The Effects of Temperature and Light in High Tunnel Primocane Red Raspberry Production Final Report

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Summary

Project establishment began on 19 April, 2012, when dormant 'Autumn Britten' red-raspberry primocanes were planted in three-replicated tunnels at the Iowa State University Horticulture Research Station near Gilbert, IA. Soil mulch was applied at the time of planting to lower root-zone temperature and retain soil-moisture. White shade cloth with a 33% shade factor was applied on 1 June, 2012 and 3 June, 2013 to obtain a 50% reduction of irradiance by including both the tunnel plastic (17%) and shade cloth (33%) effects. Shade cloth was removed on 22 Sept., 2012 and 30 Sept., 2013 when irradiance fell below optimum levels. Due to the climactic extremes of the 2012 establishment season, primocane growth and berry production were minimal. After a year of root growth and establishment in 2012, the 2013 growing season provided adequate conditions for primocane red-raspberry growth. Soil mulch provided a decrease in root-zone temperature and adequate weed control. Plants grown with shade cloth exhibited a larger leaf area as well as fresh berry weight. Yield of berries was higher without the shade cloth, but average berry size was smaller. Growers should determine if total yield or increased berry size is more important when deciding to grow high tunnel raspberries under shade cloth.

Introduction

Primocane red raspberries benefit from microclimates provided by high tunnels, and these benefits include reduced winter injury, improved cold hardiness, decreased pest incidence, and increased berry size and quality (Pritts, 2008; Domoto et al., 2009). By using high tunnels, the production season is also increased by an additional three to four weeks in spring and fall, extending the harvest period about 50% beyond scheduled field production (Heidenreich et al., 2007; Demchak, 2009; Domoto et al., 2009).

Research has shown benefits of protected-tunnel environments that result from improved climatic conditions (Stafne et al., 2001; Carew et al., 2003; Remberg et al., 2010). However, excessive root-zone and air temperatures also cause adverse effects on raspberry growth and fruit development (Bushway et al., 2008). Premature bud dormancy, delayed time-to-ripening, decreased water absorption, and reduced fruit quality and yield due to increased root-zone and air temperatures also have been demonstrated (Hoover et al., 1989; Privé et al., 1993). Further research has found water absorption, timing of floral-bud initiation, and yield in primocane red raspberry production are impacted by increased irradiance. Irradiance greater than 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ can adversely affect primocane growth (Braun and Garth, 1984; Oliveira et al., 2004).

Elevated air temperature slows down primocane height and growth rate (Heide and Sonsteby, 2011). Primocane-fruiting red raspberries initiate flowers on the distal buds during long days or warm temperatures of summer in the Northern Hemisphere (Lockshin and Elfving, 1981; Pritts, 2008). As air temperature increases from 9.9 °C to 24 °C, cane height and growth rate increase, advancing flowering and fruiting primordia (Carew et al., 2003). Similarly, 'Autumn Bliss' primocane time-to-flowering decreased as air temperature increased from 15 °C to 24 °C (Carew et al., 2003). In addition, quantity of flowering laterals increased distally down the cane as temperatures approached the optimum range (Heide and Sonsteby, 2011).

Time-to-flowering decreased as air temperature increased beyond 24 °C (Carew et al., 2003; Jett, 2011). Remberg et al. (2010) found that berry weight decreased as harvest period progressed and temperature increased. Further research indicated that air temperature greater than 25 °C approximately doubles the evapotranspiration rate in primocane-fruiting 'Heritage' and 'Reville', resulting in an increased water absorption requirement and delayed growth response (Crandall and Daubeny, 1990; Heide and Sonsteby, 2011).

Growth and development of primocanes also are sensitive to optimum root-zone temperature. Privé et al. (1993) found that primocane-fruiting cultivars exhibited increased root and shoot growth with root-zone temperatures less than 16 °C. Organic mulches decrease root-zone temperatures in various fruit crops (Teasdale and Mohler, 1991). Hoppula and Salo (2007) reported improved strawberry fruit size, yield, and leaf area due to increased soil moisture from decreased root-zone temperature and water loss. In contrast, root-zone temperatures greater than 16 °C inhibited raspberry cane elongation, decreased plant assimilation rate, and reduced fruit quality (Hoppula and Salo, 2007; Privé et al. 1993).

