grass may be due to a combination of factors, including plant metabolism and turf canopy configuration.

No species × mowing height interaction was observed in either year; therefore, creeping bentgrass and annual bluegrass ET means were pooled over mowing heights (Table 1). In 1986, annual bluegrass and creeping bentgrass turf used more water when mowed at 12 mm than at 6 mm. This agrees with previous research reporting greater water use of 'Penncross' creeping bentgrass turf maintained at 25 mm than at 7 mm (9). After 13 July 1985 and 19 July 1986, mowing height had no effect on creeping bentgrass water use rate (data not presented).

From these results, it is evident that greater differences in ET due to species and mowing height were observed in 1986 than in 1985. This is likely due to the difference in environmental conditions experienced in the 2 years (Fig. 1). More frequent rainfall and longer periods of cloud cover in 1985 may have contributed to more variable results.

In summary, annual bluegrass exhibited a lower ET rate than creeping bentgrass during several weeks in 1985 and 1986; however, differences were small. Variability in ET through the summer suggests that water conservation can be maximized by monitoring ET, and adjusting irrigation amounts to current ET data. Although turf cut at 12 mm used more water than that maintained at 6 mm, differences were small, and irrigation requirements of putting surfaces should not differ greatly from those of collars and aprons maintained at taller canopy heights.

Literature Cited

1. Danielson, R.E., W.E. Hart, C.M. Feldhake, and P.M. Haw. 1979. Water requirements for urban lawns. Colorado completion report to OWRT project B-035-WYO.
2. Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1983. Turfgrass evapotranspiration: I. Factors influencing rate in urban environments. Agron. J. 75:824–830.
3. Kim, K.S. 1983. Comparative evapotranspiration rates of thirteen turfgrasses grown under non-limiting soil moisture and progressive water stress conditions. MS Thesis, Texas A&M Univ., College Station.
4. Krans, J.V. and G.V. Johnson. 1974. Subirrigation and fertilization of bentgrass during prolonged heat stress, p. 527–533. In: E.C. Roberts (ed.). Proc. Second Intl. Turfgrass Res. Conf., American Society of Agronomy, Madison, WI.
5. Madison, J.H. 1962. Turfgrass ecology. Effects of mowing, irrigation, and nitrogen treatments of *Agrostis palustris* Huds., 'Seaside' and *Agrostis tenuis* Sibth., 'Highland' on population, yield, rooting, and cover. Agron. J. 54:407–412.
6. Minner, D.D. 1984. Cool season turfgrass quality as related to evapotranspiration and drought. PhD Diss., Colorado State Univ., Fort Collins.
7. Schmidt, R.E. and V. Snyder. 1984. Effects of N, temperature, and moisture stress on the growth and physiology of creeping bentgrass and response to chelated iron. Agron. J. 76:590–594.
8. Shearman, R.C. and J.B. Beard. 1972. Stomatal density and distribution as influenced by species, cultivar, leaf blade surface and position. Crop Sci. 12:822–823.
9. Shearman, R.C. and J.B. Beard. 1973. Environmental and cultural preconditioning effects on the water use rate of *Agrostis palustris* Huds., cultivar Penncross. Crop Sci. 13:424–427.
10. Stahnke, G.K. 1981. Evaluation of antitranspirants on creeping bentgrass (*Agrostis palustris* Huds., cv. 'Penncross') and bermudagrass [*Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis* Burtt-Davy, cv. 'Tifway']. MS Thesis, Texas A&M Univ., College Station.
11. Wu, L. and D.R. Huff. 1983. Characteristics of creeping bentgrass clones (*Agrostis stolonifera* L.) from a salinity-tolerant population after surviving drought stress. HortScience 18:883–885.

HortScience 24(2):271–275. 1989.

The Palmette Leader: A Tree Design for Improved Light Distribution

Alan N. Lakso, Terence L. Robinson, and Steven G. Carpenter
Department of Horticultural Sciences, New York State Agricultural Experiment Station, Cornell University, Geneva, NY 14456

Additional index words. *Malus domestica*, fisheye photography, photosynthesis, pruning, fruit color and quality

Abstract. **A tree design, called the "palmette leader", for improving the distribution of light within the tree canopy is described. The tree is a modification of the common central leader, and is formed by having a complete lower whorl of scaffold branches with a flat north–south-oriented palmette leader above. The large permanent gaps in the upper canopy ensure good light distribution, which was confirmed with canopy transects using fisheye photography. Preliminary evaluations of tree performance with 'McIntosh' apples (*Malus domestica* Borkh.) indicated that cumulative yields, fruit soluble solids content, and fruit dry matter were greater than well-trained central leaders, but fruit size and fruit color were similar. The improved light penetration into the center of the palmette leader compared to the central leader was found to induce higher photosynthesis of interior spur leaves exposed by summer pruning in August. Management of the palmette leader trees was found to be relatively simple.**

