HARDWOOD FLORICANE BLACKBERRY CUTTINGS & PRODUCTION OF PRIMOCANE BLACKBERRY IN NORTH DAKOTA

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Abigail Ruth Debner

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Horticulture and Forestry

November 2016

Fargo, North Dakota

North Dakota State University

Graduate School

Title

Hardwood Cuttings of Floricane Blackberry & Production of Primocane Blackberry in North Dakota

By

Abigail Ruth Debner

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Harlene Hatterman-Valenti
Chair

Dr. Todd West

Dr. R.J. Goos

Approved:

11-28-16	Dr. Richard Horsley
Date	Department Chair

ABSTRACT

Blackberry (*Rubus* L. subgenus *Rubus*, Watson) is not a commercially produced crop in North Dakota since the available floricane cultivars are not winter hardy. Two experiments were performed to evaluate alternative methods of production for commercial use. The first experiment evaluated rooting of floricane-blackberry hardwood cuttings, which could be used in an annual production system. Various cultivars, auxin treatments, and rooting methods were used to determine the best adventitious root production. Rooting success was cultivar dependent with regard to auxin concentration and low results were observed overall. The second experiment evaluated practices to improve yield in four primocane-fruiting blackberry cultivars. Three soft-tipping treatments were applied to plants in a high tunnel, silver mulch, and bare soil. Tipping did not improve yield in the high tunnel, silver mulch, or bare soil environments and double-tipping decreased yield in the silver mulch. Harvest in all three environments ended after the first hard freeze.

ACKNOWLEDGEMENTS

I would like to thank Dr. Harlene Hatterman-Valenti for the opportunity she provided me as well as for her guidance and support these past few years as my major advisor. It was a pleasure working with her and her fun personality, especially when it came to field work. She pushed me to become a better person through the example she set as a hard worker and the encouragement she provided along the way.

Many thanks also goes to my committee members Dr. Todd West, Dr. R.J. Goos, and the late Dr. James Hammond for all of their support, guidance, and help throughout this process. I couldn't have done it without you.

I would also like to acknowledge the help of Dr. Fumiomi Takeda at the USDA-ARS Appalachian Fruit Research Station for his advice and supply of material for the hardwood floricane-blackberry cuttings experiments.

My gratitude also extends to research specialist Collin Auwarter and the entire High-Value Crops Team for all of their help and hard work in making my ideas a reality and putting up with all my craziness. It has been a fun group to work with over the years and it definitely takes a team to make it all work.

I would especially like to thank the members of HVC that have truly meant the most to me and have had such an impact on my life. Collin Auwarter, for not only being a fun boss, but also a good friend. You taught me so much and believed in me even when I didn't, thank you for all the good times. Dr. John Stenger, for all of his help and advice not only with my experiment and statistics but with life as well, your friendship has meant a lot to me. I learned so much from you can honestly say that I would have been lost without your guidance. Brittany Korynta Olson, my lab mate, grad school cohort, person who kept me sane, and my most importantly, my friend. For all the help with classes, our random lab chats, late nights, constant input on the small (and

big) stuff, and advice about life I am truly grateful and will dearly miss. David Mettler, my commiserating partner in blackberries, constant source of competition, and a true friend. I'm glad I had someone who truly understood my pain and was willing to help regardless. I enjoyed keeping you in check and all the complaining we did to each other. You certainly kept me on my toes. Greg Morgenson, a pseudo member of HVC, who not only fed my plant and chocolate addiction but always had a smile on his face and something to teach me.

I am also grateful for the many additional friendships I have formed throughout my time at NDSU. These people made an impact on my time here and helped with my project in various ways, as well as provided encouragement, Nathan Jahnke, Amanda Crook, Kathryn Plotke, Eduardo Poletti, Charles Elhard, Matt Brooke, Kelsie Mettler, Pete Ihry, Alec Miller, Anthony Evinger, Nathan Godel, Justin Schiroo, Joe Tatarek, and Stephen Johnson.

Thanks also goes to the many professors that have helped me along my journey and taught me so much during my time here including, Dr. Chiwon Lee, Dr. Edward Deckard, Dr. Asunta (Susie) Thompson, and Dr. Jawahar Jyoti.

I would also like to thank my mentors and friends at Sheyenne Gardens, Neal Holland and Adam Volz. I learned so much from you through the years and knew you always believed in me and supported me in this journey.

Finally, but of most importance, I would like to thank my entire family, especially my parents Allan and Sue, my sister Anne (& Jimmy), my grandparents Glen and Lora, my uncle Dale, my aunt Sarah, and my godmother Debbie for all of their help, support, love, and patience not only throughout my academic years, but my entire life. Without your love and support I would not have made it to where I am today. It has been a long journey but you have all played a part in helping me through it. Thank you for believing in me.

DEDICATION

To my family, for always being there

And to God, through Whom all things are possible

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

CHAPTER 1. LITERATURE REVIEW

Blackberry production in the northern Midwest and Great Plains of the United States is a rather fledging venture as a result of climatic limitations. However, with the increasing awareness of their many health benefits and the growth of the local food movement, it has the potential to be an advantageous addition to local fruit growers. Most of the commercial blackberry production in the United States for both processed and fresh markets occurs in the Pacific Northwest and the South. With the continuous influx of additional cultivars and production methods, however, commercial blackberry production in northern climates may be feasible.

Growth and Plant Characteristics

Background Origin

Blackberry (*Rubus* L. subgenus *Rubus* Watson*)* belongs to the *Rosaceae* family and is not a true berry, but botanically is considered an aggregate fruit (Crandall, 1995). The fruit is composed of multiple drupelets and differs from raspberry (*Rubus* L. subgenus *Idaeobatus*, Watson) in that the drupelets remain attached to the inner receptacle after picking. Blackberry is classified as a perennial that produces biennial fruiting canes. It contains a perennial crown that produces vegetative canes, or shoots, that sprout up the first growing season and are called primocanes. The second growing season the primocanes become reproductive and are called floricanes. The inflorescence of blackberry is a panicle with the terminal flower opening first. The blackberry flower is characteristic of the *Rosaceae* family containing five petals and five sepals. It is composed of many stamens and pistils which form the individual drupelets of the aggregate fruit (Bushway et. al, 2008). The flowers are self-fertile, but pollination is increased by the presence of bees.

Blackberry is native in every continent of the world except Antarctica, and thousands of different species exist (Jennings, 1988). Blackberry has been utilized by the human race for food and medicinal purposes for over two thousand years, since the time of the ancient Greeks (Bushway et. al, 2008). However, it wasn't until the mid-1800's that blackberry was first cultivated in America with the first cultivars appearing in 1867. Breeding work has been conducted to find more suitable blackberries for shipping quality, thornlessness, and primocane-fruiting types. The first public blackberry breeding program was started at Texas A & M in 1909 by H. Ness (Jennings, 1988; Moore, 1984). Today, the University of Arkansas and Oregon State University are the two major contributors to the improvement of blackberry. As a result of the extensive cultivation and breeding work of blackberry, the true species are unknown for commercial blackberry cultivars (Moore, 1984).

Growth Habits

Different types of blackberry growth habits exist and include trailing, semi-erect, and erect (Crandall, 1995). Blackberry is naturally thorny, however, thornless mutants were first found as periclinal chimeras with the most popular being 'Thornless Evergreen' (Crandall, 1995; Jennings, 1988; McPheeters and Skirvin, 2000). Since then breeding work has been done to create pure thornless plants. Thornless blackberries have become more common and are much more desirable than their thorny relatives. The primocanes that sprout up every year have their origin in crown buds or adventitious root buds (Crandall, 1995; Strik et al., 2007). Trailing type blackberries tend to send up primocanes from just the crown buds, whereas erect and semi-erect types send up primocanes from both crown buds and root buds. This results in the erect and semi-erect types producing a greater amount of suckers than the trailing types.

Physiology

Lower temperatures and shorter day length initiates the development of vegetative axillary buds on the primocanes into flower buds on the floricanes (Crandall, 1995; Jennings, 1988). It is during this time period that the canes cease growing and begin to acquire cold hardiness by decreasing the water content present in the canes. The progression of vegetative buds to flower buds, which will bear fruit the next growing season, varies amongst cultivars with some progressing faster than others (Crandall, 1995; Takeda et al., 2002). This change from vegetative buds to flower buds is continuous once it has begun, however, too cold of winter temperatures (below 2 °C) can stop development (Takeda et al., 2002).

Low temperatures and short days also initiate an endo-dormancy period in blackberry, which requires a sufficient length of cold temperatures in order to resume growth next spring. The endo-dormancy period is broken by acquiring a significant amount of chilling hours. The chilling requirement for blackberry is when the plants are subjected to temperatures at or below 7º C (Crandall, 1995). The amount of chilling hours required differs from cultivar to cultivar and ranges anywhere from 250 to 1400 hours. After the correct amount of chilling hours has been achieved, blackberry then enters the eco-dormancy phase in which plants await favorable environmental conditions before they begin growth (Takeda et al., 2002).

Lack of Cold Hardiness

Most floricane-fruiting blackberry cultivars are not considered hardy in areas with harsh winter temperatures, such as USDA Hardiness Zone 3, and exhibit variable hardiness, with respect to cultivars, in USDA Hardiness Zone 4, both of which include North Dakota (USDA, 2012). Most cultivars on the market are listed for USDA Hardiness Zone 5 and higher. However, even cultivars that are labeled USDA Zone 4 hardy can exhibit signs of winter injury during

harsh winters. Plant tolerance to cold temperatures varies by growth habit with the erect and thorny types being hardier than the trailing and thornless types (Crandall, 1995). Hardiness among cultivars within these groups is also variable based on parentage. Most cultivars are injured or killed when the temperature falls to -29º C and some are injured or killed when the temperature approaches -18º C (Crandall, 1995; Gordon, 1991).

