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Shade effects on growth, flowering and fruit of apple

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Abstract

Light is a critical resource needed by plants for growth and reproduction. A major portion of the apple (*Malus* x *domestica* Borkh.) tree's canopy is subjected to shade during most daylight hours each day and such shade may affect productivity. The current research determined effects of morning, afternoon, and all-day shading on processes that are significant to orchard productivity. In 1996 'Ginger Gold'/M.9 apple trees were planted in the field near Kearneysville, WV and shade treatments were imposed from 2002 to 2005. Trunk and branch growth were reduced consistently by morning shade (MS) compared to no shade (NS) and full shade (FS) and afternoon shade (AS) had intermediate effects. Total branch growth from 2002 to 2005 was 164, 168, 145, and 157 cm for FS, NS, MS, and AS, respectively. Although shade affected yield inconsistently from year-to-year, total yield from 2002 to 2005 was 7.8, 201.6, 72.5, and 110.6 kg/tree for FS, NS, MS, and AS, respectively. Time of shading clearly affected yield with full shade causing the greatest reduction, followed by partial shade treatments, MS and AS. Concentrations of soluble carbohydrates, particularly sorbitol, were greater in leaves of AS compared to MS. It is postulated that MS may have adversely affected photosynthesis at a time of day that was most conducive to high net assimilation. Planting and training apple trees to minimize shade, especially morning shade, may benefit orchard productivity.

Key words: Apple, carbohydrate, fruit quality, productivity

Introduction

Apple growers are seeking more efficient, sustainable production methods that employ reduced inputs to remain globally competitive, insure consistent annual production, and to meet the increasing demand for locally grown fresh fruits. Many factors influence cropping and fruit quality potential including the environment, cultural practices, canopy growth habit, crop history, and endogenous plant hormones (Faust, 1989; Maib, 1996). A better understanding of these factors and how they interact is necessary for further advances in production efficiency. Considering that more than 90% of plant dry weight is derived from photosynthetically fixed carbon, the importance of carbon assimilation and carbon partitioning in optimizing production is evident (Flore and Lakso, 1989; Forshey and Elfving, 1989). The role of light and photosynthesis in tree fruit production, particularly apple, has been well documented (Flore and Lakso, 1989; Lakso, 1994). Much of the research has focused on altering tree size, shape, and planting systems (Robinson, *et al.*, 1991) to increase light (photosynthetic active radiation, PAR) interception and thereby maximize carbon assimilation with an ultimate goal of increased yields and enhanced fruit quality.

While recognizing the importance of these methods for increased light interception, it remains that a major portion of the apple tree's canopy is subjected to shade during most daylight hours each day. Shading to 40% of full sunlight reduced flower and fruit numbers, total yields, and fruit dry weight in five-year-old apple trees subjected to two training systems (Chen *et al.*, 1997). Several days of continuous shade soon after bloom can reduce fruit set (Byers *et al.*, 1990). Studies with partial shade are very limited (Moran and Rom, 1991) and little is known concerning the effect of limited shade during a specific diurnal period on fruiting and growth. Shade, which reduces flower bud formation and fruit set, may also interact with crop load to affect flower formation (Jackson and Palmer, 1977). Results reported by Jackson and Palmer (1980) indicate that the crop size necessary to reduce flowering is less under low light levels. This could be important in areas like the eastern U.S. that have many partly cloudy and hazy days.

When Lakso and Musselman (1976) investigated the effect of cloudiness on interior light in apple canopies, they found that diffuse light was greater under partly cloudy conditions compared to cloudless conditions resulting in increased PAR levels to the interior canopy. Whole-canopy photosynthesis measurements of apple trees have determined the general light response and demonstrated effects of cropping and heat stress (Wünsche and Palmer, 1997; Whiting and Lang, 2001; Glenn *et al.,* 2003). None of these studies have examined the plant response as a function of long-term seasonal whole-tree shading.

