shade, you can, perhaps, get a little closer to the optimum set of environmental conditions.

FRANCES SPAULDING: I wonder if you have any idea where ethylene fits into the picture of root initiation.

CHARLES HESS: It had been observed for many years, before ethylene became a very fashionable thing to study in plant physiology, that ethylene did stimulate root initiation. A good example is tomatoes. If tomatoes are exposed to a low quantity of ethylene, then lots of roots form up and down the stems; there are people who are suggesting that the effect of an auxin in stimulating root initiation is in injuring the tissues a little bit so that they will produce ethylene. It's ethylene that's doing the job as far as root initiation is concerned. At this point, I'm not really prepared to agree with that — but I can't disagree with it, either.

MODERATOR FURUTA: Our next topic will be, as presented in the program, Staking, Pruning and Spacing. And with this I think the speakers have a wide latitude; you could go almost anywhere. So I should like to introduce at this time two gentlemen who need no introduction to this group, Dr. Andy Leiser and Dr. Richard Harris.

TREE TRUNK DEVELOPMENT: INFLUENCE OF STAKING AND PRUNING[1]

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Abstract. Trunk development of young container-grown trees was strongly influenced by pruning and staking practices. Trees were produced which were able to stand without support when planted in the landscape This was done by eliminating stakes, leaving lateral branches on the trunk and spacing plants so their tops were free to move Even though rigidly-staked trees

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with their lower limbs removed grew taller, they developed less caliper at the trunk base, much less taper to the trunk and a smaller root system. Most of the trees staked during production were not able to stand upright when planted out.

The program topic: staking, pruning and spacing will be divided into two sections. I will discuss staking and pruning experiments conducted by Dr. Richard Harris, Richard Maire and Bill Stice, Dwight Long, Lanny Neel and me at ABC Nursery in Gardena, Oki Nursery in Sacramento and Saratoga Horticultural Foundation and at the University of California at Davis. The pruning and staking experiments were triggered in part by studies done in cooperation with Dr. John Kemper, School of Engineering at UCD, which showed that a sapling tree with a well tapered trunk had more uniform stress distribution than one with a non-tapered trunk.

But why should the development of the plant concern the plant propagator? In my remarks at the opening session I alluded to the "Compleate Propagator"—a propagator concerned with the end product as well as one just concerned with putting roots on a cutting. So we would like to share with you some ideas on how to put a trunk on a tree

With the advent of container production of trees in nurseries, changes in traditional cultural practices developed. These changes include closer spacing, removal of lower branches to facilitate watering and spraying and staking to prevent lodging. One result of these changes is that many trees so produced are unable to stand erect without long periods of staking when planted in the landscape. Such staking is costly and frequently results in severe damage to trunks and limbs unless staking is done carefully and is frequently inspected.

Environmental effects on wood formation and stem form have been reported by Larson (5, 6). Using low-light intensities for extending daylength, he demonstrated that both leaves and terminal buds exert an indirect control on wood formation in red pine in addition to the direct contribution of photosynthates. With Tamarack (*Larix laricina* (duRoi) K. Koch.), wind movement increased radial growth and tracheid development and decreased internodal growth. Bud and lateral branch removal decreased internodal and radial growth and tracheid development in both free-swaying and staked trees.

Trees growing in dense forest stands are prone to windfall when surrounding trees are cut (3). They are taller, have less trunk caliper and taper (i.e. decrease in caliper per unit of height) than similar trees growing in the open (1, 8). Jacobs reported that 16-year-old Monterey pines which were guyed for two years made less than 70% as much new caliper growth as trees not guyed. "After two years, trees that had been prevented from swaying were no longer stable in a normal environment." (8). Rigid staking of young myoporum trees in the

landscape resulted in trees which were taller but which had less trunk caliper and taper than trees not staked (4).

Stress distribution is much more uniform in tapered than in non-tapered sapling trunks (4). The inability of many container-grown trees to stand upright in the landscape was thought to be aggravated by rigid staking during nursery production (9).

In nature, however, trees usually develop trunks capable of standing erect.

Young tree trunks have been strengthened and leader growth retarded by leaving lateral branches on the trunk (2, 4). This is contrary to usual California nursery and landscape practice.

This experiment was designed to study the effects of the staking and pruning on trunk development of young trees.