Extreme cold temperatures during the dormancy or acclimation period can either cause injury to or death of the plant (Bushway et al., 2008; Crandall, 1995). Injury to the plant, such as death of floricanes and flower buds, can occur during the acclimation or dormant phase and prevents the plant from bearing fruit the next year. Death of the plant occurs because of crown injury during the dormant phase when it is subjected to extreme low temperatures and can be accelerated by injury or disease. Winter injury occurs when the water present in the vascular system freezes and ruptures the cell walls (Bushway et al., 2008). Plants with increased hardiness decrease the amount of water present in the canes during acclimation in the fall to prevent this occurrence (Jennings, 1988). Warm days, above -2º C followed by cold temperatures can also cause cane and bud damage in spring as the plants have started to move more water into the canes which then freezes (Crandall, 1995). Because of this, floricane-fruiting blackberry requires an adequate amount of covering in colder climates in order for the floricanes to survive the winter and bear fruit.

Overwintering

Despite the lack of cold hardiness in blackberry, cultural methods can be used to grow a blackberry crop in northern climates. One such cultural method is to overwinter the canes by covering them with an insulating layer to reduce the death of floricanes in severe cold weather. At the end of the growing season, Gordon (1991) recommends laying the primocanes

horizontally on the ground and covering the tips with soil. He then suggests placing 10 to 12 cm of mulch, such as straw, on top of the canes to act as an insulating layer. Laying the primocanes down horizontally on the ground in order to cover them can result in damage to the buds and, therefore, impact growth and yield the following year. Heavy snow loads also can lead to breakage of the canes causing the same results as leaving them uncovered. Although an effective method for cold climate blackberry fruit production, this process can be costly as well as labor intensive, and even with adequate winter coverage dieback can occur.

Health Benefits

Berries in general have been touted to provide many health benefits and, as with any fruit, are recommended as part of a regular diet. Blackberry, in particular, has been listed to provide many health benefits containing anticancer, anti-inflammatory, and antiseptic properties as well as being beneficial for cardiovascular health and reducing cholesterol (Kaume et.al, 2012; Nile and Park, 2014). These properties are due to the many phytochemicals they contain including vitamins, minerals, fibers, anthocyanins, and tannins. Blackberry is very high in vitamin C as well as anthocyanins, which are the most studied of the phenolic compounds. Anthocyanins contain the free-radical fighting antioxidants, which play a role in the anti-inflammatory and anticancer properties. Tannins lend blackberry its anti-septic properties, while ellagic acid has been implicated as an anti-mutagenic in cancer. Research is ongoing to further define additional health benefits they can provide.

Production

Location

According to the 2012 Census of Agriculture, there are 14,982 acres in the United States on which blackberries are grown with 10,586 of those acres being harvested (USDA, 2014).

Every state except Hawaii has some acreage of blackberry listed, however, not all of them have harvested acres. North Dakota is reported to have one acre of blackberry, however, no harvested acreage is reported and therefore no local berries are available for fresh consumption. As a result of its temperate and humid climate, Oregon is home to most blackberry production in the United States, with California as the second largest producer and Washington as the third (Strik et al. 2007; USDA, 2014). During the winter months, blackberries are imported into the United States from countries such as Mexico, Chile, and Guatemala (Strik et al., 2007).

Culture and Production Practices

Blackberry prefers a sandy loam soil with a pH of 5.5-6.5 that is well drained, as they do not tolerate wet soils (Bushway et al., 2008; Crandall, 1995). In order to obtain peak performance it is suggested to fertilize blackberry with 34-56 kg/ha of nitrogen during the establishment year and 56-90 kg/ha the following years (Hart et al., 2006). Annual tissue sampling of leaves as well as biennial soil sampling is recommended to ensure proper nutrition needs. Regular irrigation is recommended, especially during fruit production (Bushway et al., 2008). Drip versus overhead irrigation is not only more efficient, but it also helps reduce the incidence of disease on both the plants and the fruit. Good sanitation is also crucial in blackberry plantings to reduce the incidence of both insects and diseases.

When grown in either a home or commercial setting, certain plant spacing and plant management strategies are recommended based on the growth habit (Bushway et al., 2008). Plant spacing recommendations differ for the type of blackberry ranging from 0.6-1 m in-row for erect types to 1.8-2.5 m in-row for trailing types with 3-3.6 m spacing between rows. Since it is a naturally sprawling plant, use of trellising systems is necessary for blackberry in order to facilitate optimum plant growth, yield, and harvest. The three main blackberry trellis types

include the I, T, and V trellis systems. An I trellis system is where the plants are all trained onto a single plane on one wire. The T and V trellis systems are similar in that they allow for a split canopy by training the canes onto two wires and can also be used to separate the floricanes from the primocanes. V-trellis systems are recommended for both trailing and erect type blackberries. Primocane fruiting blackberry cultivars tend to be more erect and are therefore best managed using a T-trellis system.

Different pruning practices have been used in blackberry to increase production and reduce disease incidence (Bushway et al., 2008; Crandall, 1995). Due to the vigor of blackberry multiple flushes of primocane growth will occur during the season. While these canes will produce next year's crop, they also take nutrients away from the floricanes. Primocane suppression can be used to control the abundance of primocanes. This can either involve removal of all primocanes when they reach a height of 15-17 cm or partial primocane suppression in which a select few primocanes per linear foot are saved for floricane production the following year while the rest are removed. After the primocanes of erect blackberry types have reached an average height of 1m, the tip is removed to promote lateral branching in order to produce more inflorescences the following year. After the blackberry floricane has produced fruit it will eventually die and need to be removed from the planting to make room for new growth. This can either be done right after it has finished fruiting or later on during the dormant season.

Harvesting and Marketing

Blackberries can either be harvested by hand or with a berry picking machine depending on the intended market. Blackberries that are hand harvested are usually picked for the fresh market and are typically harvested every 2-4 days for 5-6 weeks (Crandall, 1995; Strik et al., 2007). Trained pickers place the ripe berries directly into the clamshell for selling either at

roadside stands or shipping across the nation. Although highly labor intensive, hand harvesting is necessary for the fresh market in order to achieve the best quality berries. Berries that are intended for the processed market are usually machine harvested and can be harvested at longer intervals since optimum ripeness is not as important of a factor. Quantity over quality is more important with machine harvesting and is more suited to larger scale operations.

The fresh market consists of approximately 5% of blackberry production in the United States. Most of the erect blackberry cultivars are used for the fresh market since they have thicker skins and a longer shelf life and are more suitable for shipping fresh (Strik et al., 2007). Fresh market berries have a higher cost per pound which is likely due to the high labor costs involved with hand harvesting (USDA, 2016). Although not separated from the fresh market, some blackberries are grown for U-pick operations or roadside stands (Crandall, 1995). The majority of blackberries grown in the Pacific Northwest are used for processing and are therefore machine harvested (USDA, 2016). Trailing blackberry cultivars are used mainly for processing since they have thinner skin and a shorter shelf life (Strik et al., 2007). Processed blackberries can be used for many different products such as jams, jellies, baked goods, frozen, yogurt, canned or juiced.

Propagation Methods

Typical Propagation

There are multiple methods of propagating blackberry, some of which have been used traditionally for years and other newer methods that have been developed (Crandall, 1995; Hartmann et al., 2011; Sears, 1920). Digging up the suckers produced by the plants is a classic and easy method of propagation. Another method is use of root cuttings, in which the roots of the plant are cut up into segments, overwintered in a cool location and planted in spring. These

cuttings then produce adventitious shoots that will develop into a new plant. Both of these methods work well for erect type blackberries (Crandall, 1995). Tip-layering is most often used for trailing blackberries and involves taking a cane and bending the tip to the ground and covering it with soil. The tip will produce roots and a new plant and the cane can then be severed from the parent plant at the end of the season. Leaf-bud cuttings can be used for either blackberry type and are taken from softwood tissue during the growing season (Hartmann et al., 2011). These one- or two-node cuttings are dipped in a rooting hormone and allowed to produce roots in a nursery area before being planted in the field (Crandall, 1995). More recent advances have resulted in tissue culture as a means of propagation from softwood cuttings as explant material (Crandall, 1995). This method of propagation, although slightly more expensive, has allowed a great increase in the amount of plants available for production and can be useful when propagation stock is limited (Bushway et al., 2008; Crandall, 1995).

Hardwood Floricane Cuttings

Another method of blackberry propagation is cuttings obtained from hardwood floricane material. The process is similar to leaf-bud cuttings but differs in that the cuttings are dormant versus actively growing (Hartmann et al., 2011). Although this method is not widely used as a means of mass propagation, it has been found to be successful (Bray et al., 2003; Takeda et al., 2011; Zimmerman et al., 1980). This also has the potential to be useful to cold climate growers for an annual production system as it would eliminate the need to overwinter a floricane-fruiting blackberry crop. This process requires hardwood cuttings to be taken from dormant floricane-fruiting blackberry cultivars, inducing adventitious roots, and growing them in a greenhouse to produce fruit (F. Takeda, personal communication). Instead of having blackberries shipped to this area from across the nation, or different countries, they could be grown locally throughout

the year (Strik et al., 2007). Additionally, if timed correctly nurseries could sell the rooted cuttings to homeowners who could obtain their own blackberry crop and simply remove them from their garden at the end of the season.

Primocane-Fruit Production

Primocane-Fruiting Trait

The primocane-fruiting trait in *Rubus* was observed first in red raspberry (*Rubus ideaus* L.) in the 1960's and resulted in the first commercially acceptable and most notable cultivar, 'Heritage' in 1969 (Jennings,1988; Pritts, 2008). The primocane-fruiting trait in blackberry was first observed in a plant obtained from the wild in Virginia in 1949 and was named 'Hillquist' after its discoverer L.G. Hillquist (Lopez-Medina et al., 2000). It first entered the lineage of the current primocane-fruiting cultivars in 1967 when it was used as a parent in the Arkansas breeding program (Clark, 2008). The University of Arkansas blackberry breeding program recently introduced five primocane-fruiting blackberry cultivars. The introduction of the cultivars Prime-Jim® and Prime-Jan® in 2005 have been followed by the cultivars Prime-Ark® 45 in 2011 and the thornless cultivars Prime-Ark® Freedom in 2014 and Prime-Ark® Traveler in 2015 (Clark et al., 2005; Clark and Perkins-Veazie, 2011; Clark, 2014; Clark and Salgado, 2016).