There is a need to optimize carbon assimilation in orchard systems and manage carbon partitioning to improve cropping and fruit quality. The objective of the current research was to determine effects of morning, afternoon, and all-day shading on processes that are significant to orchard productivity. The hypothesis was that shade applied at specific intervals during the day and throughout the growing season will alter dry matter production and partitioning in apple and affect yield. The long-term goal of this and related work is to optimize light interception and carbon partitioning to fruit for consistent annual cropping and high fruit quality.

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', 'Gold Rush', and 'Liberty', each on M.9 rootstock, that were 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. All trees were dormant pruned annually by the same individual to maintain uniformity to the extent possible. Once the basic central leader form was established (after the second growing season), pruning cuts were primarily (ca. 99%) thinning type cuts. Pollination was enhanced by the placement of two active bee hives within the immediate vicinity of the test block. Crop load was adjusted by hand following "June drop" to space fruit approximately 15 cm apart on limbs. Trees received the local recommended cultural and pest management program throughout the study (Pfeiffer, 1998). 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 herbicides were used in the following years.

In 2002, trees were subjected to shade with 73% shade cloth from 0700 to 1330 HR (morning shade, MS) or 1330 to 2000 HR (afternoon shade, AS) daily from 2 weeks after full bloom (WAFB) to 10 WAFB and again 16 through 23 WAFB. A 24 hr constant 73% shade treatment (full shade, FS) and a non-shade treatment (no shade, NS) were included. In years 2003-05 95% shade cloth was used for all shade treatments. In all years, periodic shade treatments were applied daily to replicate trees using specially constructed shelters controlled by electronic time clocks (Fig. 1).

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. Shade cloth was applied over the top of the shade shelters and extended down the sides to within about 45 cm of the ground. For the FS shelters all four sides were enclosed (Fig. 1A), but only the sides parallel to the row were covered in the partial shade shelters (Fig. 1 B). 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). The partial 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 partial shade shelters were manually repositioned at the end of each row in preparation for the daily shade treatments.

Treatment and sampling dates varied from year-to-year based on phenological development of the trees (Table 1). Response variables measured annually included trunk diameter (30 cm above the graft union), bloom cluster count before and after pruning, fruit count and dry weight (dw) at harvest, internal fruit quality (firmness, soluble solids, and starch index rating) at harvest, current season shoot length, and leaf and shoot carbohydrate levels (Stutte *et al.,* 1994). Total soluble carbohydrate concentrations were calculated as the sum of glucose, fructose, sucrose, sorbitol and glucose-6-phosphate. Yield efficiency (YE) and bloom efficiency were computed as a function of trunk cross-sectional area (TCSA) data. Branch growth was the mean of 20 terminal current-year shoots 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). The four shade treatments were randomly assigned to 4 reps and each experimental unit was composed of 3 or 4 tree subsamples. Data was analyzed with the Proc Mixed Model of SAS (SAS Institute, Cary, NC).

Results and discussion

Growth: In most years, unshaded trees (NS) had the most or were among the most TCSA and branch growth (Table 2). Compared to NS, no shade treatment consistently reduced branch growth but TCSA growth was reduced by MS and FS in 2003 and 2005. TCSA did not differ between NS and AS trees but branch growth was reduced by AS from 2003 to 2005. In previous work, Miller (2001) found that 27% of full sun imposed by shading for a four-hour period each day from 3 wks after full bloom (FB) until 6 wks after harvest had minimal effects on growth and fruiting. In the current study 95% shade reduced growth but timing of shade treatment each day had significant effects. Reduced sunlight in MS treatments may have reduced carbon assimilation at a time of the day when temperatures were lower and conducive to stomata opening and to photosynthesis. The AS-treated trees may have enabled photosynthesis by reducing sunlight and leaf temperatures and thus reduced stress in the afternoon.