Considerable research has been conducted over the past several decades to develop tree forms and orchard designs for improved yield, fruit quality, and harvestability of tree fruits. The criteria used differed by researcher, but generally included light interception, light distribution, fruit yield and quality, and ease of management or mechanical harvestability (Chalmers and van den Ende, 1975; Dunn and Stolp, 1975; Heinicke, 1975; Hutton et al., 1987; Lakso, 1978; Lespinase and Delort, 1986; Luckwill, 1978; McKenzie, 1972; McKenzie et al., 1978; Rosati, 1978; Wertheim, 1968).

Potential yield of apples is ultimately limited by total light interception of orchards (Hunter and Proctor, 1986; Hutton et al., 1987; Monteith, 1977); however, actual yields are not a simple function of total light interception. Localized light exposure requirements for apple spur flowering, fruit set, fruit size, and fruit color development must also be considered (Barritt et al., 1987; Jackson, 1980; Lakso, 1980; Palmer and Jackson, 1974; Robinson et al., 1983). Generally, these localized light requirements are hyperbolic (i.e., light above 50% to 60% of available gives little improvement) so that it is not necessary to provide complete exposure for every fruiting spur. Consequently, one of the goals of tree design is to adequately expose the maximum number of fruiting sites by

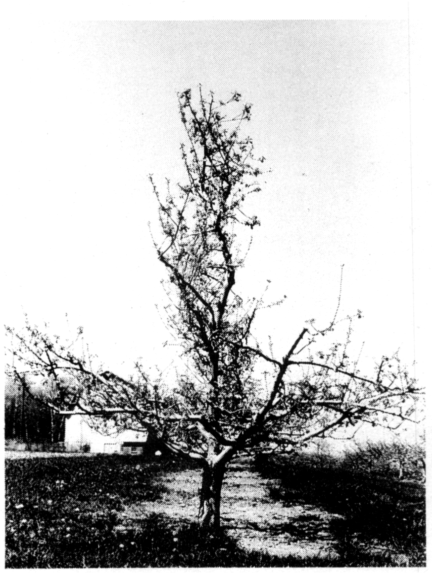

Fig. 1. A north–south view of a 19-year-old 'McIntosh'/MM.111 tree trained to a palmette leader tree form.

Received for publication 20 June 1988. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Table 1. Comparison of yield and fruit size of palmette leader, central leader, and open center 'McIntosh'/MM.111 and Alnarp 2 apple trees.[z]

Tree form	Yield (kg/tree)					Average yield		Fruit size (g)				
	1982	1983	1984	1985	1986	kg/tree	$t \cdot ha^{-1}$	1983	1984	1985	1986	Average
Palmette leader	144 a[y]	89 a	128 a	132 a	104 a	119 a	35.7 a	110 a	132 a	148 a	166 a	139 a
Central leader	144 a	95 a	103 b	134 a	67 b	108 b	32.4 b	115 a	132 a	144 a	165 a	139 a
Open center	126 a	61 b	82 b	134 a	106 a	102 b	30.5 b	120 a	136 a	127 b	160 a	136 a

[z] Trees planted in 1967 with a 4.6 × 7.3 m spacing.

[y] Mean separation within columns by Duncan's multiple range test, $P = 5\%$. Data shown are means of 14 trees for CL; 10 trees for OC; eight trees for PL, except in 1982, when there were three.

