12-2016

The Effects of Shade on Growth, Development and Yield of a Primocane Fruiting Blackberry, 'Prime-Ark 45' to Extend the Market Season

Olivia C. Caillouet
University of Arkansas

The Effects of Shade on Growth, Development and Yield of a Primocane Fruiting Blackberry, 'Prime-Ark® 45' to Extend the Market Season

Olivia Caillouet[1]

Department of Horticulture, University of Arkansas, Plant Sciences Building PTSC 316, Fayetteville, AR 72701

This thesis was written as partial fulfillment of an undergraduate Bumpers College Honors Degree Program

[1] Honors program with a major in Horticulture, Landscape, and Turf Sciences and minoring in Foundations of Sustainability

The Effects of Shade on Growth, Development and Yield of a Primocane Fruiting Blackberry, 'Prime-Ark® 45' to Extend the Market Season

Subject Category: Sustainability and Fruit Production

Additional Index Words. Plant physiology, Arkansas, adaptation, high tunnel, flower

Thesis Director

Dr. Curt R. Rom[2]

Thesis Committee:

Dr. John R. Clark[3]

Dr. M. Elena Garcia[4]

Dr. Lawton Lanier Nalley[5]

[2] University Professor, Department of Horticulture
[3] Distinquished Professor, Department of Horticulture
[4] Professor, Department of Horticulture
[5] Associate Professor of Agricultural Economics and Agribusiness, Agriculture Bldg. Room 218A

The Effects of Shade on Growth, Development and Yield of a Primocane Fruiting Blackberry, 'Prime-Ark 45' to Extend the Market Season

Horticulture, Landscape and Turf Sciences

Olivia Caillouet

December 2016

University of Arkansas

Advisor Signature: _____
Dr. Curt R. Rom

Committee Member/First Reader Signature: _____
Dr. John R. Clark

Committee Member/Second Reader Signature: _____
Dr. M. Elena Garcia

Committee Member Signature: _____
Dr. Lawton Lanier Nalley

Acknowledgements

This research would not have been possible without the support and guidance from Dr. Curt Rom. I appreciate the opportunity to gain research experience with blackberry production during my time as an undergraduate.

I would also like to thank my thesis committee, Drs. John Clark, Elena Garcia, and Lanier Nalley, for the advice and help throughout this process. Special thanks is given to Jason McAfee[6] who gave technical support and help during and after data collection. This research would not have been possible without the assistance from Heather Friedrich[7], Luke Freeman[8] and Shelby Goucher[9].

Financial support was provided by the Southern Sustainable Agriculture Research and Education (SSARE; LS12-250) grant and an additional SSARE Young Scholar Enhancement apprenticeship grant. In addition, the University of Arkansas Honors College and Horticulture Department made this experience accessible.

I would like to thank those close to family, friends, and me who offered advice and words of encouragement along the way. This undergraduate research thesis would not have been possible without those listed above.

[6] Program Technician III
[7] Program Technician III
[8] Program Technician I
[9] Fiscal Support Specialist

Table of Contents Page

Table of Figures……..7

Table of Tables ……9

Table of Appendices……..10

List of Abbreviations……..15

Abstract……17

Chapter 1: Introduction and Review of Relevant Literature

Introduction……19

Literature Review……22

Blackberry production……22

Primocane blackberries……24

Light influences on plant growth……28

Effects of shade on light levels……29

Effects of shade on temperature ……31

Literature Cited……33

Chapter 2: Effect of timing of shade on growth, development, physiology and fruiting of a primocane fruiting blackberry in a controlled environment

Introduction……39

Literature Review……40

Materials and Methods……44

Results, Discussion, Conclusions……48

Literature Cited……62

Chapter 3: The effect of time and amount of shade on growth and fruiting of 'Prime-Ark® 45' primocane blackberry in field conditions

Introduction……65

Literature Review……66

Materials and Methods……70

Results, Discussion, Conclusions……75

Literature Cited……89

Appendices: Greenhouse Tables and Figures……91

Appendices: Field Tables and Figures……114

Table of Figures Page

Figure 1. Shade-unshaded treated plants of 'Prime-Ark® 45' day 36 of the experiment trained to a single bamboo stake while grown in a greenhouse, Fayetteville, AR., 2014. 51

Figure 2. The Shaded-shaded treatment on day 1 of the experiment of 'Prime-Ark® 45' blackberry while grown in a greenhouse, 2014, Fayetteville, AR., 2014..... 52

Figure 3. All shade was removed day 59 of the experiment and 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments grew for an additional 30 days in the greenhouse, 2014, Fayetteville, AR..... 53

Figure 4. Estimated leaf chlorophyll content measured as measured by Minolta SPAD-502 Plus® monitor of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments, 2014, Fayetteville, AR..... 54

Figure 5. Cane height of a single cane of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. 56

Figure 6. Cane diameter of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. 58

Figure 7. Assimilation of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. 59

Figure 8. Estimated leaf chlorophyll as measured by SPAD content of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. 60

Figure 9. Prior to early shade treatment implementation, day 1 of the experiment, of 'Prime-Ark® 45' blackberry while grown in the field experiment, 2014..... 78

Figure 10. Assimilation measurements of the control treatment of 'Prime-Ark® 45' blackberry while grown in the field experiment, 2014..... 79

Figure 11. Assimilation measurements of a control treatment plot after implementation of early shade and middle shade treatment cloth of 'Prime-Ark® 45' blackberry grown in the field experiment, 2014..... 80

Figure 12. An example of fruit ripeness variation of 'Prime-Ark® 45' control treatment blackberries while grown in the field experiment, 2014…… 81

Figure 13. Blackberries of treatment plots of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014. …… 82

Figure 14. Estimated leaf chlorophyll content as measured by SPAD of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014. ……. 84

Figure 15. Cumulative yield berry weight of 'Prime-Ark® 45' blackberry plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014.……. 85

Figure 16. Total berry weight at each day of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…… 87

Table of Tables

Page

Table 1. Height of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 55

Table 2. Final growth and harvest measurements of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…….. 57

Table 3. Date of first flower blooms of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. …….. 61

Table 4. Estimated leaf chlorophyll content as measured by SPAD of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014. …… 83

Table 5. Cumulative yield berry weight of 'Prime-Ark® 45' blackberry of plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014. …….. 86

Table 6. Cumulative marketable yield berry weight of 'Prime-Ark® 45' blackberry of plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014. …….. 88

Table of Appendices Page

Appendix 1. Root and shoot ratio of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…… 91

Appendix 2. Estimated leaf chlorophyll content as measured by SPAD set to percent of control (100%) of 'Prime Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…….. 92

Appendix 3. Assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…… 93

Appendix 4. Assimilation set to percent of control (100%) of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…….. 94

Appendix 5. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014……. 95

Appendix 6. Evapotranspiration of 'Prime-Ark® 45' blackberry affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR……. 96

Appendix 7. Evapotranspiration set to percent of control (100%) of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR……. 97

Appendix 8. Vapor pressure deficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014……. 98

Appendix 9. Vapor pressure deficit of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 99

Appendix 10. Ambient leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…….. 100

Appendix 11. Ambient leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 101

Appendix 12. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)…… 102

Appendix 13. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)…… 103

Appendix 14. Photosynthetically active radiation of a single leaf measured at the time of assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…… 104

Appendix 15. Photosynthetically active radiation of a single leaf measured at the time of assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR. …… 105

Appendix 16. Leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…… 106

Appendix 17. The leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 107

Appendix 18. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…….. 108

Appendix 19. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 109

Appendix 20. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…….. 110

Appendix 21. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…….. 111

Appendix 22. Foliar water use efficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014…….. 112

Appendix 23. Foliar water use efficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR…… 113

Appendix 24. Assimilation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…… 114

Appendix 25. Assimilation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…… 115

Appendix 26. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…… 116

Appendix 27. Internal CO_2 concentrations of 'Prime-Ark® 45' as affected by seven shade treatments while grown in a field experiment, 2014…… 117

Appendix 28. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)…… 118

Appendix 29. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)…… 119

Appendix 30. Photosynthetically active radiation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014……. 120

Appendix 31. Photosynthetically active radiation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014……. 121

Appendix 32. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…… 122

Appendix 33. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014…… 123

Appendix 34. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014……. 124

Appendix 35. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014……. 125

Appendix 36. Total berry weight by day of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014……. 126

Appendix 37. Cumulative yield berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014. Numbers in parenthesis represented percent of the control…… 127

Appendix 38. Total average total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…… 128

Appendix 39. Total marketable berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014……. 129

Appendix 40. Total percentage of marketable weight out of total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 130

Appendix 41. Cumulative marketable yield weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014……. 131

Appendix 42. Total culled berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 132

Appendix 43. Total percentage of culled weight out of total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 133

Appendix 44. Cumulative culled berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…… 134

Appendix 45. Cumulative culled berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…… 135

Appendix 46. Berry 25 count of brix's or soluble solids (estimated sugar content) of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014. ……. 136

Appendix 47. Final destructive cane analysis of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 137

Appendix 48. Cane diameter of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 138

Appendix 49. Cane shoot length of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 139

Appendix 50. Number of nodes per cane of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 140

Appendix 51. Length between nodes of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 141

Appendix 52. Number of lateral branches per cane of ‘Prime-Ark® 45’ blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 143

Appendix 53. Number of fruit clusters of ‘Prime-Ark® 45’ blackberry as affected by seven shade treatments while grown in a field experiment, 2014…….. 143

List of Abbreviations

Abbreviation	Complete Form
A	CO_2 Assimilation ($\mu m/m^2/s^1$)
BPs	Best Practices
CK	Check or Control treatment
CEA	Controlled Enviroment Agriculture
Ci	Internal CO_2 ($\mu m/mol$)
CSA	Community Supported Agriculture
DOT	Day of Treatment
DOH	Day of Harvest
Dwt.	Dry weight (g)
Et	Foliar Evapotranspiration (mmol $H_20/m_2/s^1$)
ES	Early shade implementation
ES30	Early shade 30% cloth treatment
ES50	Early shade 50% cloth treatment
FD	Field
GH	Greenhouse
gs	Stomatal conductance (mmol $H_20/m_2/s^1$)
HT	High tunnel
LS30	Late shade 30% cloth treatment
LS50	Late shade 50% cloth treatment
LS	Late shade implementation treatment

MS	Middle shade implementation
MS30	Middle shade 30% cloth
MS50	Middle shade 50% cloth
NOP	National Organic Program
PAR	Photosynthetic Active Radiation ($\mu m/m^2/s^1$)
PGR	Plant Growth Regulator
Pn	Net Photosynthetic Rate
RH	Relative Humidity (%)
SARE	Sustainable Agriculture Research and Education
SS	Shaded-Shaded Treatment
SU	Shaded-Unshaded Treatment
TLeaf	Leaf Temperature
WUE	Water Use Efficiency (mmol CO_2/mol^1 H_20)
US	Unshaded-Shaded treatment
U.S.	United States

Abstract

This thesis examines the effects of shade on 'Prime-Ark® 45' blackberries (*Rubus spp.)* in greenhouse (GH) and field (FD) experiments aimed at improving fruit production in the southern United States Ozark Plateau region. Primocane blackberry production in the southern United States is limited in acreage of production as well as low yields 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 or by reducing temperatures that cause a poor fruit set and quality. Both the GH and the FD experiment was established in the June 2014 to evaluate the effects of shade on primocane fruiting blackberry growth, physiology and fruiting. The research objectives were experimenting the timing and intensity of shade on the potential for delayed flowering and fruiting. The GH experiment analyzed four treatments using 50% shade cloth: 1) an untreated nonshaded 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]. Each treatment had 11 single plant replicates. The number of flower buds, flowers, and individual fruits did not vary significantly among treatments in the greenhouse experiment. The last to bloom was the SU, 26 days after the CK on 28 July. These findings are significant because fruit could be shifted to 5 Sept. compared to the CK which would fruit approximately 10 Aug. A FD experiment was conducted to study the effects of various levels and time of shade treatments on 'Prime-Ark® 45' blackberries. The FD experiment differs from the GH experiment because it included two levels of shade 30% and 50% implemented at different times throughout the growing season. The FD experiment consisted of seven treatments with varying levels of shade and differing dates of treatment implementation: 1) an untreated nonshaded control [CK], 2) early shade 30% [ES30], mid shade 30% [MS30], 4) late shade 30% [LS30], 5) early shade 50% [ES50], 6) mid shade 50% [MS50], 7) late shade 50% [LS50]. The 30% and 50% treatments began 16 June [ES], 1 July [MS] and 15 July [LS]; there were 5 replications per treatment. Growth measurements were taken weekly for both experiments to measure estimated leaf chlorophyll content and leaf assimilation. No significant differences for cane length, cane diameter, node number, internode length, number of lateral branches or number of fruit clusters were observed among treatments. Field treatments ES30,

MS30 and ES50 had less fruit than LS treatments during the experiment period. It is possible that flowering and fruiting of the ES treatment could have continued after the end of this experiment due to the delay in flowering and fruiting as observed in the GH experiment. In the future shade should be applied 1 May as opposed to 16 June and could be coupled with season-extending high tunnel systems to protect fruit against freezing autumn weather.

Chapter 1: Introduction and Review of Relevant Literature

Introduction

Fruit production is an important aspect of agriculture with economic and environmental impacts in the southern region. For farmer's fruit production is a high energy intensive process that offers a wide range of obstacles that can reduce profitability and the return on investments. Through organic, sustainable practices this research aims to improve fruit quality, reduce negative environmental impacts and improve the local food system in the south. Shade was used as a management tool to reduce heat stress on berries from high solar-radiation experienced throughout the summer months in the southern region.

With a steadily growing population and unpredictable fuel prices there is an increasing importance to produce food in a sustainable, ecologically sound system. The research funded by Southern Sustainable Agriculture, Research and Education (SARE) strives to encourage soil quality, integrated pest management (IPM), and energy conservation.

Two experiments, a GH and a FD project were studied to test the effects of shade on primocane blackberry growth, flower formation timing and yield. The GH experiment was designed to complement the FD experiment and provide further insight into the impacts of shade on primocane physiology in a controlled environment. Research projects focused on the timing and intensity of shade to delay flowering and fruiting of primocane blackberries.

An overall goal of the sustainable blackberry project was to extend the market season for berry production which will allow this high value crop to be sold in periods of high demand where in the past fruit was imported. With recent studies there has been increased interest in

blackberries for their perceived health benefits. Sustainable, organic berry production offers a wide spectrum of positive impacts for farmers, consumers and the environment.

This research aims to help farmers while also improving the long-term sustainability of primocane blackberry production. This research holds significance for farmers because it intends to contribute to technologies which would allow for added value, reduced environmental degradation and an extended production season. Retail sales for organic produce have steadily increased over the years. In 1997 it was recorded that 3.6 billion dollars in organic foods was sold and a little over a decade later sales were marked at 21.1 billion in 2008 (Dimitri and Oberholtzer, 2009). For farmers the ability to grow produce organically opens an opportunity to take part in a niche market. Many fruit farmers in the southern region are small acreage, family owned and economic sustainability is vital to keep the production system operating. The chance to take part in local farmer's markets, community supported agriculture (CSA) and a direct sale to consumers is thought to strengthen the enterprise. Economic stability has been stated to increase with season extension due to increased cash flow as well as the distributed income throughout the year, while also keeping a strong connection with consumers over the entire year (ANON., 2006).

Conventional farming often has higher yields, but with this comes with environmental problems such as soil degradation and loss of diversity in both animal and plant communities (Hill, 2009). One alternative is organic farming which has been shown to have to have increased soil health as well as increased biological activity than that of conventional farming (Mäder, et al., 2002). In some cases, it is difficult to compare energy consumption on organic farms and conventional farms due to the size, location and the wide range of production methods. However, a report in 2007 stated that organic farming practices used 30-50% less energy per unit

of output than conventional farms due increased human-labor, efficiency and reduced inputs (Hill, 2009).

The research conducted in the FD and GH studies were a means for possibly extending the growing season through sustainable, organic production methods. A problem of excessive heat and solar-radiation limits primocane blackberry production in the southern region and shade may provide a means of improving the fruit set and quality. In high temperatures, blackberries tend to have poor performance related to their adaption to cooler more northern climates (Stafne, et al., 2001). Implementation of shade treatments are aimed to reduce heat stress, delaying flower and fruiting of fall bearing primocanes in the southern region so that flowering would take place during cooler temperatures.

In the past several decades' blackberries have made an economic, environmental and social impact on the small fruit industry (Clark, et al., 2008b). Consumers expect to have blackberries year round in stores and to have the ability to purchase new, higher quality berries than ever before across most regions (Finn and Clark, 2011). The ability to delay flower and fruiting could possibly improve yield quality, opening a local market for growers to tap into this high-value crop that is growing in popularity (Clark, et al., 2008b).

Literature Review

Blackberry production: Blackberry production has made economic, environmental and social impacts between the years of 1990 and 2010. Blackberries were an understory plant that could be found growing abundant in the wild within wooded areas across North America (Finn and Clark, 2011). Finn and Clark (2011) stated, around the mid to late 1800s people started to select for unique characteristics that made blackberries more appealing to consumers, thus more adequate for the market which marked the transition from canning berries to more fresh consumption. Berry production increased during the 1970s-1990s with interest from Driscoll® Company originating in Watsonville, California (Clark, et al., 2008b). It has been suggested that large commercial grower's involvement in blackberry production was a foundation for increased blackberry production worldwide and further research into better developing this crop for markets (Finn and Clark, 2011). Raspberries and blackberries have similarities in cultivation methods, physiology and marketing techniques; however, blackberries have lower production costs (Finn and Clark, 2011). Finn and Clark (2011) explained, blackberries tend to me more disease resistant and have higher rates of growth which make it a more economical crop to grow.

Blackberry production has been broken down by worldwide regions: 42% in North America, 31% in Europe and 19% in Asia (Strik, et al., 2007). North America was found to be the leading blackberry producer worldwide for profitable production systems (Strik, et al., 2007). The U.S. produced 23% of total blackberry sales in 2005 (Strik, et al., 2007). More specific, Oregon resulted in 72% of the blackberry sales, California 7% and Arkansas 4%, while all other states made up the remaining 17% of the total blackberry production in 2005 (Strik, et al., 2007). This highlighted in 2007, the Pacific northwestern area of the United States to be the most suitable

for blackberry production due to cooler temperatures. The southern region of the U.S. production is on the rise with continued research for adaptive cultivars (Drake and Clark, 2009). Rodriguez, et al., (2012) explained that between the years of 1997 and 2007 the cultivated acreage of blackberry production in Arkansas increased 277%. According to the United States Department of Agriculture (USDA) agriculture census, there has been an increase of 1,597 blackberry farms or 28% of farms that grew blackberries (including Marionberries and Dewberries) from the year 2007-2012 (USDA, 2014). With an increase in farms there was also a decline in the number of farms that produced marketable yields (USDA, 2014). It is possible to have an increase in farms and at the same time decreased sales due to low quality berries not sold at the market. Of the 1,597 additional farms established between the years 2007-2012, it was reported that 669 farms or 35% of those farms did not have harvest production (USDA, 2014). There has been an interest from producers to invest in berry production, however improved fruit set needs to be researched in the southern region to increase sales at market.

If producers are able to increase marketable yields, the literature reported that the demand for blackberries has been present. Blackberry demand has increased in relation to the reported health benefits, which has encouraged production in the U.S., as well as at the international scale (Lewers, et al., 2010). There are health benefits that are associated with berry consumption for their anthocyanin and anti-oxidant content that has driven consumer demand (Finn and Clark, 2011). Many factors attribute to the health benefits with berry consumption such as the cultivar grown, location of production and methods of cultivation. A experiment on the blackberries stated that the chemical phenolic compounds of blackberries are well understood about positive effects in combating age-related neurodegenerative diseases and bone loss

(Kaume, et al., 2012). In addition, more research must be conducted to better understand effects of metabolism and the bioavailability of nutrients in the consumption of berries that are associated with health benefits (Kaume, et al., 2012). The related benefits to the human body is one aspect that is driving the increased consumer demand seen in the recent decades (Rodriguez, et al., 2012).

Primocane blackberries: The *Rubus* genus included a wide taxonomic range of fruiting plants also referred to as brambles. The blackberry fruit was classified as an aggregate fruit, meaning the flower contains several carpels that are not joined together. The carpel of the flower is the female part of the flowering plant containing reproductive organs including the stigma, style and ovary. When flowers mature, each separate carpel creates an individual druplet, when combined create one blackberry.

The University of Arkansas breeding program discovered the primocane fruiting blackberry 27 Sept. 1997 and later determined there was potential for extended season production of this high-value fruit crop in the southern region of the U.S. (Clark, 2008a). However, there has been production problems in the southern region with lac of heat tolerance that lowers fruit quality and yield quantities. High tunnel production systems as well as shading show potential to make primocane cultivars adaptable to areas that exhibit higher temperatures.

The traditional blackberry cultivar will produce first year's growth termed primocanes (vegetative) and then in the second year of growth the same canes become floricanes that are expected to flower and fruit. The introduction of the primocane-fruiting blackberry cultivars began with the first commercial release of 'Prime-Jan®' and 'Prime-Jim®' in 2004 by Dr. John Clark at the University of Arkansas (Clark, et al., 2005). This unique type of blackberry fruits on

current-season canes (primocanes) and second-season canes (floricanes) (Clark, et al., 2005). Studies conducted on these cultivars observed that the lack of heat tolerance was a major factor limiting the commercial use and profitability of these cultivars. Several years later, 'Prime-Ark® 45' was released in 2009 and displayed increased fertility in comparison to other cultivars given the heat conditions of the southern U.S. (Ruple, et al., 2010). While there were limitations to primocane-fruiting cultivars, the harvest seasons tended to be longer than floricane cultivars and had the potential to impact the southern region production systems. Similar changes were made with primocane-fruiting red raspberries and it was anticipated that this alteration in fruiting habits would have the ability to impact current and future blackberry cultivation as well (Clark, et al., 2005).

In the past, blackberry consumption in the southern U.S. has relied on imports from the Mexico and the pacific northwest of the U.S. Blackberry production in Mexico reported wide use of the floricane blackberry, 'Tupy®'. This erected cultivar contributed to the blackberry supply in the United States during the months of October through early May with around 6,500-8,000 hectare (ha) cultivated in 2011 (Finn and Clark, 2011). The production system in Mexico was reported to use chemical manipulations to control the timing of flower and fruit formations. In Mexico, specialized production systems used chemical defoliants, pruning methods and plant growth regulators (PGRs) in combination to extend the season and experience increased yields (Strik, et al., 2012). Blackberries cultivated in Mexico underwent extensive pruning and application methods to ensure fruit production, which was supplied the United States during seasons of reduced domestic production (Strik, et al., 2012). In Mexico, flower buds are stimulated to develop using growing techniques that apply phosphoric acid (Strik, et al., 2012).

About 5-7 months after primocane emergence, growth was slowed using a mixture application of copper sulfate, urea and mineral oil (Strik, et al., 2012). Then plants are hedged and defoliated with another combination of urea, ammonium, sulfate, copper sulfate and mineral oil (Strik, et al., 2012). Hill (2009) stated, farms that require less inputs tend to be more energy efficient and less demanding per unit of output. There were many inputs used in the production of primocane blackberries in Mexico, while these were not a requirement for blackberry production.

Production from Mexico supplied the U.S. during times when domestic production was low. However, with past research there is potential to shift production to the southern U.S. aimed at improving fruit quality and reducing imports. As mentioned there are problems associated with primocane-fruiting blackberry cultivars in the southern region, due to lack of heat tolerance. Nevertheless, Primocanes are unique in the sense that they flower and fruit on current season canes as opposed to floricanes that flower and fruit on second season canes; this change in reproductive cycles leaves a lot to be learned for improved production in differing regions with varying climatic patterns (Strik, et al., 2012). From the natural evolution, floricane cultivars would bear fruit in late spring around April and May. While in Arkansas, the primocane types began bloom in late June (about the time of completion of floricane fruiting) meaning fruit began to ripen in early August (Clark, 2008a). Clark (2008a) observed, flower and fruiting of primocane cultivars in the south results in small, low quality, unmarketable fruit often poor color from sunburn when first fruits are seen in early August.

A viable option for growers to delay flower and fruit as well as extend the season for blackberry production is with the use of high tunnel production systems. A high tunnel is a modified hoop house that is often covered in plastic with the ability for the sidewalls to be rolled

up or down. This passive environment has no permanent heating or cooling system and can be described as a growing area in-between that of an open FD and GH system (Heidenreich, et al., 2012). Plants are produced in the ground with an irrigation system in place. Benefits of high tunnel production included: 1) increased profitability by extending the harvest season, 2) increased fruit quality and 3) reduced pest pressure and the need for pesticide application (Rom, et al., 2010).

However, an important consideration when high-tunnels were implemented was the cost of construction and management with an understanding of potential yields. It was stated that blackberry production in a tunnel could increase economic risk due to the cost and delayed harvest to establish plants (Rodriguez, et al., 2012). Tunnels could be combined with primocane blackberry cultivars to extend the season and protect fruits from season ending freezes, but little published research has been completed on this. Imported berries from Oregon and Mexico supply the southern region during the southern U.S. non-growing season between the months of October-May. Rodriguez explains that growers could benefit from out-of-season production by having a longer fruiting season that competes with other producers (Rodriguez, et al., 2012). According to a recent experiment, blackberries imported from Mexico increased from 4,500 kilogram (kg) in the year 2000 to around 54,545 kg in 2010 (Finn and Clark, 2011). The majority of the blackberries shipped are for fresh market consumption. If growers in the southern region could supply what has in the past been imported, it could contribute to local economic growth. Furthermore, it would provide growers with a reliable revenue and reduced energy inputs needed for the transportation of fruit from other regions.

Light influences on plant growth: Light is an essential factor for plant growth, development and physiological functions. Plants undergo a process called photosynthesis where light is the energy that drives the conversion of atmospheric carbon dioxide (CO2) and water (H2O) into glucose ($C_6H_{12}O_6$) and oxygen (O2). Two aspects to consider for the impact of light on fruit crops included: the interception of available light on plants and the distribution of light within the plants that results in maximum performance and crop development (Rom, 1991). The amount and intensity of light has a significant influence on plant growth and development. The amount of light absorbed by the leaf surface area as well as the distribution of light influenced crop yields.