MATERIALS AND METHODS

Nine species of trees having varying growth habits, commonly grown in California were used. These were: *Eucalyptus sideroxylon* A. Cunn., mulga ironbark; *Fraxinus uhedei* Longelsh., Shamel ash; *Grevillea robusta* A. Cunn., silkoak; and *Schinus terebinthifolius* Raddi., Brazilian pepper at ABC Nursery, Gardena, Los Angeles County; *Betula verrucosa* Ehrh., European white birch, and *Eucalyptus sideroxylon* at Oki Nursery, Sacramento; and *Eucalyptus polyanthemos* Schauer., round-leaf eucalyptus; *Liquidambar styraciflua* L., liquidambar or sweetgum; *Pistacia chinensis* Bunge., Chinese pistache; and *Quercus ilex* L., holly oak at Saratoga Horticultural Foundation in Santa Clara County.

The four treatments were: (1) rigid staking with the laterals removed on the lower half of the trunk (conventional nursery practice), (2) rigid staking with the laterals headed to 20-25 cm on the lower half of the trunk, (3) no staking with the laterals headed to 20-25 cm on the lower half of the trunk and (4) no staking and no pruning. Heading was to be a relative soft pinch, removing 5-10 cm, but often more was removed due to the vigorous growth. Eight trees of each species were used per treatment. Treatments began in early July, 1967 just after the trees had been transplanted from 1-gallon cans to 5-gallon or egg cans. Staked trees were tied to 2½ x 2½ x 153 cm (1 x 1 x 60 in.) stakes and unstaked trees were tied to short stakes, 10 cm above the soil level until new root growth stabilized them in the larger containers. The containers were set 60 cm on center to allow free movement of the top and for sunlight to penetrate between the plants. Pruning and tying was done every 3 to 4 weeks during the growing season. The leaders of the staked trees were tied every 15-20 cm along the stake as they grew. The height to which the laterals were pruned each time was increased so that laterals on the lower half of the trees were either headed or removed

At the start of the experiment and again in December 1967, the trees were measured for height and for caliper at the can top (about 5 cm above the ground). In order to determine taper, at the second date trunk caliper also was measured at 150 cm above the can top for staked trees 170 cm or more tall. For staked trees less than 170 cm tall and for all unstaked trees the upper caliper measurement was made 20 cm below the tip. Taper, expressed as mm diameter decrease per meter of height was calculated by the formula:

$$\text{taper} = \frac{\text{diameter difference in mm}}{\text{height difference in mm}} \times 1000$$

In early 1968, the fresh weight of roots and tops were taken for each of 4 trees from each of the 4 treatments for 6 of the 9 species (Table 3).

RESULTS

By comparing lightly-pruned (laterals headed) trees, staked and unstaked; staked trees, severely- (laterals removed) and lightly-pruned; and unstaked trees, lightly-pruned and not pruned, the influences of these several cultural practices can be separated.

Effects of staking: The staked and unstaked, lightly-pruned treatments showed that staking increased height and decreased caliper growth (and hence decreased taper) markedly of 8 of the 9 species (Table 1, Fig. 1). Those staked made 25% more height growth, 15% less caliper growth and their taper was 24% less (Table 2). A number of the staked trees had greater caliper near the top of the stake than at the base, as did the staked tree in Fig. 2. The Brazilian pepper was the only exception of the 9 species to the influence of staking in that staking had little or no influence on growth.

The root systems of the staked trees (Table 3, col. 2 and 3) tended to be lighter in weight than those not staked in 5 of the 7 sets of trees measured, although differences were not significant.

At the end of the growing season, almost all of the trees that had not been staked stood upright without support while most of the staked trees could not (Fig. 2).

Table 1. Height and caliper increases and taper of nine species of container-grown trees subjected to differential pruning and staking for 5 months.[x]

	Staked		Unstaked	
	Pruning treatment of Laterals			
Species, location[y] response	Removed	Headed	Headed	Unpruned
Betula verrucosa — Oki				
Height increase, cm	101a[z]	104a	85a	57b
Caliper increase, mm	7.8a	8.9ab	9.9ab	10.4b
Taper, mm / m	7.8a	8.2a	9.6a	13.2b
Eucalyptus polyanthemos — Saratoga				
Height increase, cm	149a	148a	107b	81b
Caliper increase, mm	9.0a	10.7a	12.7b	14.0b
Taper, mm / m	4.0a	4.1a	6.5b	11.3c
E. sideroxylon—Oki				
Height increase, cm	126a	134a	84b	76b
Caliper increase, mm	6.8a	7.2a	9.8b	12.8b
Taper, mm / m	4.6a	5.7a	8.7b	10.3b
E. sideroxylon—ABC				
Height increase, cm	144a	136a	126a	97b
Caliper increase, mm	7.8a	8.8a	9.6a	12.0b
Taper, mm / m	4.8a	5.7a	7.0a	12.4b
Fraxinua uhedei — ABC				
Height increase, cm	158	159	140	133
Caliper increase, mm	19.3	18.2	20.5	21.2
Taper, mm / m	8.9a	9.1a	13.8b	14.1b

[x]**Treatments**

Staked — trunk tied to a 1 x 1 x 60'' stake.
Unstaked — trunk not tied to a stake.
Removed — laterals on lower half of trunk removed during season.
Headed — laterals on lower half of trunk headed during season.
Unpruned — laterals on trunk not pruned.