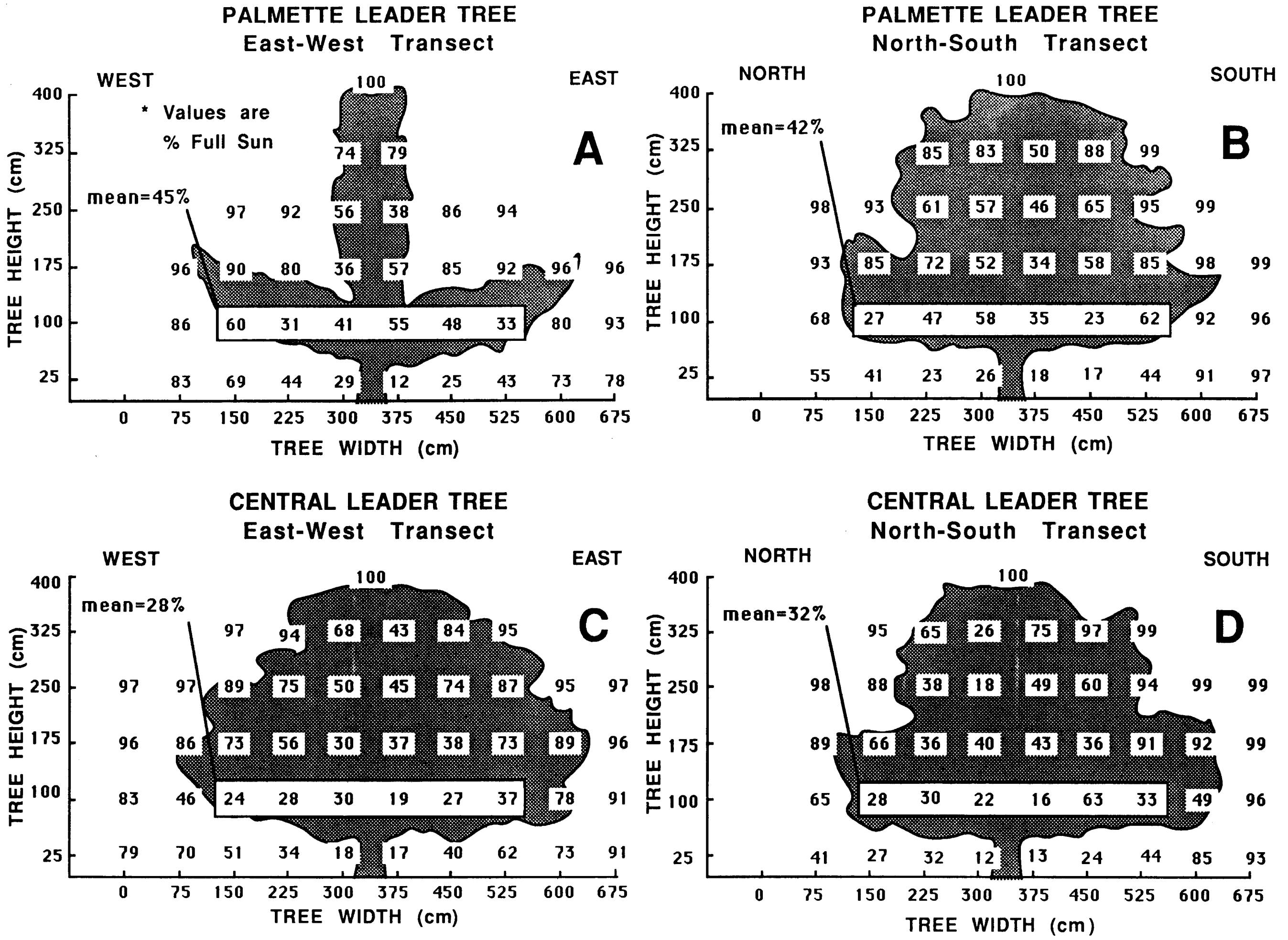

Fig. 2. Transects of light availability in a representative palmette leader (**A** and **B**) and a central leader (**C** and **D**) apple tree near harvest. Transects were run east–west (**A** and **C**) and north–south (**B** and **D**). The values of photosynthetic photon flux availability were measured by image analysis of fisheye photographs.

distributing the light uniformly within the canopy.

To reach this goal, two approaches have been used. One is the use of a relatively natural tree form that allows light penetration through the outer canopy by providing many small openings in the foliage, such as in multiple leader, central leader, or slender spindle (Heinicke, 1975; McKenzie, 1972; Wertheim, 1968). This approach can be very successful, but requires considerable expertise in judging the severity of pruning of the exterior canopy to provide the required light penetration into the interior canopy during the season. Also, if the foliage develops with unexpected vigor (due to low fruit set, wet weather, etc.), critically low light levels in the interior canopy can develop early in the season and inhibit flower bud initiation and early fruit development.

The second approach is to provide fewer large, permanent openings for light penetration into restricted canopies. Extreme examples are thin restricted planes of foliage such as narrow hedgerows, tree walls, and A, Y, T, or V forms (Chalmers and van den Ende, 1975; Dunn and Stolp, 1987; Hutton et al., 1987; Lespinase and Delort, 1986; Luckwill, 1978; McKenzie et al., 1978; Rosati, 1978; Tukey, 1978; van den Ende, 1987). This can be a successful approach, but severe restriction of canopy growth generally requires expensive support structures and significant labor to place and maintain the branches in specific locations.

