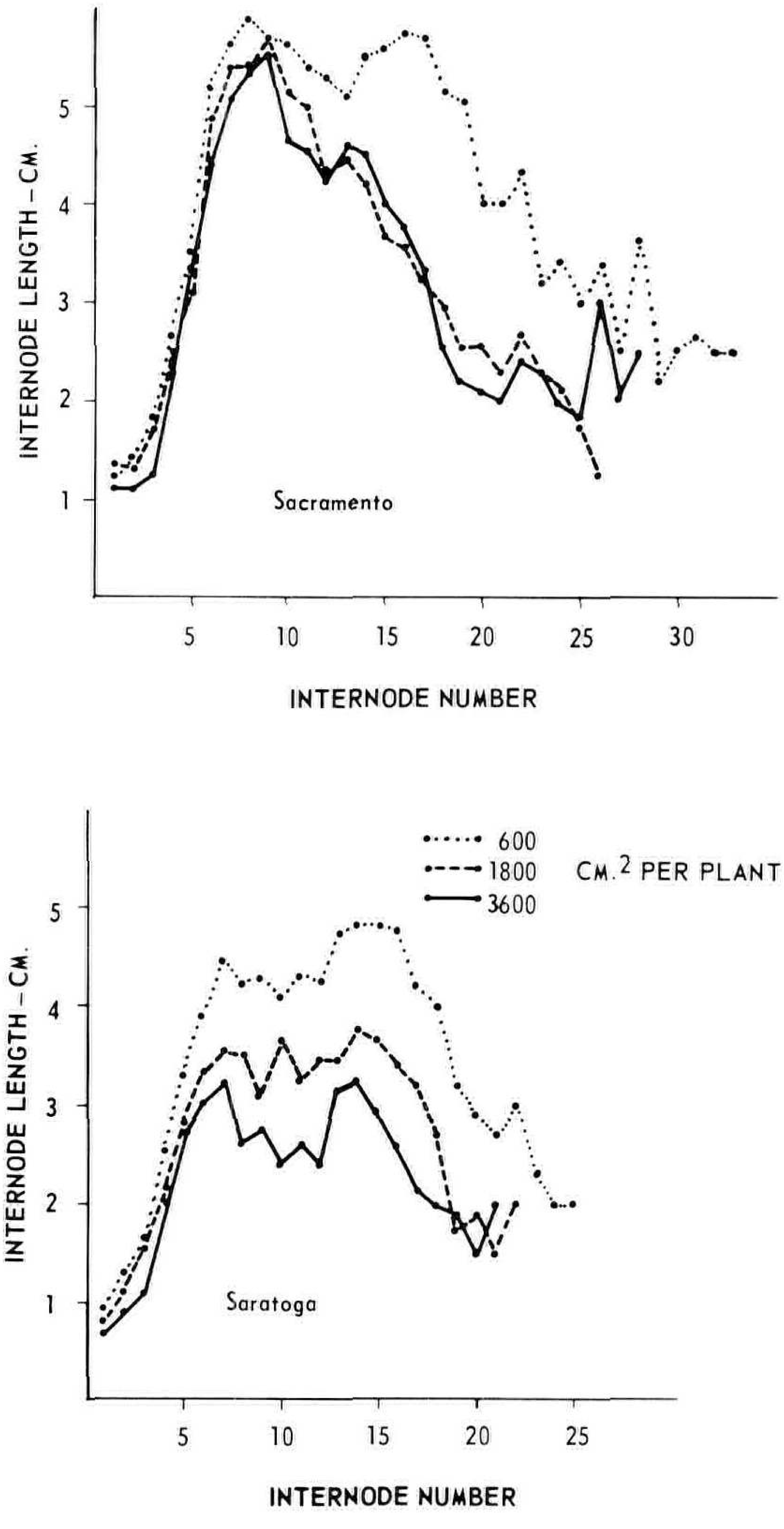

Fig. 4. Influence of area per plant on liquidambar internode length and number at Sacramento and Saratoga, 1968.

internode length after 8 nodes had formed in 16 cm of new growth (total height of 60 cm). At Sacramento, differences in internodal length of the closest-spaced liquidambars were not evident until 14 nodes had formed in a total of 56 cm of new growth (total tree height of 104 cm). Little or no difference in internode length occurred between plants at the intermediate and the greatest spacings at Sacramento.