[y]**Locations**

ABC — ABC Nursery, Gardena, Los Angeles County
Oki — Oki Nursery, Sacramento.
Saratoga — Saratoga Horticultural Foundation, Santa Clara County.

[z]Values on any line followed by different letters differ significantly at the 0.05 level or higher according to Duncan's multiple-range test.

continued

Species, location[y] response	Staked		Unstaked	
	Pruning treatment of Laterals			
	Removed	Headed	Headed	Unpruned
Grevillea robusta — ABC				
Height increase, cm	135a	135a	122b	122b
Caliper increase, mm	9.5a	11.6b	14.2c	13.5bc
Taper,mm / m	7.8a	9.7b	12.5c	11.7c
Liquidambar styraciflua — Saratoga				
Height increase, cm	113a	95b	81b	60c
Caliper increase, mm	8.5a	9.3ab	10.8c	9.9bc
Taper, mm / m	6.7a	8.0ab	9.5bc	11.2c
Pistachia chinensis — Saratoga				
Height increase, cm	101a	107a	69b	58b
Caliper increase, mm	4.5a	4.3a	6.4b	4.9ab
Taper, mm / m	4.4a	3.3a	7.1b	7.5b
Quercus ilex — Saratoga				
Height increase, cm	68a	88b	71a	63a
Caliper increase, mm	3.4a	4.4b	5.4b	6.4c
Taper, mm / m	7.3a	7.1a	8.4a	10.6b
Schinus terebinthifolius — ABC				
Height increase, cm	127a	119ab	109b	95c
Caliper increase, mm	13.6	14.4	13.6	11.6
Taper, mm / m	10.1	11.7	11.6	11.0

Effects of pruning—removal vs. heading: Comparisons between the severely- and lightly-pruned staked trees showed little or no effect on height growth except with liquidambar which grew significantly taller and holly oak which grew significantly less when severely pruned (Table 1). However, lateral removal reduced caliper growth in 5 of the 10 comparisons 11% or more (significantly in silkoak and holly oak) but had little or no effect on the others. Removal of laterals also resulted in 14% or more reduction in taper in 5 of the 10 comparisons. Only Chinese pistache had substantially greater taper when severely pruned though not significantly so. These variable results may reflect inherent differences between species in branching habit and response to pruning. Shamel ash does not branch on current growth so there were no laterals to prune. Chinese pistache and holly oak had sparse and variable branching. The other species had abundant laterals.

Fig. 1. Round leaf eucalyptus 5 months after starting the staking and pruning treatments. Left to right, Staked — lower laterals removed, Staked — lower laterals headed, Unstaked — lower laterals headed and Unstaked — unpruned.

Root systems of the staked trees were smaller in 6 of the 7 sets of trees measured when the lower laterals were completely removed compared to heading but only significantly so in the mulga ironbark grown at Oki Nursery.

Heading vs. no pruning: The lightly-pruned vs. unpruned treatments (unstaked) showed greater growth differences than the severely-pruned vs. lightly-pruned treatments (staked). Heading the laterals along the lower half of the trunk produced taller trees in all species except silkoak. The mean increase of 21% for all species was significant. The response in caliper growth was variable. Caliper was significantly reduced in mulga ironbark at both locations and in holly oak. Although caliper increase in Chinese pistache and Brazilian pepper was greater than 15%, it was not significant. Heading, compared to no pruning, reduced taper 15 to 44% in 6 comparisons and had little effect in the other 4. The reduction of 16% for all species was significant.

The effects of heading vs. no pruning on root weights was also pronounced. Of the 7 sets of trees examined, 6 had larger roots in the unpruned treatment, two significantly so.