Primocane-fruiting cultivars are unique in that, unlike the floricane-fruiting types, they will produce fruit on the upper half to one-third of the primocanes that sprout up from the crown each growing season (Clark et al., 2005; Pritts, 2008). At the end of the season the primocanes can be cut off at the ground and new ones will sprout again the next spring. If the primocanes are not removed and allowed to overwinter they will produce fruit below the primocane-fruiting zone on the floricanes the following year, allowing for a double-crop. It is not fully understood what causes the primocanes to become reproductive as they appear to be day-neutral and non-temperature

dependent (Jennings, 1988; Strik, 2012; Lopez-Medina et al., 1999). However, it has been observed that after a certain period of growth they will initiate flower bud development and this process can be accelerated by high temperatures and high nitrogen application.

Methods to Increase Production

As a result of their unique fruiting habit, primocane cultivars fruit later into the season then the floricane types (Clark et al., 2005; Pritts, 2008). As Thompson et al. (2009) in blackberry and Pritts (2008) in raspberry both noted, these primocane-fruiting cultivars have the potential to fill the off-season fresh market before the winter imports arrive. In raspberry, pruning the primocanes early in the season delayed harvest further into the season extending the off-season production periods in warmer climates (Oliveira et al., 1998). However, in cooler climates early fall frosts or fall rains can have detrimental effects on yield and so practices for extending the season have been investigated.

Yield comparisons of primocane-fruiting blackberry cultivars to floricane-fruiting cultivars have found that primocane-fruiting cultivars produce lower yields (Clark et al., 2005; Clark and Perkins-Veazie, 2011; Clark, 2014). Production practices such as soft-tipping, which is removal of the apical meristem, have been found to increase yield in milder climates (Drake and Clark, 2003; Thompson et al., 2009; Strik et al., 2008). Tipping removes apical dominance and allows the lateral buds to break which end up producing branches each with the potential to produce an inflorescence. Since tipping can delay the primocane bloom and fruit production, it is not known how beneficial this would be in colder climates that have early frosts dates without a form of season extension.

Research has been conducted to study the effect that high tunnels have in extending the fruiting season of primocane-fruiting blackberry and raspberry cultivars. A high tunnel is

essentially an unheated greenhouse and consists of a plastic covered metal frame that is placed over a crop to extend the season (Heidenreich et al., 2012). High tunnels are usually covered with a single layer of plastic and rely on passive ventilation via roll-up sidewalls or removable end walls. Crops are planted directly into the ground and require irrigation. Success has been documented in extending the season and increasing yield in milder climates in both primocane-fruiting blackberry and raspberry (Thompson et al., 2009; Hanson et al., 2011; Yao and Rosen, 2011). The reduced presence of disease has also been observed in primocane-fruiting raspberries grown in a high tunnel compared to the field (Hanson et al., 2011).

While blackberry is grown in North Dakota, no commercial crop currently exists for local food production. The lack of commercially available hardy cultivars requires implementation of cultural techniques to realize a blackberry yield in this climate. The intent of the following experiments is to find new methods that growers can utilize for blackberry production in North Dakota.

Literature Cited

Bushway, L., M. Pritts, and D. Handley. 2008. Raspberry and blackberry production guide for the Northeast, Midwest, and eastern Canada. Natural Resource, Agriculture, and Engineering Service Cooperative Extension. Ithaca, New York.

Bray, M.M., C.R. Rom, and J.R. Clark. 2003. Propagation of thorn less Arkansas blackberries by hardwood cuttings. Discovery (Univ. of Arkansas) 4:9-13.

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

Clark, J.R. 2014. 'Prime-Ark® Freedom' Primocane-fruiting thornless blackberry. HortScience 49:1097-1101.

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

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

Clark, J.R. and A. Salgado. 2016. 'Prime-Ark® Traveler' Primocane-thornless blackberry for the commercial shipping market. HortScience. 51:1287-1293.

Clark, J.R. 2014. 'Prime-Ark® Freedom' Primocane-fruiting thornless blackberry. HortScience 49:1097-1101.

Crandall, P.C. 1995. Bramble production: The management and marketing of raspberries and blackberries. Food Products Press. Binghamton, NY.

Drake, C. and Clark, J.R. 2003. Effects of pruning and cropping on field-grown primocane-fruiting blackberries. HortScience 38:260-262.

Gordon, D. 1991. Brambles, p. 201-233. In: Growing fruit in the upper Midwest. University of Minnesota Press. Minneapolis, MN.

Hanson, E., M. Von Weihe, A.C. Schilder, A.M. Chanon, and J.C. Schreerens. 2011. High tunnel and open field production of floricane- and primocane-fruiting raspberry cultivars. HortTechnology. 21:412-418.

Hart, J., B. Strik, and H. Rempel. 2006. Caneberries. Oregon State University Extension Service. EM 8903-E.

Hartmann, H.T., D.E. Kester, F.T. Davies, Jr., and R.L. Geneve. 2011. Plant Propagation: Principles and practices. 8th ed. Prentice Hall, Upper Saddle River, NJ.

Heidenreich, C.M., M. Pritts, K. Demchak, E. Hanson, C. Weber, and M.J. Kelly. 2012. High tunnel raspberries and blackberries. Dept. of Hort. Cornell Univ. Publication No. 47. 9 Dec. 2014. http://www.fruit.cornell.edu/berry/production/pdfs/hightunnelsrasp2012.pdf.

Jennings, D. L. 1988. Blackberries, p. 39-58. In: Raspberries and blackberries: their breeding, diseases and growth. Academic Press Inc., San Diego, Cal.

Kaume, L., Howard, L.R., and Devareddy, L. 2011. The Blackberry Fruit: A Review on Its Composition and Chemistry, Metabolism and Bioavailability, and Health Benefits. Journal of Agricultural and Food Chemistry 60:5716-5727.

Lopez-Medina, J., J.N. Moore, and K.S. Kim. 1999. Flower bud initiation in primocane-fruiting blackberry germplasm. HortScience. 34:132-136.

Lopez-Medina, J., J.N. Moore, and R.W. McNew. 2000. A proposed model for inheritance of Primocane fruiting in tetraploid erect blackberry. J. Amer. Soc. Hort. Sci. 125:217-221.

Moore, J. 1984. Blackberry breeding. HortScience. 19:183-185.

McPheeters, K. and R.M. Skirvin. 2000. 'Everthornless' blackberry. HortScience. 35:778-778.

Nile, S.H. and Park, S.W. 2014. Edible berries: Bioactive components and their effect on human health. Nutrition 30:134-144.

Oliveora, P.B., C.M. Oliveira, P.V. Machado, L.Lopes-da-Fonseca, and A.A. Moneiro. 1998. Improving off-season production of primocane-fruiting red raspberry by altering summer-pruning intensity. HortScience 33:31-33.

Pritts, M. 2008. Primocane-fruiting raspberry production. HortScience 43:1640-1641.

Sears, F.C. 1920. Productive small fruit culture. Washington Square Press. Philadelphia, PA.

Strik, B.C. 2012. Flowering and fruiting on command in berry crops. Acta Hort. 926: 197-214.

Strik, B.C., J.R. Clark, C. E. Finn, and M.P. Bañados. 2007. Worldwide blackberry production. HortTechnology 17:205-213.

Strik, B.C., J.R. Clark, C.E. Finn, and G. Buller. 2008. Management of primocane-fruiting blackberry to maximize yield and extend the fruiting season. Acta Hort. 777:423-438.

Takeda, F., B.C. Strik, D. Peacock and J.R. Clark. 2002. Cultivar differences and the effect of winter temperature on flower bud development in blackberry. J. Amer. Soc. Hort. Sci. 127:495-501.

Takeda, F., T. Tworkosi, C.E. Finn, and C.C. Boyd. 2011. Blackberry propagation by non-leafy floricane cuttings. HortTechnology 21:236-239.

Thompson, E., B.C. Strik, C.E. Finn, Y. Zhao, and J.R. Clark. 2009. High tunnel versus open field: management of primocane-fruiting blackberry using pruning and tipping to increase yield and extend the fruiting season. HortScience 44:1581-1587.

USDA. 2012. USDA Plant Hardiness Zone Map. Agricultural Research Service, U.S. Department of Agriculture. 01 Sept 2016. http://planthardiness.ars.usda.gov.

USDA. 2014. 2012 Census of Agriculture United States Summary and State Data. United States Department of Agriculture National Agricultural Statistics Service. Volume 1 Part 51. 01 Sept 2016. https://www.agcensus.usda.gov/Publications/2012/#full_report.

USDA. 2016. Noncitrus Fruits and Nuts 2015 Summary. United States Department of Agriculture National Agricultural Statistics Service. ISSN: 1948-2698. 01 Sept 2016. https://www.nass.usda.gov/Publications/Ag_Statistics/2015/index.php.

Yao, S. and C.J. Rosen. 2011. Primocane-fruiting raspberry production in high tunnels in a cold region of the upper Midwestern United States. HortScience. 21:429-434.

Zimmerman, R.H., G.J. Galleta, and O.C. Broome. 1980. Propagation of thornless blackberries by one-node cuttings. J. Amer. Soc. Hort. Sci. 105:405-407.

CHAPTER 2. HARDWOOD CUTTINGS OF FLORICANE BLACKBERRY

Abstract

Floricane-fruiting blackberry (*Rubus* L. subgenus *Rubus*, Watson) is not a viable crop in North Dakota because of the lack of winter hardiness. Several experiments were performed to examine the use of one-node hardwood floricane blackberry cuttings to be used in an annual production system. Experiments evaluated seven cultivars, various auxin concentrations and formulations, and rooting methods to determine the best procedure for adventitious root production. Rooting success with different auxin applications was variable among cultivars and some cultivars had better rooting success with no auxin application. Lower concentrations and the talc formulation of auxin produced the best results among most cultivars. Rooting success of cuttings was low regardless of rooting method used. Continued work needs to be done to find ways of increasing rooting success before recommending this method as a means of propagation to the nursery trade.

Introduction

Low temperatures and short days are required to initiate flower buds on floricane-fruiting blackberry plants, but this also causes the plants to become dormant. Blackberries are traditionally propagated from leaf bud cuttings and tip layering during the growing season (Hartmann et al., 2011). Hardwood cuttings are not widely used and have a lower success rate. However, use of hardwood canes for floricane-fruiting blackberry cuttings in an annual production system is necessary for fruit production, since the dormancy period requirement for flower bud initiation has been met.