Light can be measured in wavelengths which can be short or long depending on their energy levels. The primary pigment in plants responsible for photosynthesis was chlorophyll which reflected green light, while red and blue spectrums were absorbed (Carter, 2014). Photoreceptors are proteins that are sensitive to light, these controlled almost all functions of plant development and growth. These proteins control the ability to produce flower and fruit formations which were associated with day length (Briggs and Olney, 2001). Many relevant traits for berries are influenced by photoreceptors such as dormancy of buds, size or shape of leaves, stem length, chloroplast development and even flowering time (Hudson, 2003). Photosynthetically Active Radiation (PAR) referred to the wavelengths of light in which the plant utilized in the process of photosynthesis. Blue light is measured as (460-480 nm) and red light is (650-700 nm); both are available to plants through the process of photosynthesis (Carter, 2014). Lombardini, et al., (2009) explained, the source of light was vital and the more efficient absorption of light resulted in alterations of dry matter allocation of plants. This literature suggested that light can be manipulated to alter plant physiology and crop yields.

The photosynthetic process was influenced by the size of the plant canopy in addition to the leaf surface area. The total surface area was influenced by previous season cropping levels, mineral nutrients, soil moisture levels, PGRs, pruning, light distribution, and cultivar types (Barritt, et al., 1991). It has been shown with apple production that light interception and leaf area (cm^2)/ ha are correlated (Barritt, et al., 1991). Increased light intensity levels could also alter overall primocane yields similar to responses contributed to increased temperatures (Oliveira, et al., 2004).

Effects of shade on light levels: Some outcomes of shadecloth on plant development included: physical plant protection from (birds, wind and hail), impact on environmental factors (humidity, light and temperature) and increased diffused light that may absorb or reflect particular light wavelengths; all of which influenced plant growth and development (Stamps, 2009). Stamps (2009) explained, the use of shade increased the relative humidity (RH) inside the shade structures compared to outside the shading structure. There were many aspects of plant development that could be altered with shadecloth and as such should be monitored to determine the potential impacts on crop yields, fruit set as well as fruit quality in terms of marketable or unmarketable fruit. Shadecloth has also shown to have increased light scattering by up to 50% or more, this can affect plant growth and development (Stamps, 2009). It was found that shade netting on blackberries extended the ripening period and increased cumulative yields due to the less concentrated fruit development (Rotundo, et al., 1999).

The use of shade altered light, which influenced the leaf chlorophyll content. Shade leaves had lower photosynthetic rates than that of none shaded plants and have been reported to contain more total chlorophyll than sun leaves (Björkman, 1968). Further examination of light

effects of shaded leaves found that higher chlorophyll content was due to the adaption of leaves to environments with low light over time (Rotundo, et al., 1999). This suggested that plants have the ability to adapt to changing environmental parameters with regard to varying light levels. Plants ability to adapt to changing light environments can be used to alter growing conditions and hold the potential to improve crop yields of primocane cultivars in the southern region.

An experiment of shade effects on apple trees reported that constant shade of 73%-95% reduced canopy temperatures in comparison to temperatures outside of the shade structures, but also reduced plant size, yields and encouraged shoot extension (Miller, 2001). In contrast, low levels of light can be detrimental to plant development and experience reduced cropping to unfavorable amounts. Understanding the implications of various levels of shade on photosynthesis, plant growth, development and plant physiology has been crucial to improving fruit yields of various rosacea species.

Photosynthetic capacity of leaf canopy of peaches explained that the studies of photosynthetic acclimation to light over simplified the complexity of natural light environments in plant canopies (DeJong and Doyle, 1985). Environmental conditions are much more complex in natural environments due to abiotic and biotic factors then first suggested by DeJong and Doyle (1985). When light measurements were determined within apple canopies, it was observed that haze and clouds fluctuated before a set of instantaneous light measurements were completed in a forest canopy (Campbell and Marini, 1992). There are many environmental influences such as clouds, seasonal changes and competitive plant vegetation that could influence the availability as the quality of light. The day-to-day changes of light levels within plant

canopies are known to differ in available light quality as well as quantity and impact the development of fruit (Rom, 1991).

Effects of shade on temperature: Heat and light might have direct positive correlations. As light levels increased beyond optimum range of 600 $\mu mol \bullet m^{-2}s^{-1}$ and soil and air temperatures exceeded 16 °C and 24 °C, primocanes entered a state of bud dormancy, reduced fruit weight as well as quality (Oliveira, et al., 2004). Given its complexity there are multiple considerations that need to be evaluated when determining impacts of shade on plant growth and development and physiological responses. Stamps (1994) reported, that reductions in radiation resulted from netting could affect temperatures of the surrounding air, soil and plants as well as influence the RH within the shaded structures. Some net shade houses increased the temperatures inside the structures (Stamps, 1994). This highlighted the need for further research to determine the optimal intensity and implementation of shade to obtain desired fruit set and fruit quality of primocanes. Despite heat injury of plants, it was predicted that photosynthesis would decline with higher temperatures because photorespiration increased with temperature and was the growth limiting factor (Schuster and Monson, 1990). High temperatures above 32 °C have been found to reduce photosynthesis which was stated to have negative influences on bud, flower and fruit formation of primocane cultivars (Clark, 2008a).

Photosynthesis was not the only physiological response that high temperatures effected during plant development. Research on *Rubus* raspberry cultivars in hot environments set the stage for improved primocane blackberry use in the southern U.S. The gas exchange of 'Titan' primocane leaves declined as temperature increased (Fernandez, et al., 1994). High temperatures reduced the process of gas exchange or assimilation (A). High temperatures

inhibited assimilation and reduced the rate of stomates opening and closing (Fernandez, et al., 1994). In addition, A rates were not the only component of plant gas exchange affected by solar radiation intensity, but that dark respiration also decreased with shade (Lombardini, et al., 2009). High temperatures were found to damage cellular structures and metabolic pathways and contributed to secondary water stress (Levitt, 2012). Plant growth and development altered with heat stress and drought tolerance exhibited leaf rolling, leaf shading and reduced leaf area (Morgan, 1984). Shade on blackberries was reported to decrease both assimilation and transpiration rates (Rotundo, et al., 1999). Plant physiological functions have been reported to have optimal ranges. If assimilation and transpiration fall below an optimal range for fruit production, the decreased rates are not favored in production systems. While shade has been reported to have increased temperatures within shading structures, shade could be used to delay flower formation thus avoiding flower formation in some of the hottest months (July and August) in the southern region.

Plant physiological processes have been altered by light and temperature which have influenced reproductive structures (flowers and fruits). The objective of this research was to evaluate the effects of shade on primocane-fruiting 'Prime-Ark® 45' to delay flower formation. The implementation of varying levels of shade throughout the 2014 growing season studied improving the adaption of a primocane blackberry to the southern region by improved fruit quality and quantity with an objective of increased area of cultivation along with increased yields in the southern U.S.

Literature Cited

ANON. 2006. Sustainable Agriculture Network. Marketing strategies for farmers and ranchers. Sustainable Agr. Res. Educ. 10 Apr. 2016. <http://www.sare.org/Learning-Center/Bulletins/Marketing-Strategies-for-Farmers-and-Ranchers>.

Barritt, B.H., C.R. Rom, I. Bonnie, J. Konishi, and M.A. Dilley. 1991. Light level influences spur quality and canopy development and light interception influence fruit production in apple. HortScience 26:993-999.

Björkman, O. 1968. Carboxydismutase activity in shade-adapted and sun-adapted species of higher plants. Physio. Plant. 21:1-10.

Briggs, W.R. and W.R. Olney. 2001. Photoreceptors in plant photomorphogenesis to date. Five phytochromes, two cryptochromes, one phototropin, and ane superchrome[1]. Plant Physiol. 125:85-88. 10 Apr. 2016 <http://www.plantphysiol.org/content/125/1/85.full.pdf+html>.

Carter, J.S. 2014. Photosynthesis. 22 Sept. 2015. <https://www.google.com/search?client=safari&rls=en&q=university+of+cincinnati&ie=UTF-8&oe=UTF-8>.

Campbell, R.J. and R.P. Marini. 1992. Instantaneous light measurements predict relative cumulative light levels within an apple canopy. J. Amer. Soc. Hort. Sci. 117(4):678-684. 10 Apr. 2016. <http://journal.ashspublications.org/content/117/4/678.abstract>.

Clark, J.R., J.N. Moore, J. Lopez-Medina, C.E. Finn, and P. Perkins-Veazie. 2005. 'Prime-Jan' ('APF-8') and 'Prime-Jim' ('APF-12') primocane-fruiting blackberries. HortScience 40:852-855.

Clark, J.R. 2008a. Primocane-fruiting blackberry breeding. HortScience 43:1637-1639.

Clark, J.R., C.E. Finn, P. Bañados (ed.), and A. Dale (ed.). 2008b. New trends in blackberry breeding. Proc. IXth Intl. Rubus and Ribes Symp. Acta Hort. 777:41-47. 16 Sept. 2014.

DeJong, T.M. and J.F. Doyle. 1985. Seasonal relationships between leaf nitrogen content (photosynthetic capacity) and leaf canopy light exposure in peach (Prunus persica). Plant, Cell and Environ. 8:701-706.

Dimitri C, and L. Oberholtzer. 2009. Consumers, marketing U.S. organic foods: recent trends from farms to consumers. Econ. Info. Bul. U.S. Dept. Agr. 58:1-36. 09 Apr. 2016. <http://www.ers.usda.gov/media/185272/eib58_1_.pdf>.

Drake, C.A. and J.R. Clark. 2009. Effects of pruning and cropping on field-grown primocane fruiting blackberries. HortScience 38:260-262. 05 Sept. 2014. <http://hortsci.ashspublications.org/content/38/2/260.full.pdf+html>.

Fernandez, G.E., and M.P. Pritts. 1994. Growth, carbon acquisition, and source–sink. J. Amer. Soc. Hort. Sci. 119(6):1164-1168. 09 Apr. 2016. <http://journal.ashspublications.org/content/119/6/1163.full.pdf+html>.

Finn, C.E. and J.R. Clark. 2011. Emergence of blackberry as a world crop. Chronica Hort. 51(3):13-18.

Heidenreich, C., M. Pritts, K. Demchak, E. Hanson, C. Weber, and M.J. Kelly. 2012. High tunnel raspberries and blackberries. 47:1-51. 09 Apr. 2016. <http://www.fruit.cornell.edu/berry/production/pdfs/hightunnelsrasp2012.pdf>.

Hill, H. 2009. Comparing energy use in conventional and organic cropping systems. ATTRA. 1-8.

Hudson, M. 2003. Photoreceptor biotechnology. Univ. of Illinois, Dept. of Crop Sci. Urbana: Nature Publishing Group. 09 Mar. 2016. <http://stan.cropsci.uiuc.edu/publications/photoBio_chapter.pdf>.

Kaume, L.R., L.R. Howard, and L. Devareddy. 2012. The blackberry fruit: a review on its composition and chemistry, metabolism and bioavailability, and health benefits. J. Agr. Food Chem. 60(23):5716-5727.

Levitt, J. (2012). Responses of plants to environmental stresses (Vol. 2). Academic Press Inc.

Lewers, K.S., S.Y. Wang, and B.T. Vinyard. 2010. Evaluation of blackberry cultivars and breeding selections for fruit quality traits and flowering and fruiting dates. Crop Sci. 50:2475-2491. 09 Apr. 2016. <http://naldc.nal.usda.gov/naldc/download.xhtml?id=48683&content=PDF>.

Lombardini, L., H. Restrepo-Diaz, and A. Volder. 2009. Photosynthetic light response and epidermal characteristics of sun and shade pecan leaves. J. Amer. Soci. Hort. Sci. 134(3):372-378. 09 Apr. 2016. <http://journal.ashspublications.org/content/134/3/372.full.pdf+html>.

Mäder, P., A. Fließbach, D. Dubois, L. Gunst, Padruot, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Sci. 296:1694-1697.

Miller, S.S. 2001. The effect of continuous and periodic whole-tree shade on the performance of 'Ginger Gold'/M.9 Apple Trees. Proc. 77th Cumberland-Shenandoah Fruit Workers Conf. 09 Apr. 2016. <http://www.ars.usda.gov/SP2UserFiles/Place/80800000/Shade%20CSFWC01.pdf>.

Morgan, J.M. 1984. Osmoregulation and water stress in higher plants. Annu. Rev. Plant Physiol. 35:299-3191. 10 Apr. 2016. <https://scholar.google.com/scholar?q=osmoregulation+and+water+stress+in+higher+plants&hl=en&as_sdt=0&as_vis=1&oi=scholart&sa=X&ved=0ahUKEwiR1rno_YTMAhWHm4MKHUIZCN0QgQMIGjAA>

Oliveira, P.B., C.M. Oliveira, and A.A. Monteiro. 2004. Pruning date and cane density affect primocane development and yield of 'Autumn Bliss' red raspberry. J. Amer. Soc. Hort. Sci. HortSci. 39(3):520-524. 09 Apr. 2016. <http://hortsci.ashspublications.org/content/39/3/520.full.pdf+html>.

Rodríguez, H.G., J. Popp, M. Thomsen, H. Firedrich, and C.R. Rom. 2012. Economic analysis of investing in open-field or high tunnel primocane-fruiting blackberry production in northwestern Arkansas. Production and Marketing Reports. 22(2):245-251. 10 Apr. 2016. <http://horttech.ashspublications.org/content/22/2/245.full>.

Rom, C.R. 1991. Light thresholds for apple tree canopy growth and development. HortScience 26:989-992. 10 Apr. 2016. <http://hortsci.ashspublications.org/content/26/8/989.full.pdf>.

Rom, C.R., M.E. Garcia, D.T. Johnson, J. Popp, H. Friedrich, and J. McAfee. 2010. High tunnel production of organic blackberries and raspberries in Arkansas. Acta Hort. 873:269-276.

Rotundo A., M. Forlani, C. Di Vaio, and S. Scannerini (ed.). 1999. Influence of shading net on vegetative and productive characteristics, gas exchange and chlorophyll content of the leaves in two blackberry (Rubus ulmifolius Schott.) cultivars. Acta Hort. Proc. Plant Biotechnol. Tool. 457:333-340. 10 Apr. 2016. <http://www.actahort.org/books/457/457_42.htm>.

Ruple, A.L., J.R. Clark, and M.E. Garcia. 2010. An evaluation of fertility in Arkansas primocane-fruiting blackberries. J. Amer. Soc. Hort. Sci. HortScience 45:1000-1005. 10 Apr. 2016. <http://hortsci.ashspublications.org/content/45/7/1000.full>.

Schuster W.S. and Monson, R.K. 1990. An examination of the advantages of C3-C4. Plant Cell and Environ. 13:903-912.

Stafne, E.T., J.R. Clark, and C.R. Rom. 2001. Leaf gas exchange response of 'Arapaho' blackberry and six red raspberry cultivars to moderate and high temperatures. J. Amer. Soc. Hort. Sci. HortScience 36:880-883. 10 Apr. 2016. <http://hortsci.ashspublications.org/content/36/5/880.abstract>.

Stamps, R.H. 1994. Evapotranspiration and nitrogen leaching during leatherleaf fern production in shadehouses. Florida Dept. Environ. Protection. Palatka, Florida.

Stamps, R.H. 2009. Use of colored shade netting in horticulture. J. Amer. Soc. Hort. Sci. HortScience 44:239-241. 10 Apr. 2016 <http://hortsci.ashspublications.org/content/44/2/239.full>.

Strik, B.C., J. R. Clark, C.E. Finn, and M.P. Bañados. 2007. Worldwide blackberry production. J. Amer. Soc. Hort. Sci. HortTechnology 17:205-213. 10 Apr. 2016. <http://horttech.ashspublications.org/content/17/2/205.abstract>.

Strik, B.C., E.C. Finn, and B. Tanović (ed.). 2012. Blackberry production systems: A worldwide perspective. Proc. Xth Intl. Rubus Ribes Symp. Acta Hort. 946:341-347. 10 Apr. 2016. <http://www.actahort.org/books/946/946_56.htm>.

U.S. Department of Agriculture. 2014. 2012 Census of Agriculture: United States Summary and State Data. 13 Sept. 2015. <http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf>.

Chapter 2: Effect of timing of shade on growth, development, physiology and fruiting of a primocane fruiting blackberry in a controlled environment

Introduction

A controlled environment greenhouse (GH) experiment was conducted to compliment a field (FD) experiment that examined the shade effects of primocane-fruiting blackberries. The controlled environment GH experiment reduced variability and environmental stresses that may have occurred in the FD experiment and provided near optimal growing conditions, FD production systems are vulnerable to changing environmental parameters, while the GH research provided greater control over water, light, temperature, insect and disease pressures. The greater control over external factors could provide greater insight into the shade effects on Primocane blackberry physiology, flower and fruit development that may be confounded with other environmental factors in the FD.

Literature Review

Blackberry production in Arkansas, the region and the U.S. has increased. Rodriguez, et al., (2012) showed that the cultivated acreage of blackberry production in Arkansas increased 277% between the years of 1997 and 2007. The new autumn-bearing, primocane fruiting blackberries expand the market season for the fruit. However, studies have shown that fruiting during hot seasons resulted in poor pollination, fruit set and fruit quality. Stanton, et al., (2007) tested three levels of temperature on primocane blackberries cultivars in growth chambers and it was found that increased temperatures had a direct correlation with lower percent of flowers and fruits. Primocane fruiting blackberries flower during July and August, in general the hottest months of the year. These new genotypes have not been proven to be well adapted to Arkansas conditions.

Based upon preliminary field experiments and observations (Rom, 2014, personal communication), it was hypothesized that shade could delay flowering in primocane-fruiting blackberries. If that was true, the flowering and fruiting period could be shifted to a more favorable season for fruit set and quality. 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.

Shade had the potential to delay flower and fruiting of other species, which resulted in extended crop production as well as increased marketability. The completion of this experiment in a greenhouse environment had some benefits in regard to observed effects of shade on primocane blackberries. Abiotic factors included percepitiation, temperature, light intensity, air quality, humidity and soil conditions which could impact plant growth and development. Yields

in the FD would have been greater if not affected by high rates of precipitation (Strik, et al., 2008). Enviromental conditions in the FD experiement influenced the crop quality and quanity in the Midwest during the warmest year on record (Nonnecke and Riesselman, 2012). The inability to control enviromental parameters in the FD added additional factors that impacted research data. The GH enviorment had the potential to provide more control over the growing conditions and add clarity to the affects of shade on primocane growth, physiology and development.

The specific leaf weight of leaves in peach plants was found to decrease with the implentation of shade (Marini and Sowers, 1990). It was also found that apple plants grown in a GH controlled enviroment had reduced photosyntheitc measurments when 20% light reduction shade fabric was implemented and rates slowed in full sun (Barden, 1978). Marini and Sowers (1990) reported that shade needed to be implemented for longer periods of time than 3 weeks to experience changes in leaf photosynthesis morphology with peach plants. Furthermore, the specific leaf weight (SLW) of peaches was found to decline more under shade compared to the unshaded control and then increased at greater levels when the shade was removed (Marini and Sowers, 1990). The shoot lengths were longer as the percentage of light shade reduction cloth was increased (Marini and Sowers, 1990). Marini and Sowers (1990) explained that specific leaf weight may be a good indicator to determining previous light enviroments while the abiltiy to estimate levels of photosyntheic capability (Pn) is limited to younger leaves (Marini and Barden, 1981). It was found that 40% light shade redution netting increased the cane length and also increased the dry matter acumulation of two blackberry cultivars compared to the control (Rotundo, et al., 1999).

Shade altered more than shoot and cane length or dry matter accumualation. Plants grown in low light enviroments were unable to undergo high rates of photosynthesis; however, they could perform at the low light intensities (Boardman, 1977). Boardman (1977) stated that shaded plants have been found to have large grana stacks, containing as many as 100 thylakoids per granum, which might have been contributed to increased efficiency in comparison to full sun tolerant plants. Rotundo, et al., (1999) reported that the 40% shade netting increased chlorophyll content of two floricane blackberry cultivars that might have contributed to adaption to low light enviroments. Rates of photosynthesis, transpiration and stomatal conductance were also lowered for shaded blackberry leaves (Rotundo, et al,. 1999).

There was a experiment which focused on shade implemented on apple trees as a means of thinning fruit set in the early stages of fruit development (Morandi, et al., 2011). The findings reported that reduced light levels through shade may have altered fruit devleopment as well as quanity (Morandi, et al., 2011). Two days of shade on young apple trees reduced the rate of fruit growth by half in comparision to the unshaded control (Morandi, et al., 2011). Morandi, et al., (2011) reported that shading decreased rates of A, which had a direct influence on flow rates of phloem and contributed to the decrease in fruit growth rate each day of the experiment.

In addition to assimilation, fruit development and quality has been altered with shade. Two shade levels, 0% control and 40% shade were implemented on 'Kiowa®' thorny, primocane blackberries 20 May 2008 and plants grown under shade were found to have higher cummulative yields compared to all other treatments (Makus, 2010). Makus (2010) stated, shading berries reduced the berry pulp temperatures which resulted in higher juice yields (mg/g) and resulted in larger berries compared to all other treatments.

Research in a controlled environment reduced variability and externalities that influenced plant growth and development and therefore isolated treatment effects. This might have provided isolated treatment effects of various levels of shade on primocane-fruiting physiology with an emphasis on flower and fruit development. The objective of this experiment was to determine the effects of changing light environments on the growth and development of primocane fruiting blackberries with the goal of delaying bloom in primocane blackberry cultivars so production systems can be adapted to the southern region.

Materials and Methods

The greenhouse (GH) was located at the University of Arkansas System Division of Agriculture, Arkansas Agriculture, Research and Extension Center (AAREC), Fayetteville Arkansas (Latitude: 36°"N; Longitude: 94°"W). Potted blackberry plants were grown in a double layer 6 mm polyethylene covered climate controlled Quonset GH that is 12. 5 m (L) x 9 m (W) x 3 m (H) and has a north south orientation. GH temperatures were controlled by a pad-and-fan cooling system during the summer.

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

Potted plants were placed on wire-mesh benching systems and the height of the benches was lowered throughout the experiment as the plants height increased. During the experiment, canes were pruned of lateral bud break and trained to bamboo stakes. Every week suckers (adventitious shoot that arise from the base of the plant) were removed to prevent to reallocation of dry matter away from the terminal shoot. When canes reached heights of approximately 1.5 m, the bamboo stakes were doubled to increase structural support for potted plants (Figure 1). Blackberry plants were watered as needed and amount varied depending on cloud coverage, outside temperature and humidity inside the GH. When plants were watered the potted plants were filled from the media line to the top of the pot around 5 cm in height and was allowed to absorb.

Osmocote® (14-14-14, Scoots Miracle-Gro Company) fertilizer was applied as needed to each potted plant throughout the experiment in amounts of 1 tablespoon (tbsp) then light watered was applied. In addition, one application of Marathon® (Imidacloprid, 1-[(6-Chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine, Olympic Horticultural Products) nursery insecticide was applied 28 July 2014 to combat an armyworm (*Spodoptera exempta*) infestation that caused some defoliation of plants.

Treatments: Beginning on 4 June 2014, when canes average 25 cm in height, 44 plants were assigned one of four random 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] (Figure 2). Plants grew for 29 days at which time shade treatments were changed. Shade cloth was either added or removed 2 July 2014 which affected 2) US, now shaded and treatment 4) SU, now unshaded. All 44 potted plants were allowed to grow 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 (Figure 3). Potted plants were rearranged at random starting 35 days of treatment (DOT) implementation every week to limit impact of microclimates within the GH that could have affected plant growth and development. Shade was provided by 50% shade neutral density cloth covering metal frame structures over the GH benches. There were 11 single plant replicates of each treatment. Plants within each treatment were assigned separate benches by positioned at the south end of the GH nearest the cooling system. Plants were not in a randomized design due to greenhouse space and management limitations.

Measurements: Starting the same week as treatments, physiological measurements were begun. Measurements were made weekly for 13 weeks of cane diameter (6 cm above the soil line), cane height (cm), estimated leaf chlorophyll content (Minolta model: 502 Plus®) and CIRAS-2® portable gas exchange monitor equipped with a Parkinson® leaf chamber) (Figure 4). The terminal leaf of the leaflet near the middle leaf margin lamina was used for measurements. The leaf was chosen four to five nodes down from the terminal cane tip of each potted plant and was used for estimated leaf chlorophyll and assimilation measurements. Estimated leaf chlorophyll and assimilation measurements were taken using the same leaf, but leaf selection varied weekly. Only healthy leaves were used in measurements of estimated leaf chlorophyll content and assimilation measurements.

Leaf assimilation was measured on a 6.25 cm^2 area of leaf. Cuvette-chamber conditions were set for incoming [$C0_2$] of 385 ppm, cuvette temperature of 28 ^oC, RH of 50%. Saturating light conditions of 1,200 umols/m^2/s^1 were provided with the PP Systems ® PLC3 Universal LED Light head attached to the cuvette chamber. Assimilation was measured after apparent steady-state conditions after 120-180 s.

The date of first flowers seen in each treatment was recorded. The final height (cm), cane diameter 6 cm above the soil line (mm), number of flower buds, flowers and fruits was recorded for each plant in all treatment plots. Destructive harvest for all plants were made 14 Aug. The total weight of buds (g), flowers (g) and fruits (g) was measured for all potted plants. The total leaf area (cm^2) and total number of leaves for each potted plant was recorded. After the fresh plant data were collected, the canes, stems, leaves, and reproductive organs were placed in paper bags within a dryer 20 Aug. for approximately 336 hours at 70 °C and weighted. Dry weights

of plant biomass included: leaves (g), stems (g) and roots (g) and total biomass was calculated. One plant in the US treatment not included in the data set due to factors that terminated its growth prior to the end of the GH experiment and data are excluded from analysis. Observations were made about changing climatic conditions outside of the GH that included temperature, rainfall and cloud coverage.

