The Effect of Continuous and Periodic Whole-Tree Shade On the Performance of 'Ginger Gold'/M.9 Apple Trees [1]

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The influence of sunlight on apple tree growth and fruit development has been well documented (Ferree, 1985; Jackson, 1980). Training systems have been developed and are recommended to growers that maximize light exposure (Robinson, et al., 1991). However, a major portion of the apple tree's canopy is subjected to shade during most daylight hours each day. When shading reduces light levels, fruit bud formation is reduced and the buds that are formed are often small and weak (Auchter, et al., 1926). Several days of continuous shade soon after bloom can reduce fruit set (Byers, et al., 1990). Shade reduces shoot growth and leaf weight, but may increase leaf size (Jackson and Palmer, 1977a). Lack of adequate light levels can also reduce yield (Jackson and Palmer, 1977b; Hunter and Proctor, 1986) and lower fruit quality (color, firmness, soluble solids concentration) (Heinicke, 1966; Jackson, et al., 1971).

Over the years the author has observed apparent differences in cropping when whole trees or portions of the canopy are naturally shaded in the morning compared to shade in the afternoon hours. The purpose of the present study was to evaluate the effect of shade when applied to whole apple trees during a given period of time each day on a season-long basis. Imposed shade treatments were compared to trees grown under natural sunlight conditions.

Materials and Methods

'Ginger Gold'/M.9 apple trees were planted in a solid block of three rows with 20 trees per row in 1996. Border trees, consisted of 'Pink Lady', 'GoldRush', and 'Liberty', each on M.9 rootstock, planted as a single row on both sides of the test block and on the end of each test row. Trees were spaced 2.4 m apart in rows spaced 4.9 m apart and were oriented in a north-south direction. Trees were headed to about 76 cm at planting and trained as a central leader with a metal pole supported by one wire at a height of 1.5 m above the ground. Trees received the local recommended cultural and pest management program throughout the study. A weed-free strip was maintained under the tree canopy on both sides of the row from the trunk to the drip line. In the first growing season a mechanical rotary hoe was used to obtain the weed-free strip and recommended

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herbicides were used in the following years. A dilute foliar spray of 6-BA (400 mg·L^{-1}) was applied in early May of the second leaf to encourage branch development. All trees were delayed dormant pruned on an annual basis in Apr after counting flower buds.

Shade treatments were initiated about 3 to 4-weeks after full bloom (FB), beginning in the third leaf (1998) and repeated in 1999 through 2001, except in the first year (1998) when mechanical problems with the shade shelters delayed application of the treatments until 7 weeks after FB. Shade treatments were terminated each year on 30 September. The following treatments were applied to two adjacent trees with 4 replicated plots per treatment: 1) natural sunlight [check (C)], 2) constant or continuous shade (CS) 24 hours per day, 3) partial shade (PS) applied daily from 0800 to 1100 HR, 4) PS applied daily from 1100 to 1400 HR, and 5) PS applied daily from 1400 to 1700 HR. By 2001 tree size had increased so the shade shelters used for the PS treatments could only accommodate a single tree per plot. The time for PS treatment was altered in 2001 so that trees originally shaded at 0800 to 1100 HR were shaded at 0700 to 1330 HR and trees originally shaded at 1400 to 1700 HR received shade from 1330 to 2000 HR daily. Trees that were originally shaded from 1100 to 1400 HR were not artificially shaded in 2001. In addition, four trees in the CS plots were not artificially shaded in 2000, but the shade was reapplied in 2001. Likewise, four original C trees were given CS in 2000 and then treated as C trees in 2001.

Special steel structures were designed and built to surround the test trees and support the shade material in this study (Fig. 1).