Table 2. Relative influence of staking and pruning trunk laterals for 5 months on height, caliper and taper of container-grown trees.[x]

Species, location[y]	Staked / Unstaked[z]			Staked			Unstaked		
	Laterals Headed			laterals Removed / Headed			laterals Headed / Unpruned		
	Height %	Caliper %	Taper %	Height %	Caliper %	Taper %	Height %	Caliper %	Taper %
Betula verrucosa — Oki	122	90	85	97	88	95	150 *	95	73 * *
Eucalyptus polyanthemos— SHF	138 *	84 *	63 * *	100	84	98	133	91	58 * *
E. sideroxylon—Oki	158 * *	73 * *	66 *	94	94	81	110	77 * *	84
E. sideroxylon—ABC	108	92	81	106	89	84	130 *	80 *	56 * *
Fraxinus uhedei— ABC	113	89	66 * *	99	106	98	106	97	98
Grevillea robusta—ABC	110 *	82 * *	78 * *	100	82 *	80 *	100	105	107
Liquidambar styraciflua—SHF	117	86 *	84	119 *	91	84	136 *	109	85
Pistachia chinensis—SHF	154 * *	67 *	46 * *	95	105	133	118	131	95
Quercus ilex—SHF	125 *	81	85	76 * *	77 *	103	113	84 *	79 *
Schinus terebinthifolius—ABC	109	106	101	107	94	86	115 *	117	105
Mean	125 * *	85 *	76 * *	99	91	94	121 * *	99	84 *

[x]**Treatments**

Staked — trunk tied to a 1 x 1 x 60" stake
Unstaked — trunk not tied to a stake
Removed — laterals on lower half of trunk removed during season
Headed — laterals on lower half of trunk headed during season
Unpruned — laterals on trunk not pruned

[z]Comparisons are between treatments in CAPITALS and are expressed as percentage that the first is of the second, e g $\frac{\text{staked}}{\text{unstaked}} \times 100$

[y]**Locations**

ABC — ABC Nursery, Gardena, Los Angeles County
Oki — Oki Nursery, Sacramento
SHF — Saratoga Horticultural Foundation, Santa Clara County.

* Treatments significantly different at the 0 05 level or higher

* * Treatments significantly different at the 0.01 level or higher

Table 3. Fresh weight of roots of six species of container-grown trees subjected to differential pruning and staking for 5 months.[x]

	Staked		Unstaked	
	Pruning treatment of laterals			
Species, location[y]	Removed	Headed	Headed	Unpruned
	gm	gm	gm	gm
Betula verrucosa — Oki	408	442	458	405
Eucalyptus polyanthemos — SHF	540	544	414	540
E. sideroxylon — Oki	266a[z]	573bc	356ab	741c
E. sideroxylon — ABC	87a	127a	138a	202b
Liquidambar styraciflua — SHF	624a	798ab	822b	876b
Quercus ilex — SHF	288	326	444	501
Schinus terebinthifolius — ABC	279	271	297	339
Mean	356 a	441ab	418a	515b

[x] **Treatments**

Staked — trunk tied to a 1 x 1 x 60'' stake.
Unstaked — trunk not tied to a stake.
Removed — laterals on lower half of trunk removed during season.
Headed — laterals on lower half of trunk headed during season.
Unpruned — laterals on trunk not pruned

[y] **Locations**

ABC — ABC Nursery, Gardena, Los Angeles County.
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[z] Values on any line followed by different letters differ significantly at the 0.05 level or higher according to Duncan's multiple-range test.

