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Effect of timing of shade on growth, development, physiology, and fruiting of a primocane fruiting blackberry in a controlled environment

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Abstract

Primocane blackberry production in the upper south is limited by high temperatures during the bloom and early fruiting period, resulting in poor fruit set and poor fruit quality. Shade may have the potential to delay bloom and flowering to a more favorable season. A greenhouse study was established to evaluate the effects of shade on primocane blackberry growth, physiology, and fruiting. Single rooted plants of 'Prime-Ark[®] 45' were planted in 12-liter pots and grown in a greenhouse at the University of Arkansas System Division of Agriculture, Agriculture Research and Extension Center, Fayetteville, Arkansas. At approximately 0.25 m in height, one of the four following treatments was imposed with eleven single plant replications: 1) an untreated control (CK), 2) unshaded for 29 days then shaded for 30 days (US), 3) shaded for 29 days then shaded for 30 days (SS), and 4) shaded for 29 days and unshaded for 30 days (SU). Plants in the SU treatment were significantly taller than the SS and CK. Dry weight of leaves was consistent for all treatments except for SS which was significantly lower than the others. The CK bloomed first followed by US and SS. The last to bloom was the SU, 26 days after the CK. In conclusion, there was a delay of 'Prime-Ark 45' flower formation when 50% shade cloth was implemented and removed in the SU treatment. Further research needs to be completed to find the optimal intensity and timing of shade implementation that will improve fruit set in the southern region.

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Meet the Student-Author



Olivia Caillouet

I am from Little Rock, Arkansas, and graduated with honors from Little Rock Central High in 2012. I will graduate in December 2016 with a degree in Horticulture and minor in Sustainability. I was awarded 1st place in the southern regional American Society for Horticultural Science (ASHS) undergraduate oral paper competition February 2016 and received 3rd place in the poster competition at the National ASHS conference August 2015. Furthermore, I was awarded 2nd place in the Arkansas Academy of Science (AAS) oral undergraduate competition and received 3rd place in the Honors College Student Board Poster Competition in 2016. I am a State Undergraduate Research Fellowship (SURF) grant recipient for work in Fayetteville, Arkansas and Mozambique, Africa. During my time at the University of Arkansas I have served as the Horticulture Club treasurer and vice president; worked as the Bentonville Farmer's Market Assistant Manager; completed an internship on a certified organic citrus farm in Big Sur, California; and was a summer intern at a farm in Adjuntas, Puerto Rico. I plan to pursue graduate school after graduation and then embark upon my career focused on food security at the local as well as global scale.

I would like to thank Jason McAfee for all his help and guidance throughout this research process. Curt Rom was instrumental in this journey and his advice and support is appreciated. I would also like to thank my Honors Thesis committee members, Curt Rom, John Clark, Elena Garcia, and Lawton Nalley for the time and energy provided to make this process enjoyable and fulfilling. Lastly, thank you to my team Luke Freeman, Spencer Fiser, Julia Stover, and Heather Friedrich.

Introduction

Blackberry production in Arkansas, the region and the United States is increasing. Rodriguez et al. (2012) showed that the cultivated acreage of blackberry production in Arkansas increased 277% between the years of 1997 and 2007. The introduction of the autumn-bearing primocane-fruiting blackberry cultivars began with the release of 'Prime-Jan[®]' and 'Prime-Jim[®]' in 2004 by the University of Arkansas System Division of Agriculture (Clark et al., 2005). This unique type of blackberry fruits on current-season canes (primocanes) compared to traditional summer-fruiting blackberries which bear on second-season canes (floricanes) (Clark et al., 2005).

The new autumn-bearing, primocane fruiting blackberries expand the market season for the fruit. However, studies have shown that fruiting during hot seasons results in poor pollination, fruit set, and fruit quality. Stanton et al. (2007) tested three levels of temperature on primocane blackberry cultivars in growth chambers and it was found that increasing temperatures were directly correlated with lower percent of flowers and fruits. Primocane fruiting blackberries flower in Arkansas and the upper mid-South during July and August, traditionally

the hottest months of the year. These new genotypes have not been found to be well adapted to Arkansas conditions.