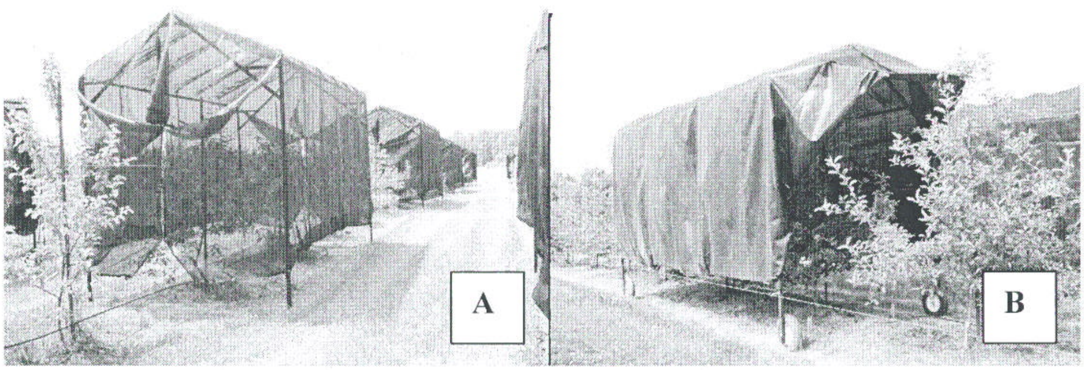

Fig. 1. Shade shelters used to apply constant shade (CS) (A) or partial shade (PS) (B) to 'Ginger Gold'/M.9 apple trees. Structures used for CS and PS were the same dimensions except rubber tired wheels were added to the PS shelters to facilitate positioning at specific times each day.

The shade shelters measured 2.43 m wide by 5.67 m long and 3.23 m tall at the highest point in the center. A black polypropylene shade fabric (Hummert International, St. Louis, MO) providing 73% or 95% actual shade was used. The 73% shade material was used for the CS treatments throughout the study. The PS treated trees had 73% shade in 1998 and 1999 and 95% shade in 2000 and 2001. Shade cloth was applied over the top (roof) of the shade shelters and extended down the sides to within about 45 cm of the ground. For the CS shelters all four sides were enclosed (Fig 1A), but only the sides parallel to the row were covered in the PS shelters (Fig 1B). Metal poles were secured to each end of the shelter's roof extending about 1.0 m down the tree row and the shade cloth was placed over these poles forming an awning (Fig 1B). This provided more uniform shade to test trees in the PS test plots. The PS shade shelters were connected to a cable and winch system operated by a time clock that was designed to pull the shelter over the test tree plots at the designated time each day. At the end of the day or at dawn the next day the PS shelters were manually repositioned at the end of each row in preparation for the daily shade treatments.

Canopy photosynthetic photon flux (PPF) levels and canopy temperature were recorded continuously in one tree representing each treatment. Air temperature was recorded with an Optic StowAway Temp data logger (Spectrum Technologies, Inc., Plainfield, IL) placed in a white wooden weather shelter attached to the upper tree post support wire. PPF was recorded at 10-min intervals with a quantum light sensor (models 3600 and 3668, Spectrum Technologies, Inc.) attached to a pole erected in the tree canopy and located half way between the center of the canopy and the drip-line of the tree at a height of 2.0 m. Incident PPF and ambient air temp were recorded in a vacant tree spot in the block as described above. Only a select portion of the voluminous temperature and light data will be reported at this time.

Response variables measured annually included trunk diameter, bloom cluster count, fruit count and weight at harvest, internal fruit quality (firmness, soluble solids, and starch index rating) at harvest, current season shoot length, and leaf and shoot carbohydrate levels. Yield efficiency (YE) and bloom efficiency were computed from trunk cross-sectional area (TCSA) data. Only the effects on bloom, tree growth, fruit weight, and yield will be reported at this time. Trunk diameter was measured 20 cm above the graft union. Shoot length was the mean of 20 terminals selected at random per tree. Bloom cluster count was the total number of blossom clusters per tree taken between pink and full bloom. Fruit was harvested in August when the starch index rating reached a 3.0 level (Blanpied and Silsby, 1992). Data was analyzed using SAS ANOVA (SAS Institute, Cary, NC) and means separated with Duncan's new multiple range test.