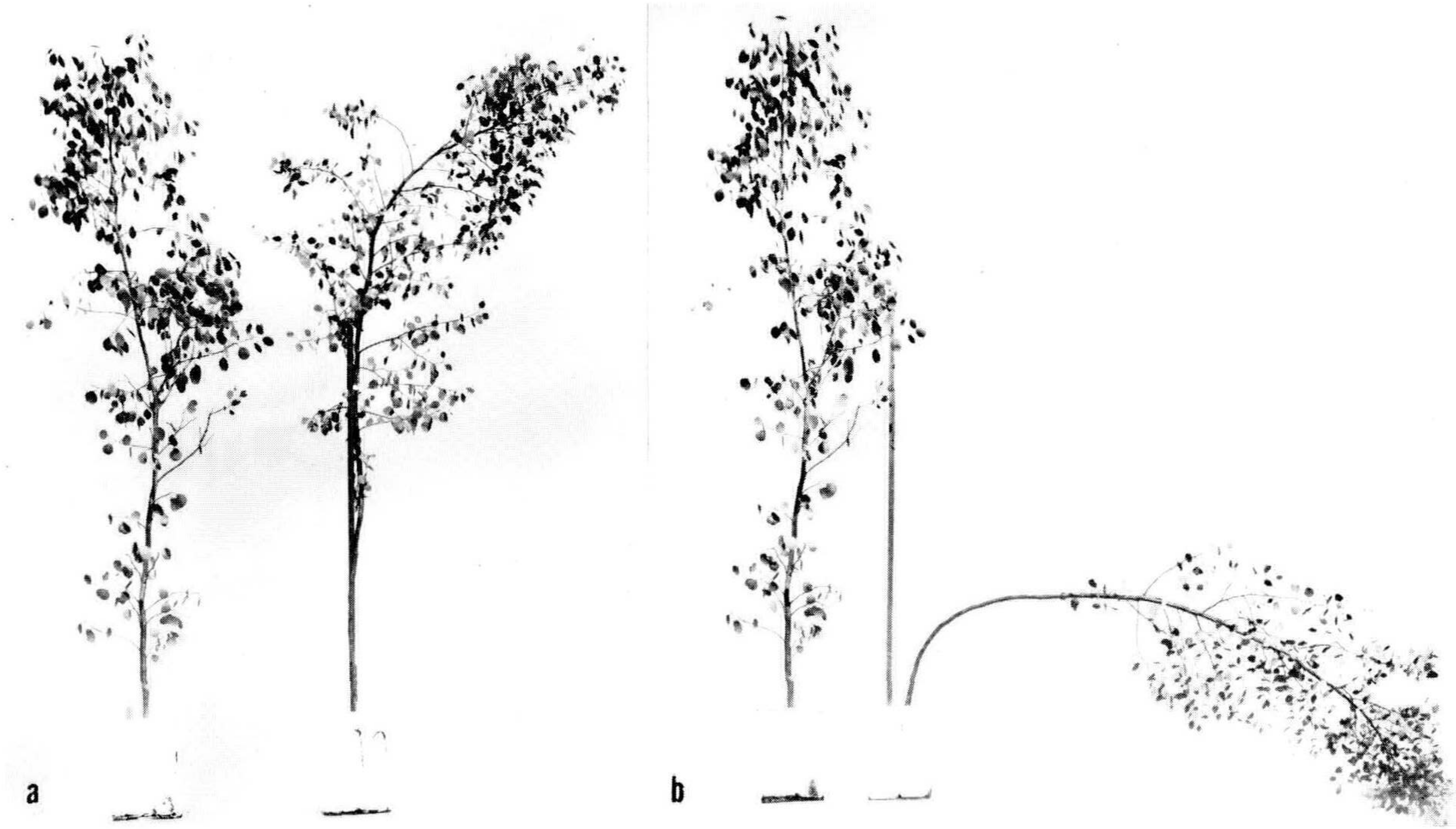

Fig. 2. Influence of staking for 11 months on round leaf eucalyptus . (a) Left, tree grown without stake and lower laterals on trunk headed to about 8''; tree tied to 1 x 1'' stake and lower laterals removed. (b) Right, tree untied from the stake.