Flowering: The numbers of flower clusters per cm^2 TCSA were

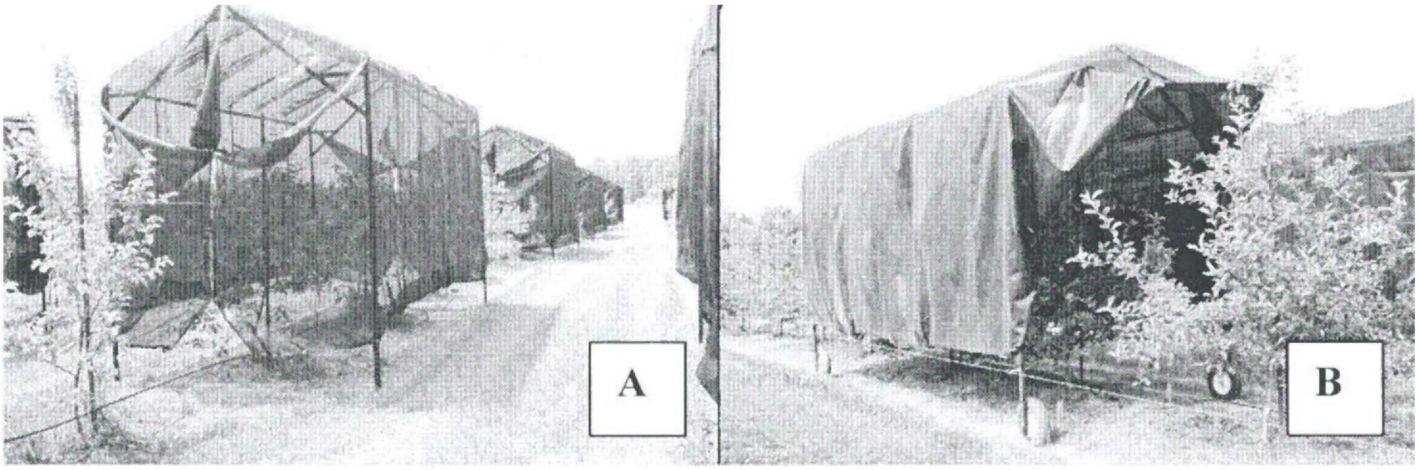

Fig. 1. Shade shelters used to apply full shade (FS) (A) or partial shade (MS, AS) (B) to 'Ginger Gold'/M.9 apple trees. Structures were the same dimensions except rubber tired wheels were added to the partial shade shelters to facilitate positioning at specific times each day

Table 1. Time of bloom, imposed shade, sampling for carbohydrates, and harvest. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS). Shade cloth was 73% in 2002 and 95% in 2003-05

Year	Bloom	Harvest	Shade treatment			Sample dates
			FS	MS	AS	
2002	Apr. 18	Aug. 14-15	73% May 6-Oct. 2	73% May 6-Oct. 2	73% May 6-Oct. 2	Jul. 1, Jul. 31, Aug. 27, Oct. 1
2003	Apr. 22	Aug. 21-22	95% May 13-Jul. 1 then Aug. 19-Sep. 17	95% May 13- Sep. 17	95% May 13- Sep. 17	Jun. 5, Jul. 1, Jul. 29
2004	Apr. 21	Aug. 16-19	95% May 14-Jul. 7 then Sep. 1-Oct. 22	95% May 14- Oct. 22	95% May 14- Oct. 22	Jun. 9, Jul. 6, Aug. 9, Aug. 31
2005	Apr. 25	Aug. 15-17	95% May 18-Jul. 11 then Sep. 1-Oct. 19	95% May 18- Oct. 19	95% May 18- Oct. 19	May 17, Jun. 16, Jul. 11

counted to evaluate the biological cropping potential before pruning and reduced crop load that may reflect a managed tree after pruning (Table 3). Number of clusters before pruning rose and fell from one year to the next, with trees receiving NS, MS, and AS treatments (Table 3). The MS and AS were in positive synchrony and varied together from year-to-year; they were in opposite flowering cycle with NS. This biennial bearing obfuscated effects of shading. For example, in 2005 one might interpret MS and AS to have decreased the number of blooms per cm^2 TCSA (4.5 and 4.3, respectively) compared to NS (17.7) (Table 3). However, the reduced number of clusters may also be due to high bloom in 2004 resulting in reduced bloom in 2005. Heavy bloom years often follow light bloom years leading to alternate years of high yield (Westwood, 1978). The number of clusters before pruning appeared to be declining with time in FS trees. The number of clusters following pruning generally followed the same trends as the cluster count before pruning.