The Sacramento-grown liquidambar produced a great number of leaves and made more height and trunk caliper growth by July 9 when the trees were withdrawn from the experiment than did those at Saratoga during the entire 1968 growing season. However, by July 9 at Sacramento, the growth rate had declined to 40% of its maximum, with a reduction in differences between the internodal length of trees at different spacings, Fig. 4. At Saratoga, length of newly formed internodes remained fairly uniform throughout the summer although they were shorter than at Sacramento. The initial high rate of growth at Sacramento was probably the result of high rates of fertilization, high light flux and warm spring weather. The decline in growth rate may have been due to an interaction between water stress brought on by the large leaf area per plant, an increasingly restrictive root system, and the hot, dry, summer weather. On the other hand, Saratoga is subject to morning overcast and cooler temperatures during the spring and summer. This and lower nutritional levels could account for the differences observed between the two locations.

Although these experiments demonstrated the influence of spacing on tree growth, they did not reveal which of the probable causes might be responsible. Maximum height of many plants is attained at intensities considerably below that of full summer sunlight (10). If reduced light intensity was a factor, then the stimulus must come from the lower portion of the plants, since the region of stem elongation of the plants, particularly of liquidambar, was equally exposed to light regardless of the spacing. Experiments to determine effects of light on low foliage have been inconclusive (7).

Transpiration also may affect stem elongation depending on plant spacing. Transpiration of plants at the greater spacings may be increased due to greater exposure to radiation, greater air movement and more leaves than plants closely spaced. Water deficits may be more frequent and severe on plants at greater spacings. Shoot growth of such plants would be reduced (5).

Reduced movement of the region of shoot development and elongation of closely-spaced trees may be responsible for their greater height growth. Staked trees which were less free to move, grew taller than unstaked trees (4). Liquidambar has been shown to be sensitive to brief periods of motion which caused a decrease in node production and internode length (6). Trunk motion as influenced by tree spacing could account for the differences observed at each location.

The influence of trunk motion on shoot growth is being studied further. Experiments now underway with liquidambar and corn, *Zea mays* 'Golden Bantam', confirm the marked reduction in stem elongation caused by a daily short period of stem movement, Fig. 5. Growth of liquidambar and corn in a greenhouse was reduced 50% by a daily, 30-second period to trunk motion (plants were held at about half their height (at about 50 cm) with one hand and moved back and forth about 10 cm two to three times per second).

Fig. 5. Terminal growth of liquidambar as influenced by shaking for 30 seconds daily for 40 days (left): not shaken (right): Arrows indicate height of plants when treatment started on August 18, 1971.

This may seem to be only of academic interest, but it may offer some interesting possibilities in nursery production. One problem is that seedlings are often left in the seed flat and first liner pot so long their trunks become tall and spindly. A short period of motion either by moving the flat or using air might result in sturdier plants more tolerant to transplanting. Such studies are now underway.

Further experiments will be needed to determine the mechanism responsible for greater stem elongation of closely-spaced trees.

Adequate spacing the first season gave benefits in the form of increased trunk caliper growth with a minimum sacrifice in height growth. It appears, Figs. 1 and 2, that there was little benefit in using a spacing greater than the intermediate area (600 cm^2 for gallon cans, 1800 cm^2 for 5-gallon cans). A slightly closer spacing than the intermediate might give adequate plant development with more economical use of space In these experiments, the containers were placed in a square arrangement. However, for practical nursery operations, the plants might be better arranged in double rows (preferably in a north-south direction) with greater spacing between than within rows. The spacings used by some nurseries approximate the intermediate spacings of these experiments.