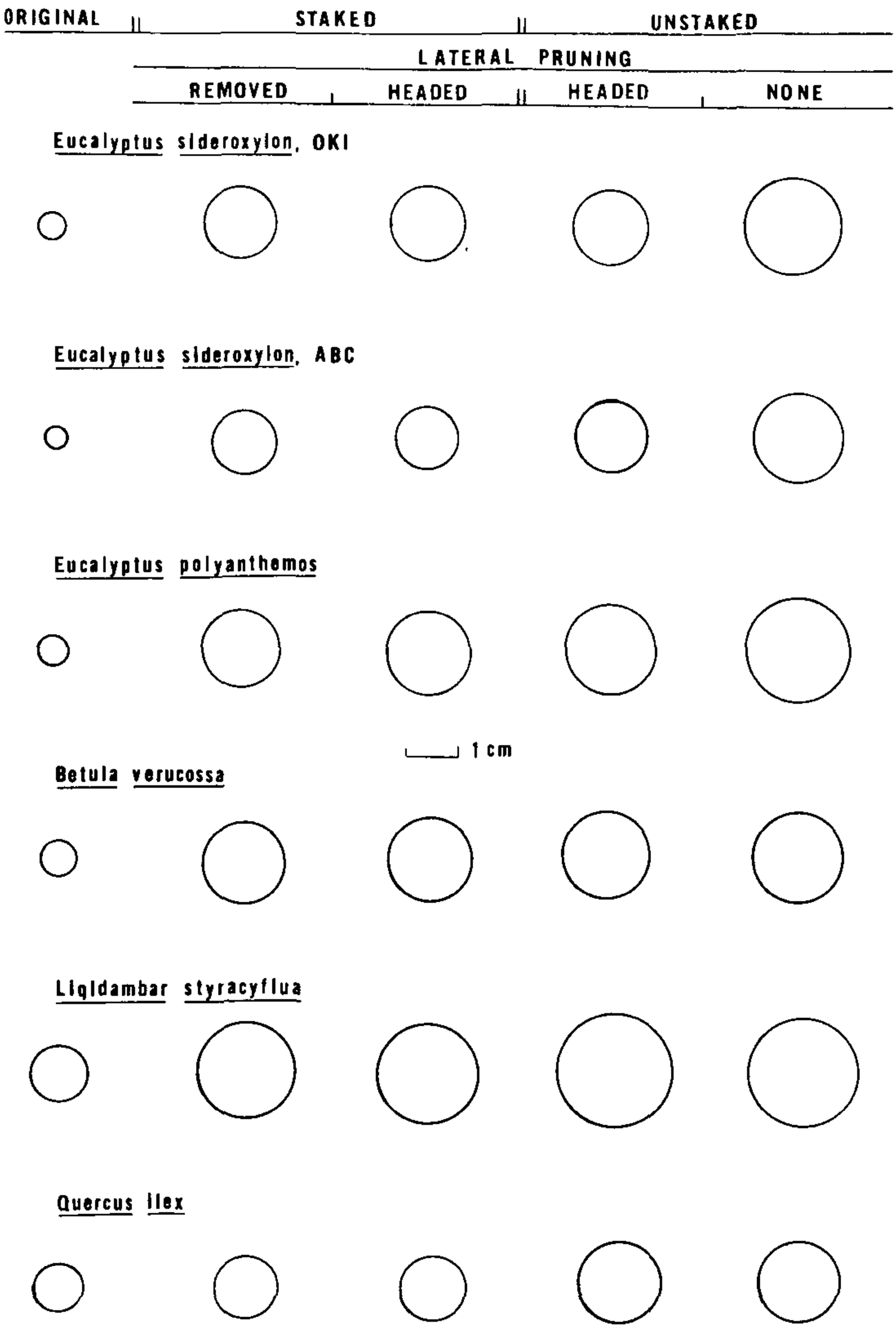

Fig. 3 Cross sectional areas of 5 species of container-grown trees after 5 months of differential staking and pruning.[1]

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[1] **Treatments**

STAKED — trunk tied to a 1 x 1 x 60'' stake.
UNSTAKED — trunk not tied to a stake.
REMOVED — laterals on lower half of trunk removed during season
HEADED — laterals on lower half of trunk headed during season.
UNPRUNED — laterals on trunk not pruned.