Fruit: No fruit developed under FS. As with flower clusters the density of fruit per cm^2 TCSA appeared to be following a biennial pattern under NS, MS, and AS. From 2002 to 2004 the NS treatment had the largest number of fruit per tree. Fruit number and weight per tree were both reduced by and did not differ between MS and AS treatments (Table 4). In contrast, vegetative growth was reduced more by MS than AS suggesting that fruit sinks were more sensitive to shade than vegetative sinks as described by Bapete and Lakso (1998) (Tables 2 and 4). Previous work demonstrated that vegetative growth may retard flower or fruit growth due to shade. Early season shading of more than 60% full sunlight decreased partitioning of carbohydrates to fruit and vegetative stem growth was favored over fruit in 'Empire' trees (Bepete and Lakso, 1998). Shade reduced fruit retention and yield in both the year of shading and the following year (Jackson and Palmer, 1977). Three days of 80% shade resulted in up to 70% fruit abscission (McArtney *et al.,* 2004). In 2003 and 2005, the largest fruit weight was associated with NS even though crop load was greater than or as great as MS and AS (Tables 3 and 4). Total dry weight of apples can be reduced by 12% and 30% with 73 % shade applied for partial and all day, respectively (Moran and Rom, 1991).

Shading did not consistently affect fruit quality. Fruit firmness, starch and soluble sugars tended to be greatest in NS but fruit quality measures differed between MS and AS (Table 5). Fruit firmness tended to be lower and starch index higher in MS than AS, suggesting that fruit maturity advanced more quickly in fruit under MS than AS.

Carbohydrates: Stem and leaf samples were collected at the same time each day, always just before shade was removed from MS and before shade was installed in AS. So, AS and NS were exposed equally to sun each morning when samples were collected. A second sampling note is that in May 2005 leaves and stems were sampled before shade was installed.

Table 2. Trunk cross-sectional area (TCSA) and branch growth of 'Ginger Gold' apple trees grown under four shade treatments from 2002 to 2005. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS)

Shade treatment	Year 2002	2003	2004	2005
	TCSA (cm^2)			
FS	28.0 b[*]	34.4 b	37.1 b	40.4 b
NS	42.1 a	52.8 a	58.1 a	73.8 a
MS	30.2 b	32.7 b	38.4 b	42.0 b
AS	46.2 a	50.7 a	61.2 a	65.3 a
	TCSA growth (cm^2/yr)			
FS	6.4 ab	4.2 b	2.7 b	3.2 b
NS	10.0 a	10.6 a	5.2 b	15.7 a
MS	2.5 b	2.5 b	5.6 b	3.5 b
AS	11.3 a	4.5 b	10.4 a	4.0 b
	Branch length (cm)			
FS	41.6 a	35.9 b	43.4 a	43.2 b
NS	35.3 c	42.2 a	43.9 a	46.8 a
MS	33.8 c	34.7 b	40.0 b	36.7 c
AS	38.8 b	35.9 b	40.6 b	41.7 b

[*] Within each variable and year, means followed by the same letter do not differ in the Proc. Mixed procedure (P=0.05)

Table 3. Bloom and fruit load of 'Ginger Gold' apple trees grown under four shade treatments from 2002 to 2005. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS)