The light environment can have an effect on flower formation and fruiting in rosaceae crops (Marini and Sowers, 1990). Based upon preliminary field experiments and observations (Curt Rom, pers. comm.), it was hypothesized that shade could delay flowering in primocane-fruiting blackberries. Based upon previous work, light saturation of blackberries occurred at 750-900 $\mu\text{moles}/\text{m}^2/\text{s}^1$ light flux which is approximately equivalent to 50% full sun on an average Arkansas day. Shade treatments would generally have allowed at or near light saturation allowing achievement of near maximum average photosynthesis rates (Curt Rom, pers. comm.). It is well studied that light is the driving energy source for photosynthesis which influences the rate of growth as well as development of plant organs (Janick, 1986). However, Janick (1986) states that when a plant reaches maturity, it is capable of flowering, but will not make the transition from a vegetative stem primordia into floral primordia unless the environment exposed to at the time of maturity is conducive.

A study on blackberries in a greenhouse tested a full sun control, 20%, 50%, and 70% irradiance to full sun (Gal-

lagher et al., 2014). Gallagher et al. (2014) reported the flower and fruit period was more concentrated when 70%-100% irradiance to full sun was implemented during initiation, meaning lower light levels may result in delayed flower differentiation and or incomplete development.

Rotundo et al. (1998) found that 40% shade reduction cloth extended the fruiting period 25 days for eight-year-old plantings of 'Black Satin' florican blackberries and 28 days for 'Smoothstem' blackberries compared to the unshaded control in the Basilicata region of southern Italy at an altitude of approximately 630 m. Furthermore when shade was implemented in late July 1996 until late October, these two blackberry cultivars had an increased cumulative fruit production the following year, 1997, by 9% and 12%, respectively, compared to control (Rotundo et al., 1998). Through increasing or decreasing levels of light it is thought that the development of flower formation during the first three vegetative states: induction, initiation, and differentiation may be manipulated to shift primocane blackberry flower development.

There have been very few studies on the effects of shade on blackberries and no studies on the effects of shade on primocane blackberries were identified. Despite little re-

search, there is reason showing adaptations to shading by blackberries. In a previous study, Rotundo et al. (1998) reports that two blackberry cultivars responded to reduced lighting under 40% shade netting through increased levels of chlorophyll production. Rates of photosynthesis, transpiration and stomatal conductance were also lower for shaded blackberry leaves (Rotundo et al., 1998). Makus (2010) states that two light-level treatments, 0% control and 40% shade, were implemented on blackberries 20 May 2008 and plants grown under shade had significantly higher cumulative yields compared to all other treatments. When 'Prime-Ark® 45' was released, it was reported that the first bloom date at the University of Arkansas System Division of Agriculture's Fruit Research Station, in Clarksville, Arkansas was 30 June and first ripe fruit was 8 Aug. which was the latest of the primocane cultivars tested (Clark and Perkins-Veazie, 2011). The date of shading for this experiment was chosen based on previous research so that light conditions would be altered during the vegetative stage of development.

Research in a controlled environment reduces variability and externalities that influence plant growth and development and therefore can isolate treatment effects.



Fig. 1. An illustration of the shade-unshaded treated plants of 'Prime-Ark® 45' day 36, 6 days after removing the initial shade treatment, while grown in a greenhouse, Fayetteville, Arkansas, 2014.

This has the potential to provide isolated treatment effects of various levels of shade on primocane-fruiting physiology with an emphasis on flower and fruit development. The objective of this study was to determine the effects of changing light environments on the growth and development of primocane fruited blackberries. If these effects were observed, the flowering and fruiting period could be shifted to a more favorable season for fruit set and quality.

Materials and Methods

A greenhouse experiment was designed to complement a field experiment (Caillouet, et al., 2016) that evaluated the effects of various shade treatments on primocane-fruited blackberries. The greenhouse is located at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center (AAREC), Fayetteville Arkansas (Latitude: 36° N; Longitude: 94° W). Experimental plants were grown in a double-layer, 6-mm polyethylene covered climate controlled greenhouse that is 12.5 m (L) × 9 m (W) × 3 m (H) and has a north-south orientation. Greenhouse temperatures were controlled by a thermostatically controlled pad-and-fan cooling system during the summer with a 25/35 °C day/night temperature set point.

Plant Material and Management

Sixty bare-root dormant cuttings of 'Prime-Ark 45' were purchased from Berry and Plant Company (Plymouth, Indiana) and planted in 12-L pots using certified organic peatmoss and perlite based growing media (Sunshine® Natural and Organic Mix (Sungro Products) in early April, 2014.