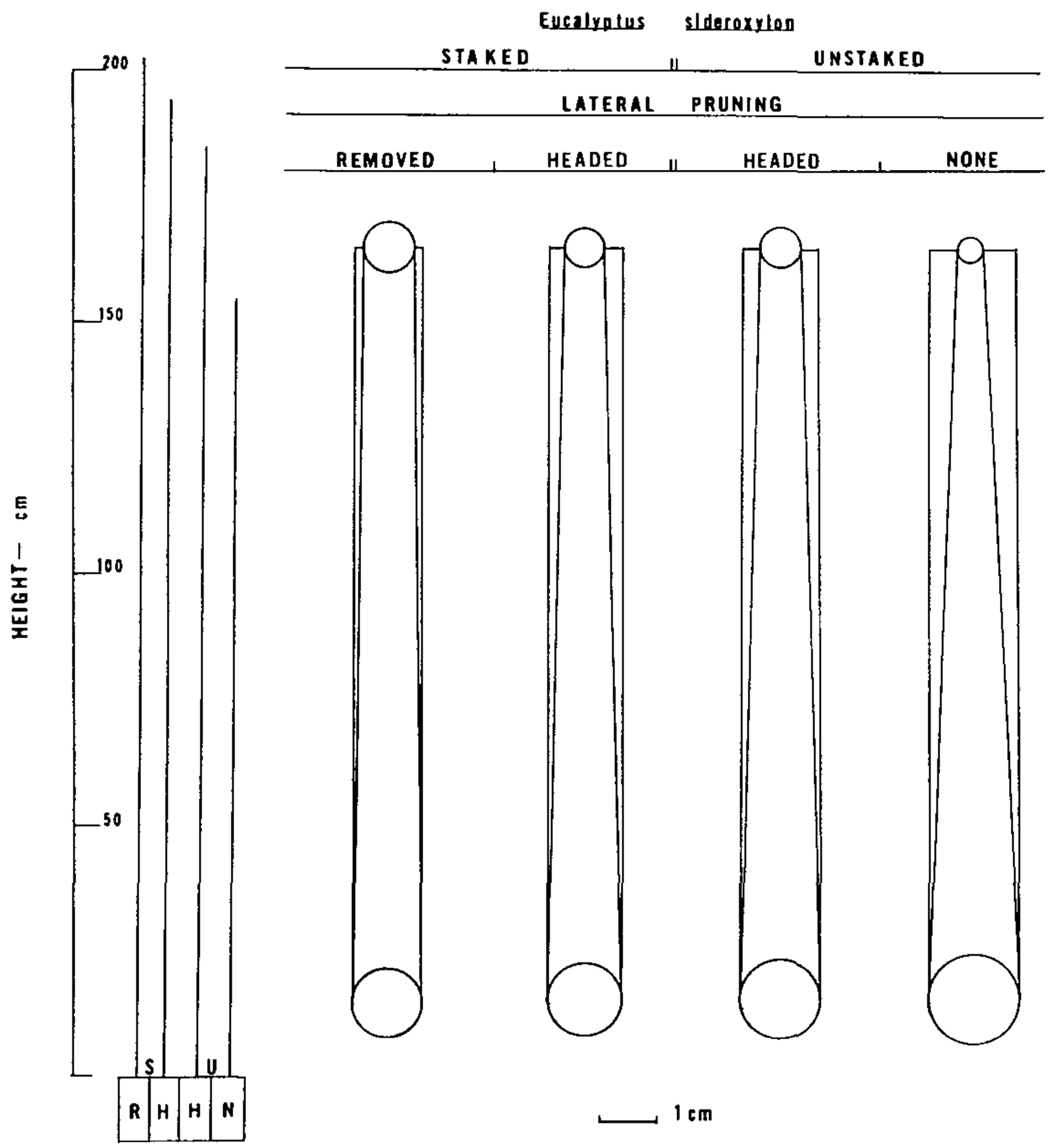

Fig. 4. Diagrammatic representation of relative height and taper of Eucalyptus sideroxylon grown at ABC Nursery with differential pruning and staking for 5 months.

DISCUSSION

If one assumes no interaction between staking and pruning, the influence of removing laterals compared to not pruning them can be estimated by multiplying from Table 2 the percentage for the "Headed Unpruned" by that for the "Removed Headed", and dividing by 100. For example, for mulga ironbark at ABC Nursery, the total influence of lateral removal on height would be 130 x 106 / 100 = 138 % or on caliper would be 80 x 89 / 100 = 71 %.

The magnitude of the effects of pruning and staking on trunk development are summarized in three graphic presentations. The cross sectional areas at the can top for several representative species are given in Fig. 3. The relative heights, caliper and taper for