Primocane fruit yield also is correlated with increased irradiance (Oliveira et al., 2004). Primocane-fruiting red raspberries initiate flowers when irradiance is the highest (Carew et al., 2003). Bud dormancy, delayed time-to-ripening, and decreased fruit quality and weight result when irradiance exceeds 600 $\mu mol \cdot m^{-2} s^{-1}$ (Oliveira et al., 2004; Remberg et al., 2010). Moreover, fruit yield is negatively correlated with decreased cane and leaf light interception as the result of increased adventitious shoots and flowering laterals (Oliveira et al., 2004).

Despite widespread findings of the effects of increased air-and root-zone temperature, and irradiance, research linking these critical factors with the physiological characteristics of growth and fruit yield of primocane-fruiting red raspberry is limited. Our objectives were to (1) assess the relationship between temperature and irradiance and their influence on primocane growth and development and (2) evaluate the efficacy of shade cloth and soil mulch in reducing temperature and irradiance during high tunnel primocane red raspberry production.

Materials and Methods

Experiments were conducted at the Iowa State University (ISU) Horticulture Research Station (lat. 42°06'30" N; long. 93°35'08" W), rural Ames, IA in the 2012 and 2013 growing seasons. Initial soil samples indicated a Clarion-Webster loam soil series consisting of 3.6% organic matter and having a pH of 6.5. Day neutral strawberry (*Fragaria ×ananassa*) planting in 2011 preceded raspberry establishment. Three identical tunnel structures (11.0 x 4.3 m) covered with 6-ml polyethylene plastic were utilized (FarmTek, Dyersville, IA).

Dormant, one-year-old canes of primocane red raspberry ‘Autumn Britten’ (Nourse Farms, South Deerfield, MA) were planted on 18 April, 2012 in raised beds 9.1 m long and 61 cm wide. Canes were spaced 46 cm apart within rows and 120 cm between rows. Raspberry canes were trained on a temporary T-trellis, with twine located at heights of 90 and 180 cm. Plants were watered and fertilized by trickle irrigation at recommended rates (Bushway et al., 2008). At planting, switchgrass mulch (Armstrong Research Farm, Lewis, IA) was applied to a depth of 15.2 cm.

Before treatment application, tunnel polyethylene-plastic covering exhibited a 17% irradiance reduction as measured with a quantum sensor (LI-190) data logger (LI-1400) (LI-COR Inc., Lincoln, NE). White shade cloth that provided 33% shade factor (Hummert International, Springfield, MO) was installed on 1 June, 2012 and 3 June, 2013 under the polyethylene-plastic covering, resulting in the 50% target reduction of irradiance, as suggested by Willits (2003). Irradiance was measured weekly, at 12:00 p.m., above the soil surface at plant canopy heights of 30 and 90 cm using an LI-191 line quantum sensor. Irradiance was also measured at three randomly selected locations under shade cloth treatments using an LI-190 quantum sensor, and LI-1400 data logger (LI-COR, Lincoln, NE). Shade cloth was removed on 22 Sept., 2012, and 30 Sept., 2013 when irradiance had decreased below 600 $\mu mol \cdot m^{-2} s^{-1}$.

Air- and root-zone temperature were recorded under main and sub-plot treatments of high tunnel and open field at the primocane shoot apex and a root-zone depth of 10.2 cm with WatchDog™ B-Series Temperature Loggers (Spectrum Technologies, Plainfield, IL). Temperature was recorded at 60-min intervals and was averaged over every 24-hr period. Data on total cane height, leaf number, and number of vegetative laterals were collected at the end of the harvest period from five randomly selected canes in 2012, and six randomly selected canes in 2013, from each treatment. For fruiting characteristics, we determined the number of fruiting laterals per cane, length of flowering laterals, and fruit number per cane. Berries were harvested every 2 to 4 days, and total weight, fruit yield, and average fresh and dry weight of berries were recorded. Mean fresh and dry berry weights were calculated from the average of ten fresh and dried berries from each treatment over the harvest period. Leaf area per cane was quantified with a Li-Cor LI-3100C Area Meter (LI-COR, Lincoln, NE) on the five and six canes in each treatment in 2012 and 2013, respectively.