A compromise of these approaches can be useful if a few large openings in the exterior canopy are provided to guarantee good light penetration, while the rest of the canopy is allowed to grow relatively naturally. This arrangement can provide the necessary light distribution while reducing the demands for support systems and management time and expertise. A tree form developed with this approach is reported here.

The objectives of this study were to design and evaluate a tree form for apples to meet the following criteria: a) good light distribution within the canopy, b) good yields and high fruit quality, c) ease of management, and d) convertibility from currently used tree forms. The tree form described in this report is referred to as the palmette leader (PL).

An apple orchard of 'McIntosh'/MM.111 and Alnarp 2 (A.2), planted in 1967 at Geneva N.Y., was well-trained to central-leader (CL) and open-center (OC) tree forms with rows in a north–south orientation. The spacing was 4.6 × 7.3 m (299 trees/ha) and mature tree height was 4 m and tree width

Table 2. Comparison of fruit color and quality from palmette leader, central leader, and open center 'McIntosh'/MM.111 and Alnarp 2 apple trees.[z]

Tree form	Portion of surface red (%)			Fruit quality—1985			
	1984	1985	1986	Firmness (N)	Soluble solids	Total acidity (%)	Dry matter (%)
Palmette leader	60 a[y]	47 ab	70 a	46 a	12.4 a	0.36 a	14.2 a
Central leader	64 a	49 a	72 a	45 a	11.8 b	0.36 a	13.8 b
Open center	59 a	37 b	70 a	46 a	11.7 b	0.35 a	13.0 c

[z] Trees planted in 1967 with a 4.6 × 7.3 m spacing.

[y] Mean separation within columns by Duncan's multiple range test, $P = 5\%$. Data shown are means of eight trees for PL and CL, but only five for OC.

was 5.2 m. This orchard represents relatively widely spaced rows with relatively little row-to-row shading. In Spring 1982, three randomly chosen CL trees were converted to the PL form as described below for preliminary evaluation of the tree form. In 1983, five more randomly chosen CL trees were converted to PL forms, giving a completely randomized design with eight total PL trees in the trial. There were five PL trees on MM.111 and three on A.2; there were five CL trees on MM.111 and nine on A.2; there were six OC trees on MM.111 and four on A.2. There were no significant differences between rootstocks between or within tree form treatments, which allowed pooling the data across rootstocks to compare the three tree forms.

The PL form was developed in the following way. Large gaps in the upper canopy were developed for light penetration by removal of all upper scaffold branches growing in east or west directions off of the leader. This gave a leader that had only north- or south-oriented branches, resulting in a flat palmette form in the N–S direction; thus, the term palmette leader (Fig. 1). The lower whorl of scaffold branches remained intact and were pruned in a normal manner. The OC trees were randomly selected and converted in 1975 from central leaders by the removal of the central leader above the lower whorl of scaffolds (Lakso et al., 1975).

The CL, OC, and PL trees were summer-pruned as needed in August of each year. The summer pruning primarily consisted of removal of unwanted watersprouts. The larger structural thinning and heading cuts were done during dormant pruning.

Performance of the PL was evaluated by comparing yields and fruit quality to the CL and OC trees over a 5 year period. Fruit redness of a 20-apple random sample from each tree was rated visually as percent of skin surface with "good red" color. Internal quality on the same 20-apple sample was evaluated at 60 to 80 days after harvest by measuring fruit firmness, soluble solids concentration (SSC), total acidity, and dry matter (Robinson et al., 1983).

The distribution of light within the PL and CL tree canopies was measured in 1984 by taking fisheye photographs on a uniformly overcast day at 75-cm grid points on both an east–west and a north–south transect through the center of one CL and one PL tree at harvest. The fisheye photographs were analyzed by digitizing the image and then calculating both the percent diffuse light from percent sky and percent direct light from the solar track. The two values were averaged to obtain percent full sun values by using the seasonal ratio of diffuse/direct light for Geneva, N.Y. in 1984 (37% diffuse, 63% direct).

Interior canopies of CL trees became much more heavily shaded before summer pruning than those of PL trees. The effects of differential shading in PL and CL trees on the photosynthetic ability of interior spur leaves exposed by summer pruning was evaluated.