Research has been conducted on the procedure for rooting hardwood cuttings of floricane-fruiting blackberry and has produced varied success based on the type of cultivar used

(Bray et al., 2003; Gonclaves et al., 2012; Lopez-Medina and Moore, 1997; Takeda et al., 2011; Zimmerman et al., 1980). Takeda et al. (2011) developed a protocol for rooting one-node floricane cuttings for 'Siskiyou' and 'Triple Crown' after the canes had undergone an outdoor dormancy period. They reported that applying the cytokinin, 6-benzyladenine (BA), to the buds promoted shoot growth of the cuttings. This application was found to increase shoot growth but it also decreased adventitious root growth as compared to non-treated cuttings. 'Siskiyou' produced a high percentage of cuttings with adventitious roots, while 'Triple Crown' had most roots forming at the base of the buds. Auxin was not applied to any of the cuttings in this experiment; however, the authors did note that application of auxin might improve rooting.

Root initiation on blackberry cuttings appears to be cultivar dependent regardless of the method. Bray et al. (2003), using three thornless cultivars (Apache, Arapaho, and Navaho), found that auxin application to the cut end of hardwood cuttings is variable among cultivars. In 'Apache', the application of 0.3% indole-butyric acid (IBA) as a 1-3 second quick dip solution caused an increase in root formation, but in 'Arapaho' and 'Navaho' the application of auxin actually decreased root formation. This study also found that the cuttings rooted well in a peat-perlite media mix under intermittent misting. In contrast, Takeda et al. (2011) found that a peat based media in an enclosed system consisting of sealed plastic bags with weekly misting produced the most positive root formation.

Auxin is a naturally occurring plant hormone that regulates the functions of apical dominance, formation of abscission layers, and plant growth towards light (Hartmann et al., 2011; Raven et al., 2005). It occurs naturally in the form of indoleacetic acid (IAA), but has been synthesized in the forms of indole-3-butyric acid (IBA) and α-naphthalene acetic acid (NAA). The IBA form of auxin has also been found to occur naturally, albeit in small amounts. Auxin

plays a critical role in the vegetative propagation of plants by stem cuttings as it promotes the formation of adventitious roots. Varying concentrations of auxin are recommended for different species and stem cutting types such as softwood, hardwood, semi-hardwood, and herbaceous. It is most commonly applied as a liquid quick dip or as a talc based formulation. There are currently no widely accepted recommendations for the use of auxin in hardwood cuttings of blackberry and minimal research exists on the appropriate form and concentration to use.

Research Objective

The objective of the hardwood cuttings of floricane-fruiting blackberry research is to evaluate the most effective method of rooting that could be used for cuttings in an annual production system. This research will seek to answer the following questions. Does the application of auxin rooting hormone have an influence on the cuttings' adventitious root growth? Is rooting percentage increased or decreased by the use of one-node or two-node cuttings? Do the cultivars act the same or different in each treatment? Is there a cultivar that is superior to the rest in producing adventitious root growth? Does age or how the cuttings are grown play a role in root formation?

Several experiments were performed with dormant hardwood blackberry cuttings to find the most feasible rooting method. Cuttings were taken from plant material from two different sources with the older material taken from plants grown at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, and the younger material grown in 2.8 liter plastic nursery containers on the NDSU campus and overwintered in a cooler held at 3 °C. Different cultivars were used to determine whether the production of roots was cultivar dependent. Each experimental setup and evaluation was based on results observed in prior experiments.

Experiment One

Materials and Methods

The objective of this experiment was to determine whether cultivar, age of the plant, and type of rooting method had an impact on producing adventitious roots of dormant hardwood blackberry cuttings. The two trailing floricane-fruiting blackberry cultivars that were evaluated for the first experiment included the thorny 'Siskiyou' (Finn et al., 1999) and the thornless 'Triple Crown' (Galletta et al., 1998). Cuttings were taken from 12-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours during December of 2014. Cuttings were also taken from two-year-old plants in 2.8 liter plastic nursery containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus that was set at 3 °C.

Cuttings were approximately four cm long with the bud located in the center of the cutting. Cuttings were then dipped for two minutes in a fungicide solution at a rate of 12.2 g/ 3784 ml (50 WP Captan, Arysta LifeScience, Cary, NC, USA). Cuttings from West Virginia had been dipped in the same solution for the same time period prior to arrival. Half of the cuttings were placed in a medium mixture of one peat: one perlite (v:v) in five cm square plastic containers. Care was taken to ensure that the bud on the cuttings was not buried beneath the surface of the medium. The other half were placed between moistened paper towels (Viva®, Kimberly-Clack Corporation, Neenah, WI, USA) as reported by Takeda et al. (2011). Each cutting was then placed in a plastic bag (Ziploc®, SC Johnson and Son, Inc., Racine WI, USA) that was kept open 2.5 cm for air ventilation and subjected to low light conditions at approximately 15 $\mu mol/m^{-2}/s^{-1}$ as recommended by Takeda et al. (2011) on a light bank grow cart in a lab room with an 8/16 day/night cycle.

The cuttings were held at room temperature (22º C) during the rooting period and runs were kept in separate laboratory rooms. Plants were misted weekly with tap water to maintain moisture levels. Cuttings were analyzed for adventitious root formation at the base of the bud and data was collected every two weeks for a total of four weeks on average root length, root number, shoot length, and percent of cuttings rooted. Roots counted were 2 mm in length and greater and shoots were measured when exceeding a length of 2 mm. Cuttings were also given a root rating of 0-5 with 0 = dead, 1 = no callus or roots, 2 = callus formation, 3 =few, short roots, 4 = moderate, well-developed roots, and 5 = many, extensive roots.

The experimental design was a completely randomized design arranged as a 2x2x2 factorial (two cultivars, two plant ages, and two rooting methods) with ten replications and two runs. Since the data had a high occurrence of zeros, the square root transformation for data (root length, root number, root rating, and shoot length + 1) was performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Weeks were analyzed individually as a result of the high amount of death between evaluation periods. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

No significant differences were found for root number, root rating, average root size, shoot length, or percent of cuttings rooted between cultivars, rooting methods, or plant ages

(Table 2.1). Cuttings deteriorated from the first data evaluation to the next as a result of rot and fungal infection despite being pre-treated with a fungicide.

Table 2.1. Effect of plant age, cultivar, and rooting method on live root length, live root number, root rating, shoot length, and percent of cuttings rooted two and four weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

	Live Root Length (cm)	Live Root Number	Root Rating	Shoot Length (cm)	Rooted (%)
		Two Weeks			
Plant Age					
Younger	0.11	0.6	1.9	0.66	11
Older	0.38	3.5	2.5	1.11	30
Significance[z]	NS	NS	NS	NS	NS
Cultivar					
Siskiyou	0.48	4.0	2.5	0.82	40
Triple Crown	0.01	0.0	1.9	0.96	1
Significance	NS	NS	NS	NS	NS
Rooting Method					
Peat Perlite	0.28	1.8	2.2	1.00	19
Paper Towel	0.20	2.2	2.2	0.76	23
Significance	NS	NS	NS	NS	NS
		Four Weeks			
Plant Age					
Younger	0.14	0.5	0.4	0.50	3
Older	0.76	3.0	2.1	1.43	30
Significance	NS	NS	NS	NS	NS
Cultivar					
Siskiyou	0.87	3.3	1.2	0.84	26
Triple Crown	0.03	0.2	1.3	1.10	6
Significance	NS	NS	NS	NS	NS
Rooting Method					
Peat Perlite	0.46	1.7	1.2	1.09	11
Paper Towel	0.45	1.9	1.3	0.85	21
Significance	NS	NS	NS	NS	NS

[z]NS =Not significant at $P \leq 0.05$.

Discussion

The lower numbers observed in week four are most likely a result of the fact that the cuttings declined from the first evaluation period to the second. Even though the cuttings had been dipped in a fungicide solution prior to rooting, they still succumbed to a fungal invasion as

well as rot. This is contrary to what both Bray et al. (2003) and Takeda et al. (2011) observed, where their cuttings maintained themselves for a number of weeks after initial rooting was observed. Although not statistically significant, 'Siskiyou' appeared to have greater rooting success compared to 'Triple Crown' and was similar to what Takeda et al. (2011) observed. However, overall rooting success was lower than what Takeda et al. (2011) found with these cultivars.

Experiment Two

Materials and Methods

The objective of this experiment was to determine whether age of the plant, cultivar, rooting method and auxin concentration or formulation have an impact on the production of roots. The two trailing floricane-fruiting blackberry cultivars that were evaluated for the second experiment included the thorny 'Siskiyou' (Finn et al., 1999) and the thornless 'Triple Crown' (Galletta et al., 1998). Cuttings were taken from 12-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours during January of 2015 for the first run. Cuttings were also taken from two-year-old plants in 2.8 liter nursery containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus at 3 °C. For the second run of the experiment, cuttings were taken from 13-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours during January of 2016. Cuttings were also taken from three-year-old plants in 2.8 liter containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus at 3 °C.

Cuttings were approximately four cm long with the bud located in the center of the cutting. Cuttings were then dipped for two minutes in a fungicide solution as described in experiment one. Cuttings from West Virginia had been dipped in the same solution for the same time period prior to arrival. Auxin was applied as a 10-second quick dip at rates of 1000 ppm and 3000 ppm liquid solution of indole-3-butyric acid potassium salt (K-IBA) and distilled water to the proximal end of the cuttings. Auxin was also applied in powder form at rates of 0.1% IBA (Hormex® #1, Maia Products, Inc, Westlake Village, CA, USA) and 0.3% IBA (Hormex® #3) with cuttings dipped in water before being dipped in the powder. An untreated group was also established in which cuttings were only dipped in water.

Half of the cuttings were placed in a medium mixture of one peat: one perlite (v:v) in 1206 cell packs (T.O. Plastics, Clearwater, MN, USA). Care was taken to ensure that the bud on the cuttings was not buried beneath the surface of the medium. The remaining cuttings were placed between moistened paper towels (Viva®, Kimberly-Clark Corporation, Neenah, WI, USA), placed in plastic bags (Ziploc®, SC Johnson and Son, Inc., Racine WI, USA), and subjected to the same environmental conditions as described in experiment one. Cuttings were evaluated at the end of two weeks for the same variables as described in experiment one.