Flower bud development data were taken throughout the 2013 growing season on three randomly selected canes in each treatment. Julian dates of flower initiation, bud break, petal fall, and first harvest were recorded.

A split-plot, randomized complete block design was used. Main-plot treatment of 50% shade cloth (33% shade plus 17% tunnel plastic reduction) was assigned randomly to three replicated tunnels, creating a block effect of either shade cloth with tunnel plastic covering (“50% shade”) or tunnel plastic-covering alone at 17% shade (“tunnel”). Sub-plots were selected randomly for switchgrass (*Panicum virgatum* L.) mulch under main plot treatments of 50% shade or tunnel, creating two additional treatments of shade cloth with switchgrass mulch (“50% shade plus mulch") and tunnel-plastic covering plus mulch ("tunnel plus mulch"). Data were subjected to analysis of variance, and least square means were separated with LSD mean separation at $P \leq 0.05$ (SAS, Version 9.3).

Results

Irradiance.

Open-field irradiance in 2012 ranged from 995 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 20 Sept. to 2066 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 26 July; whereas in tunnels with 6-ml woven polyethylene-plastic, tunnel irradiance was 727 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 20 Sept. to 1682 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 21 July. In 2012, thirty-three percent shade cloth plus the tunnel's plastic covering reduced irradiance by an additional 123 and 829 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 20 Sept. and 21 July, respectively.

In 2013, open-field irradiance radiance ranged from 1340 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 24 Sept. to 1990 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 3 June; whereas in tunnels with 6-ml woven polyethylene-plastic, tunnel irradiance was 1285 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 4 Sept. to 1574 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on 3 July. Seasonal reduction of irradiance averaged 58.6% under the combination of 50% shade cloth and plastic covering of the tunnel during both growing seasons.

Temperature.

2012. Maximum daily open-field air temperature ranged from 26.6 to 37.7 °C for three weeks in July, with lows in the mid-teens to mid-twenties during the same period. Air-temperature means with 50% shade cloth plus tunnel plastic covering were 24.5, 27.1, 22.1, and 17.0 °C for the months of June, July, August, and Sept., respectively.

Switchgrass mulch reduced root-zone temperature in high tunnel primocane raspberry production by 2.5 °C. Compared to the open-field plot, root-zone temperature reduction with shade cloth and mulch ranged from 3.6 °C in July to 1.4 °C in Sept., whereas mulch alone (without shade cloth) reduced root-zone temperature by 3.0 and 0.5 °C in July and Sept., respectively (Fig. 1). Mean root-zone temperature was increased by 0.8 °C in the absence of soil mulch compared with mulch (Fig. 1).

2013. Maximum root-zone temperature occurred on Aug. 28 under all treatments in the high tunnel. On Aug. 28, main plot treatment of 50% shade increased root-zone temperature by 1.6°C compared to the open-field plot, with an additional increase of 1.5°C increase of root-zone temperature of tunnel plastic alone (Fig. 2). Compared to the control treatment of tunnel plastic alone, maximum root-zone temperature was reduced by 3.7 and 4.9°C with the presence of tunnel plus soil mulch and 50% shade cloth plus mulch, with a mean reduction of 3.5°C with the presence of soil mulch. Optimum mean root-zone temperature was best achieved by 50% shade cloth and soil mulch, with an increase 0.7°C. Root-zone temperature increased in variability in the absence of soil mulch (Fig. 2).

Fruit and Growth Development.