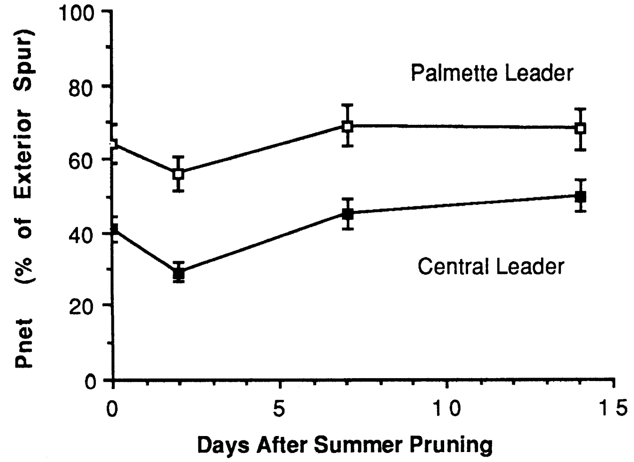

Fig. 3. Time course of light-saturated net photosynthesis of interior apple spur leaves of palmette leader and central leader trees after summer pruning done 90 days after bloom. Photosynthesis expressed as percentage of the rate of the best-exposed exterior spurs on the test trees. Vertical bars represent LSD, $P = 5\%$, n = 10.

Five representative interior spurs on lower scaffolds within 75 cm of the trunk were selected and three exterior spurs were marked in each of two PL and two CL trees. Fisheye photographs were taken at each spur immediately before summer pruning in mid-August and were analyzed as described previously to estimate pre-pruning spur exposure. Photosynthetic rates of the interior spur leaves in the late morning at light saturation were compared to continuously well-exposed exterior spur leaves in each tree form at 0, 2, 7, and 14 days after summer pruning. Photosynthesis was determined with an ADC portable photosynthesis system with a broadleaf Parkinson leaf chamber (Analytical Development Corp., Hoddesdon, Herts, U.K.). Readings were taken at midday with at least 1200 $\mu mol \cdot s^{-1} \cdot m^{-2}$ photosynthetic photon flux density to ensure light saturation, and readings were alternated between treatments after every three readings to minimize time effects. Equilibrium temperatures on different days varied between 21 and 29C, and the humidity at measurement was generally within 15% of ambient.

The major objective of this work was to modify the geometric form of the tree through the removal of the upper scaffold branches growing in the east–west direction to improve the distribution of incident light. Light penetration into the tree center was found to be improved, even though, in this orchard, the CL trees were well-pruned for light penetration and the fisheye transects were taken late in the season after summer pruning (Fig. 2). The minimum light values in the PL tree center were improved, indicating that essentially all of the canopy could be productive (i.e., almost all locations received near or above the desired 30% of available light). The average of the six central light values at 1-m height was 45% of full sun for the PL and 28% for the CL on the east–west transect. Along the north–south transect, the PL averaged 42% of full sun, while the CL averaged only 32%.

Quantitative observations. Overall distribution of light within the canopy was improved in the PL trees, as indicated by the relatively small variation in light exposure throughout the canopy. This meets the goal of distributing light as uniformly as possible over many fruiting sites within the tree with all sites receiving adequate, but not exces-

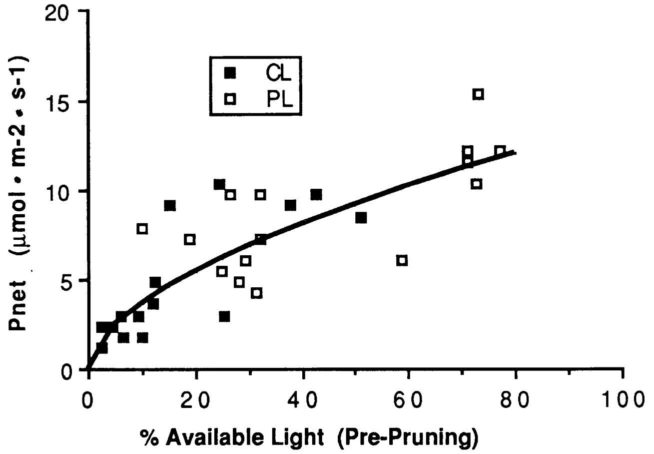

Fig. 4. Light-saturated net photosynthesis of interior spur leaves of palmette leader and central leader apple trees at 2 days after re-exposure by summer pruning as a function of prior spur exposure to light. The regression is: $Y = 0.995X^{0.57}$, $R^2 = 0.68$.

sive, exposure. The thin north–south-oriented leader allows exposure of east-oriented lower branches in the morning and exposure of west-oriented branches in the afternoon.