Results and Discussion

One growing season of CS (73%) reduced trunk diameter of 'Ginger Gold'/M.9 (Table 1). The annual increase in trunk diameter during the next three growing seasons for CS trees was equal to or less than that for the check trees. As a result, CS trees had a smaller trunk diameter after 4 growing seasons than check trees or trees shaded in the afternoon or trees receiving 3 years PS from 1100 to 1400 HR followed by a no shade year. PS (73%) applied from 0800 to 1100 HR reduced trunk diameter after one and two growing seasons, but trunk diameter of these trees was not different from check trees after a third and fourth year of PS. It is suggested that PS in the early part of the day imposes a stress on the younger trees that is overcome as the tree ages. The negative effect of CS on trunk diameter appears to be reduced if trees are given a natural sunlight environment for one year. In contrast, one year of CS applied to an older tree (fifth leaf, 2000) did not result in reduced trunk size. Limited information has been reported concerning the effect of whole-tree shade on trunk growth, but these results appear to agree with reports on the effects of shade on tree size (Auchter, et al., 1926; Jackson and Palmer, 1977a).

Shoot growth was not recorded at the conclusion of the first year (1998) of shade treatments. There was no difference in shoot extension growth among treatments after two seasons (1999) (Fig.2). However, in the third season of treatment those trees receiving CS for 3 years or CS only in 2000 (C-C-CS) had longer shoots than C or PS trees. Jackson and Palmer (1977a) and Moran and Rom (1991) also reported an increase in stem length from shade treatments, but their effect was noted in the first year of treatment. The lack of shoot growth response to CS in 1999 is not easily explained since trees receiving CS for the first time in 2000 responded with increased shoot growth. However, the results suggest that reserves for growth were not limiting in 2000, but were limiting in 1999.

Bloom clusters per cm^2 TCSA were reduced after one year of CS, but PS (73%) had no effect (Table 2). In subsequent years, CS treated trees had numerically fewer bloom clusters than check trees but the differences were not significant from check trees. Since a heavy bloom often follows light bloom years (Westwood, 1978), it appears these CS trees were attempting to recover from the initial shade effect in 2000. Two years (1998 and 1999) of PS (73%) at all time periods reduced the number of bloom clusters in 2000. Bloom count for PS treated trees in 2001 was not different from check trees, as might be expected following a year of reduced bloom. There was a trend toward a reduced bloom count on trees treated as C trees for 2 seasons followed by one year of CS, but differences were not significant.

Shade treatments had no effect on fruit numbers at harvest in the first year (1998) (Table 3). The delay in application of the shade material until 7-weeks after FB was apparently sufficient to allow normal fruit set to occur (Byers, et al., 1990). Fruit numbers were reduced in CS treated trees in the second season of treatment, as might be expected. In subsequent years all CS and PS treatments showed reduced fruit numbers at harvest compared to check trees. The reduction in 2000 can be directly related to the reduction in bloom in 2000. Trees treated as C trees in the first two years followed by a CS treatment in the third year and then returned to C treatment in the fourth year did not have reduced fruit numbers in 2001. However, when trees were given CS in 1998-1999, left unshaded in 2000 and were returned to CS in 2001, there appeared to be a slight recovery in fruit count at harvest when not shaded, but there was a dramatic reduction in fruit count when the trees were given CS the following year. These results suggest that shade treatments may have had a direct effect on fruit set in 2001, a response not evident in 1999. While shade treatments were applied at about the same time after FB in these two years, the stage of fruit development may have differed. No data was taken on the size of fruitlets at the time shade materials were applied.

There was little or no effect of shade treatment on mean fruit weight (data not shown) except in the first year of shading when fruit from CS treated trees was smaller than C fruit (179 g/fruit for CS vs. 230 g/fruit for C fruit). When C trees were shaded in 2000 and not shaded in 2001, fruit size was reduced in 2001 compared to trees that had never been shaded.