2012. Thirty-three percent shade and soil mulch were associated with an 11% reduction of primocane-fruiting raspberry weight (Table 1) in 2012. Cooler root-zone temperature had a greater effect on fruit yield, with a 35.5% increase at the beginning of harvest when root-zone temperature ranged from 19.3 to 26.2 °C. As mean root-zone temperature decreased below 18.4 °C, treatments became analogous and production started to decline. In the absence of soil mulch, primocanes under 50% shade cloth were slow to yield large quantities of fruit. As the season progressed and air- and root-zone temperatures decreased, greater berry yield was produced in treatments without shade cloth and mulch.

Shade and mulch did not influence the growth and development parameters in the first year of establishment and partial production (Table 2). Poor canopy development, including the number of laterals produced, number of leaves, and leaf area, was observed in plots without mulch, but results were inconclusive. While mulch and 50% shade cloth plus mulch increased mean cane height by 23.6 and 52.1 cm, respectively, there were no changes in the development of fruiting laterals or time-to-ripening (Table 2).

2013. Total berry yield was reduced with 50% shade plus mulch compared to tunnel alone plus mulch. Average fresh berry weight increased by 11% where 50% shade was the treatment. When mulch was incorporated with shade (50% plus shade), average fresh berry weight declined slightly over the growing season (Table 1).

Primocane cane height was reduced by in the presence of 50% shade compared to tunnel plastic alone. While soil mulch cooled the root-zone temperature to near optimum temperature for primocane growth, there were no changes in cane height when soil mulch was the sole factor. Cane height did not affect the number of vegetative and flowering laterals. Leaf area increased 2.5 times with 50% shade compared to 50% shade plus mulch. Increased leaf area was not associated with increased leaf number except with 50% shade. Flower lateral length was reduced significantly when 50% shade plus mulch was used. No difference of canopy light transmission was seen between treatments (data not shown).

Discussion

According to the National Oceanic and Atmospheric Administration (NOAA) National Climactic Center, 2012 was the warmest year on record for the lower 48 states nationally, and the third-warmest year on record for Iowa (NOAA, 2012). Due to extreme temperatures in 2012, air temperature located at the primocane shoot apex was not influenced by shade cloth in tunnel production. In comparison, the spring of 2013 was the wettest on record, resulting in extremely saturated soils for the months of March, April, and May. Adventitious shoots just out of dormancy were submerged in water for two consecutive weeks in April. As a result, primocane growth was delayed and overall cane growth was stunted.

In the increased air- and root-zone temperatures of 2012, floral primordial development continued into the summer when irradiance was twice the optimal range. Adventitious shoot and lateral growth were not affected by decreased irradiance from 50% shade cloth in 2012 but were affected in 2013 (Table 2). Similar to previous research by Oliveira et al. (2004) and Remberg et al.(2010), berry size decreased under increased tunnel irradiance and root-zone temperatures. Shade cloth reduced cane height and the number of leaves produced on the primocanes but leaf area was larger. This indicates that leaf area with tunnel plastic consisted of a large number of small leaves with increased internode spacing.

Consistent with previous research by Carew et al. (2003), fruit development and yield were favored when root-zone temperatures were 17.5 to 24 °C. Although no difference was found between timing of flower bud development at varying root-zone temperatures, decreased fruit yield was observed when root-zone temperatures increased beyond 25 °C. In 2012, use of mulch was associated with increased berry weight but in 2013 had no effect.

Similar to Remberg et al. (2010), we found that increased irradiance decreased fresh berry weight, but flowering progressed regardless of irradiance and advancement of harvest season. This recognizes a possible inverse relationship with accumulated growing degree days and yield as suggested by Oliveira et al. (2004). Furthermore, differentiation of floral buds occurred when air temperature was 20 to 30 °C.

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Table 1. Fruiting characteristics of primocane red raspberry 'Autumn Britten' produced in high tunnels in 2012 and 2013. Data represent means of three pooled high tunnels across main and sub-plot treatments of 50% shade, 50% shade plus mulch, tunnel plastic, and tunnel plastic plus mulch.