Shade treatment	Year 2002	2003	2004	2005
	Cluster (number / cm^2 TCSA) before pruning			
FS	22.8 a[*]	12.5 a	8.0 bc	5.8 b
NS	10.8 c	14.9 a	3.0 c	17.7 a
MS	19.2 ab	1.0 b	16.6 a	4.5 b
AS	14.4 bc	0.9 b	10.2 ab	4.3 b
	Cluster (number / cm^2 TCSA) after pruning			
FS	13.9 a	7.6 a	4.2 b	4.2 b
NS	5.5 c	8.4 a	0.7 c	9.2 a
MS	10.4 ab	0.7 b	9.4 a	3.5 b
AS	7.0 bc	0.2 b	4.6 bc	2.9 b
	Fruit (number / cm^2 TCSA)			
FS	1.2 c	0.0 b	0.0 b	0.0 c
NS	8.7 a	4.7 a	6.1 a	1.6 b
MS	2.7 bc	4.9 a	0.6 b	3.2 a
AS	2.9 b	4.0 a	0.6 b	3.1 a

[*] Within each variable and year, means followed by the same letter do not differ in the Proc. Mixed procedure (P=0.05).

Table 4. Yield of 'Ginger Gold' apple trees grown under four shade treatments from 2002 to 2005. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS)

Shade treatment	Year 2002	2003	2004	2005
	Fruit harvested (no. / tree)			
FS	30.7 c*	0.0 c	0.0 b	0.0 b
NS	362.5 a	246.5 a	340.5 a	139.6 a
MS	82.7 bc	176.7 b	23.7 b	133.2 a
AS	132.5 b	243.5 ab	36.7 b	210.7 a
	Fruit harvested (kg / tree)			
FS	7.8 c	0.0 d	0.0 b	0.0 b
NS	66.6 a	47.2 a	57.1 a	30.7 a
MS	19.5 bc	24.4 c	4.9 b	23.7 a
AS	32.3 b	35.8 b	6.6 b	35.9 a
	Fruit weight (g / fruit)			
FS	256.9 a	0.0 c	0.0 b	0.0 c
NS	190.1 b	195.5 a	171.4 a	221.1 a
MS	240.0 a	140.1 b	172.0 a	179.2 b
AS	245.8 a	149.8 b	163.1 a	178.7 b

* Within each variable and year, means followed by the same letter do not differ in the Proc. Mixed procedure (P=0.05).

Table 5. Fruit characteristics of 'Ginger Gold' apple trees grown under four shade treatments from 2002 to 2005. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS)

Shade treatment	Year 2002	2003	2004	2005
	Fruit resistance to pressure (kg)			
FS	7.6 a*	no fruit	no fruit	no fruit
NS	7.3 ab	8.1 a	6.4 b	8.7 a
MS	7.2 b	7.5 c	6.3 b	7.8 b
AS	7.4 a	7.9 b	6.8 a	8.0 b
	Fruit starch index (low=9, high=1)			
FS	2.5 b	no fruit	no fruit	no fruit
NS	3.9 a	2.3 c	5.7 a	1.7 a
MS	3.7 a	3.5 a	5.4 ab	1.6 a
AS	2.3 b	2.9 b	4.9 b	1.7 a
	Fruit soluble sugars (%)			
FS	12.0 b	no fruit	no fruit	no fruit
NS	12.4 a	12.3 a	11.4 a	12.7 a
MS	11.9 b	11.0 b	11.5 a	10.6 b
AS	11.4 c	10.8 b	11.6 a	10.5 b

* Within each variable and year, means followed by the same letter do not differ in the Proc. Mixed procedure (P=0.05).

Table 6. Soluble sugar concentration in leaf and stem of 'Ginger Gold' apple trees grown under four shade treatments from 2002 to 2004. Shade treatments included Full Shade (FS), No Shade (NS), Morning Shade (0730 – 1330, MS), and Afternoon Shade (1330 – 2000, AS)

