7. Sugiura, A., K. Yonemori, H. Harada, and T. Tomana. 1979. Changes of ethanol and acetaldehyde contents in Japanese persimmon fruits and their relation to natural deastringency (in Japanese with English summary). Studies from Inst. Hort., Kyoto Univ., 9:41–47.
8. Swain, T. and W.E. Hillis. 1959. The phenolic constituents of *Prunus domestica*. I. The quantitative analysis of phenolic constituents. J. Sci. Food Agr., 10:63–68.
9. Yonemori, K., J. Matsushima, and A. Sugiura. 1980. Studies on tannin substances of Japanese persimmons, especially their difference between nonastringent and astringent type fruits. (in Japanese). Japan. Soc. Hort. Sci., Spring Meet. p.72–73. (Abstr.).
10. Yonemori, K., J. Matsushima, and A. Tamaki. 1982. Studies on kaki tannins: chemical difference in tannin substances between nonastringent and astringent type persimmons (in Japanese). Japan. Soc. Hort. Sci., Autumn Meet. p. 20–21. (Abstr.).

HortScience 18(3):321–322. 1983.

The Effect of Artificial Shading on Cold Hardiness of Peach and Sour Cherry

J.A. Flore, G.S. Howell, and C.E. Sams[1]
Department of Horticulture, Michigan State University, East Lansing, MI 48824

Additional index words. carbohydrate, solar radiation, bud, *Prunus persica, Prunus cerasus*

Abstract. **Shade treatments giving 36% full sun or less reduced both hardiness and shoot cross-sectional area of one-year-old sour cherry (*Prunus cerasus* L. cv. Montmorency) and peach [*Prunus persica* (L.) Batsch cv. Redhaven]. Shade significantly reduced soluble carbohydrate in 'Redhaven'.**

Light level can be a limiting factor in cold resistance (7, 11, 14) and numerous morphogenic and reproductive responses of trees are affected by solar radiation. Shading reduces flower bud formation, fruit size and quality, total dry weight, and photosynthetic rate (4, 5, 8, 9, 10). Since practices that alter the exposure of plants to light or that emphasize the importance of healthy leaves may affect hardiness through their influence on carbohydrate production and accumulation (14), it is logical to predict that shading may have a detrimental effect on cold hardiness. The objective of this study was to determine the effect of shade on shoot growth, water status, carbohydrates, and cold hardiness of peach and sour cherry.

One-year-old 'Redhaven' peach on Halford rootstock and 'Montmorency' sour cherry on Mahaleb rootstock were pruned to one 20–25 cm shoot, and planted in 18-liter pots in 1 sand:1 sphagnum peatmoss:1 soil (by volume) on May 5, 1979. Fertilizer, pesticides, and water were applied as required. Trees were grown under full sun until June 20, 1979, when 10 trees of each species were placed under shade equivalent to 36%, 21%, or 9% of full sun. The youngest expanding leaf below the terminal was tagged to distinguish pre- from postshade growth. Controls were grown without shading. Solar radiation was reduced with pipe frame structures (3.7 × 2.4 × 1.8 m) covered with black polypropylene shade fabric (A.H. Hummert Co., St. Louis, Mo.) which transmitted an average of 36%, 21% or 9% PAR (photosynthetically active radiation measured with a LI-COR LI-1905 quantum sensor connected to a Model LI-500 integrator) when compared to full sum. Ventilation prevented temperature differences of greater than ± 3°C and relative humidity differences greater than ± 5%. Spectral radiometer (ISCO Model SR portable spectroradiometer, Lincoln, Neb.) determinations confirmed that all wavelengths in the 380–750 nm range were reduced equally.

Shoot length above the tag and shoot cross-sectional area at the point tagged (to distinguish pre- from postshade growth) were recorded on September 11 and 12, 1979.

Hardiness was determined on November 29, 1979 using procedures similar to those described previously (13). Briefly, postshade terminal shoot sections (15 cm) were collected to provide 6–8 sections per treatment per tree per species. Stem pieces were taped to aluminum foil strips, labeled, and rolled into a bundle. A 26-guage copper–constantan thermocouple was attached with tape to one stem piece in the center of the bundle, and the latter was placed in a vacuum flask. The thermocouple was connected to a potentiometer with a pen recorder that monitored temperature in the foil roll. The flasks were placed in a Revco "Ultralow" freezer and temperature declined at a rate of about 2–3°C hr^{-1}. This rate allowed for uniform temperature decline of all twig pieces in a bundle. As the stems cooled, flasks were removed at 2.5° intervals within a predetermined temperature stress range so that warmest temperatures would cause damage and the coldest would kill all tissues. Tissue browning was used as the basis for viability evaluation (12). The T_{50} value was calculated using the Spearman-Kärber method (1), and viability values were separated by the modified Friedman test (3).