Each treatment had eleven single plant replications. Data were analyzed with Proc GLM procedure in SAS® statistical software (SAS version 9.3, SAS Institute Inc., Cary, NC) and mean separation was calculated by least significant difference (LSD) ($\alpha = 0.05$).

Results, Discussion and Conclusion

Plants in the SU treatment were the tallest compared to other treatments (Table 1, Figure 5). The other treatments all had similar heights until shade was changed after 29 days, with no significant difference in the US but significantly less biomass in the SS treatment (Table 1 and Table 2). Shade treatment plants had reduced plant growth and development, especially dry weights compared to the unshaded control. Although there were differences for height, cane diameter and dry weights (shoots, leaves, roots, and total dry weight), there were no significant differences for leaf number, leaf area, average leaf size, number of flowers and dry weight of flowers (Table 2 and Figure 6).

Leaf dry weight was similar for all treatments except for SS which was significantly less (Table 2). 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 shade.

Treatments CK and US, had the highest rates of CO_2 assimilation (A) at the start of the experiment and were different from SS and SU which were the least (Figure 7). 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 A levels were greater than US; all treatments were different from US at the conclusion of A data collection (Figure 7).

After shade treatments were changed on day 29 of the experiment, the estimated leaf chlorophyll (CHL) content (SPAD) was greatest for CK and SU, while SS and US were the same and less than CK and SU (Figure 8). At the end of the experiment when the final estimated leaf

chlorophyll content measurements were taken, SS and CK were the same and resulted in the highest estimated leaf chlorophyll content values compared to other treatments; while SU and US plants were the same and had the least estimated leaf chlorophyll content (Figure 8). This supports previous research by Rotundo, et al., (1999) that plants may adapt to continuous shade such as the SS treatment plants, which increased levels of estimated leaf chlorophyll content compared to other treatments and resulted in the same amounts as the CK (Figure 8). The dry weight root and shoot ration were calculated by adding the weight of roots and shoots for an average of each cane per treatment (Appendix 1). Additional measurements were recorded using SPAD and CIRAS-2®.

The estimated leaf chlorophyll content is set to percent of control (100%) (Appendix 2). Assimilation was recorded and percent of control (100%) (Appendix 3 and 4). At the time of assimilation other measurements were taken that included: evapotranspiration, evapotranspiration set to percent of control (100%), vapor pressure deficient, ambient leaf temperature, relative humidity of the Parkinson® leaf chamber, photosynthetically active radiation, leaf temperature, internal concentration CO_2, stomatal conductance and foliar water use efficiency was recorded (Appendix 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23).

Flowers were distinguished depending on if they were opened flowers with petals or fruit compared to unopened flowers; unopened flowers, opened flowers and buds, 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 (28 days after treatment) followed by US on 17 July (43 days after treatment) and SS on 27 July (53 days after treatment; Table 3). The last to bloom was the SU, 26 days after the CK on 28 July (54 days after treatment) (Table 3). 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, 2008a).

Results from the controlled environment GH experiment supported the hypothesis that shading primocane-fruiting potted plants does influence plant physiology, growth and development. Shading in the SU treatment resulted in a delay of flower and fruit set. Results displayed treatment US resulted in the largest number of flowers at the end of the experiment, SS had the largest number of flower buds and CK had the largest number of fruits at the conclusion of the experiment. This experiment met the objective to gain further insight into effects of 50% shade cloth on primocane delayed flower formation and adaption to the southern region. Further research is needed on other primocane cultivars, with different levels of shade as well as the translation of information to FD production systems in the southern region.

Figure 1. Shade-unshaded treated plants of ‘Prime-Ark® 45’ day 36 of the experiment trained to a single bamboo stake while grown in a greenhouse, Fayetteville, AR., 2014.

Figure 2. The Shaded-shaded treatment on day 1 of the experiment of ‘Prime-Ark® 45’ blackberry while grown in a greenhouse, 2014, Fayetteville, AR., 2014.

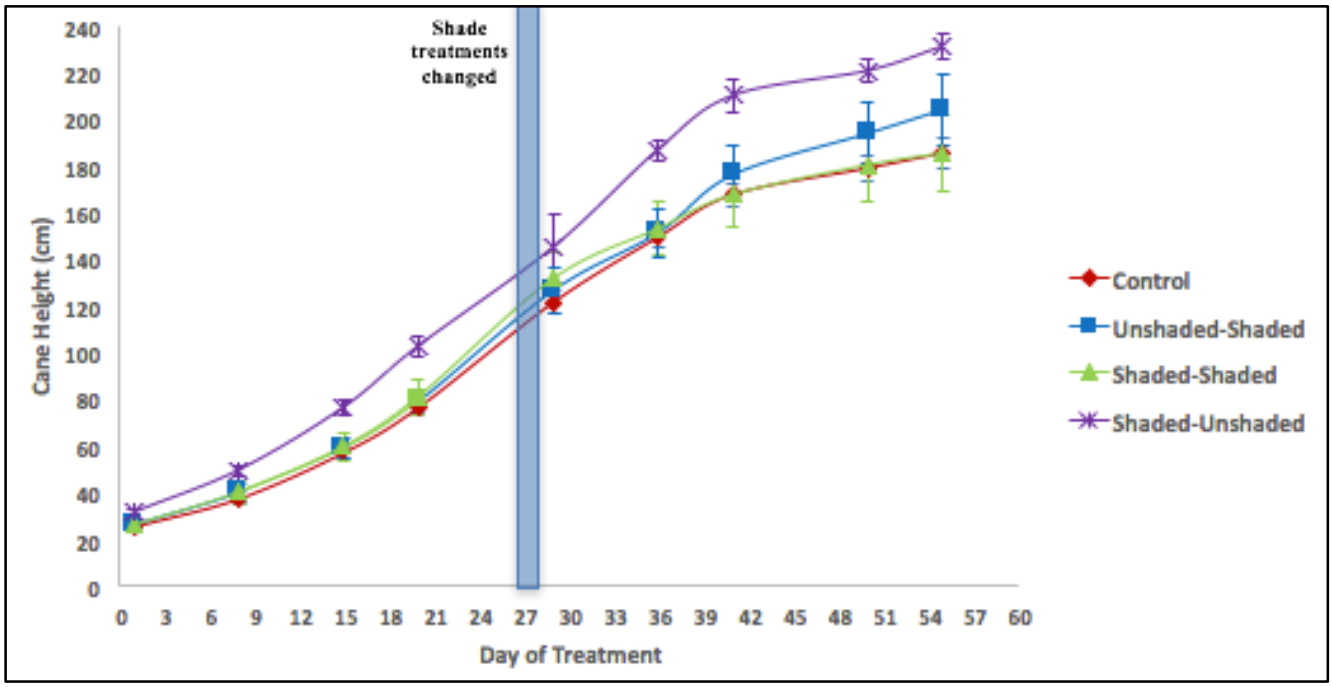
Figure 3. All shade was removed day 59 of the experiment and ‘Prime-Ark® 45’ blackberry grown in pots as affected by four shade treatments grew for an additional 30 days in the greenhouse, 2014, Fayetteville, AR.

Figure 4. Estimated leaf chlorophyll content measured as measured by Minolta SPAD-502 Plus® monitor of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments, 2014, Fayetteville, AR.

Table 1. Height of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

	First Interval				Second Interval					
Treatment	DOT[X] 1	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55	DOT 62
Control	26	38	58 b[Z]	77 b	122 b	150 b	168 b	179 b	186 b	196 b[Y]
Unshaded-Shaded	26	41	59 b	80 b	127 b	152 b	177 b	194 ab	205 ab	228 a
Shaded-Shaded	26	40	60 b	81 b	132 b	153 b	168 b	181 b	186 b	189 b
Shaded-Unshaded	32	49	77 a	103 a	159 a	187 a	210 a	221 a	231 a	246 a
Prob > F	ns	ns	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.0002

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[Y]This week photosynthetic measurements were taken without the LSD light head.
[X]DOT = days of treatment



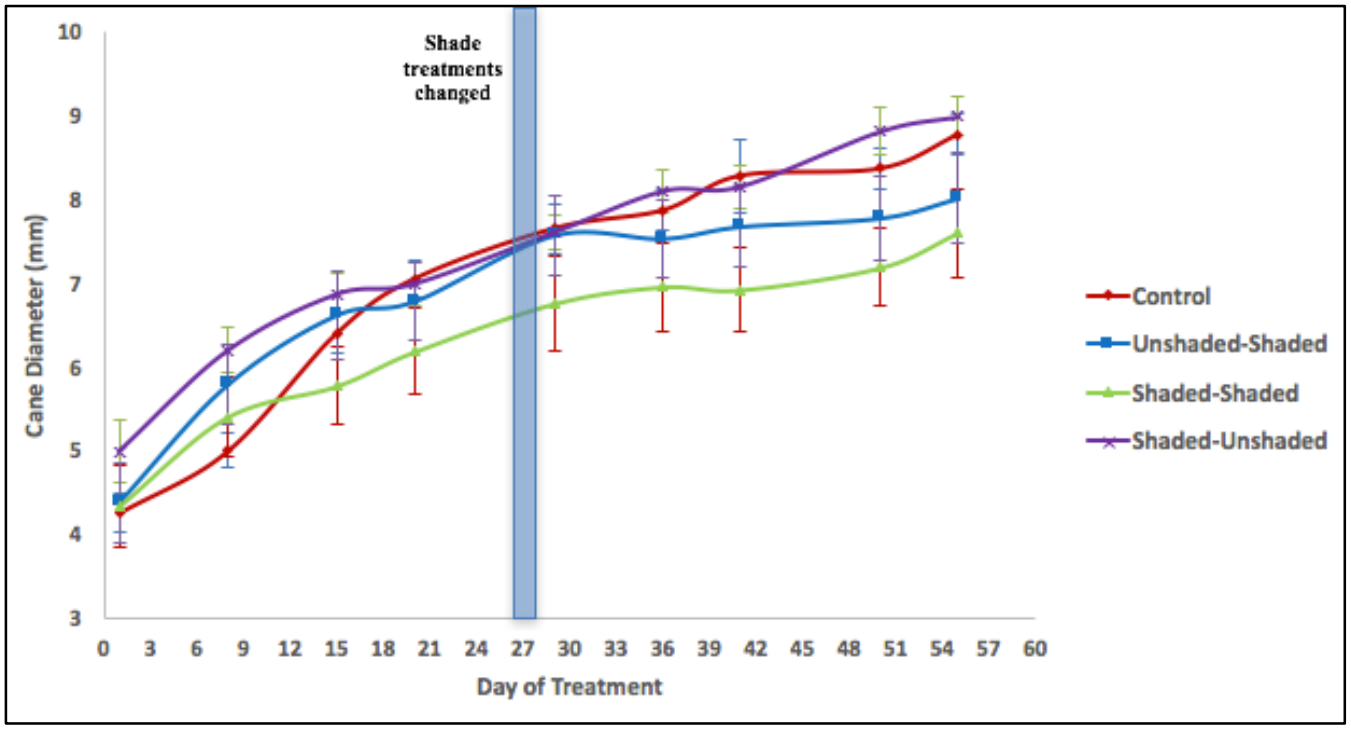
The vertical bars on the graph represent the +/- standard deviation in the data set.

Figure 5. Cane height of a single cane of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

Table 2. Final growth and harvest measurements of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

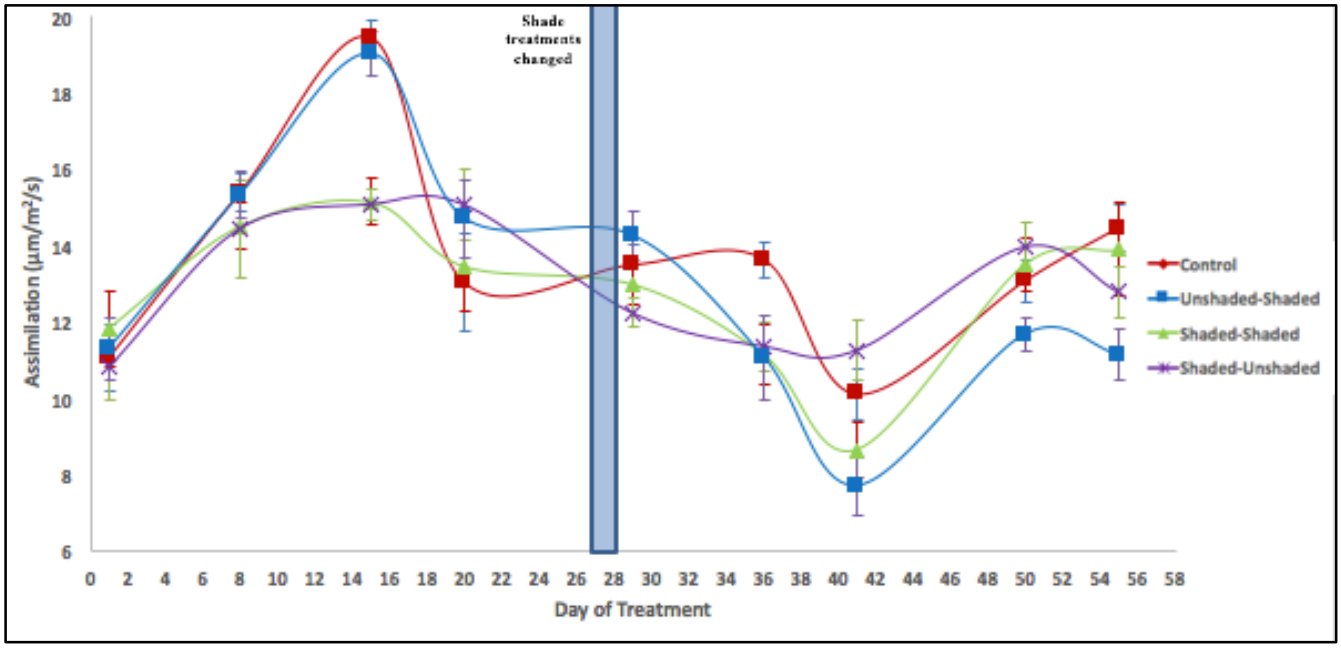
	Shoots		Leaves			Flowers	Dry Weight				
Treatment	Height (cm)	Diameter (mm)	No.	Area (cm^2)	Avg. Size (cm^2)	No.	Shoots (g)	Leaves (g)	Roots (g)	Flowers (g)	Total (g)
Control	197 c[Z]	9 ab	41	5955	146	3	37 a	53 a	106 a	2.27	196 a
Unshaded-Shaded	227 ab	9 ab	44	7917	189	11	35 ab	51 a	75 b	3.36	162 b
Shaded-Shaded	204 bc	8 b	42	7166	183	6	26 b	34 b	64 b	1.09	124 b
Shaded-Unshaded	251 a	10 a	49	7077	145	9	42 a	52 a	94 ab	1.9	188 ab
Prob > F	0.0025	0.05	ns	ns	ns	ns	0.009	0.0017	0.0347	ns	0.0185

[Z] Mean separation followed by different letters are significantly different, α=0.05.



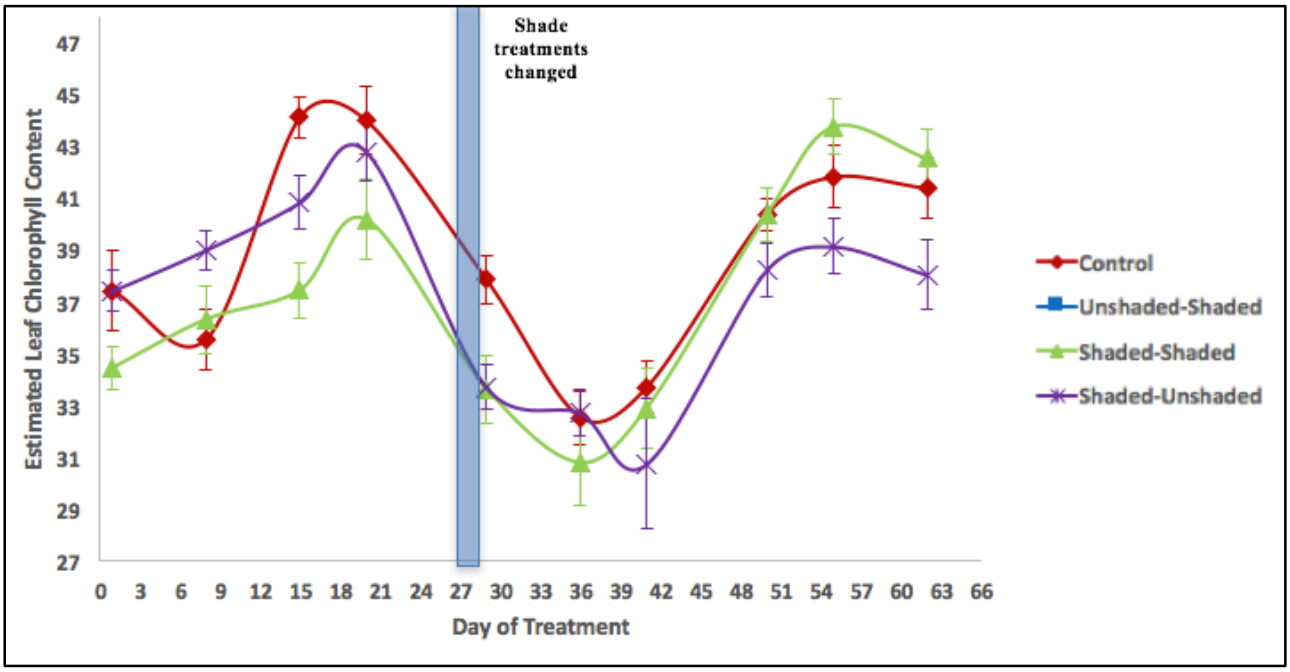
The vertical bars on the graph represent the +/- standard deviation in the data set.

Figure 6. Cane diameter of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



The vertical bars on the graph represent the +/- standard deviation.

Figure 7. Assimilation of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



The vertical bars on the graph represent the +/- standard deviation in the data set.

Figure 8. Estimated leaf chlorophyll as measured by SPAD content of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

Table 3. Date of first flower blooms of a single cane of 'Prime-Ark® 45' blackberry grown in pots as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

Treatment	Date
Treatment 1 (Control)	2 July 2016
Treatment 2 (Unshaded, Shaded)	17 July 2016
Treatment 3 (Shaded, Shaded)	26 July 2016
Treatment 4 (Shaded, Unshaded)	28 July 2016

*There are no statistical differences in the table above.

Literature Cited

Barden, J.A. 1978. Apple leaves, their morphology and photosynthetic potential. HortScience 13:644-647.

Boardman, N.K. 1977. Comparative photosynthesis of sun and shade plants. Annu. Rev. Plant Physiol. 28:355-377. Accessed 4 Apr 2016. Available at: <http://www.annualreviews.org/doi/abs/10.1146/annurev.pp.28.060177.002035>.

Clark, J.R. 2008a. Primocane-fruiting blackberry breeding. HortScience 43:1637-1639.

Clark, J.R. and P. Perkins-Veazie. 2011. 'APF-45' Primocane-fruiting blackberry. HortScience 46(4):670-673.

Makus, D.J. 2010. Weed control and canopy light management in blackberries. Intl. J. Fruit Sci. 10(2):177-186. 04 Apr. 2016.

Marini, Richard P. and J.A. Barden. 1981. Seasonal correlations of specific leaf weight to net photosynthesis and dark respiration of apple leaves. Junk Publ., Netherlands. Photosyn. Res. 2:251-258.

Marini, Richard P. and D.L. Sowers. 1990. Net photosynthesis, specific leaf weight, and flowering of peach as influenced by shade. HortScience 25:331-334. 05 Apr. 2016. <http://hortsci.ashspublications.org/content/25/3/331.abstract >.

Morandi, B., M. Zibordi, P. Losciale, L. Manfrini, E. Pierpaoli, and L.C. Grappadelli. 2011. Shading decreased the growth rate of young apple fruit by reducing their phloem import. Scientia Hort. 127:347-352.

Nonnecke, G.R. and L. Riesselman. 2012. The effects of temperature and light in high tunnel primocane red raspberry production: Year 1. Iowa State Univ., Dept. Hort. 10 Apr. 2016. <http://webcache.googleusercontent.com/search?q=cache:AdElzdVsSPkJ:www.raspberryblackberry.com/wp-content/uploads/2012-The-Effects-of-Temperature-and-Light-in-High-Tunnel-Primocane-Red-Raspberry-Production-Year-1.pdf+&cd=1&hl=en&ct=clnk&gl=us>.

Rodríguez, H.G., J. Popp, M. Thomsen, H. Firedrich, and C.R. Rom. 2012. Economic analysis of investing in open-field or high tunnel primocane-fruiting blackberry production in northwestern Arkansas. Production and Marketing Reports. 22(2):245-251. <http://horttech.ashspublications.org/content/22/2/245.full> Accessed 10 April 2016.

Rotundo A. M. Forlani, C. Di Vaio, and S. Scannerini (ed.). 1999. Influence of shading net on vegetative and productive characteristics, gas exchange and chlorophyll content of the leaves in two blackberry (Rubus ulmifolius Schott.) cultivars. Acta Hor. 457:333-340.

Stanton, M.A., J.C. Scheerens, R.C. Funt, J.R. Clark. 2007. Floral competence of primocane-fruiting blackberries Prime-Jan and Prime-Jim grown at three temperature regions. HortScience 42:508-513.

Strik, B. C., J.R. Clark, C.E. Finn, G. Buller, P. Bañados (ed.), and A. Dale (ed.). 2008. Management of primocane-fruiting blackberry to maximize yield and extend the fruiting season. Proc. IXth Intl. Rubus and Ribes Symp. Acta Hort. 777:423-428.

Chapter 3: The effect of time and amount of shade on growth and fruiting of 'Prime-Ark® 45' primocane blackberry in field conditions

Introduction

A FD experiment was completed to evaluate the effects of various levels of shade applied at different times throughout the growing season on 'Prime-Ark® 45' blackberries. Observations and a preliminary experiment of 2013 indicated that shading may be used to delay and synchronize bloom in autumn-bearing primocane blackberries. This experiment was a repetition of the 2013 experiment to confirm previous results. Research in the FD provided insight into management strategies of primocane-fruiting blackberries in the southern region.

Primocane fruiting blackberry production in Arkansas is limited by heat during the flowering and early fruiting season. Shade could both alter temperature due to direct radiation, or delay flowering and fruiting to more favorable growth period. This experiment was designed to test three levels of shade (0% [control], 30% and 50% shading) applied at two times during the growing season on growth, development, physiology of flowering and fruiting of 'Prime-Ark® 45' blackberries. This experiment has given insight into the effects of shade on 'Prime-Ark® 45' blackberry physiology, growth and flowering and fruiting in the FD. It was found that shade may be used to delay flowering, reduce heat stress, resulting in higher fruit quantities. However, FD studies also indicated some ES treatments reduced cropping compared to LS treatments. Continued research is needed to improve this production system for niche market in the southern region.

Literature Review

When temperatures are above 29.4 °C, heat stress has been found to be detrimental to flower and fruit production of autumn bearing primocane blackberries (Stanton, et al., 2007). This limits the production of the new cultivars of primocane blackberries for production in Arkansas which begin flowering in July or August during times of high temperatures. Observations and a preliminary experiment in 2013 indicated that shading may be used to delay and synchronize bloom to a cooler, more favorable environment in autumn-bearing primocane blackberries. A field experiment was conducted 2014 to evaluate the effects of various levels of shade applied at different times throughout the growing season on 'Prime-Ark® 45' blackberries in order to confirm previous observations.

Blackberry demand and production worldwide are increasing by advanced cultivars and with high tunnel and field production systems (Strik, et al., 2007). Small fruit crops, blackberries in particular, are economically viable and could serve as a sustainable income for farmers while supplying consumers in the southern region with local produce. Traditional blackberries are a biennial plant with the first year cane, the primocane, arising from a perennial root system, remaining vegetative. After a winter dormant period, the second-year cane, the floricane, flowers in spring, fruits, and dies. A new genotype of an autumn-bearing fall harvested primocane fruiting blackberries have been developed at the University of Arkansas System Division of Agriculture. Superior cultivars of the primocane fruiting autumn-producing blackberries are being released and being grown. This has significantly expanded the blackberry production and market season.

Although very productive in cooler climates, these new genotypes have limited adaptability in Arkansas due to high temperatures during the flowering and fruit set period of

July and August. It has been suggested that shade cloth could reduce fruit temperatures while also increasing fruit size and the amount of marketable berries with crop season extension (Makus, 2010). Therefore, there are two proposed methods for improving fruit of primocane cultivars: one method is to shade fruit, while a second is implement shade during flower production to shift fruit to a time where heat is avoided. The light treatments during flower formation were not meant for fruit temperature reduction in this experiment. It has been thought that shade may delay flowering of primocane bearing cultivars to a more favorable season, although the research is scarce. The purpose of this experiment was to use light as a means of shifting the flower and fruit fruiting sequence of primocane blackberries to avoid heat.

Based upon previous work, light saturation of blackberries occurred at 750-900 umoles/m^2 /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). Plant organs such as stems, leaves, and flowers reach a genetically programmed minimal age of development, which varies by species and determines when the plant is capable of flower formation (Durner, 2013). 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 it was exposed to at the time of maturity is conducive

An experiment on apple trees, another rosacea species implemented three treatments: a nonshaded control, continuous 80% shade, and intermittent shade that provided both full sun

and full shade (Barden, 1977). The experiment by Barden (1977) found that plant growth was dependent upon accumulated photosynthetically active radiation rather than the level of light provided. An experiment on blackberries in a greenhouse tested a full sun control, 20%, 50%, and 70% irradiance to full sun (Gallagher, et al., 2014). Gallagher, et al., (2014) reported the flower and fruit period were 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. It is proposed in this experiment that the use of 30% and 50% shade isolated the light intensity factor and would not reduce the photosynthetically active radiation required for growth, but delay vegetative bud development.