Sample date	Shade treatment	Soluble sugar concentration (mg / g) Leaf Glucose-6-phosphate	Leaf Sorbitol	Leaf Total	Stem Glucose-6-phosphate	Stem Sorbitol	Stem Total
July 1, 2002	FS	109 a*	82 a	220 a	42 a	36 a	96 ab
	NS	95 b	82 a	205 b	43 a	33 a	93 b
	MS	112 a	56 b	191 c	43 a	35 a	93 ab
	AS	110 a	76 a	213 ab	48 a	35 a	99 a
July 31, 2002	FS	105 a	68 b	208 b	36 ab	33 a	82 bc
	NS	92 b	58 b	179 c	35 b	29 b	77 c
	MS	112 a	59 b	207 b	40 a	35 a	90 a
	AS	108 a	80 a	230 a	39 ab	35 a	88 ab
Aug 27, 2002	FS	87 b	69 a	200 b	30 b	32 a	80 b
	NS	90 b	64 ab	194 b	30 b	36 a	83 ab
	MS	115 a	53 b	199 b	38 a	37 a	90 a
	AS	111 a	77 a	233 a	39 a	36 a	90 a
Aug 31, 2004	FS	108 bc	71 ab	212 a	36 a	35 a	89 a
	NS	100 c	77 a	209 ab	35 a	35 a	86 a
	MS	122 a	49 c	189 c	36 a	26 b	73 b
	AS	113 ab	63 b	199 bc	35 a	26 b	73 b
May 7, 2005	FS	116 a*	66 a	212 a	90 a	55 a	179 a
	NS	108 a	74 a	216 a	94 a	62 a	189 a
	MS	109 a	70 a	212 a	98 a	58 a	192 a
	AS	109 a	73 a	212 a	99 a	59 a	192 a
June 6, 2005	FS	126 a	31 c	165 c	79 a	16 c	105 b
	NS	107 b	74 b	204 b	54 c	39 a	112 ab
	MS	nm	nm	nm	61 b	32 b	110 ab
	AS	116 ab	85 a	221 a	61 b	34 b	114 a
July 11, 2005	FS	114 a	39 b	170 b	65 a	17 b	92 a
	NS	105 ab	76 a	214 a	38 b	34 a	86 a
	MS	104 ab	44 b	174 b	41 b	30 a	86 a
	AS	101 b	80 a	213 a	40 b	33 a	88 a

* Within each variable and year, means followed by the same letter do not differ in the Proc. Mixed procedure (P=0.05).

On July 1, 2002, total carbohydrate (TC) in tree leaves was greatest in FS and least in MS treatments (Table 6). By August 2002, TC was greatest in AS and was less but did not differ among the other shade treatments. Sorbitol is the main transport carbohydrate in apple and sorbitol was low in leaves of MS-treated trees during July 1 and August 27, 2002. In June and July 2005, leaf TC was significantly less in FS and MS than NS and AS-treated trees. As in 2002, elevated levels of TC in leaves were associated with greater levels of sorbitol during June and July 2005.

During 2002 total carbohydrate (TC) in stems was similar among all shade treatments (Table 6). However, the partial shade treatments generally had the highest TC which was associated with higher glucose-6-phosphate on July 31 and August 27, 2002. Glucose-6-phosphate is a significant precursor to sucrose, sorbitol and starch (Zhou and Cheng, 2008). Elevated concentrations of glucose-6-phosphate may indicate increased sugar transport and storage carbohydrate (starch) which may provide a necessary energy reserve for trees under shade. It is possible with a greater crop load, such as with the NS, MS, and AS treatments in June and July, 2005 (Table 4), that shading would diminish carbohydrates (Table 6). That does not appear to have occurred in this study. However, storage carbohydrates such as starch that were not measured in this study may be an important buffer.

A major portion of an apple tree's canopy is subjected to shade during most daylight hours each day and such shade may affect productivity. Shading may result from competition between trees and between growing meristems on the same tree. Canopy complexity may accentuate such intra-canopy competition. In the current experiment vegetative growth and yield were studied when shade was applied to the whole canopy. Full shade eliminated the crop and morning shade reduced growth and yield more than afternoon shade. Soluble carbohydrates in stems and leaves were inconsistent but were generally higher with no shade. Partial-day shade, notably afternoon shade, often had growth and yield that was equivalent to no shade. This suggests that morning shade may have adversely affected photosynthesis at a time of day that was most conducive to high net carbon assimilation. Training systems that reduce intra-canopy shading may help maximize yield although suppression of elevated temperatures may be necessary.

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