When plants were approximately 0.25 m in height, 44 plants for the experiment were selected for uniformity of growth. During the study period, canes were pruned of axillary lateral bud break and trained to bamboo stakes. Every week suckers (adventitious shoots that arise from the base of the plant) were removed. When canes reached heights of approximately 1.5 m, the bamboo stakes were doubled to increase structural support for potted plants (Fig. 1). Blackberry plants were watered as needed. Potted plants were placed on wire benching systems and the height of the wire benches was lowered throughout the experiment as the plant's height increased.

Osmocote® fertilizer was applied in amounts of 15 g to each potted plant then lightly watered throughout the experiment. In addition, one application of insecticide (Imidacloprid) (Marathon®) was applied at a rate of 0.26 g/L until plants dripped on 28 July 2014 to control armyworms (*Spodoptera exempta*).

Treatments

After selection (described above), on 4 June 2014, selected plants were randomly assigned one of four treatments: 1) an untreated control (CK), 2) unshaded for 29 days then shaded for 30 days (US), 3) shaded for 29 days then shaded for 30 days (SS), and 4) shaded for 29 days and unshaded for 30 days (SU) (Fig. 2). Plants grew for 29 days at which time shade treatments were changed. Shade cloth was either added or removed 2 July 2014 to treatment 2) US, now shaded and treatment 4) SU, now unshaded for an additional 30 days with these treatments. After a 59-day period of treatments, all shade structures were removed and the plants were allowed to grow, flower, and fruit for an additional 30 days (Fig. 2).



Fig. 2. An illustration of all treated plants of 'Prime-Ark® 45' day 59, when all shade was removed, while grown in a greenhouse, Fayetteville, Arkansas, 2014.

Shade was provided by 50% shade neutral density cloth covering metal frame structures over the greenhouse benches. There were 11 single plant replicates of each treatment. Plants were placed with a single treatment per bench, and plants randomized within the bench surface. There was not a block design to this experiment due to limited greenhouse space.

Measurements

Starting the same week as treatments, measurements were taken. Weekly measurements of cane diameter (6 cm above the soil line), cane height (cm), estimated chlorophyll content (Minolta® SPAD) on the 4th or 5th leaf from the terminal cane tip and gas exchange (CIRAS-3® portable gas exchange monitor equipped with a Parkinson® leaf chamber) were taken once weekly over a period of 13 weeks. For chlorophyll estimates and gas exchange, the center most leaflet of the pentafoliate, four to five nodes below the terminal cane tip of each potted plant was used.

Leaf gas exchange was measured on a 6.25 cm² area of leaf. Cuvette-chamber conditions were set for incoming [CO₂] of 385 ppm, cuvette temperature of 28 °C, and inflow air relative humidity (RH) of 50%. Saturating light conditions of 1200 μmol/m²/s¹ were provided with the PP Systems® PLC3 Universal LED Light head attached to the cuvette chamber. Gas exchange was measured after apparent steady-state conditions after 120-180 s.

The individual first date of replicated flower formation was recorded for each treatment and was not analyzed statistically. At the end of the 89-day study period, the final height (cm), cane diameter 6 cm above the soil line (mm), and number of flower buds, flowers, and fruits were recorded. Plants were destructively harvested. The total weight of buds (g), flowers (g), and fruits (g) was measured. The total leaf area (cm²) and total number of leaves for each potted plant were recorded. After the fresh plant data were collected, the canes, stems, leaves, and reproductive organs were placed in paper bags within a dryer for 336 hours at 70 °C and weighted (g of dwt). Dry weight of leaves, stems, and roots was recorded to equal the total dry weight of plant biomass.

A completely randomized design was used for analysis. Data were analyzed with Proc GLM procedure in SAS statistical software (SAS v. 9.3, SAS Institute Inc., Cary, N.C.) and mean separation was calculated by least significant difference (LSD) ($\alpha = 0.05$).

Results and Discussion

Plants in the SU treatment were the tallest compared to other treatments (Table 1, Fig. 3). The other treatments all had similar heights until shade was changed after 29

days for SU and US (Fig. 3). Treatments US and SU were greater than the CK, however SS was not different from CK or US (Table 1). The results for cane diameter were similar to cane height; SU had greatest stem diameter and SS was significantly thinner than SU while the control and US shoots were intermediate in diameter (Table 1).