The anthrone test was used to measure soluble carbohydrate. Shoot tissue was freeze-dried at −40°C, then ground in a #20 mesh Wiley mill. The tissue was further ground (100 mg/liter) with 80% EtOH in mortar and pestle and the suspension centrifuged at 1500 rpm for 5 min. The supernatant was diluted with water (0.5 mg tissue/ml H_2O), a 1-ml extract was placed in a 10-ml test tube, and 5 ml anthrone reagent (2 g anthrone/liter 95% H_2SO_4) was added to each extract. Test tubes were placed in a water bath (70°) for 15 min., then cooled at 20° for 20 min. Absorbance was determined at 620 nm for the 1-ml extract using water as a blank. A standard curve was obtained using α-D-glucose at 20, 40, 60, 80, and 100 μg/ml. Data are expressed as mg soluble carbohydrate per gram dry weight of the tissue.

Shoot section fresh weight, dry weight, and percent water content (fresh-weight basis) were determined by weighing the samples shortly after excision and again after 60 hr at 80°C.

Wood and bud hardiness of both sour cherry and peach were reduced significantly by shading (Tables 1 and 2). For cherry, T_{50} values rose in both shoots and buds from −22.5°C for 100% full sun (FS) to −15.5° for 9% FS; values for all shade treatments were significantly different from those of the controls. Shoot cross-sectional area, but not shoot length, was reduced significantly by shading. In peach, T_{50} rose from −22.5° to −13.0° and from −17.5° to −13.0° for wood and vegetative buds, respectively. However, the effect was not significant at light levels above 21% FS. Hardiness was consistently greater in wood than in buds except at 9% FS. Shoot cross-sectional area and soluble carbohydrate decreased with shading (significant only at 9% FS), whereas shading tended to increase shoot length.

Significant negative correlation coefficients existed for solar radiation vs. T_{50} values for wood and bud hardiness and percent full sun, and shoot cross-sectional area for both peach and cherry (Table 3). Soluble carbohydrate and water content were also correlated negatively with T_{50} values for peach

Received for publication December 6, 1982. Michigan Agricultural Experiment Station Journal Article No. 10666. 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.

[1]Present address: Horticultural Crops Quality Lab., Horticultural Science Institute, USDA-ARS, BARC-W, Beltsville, MD 20705.

Table 1. The effect of various degrees of shade on shoot length, shoot cross-sectional area, and hardiness of wood and buds on November 29, 1979 of 'Montmorency' sour cherry. Treatment began June 29, 1979.

Full sun (%)	Shoot length (cm)	Shoot cross-sectional area (mm^2)	Hardiness (T_{50})[y]	
			Wood	Bud
100	23.0	23.8 a[z]	−22.5 a	−22.5 a
36	22.6	15.2 ab	−20.0 b	−20.0 b
21	25.3	15.9 ab	−17.5 c	−17.5 c
9	22.1 NS	9.6 b	−15.5 d	−15.5 d

[z]Mean separation by Duncan's multiple range test, 5% level.
[y]T_{50} calculated using the Spearman-Kärber equations and mean separation within a column by the modified Friedman test, 5% level.

Table 2. The effect of various degrees of shade on shoot length, shoot cross-sectional area, shoot carbohydrate content, shoot water content, and hardiness of wood and buds on November 29, 1979 of 'Redhaven' peach. Treatment began June 20, 1979.

Full sun (%)	Shoot length (cm)	Shoot cross-sectional area (mm^2)	Soluble carbohydrate (mg/g dry wt)	Water content (% H_2O)	Hardiness (T_{50})[y]		
					Wood	Flower buds	Vegetative buds
100	36.8	13.2 a[z]	109.3 a[z]	51.6	−22.5 a	−17.5 a	−17.5 a
36	44.8	11.9 ab	110.8 a	48.2	−22.5 a	−17.0 a	−17.5 a
21	44.0	10.2 ab	107.5 a	48.3	−16.0 b	−12.5 b	−15.0 b
9	41.0 NS	7.5 b	97.6 b	46.0 NS	−13.0 c	---[x]	−13.0 c

[z]Mean separation by Duncan's multiple range test, 5% level.
[y]T_{50} calculated using the Spearman-Kärber equations and mean separation within a column by the modified Friedman test, 5% level.
[x]Insufficient number of replicates for analysis.

Table 3. Correlation coefficients for percent full sun, shoot length, shoot cross-sectional area, soluble solids, and water content vs. wood, flower, and bud hardiness for 'Redhaven' peach and 'Montmorency' sour cherry.