Yield (data not shown) and YE (kg fruit per cm^2 TCSA) (Table 4) produced results similar to that for fruit count at harvest. CS reduced yields and YE. Trees shaded for 4 years, initially from 0800 to 1100 HR and later from 0700 to 1330 HR, showed reduced yields and YE similar to those trees that received CS during the same period.

Mean temperatures for June 2001 showed differences ($P \leq 0.05$) between ambient and shade treatments during the two daily time periods. Mean temperature for trees under 73% and 95% shade during the 0700 to 1330 HR was 23.1°C and 22.7°C, respectively compared to 26.2°C for the ambient temperature. Temperatures during the 1330 to 2000 HR period differed between the two levels of shade (27.2°C for 73% shade vs 26.5°C for 95% shade) and with ambient temperature (28.4°C). Mean incident light levels, measured as PPF ($\mu mol \cdot m^{-2} \cdot s^{-1}$), for June 2001 were 934 and 791 for the periods 0700 to 1330 HR and 1330 to 2000 HR, respectively. Light levels measured under 73% and 95% shade for these same periods were slightly less than that expected from levels calculated for 27% and 5% of the mean incident light.

Conclusions

The following conclusions have been drawn from these whole-tree shade studies.

- Constant shade (CS) at 73% reduced bloom, yield, and trunk diameter, but increased shoot growth in some years.
- Partial shade (PS) on a daily basis may reduce bloom, fruit numbers at harvest, and yield, but had little or no effect on shoot length. There appears to be some cumulative effect of PS over time (years). PS at 95% has a greater effect than 73% PS. Shade applied early in the day (0800 to 1100 HR or 0700 to 1330 HR) has a greater effect than shade applied only at mid-day (1100 to 1400 HR) or in the latter half of the day (1400 to 1700 HR or 1330 to 2000 HR).
- Trees can respond to and recover from CS (73%) in one season
- Whole-tree shade significantly reduces canopy temperature and incident PPF.
- Younger trees (third leaf) may respond differently than older trees (sixth leaf) to shade.

Literature Cited

Auchter, E.C., A. L. Schrader, F.S. Lagasse, and W.W. Aldrich. 1926. The effect of shade on the growth, fruit bud formation and chemical composition of apple trees. Proc. Amer. Soc. Hort. Sci. 23:368-382.

Byers, R.E., J.A. Barden, and D.H. Carbaugh. 1990. Thinning of spur 'Delicious' apples by shade, terbacil, carbaryl, and ethephon. J. Amer. Soc. Hort. Soc. 115:9-13.

Ferree, D.C. 1985. Light requirements for quality apple production. Trans. Ill. State Hort. Soc. 119:107-111.

Heinicke, D.R. 1966. Characteristics of McIntosh and Red Delicious apples as influenced by exposure to sunlight during the growing season. Proc. Amer. Soc. Hort. Sci. 89:10-13.

Hunter, D.M. and J.T.A. Proctor. 1986. The correlation of light interception with yield and fruit color of McIntosh apple strains. Fruit Var. J. 40(3):79-83.

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

Jackson, J.E. and J.W. Palmer. 1977a. Effects of shade on the growth and cropping of apple trees. I Experiemntal details and effects on vegetative growth. J. Hort. Sci. 52:245-252.

Jackson, J.E. and J.W. Palmer. 1977b. Effects of shade on the growth and cropping of apple trees. II Effects on components of yield. J. Hort. Sci. 52:253-266.

Jackson, J.E., R.O. Sharples, and J.W. Palmer. 1971. The influence of shade and within-tree position on apple fruit size, colour and storage quality. J. Hort. Sci. 46:277-287.

Moran, R.E. and C. Rom. 1991. The effects of diurnal light on photosynthesis and growth of greenhouse grown apple. HortSci. 26:497. Abstr.

Robinson, T.L., A.N. Lakso, and Z. Ren. 1991. Modifying apple tree canopies for improved production efficiency. HortScience 26:1005-1011.