The shade treatments affected plant biomass. The CK and SU treatments resulted in the greatest total plant bio-

Table 1. Final growth and harvest measurements of treated plants of 'Prime-Ark® 45' day 89, while grown in a greenhouse, Fayetteville, Arkansas, 2014.

Treatment	Shoots Height (cm)	Shoots Diameter (mm)	Leaves Area (cm ²)	Leaves Area (cm ²)	Avg. Size (cm ²)	Total Fruit structures		% Open Flowers		% Closed Flowers		Dry Weights		
						(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	Shoots (g)	Leaves (g)	Roots (g)
Control	197c†	9ab	41	5955	146	299	206	98	2	37a	53a	106a	196a	
Unshaded/ Shaded	227ab	9ab	44	7917	189	250	72	95	5	35ab	51a	75b	162ab	
Shaded/ Shaded	204bc	8b	42	7166	183	159	65	75	25	26b	34b	64b	124b	
Shaded/ Unshaded	251a	10a	49	7077	145	143	37	74	26	42a	52a	94ab	188a	
Prob > F	0.0025	0.05	ns	ns	ns	ns	ns	ns	ns	0.009	0.0017	0.0347	0.0185	

† Mean separation followed by different letters are significantly different, $\alpha = 0.05$, n = 11. ns = there are no statistical differences among treatments.

mass, with no significant difference in the US but significantly less biomass in the SS treatment (Table 1). Plants shaded had reduced plant growth and development, especially dry weights. Although there were differences for height, cane diameter, and dry weights (shoots, leaves, roots, and total dry weight), there were no significant differences for other growth variables.

Leaf dry weight was similar for all treatments except for SS which was significantly less than the other treatments (Table 1). The results from this experiment agree with previous findings made by Marini and Sowers (1990) with another Rosacea species, peaches, in which specific leaf weight was found to decline with increased levels of shade.

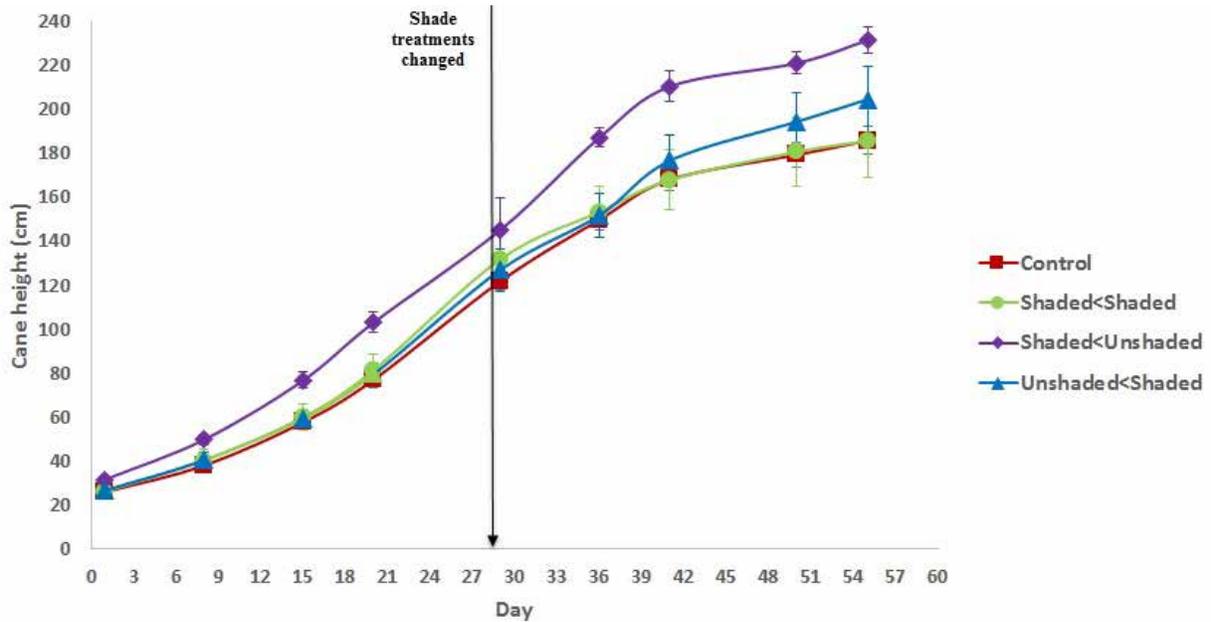


Fig. 3. Cane height (cm) of treated plants of 'Prime-Ark® 45', while grown in a greenhouse, Fayetteville, Arkansas, 2014. The vertical bars on the graph represent the +/- standard deviation in the data set. Standard deviation takes variances into consideration while increasing the statistical confidence of the results. The bar represents when shade treatments were changed. n = 11.