Treatment	Berry yield (g)		Berry number		Fresh berry weight (g)[y]		Dry berry weight (g)[y]
	2012	2013	2012	2013	2012	2013	2013
Tunnel alone (17% shade)[z]							
No mulch	1348.9 a	22901.9 ab	216 a	8673 a	2.7 a	2.7 b	.37 a
Plus mulch	1481.7 a	25657.1 a	572 a	9836 a	2.6 a	2.6 b	.36 a
Tunnel (17% + 33% shade cloth)[z]							
No mulch	1164.2 a	22185.9 ab	482 a	8148 a	2.7 a	2.9 a	.39 a
Plus mulch	945.6 a	19458.2 b	342 a	6800 a	2.3 b	2.8 ab	.38 a

[z] Means followed by the same letter within columns are not different from one another based on LSD of mean separation ($P \leq 0.05$).
[y]Fresh and dry berry weight from an average of ten berry weight sample.

Table 2. Growth and physiological characteristics of primocane red raspberry 'Autumn Britten' produced in high tunnels in 2012 and 2013. Data represent means of three pooled high tunnels across main and sub-plot treatments of 50% shade, 50% shade plus mulch, tunnel plastic, and tunnel plastic plus mulch.

	Height (cm)		Adventitious lateral no.		Leaf no.		Leaf area (cm²)		Flower length (cm)[y]
Treatment	2012	2013	2012	2013	2012	2013	2012	2013	2013
Tunnel alone (17% shade)[z]									
No mulch	111.1 a	118.2 a	67.1 a	25.7 a	151.5 a	174.5 ab	3262 a	3361 b	10.3 ab
Plus mulch	129.7 a	118.3 a	47.8 a	36.1 a	192.3 a	288.6 a	3906 a	5475 b	14.2 ab
Tunnel (+ 33% shade cloth)[z]									
No mulch	106.1 a	96.0 b	31.5 a	38.0 a	109.1 a	269.0 ab	2878 a	8538 a	16.7 a
Plus mulch	158.2 a	100.2 ab	94.5 a	23.1 a	198.2 a	159.8 b	4980 a	3505 b	8.0 b

[z] Means followed by the same letter within columns are not different from one another based on LSD of mean separation ($P \leq 0.05$).
[y]Flowering lateral length averaged from five randomly selected flowering laterals.

Key for treatments listed in Figures 1 and 2 on following page: Tunnel = 17% shade effect from tunnel covering and no soil mulch; 50% Shade = 33% shade cloth + 17% shade from tunnel covering and no soil mulch; Tunnel plus mulch = 17% shade from tunnel covering and soil mulch; 50% Shade plus mulch = 33% shade cloth + 17% shade from tunnel covering and soil mulch applied.