Westwood, M.N. 1978. Temperate-zone pomology. W. H. Freeman and Co., San Francisco

Table 1. Effect of whole-tree constant shade (CS) and partial shade (PS) treatments on the trunk diameter of young 'Ginger Gold'/M.9 apple trees planted in 1996.

Treatments [z]		Trunk diameter (cm)			
1998 –2000	2001	1998	1999	2000	2001
Check (C)	C	4.20 a[y]	4.70 ab	5.70 a	6.62 a
Constant Shade (CS)	CS	3.33 c	3.90 c	4.24 c	4.85 b
PS 0800-1100[x]	PS 0700-1330	3.76 b	4.41 b	5.15 ab	5.91 ab
PS 1100-1400	C	3.86 ab	4.64 ab	5.49 ab	6.36 a
PS 1400-1700	PS 1330-2000	4.27 a	5.03 a	5.79 a	6.65 a
CS-CS-C	CS	----	----	4.86 bc	5.67 ab
C-C-CS	C	----	----	5.07 ab	5.87 ab

[z] See text for details of individual shade treatments.
[y] Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.
[x] Hours daily during which shade imposed.

Fig. 2. Effect of whole-tree constant shade (CS) or partial shade (PS) treatments on shoot growth of 4th (1999) and 5th (2000) leaf 'Ginger Gold'/M.9 apple trees. Shade treatments applied 1998 through 2000; see text for description of shade treatments. No statistical differences in 1999; letters for 2000 bars represent differences between treatments, Duncan's multiple range test, $P = 0.05$.

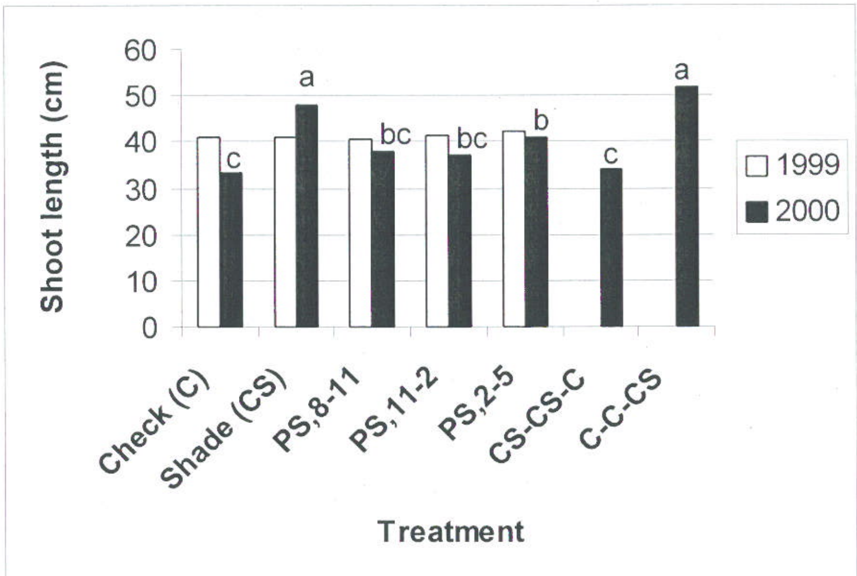

Table 2. Effect of whole-tree constant shade (CS) or partial shade (PS) treatments on the bloom of young 'Ginger Gold'/M.9 apple trees planted in 1996.

Treatment[z] 1998 - 2000	Bloom clusters per cm^2 TCSA 1999	2000	2001
Check (C)	23.6 a[y]	22.4 a	26.0 ab
Constant Shade (CS)	7.4 b	16.1 ab	14.8 b
PS 0800 – 1100 HR	23.4 a	10.0 b	27.8 ab
PS 1100 – 1400 HR	22.7 a	8.6 b	31.2 a
PS 1400 – 1700 HR	17.2 a	10.5 b	25.3 ab
CS-CS-C	----	----	27.8 ab
C-C-CS	----	----	19.6 ab

[z] See text for details of individual shade treatments.
[y] Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.
[x] Hours daily during which shade imposed.