Flower bud initiation of several primocane fruit blackberry cultivars under field conditions was statistically different when number of nodes reached 25 between 14 and 28 May 1997 (Lopez-Medina, et al., 1999). This research was the first of its kind and provided the foundation to further understand primocane blackberry flower initiation development under nonshaded conditions, which may be used to manipulate flower development in the future (Lopez-Medina, et al., 1999). This previous research gave insight for determining when shade treatments (ES, MS, and LS) would be implemented in the field for this experiment. Rotundo, et al., (1998) shaded blackberry cultivars starting the last ten days in June lasting until the last ten days in October, which lasted throughout the hottest summer months in Italy. Rotundo, et al., (1998) found that 40% shade reduction cloth extended the fruiting period 25 days for eight-year-old plantings of 'Black Satin' floricane 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 the control (Rotundo, et al., 1998).

Through decreasing levels of light, it is thought that the development of flowers during the first three vegetative states—induction, initiation, and differentiation—may be manipulated to shift primocane blackberry flower development. The objective of this experiment was to determine if various levels of shade (30% and 50%) used at different times of the pre-flowering season (ES, MS and LS) could alter the flowering and fruiting season of a new genotype of autumn-producing primocane fruiting blackberries in Arkansas. The hypothesis was that shading may affect flowering and fruiting differentially based upon the time of the season and the stage of growth.

Materials and Methods

Location: The field (FD) experiment was located in the horticulture unit organic block of the University of Arkansas Agriculture Research and Extension Center in Fayetteville, Arkansas (Latitude: 36°6'8" N; Longitude: 94°10'17" W). The FD was managed following National Organic Production (NOP) standards that enforce regulations on organic food production in the United States (NOP, 2014).

Plant Materials and Experimental Design: The field plot was established in 2011 for pruning studies of 'Prime-Ark® 45 plants and shade studies began in 2013. 'Prime-Ark® 45 plants were obtained from Boston Mountain Nurseries, (Mountianburg, AR). The experiment was designed in a 3 X 3 factorial with five replicated plots of each treatment in a complete randomized design. The plant spacing was 30.5 cm in row with a total of six rows. There were 2.7 m between rows and 50 cm between plant crowns within the row. Plants were grown in the FD with Captina (Fine-silty, siliceous, active, mesic Typic Fragiudult) silt loam soil.

Shade structures were placed over 1.8 m row sections and considered as experiment plots. Size and dimension of shading structure were 1.5 m (L) X 1.2 m (W) X 2.1- 2.4 m (H). The experiment was designed to test three levels of shade (0% [control], 30% and 50% shading) applied for 30-45 days at three different times during the summer growing cycle. The experiment had seven treatments with various levels of shade and differing dates of treatment implementation: 1) an untreated control [CK], 2) early shade 30% [ES30], 3) mid shade 30% [MS30], 4) late shade 30% [LS30], 5) early shade 50% [ES50], 6) mid shade 50% [MS50], 7) late shade 50% [LS50]. The 30% and 50% treatments were implemented 16 June [ES], 1 July [MS] and 15 July [LS] during the 2014 summer season. The treatment plots were observed prior to

implementation of the ES treatment (Figure 9). There were five replications for all treatments. Buffer plots were established between treatment plots to isolate treatments and minimize cross-treatment effects.

Plot Management: Rye straw hay was spread between the bases of all blackberry crowns 23 May to control walk-row and in-row competitive vegetation. Canes were pruned to the crown each winter and new primocanes were thinned to five primocane canes per crown in the spring. Canes were tipped by pruning the growing tip of 5-10 cm 6 June to encourage lateral bud break. Previously formed flowers were removed from canes under shade treatments when cloths were implemented on 16 June (Figure 9). This was done to insure uniformity among treatment plots and provide accurate observations regarding effects on shade flower and fruiting formation. The field was irrigated as needed according to Irrometers when soil moisture tension reached approximately 10 cbars. The irrigation was inline drip tube with 30.5 cm spacing and a flow rate of 1.9 L/hour. Plants were fertilized every spring using Bradfield Organics® Luscious Lawns Mix (3-1-5) which was applied in banded rows. Seasonal pest control sprayed for spotted wing drosophylla using Naturalyte® (Spinosad A and D and Propylene glycol, DOW AgroSciences Company) Insect Control at a rate 0.01 L per 0.40 ha.

Research Variables and Data Collection: Two healthy, vigorous primocanes in each treatment plot were tagged as sub-samples within each plot. Prior to the initiation of the 15 July, shade treatment structures, canes were chosen as subsamples in each treatment plot and tagged. The primocanes were selected on uniformity, growth and overall health.

Weekly assimilation measurements were recorded from tagged plants from each treatment plot using a CIRAS-2® portable gas exchange monitor equipped with a Parkinson®

leaf chamber (Figure 10) which, but was not limited to: assimilation (A), evapotranspiration (Et), and stomatal conductance (gs). At the time of assimilation other measurements were taken that included: internal concentration CO_2, relative humidity of the Parkinson® leaf chamber, photosynthetically active radiation, evapotranspiration and stomatal conductance (Appendix 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38 and 39).

The first assimilation measurements were collected on 25 June and once every seven-day period until 18 Aug (Figure 11). The area of the leaf measured was 6.25 cm^2. The terminal leaf of the leaflet near the middle leaf margin lamina was used for measurements. The leaf was chosen four to five nodes down from the terminal cane tip of each plant and was used for estimated leaf chlorophyll and assimilation measurements. Estimated leaf chlorophyll and assimilation measurements were taken using the same leaf, but leaf selection varied weekly. Only healthy leaves were used in measurements of estimated leaf chlorophyll content and assimilation measurements. CIRAS was set at a flow rate of 300, the RH setting was 50%, and the incoming CO_2 concentration was 390 ppm with a leaf temperature 28 °C. Measurements were taken with the CIRAS light head and set to PAR 1,200 μmols/m^2/s^1. If leaves were moist from morning dew or precipitation, they were dried with paper towels prior to data collection.

Measurements began around 7:30 $_{AM}$ lasting until 12:00 $_{PM}$ for the FD plots or until all plots were recorded in a randomized order. The center most leaf located four to five nodes from the tip was used for each reading.

Chlorophyll estimates were made with the Minolta model: SPAD-502 Plus® monitor measured on the same leaf used for foliar assimilation measurements. Estimated leaf chlorophyll content were measured can be related to foliar nitrogen content.

Soil moisture for each treatment plot was collected 21 Aug. Furthermore, in the morning soil moisture was collected in each treatment plot of the organic blackberry block with the TDR reflectrometry, Model FieldScout TDR 300, at a depth of 12 cm 25 June (Data not presented).

Plots began to fruit 60 days after first shade treatment on 18 Aug. After ripening fruit was harvested from FD treatment plots twice every seven day period (most Tuesdays and Fridays) after the first ripe fruit was seen (Figure 12). Towards the end of the experiment, the ripe fruit from each treatment plot was harvested once every seven-day period. The total berry weight (g) for each treatment was recorded (Figure 13). There were a total of 50 days of harvest.

The blackberries were culled, sorting berries between marketable and unmarketable fruit for the first seven weeks. Criteria for the marketable berries were firmness, size, without disease or mold and limited punctures to druplets. Once graded, the weight of the berries for unmarketable, marketable along with the weight of 25 randomly chosen marketable berries was recorded for each plot and determined the average berry weight for treatment plots. Twice during the harvest collection of berries, 29 Aug. and 12 Sept., five randomly selected marketable berries were measured for the soluble solids content. “Total Berry Weight” was used to describe the individual harvest by date (Appendix 36). The term “Cumulative Yield” of berry weight was used for all days of harvest combined and was calculation by adding weights per treatments from past harvest days to equal total yields per treatment plots (Appendix 37).

The average berry weight was calculated by dividing the 25 berry count total weight by 25 berries for each treatment by individual harvest date (Appendix 38). Total marketable berry weight was the weight of marketable berries by individual harvest dates (Appendix 39). Total percent marketable berry weight was calculated by dividing the weight of marketable berries by

total weight of harvest per treatment by individual harvest dates (Appendix 40). The cumulative marketable yield was the weight of marketable berries for all days of harvest combined (Appendix 41).

After the conclusion of fruit data collection on 19 Oct., the tagged canes in each FD treatment plot were destructively harvested for final growth measurements. The measurements included: cane diameter (6 cm above the soil line) (mm), cane shoot length (cm), number of nodes, number of lateral branches formed after pruning, number of flower clusters per cane, and the number of fruit clusters for each cane.

Results, Discussion and Conclusion

The estimated leaf chlorophyll content at 36 DOT of plants in the LS50 treatment was statistically greater than all other treatments except CK and LS30 (Table 4 and Figure 14). At DOT 36, there were no treatments that had chlorophyll contents significantly different from the CK. However, at DOT 45, the CK, MS30, LS30 and LS50 had greater chlorophyll contents than MS50, while ES30 was not different from any other treatments. These data indicated that over the course of the experiment, there were only two days out of eight when statistical differences were measured for chlorophyll content among treatments (Table 4 and Figure 14).

Fruits were harvested beginning at 60 days after the onset of the experimental treatments. Day of Harvest (DOH) is used to compare fruit harvest of the differing treatments. There was no apparent difference in the dates of first harvest among the treatments. Plants in the LS30 and LS50 treatments produced greater cumulative yield berry weight than ES30, MS30 and ES50 treatments, while all treatments were not different from the CK (Figure 15 and Table 5). The cumulative harvested berry weight which was greatest for LS30 and LS50 began to differentiate in harvest berry weight from ES30 starting 22 DOH and continued until the conclusion of the experiment, 49 DOT (Figure 15 and Table 5). At approximately 33 DOT, LS30 and LS50 treated plants had average yields above 1500 g per plot compared to ES30, MS30 and ES50 that had average berry yields less than 1000 g (Figure 15 and Table 5).

The total cumulative berry weights peaked for all treatments around DOH 20 (Figure 16). While this does not show significant differences, it is useful for understanding the increase, peak and decline in yields per plot (Figure 16).

After sorting fruit to segregate marketable and nonmarketable fruit, the mean cumulative marketable yields were 269% greater for LS30-treated plants compared to ES30 treated plants which were the least (Table 6). There were no statistical differences among treatments for culled berry weights and soluble solids (Appendix 42, 43, 44, 45 and 46).

No significant differences for cane length, cane diameter, node number, internode length, number of lateral branches or number of fruit clusters were observed among treatments (Appendix 47, 48, 49, 50, 51, 52 and 53). The short-term shade treatments were made after canes were tipped, setting their final height, and after lateral bud break had occurred. Therefore, shade did not affect gross growth in this experiment.

The hypothesis was that that shade would affect flower formation and subsequently fruit formation of primocane blackberries in the field. There was no effect on plant growth and some shade treatments did reduce yield although it was observed in the GH experiment. Field treatments ES30, MS30 and ES50 had less fruit than LS treatments during the experiment period. Gallagher, et al., (2014) stated that flower and fruit were more concentrated when lower light levels were implemented during the flower initiation stage. Since previously formed flowers were removed prior to the ES treatments, it is possible that shade was not applied early enough during the vegetative stages of initiation. Also, the experiment was terminated prior to the end of all flowering and fruit harvest. This could explain why there was no difference in plant growth, but yields were lower in some ES treatments.

As observed in the GH experiment, shade delayed flowering and fruiting. Rotundo, et al., (1998) found that 40% shade extended the fruiting period by 25 days for several floricane blackberry cultivars; however, this study is unable to compare results because the fruiting season

was ended due to limiting weather. It is possible that flowering and fruiting of the ES treatment could have continued after the end of this experiment due to the delay in flowering and fruiting as observed in the GH experiment. If that was the case, in the future shade should be applied 1 May as opposed to 16 June. Field canes were approximately 60 cm in height at the start of the experiment and the first shaded treatment was implemented 16 June. Lopez-Medina, et al., (1999) stated, flower bud initiation of several primocane fruit blackberry cultivars was observed between 14 and 28 May 1997, which further supports that shade needs to be implemented May 1 in future experiments. Earlier shade could be coupled with season-extending high tunnel systems to protect fruit against freezing autumn weather that would end field production. This is among first research of its kind and more work needs to be completed to determine if shade is a possible management tool for delaying flower formation and cropping. This work demonstrated both potential and problems of shading primocane blackberries. If shaded early in the season, it may delay bloom without affecting yield if shade is removed. However, if shaded at other times, it may reduce yields. Shade late in the season during fruiting, may increase fruit size and marketable yield. These preliminary studies indicate that the effects of shading are very time dependent, although more work needs to be done. The potential of shading in combination with high tunnels may provide an opportunity for primocane fruiting, autumn-bearing blackberries in Arkansas and the southern region of the United States.

Figure 9. Prior to early shade treatment implementation, day 1 of the experiment, of ‘Prime-Ark® 45’ blackberry while grown in the field experiment, 2014.

Figure 10. Assimilation measurements of the control treatment of ‘Prime-Ark® 45’ blackberry while grown in the field experiment, 2014.

Figure 11. Assimilation measurements of a control treatment plot after implementation of early shade and middle shade treatment cloth of ‘Prime-Ark® 45’ blackberry grown in the field experiment, 2014.

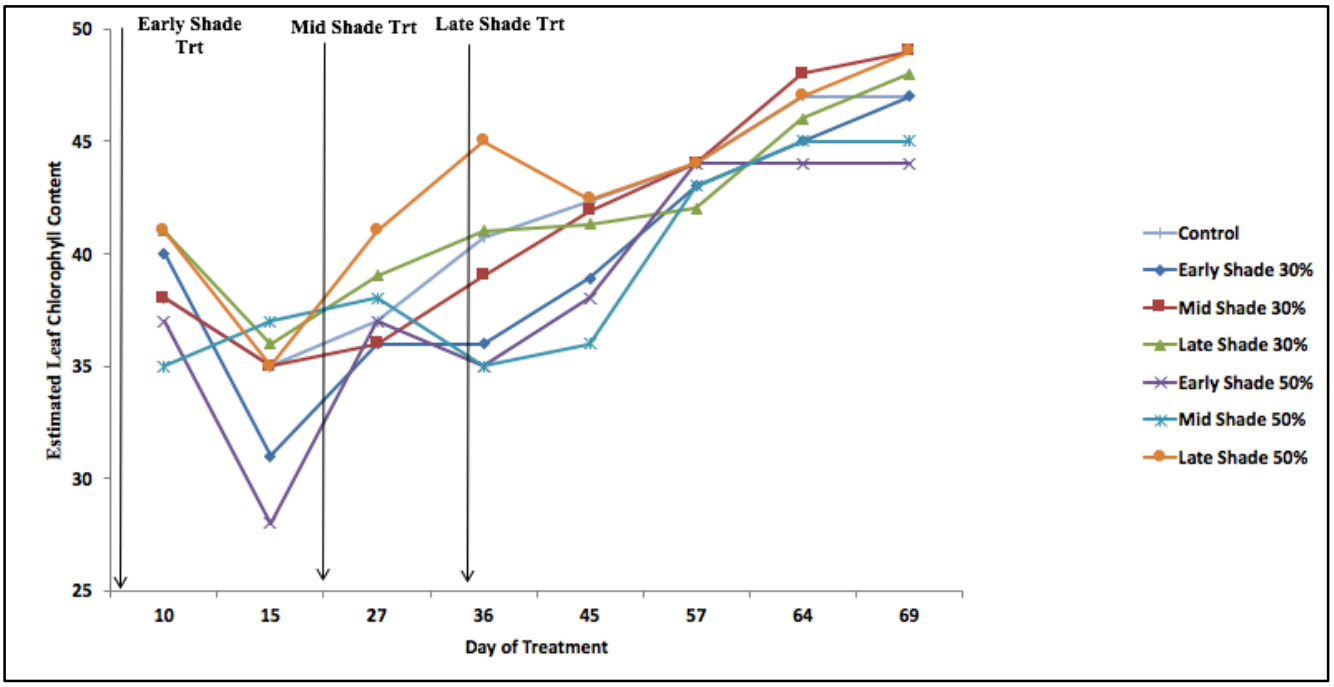
Figure 12. An example of fruit ripeness variation of ‘Prime-Ark® 45’ control treatment blackberries while grown in the field experiment, 2014.

Figure 13. Blackberries of treatment plots of ‘Prime-Ark® 45’ blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

Table 4. Estimated leaf chlorophyll content as measured by SPAD of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

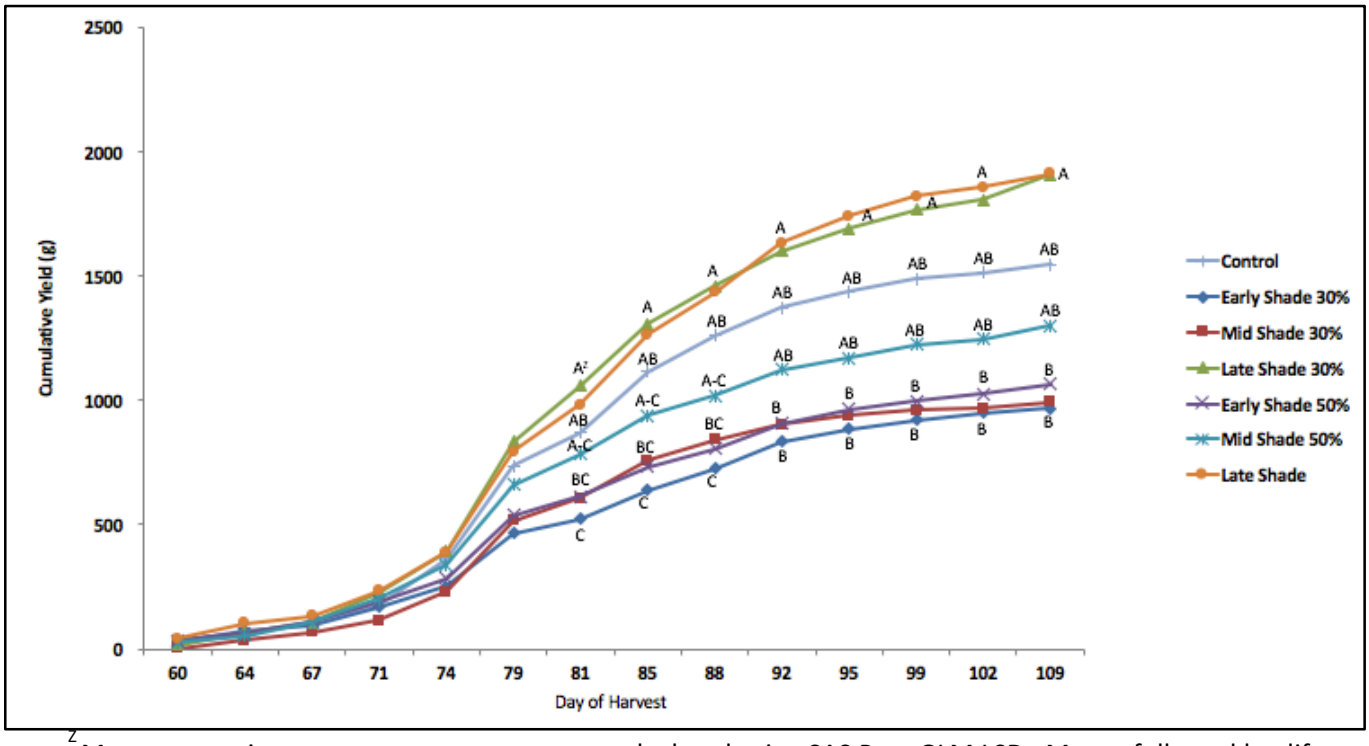
	Estimated Leaf Chlorophyll Content							
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	38	35	37	40.7 abc[Z]	42.3 a	44	47	47
Early Shade 30%	40	31	36	36 bc	38.9 abc	43	45	47
Middle Shade 30%	38	35	36	39 bc	41.9 ab	44	48	49
Late Shade 30%	41	36	39	41 ab	41.3 ab	42	46	48
Early Shade 50%	37	28	37	35 c	38 bc	44	44	44
Middle Shade 50%	35	37	38	35 c	36 c	43	45	45
Late Shade 50%	41	35	41	45 a	42.4 a	44	47	49
Prob > F	ns	ns	ns	0.01	0.03	ns	ns	ns

[Z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD.
Means followed by different letters are statistically different from one another ($\alpha < 0.05$, n = 5).
[X]DOT = days of treatment



*There are no statistical differences represented in the figure above.

Figure 14. Estimated leaf chlorophyll content as measured by SPAD of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



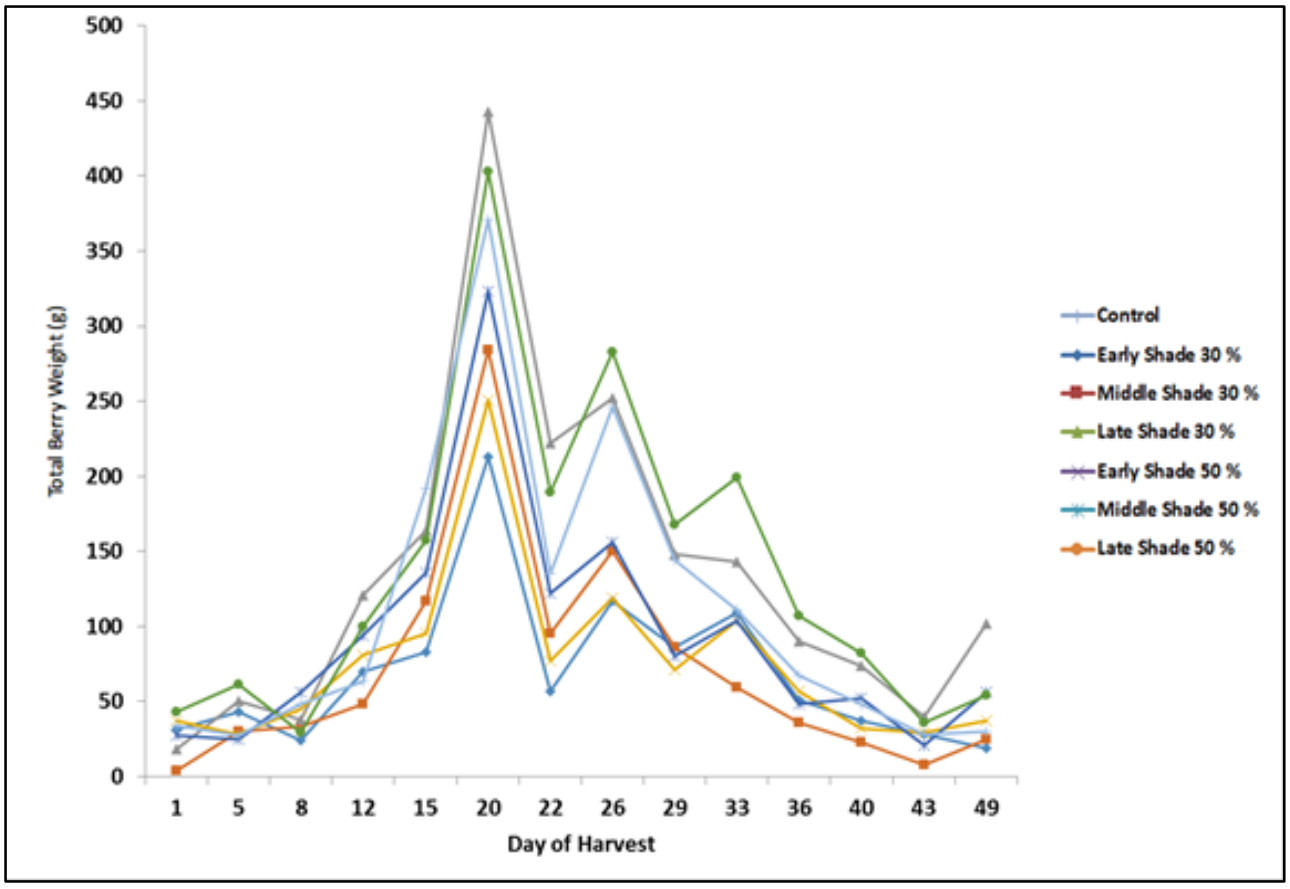
[z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD. Means followed by dif ferent letters are statistically different from one another ($\alpha < 0.05$, n = 5).

Figure 15. Cumulative yield berry weight of 'Prime-Ark® 45' blackberry plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014.

Table 5. Cumulative yield berry weight of 'Prime-Ark® 45' blackberry of plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014.

Treatment	Cumulative Yield Berry Weight (g)	SE
Control	1544.6 ab[z]	283.5
Early Shade 30%	968.4 b	74.6
Middle Shade 30%	993.6 b	86.6
Late Shade 30%	1907.4 a	344.2
Early Shade 50%	1063.4 b	171.7
Middle Shade 50%	1300.8 ab	117.9
Late Shade 50%	1912 a	240.7
Prob > F	0.01	

[z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD. Means followed by dif ferent letters are statistically different from one another ($\alpha < 0.05$, n = 5).
SE= Standard Error



*There are no statistical differences in the table above.

Figure 16. Total berry weight at each day of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

Table 6. Cumulative marketable yield berry weight of 'Prime-Ark® 45' blackberry of plants across all harvest dates as affected by seven shade treatments while grown in the field experiment, 2014.

Treatment	Cumulative Marketable Yield (g)	SE
Control	585 ab[z]	104
Early Shade 30%	244 d	72
Middle Shade 30%	355 cd	40
Late Shade 30%	657 a	100
Early Shade 50%	399 b-d	64
Middle Shade 50%	473 a-c	62
Late Shade 50%	579 ab	61
Prob > F	0.006	

[z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD. Means followed by dif ferent letters are statistically different from one another ($\alpha < 0.05$, $n = 5$).
SE= Standard Error

Literature Cited

Barden, J.A. 1977. Apple tree growth, net photosynthesis, dark respiration, and specific leaf weight as affected by continuous and intermittent shade. J. Amer. Soc. Hort. Sci. 102(4):391-394.

Durner, E.F. 2013. Principles of horticulture physiology. (Centre for Agriculture and Biosciences International (CABI), Boston, Mass., USA.

Gallagher, E.J., K.W. Mudge, M.P. Pritts, and S.D. DeGloria. 2014. Growth and development of 'Illini Hardy' blackberry (Rubus subgenus Eubatus Focke) under shaded systems. Agroforesty Systs. 89:1-17. 8 July 2016.