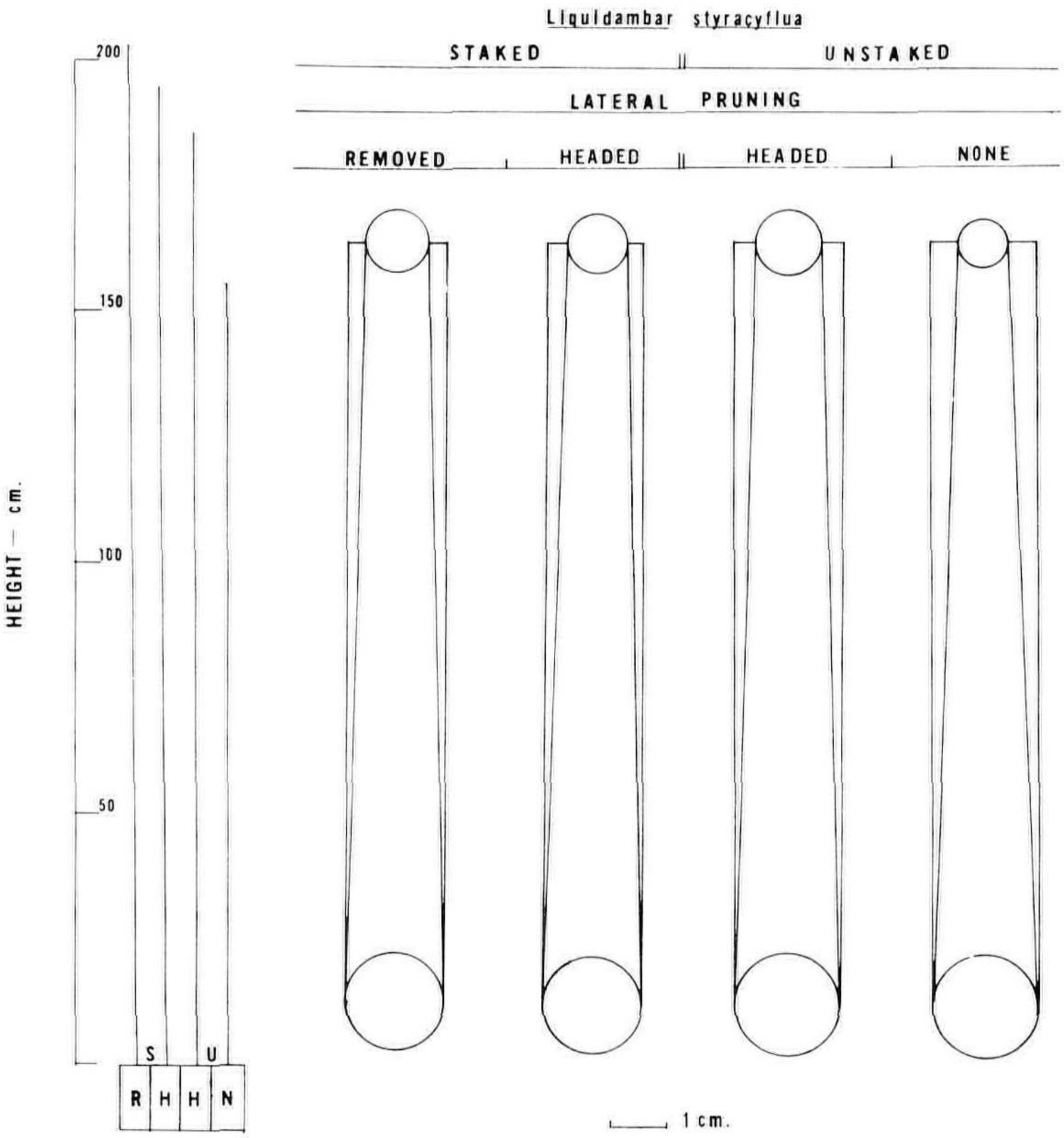

Fig. 5. Diagrammatic representation of relative height and taper of *Liquidambar styraciflua* grown at Saratoga Horticultural Foundation with differential pruning and staking for 5 months.

Eucalyptus sideroxylon at ABC Nursery are shown in Fig. 4, and of *Liquidambar styraciflua* are shown in Fig. 5.

The pruning treatments had a greater influence on root weight than did staking. Comparing all 7 sets examined, removal of laterals vs. heading and heading vs. no pruning, each increase in severity of pruning resulted in about 20% reduction in root weight. The removal of laterals decreased root weight about 30% compared to the no pruning treatment.

Refinement of cultural practices to optimize height growth and trunk development should be undertaken. Some of the variability in response may have been due to the infrequent attention (3-4 weeks) given during this experiment and therefore the rather severe heading of laterals at each pruning. Severe pruning decreases lateral growth (2). More frequent but lighter pruning might be more effective and might result in more consistent plant response.

Additional research on the effects of pruning and staking on root growth would be desirable. The root observations made were not planned originally in this research. The harvest dates were such that the more rapidly growing plants may have filled the container early in the growing season and they may have had reduced growth late in the season. The result would have been to allow the slower growing plants to catch up and reduce the differences between treatments. The differences in root growth between *Eucalyptus sideroxylon* grown at the 2 locations is an intriguing question (Table 3). Seed sources, soil mixes, fertility programs and environment varied between these nurseries.

Treatments might have been more effective if started when the plants were first moved to gallon cans. This is indicated by observations at Davis where eucalyptus and many other species have been grown successfully without stakes if they are given adequate space and are not left too long in liner pots or gallon cans.

Even though differences between certain treatments were not always significant, the consistent trends in height reduction and increased caliper growth and taper and in root weights as the severity of pruning decreased and stakes were removed give validity to the following generalization. Rigid staking and severe pruning of lower laterals of young nursery trees produces plants with greater height at the expense of caliper, taper and root development. Thus, if one is to produce young trees which can stand in the landscape without staking, the use of rigid staking should be avoided and pruning should be done in moderation.

Although the unpruned, unstaked treatment resulted in trees with the largest caliper, taper and root systems, this procedure may have limited nursery application due to reduction in height growth, additional growing space required and difficulty of maintenance. It should be emphasized that these plants were grown on 60 cm spacings.

The treatment "laterals headed, unstaked" produced trees judged to be an acceptable compromise between height growth and trunk development. Trees produced by this treatment had satisfactory height growth for the species, a full crown (good apparent size) and trunks capable of standing erect without stakes (Fig. 1 and 2).

Some species are more adapted than others to growing upright without support. Even within some species, upright growth may be quite variable depending on seed source or variation within seed source. A tree's ability to stand alone usually can be determined by the end of the liner stage. Those that can stand alone should be separated from those that cannot. The first group can be grown without support if given proper spacing. Depending on the number and their condition, the others can be grown on with minimum staking or discarded. Modifications in nursery staking practice should start with those species that easily grow upright and extended to other species as suitable cultural practices are developed.

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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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