The yields of the PL trees were equal to those of the CL trees in 3 of the 5 years and greater than those of the CL trees in the other 2 years (Table 1). This distribution resulted in a 55 kg/tree greater cumulative yield for the PL trees over the CL control trees. There was no significant yield difference between the CL and OC trees in the 5-year average. Fruit size was not significantly affected by tree form, except for smaller fruit size of the OC trees in 1985. It is noteworthy that the average fruit size on the PL trees was not significantly different than the CL and OC trees, even though cumulative yields were higher for the PL form.

Fruit redness was similar for PL and CL trees, but the fruit color on the OC trees was poorer in 1985 (Table 2). This lack of color difference between the PL and CL trees, in spite of improved light partitioning, likely was due to summer pruning in August, which improved the late-season exposure of the CL trees. Fruit SSC and percent dry matter were significantly higher with the PL than with the CL or OC trees. This improvement appears to be a result of the improved light distribution in the PL trees, as indicated by the data in Fig. 2. Fruit firmness and acidity were not affected by tree form. The effects noted for SSC and dry matter are more indicative of long-term differences in light microclimate.

The high light availability in the center of the PL, compared to the CL, was reflected in improved photosynthetic activity of interior spur leaves after summer pruning (Fig. 3). Canopy shade has been found to induce an accelerated decline in leaf photosynthesis in apple and grape (Porpiglia and Barden, 1980; Lakso, unpublished data) as a function of time and shade intensity. These results indicate that the better interior light exposure in the PL form through the mid-season led to higher photosynthetic activity of interior leaves when summer pruning is done later in the season. In agreement with the results of Porpiglia and Barden (1981), little recovery of photosynthesis was noted after summer pruning (Fig. 3).

The differences in photosynthetic activity of interior leaves in PL and CL trees after summer pruning were due primarily to the pre-pruning light exposure, as indicated by the similar relationship of post-pruning photosynthesis to pre-pruning light exposure in both tree forms (Fig. 4).

Experience and general observations. Experience with the PL tree form in these preliminary trials and in larger trials underway in commercial orchards indicate:

1) Since the palmette top need only be flat and north–south-oriented, it can be formed by multiple leaders in trees without a well-placed single CL. Also, the spread and density of the leader is not particularly critical since the leader is flat and light penetration into the tree center is not dependent on transmission through the leader.

2) Light microclimate data and preliminary field observations suggest that the PL will be particularly useful in east–west rows since the north–south-oriented palmette eliminates the shaded north side that is problematic in east–west rows (Fig. 2B and D). This gives the advantages of north–south-oriented canopies when row orientation must be dictated by other considerations.

3) Pruning of the PL tree is simplified, since light does not have to filter through layers of canopy. Our observations indicate that the time required for both summer and winter pruning of PL trees is less than that required for either CL or OC forms. Maintenance of the basic geometric form is easy to teach to pruners since a high level of expertise is not required. Most of the pruning can be accomplished from the ground with only minimal pruning of the top.

When existing trees are converted to the PL form, it is important that the center of the tree have adequate spurs and foliage to produce fruit when re-exposed by the leader pruning. Otherwise, cropping will be reduced in the first years after conversion. If extremely large limbs must be removed to convert the tree to a PL form, the conversion should be accomplished over 2 or 3 years so that a large percentage of the productive canopy is not removed in any one year. Otherwise production may be reduced from 10% to 40% and tree vigor increased. The PL tree form is best suited for medium- and high-density orchards. In low-density orchards (<200 trees/ha), the trees are considerably larger than can be grown effectively in the PL form since a large branch may have a canopy depth of several meters. If such large trees are converted to PL trees, yield likely would be reduced.

Experience with the PL indicates that it may be useful as a technique for maintaining fruit quality and yield in the second and third decade of an orchard's life.

Literature Cited

Barritt, B.H., C.R. Rom, K.R. Guelich, and M.A. Dilley. 1987. Canopy position, and light effects on spur, leaf and fruit characteristics of 'Delicious' apple. HortScience 22:402–404.

Chalmers, D.J. and B. van den Ende. 1975. The "Tatura Trellis": a new design for high yielding orchards. J. Agr. Victoria 73:473–476.

Dunn, J. and M. Stolp. 1987. Apples on the Lincoln Canopy—mechanized management. HortScience 22:568–572.

Heinicke, D.R. 1975. High-density apple orchards—planning, training and pruning. USDA Agr. Hdbk. 458.

Hunter, D.M. and J.T.A. Proctor. 1986. Correlation of light interception with yield and fruit color of McIntosh apple strains. Fruit Var. J. 40:799–803.