The experimental design was a randomized complete block design arranged as a split plot with the whole plot consisting of the two rooting methods and the sub plot consisting of a 2x2x5 factorial of cultivars, plant age, and auxin concentrations with four replications and two runs. Since the data had a high occurrence of zeros, the square root transformation for data (root length, root number, root rating, and shoot length + 1) was performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3,

Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

The interaction between auxin treatments and rooting method was significant for root rating and shoot length (Table 2.2). The untreated cuttings in the peat perlite mixture had a significantly lower root rating as compared to the 0.3% IBA talc treatment. In the paper towel method, cuttings in the talc treatment (0.3% IBA talc) had a higher root rating than the liquid quick dip of the same concentration (3000 ppm) (Table 2.2). Cuttings treated with 3000 ppm liquid quick dip had a lower root rating than the talc treatments, as well as the untreated cuttings in the paper towel method. The interaction between auxin treatment and rooting method indicated that the shoot size was greatest for cuttings in untreated, 0.1% IBA talc, and 0.3% IBA talc treatments in the peat perlite mixture. Shoot lengths were longer for cuttings in the peat perlite mixture compared to cuttings placed in the paper towel method. No significant differences were found for root length, root number, or percent of cuttings rooted. No significant differences were found between cultivars or plant ages for any of the variables measured (Table 2.3).

Table 2.2. Effect of auxin treatment and rooting method on root length, root number, root rating, shoot length, and percent of cuttings rooted two weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

	Root Length (cm)		Root Number		Root Rating		Shoot Length (cm)		Rooted (%)	
Auxin	Peat Perlite	Paper Towel	Peat Perlite	Paper Towel	Peat Perlite	Paper Towel	Peat Perlite	Paper Towel	Peat Perlite	Paper Towel
Untreated	0.25	0.10	0.9	1.8	1.9 bc	2.1 ab[z]	0.88 a	0.02 c	22	21
0.1 % IBA talc	0.42	0.12	2.2	1.1	2.0 ab	2.1 ab	0.93 a	0.06 c	28	36
0.3% IBA talc	0.41	0.14	2.5	1.2	2.3 a	2.1 ab	0.97 a	0.08 c	42	38
1000 ppm IBA quick dip	0.26	0.09	1.2	0.6	2.0 ab	1.9 bc	0.43 b	0.00 c	29	18
3000 ppm IBA quick dip	0.32	0.02	1.5	0.2	2.0 ab	1.5 c	0.34 b	0.00 c	29	17
Significance[y]	NS		NS		*		*		NS	

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test (P>0.05.
[y]NS,* =Not significant or significant, respectively, at P≤0.05.

Table 2.3. Cultivar and plant age differences on root length, root number, root rating, shoot length, and percent of cuttings rooted two weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

	Root Length (cm)	Root Number	Root Rating	Shoot Length (cm)	Rooted (%)
Cultivar					
Siskiyou	0.42	2.6	2.2	0.30	52
Triple Crown	0.01	0.1	1.8	0.45	4
Significance[z]	NS	NS	NS	NS	NS
Plant Age					
Younger	0.13	0.7	1.8	0.23	21
Older	0.29	1.9	2.2	0.52	35
Significance	NS	NS	NS	NS	NS

[z]NS =Not significant at P≤0.05.

Discussion

Since more light was available to cuttings in the peat perlite mixture compared to the paper towel method this may have caused the differences in shoot length and was also observed by Takeda et al. (2011). Interestingly, it was observed that cuttings with the longer shoot lengths tended to have the least amount of roots. Adventitious rooting in hardwood cuttings is dependent on stored carbohydrates in the cutting (Hambrick et al., 1991; Hartmann et al., 2011). Bud break and shoot growth are also energy consuming processes which use stored carbohydrates and according to Hartmann et al. (2011), excessive shoot growth can have detrimental effects on root production. Therefore, shoot production is not necessarily a desirable effect when no root production has first occurred, as the cutting will use up its stored carbohydrates. Although 'Siskiyou' was observed to have better root formation than 'Triple Crown', they were not statistically different from one another. However, this observation provides some evidence that adventitious root production is likely cultivar dependent which has also been found in softwood cuttings of trailing and erect types and hardwood cuttings of erect types (Bray et al., 2003; Busby and Himelrick, 1999; Gonclaves et al., 2012; Lopez-Medina and Moore, 1997; Zimmerman et al., 1980).

Experiment Three

Materials and Methods

The objective of this experiment was to determine which cultivar in combination with auxin concentration and rooting method produced the best rooting in cuttings taken from young plants. The six floricane-fruiting blackberry cultivars that were evaluated for the third experiment included erect and semi-erect types as well as thornless and thorny. The six cultivars used include the erect thornless cultivars Apache (Clark and Moore, 1999), Arapaho (Moore and

Clark, 1993), Osage (Clark, 2013), and Ouachita (Clark and Moore, 2005), the trailing thorny cultivar Kiowa (Moore and Clark, 1996), and the trailing, thornless cultivar Triple Crown (Galletta et al., 1998). Plants were placed in a walk-in cooler set at 3º C to satisfy the necessary chilling hours. After the plants were exposed to enough chilling hours to break dormancy, one-node hardwood cuttings were taken during February of 2015. Cuttings were approximately four cm long with the bud located in the center of the cutting. Cuttings were then dipped for two minutes in a fungicide solution as explained in experiment one.

Application of the rooting hormone auxin was applied to two-thirds of all the cuttings. The auxin was applied at rates of 1000 ppm (0.1%), 3000 ppm (0.3%), 5000 ppm (0.5%), and 8000 ppm (0.8%) liquid solution of K-IBA and distilled water as 10 second dips to the proximal end of the cuttings. The final one-third of the cuttings did not receive an auxin treatment and acted as an untreated control. Half of the cuttings were rooted in five cm square plastic pots filled with a medium mixture of one peat: one perlite (v:v) and the other half placed between moistened paper towels (Viva®, Kimberly-Clark Corporation, Neenah, WI, USA) with reps placed in separate plastic bags. Cuttings were subjected to the same environmental conditions as described in experiment one. They were evaluated every two weeks for a total of four weeks on the same variables as described in experiment one.

The experimental design for this study was a randomized complete block design with seven replications for each treatment arranged as a 6x5x2 factorial (six cultivars, five auxin treatments, and two rooting methods) and consisted of two runs. The square root transformation for data (root length, root number, root rating, shoot length, and rooted percent + 1) was performed prior to analysis. Since the data had a high occurrence of zeros, the square root transformation for data (root length, root number, root rating, and shoot length + 1) was

performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Weeks were analyzed individually as a result of the high amount of death between evaluation periods. Tests of simple effects were performed using the SLICE function in SAS® on significant three-way interactions to evaluate the cultivars and auxin concentrations within each rooting method.

Results

Root Rating

The interaction of cultivar and auxin treatment was significant for both evaluation periods (Table 2.4). The overall trend observed for both two and four weeks after initiation was that increasing auxin concentrations led to decreased root ratings in most of the cultivars. Cuttings from ‘Arapaho’, ‘Ouachita’, and ‘Triple Crown’ treated with 8000 ppm IBA had the lowest root rating compared to the other treatments (Table 2.4). The interaction between auxin treatment and rooting method for all cultivars was significant four weeks after initiation (Table 2.5). Untreated cuttings in the peat perlite mixture had the highest root rating. As auxin concentration increased within each rooting method, the root rating decreased.

Table 2.4. Effect of cultivar and auxin treatment on root rating two and four weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

Auxin	Root Rating					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
			Two Weeks			
Untreated	1.7 bcd[z]	2.0 ab	1.4 defgh	1.7 bcde	2.0 ab	2.0 ab
1000 ppm IBA quick dip	1.4 defgh	2.2 a	1.2 fgh	1.1 gh	2.2 a	1.7 bcde
3000 ppm IBA quick dip	1.1gh	2.0 ab	0.6 k	1.1 ghi	1.9 abc	1.6 cdef
5000 ppm IBA quick dip	1.1 ghi	1.9 abc	1.2 fgh	0.6 k	1.7 abc	1.0 hij
8000 ppm IBA quick dip	0.7 ijk	1.5 def	0.7 jk	0.4 k	1.4 defg	0.5 k
			Four Weeks			
Untreated	0.6 cd	1.0 b	1.0 ab	0.3 efg	1.3 a	0.5 de
1000 ppm IBA quick dip	0.1 fgh	0.3 ef	0.1 fgh	0.0 gh	0.9 bc	0.0 h
3000 ppm IBA quick dip	0.0 gh	0.0 gh	0.0 h	0.0 h	0.2 fgh	0.0 h
5000 ppm IBA quick dip	0.0 h	0.0 h	0.0 h	0.0 h	0.1 fgh	0.0 h
8000 ppm IBA quick dip	0.0 h	0.0 h	0.0 h	0.0 h	0.0 h	0.0 h

[z]Means followed by the same letter within the same time period are not significantly different according to a pairwise t-test (P>0.05).

Table 2.5. Effect of auxin and rooting method on root rating four weeks after initiation of one-node hardwood blackberry cuttings in the rooting methods.

Auxin	Root Rating	
	Paper Towel	Peat Perlite
Untreated	0.4 b[z]	1.1 a
1000 ppm IBA quick dip	0.2 b	0.3 c
3000 ppm IBA quick dip	0.1 c	0.0 cd
5000 ppm IBA quick dip	0.0 cd	0.0 cd
8000 ppm IBA quick dip	0.0 d	0.0 d

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Root Length

The three-way interaction amongst rooting method, cultivar, and auxin treatment was significant two weeks after initiation and the cultivar by auxin interaction was evaluated within each rooting method separately. No significant differences were found in the paper towel method among auxin concentrations or cultivars (data not shown), which had extremely low rooting success. In the peat perlite mixture, auxin concentration did not have an effect on root length for 'Triple Crown', 'Apache', or 'Kiowa' cuttings (Table 2.6). 'Arapaho' and 'Ouachita' cuttings had longer root lengths with lower auxin concentrations (1000 and 3000 ppm) while 'Osage' cuttings did the best with no auxin application at all.