Equally important as spacing, would be moving the plants to larger containers at greater spacing before the plants reach a size that would begin to adversely affect their development. Internode length at Saratoga was influenced between each of the three spacings but only between the intermediate and closest spacings at Sacramento. Therefore, it would appear that trees in the interior valleys could be spaced closer than those grown in the coastal valleys.

Container spacing and arrangement and time of transplanting to larger containers for most efficient use of land in keeping with other nursery practices need more study.

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MODERATOR FURUTA: This has been a most stimulating and thought-provoking discussion by these two gentlemen. Now, I am sure we will have several questions.

BOB WARNER: You had different growth in the two different locations. Was one more windy than the other, maybe? You would have some influence due to this.

RICHARD HARRIS: Of course, I was going under the naive assumption that light was going to be the factor involved and so we really don't have any accurate observations of what the wind conditions were. However, I think that possibly wind could have been the factor that would separate these out. But again we don't have careful observations on this. We need to get back to this.

BOB WARNER: Well, the shorter plants would be stronger, wouldn't they?

RICHARD HARRIS: We assume they will. Now again, we've only carried these trials on for 40 days or so. There is an increase in the trunk diameter from this and so again it would go back that we would feel that the shorter plant, greater taper, greater base development, would be more upright. In fact, this may have an implication in seedling production in the seed flat and in the peat pot. There is a tendency to leave them too long; they become leggy, they're not very stable. It could be that there might be a way of not shaking the plants individually, but maybe as a group—which would cause them to be shorter and make them more sturdy.

BOB WARNER: It would be interesting to determine the yield of the corn. There is a tendency now for developing shorter strains of corn and increasing the yields.

RICHARD HARRIS: Right, well this is due to genetic differences

VOICE: What would be the advantage of raising bonsai plants on a vibrating table?

RICHARD HARRIS: You've got yourself a project!

DAVID RUDÉ: Dr. Hess, please. What about the use of a complete fog system for propagation, a closed system? What is the maximum temperature you have found you can use within such a system? What are the results on the speed of rooting?

CHARLES HESS: One of the systems I didn't describe, one that was used even before mist was introduced, was the Bink's system of propagation, which essentially consisted of a source of water with a stream of air. Well, it is a sort of atomizer, which again is almost like a humidifier, providing a fog within the greenhouse. We put this sort of a system, when I was at Cornell with Bill Snyder, into a plastic tank. It was like a steam bath effect; the temperatures in there would get up to about 120° F. or so and things seemed to move along quite well. Now what the maximum temperature could be, I can't say because you have to consider air temperature and leaf temperature. Leaf temperature may be a little bit lower under these conditions than the air temperature. The Phytotektor system also would give about 120° F. air temperature inside. Under these conditions of very high water supply, a film of water on the leaves and then, as a result also a very high rooting medium temperature, the rate of root initiation on the cuttings was very, very good.

DAVID RUDÉ: In regard to the Phytotektor System and the Bink's Fog System—what was the bottom heat in each?

CHARLES HESS: In each of these two cases there was no bottom heat. You just depend upon the high temperature within the chamber itself to also raise the rooting medium temperature. Now as far as medium temperatures are concerned, we use as a working guideline, because we have the same problem that individual species will vary—about 75° F. rooting medium temperature. I would say we shoot for this as a broad spectrum figure.

I would like to ask Dick Harris a question. Since, in some of your earlier studies, you were working with the role of ethylene synthesis and so forth, do you feel that ethylene is involved in the responses that you were seeing in your experiments?

RICHARD HARRIS: I think very definitely that this is something that we need to follow up; it seems like ethylene may be involved in the mechanism here, and possibly even growth retardants may act.