Hutton, R.J., L.M. McFadyen, and W.J. Lill. 1987. Relative productivity and yield efficiency of canning peach trees in three intensive growing systems. HortScience 22:552–560.

Jackson, J.E. 1978. Utilization of light resources by high density planting systems. Acta Hort. 65:61–70.

Jackson, J.E. 1980. Light interception and utilization by orchard systems. Hort. Rev. 2:208–267.

Jackson, J.E. 1985. Future fruit orchard design: economics and biology, p. 441–459. In: M.G.R. Cannell and J.E. Jackson (eds.). Attributes of trees as crop plants, Inst. Terrest. Ecol., Abbots Ripton, Hunt. U.K.

Lakso, A.N., W.F. Millier, R.A. Pellerin, and S.G. Carpenter. 1978. Conversion of central leader apple trees for improved mechanical harvest. J. Amer. Soc. Hort. Sci. 103:284–287.

Lakso, A.N. 1980. Correlations of fisheye photography to canopy structure, light climate and biological responses to light in apple trees. J. Amer. Soc. Hort. Sci. 105:43–46.

Lespinasse, J.-M. and J.F. Delort. 1986. Apple tree management in vertical axis: appraisal after ten years of experiments. Acta Hort. 160:139–155.

Luckwill, L.C. 1978. Meadow orchards and fruit walls. Acta Hort. 65:237–243.

McKenzie, D.W. 1972. Intensive orchards in New Zealand. The Orchardist of New Zealand. 44:175–181.

McKenzie, D.W., J.S. Dunn, M. Stolp, and R.J. Hutton. 1978. Horizontal canopy orchards for mechanical harvesting. Acta Hort. 65:267–276.

Monteith, J.L. 1977. Climate and the efficiency of crop production in Britain. Phil. Trans. R. Soc. London, Ser. B 281:277–294.

Palmer, J.W. and J.E. Jackson. 1974. Effects of tree population and variations in spacing within and between rows of Golden Delicious on M.9. Rpt. E. Malling Res. Sta. 1973. p.66–68.

Porpiglia, P. and J.A. Barden. 1980. Seasonal trends in net photosynthetic potential, dark respiration, and specific leaf weight of apple leaves as affected by canopy position. J. Amer. Soc. Hort. Sci. 105:920–923.

Porpiglia, P.J. and J.A. Barden. 1981. Effects of pruning on penetration of photosynthetically active radiation and leaf physiology in apple trees. J. Amer. Soc. Hort. Sci. 106:752–754.

Robinson, T.L., E.J. Seeley, and B.H. Barritt. 1983. Effect of light environment and spur age on 'Delicious' apple fruit size and quality. J. Amer. Soc. Hort. Sci. 108:855–861.

Rosati, P. 1978. Tall hedgerow orchards. Acta Hort. 65:255–260.

Tukey, L.D. 1978. The thin-wall trellis hedgerow system. Acta Hort. 65:261–266.

van den Ende, B., D.J. Chalmers, and P.H. Jerie. 1987. Latest developments in training and management of fruit crops on Tatura Trellis. HortScience 22:561–568.

Wertheim, S.J. 1968. The training of the slender spindle. Publ. Proefstation Fruitteelt, Wilhelminadorp, NL no. 7.

HortScience 24(2):275–277. 1989.

Growth and Mineral Nutrition of Young Orange Trees Grown with High Levels of Silicon

Heinz K. Wutscher

U.S. Department of Agriculture, Agricultural Research Service, 2120 Camden Road, Orlando, FL 32803

Additional index words. *Citrus sinensis*, solution culture

Abstract. **One-year-old 'Hamlin' and 2-year-old 'Valencia' orange [*Citrus sinensis* (L.) Osbeck] trees on rough lemon (*C. limon* Burm. f.) rootstock were grown in solution culture for 7 months. The solutions of the two treatments were identical, except for Si. The KNO_3 in the −Si solution was substituted by K_2SiO_3 and NH_4NO_3 to supply 66 ppm Si in the +Si solution. Solution pH was initially adjusted with HNO_3 and NH_4OH and maintained at 7 ± 0.5 by addition of dolomite. Plant weight at 28-day intervals showed significant differences in fresh weight increase between treatments only in the first 2 months. Analysis of eight different tree tissues for Si and 14 other elements showed strong correlations between Si levels and levels of P, S, Mg, Fe, Mn, Zn, Cu, and Mo, especially in the leaves, bark, and feeder roots. Si accumulated mostly in the leaves and the feeder roots, a pattern that was also found in field-grown, 17-year-old 'Hamlin' on rough lemon trees.**

Silicon is essential for certain silicon-accumulating plants (5, 11), but, in other plants, it seems to be essential only at the "functional" level (7); i.e., these plants can complete their life cycle without Si (4). Much of the work on silicon nutrition has been done with grasses that have especially high silicon requirements (1, 6, 12); less attention has been given to the role of silicon in other crops, such as citrus (3).