Janick, J. 1986. Horticulture science fourth edition. W.H. Freeman and Company, USA.

Lopez-Medina, J., J.N. Moore, and K. Kyung-S. 1999. Flower bud initiation in primocane-fruiting blackberry germplasm. HortScience 34(1):132-136. 30 June 2016.

Makus, D.J. 2010. Weed control and canopy light management in blackberries. Intl. J. Fruit Sci. 10(2):177-186. 04 Apr. 2016. <http://www.ars.usda.gov/research/publications/Publications.htm?seq_no_115=252647&pf=1>

National Organic Production. 2014. National organic program handbook: guidance and instructions for accredited certifying agents and certified operations. United States Dept. of Agr. 1 Aug. 2016. <https://www.ams.usda.gov/sites/default/files/media/Program%20Handbk_TOC.pdf>.

Rotundo A. M. Forlani, C. Di Vaio, and S. Scannerini (ed.). 1998. Influence of shading net on vegetative and productive characteristics, gas exchange and chlorophyll content of the

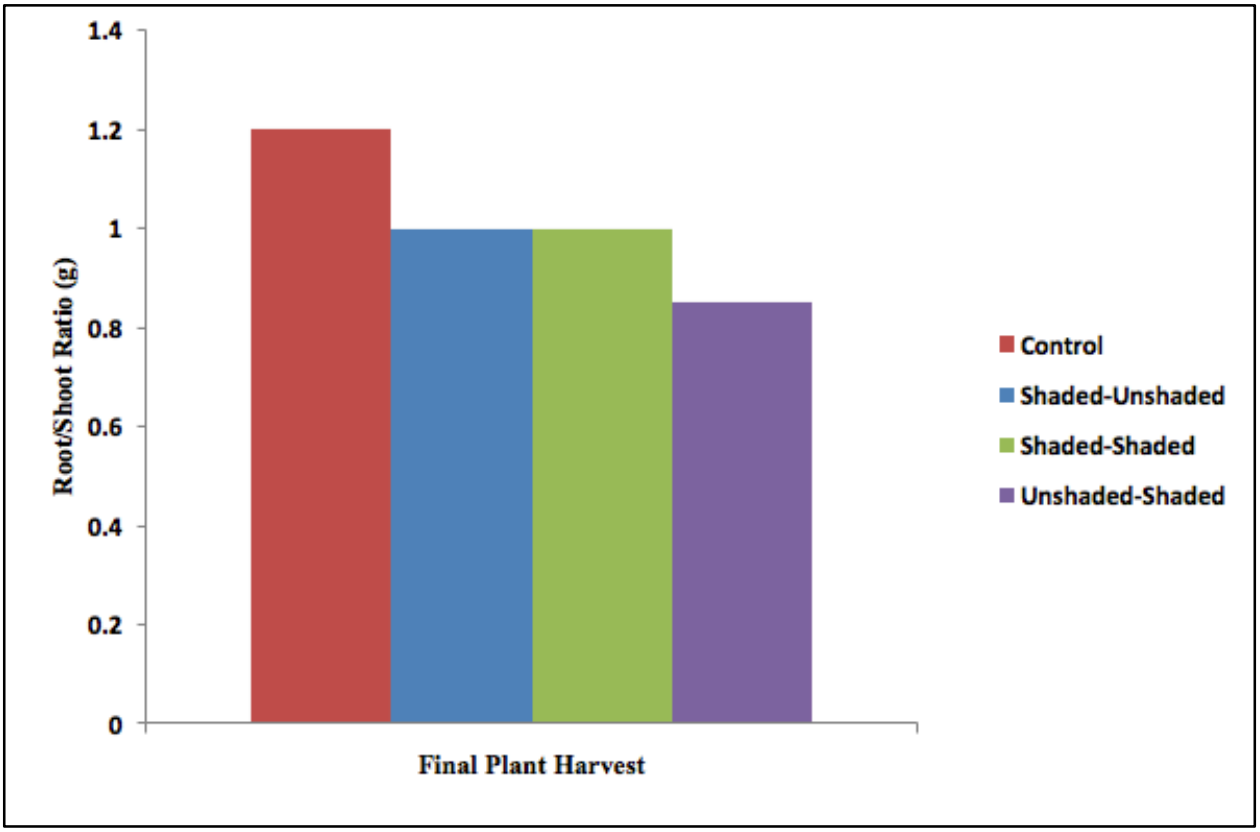
leaves in two blackberry (Rubus ulmifolius Schott.) cultivars. Acta Hort. Proc. Plant Biotechnol. Tool. 457:333-340. 10 Apr. 2016. <http://www.actahort.org/books/457/457_42.htm>.

Stanton, M.A., J.C. Scheerens, R.C. Funt, and J.R. Clark. 2007. Floral competence of primocane-fruiting blackberries Prime-Jan and Prime-Jim grown at three temperature regions. HortScience 42:508-513.

Strik, B.C., J. R. Clark, C.E. Finn, and M.P. Bañados. 2007. Worldwide blackberry production. J. Amer. Soc. Hort. Sci. HortTechnology 17:205-213. 10 Apr. 2016. <http://horttech.ashspublications.org/content/17/2/205.abstract>.

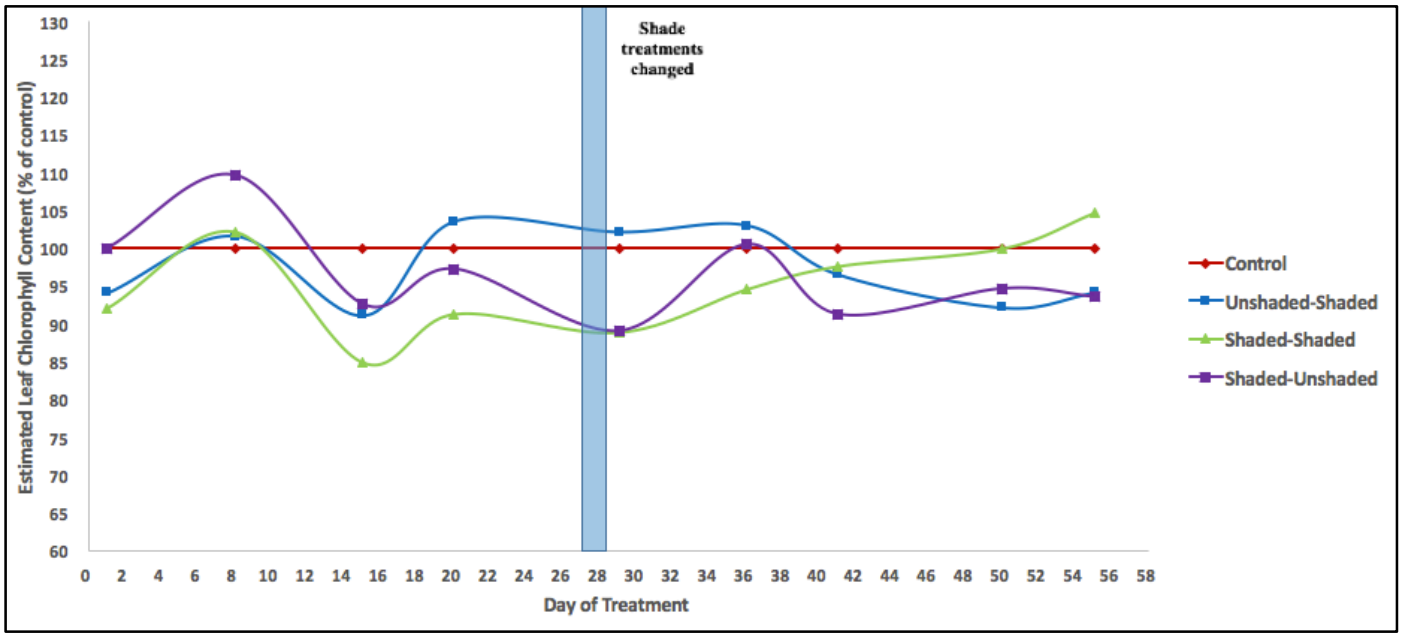
Appendices: Greenhouse Tables and Figures

Appendix 1. Root and shoot ratio of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.



*There are no statistical differences in the figure above.
(Dry weight for roots/dry weight for top of plant = root/shoot ratio)

Appendix 2. Estimated leaf chlorophyll content as measured by SPAD set to percent of control (100%) of 'Prime Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



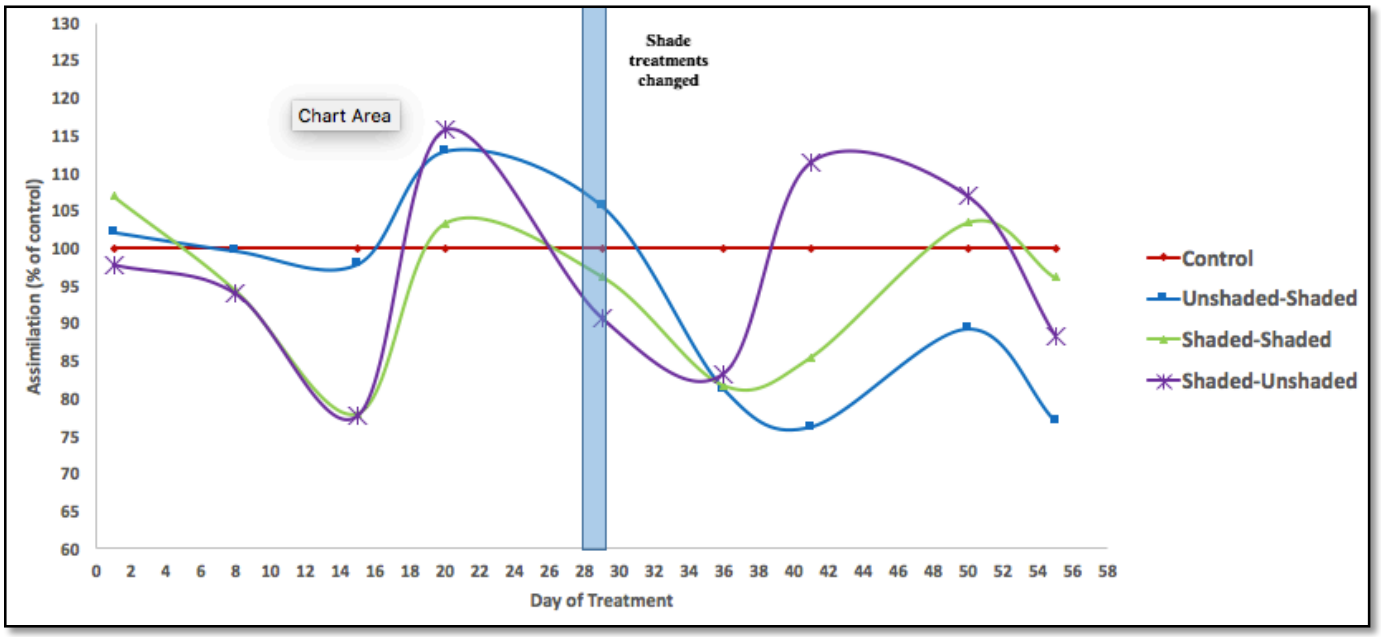
*There are no statistical differences represented in the figure above.

Appendix 3. Assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

	Assimilation (µmol/m^2/s1)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	11.1	15.4	19.4 a[Z]	13	13.5	13.6	10.1 ab	13.1	11.8 a
Unshaded-Shaded	11.3	15.3	19 a	14.7	14.2	11.1	7.7 c	11.7	5.8 bc
Shaded-Shaded	11.8	14.5	15.1 b	13.5	13	11.1	8.6 bc	13.5	4.4 c
Shaded-Unshaded	10.8	14.4	15.1 b	15.1	12.2	11.4	11.3 a	14	7.3 b
Prob > F	ns	ns	<0.0001	ns	ns	ns	0.05	ns	<0.0001

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 4. Assimilation set to percent of control (100%) of ‘Prime-Ark® 45’ blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.

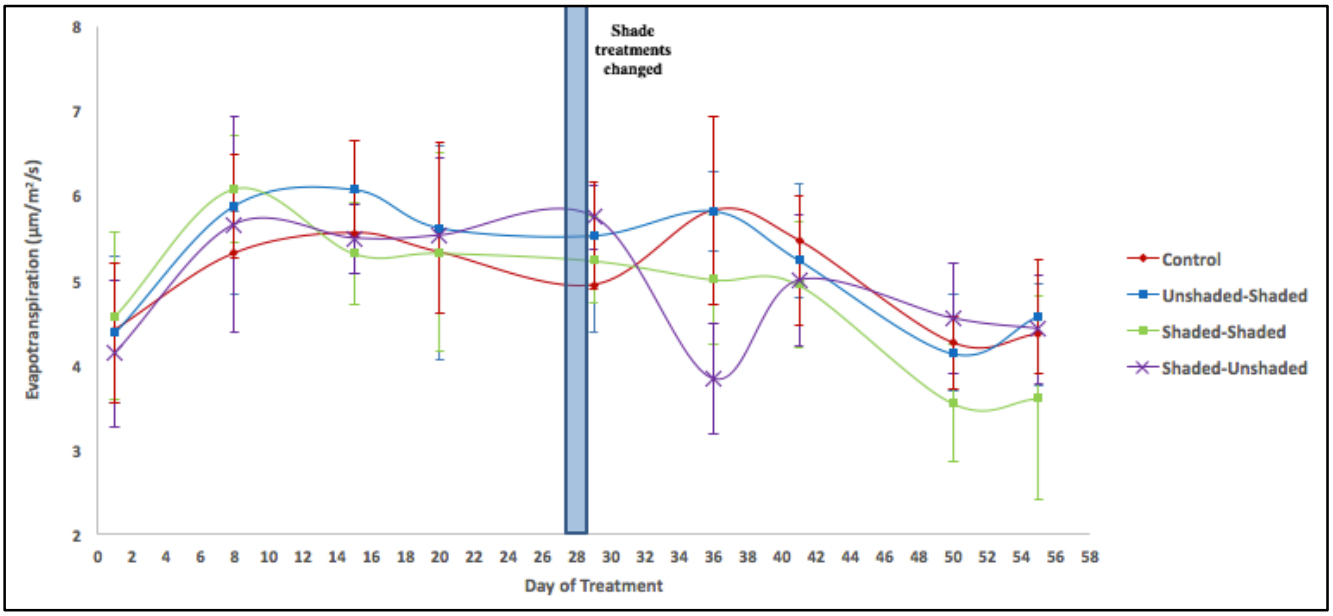


Appendix 5. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

	Evapotranspiration (mmol $H_2O/m^2/s^1$)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	4.41	5.3 c[Z]	5.5 b	5.3	4.9 b	5.8 a	5	4.3 a	6a
Unshaded-Shaded	4.4	5.9 ab	6a	5.6	5.5 a	5.8 a	5	4.1 a	4 b
Shaded-Shaded	4.6	6.1 a	5.3 b	5.3	5.2 ab	5 b	5	3 b	5 b
Shaded-Unshaded	4.1	5.7 bc	5.4 b	5.5	5.7 a	3.8 c	5	4.5 a	5 b
Prob > F	ns	0.001	<.0001	ns	0.04	<.0001	ns	0.0003	0.03

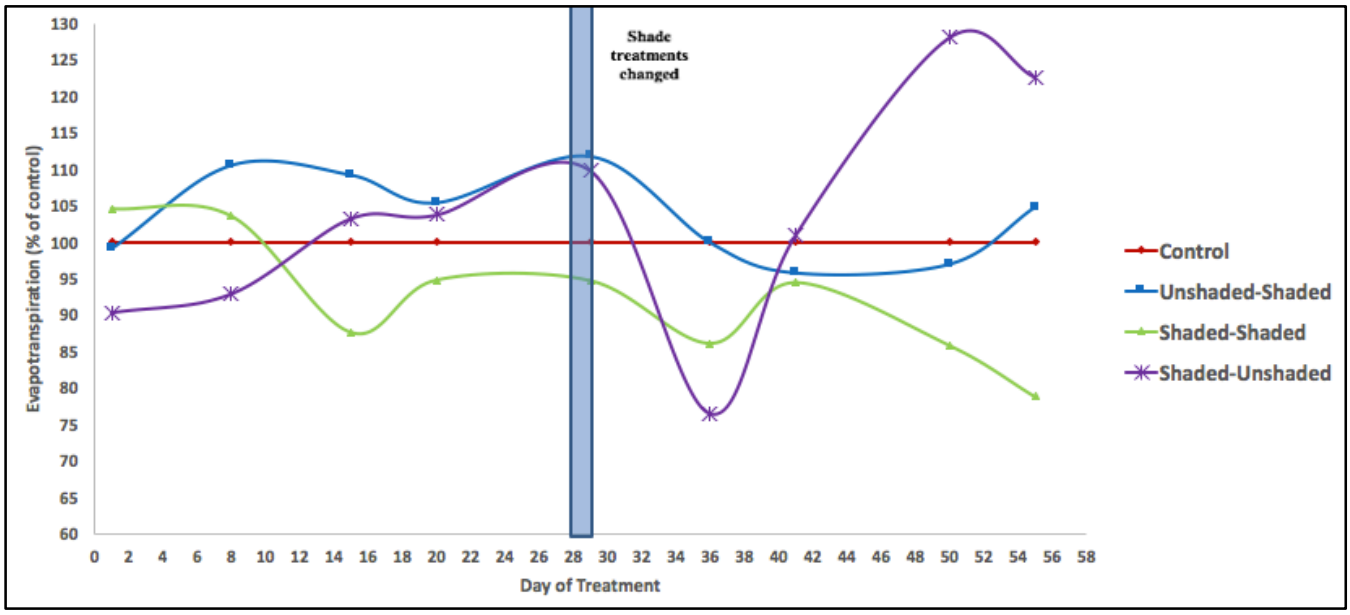
[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 6. Evapotranspiration of ‘Prime-Ark® 45’ blackberry affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



The vertical bars on the graph represent the +/- standard deviation in the data set.

Appendix 7. Evapotranspiration set to percent of control (100%) of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences represented in this unanalyzed data

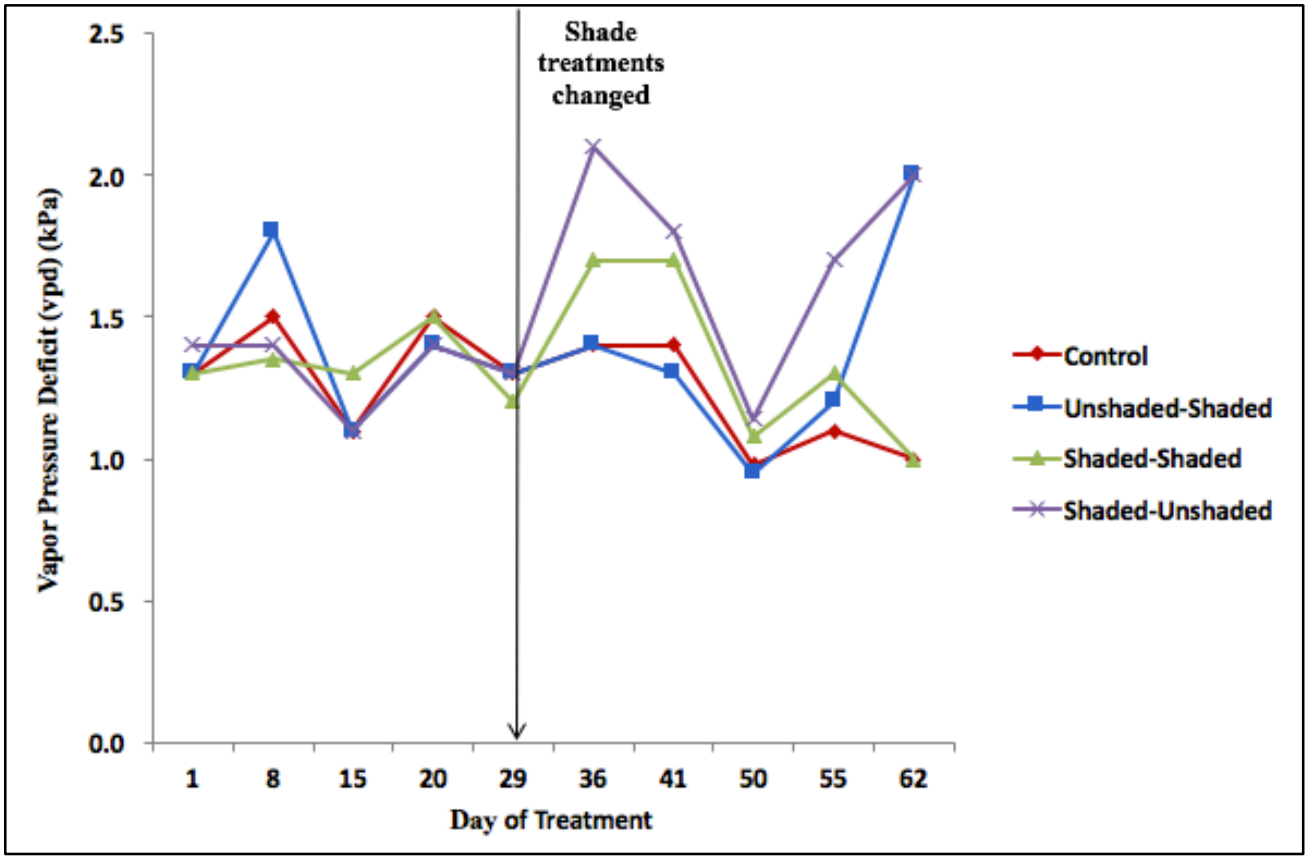
Appendix 8. Vapor pressure deficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

Vapor Pressure Deficiency (VPD) (kPa)

Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	1.3	1.5 a[Z]	1.1 b	1.5	1.3	1.4 b	1.4 bc	0.98 bc	1 b
Unshaded-Shaded	1.3	1.8 ab	1.1 b	1.4	1.3	1.4 b	1.3 c	0.95 c	2 a
Shaded-Shaded	1.3	1.35 c	1.3 a	1.5	1.2	1.7 b	1.7 ab	1.08 ab	1 b
Shaded-Unshaded	1.4	1.4 bc	1.1 b	1.4	1.3	2.1 a	1.8 a	1.14 a	2 a
Prob > F	ns	0.0009	<.0001	ns	ns	<.0001	0.02	0.02	0.0005

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 9. Vapor pressure deficit of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



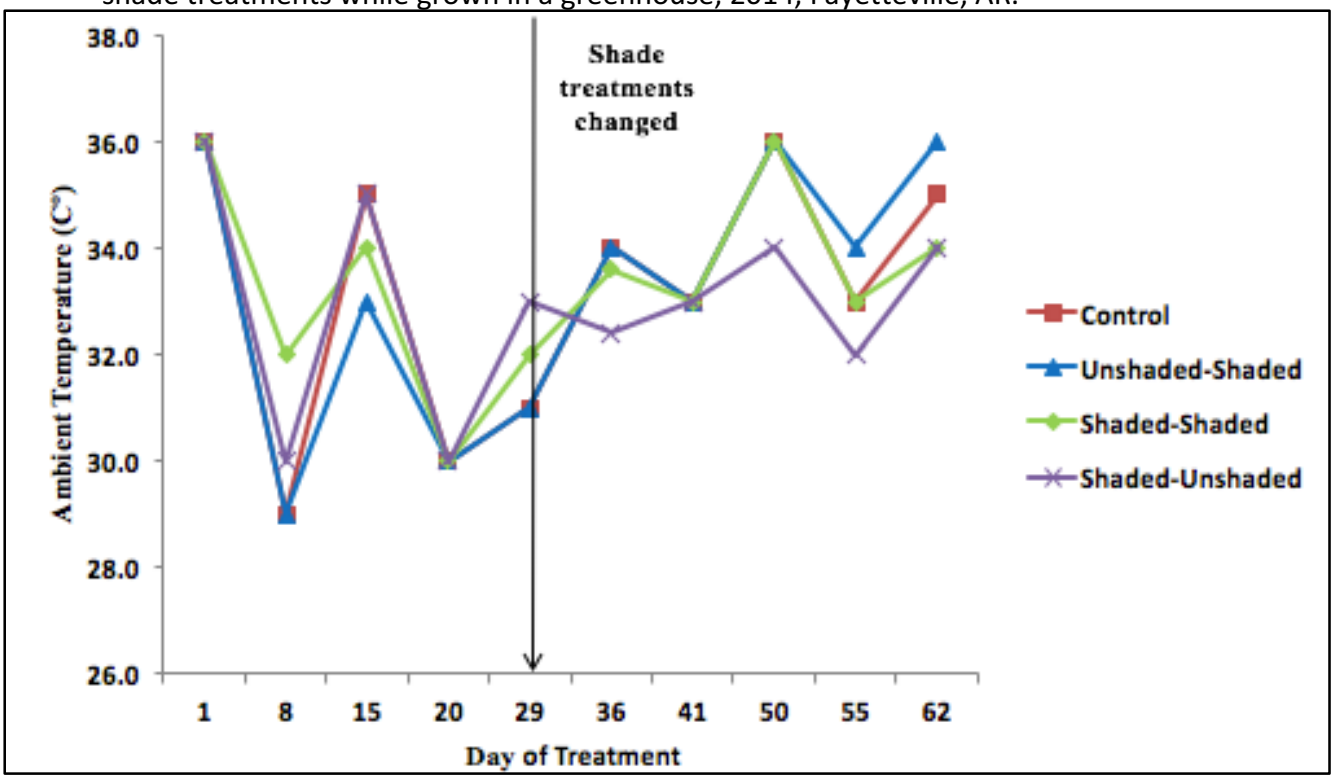
*There are no statistical differences in the figure above.

Appendix 10. Ambient leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

	Ambient Leaf Temperature (°C)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	36	29 c[Z]	35 a	30	31 b	34 a	33	36 a	35 b
Unshaded-Shaded	36	29 c	33 c	30	31 b	34 a	33	36 a	36 a
Shaded-Shaded	36	32 a	34 bc	30	32 b	33.6 ab	33	36 a	34 bc
Shaded-Unshaded	36	30 b	35 ab	30	33 a	32.4 b	33	34 b	34 c
Prob > F	ns	<0.0001	0.0009	ns	0.005	0.04	ns	0.0002	0.001

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 11. Ambient leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences in the table above.