Table 2.6. Effect of cultivar and auxin on live root length mixture two weeks after initiation of one-node hardwood blackberry cuttings within the peat perlite mixture.

Auxin	Live Root Length (cm)					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0.00 e[z]	0.00 e	0.00 e	0.29 ab	0.00 e	0.04 de
1000 ppm IBA quick dip	0.00 e	0.24 bc	0.00 e	0.00 e	0.37 a	0.00 e
3000 ppm IBA quick dip	0.00 e	0.15 cd	0.00 e	0.00 e	0.03 e	0.00 e
5000 ppm IBA quick dip	0.00 e	0.00 e	0.00 e	0.00 e	0.03 e	0.04 de
8000 ppm IBA quick dip	0.00 e	0.00 e	0.00 e	0.00 e	0.00 e	0.00 e

[z]Means followed by the same letter within each rooting method are not significantly different according to a pairwise t-test (P>0.05).

Root Number

The interaction between cultivar and auxin was significant two weeks after initiation in the rooting methods. 'Arapaho' and 'Ouachita' cuttings had more roots with lower concentrations of auxin (Table 2.7). 'Osage' cuttings had the highest root number with no auxin application. Auxin concentration made no difference for 'Apache', 'Kiowa' or 'Triple Crown' on the number of roots produced per cutting.

Table 2.7. Effect of cultivar and auxin on live root number two weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

Auxin	Live Root Number					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0.00 c	0.00 c	0.00 c	0.39 a	0.00 c	0.11 bc
1000 ppm IBA quick dip	0.00 c	0.39 a[z]	0.00 c	0.00 c	0.39 a	0.00 c
3000 ppm IBA quick dip	0.00 c	0.28 ab	0.00 c	0.00 c	0.11 bc	0.04 c
5000 ppm IBA quick dip	0.00 c	0.14 bc	0.00 c	0.00 c	0.14 bc	0.04 c
8000 ppm IBA quick dip	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

The three-way interaction of rooting method, cultivar, and auxin was significant four weeks after initiation of the experiment for number of live roots and the auxin by cultivar interaction was evaluated within each rooting method separately (Table 2.8). No differences were found in the paper towel method for cultivars or auxin concentrations (data not shown), which had extremely low rooting success. ‘Ouachita’ cuttings with 1000 ppm IBA had the most roots out of all the cultivar and auxin combinations in the peat perlite mixture.

Table 2.8. Effect of cultivar and auxin on live root number four weeks after initiation of one-node hardwood blackberry cuttings within the peat perlite mixture.

Auxin	Live Root Number					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0.0 b	0.1 b	0.0 b	0.0 b	0.0 b	0.1 b
1000 ppm IBA quick dip	0.0 b	0.1 b	0.0 b	0.0 b	0.6 a	0.0 b
3000 ppm IBA quick dip	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
5000 ppm IBA quick dip	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
8000 ppm IBA quick dip	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Percent of Cuttings Rooted

The three-way interaction for auxin, cultivar, and method was significant two weeks after initiation and the auxin by cultivar interaction was evaluated within each rooting method separately. No significance was found in the paper towel method between cultivars or auxin treatments (data not shown), which had extremely low rooting success. For the peat perlite mixture, untreated 'Osage' cuttings had higher rooting percentages compared to when they were treated with auxin (Table 2.9). Application of some auxin concentrations increased the rooting percentage of 'Arapaho' and 'Ouachita' cuttings. Auxin application made no difference for 'Apache', 'Kiowa', and 'Triple Crown' cuttings. For four weeks after initiation the peat perlite had a higher rooting percentage than the paper towel (Table 2.10).

Table 2.9. Effect of cultivar and auxin on the percent of cuttings rooted two weeks after initiation of one-node hardwood blackberry cuttings within the peat perlite mixture.

Auxin	Rooted (%)					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0 e[z]	0 e	0 e	23 bc	0 e	8 de
1000 ppm IBA quick dip	0 e	17 bcd	0 e	0 e	35 a	0 e
3000 ppm IBA quick dip	0 e	27 ab	0 e	0 e	6 de	0 e
5000 ppm IBA quick dip	0 e	0 e	0 e	0 e	15 cd	0 e
8000 ppm IBA quick dip	0 e	0 e	0 e	0 e	0 e	0 e

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Table 2.10. Rooting percentage of one-node hardwood blackberry cuttings four weeks after initiation in both rooting methods.

Method	Rooted (%)
Peat Perlite	1 a[z]
Paper Towel	0 b

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Shoot Length

The interaction between cultivar and auxin treatment was significant two weeks after initiation (Table 2.11). Shoot length of cuttings decreased with increasing auxin concentrations for ‘Arapaho’ and ‘Ouachita’, however, in ‘Triple Crown’ shoot length increased with increasing auxin concentrations. Shoot length of cuttings for ‘Apache’, ‘Kiowa’, and ‘Osage’ responded variably with different auxin concentrations. The interaction between auxin and rooting method was significant four weeks after initiation with untreated cuttings in the peat perlite mixture having the longest shoot length (Table 2.12). Shoot length decreased with the application of auxin concentrations 3000 ppm IBA and higher in both rooting methods. The interaction between cultivar and auxin treatment was also significant four weeks after initiation, with the general trend observed of shoot length decreasing as auxin concentration increased (Table 2.13). Untreated cuttings had the longest shoots for ‘Apache’, ‘Arapaho’, ‘Kiowa’, and ‘Ouachita’. For ‘Osage’ and ‘Triple Crown’ shoots were similar sizes no matter what auxin concentration was used.

Table 2.11. Effect of cultivar and auxin on shoot length two weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

Auxin	Shoot Length (cm)					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0.20 cdef[z]	0.66 a	0.19 cdefg	0.29 c	0.49 b	0.03 defghi
1000 ppm IBA quick dip	0.08 defgh	0.51 ab	0.08 defgh	0.06 efgh	0.46 b	0.04 ghi
3000 ppm IBA quick dip	0.04 gh	0.46 b	0.00 i	0.09 defghi	0.21 cde	0.06 defghi
5000 ppm IBA quick dip	0.02 hi	0.35 bc	0.07 efgh	0.05 fgh	0.20 cdefg	0.09 defghi
8000 ppm IBA quick dip	0.24 cd	0.21 cde	0.04 gh	0.04 gh	0.10 defghi	0.00 i

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Table 2.12. Effect of auxin and rooting method on shoot length four weeks after initiation of one-node hardwood blackberry cuttings in the rooting methods.

Auxin	Shoot Length (cm)	
	Paper Towel	Peat Perlite
Untreated	0.13 b[z]	0.32 a
1000 ppm IBA quick dip	0.03 cd	0.08 b
3000 ppm IBA quick dip	0.00 d	0.01 d
5000 ppm IBA quick dip	0.00 d	0.01 d
8000 ppm IBA quick dip	0.00 d	0.00 d

[z]Means within the same method followed letter are not significantly different according to a pairwise t-test (P>0.05).

Table 2.13. Effect of cultivar and auxin on shoot length four weeks after initiation of one-node hardwood blackberry cuttings in both rooting methods.

Auxin	Shoot Length (cm)					
	Apache	Arapaho	Kiowa	Osage	Ouachita	Triple Crown
Untreated	0.11 c[z]	0.39 a	0.23 b	0.08 cd	0.47 a	0.08 cd
1000 ppm IBA quick dip	0.01 d	0.07 cd	0.00 d	0.00 d	0.25 b	0.00 d
3000 ppm IBA quick dip	0.00 d	0.00 d	0.00 d	0.00 d	0.03 cd	0.00 d
5000 ppm IBA quick dip	0.00 d	0.00 d	0.00 d	0.00 d	0.04 cd	0.00 d
8000 ppm IBA quick dip	0.00 d	0.00 d	0.00 d	0.00 d	0.00 d	0.00 d

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Discussion

Cultivar performance for root production was extremely variable in this experiment in relation to the concentration of auxin applied. The cultivars that did seem to perform more consistently in this experiment with regard to root number, root length, and rooting percentage were Arapaho, Ouachita, and Osage with little or no auxin. 'Ouachita' and 'Arapaho' seemed to benefit the most from a low application of auxin while 'Osage' rooted without any auxin. 'Triple Crown' had very limited rooting success whether auxin was applied or not and 'Apache' and 'Kiowa' were the worst cultivars. This is contrary to what Bray et al. (2003) found, where the best rooting occurred in 'Apache' with 0.3% auxin treatment and rooting of 'Arapaho' decreased with application of 0.3% auxin.

The success of 'Arapaho' and 'Ouachita' is somewhat surprising since they are erect cultivars and typically propagated via root cuttings (Caldwell, 1984). It was expected that some of the trailing cultivars such as Kiowa or Triple Crown would have performed better since they are commonly propagated by tip layering because of the ease with which they form adventitious roots (Caldwell, 1984; Crandall, 1995). However, Goncalves et al. (2012) found that 'Ouachita' rooted better compared to 'Arapaho' and that 'Ouachita' rooted just as well as the trailing cultivar Karaka. Additionally, Lopez-Medina and Moore (1997) found that 'Arapaho' had the highest rooting success compared to three other erect cultivars, none of which were evaluated in this experiment.

Interestingly, cultivars did not respond well to higher auxin concentrations in regards to rooting and shoot length for a majority of the cultivars in both rooting methods. Hartmann et al. (2011) states that higher concentrations of auxin can have deleterious effects on cuttings and even cause death, but the concentrations used here were not unusually high for hardwood

cuttings. Busby and Himelrick (1999) recommended a range of 3000 to 8000 ppm liquid dips for rooting softwood cuttings of blackberry and did not mention deleterious effects on cuttings with the higher concentrations. However, their quick dip was only for 5 seconds whereas in this experiment the quick dip was for 10 seconds. It could be that the additional length of time in the auxin was not beneficial at higher concentrations.