Table 3. The effect of whole-tree constant shade (CS) or partial shade (PS) treatments on the number of fruit at harvest in 'Ginger Gold'/M.9 apple trees planted in 1996.

Treatments [z]		Fruit count at harvest (no./tree)				Cumul.
1998 –2000	2001	1998	1999	2000	2001	1998-'01
Check (C)	C	29 a[y]	94 a	196 a	302 a	621
Constant Shade (CS)	CS	30 a	18 b	22 c	23 d	93
PS 0800-1100[x]	PS 0700-1330	35 a	80 a	76 bc	79 cd	270
PS 1100-1400	C	42 a	110 a	82 bc	172 b	406
PS 1400-1700	PS 1330-2000	31 a	101 a	109 b	147 bc	388
CS-CS-C	CS	----	-----	74 bc	16 d	138
C-C-CS	C	----	-----	51 bc	279 a	453

[z] See text for details of individual shade treatments.
[y] Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.
[x] Hours daily during which shade imposed.

Table 4. The effect of whole-tree constant shade (CS) or partial shade (PS) treatments on yield efficiency in 'Ginger Gold'/M.9 apple trees planted in 1996.

Treatments [z]		Yield efficiency (kg/cm^2 TCSA)			
1998 –2000	2001	1998	1999	2000	2001
Check (C)	C	0.50 b[y]	1.03 a	1.50 a	1.74 a
Constant Shade (CS)	CS	0.67 ab	0.33 b	0.34 c	0.29 d
PS 0800-1100[x]	PS 0700-1330	0.70 ab	0.96 a	0.77 bc	0.57 d
PS 1100-1400	C	0.78 a	1.14 a	0.74 bc	1.15 b
PS 1400-1700	PS 1330-2000	0.47 b	0.95 a	0.89 bc	0.77 c
CS-CS-C	CS	-----	-----	0.97 b	0.18 d
C-C-CS	C	-----	-----	0.38 c	1.77 a

[z] See text for details of individual shade treatments.
[y] Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.
[x] Hours daily during which shade imposed.

Interpretative Summary

The importance of light in the growth and production of apple is well documented. However, much of an apple tree's canopy may be enveloped in shade during the day. Shade reduces fruit bud formation, affects leaf structure and photosynthesis, and results in lower fruit quality. The objective of this study was to examine the effect of constant shade (24 hrs. per day) or periodic shade (3 or 6.5 hrs per day), applied on a daily basis, on growth and fruiting in dwarf apple trees. Constant shade at 73% reduced trunk diameter, bloom clusters, and yields, but increased shoot extension growth. Periodic shade had little or no effect on growth, but did show a cumulative effect over years on bloom and yield. Shade applied in the morning had more of an effect than shade applied after 1330 hrs. This information is useful to extension fruit specialists and fruit growers in training and pruning apple trees, and to researchers designing light and shade studies.

Technical Summary (Abstract)

Third leaf 'Ginger Gold'/M.9 apple trees were covered with 73% shade cloth on a continuous (CS) basis from mid- or late May through September beginning in 1998 and continuing through 2001. An additional group of trees received 73% (1998-1999) or 95% (2000-2001) shade (PS) for a period of 3 hrs (1998-2000) or 6.5 hrs (2001) each day from May through September. The initial season of CS reduced trunk diameter; in subsequent years, trunk growth for CS trees was equal to or less than that of check (C) trees. PS applied from 0800-1100 HR reduced trunk diameter after one and two years, but not in the third and fourth years. Shoot growth was increased by CS, but not by PS. Bloom was reduced after one year of CS. In subsequent years there was a trend for reduced bloom from CS, but differences were not significant. Bloom was reduced after two seasons of PS. These trees returned bloom the following year. Both CS and PS treatments reduced fruit numbers at harvest and yield efficiency. Whole tree shade (73% or 95%) reduced canopy temperature and incident photosynthetic photon flux. Results indicated that trees can respond to and recover from CS in one growing season.