Appendix 12. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)

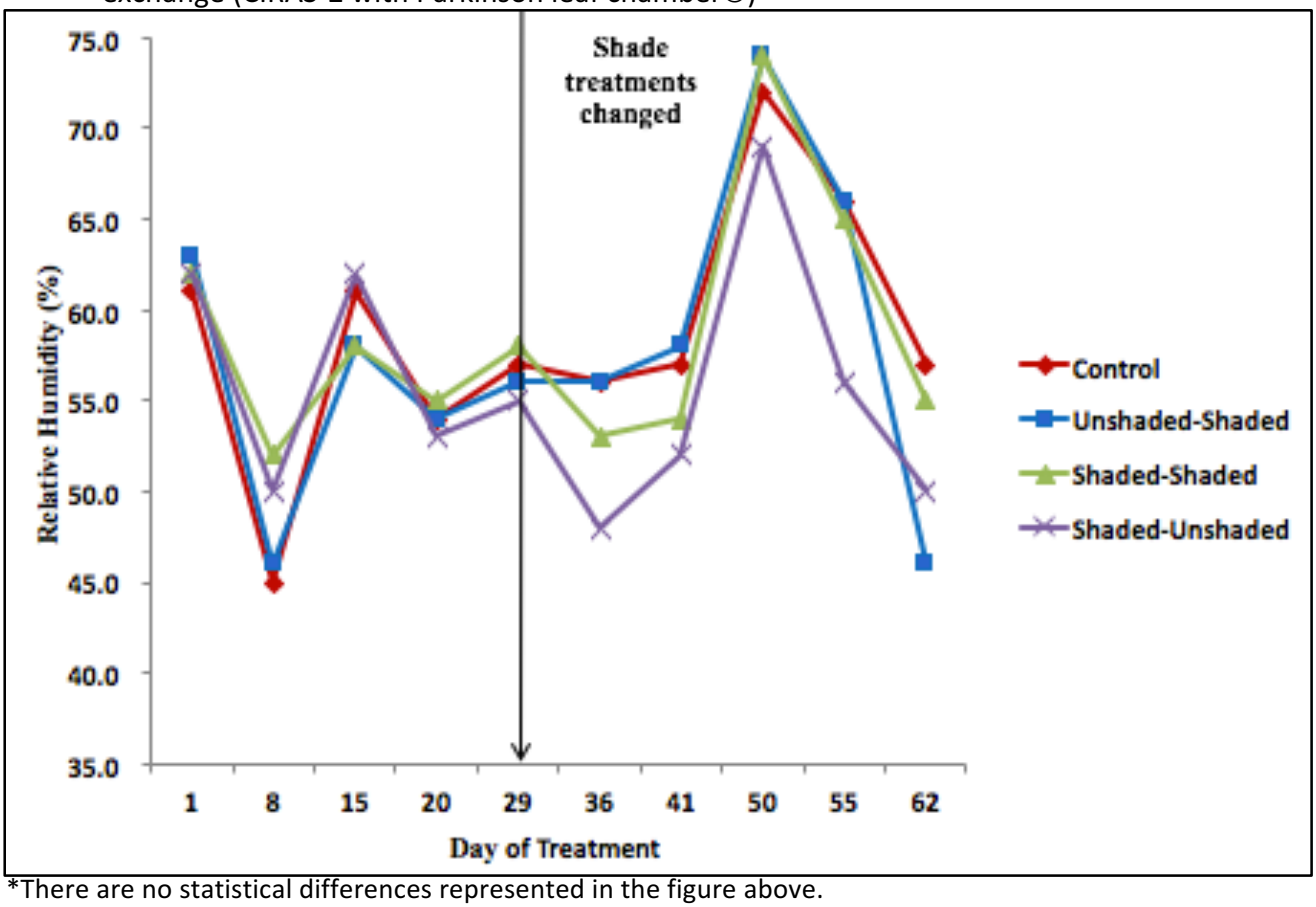
	Relative Humidity (RH) (%)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	61	45 c[Z]	61 a	54	57	56 a	57 ab	72 b	57 a
Unshaded-Shaded	63	46 c	58 b	54	56	56 a	58 a	74 a	46 c
Shaded-Shaded	62	52 a	58 b	55	58	53 a	54 bc	74 a	55 a
Shaded-Unshaded	62	50 b	62 a	53	55	48 b	52 c	69 c	50 b
Prob > F	ns	<0.0001	<0.0001	ns	ns	<0.0001	0.005	<0.0001	<0.0001

[Z]Mean separation followed by different letters are significantly different, α=0.05.

[X]DOT= days of treatment

[Y]DOT = measurements taken without light head

Appendix 13. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®)



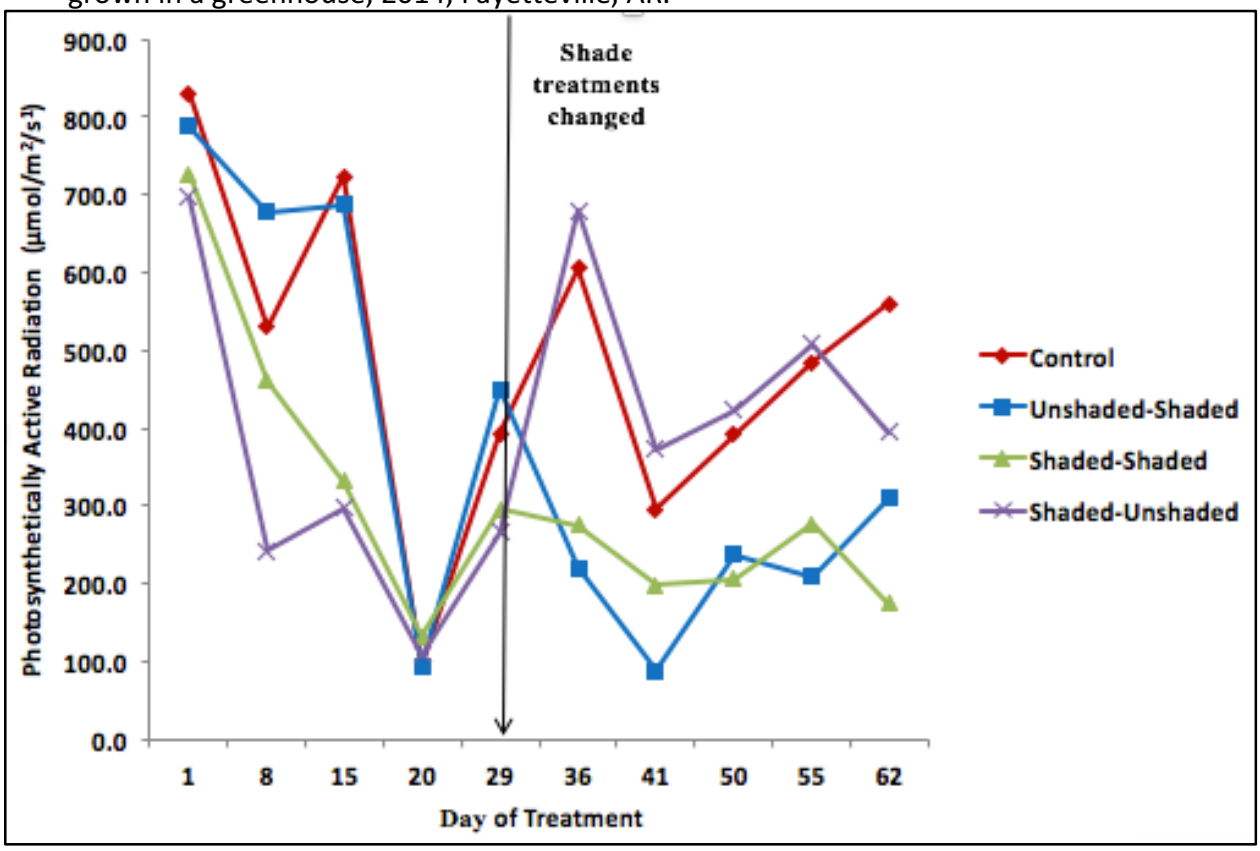
*There are no statistical differences represented in the figure above.

Appendix 14. Photosynthetically active radiation of a single leaf measured at the time of assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

	Photosynthetically active radiation (PAR) (µmol/m^2/s^1)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	831	530	723 a[Z]	95	393 ab	605 a	295 ab	392 a	560 a
Unshaded-Shaded	788	678	688 a	94	450 a	219 b	87 c	237 b	310 b
Shaded-Shaded	726	461	331 b	132	296 b	275 b	197 bc	206 b	174 c
Shaded-Unshaded	697	242	297 b	108	265 b	680 a	373 a	423 a	394 b
Prob > F	ns	0.001	<.0001	ns	0.03	<.0001	0.0002	<.0001	<.0001

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 15. Photosynthetically active radiation of a single leaf measured at the time of assimilation of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences represented in the figure above.

Appendix 16. Leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

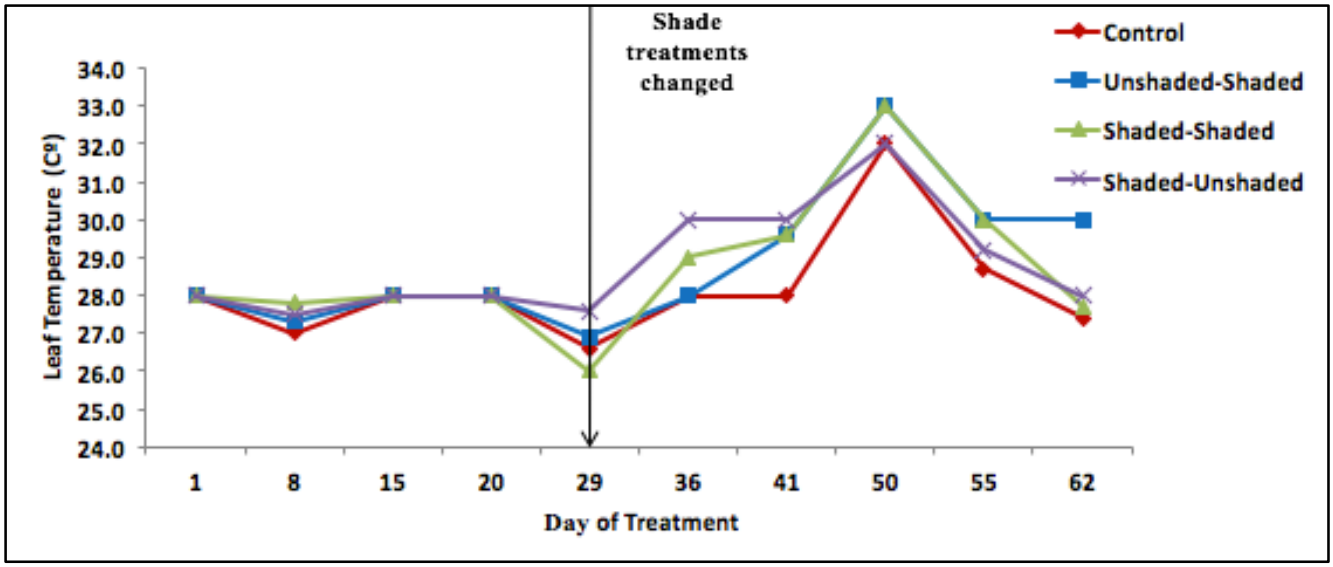
	Leaf Temperature (Tleaf) (°C)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	28	27 c[Z]	28	28	26.6 bc	28 b	28	32 b	27.4 bc
Unshaded-Shaded	28	27.3 b	28	28	26.9 b	28 b	29.6	33 a	30 a
Shaded-Shaded	28	27.8 a	28	28	26 c	29 b	29.6	33 a	27.7 c
Shaded-Unshaded	28	27.5 b	28	28	27.6 a	30 a	30	32 b	28 b
Prob > F	ns	<.0001	ns	ns	0.001	0.006	ns	0.0001	<.0001

[Z]Mean separation followed by different letters are significantly different, α=0.05.

[X]DOT= days of treatment

[Y]DOT = measurements taken without light head

Appendix 17. The leaf temperature of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences represented in the figure above.

Appendix 18. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

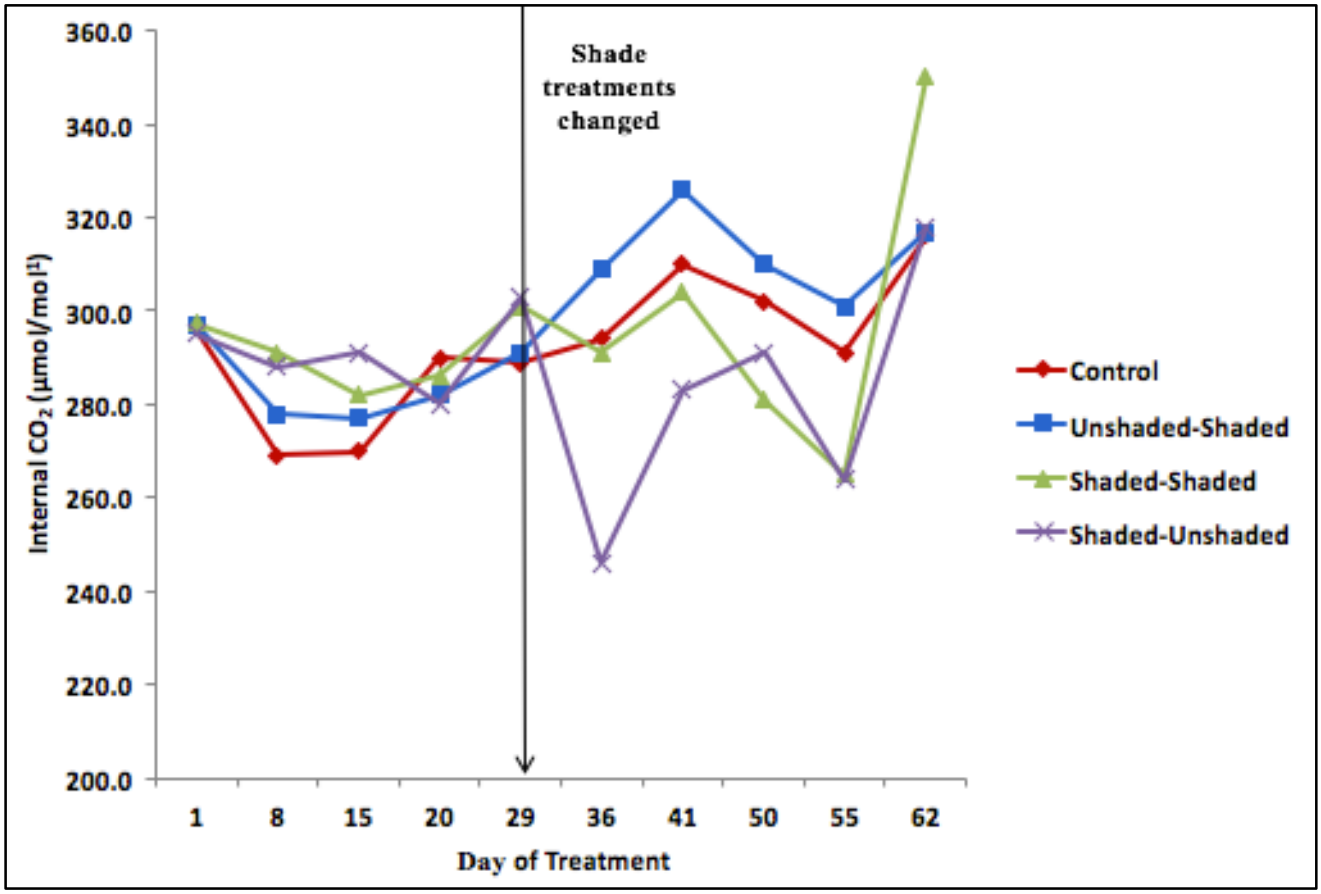
	Internal CO_2 (Ci) (µmol/mol[1])								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	296.3	269 c[Z]	270 c	290	289	294 ab	310 ab	302 ab	316 b
Unshaded-Shaded	297.1	278 bc	277 bc	282	291	309 a	326 a	310 a	317 b
Shaded-Shaded	297.5	291 a	282 b	286	301	291 b	304 b	281 c	350 a
Shaded-Unshaded	295.3	288 ab	291 a	280	303	246 c	283 c	291 bc	318 b
Prob > F	ns	0.006	<.0001	ns	ns	<.0001	0.0003	0.0007	0.0002

[Z]Mean separation followed by different letters are significantly different, α=0.05.

[X]DOT= days of treatment

[Y]DOT = measurements taken without light head

Appendix 19. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



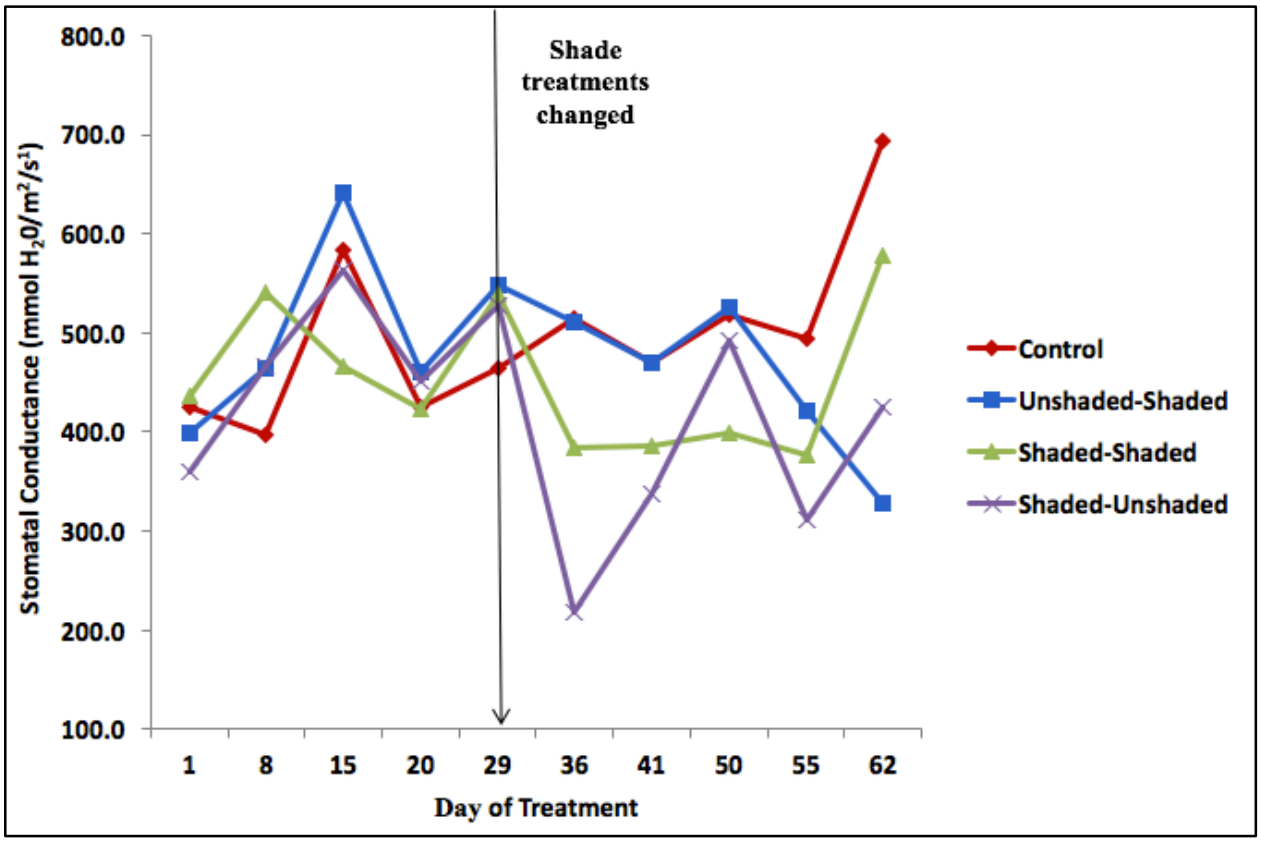
*There are no statistical differences represented in the figure above.

Appendix 20. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

	Stomatal Conductance (gs) (mmol $H_20/m^2/s^1$)								
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	424.7	398 c[Z]	583 ab	426	465	515 a	469	519 a	694 a
Unshaded-Shaded	398.3	465 b	642 a	460	548	510 a	470	525 a	329 c
Shaded-Shaded	435.5	541 a	466 c	423	539	384 b	386	399 b	578 ab
Shaded-Unshaded	360.7	467 b	564 b	452	528	219 c	338	493 a	426 bc
Prob > F	ns	0.0005	0.0002	ns	ns	<.0001	ns	0.03	0.003

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOT= days of treatment
[Y]DOT = measurements taken without light head

Appendix 21. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences represented in the figure above.

Appendix 22. Foliar water use efficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014.

Water Use Efficiency (WUE) (mmol CO_2/ mol[1] CO_2)

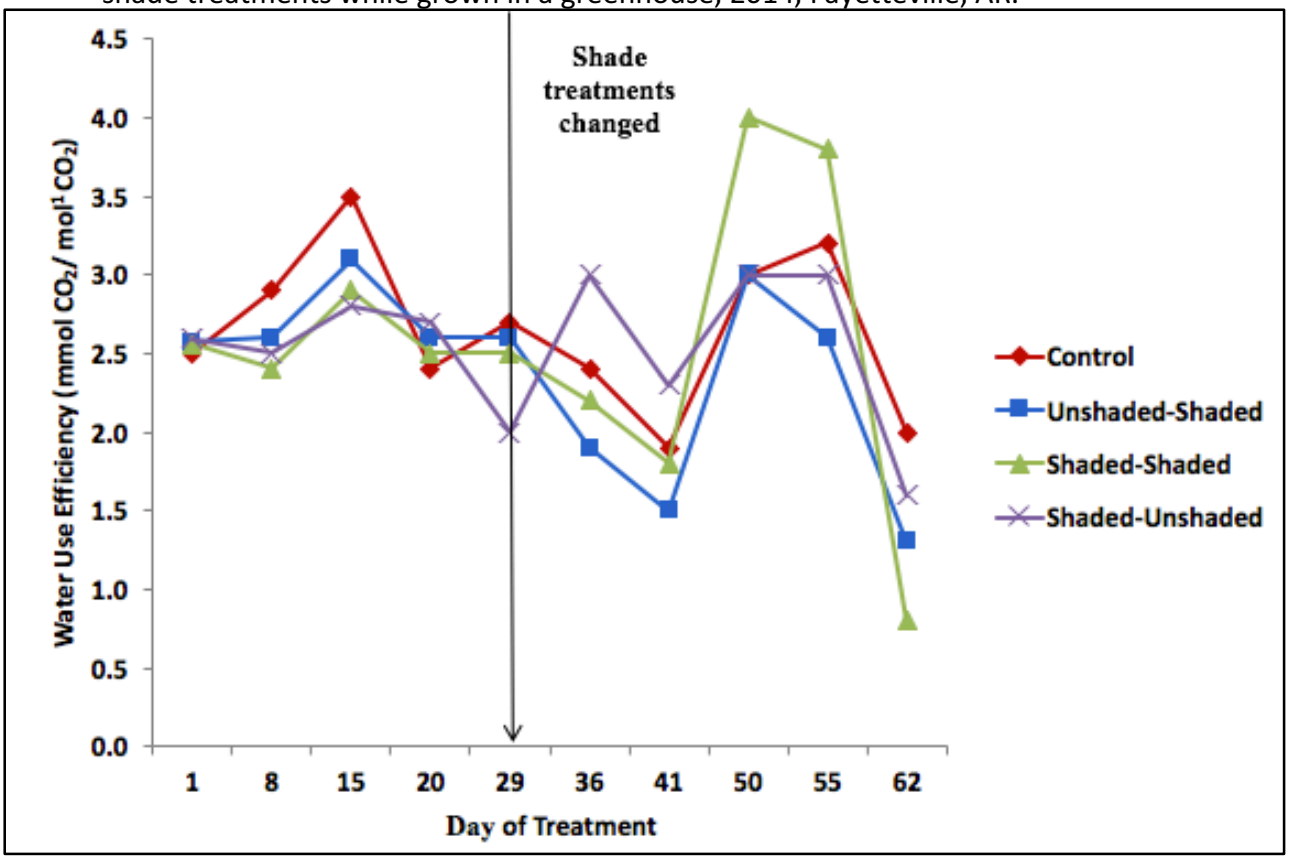
Treatment	DOT 1[X]	DOT 8	DOT 15	DOT 20	DOT 29	DOT 36	DOT 41	DOT 50	DOT 55[Y]
Control	2.5	2.9 a[Z]	3.5 a	2.4	2.7 a	2.4 b	1.9 b	3 b	2 a
Unshaded-Shaded	2.6	2.6 b	3.1 b	2.6	2.6 a	1.9 c	1.5 c	3 b	1.3 bc
Shaded-Shaded	2.6	2.4 b	2.9 bc	2.5	2.5 a	2.2 bc	1.8 bc	4 a	0.8 c
Shaded-Unshaded	2.6	2.5 b	2.8 c	2.7	2 b	3 a	2.3 a	3 b	1.6 b
Prob > F	ns	0.009	<.0001	ns	0.003	<.0001	0.0004	0.001	<.0001

[Z]Mean separation followed by different letters are significantly different, α=0.05.

[X]DOT= days of treatment

[Y]DOT = measurements taken without light head

Appendix 23. Foliar water use efficiency of 'Prime-Ark® 45' blackberry as affected by four shade treatments while grown in a greenhouse, 2014, Fayetteville, AR.



*There are no statistical differences represented in the figure above.