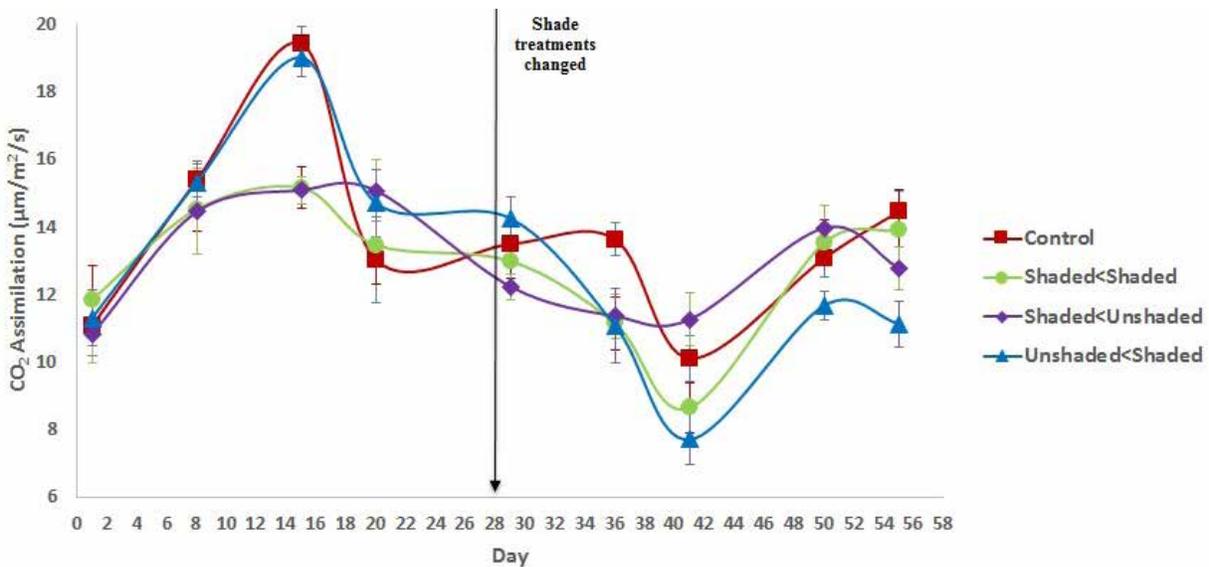


Fig. 4. CO₂ assimilation (A) of treated plants of 'Prime-Ark® 45', while grown in a greenhouse, Fayetteville, Arkansas, 2014. The bar represents when shade treatments were changed. n = 11.

Treatments CK and US, had the highest rates of CO₂ assimilation (A) at the start of the experiment and were different from SS and SU which were the least (Fig. 4). Plants adapted to the alteration in light conditions when shade treatments were changed as observed by the maintenance of similar A patterns within a treatment. The SS treatment adjusted to shading and was greater than US; all treatments were different from US at the conclusion of A data collection (Fig. 4).

After shade treatments were changed day 29 of the experiment, the estimated chlorophyll (CHL) content (SPAD) was greatest for CK and SU; while SS and US were the same and less than CK and SU (Fig. 5). At the end of the experiment when the final SPAD measurements were taken, SS and CK were the same and resulted in the highest SPAD values compared to other treatments; while SU and US plants were the same and had the least estimated CHL content (Fig. 5). This supports previous research findings that plants may adapt to continuous shade such as the SS treatment plants, which increased levels of estimated CHL content compared to other treatments and resulted in the same amounts as the CK (Fig. 5).

Flowers were distinguished depending on if they were opened flowers with petals or fruit compared to unopened flowers. The unopened flowers, opened flowers, and fruits were summed for total potential fruiting units (Table 1). The number of flower buds, flowers, and individual fruits did not vary significantly among treatments (Table 1).