As mentioned previously in the other experiments and also observed here, frequently when shoots were produced on the cuttings, roots did not form as readily. Low concentrations of auxin were beneficial to root production in 'Arapaho' and 'Ouachita' cuttings but no auxin was beneficial for shoot growth. This was to be expected as Blythe et al. (2007) mentioned that increasing auxin concentration can produce detrimental effects on shoot growth. In the case of 'Arapaho' and 'Ouachita', auxin application might be beneficial to promote root formation and not shoot elongation, especially since root formation is desirable prior to shoot elongation.

These results also indicated that a peat perlite mixture might produce more desirable results than using paper towels as a rooting environment. However, more resources and space would be required for this method so a grower would have to weigh the pros and cons of each method to see if the costs would outweigh the benefits. The low root numbers and lengths relay the fact that this experiment had a low success rate regardless of cultivar, auxin, or rooting method, especially when compared to similar studies of hardwood cuttings (Bray et al., 2003; Gonclaves et al., 2012; Takeda et al., 2011; Zimmerman et al., 1980). The low rooting results obtained overall, do suggest that this is not an efficient method of propagating these cultivars and further research is required.

Experiment Four

Materials and Methods

The objective for this study was to determine if one-node versus two-node cuttings would produce a better rooted cutting. The thornless trailing cultivar Triple Crown (Galletta et al., 1998) was used for this experiment. Cuttings were taken from two-year-old plants in 2.8 liter plastic nursery containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus at 3 °C during March of 2015.

Single-node cuttings were approximately four cm long with the bud located in the center of the cutting. Double-node cuttings varied in length according to where the buds were located but were generally around 8-10 cm long. Cuttings were treated with a fungicide solution as described in experiment one. A 10-second quick dip of auxin was applied at rates of 1000 ppm and 3000 ppm liquid solution of K-IBA and distilled water to the proximal end of the cuttings. An untreated control group was also established in which cuttings were dipped only in water.

All of the cuttings were placed in 1206 packs (T.O. Plastics, Clearwater, MN, USA) in a medium mixture of one peat: one perlite (v:v) and placed in plastic bags (Ziploc®, SC Johnson and Son, Inc., Racine WI, USA). Care was taken to ensure that the bud on the cuttings was not buried beneath the surface of the medium. They were subjected to the same environmental conditions as described in experiment one. Data was collected two and four weeks after initiation of the experiment on the same variables as described in experiment one.

The experimental design was a randomized complete block design arranged as a 2x5 factorial (two node types and five auxin concentrations) with four replications and two runs. The square root transformation for data (root length, root number, root rating, shoot length, and rooted percent + 1) was performed prior to analysis. Transformed data were analyzed as a

combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

Evaluation of 'Triple Crown' cuttings after two and four weeks revealed no root formation from either one or two node cuttings (data not shown). No significance was found for root rating or shoot length (data not shown). It was observed, however, that a majority of the cuttings had produced callus tissue at the cut ends of the cutting. Most of the cuttings died in the time between the two evaluation periods as a result of rot or fungal infection.

Discussion

Based on prior experiments some rooting success was expected for 'Triple Crown' and is in stark contrast to what was noted by Takeda et al. (2011). Although no significant differences were found between the source of the cuttings (age and location) in the prior experiments, the lack of success in this experiment could be a result of younger, not as well-developed cuttings. Since a two-node cutting would have more stored carbohydrates, it might have been expected to perform better with regards to rooting. However, Zimmerman et al. (1980) compared one-node and three-node hardwood cuttings and found that one-node cuttings rooted better and had better survival rates. Their cuttings were evaluated after six weeks in an intermittent mist system however, and had the cuttings in this experiment survived past four weeks similar results might have been achieved.

Experiment Five

Materials and Methods

The objective of this experiment was to determine whether different types of growing media would initiate better rooting. Based on prior success with 'Siskiyou' (Finn et al., 1999) observed by Takeda et al. (2011) and the recommendation of F. Takeda (personal communication), this thorny floricane-fruiting cultivar was used. Cuttings were taken from 12-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours in March of 2015.

Cuttings were approximately four cm long with the bud located in the center of the cutting and treated with a fungicide solution as described in experiment one. Four different growing media were used in which cuttings were placed and included sand, one peat: one perlite (v:v), perlite, and 162 cell sheet Oasis® Rootcubes® (Oasis® Grower Solutions, Smithers Oasis, Kent OH, USA). Cuttings were placed in an incubator (Percival Scientific Perry, IA, USA) maintained at 22 °C and ~90% humidity at a light level of 15 $\mu mol/m^{-2}/s^{-1}$ with a 8/16 day/night cycle. Runs were placed in separate incubators. Data was collected at the end of two weeks on the same variables as explained in experiment one.

At the end of two weeks, cuttings that had produced roots were subjected to various acclimation procedures. Cuttings were placed in aerated water just so the roots were covered in both regular water and water fertilized with 24-8-16 water soluble Miracle-Gro® (The Scotts Company, LLC., Maysville, OH, USA) at a rate of 2.46 g/ 3.78 l for one week and were then transplanted into Sunshine® #1 growing mix (Sun Gro® Horticulture, Agawam, MA, USA). Cuttings were also directly planted into Sunshine® #1 and placed in the greenhouse under an

intermittent mist system. Additionally, cuttings were maintained in their respective growing media and allowed to stay in the incubator.

The experimental design was a complete randomized design with four replications and two runs. Since the data had a high occurrence of zeros, the square root transformation for data (root length, root number, root rating, and shoot length + 1) was performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

No significant differences were found between the sand, peat perlite mixture, 100% perlite, or Oasis® Rootcubes® for root length, root number, root rating, shoot length, or percent of cuttings rooted (Table 2.14). None of the acclimation methods that the cuttings were subjected to after adventitious root formation, were successful in keeping the cuttings alive. After about a week in each of the different methods the cuttings visibly declined, and subsequently died (data not shown).

Table 2.14. Effect of rooting method on root length, root number, root rating, shoot length, and percent of cuttings rooted of one-node 'Siskiyou' blackberry hardwood cuttings.

Method	Root Length (cm)	Root Number	Root Rating	Shoot Length (cm)	Rooted (%)
Peat Perlite	0.10	1.44	2.31	1.22	28
Oasis® Rootcubes®	0.36	3.77	2.39	1.25	43
Perlite	0.21	1.46	2.41	1.25	40
Sand	0.12	0.68	2.19	1.18	36
Significance[z]	NS	NS	NS	NS	NS

[z]NS=Not significant at P≤0.05.

Discussion

The results generated from this study indicate that similar adventitious root production will occur for 'Siskiyou' in a variety of rooting media. Zimmerman et al. (1980) also found no differences between one peat: one perlite (v:v), sand, perlite, and Oasis® Rootcubes® rooting media with soft-wood cuttings of blackberry. They did note, however, that extensive roots were produced in the sand medium which was not observed in this study and could be a phenomenon exclusive to soft-wood cuttings. A commonly used medium for blackberry cuttings is one peat: one perlite (v:v) and is easy to implement (Busby and Himelrick, 1999; Lopez-Medina and Moore, 1997; Zimmerman et al., 1980). An advantage of this medium is that transplanting of the cutting after root formation does not need to occur right away as more moisture is maintained. Roots are also more likely to form a plug and be more protected when transplanting does occur. Oasis® Rootcubes® have similar advantages, however, this is a costlier method than using a peat and perlite mixture.

For the acclimation of the cuttings, it did not seem to matter whether the roots were longer or shorter, after a period of time they started to turn brown and eventually desiccate, regardless of acclimation method used. This could have occurred because of the disturbance they experienced when data was taken on the cuttings. Lack of success with acclimation indicates further research into this area is needed.

Experiment Six

Materials and Methods

The objective of this experiment was to compare different types of auxin to determine the effect on rooting of two different cultivars for two different plant ages. The two floricane-fruiting blackberry cultivars that were evaluated included the thorny Siskiyou (Finn et al., 1999) and the thornless Triple Crown (Galletta et al., 1998). Cuttings were taken from 13-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours in January of 2016. Cuttings were also taken from three-year-old plants in 2.8 liter containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus at 3 °C. Cuttings were the same size and treated with the same fungicide solution as described in experiment one.

Auxin was applied as a 10-second quick dip at rates of 1000 ppm and 3000 ppm liquid solution of K-IBA and distilled water to the proximal end of the cuttings. Auxin was also applied as a 10-second quick dip at rates of 1000 ppm and 3000 ppm liquid solution 1-naphthaleneacetic acid (NAA) and 50% ethanol with 50% distilled water to the proximal end of the cuttings. An untreated control group in which cuttings were dipped in water was also used. Cuttings were then placed between moistened paper towels and placed in plastic bags (Ziploc®, SC Johnson and Son, Inc., Racine WI, USA). They were subjected to the same environmental conditions as described in experiment one. Data was collected two weeks after initiation on the same variables as described in experiment one.

The experimental design of this experiment was a randomized complete block design arranged as a 2x2x5 factorial (two cultivars, two plant ages, and five auxin concentrations) with three replications and two runs. Since the data had a high occurrence of zeros, the square root

transformation for data (root length, root number, root rating, and shoot length + 1) was performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

No significant differences were found for the number of roots, root length, root rating, shoot length, or percent of cuttings rooted for plant age, cultivar, or auxin treatment (Table 2.15). All the cuttings eventually succumbed to a fungal invasion, even though they had been pre-treated with a fungicide solution.

Table 2.15. Effect of plant age, cultivar, and auxin on root length, root number, root rating, shoot length, and percent of cuttings rooted for one-node 'Siskiyou' hardwood cuttings.

	Root Length (cm)	Root Number	Root Rating	Shoot Length (cm)	Rooted (%)
Plant Age					
Younger	0.01	0.07	1.67	0.05	4
Older	0.01	0.08	2.00	0.04	5
Significance[z]	NS	NS	NS	NS	NS
Cultivar					
Siskiyou	0.02	0.15	1.8	0.07	9
Triple Crown	0.00	0.00	1.8	0.02	0
Significance	NS	NS	NS	NS	NS
Auxin					
Untreated	0.02	0.21	2.00	0.04	9
1000 ppm NAA quick dip	0.02	0.08	1.71	0.03	6
3000 ppm NAA quick dip	0.00	0.00	1.58	0.00	0
1000 ppm IBA quick dip	0.01	0.04	1.88	0.08	3
3000 ppm IBA quick dip	0.01	0.04	2.00	0.07	3
Significance	NS	NS	NS	NS	NS

[z]NS=Not significant at P≤0.05.