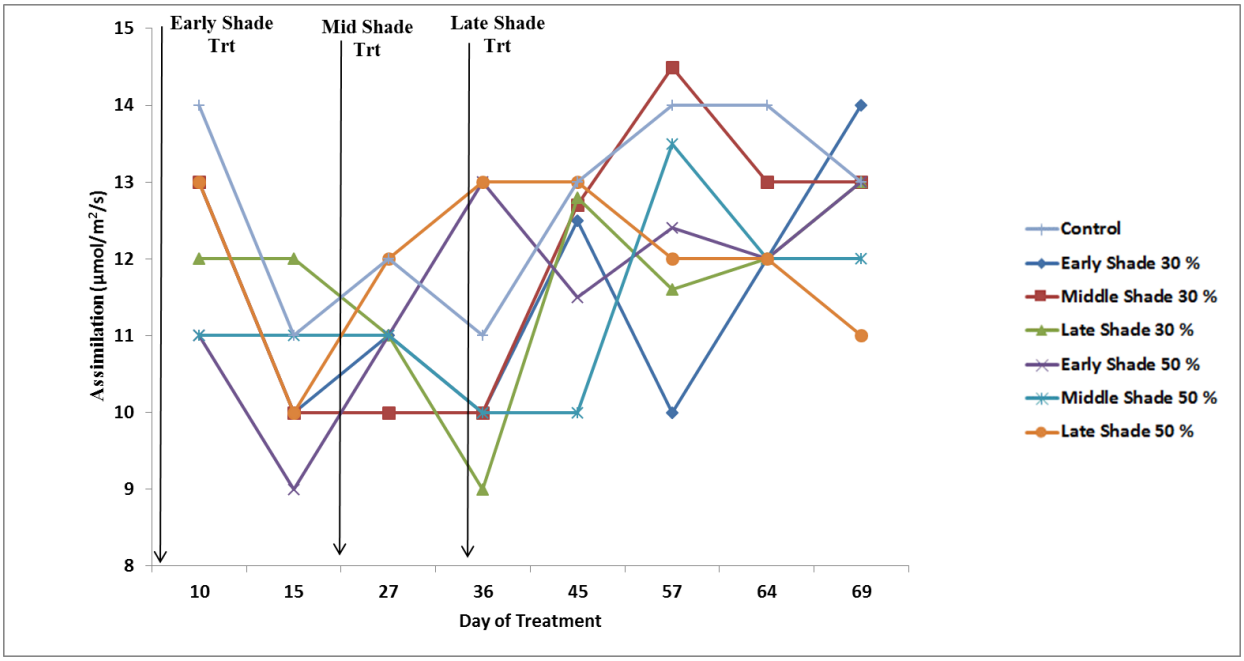
Appendices: Field Tables and Figures

Appendix 24. Assimilation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

	Assimilation (A) (µmol/m^2/s^1)							
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	14	11	12	11	13	14 ab[Z]	14	13
Early Shade 30%	13	10	11	10	12.5	10 c	12	14
Middle Shade 30%	13	10	10	10	12.7	14.5 a	13	13
Late Shade 30%	12	12	11	9	12.8	11.6 bc	12	13
Early Shade 50%	11	9	11	13	11.5	12.4 abc	12	13
Middle Shade 50%	11	11	11	10	10	13.5 ab	12	12
Late Shade 50%	13	10	12	13	13	12 abc	12	11
Prob > F	ns	ns	ns	ns	ns	0.05	ns	ns

[Z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD. Means followed by dif ferent letters are statistically different from one another ($\alpha < 0.05$, n = 5).
[X]DOT= days of treatment

Appendix 25. Assimilation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



*There are no statistical difference represented in the figure above.

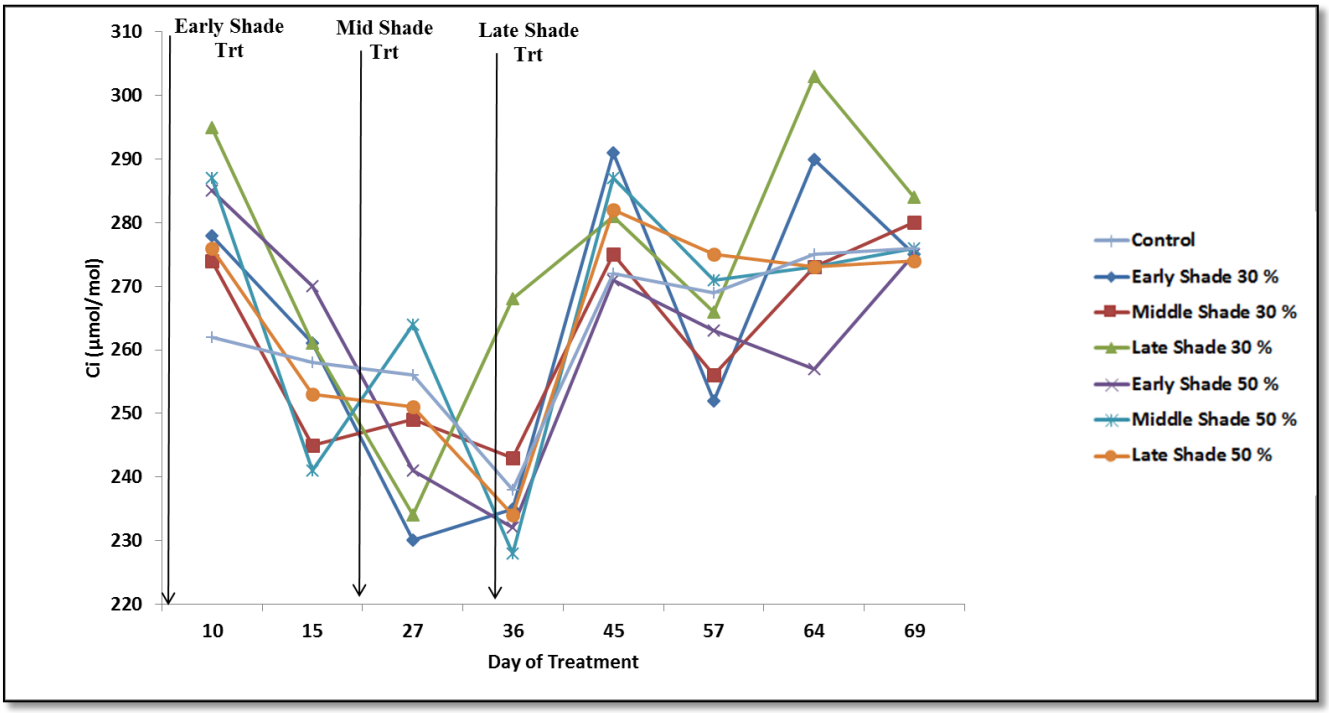
Appendix 26. Internal CO_2 concentrations of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

	Internal CO_2 (Ci) (µmol/mol[1])							
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	262*	258	256	238	272	269	275	276
Early Shade 30%	278	261	230	235	291	252	290	275
Middle Shade 30%	274	245	249	243	275	256	273	280
Late Shade 30%	295	261	234	268	281	266	303	284
Early Shade 50%	285	270	241	232	271	263	257	275
Middle Shade 50%	287	241	264	228	287	271	273	276
Late Shade 50%	276	253	251	234	282	275	273	274
Prob > F	ns	ns	ns	ns	ns	ns	ns	ns

*There are no statistical differences represented in the figure above.

[X]DOT= days of treatment

Appendix 27. Internal CO_2 concentrations of 'Prime-Ark® 45' as affected by seven shade treatments while grown in a field experiment, 2014.



*There are no statistical differences represented in the figure above.

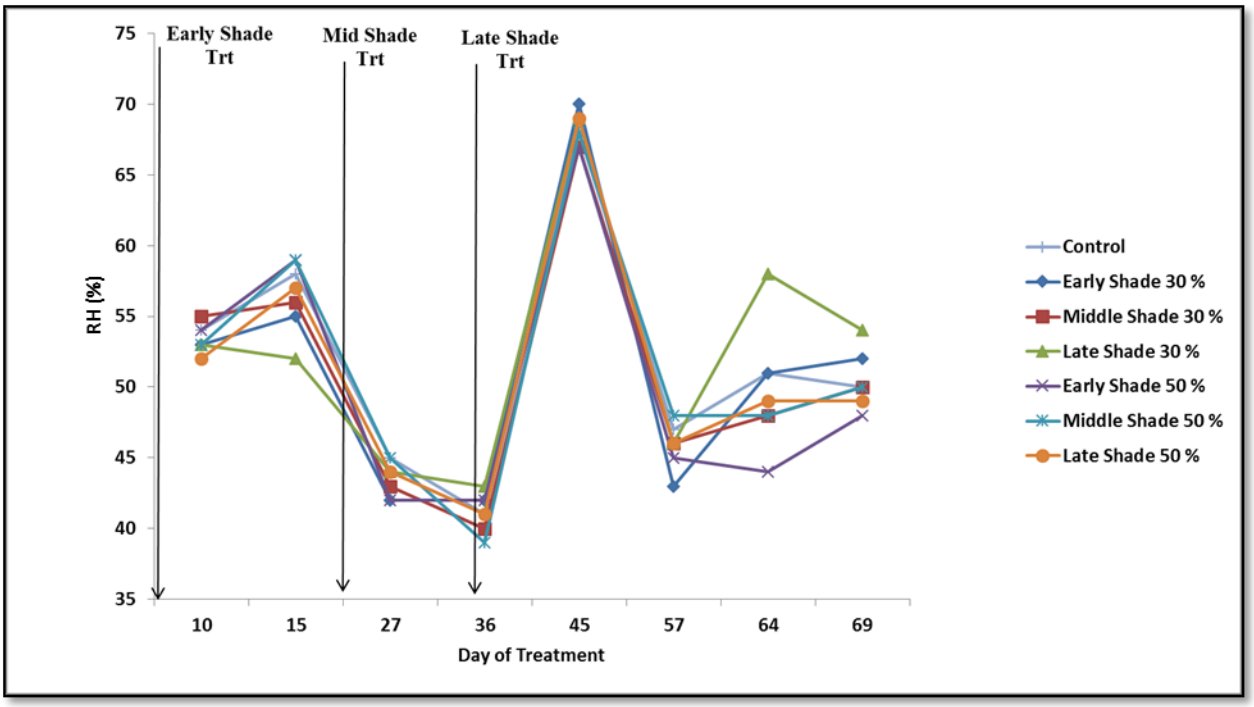
Appendix 28. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®).

	Relative humidity (RH) (%)							
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	54*	58	45	41	68	47	51	50
Early Shade 30%	53	55	42	42	70	43	51	52
Middle Shade 30%	55	56	43	40	67	46	48	50
Late Shade 30%	53	52	44	43	69	46	58	54
Early Shade 50%	54	59	42	42	67	45	44	48
Middle Shade 50%	53	59	45	39	68	48	48	50
Late Shade 50%	52	57	44	41	69	46	49	49
Prob > F	ns	ns	ns	ns	ns	ns	ns	ns

*There are no statistical differences represented in the figure above.

[X]DOT= days of treatment

Appendix 29. Chamber relative humidity of a leaf of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014, while measuring gas exchange (CIRAS-2 with Parkinson leaf chamber®).



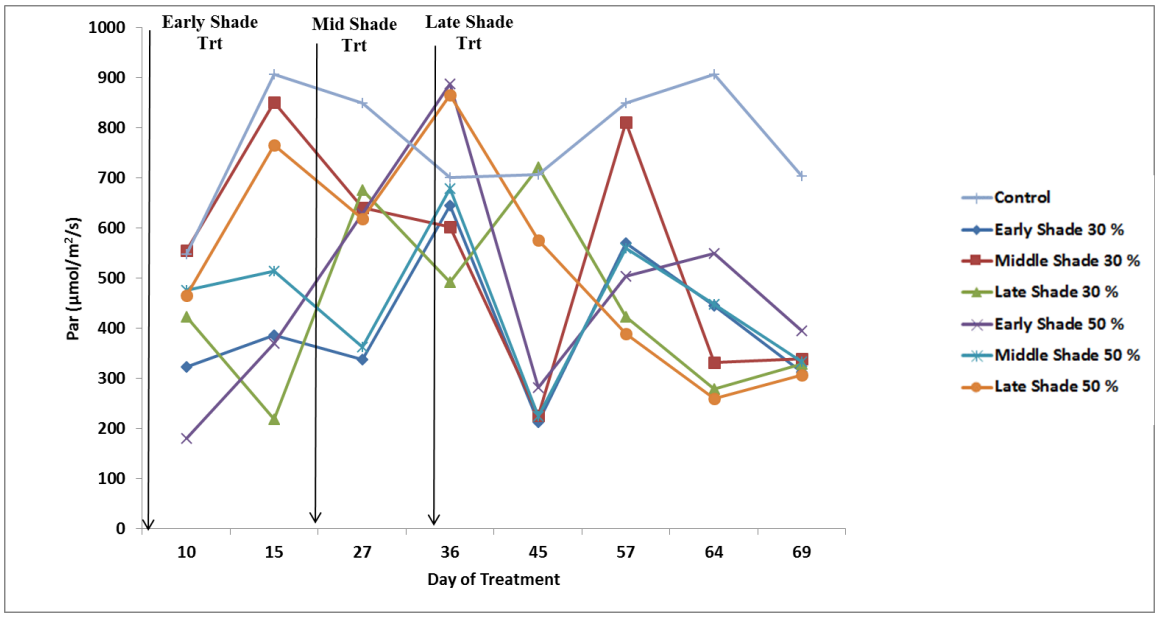
*There are no statistical differences represented in the figure above.

Appendix 30. Photosynthetically active radiation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

Photosynthetically active radiation (PAR) (µmol/m^2/s^1)								
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	548	907	849	700	706	849	906 a[Z]	703
Early Shade 30%	322	386	338	644	213	570	445 b	313
Middle Shade 30%	555	850	641	602	226	811	331 b	339
Late Shade 30%	423	218	676	492	721	422	279 b	329
Early Shade 50%	180	370	628	887	282	503	549 ab	395
Middle Shade 50%	475	514	362	678	224	560	447 b	333
Late Shade 50%	466	766	618	865	576	389	259 b	306
Prob > F	ns	ns	ns	ns	ns	ns	0.03	ns

[Z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD.
Means followed by different letters are statistically different from one another ($\alpha < 0.05$, n = 5).
[X]DOT= days of treatment

Appendix 31. Photosynthetically active radiation of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



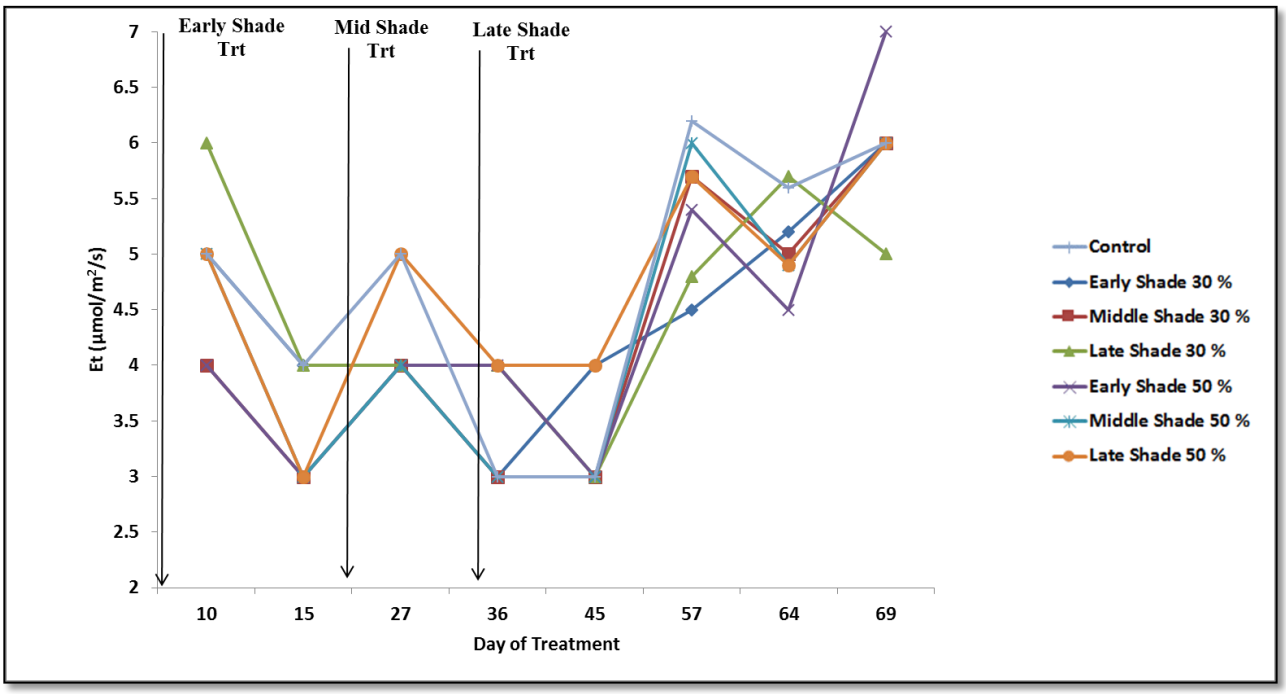
*There are no statistical differences represented in the figure above.

Appendix 32. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

	Evapotranspiration (Et) (μmol H_20/ m^2/s^1)							
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	5	4	5	3	3	6.2 a[Z]	5.6 ab	6
Early Shade 30%	5	4	4	3	4	4.5 c	5.2 abc	6
Middle Shade 30%	4	3	4	3	3	5.7 ab	5 abc	6
Late Shade 30%	6	4	4	4	3	4.8 bc	5.7 a	5
Early Shade 50%	4	3	4	4	3	5.4 abc	4.5 c	7
Middle Shade 50%	5	3	4	3	3	6.0 a	4.9 bc	6
Late Shade 50%	5	3	5	4	4	5.7 ab	4.9 bc	6
Prob > F	ns	ns	ns	ns	ns	0.04	0.05	ns

[Z] Mean comparisons among treatments were calculated using SAS Proc GLM LSD. Means followed by dif ferent letters are statistically different from one another ($\alpha < 0.05$, n = 5).
[X]DOT= days of treatment

Appendix 33. Evapotranspiration of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



*There are no statistical difference represented in the figure above.

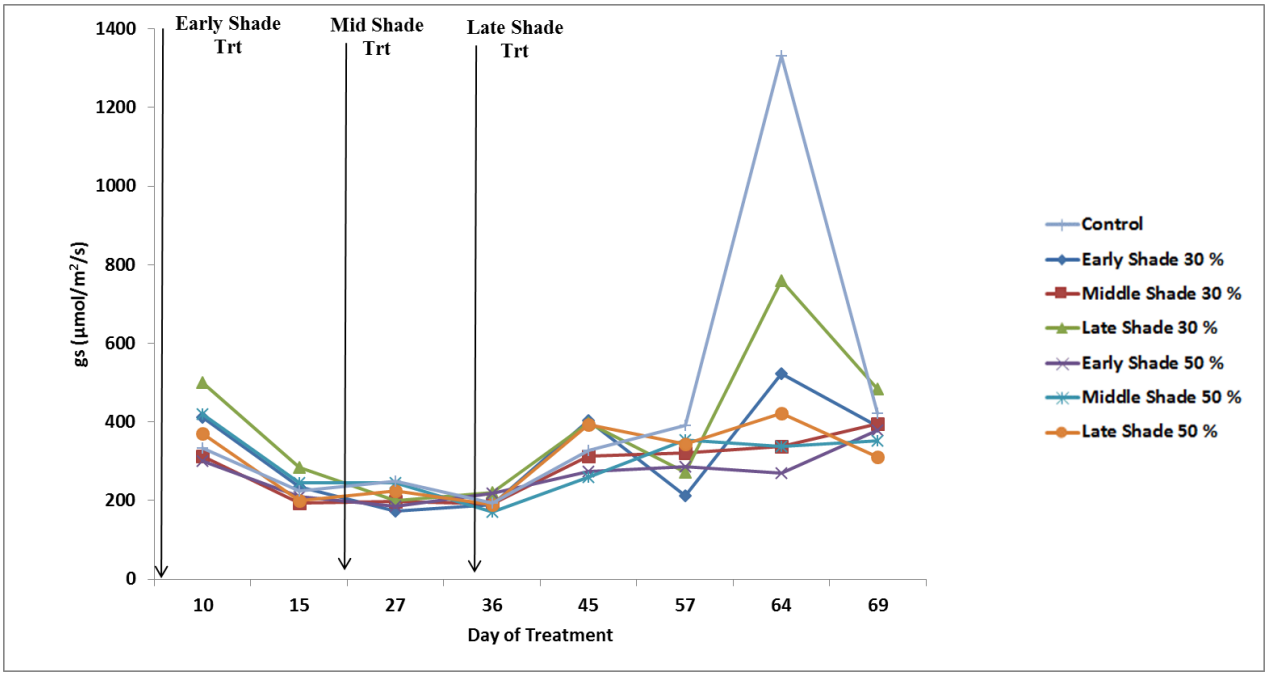
Appendix 34. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.

Stomatal Conductance (gs) (μmol H_20/ m^2/s^1)								
Treatment	DOT 10[X]	DOT 15	DOT 27	DOT 36	DOT 45	DOT 57	DOT 64	DOT 69
Control	334*	224	250	193	327	392 a[Z]	1331	422
Early Shade 30%	412	234	174	190	404	212 c	522	389
Middle Shade 30%	312	194	198	192	313	322 abc	338	395
Late Shade 30%	500	284	200	220	397	271 bc	759	484
Early Shade 50%	300	210	185	219	273	286 abc	269	379
Middle Shade 50%	419	244	246	171	259	355 ab	338	352
Late Shade 50%	370	200	224	189	394	344 ab	421	311
Prob > F	ns	ns	ns	ns	ns	ns	ns	ns

*There are no statistical difference represented in the table above.

[X]DOT= days of treatment

Appendix 35. Stomatal conductance of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



*There are no statistical difference represented in the figure above.

Appendix 36. Total berry weight by day of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

	Total Berry Weight (g)													
Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22	DOH 26	DOH 29	DOH 33	DOH 36	DOH 40	DOH 43	DOH 50
Control	34	27	48	63	192 a[Z]	371	135 abc	246	144	111	67	48	28	30 b
Early Shade 30%	31	43	24	70	83 c	213	57 c	117	86	109	51	37	28	19 b
Middle Shade 30%	4	30	33	48	117 bc	284	95 c	150	86	59	36	23	8	25 b
Late Shade 30%	18	50	38	121	164 ab	443	222 a	252	148	143	90	74	40	102 a
Early Shade 50%	37	28	45	81	95 bc	251	77 c	119	71	104	57	32	29	37 b
Middle Shade 50%	27	25	56	94	136 abc	323	122 bc	156	80	104	48	52	21	56 ab
Late Shade 50%	43	61	29	100	157 ab	403	189 ab	283	168	199	107	82	36	54 b
Prob > F	ns	ns	ns	ns	0.05	ns	0.01	ns	ns	ns	ns	ns	ns	0.02

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOH= day of harvest

Appendix 37. Cumulative yield berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014. Numbers in parenthesis represented percent of the control.

Treatment	Cumulative Yield Berry Weight (g)
Control	1124*
Early Shade 30%	739 (65.7)
Middle Shade 30%	713 (63.4)
Late Shade 30%	1296 (115.3)
Early Shade 50%	773 (68.7)
Middle Shade 50%	892 (79.4)
Late Shade 50%	1411 (125.5)

*There are no statistical differences represented in the table above.

Appendix 38. Total average total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

Total Average Berry Weight (g)

Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22
Control	3.8*	5	4.2	4	4.7	5	5.2
Early Shade 30%	5.6	5	5.3	4.4	4.5	5.3	4.8
Middle Shade 30%	5.3	5	5.2	5	5.1	5.2	4.8
Late Shade 30%	4.3	5	5	5.2	5	5.5	4.9
Early Shade 50%	5.6	6	4.6	4.9	5	5.4	5.3
Middle Shade 50%	4.8	6	5.2	4.8	5.3	6.2	4.6
Late Shade 50%	4.8	6	5	4.8	5.3	5.2	4.9
Prob > F	ns	ns	ns	ns	ns	ns	ns

*There are no statistical differences represented in the figure above.
[X]DOH= day of harvest

Appendix 39. Total marketable berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

	Total Marketable Berry Weight (g)						
Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22
Control	14	23	34	38	140	253	86 abc[Z]
Early Shade 30%	30	26	14	39	59	112	32 c
Middle Shade 30%	5	7	22	28	85	161	51 bc
Late Shade 30%	7	27	29	92	130	244	128 a
Early Shade 50%	24	16	31	58	72	143	55 bc
Middle Shade 50%	22	26	42	60	109	166	67 bc
Late Shade 50%	30	32	21	62	100	234	100 ab
Prob > F	ns	ns	ns	ns	ns	ns	0.05

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOH= day of harvest

Appendix 40. Total percentage of marketable weight out of total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

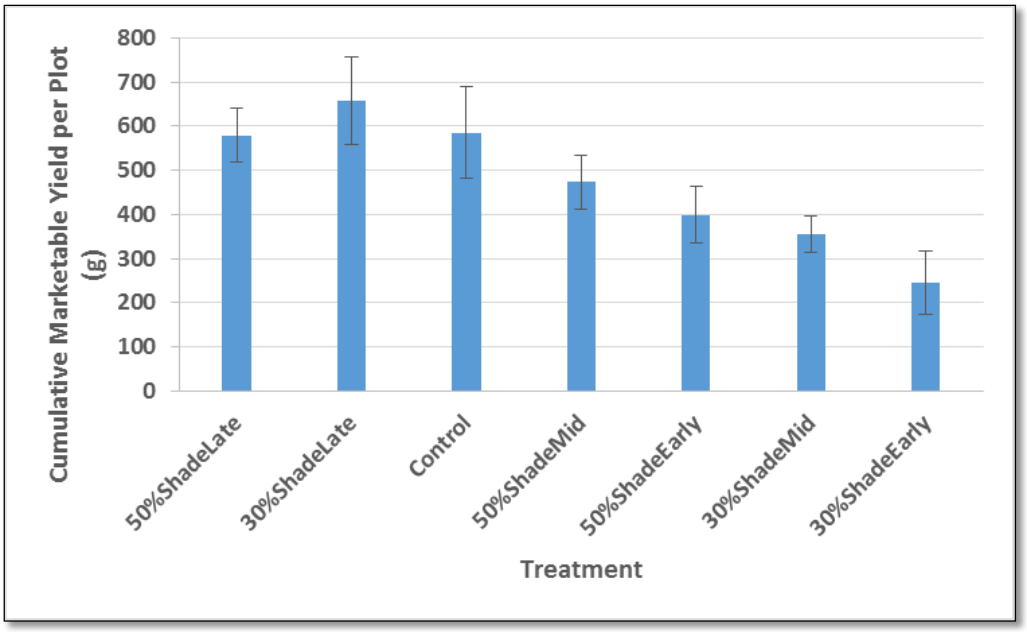
Total Percent Marketable Weight of Total Berry Weight (%)

Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22
Control	43*	79	65	61	70	68	62
Early Shade 30%	71	56	52	57	71	55	54
Middle Shade 30%	53	28	66	53	71	54	50
Late Shade 30%	57	53	74	75	80	55	57
Early Shade 50%	66	45	64	66	75	58	66
Middle Shade 50%	64	50	79	62	80	52	55
Late Shade 50%	64	44	56	62	65	56	54
Prob > F	ns	ns	ns	ns	ns	ns	ns

*There are no statistical differences represented in the figure above.