For the first date of individual flower appearance, shading in the SU treatment resulted in a delay of flower and

fruit set. The CK plants bloomed first 2 July followed by US on 17 July and SS on 27 July (Table 2). The last to bloom was the SU, 26 days after the CK on 28 July (Table 2). Given the research presented by Clark and Perkins-Veazie (2011) where fruit was formed 39 days after first flower, these findings are significant because fruit could be shifted to 5 Sept. compared to the CK which would fruit approximately 10 Aug. This shift of bloom time could be long enough to avoid heat stress that has been stated to be the challenge with primocane cultivars fruiting in Arkansas late July and August (Clark, 2008).

Results from the controlled environment greenhouse experiment support the original hypothesis that shading primocane fruiting potted plants does influence plant physiology, growth, and development. This experiment met the objective to gain further insight into effects of 50% shade cloth on primocane fruiting blackberries. Further research is needed, with different levels of shade as well as the translation of information to field production systems in the southern region to determine if shade can be used effectively and economically to shift the flowering period of primocane blackberries without significant negative effects on growth.

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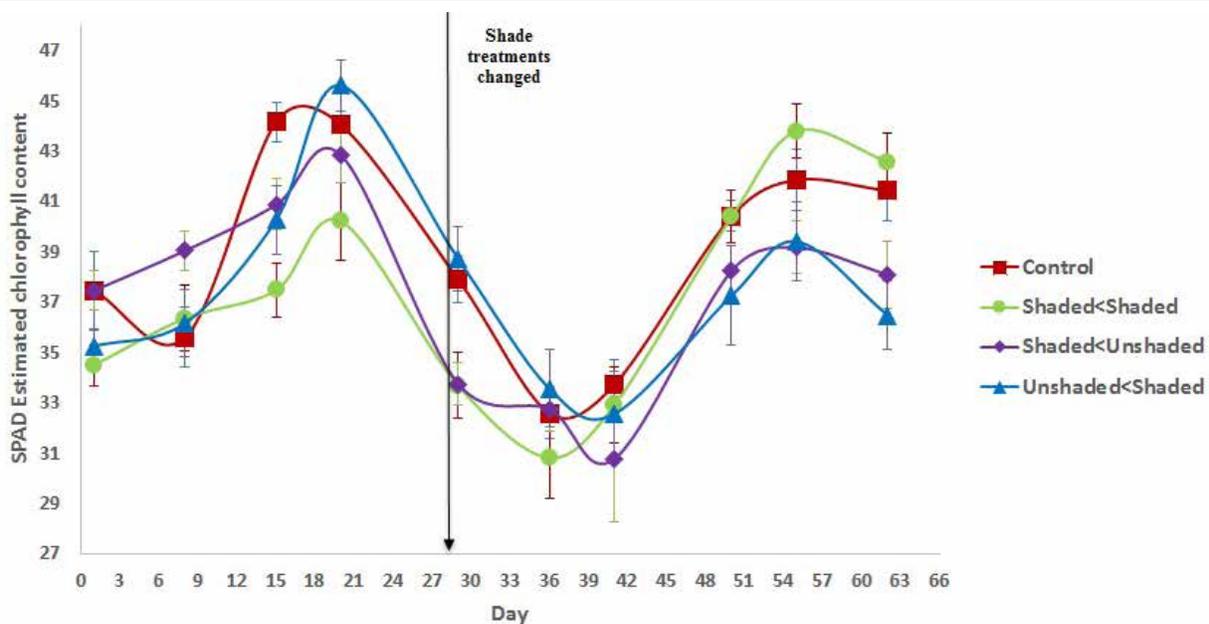


Fig. 5. Estimated chlorophyll content measured with Minolta SPAD-502 Plus® monitor of treated plants of 'Prime-Ark® 45', while grown in a greenhouse, Fayetteville, Arkansas, 2014. The bar represents when shade treatments were changed. n = 11.

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Table 2. Date of first flower blooming within a treatment group of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, Arkansas.

Treatment	Date
Control	2 July 2014
Unshaded, Shaded	17 July 2014
Shaded, Shaded	26 July 2014
Shaded, Unshaded	28 July 2014

There are no statistical differences in the table above.