Treatment with basic slag, which consists in large part of calcium silicate, increased water-soluble Si in the soil (15) and alleviated the symptoms of orange trees affected by citrus blight (14), a tree decline whose cause is still unknown (10). Well water in central Florida contains 6 ppm Si (13). A solution culture experiment was set up in a greenhouse to investigate the effect of Si levels 11 times as high as in well water under controlled conditions.

Eight 1-year-old 'Hamlin' and six 2-year-old 'Valencia' orange trees on rough lemon rootstock grown in sand in pots were transferred as whips, without leaves or branches, into 10-liter solution culture crocks in Apr. 1986. The 'Hamlin' trees had been grown in the greenhouse; the 'Valencia' trees were grown in a field nursery for 18 months before they were planted in pots in the greenhouse after they froze back to the bud union. The trees were grown in deionized water for 10 days before nutrient solution was added. The controls (one-half of the trees) grew in a nutrient solution (−Si) described by Smith (9), the other half of the trees grew in a similar solution, except for substitution of KNO_3 by K_2SiO_3 and NH_4NO_3. The nutrient concentrations in the solution were (all ppm): 165 N, 9 P, 80 K, 90 Ca, 667 Mg, 16 Na, 3 Fe, 3 Mn, 0.15 Mo, and 16 S. The +Si solution contained 66 ppm Si, the −Si solution <1 ppm Si. Deionized water was used to prepare the solutions and to maintain the solution levels in the cultures. The solutions were changed every 14 days. Plants were weighed at the beginning of the experiment and at 28-day intervals (at every second solution change) throughout the study. The pH of both solutions was adjusted to 7.0 with HNO_3 and NH_4OH and maintained within ±0.5 pH of 7 by addition of ≈9 g of dolomite (8). The electrical conductivity of the fresh solutions and of each culture after 2 weeks was measured with a Wheatstone Bridge. At the end of the experiment, in Nov. 1986, each plant was weighed and then dissected into leaves, twigs, scion bark, scion wood, rootstock bark, rootstock wood, large roots (>2 mm diameter), and feeder roots. The same tissues of four 17-year-old 'Hamlin' on rough lemon trees growing in a commercial grove were sampled in Mar. 1987 for comparison with the greenhouse-grown trees.

The leaves and bark were washed in detergent solution, rinsed once with tap water and then four times in distilled water. The large roots and feeder roots were washed in a stream of tap water, and rinsed and immersed in distilled water for 3 min. After 48 hr in a 65C draft oven, dry weight was recorded and the samples ground to 20 mesh for analysis for N, P, K, Ca, Mg, Na, S, Fe, Mn, Zn, Cu, B, Cl, and Mo by standard methods (13). Silicon analysis by Bowman and Willis' method (2) included preparing a melt in platinum crucibles and atomic absorption spectrophotometry.

Table 1. Silicon levels in eight tissues of 'Hamlin' and 'Valencia' orange trees on rough lemon rootstock grown in solution culture and 17-year-old 'Hamlin' trees in a commercial grove.

	Silicon levels (ppm)[z]				
	Valencia[y]		Hamlin[y]		
Tissue	+Si	−Si	+Si	−Si	Hamlin trees in a commercial grove[x]
Leaves	1356[w] a	408 a	1467[w] a	432 b	1716 b
Twigs	442 c	429 a	407 b	419 b	438 c
Scion bark	402 c	415 a	404 b	368 b	474 c
Scion wood	383 c	362 b	373 b	357 b	438 c
Rootstock bark	801[w] b	348 b	1382 a	5035 a	797 bc
Rootstock wood	416 c	405 a	415 b	541 b	898 bc
Large roots	494 c	436 a	490 b	468 b	522 c
Feeder roots	754[w] b	568 a	713[w] b	576 b	4079 a

[z] Mean separation within columns by Duncan's multiple range test, 5% level.

[y] Means of three trees.

[x] Means of four trees.

[w] Difference between +Si and −Si treatments significant, 5% level.

Received for publication 1 Feb. 1988. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.