[X]DOH= day of harvest

Appendix 41. Cumulative marketable yield weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in the field experiment, 2014.



*Error bars represent standard error from the mean (n=5).

Appendix 42. Total culled berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

	Total Culled Berry Weight (g)						
Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22
Control	20	10	14	24	52 ab[Z]	119	49 c
Early Shade 30%	11	17	10	31	25 c	101	26 c
Middle Shade 30%	5	23	11	20	31 bc	123	45 c
Late Shade 30%	11	23	9	30	34 bc	200	94 a
Early Shade 50%	12	11	15	23	23 c	107	23 c
Middle Shade 50%	22	15	14	33	27 c	158	56 bc
Late Shade 50%	13	30	8	38	57 a	170	89 ab
Prob > F	ns	ns	ns	ns	0.01	ns	0.03

[Z]Mean separation followed by different letters are significantly different, α=0.05.
[X]DOH= day of harvest

Appendix 43. Total percentage of culled weight out of total berry weight by harvest date of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

Total Culled Weight of Total Berry Weight (%)							
Treatment	DOH 1[X]	DOH 5	DOH 8	DOH 12	DOH 15	DOH 20	DOH 22
Control	57*	21	35	39	30	32	38
Early Shade 30%	29	44	48	44	29	46	46
Middle Shade 30%	48	72	34	48	29	45	50
Late Shade 30%	43	47	26	25	20	45	43
Early Shade 50%	34	55	36	34	25	42	34
Middle Shade 50%	36	50	21	38	20	48	45
Late Shade 50%	36	56	44	38	35	44	46
Prob > F	ns	ns	ns	ns	ns	ns	ns

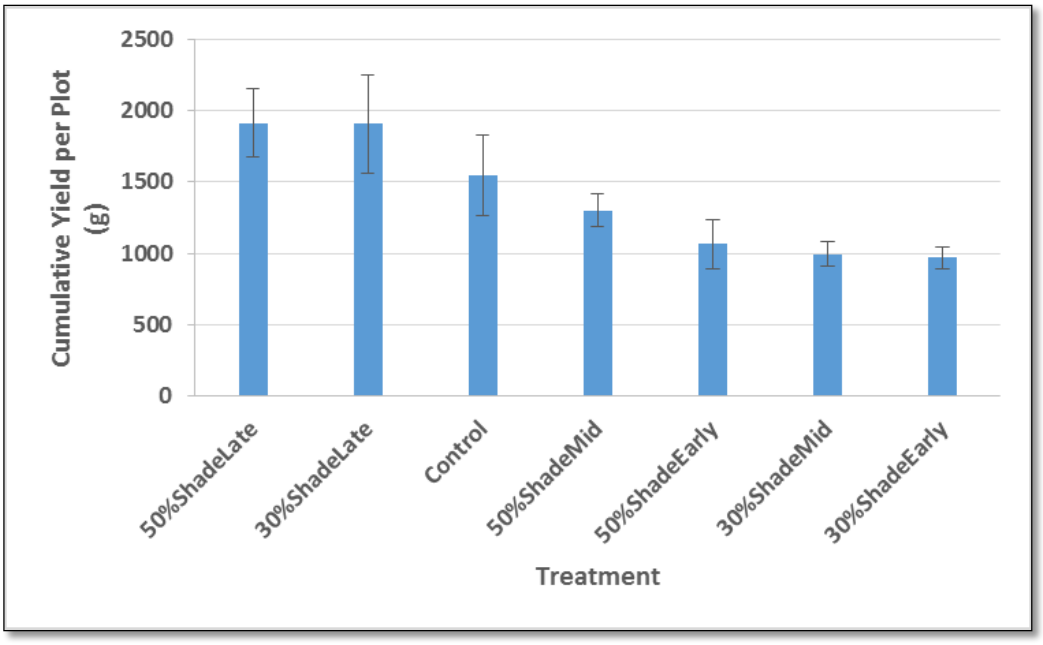
*There are no statistical differences represented in the figure above.
[X]DOH= day of harvest

Appendix 44. Cumulative culled berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

Treatment	Cumulative Culled Yield (g)	SE
Control	49*	42
Early Shade 30%	26	123
Middle Shade 30%	49	21
Late Shade 30%	94	116
Early Shade 50%	23	116
Middle Shade 50%	56	42
Late Shade 50%	89	83
Prob > F	ns	

*There are no statistical differences represented in the figure above.

Appendix 45. Cumulative culled berry weight across all days of harvest of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



*Error bars represent standard error from the mean (n=5).

Appendix 46. Berry 25 count of brix's or soluble solids (estimated sugar content) of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

Brix's or Soluble Solids (estimated sugar content)		
Treatment	DOH 15[X]	DOH 29
Control	11.6*	7.9
Early Shade 30%	10.7	7.6
Middle Shade 30%	11.3	8.5
Late Shade 30%	10.8	6.3
Early Shade 50%	11.4	7.1
Middle Shade 50%	11.7	7.4
Late Shade 50%	10.8	6.5
Prob > F	ns	ns

*There are no statistical differences represented in the table above.

[X]DOH= Day of Harvest

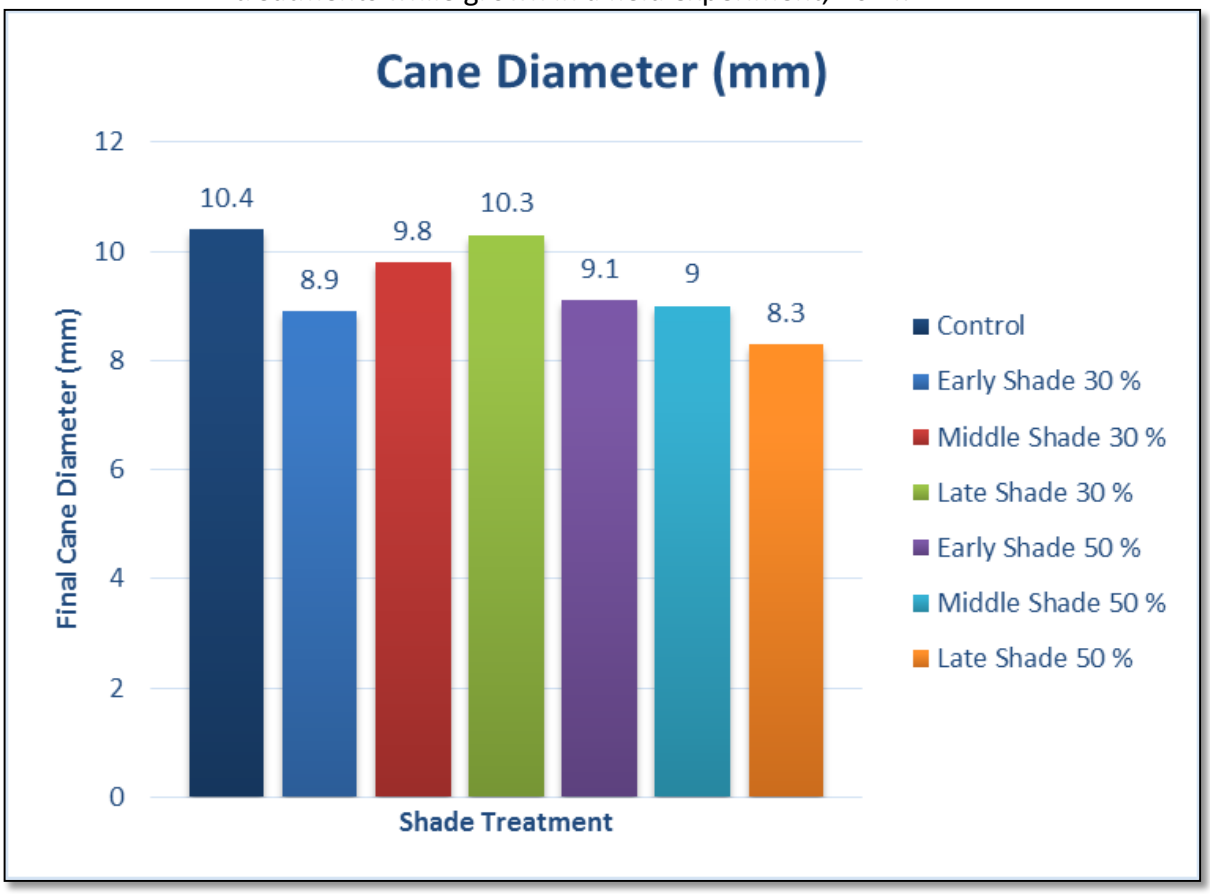
Appendix 47. Final destructive cane analysis of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.

Field Destructive Cane Analysis

Treatment	Cane Diameter (mm)	Shoot Length (cm)	Node Number (No.)	Length between Nodes (cm)	Number of Lateral Branches (No.)	Number of Fruit Clusters (No.)
Control	10.4*	130	18.8	7	1.9	0.5
Early Shade 30%	8.9	124	17.4	7.3	2	0.5
Middle Shade 30%	9.8	115	17.4	6.7	2.2	0.8
Late Shade 30%	10.3	127	17.7	8	2.7	1.3
Early Shade 50%	9.1	123	16.2	7.7	1.6	0.6
Middle Shade 50%	9	127	18.9	6.9	1.6	0.1
Late Shade 50%	8.3	113	14.6	8.1	1.4	0.4
Prob > F	ns	ns	ns	ns	ns	ns

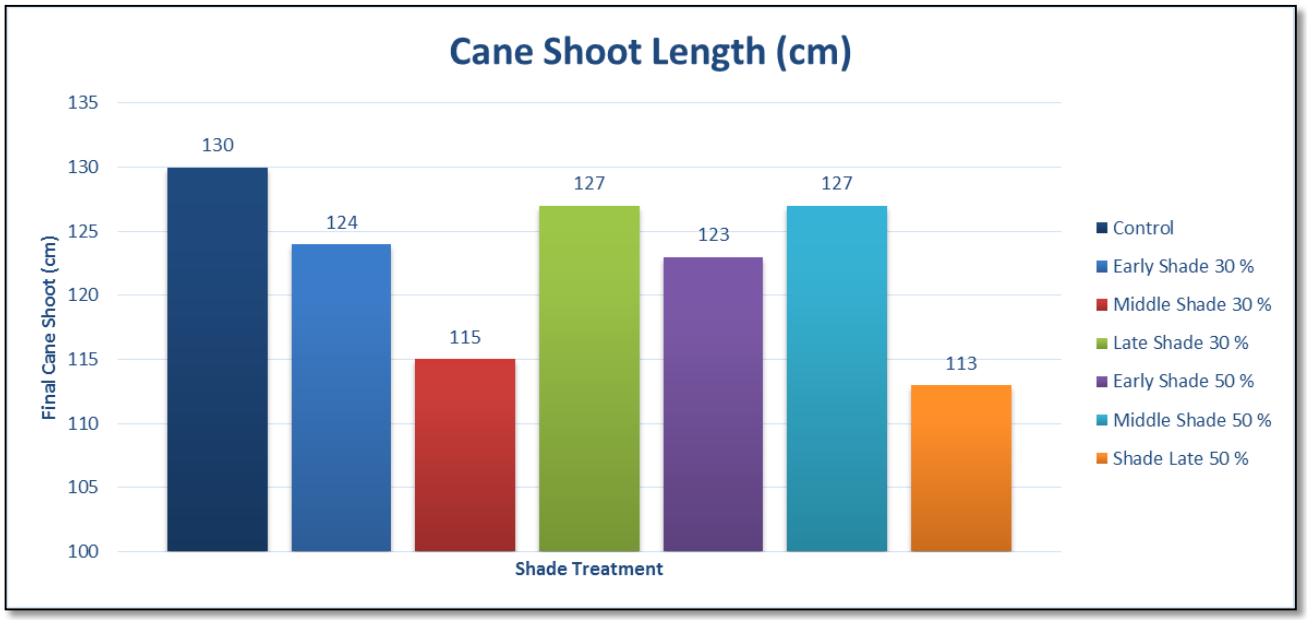
*There are no statistical differences represented in the figure above.

Appendix 48. Cane diameter of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



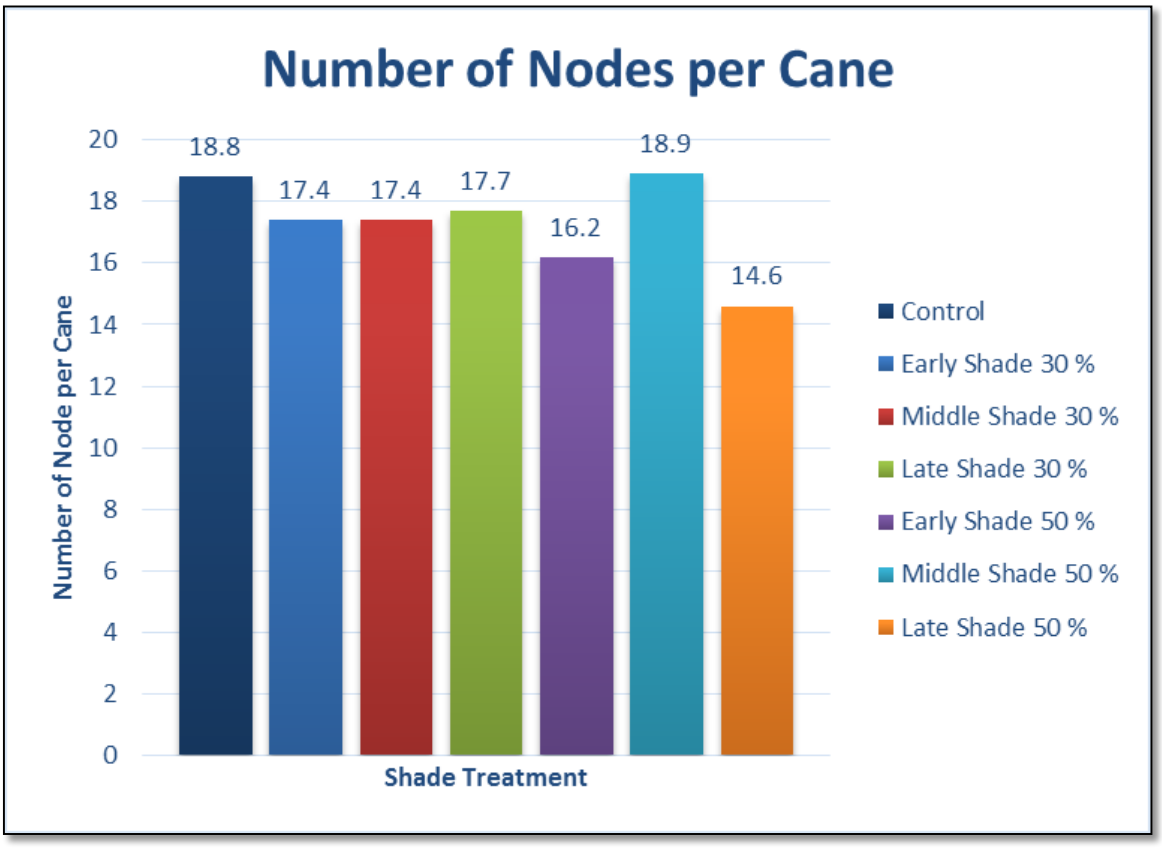
*There are no statistical differences represented in the figure above.

Appendix 49. Cane shoot length of ‘Prime-Ark® 45’ blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



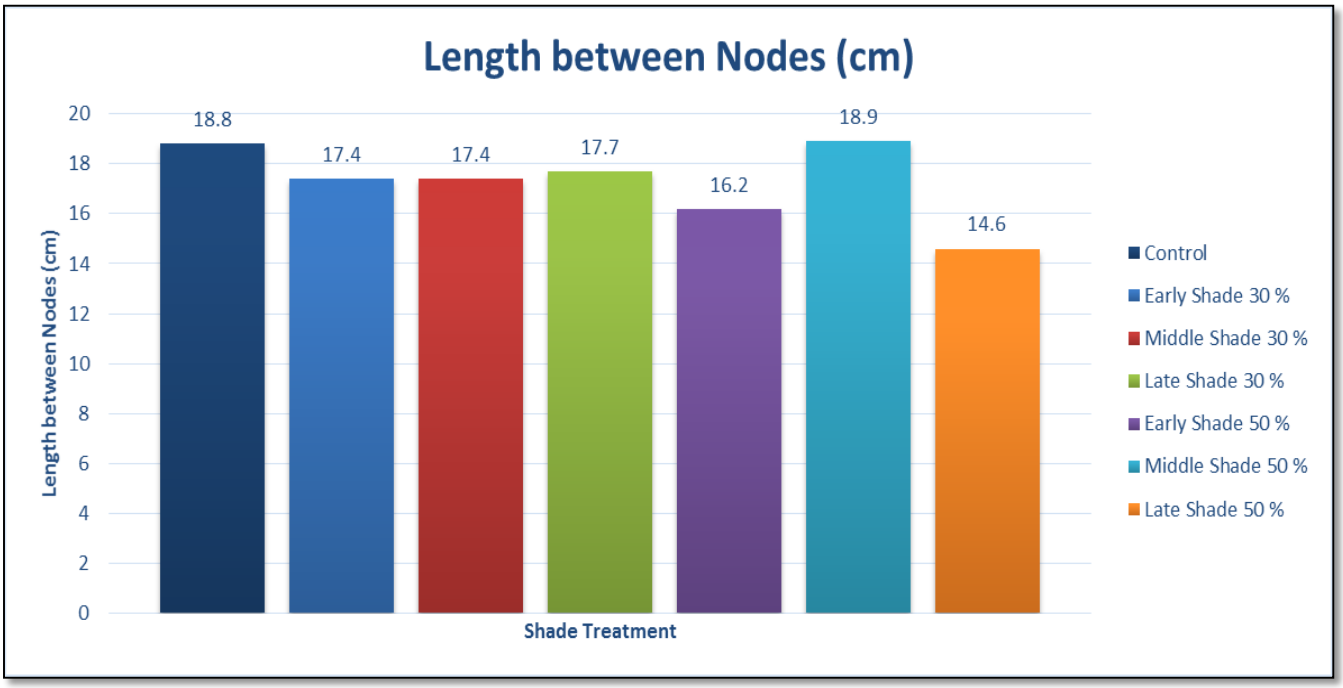
*There are no statistical differences represented in the figure above.

Appendix 50. Number of nodes per cane of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



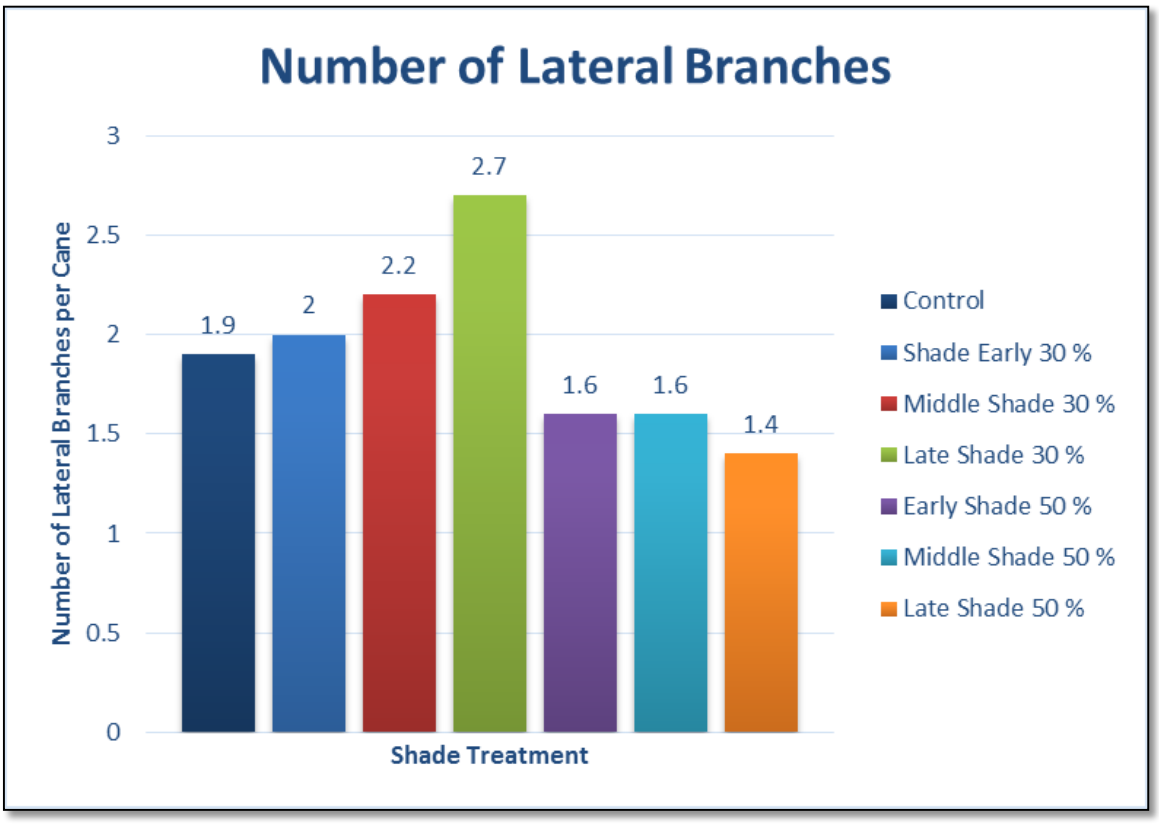
*There are no statistical differences represented in the figure above.

Appendix 51. Length between nodes of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



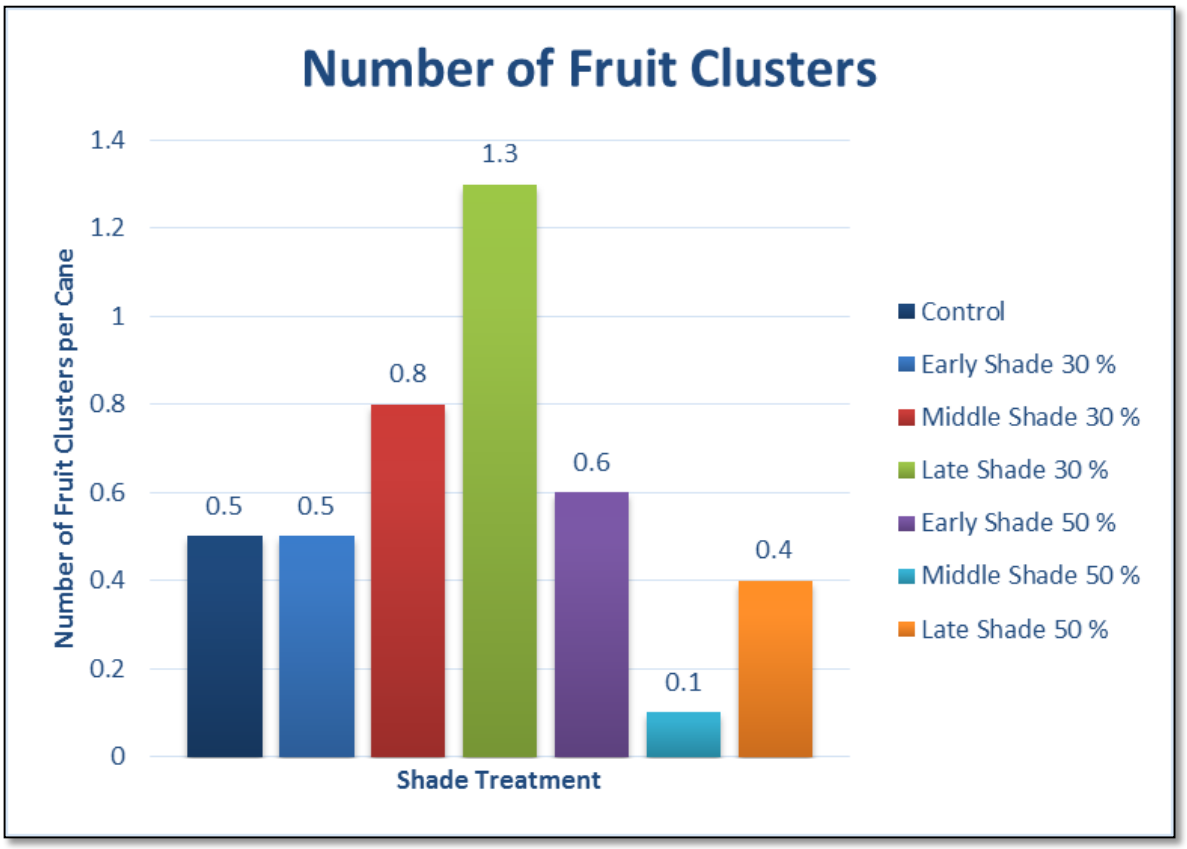
*There are no statistical differences represented in the figure above.

Appendix 52. Number of lateral branches per cane of 'Prime-Ark® 45' blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



*There are no statistical differences represented in the figure above.

Appendix 53. Number of fruit clusters of ‘Prime-Ark® 45’ blackberry as affected by seven shade treatments while grown in a field experiment, 2014.



*There are no statistical differences represented in the figure above.