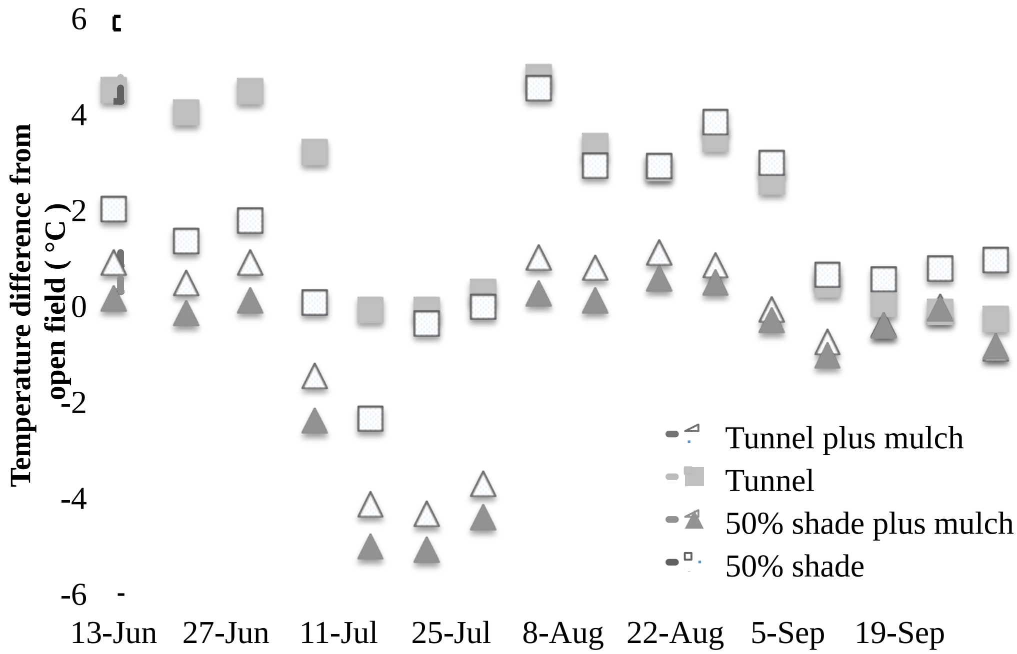

Fig. 1. Main and sub-plot treatment effects from 50% shade cloth (shade) and switchgrass soil mulch (mulch) on mean root-zone temperature differences from open-field, at a depth of 10.2 cm. Data represent daily means of three pooled high tunnel replications compared to open-field production. Temperature was recorded at 60 min intervals and averaged over every 24 hr period in 2012.

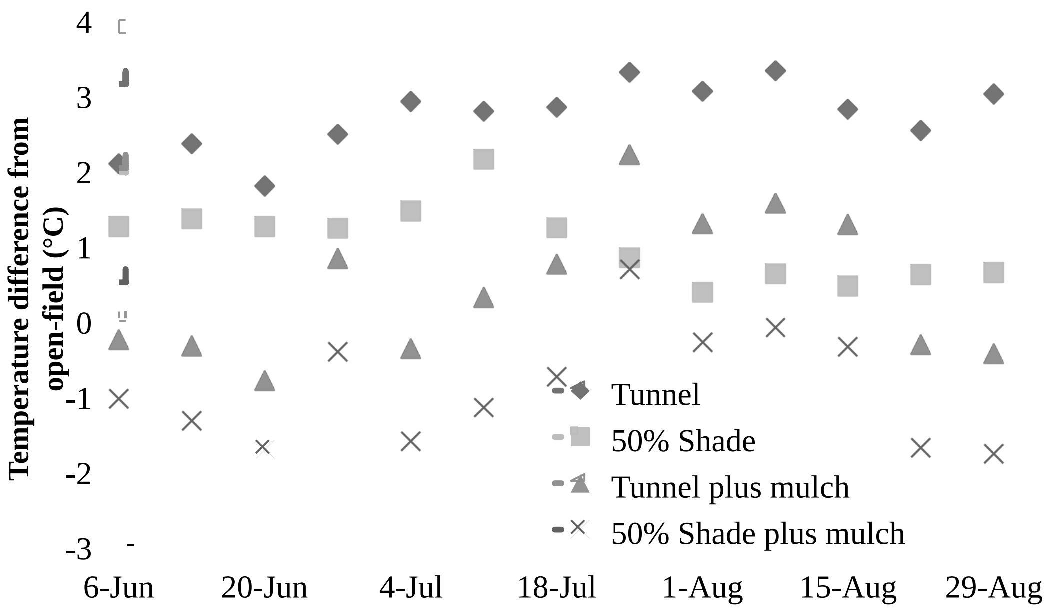

Fig. 2. Main and sub-plot treatment effects from 50% shade cloth (shade) and switchgrass soil mulch (mulch) on mean root-zone temperature differences from open-field, at a depth of 10.2 cm. Data represent daily means of three pooled high tunnel replications compared to open-field production. Temperature was recorded at 60 min intervals and averaged over every 24 hr period in 2013.

Photo 1: ‘Autumn Britten’ primocanes grown with switchgrass mulch and under shade cloth (50% shade obtained from 17% shade effect of tunnel covering and 33% shade cloth).

Photo 2: Leah Riesselman (graduate student) and Austin Schott (student intern) recording light transmission through canopy irradiance.

Photo 3: Elly Arganbright and Austin Schott (student interns) collecting berry harvest in high tunnel plots in 2013.