I would like to go back and maybe give you a take-home message on this plant spacing; that is—what spacing should you use? This is on trunk area increase with area per plant. You notice we obtained, as I mentioned earlier, the greatest increase from the closest spacing to the intermediate and then not quite so much as we go to the greater spacing. Possibly an intermediate spacing might be reasonable to consider in spacing the plants so as to get an increase in trunk area without too much of a sacrifice in tree height. This intermediate spacing for the 5-gallon container was 17'' on centers. This was a square layout. In a nursery, of course, you'd probably want to go to a rectangular layout, which would be more efficient for the various other operations in the nursery. But something that would be at this spacing—area per plant—or just a little bit less, might be a reasonable place to start.

HERMAN SANDKUHL: Do you know why the corn or the *Liquidambar,* after shaking, had a much better green color?

RICHARD HARRIS: I don't. The first time we did this we weren't aware of the difference in color. Maybe we just didn't pick it up. It could be that actually there is not as much growth being made, so the nitrogen that is there—and these were fertilized every time that they were irrigated—is available in greater amounts to the leaves that were there. It's sort of interesting that even the old leaves that were on the plant before the shaking started, also greened up. I don't have a specific answer on that, however.

CHARLES HESS: Your analogy to the growth retardants also carries through because plants which have been exposed to B-9 or other growth retardants generally are more green than the controls.

MODERATOR FURUTA: We should go on now to the subject that has been listed on the program as "What is New in Soil Mixes for Propagation and Containers". We have three gentlemen who will address themselves to this topic for a while and then we will open it up to discussion. I want Drs. Hess and Harris and Leiser to be around then because we will direct questions to them, too, as the opportunity comes. The first speaker is Dr. Jack Paul, of the Department of Environmental Horticulture at the University of California, Davis. He has been doing considerable work in this area of soil mixes. Jack Paul:[1]

MODERATOR FURUTA: Thank you, Jack. You'll have a chance to ask questions and to continue this discussion after we hear from the other speakers. Next is a colleague of mine with the University of California Agriculture Extension Service, a soils and water specialist, Dr. Roy Branson from the University of California Riverside Campus. Roy:[2]

[1] Ed Note Dr Paul discussed some of his studies in soil fertility.

[2] Ed Note. Dr Branson presented some of his concepts of soil mixes and plant nutrition.

MODERATOR FURUTA: Thank you Roy. Our third speaker on the panel is Mr. O. A. Matkin. He has been involved in the area of soil mixes for probably more years than he's willing to admit at this time. Matt:

SOIL MIXES TODAY

O. A. MATKIN

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In the last 10 years there really haven't been any new innovations. There has been a great deal of change from systems "by guess" to systems "by design." It was well over a decade ago that a "system" was proposed. The purpose at that time was to remove guesswork, chance, and frequent misfortune from the procedure of growing plants, particularly in containers. Since that time there has been a startling and worldwide change in philosophy and procedure in the preparation and handling of growing media. Although the approach has fostered the use of ingredients which contain *no* soil, its utilization has led to greater understanding and more intelligent use of "natural" soils.

Reference is made, of course, to the UC System of Producing Healthy Container Grown Plants. It is still available as *Manual 23* from Agricultural Publications, University of California, Berkeley, California

The early development of suitable growing media for containers was greatly hampered by man's inability to recognize the fundamental differences between field and container growing. Too much emphasis was placed on fertility and too little on soil structure.

The modern grower recognizes that the soil mix is comprised of both physical and chemical properties and is not the complete answer to all of his production problems. He has become increasingly aware of the influence of the many other environmental factors. The very best soil mix can still leave the door open to disaster if sanitation, for instance, is disregarded. This philosophy was the principal purpose of the UC system approach. There are many adaptations of this basic approach that are currently in popular use. These are briefly reviewed as follows:

Container nurserymen have generally leaned toward media high in low cost organic materials such as sawdust or bark, blended with sand or sandy loam. This results in a lightweight mix for economy in shipping and also has substantial advantage in ease of maintaining low salinity because of high water infiltration rates. The physical properties of these mixes are conducive to excellent root growth.