Variable	Correlation coefficient (r)		
	Wood	T_{50} for Flower bud	Vegetative bud
Redhaven peach			
% full sun	−0.76*	−0.71*	−0.75*
shoot length	0.18	0.50	0.12
shoot cross-sectional area	−0.95*	−0.94*	−0.97*
soluble carbohydrate	−0.88*	−0.85*	−0.93*
water content	−0.77*	−0.56	−0.79*
Montmorency cherry			
% full sun	−0.93*		−0.93*
shoot length	0.04		0.04
shoot cross-sectional area	−0.92*		−0.92*

*Significant at the 5% level.

(all significant except for water content of flower buds) (Table 3). Shoot length was not correlated with hardiness in any case.

Shading caused the production of larger, thinner leaves in both cherry and peach and photosynthesis was reduced (per unit area) in comparison with leaves grown under full sunlight (8, 10). This reduction in photosynthetic capacity was probably responsible for the decrease in soluble carbohydrate observed for peach.

Factors that influence carbohydrate level—such as exposure to light (7, 11, 14) and defoliation (6, 13)—indicate that a loss of photosynthetic capacity is detrimental to tissue survival during winter, probably because of reduced carbohydrate accumulation. Our data demonstrate that under experimental conditions, shading can have a sizable effect on hardiness. How important shading is in mature, bearing trees grown under field conditions is unknown. Light levels less than 20% FS are often observed in cherry (4, 5) and peach canopies (8, 9). Both hedgerow-planting systems and summer pruning affect shading; both of these practices are gaining favor. At Michigan's latitude, shading is generally greater on the lower NW sector of the tree then in the upper SE sector, and Cain and Andersen (2) found that hardiness was significantly lower in the former; this provides circumstantial evidence that shading can influence hardiness under field conditions. Also, shading greatly reduced hardiness of buds and canes of grapevines (7).

As we convert to higher-density orchards, the problem of within- and between-tree shading will become more acute. The effect of this on hardiness and tree longevity under field conditions needs to be resolved so that appropriate orchard designs, training systems, and cultural practices can be employed to minimize winter injury.

Literature Cited

1. Bittenbender, H.C. and G.S. Howell, Jr. 1974. Adaptation of the Spearman-Kärber method for estimating the T_{50} of cold stressed flower buds. J. Amer. Soc. Hort. Sci. 99:187–190.
2. Cain, D.W. and R.L. Andersen. 1976. Sampling procedures for minimizing nongenetic wood hardiness variation in peach. J. Amer. Soc. Hort. Sci. 101:668–671.
3. Evert, D.R. and G.S. Howell, Jr. 1979. The modified Friedman test—a simple alternative to the F-test for the randomized complete-block design. HortScience 14:19–20.
4. Flore, J.A. 1980. The effect of light on cherry trees. Proc. Mich. State Hort. Soc. 110:119–122.
5. Flore, J.A. 1981. Influence of light interception on cherry production and orchard design. Proc. Mich. State Hort. Soc. 111:161–169.
6. Howell, G.S., Jr. and S.S. Stackhouse. 1973. The effect of defoliation time on acclimation and dehardening in tart cherry (*Prunus cerasus* L.) J. Amer. Soc. Hort. Sci. 98:132–136.
7. Howell, G.S., Jr. and N.J. Shaulis. 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. Amer. J. Enol. Vitic. 31:158–161.
8. Kappel, F. 1980. Characterization of the light microclimate in four peach tree canopies and the effect of shading on the growth and leaf photosynthesis of peach trees. MS Thesis, Michigan State Univ., East Lansing.
9. Kappel, F. 1981. Peach tree training systems for improved yields. Compact Fruit Tree 14:147–151.
10. Sams, C.E. 1980. Factors affecting the leaf and shoot morphology and photosynthetic rate of sour cherry (*Prunus cerasus* L. 'Montmorency'). PhD Thesis, Michigan State Univ., East Lansing.
11. Steponkus, P.L. and F.O. Lanphear. 1968. The relationship of carbohydrates to cold acclimation of *Hedera helix* L. cv. Thorndale. Physiol. Plant. 21:777–781.
12. Stergios, B.G. and G.S. Howell, Jr. 1973. Evaluation of viability tests for cold stressed plants. J. Amer. Soc. Hort. Sci. 98:325–330.
13. Stergios, B.G. and G.S. Howell, Jr. 1977. Effects of defoliation, trellis height, and cropping stress on the cold hardiness of Concord grapevines. Amer. J. Enol. Vitic. 28:33–42.
14. Weiser, C.J. 1970. Cold resistance and acclimation in woody plants. HortScience 5:403–410.