Discussion

Rooting percentages of both cultivars were low, especially in comparison to the results found by Takeda et al. (2011). It was thought that perhaps utilizing NAA in this experiment might produce better rooting. It has been found in other species, such as Douglas-fir (*Pseudotsuga menziesii*) that NAA works better for rooting than IBA as noted in Hartmann et al. (2011), however this was not found to be the case with hardwood floricane blackberry cuttings in this experiment. A combination of IBA and NAA might have produced better results than each of the auxins alone as mentioned by Hartmann et al. (2011) and could be a source of future investigation. Auxin with 50% ethanol can be absorbed through the epidermis, and therefore increase rooting potential (Blythe et al., 2007). However, even though the NAA was mixed with 50% ethanol in order to get it into solution no differences were observed compared to the solutions of K-IBA.

Experiment Seven

Materials and Methods

The objective of this experiment was to determine if different auxin concentrations, types, or formulations had an impact on adventitious root formation in ‘Siskiyou’ with two different plant ages. Cuttings were taken from 13-year-old plants at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, from plants that had achieved the correct amount of chilling hours in January of 2016. Cuttings were also taken from three-year-old plants in 2.8 liter containers that had achieved the correct amount of chilling hours in a cooler on the NDSU campus at 3 °C. Cuttings were the same size and treated with the same fungicide solution as described in experiment one.

Auxin was applied as a 10-second quick dip at rates of 1000 ppm, 3000 ppm, 5000 ppm, and 8000 ppm liquid solution of K-IBA and distilled water and 1000 ppm, 3000 ppm, 5000 ppm, and 8000 ppm liquid solution of NAA of 50% ethanol and 50% distilled water to the proximal end of the cuttings. Auxin was also applied in powder form at rates of 0.1% IBA (Hormex® #1, Maia Products, Inc., Westlake Village, CA, USA), 0.3% IBA (Hormex® #3) and 0.8% IBA (Rhizopon AA #3, Hortus USA Corp.) with cuttings dipped in water before being dipped in the powder. An untreated control group was also established in which cuttings were dipped in water. Cuttings were then placed between moistened paper towels (Viva®, Kimberly-Clack Corporation, Neenah, WI, USA) and placed in plastic bags (Ziploc®, SC Johnson and Son, Inc., Racine, WI, USA) and subjected to the same environmental conditions as described in experiment one. Cuttings were evaluated at the end of two weeks for the same variables as described in experiment one.

The experimental design was a randomized complete block design with a 2x12 factorial (two plant ages, and 12 auxin concentrations) with four replications and two runs. Since the data had a high occurrence of zeros, the square root transformation for data (root length, root number, root rating, and shoot length + 1) was performed prior to analysis. Percentage data was transformed using the arcsine square root transformation method. Transformed data were analyzed as a combined analysis using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Runs were combined since their error mean squares differed by less than a factor of 10 and were considered homogenous. Means were separated, where appropriate, using a pairwise t-test with a $P \leq 0.05$. Means were presented as untransformed data.

Results

Root Length

The talc based auxin treatments 0.1% IBA, 0.3% IBA, and 0.8% IBA produced similar results for root length of the cuttings (Table 2.16). However, cuttings in these treatments and the untreated all had longer average root lengths than the rest of the auxin treatments, which were liquid quick dips. Cuttings in the 0.1% IBA treatment had the longest roots compared to the other auxin treatments except for the 0.3% IBA treatment. The 0.3% IBA, 0.8% IBA and untreated all produced the same average root length for cuttings.

Root Number

For root number, cuttings in the talc based auxin treatments 0.1% IBA, 0.3% IBA, and 0.8% IBA were not significantly different than each other, but performed better than the rest of the auxin treatments, which were liquid quick dips (Table 2.16). Cuttings in the 0.8% IBA talc performed the same as the untreated. The 0.1% IBA, 0.3% IBA, and 0.8% IBA auxin treatments along with the untreated had cuttings with greater root numbers than the rest of the auxin treatments, which did not differ amongst each other.

Root Ratings and Percent of Rooted Cuttings

The 0.1% IBA, 0.3% IBA, 0.8% IBA and untreated cuttings produced root ratings that were not significantly different than one another, but were higher than the rest of the auxin treatments (Table 2.16). It can be observed that increasing auxin concentrations tended to result in lower root ratings, even across auxin types. Percent of cuttings that rooted was highest for cuttings in the 0.1% IBA talc with the untreated exhibiting the same effect as the 0.3% and 0.8% talc (Table 2.16). Cuttings taken from older material from the USDA-ARS were found to have a higher rooting percentage than those taken from younger material from NDSU (Table 2.17).

Shoot Length

Although not indicative of rooting success it was found that the cuttings which produced the longest shoots after breaking bud were also from treatments 0.1% IBA, 0.3% IBA, and 0.8% IBA as well as 1000 ppm IBA quick dip, and were not different from one another (Table 2.16). It was noted that most of the cuttings did break bud and produce a shoot even though no roots were produced.

Table 2.16. Effect of auxin treatments on root length, root number, root rating, shoot length, and percent of cuttings rooted for one-node hardwood cuttings of 'Siskiyou' blackberry.

Auxin	Root Length (cm)	Root Number	Root Rating	Shoot Length (cm)	Rooted (%)
Untreated	0.09 b[z]	0.50 bc	2.19 a	0.13 bcde	44 b
0.1 % IBA talc	0.19 a	2.05 a	2.56 a	0.33 a	69 a
0.3% IBA talc	0.14 ab	1.62 a	2.13 a	0.21 abc	38 b
0.8% IBA talc	0.11 b	1.44 ab	2.19 a	0.25 ab	38 b
1000 ppm IBA quick dip	0.01 c	0.13 c	1.63 b	0.19 abcd	6 c
3000 ppm IBA quick dip	0.04 c	0.31 c	1.50 b	0.11 bcde	13 c
5000 ppm IBA quick dip	0.01 c	0.06 c	1.38 b	0.12 bcde	6 c
8000 ppm IBA quick dip	0.00 c	0.00 c	0.81 cd	0.00 e	0 c
1000 ppm NAA quick dip	0.01 c	0.13 c	1.31 b	0.00 e	6 c
3000 ppm NAA quick dip	0.00 c	0.00 c	1.19 bc	0.08 cde	0 c
5000 ppm NAA quick dip	0.00 c	0.00 c	0.69 d	0.00 e	0 c
8000 ppm NAA quick dip	0.00 c	0.00 c	0.38 d	0.05 de	0 c
Significance[y]	*	*	*	*	*

[z]Means followed by the same letter within a column are not significantly different according to a pairwise t-test (P>0.05).
[y]NS, *=Not significant or significant, respectively, at P≤0.05.

Table 2.17. Rooting percentage of hardwood cuttings of 'Siskiyou' blackberry taken from material harvested from older and younger plants.

Age	Rooted (%)
Younger	15 b[z]
Older	22 a

[z]Means followed by the same letter are not significantly different according to a pairwise t-test (P>0.05).

Discussion

The goal of this experiment was to elucidate the best auxin treatment for adventitious rooting in 'Siskiyou', a cultivar known for its rooting success. The general trend observed was that the untreated and talc form of auxin performed better than the liquid quick dips. This was a rather interesting find as Hartmann et al., (2011) noted that it is more often the case that the liquid quick dips perform better than the talc in auxins of similar concentrations. This is a result of the talc not adhering very well to the cutting, resulting in a variable concentration of the auxin actually being applied to the cutting. A few species have been noted to have better success with talc based auxin and include *Elaeagnus*, *Rhododendron,* and *Ilex* (Hartmann et al., 2011*).* This may also be the case with hardwood blackberry cuttings, however in experiment two no differences were found between auxin formulations of similar concentrations. Other means of auxin application that could be investigated include the dilute soaking method, or application of the quick dip prior to dipping in the talc (Blythe et al., 2007; Hartmann et al., 2011). Since the untreated was not significantly different from some of the auxin applications and in some cases better, it may not be necessary to apply auxin in order to increase adventitious root production of hardwood floricane blackberry cuttings.

Conclusion

The lack of significance in most of these experiments and the low adventitious root numbers observed indicate that this method of blackberry propagation in particular is extremely variable and lacking in efficiency. There are currently no widely accepted universal recommendations for hardwood blackberry cuttings with regard to auxin concentrations and appropriate rooting method. As is evidenced from this study as well as prior work, rooting of hardwood blackberry cuttings is variable from cultivar to cultivar and also with auxin treatments

within cultivars (Bray et al., 2003; Gonclaves et al., 2012; Lopez-Medina and Moore, 1997; Takeda et al., 2011; Zimmerman et al., 1980). The many times that the untreated was not significantly different than the auxin treatments seems to indicate that auxin is not necessary for rooting. However, when auxin was applied it was found that lower concentrations were beneficial as well as the talc formulations of auxin, but again it is cultivar dependent. From these experiments it appears that 'Siskiyou' roots fairly well, but it was not shown statistically that this is a superior cultivar with respect to adventitious root production. As previously discussed it was expected to find increased rooting with trailing versus erect types, however this was not shown. Along with cultivar and plant type, source of the cutting material in regard to plant age and how is it is grown was also something taken into consideration in some of these experiments.

The use of two different plant ages each from a different location was to determine whether the age of the cuttings or the way in which they were grown had an impact on adventitious root production. Since the two ages of the plant material did not come from the same location it cannot be determined whether the age of the plants or the location from which they came produced an impact on rooting. However, the only difference between the plant ages was found in experiment seven with older cuttings having a higher rooting percentage. Additional work should be continued to see the impact of age or location on adventitious root production of hardwood floricane cuttings.

According to Hartmann et al. (2011), when rooting hardwood cuttings, ample material should be taken in order to have enough stored carbohydrates to produce roots. When cuttings produce shoots before roots it is thought that they use most of the available stored energy they possesses and are thus unable to produce roots. Similarly, callus production is an energy consuming process and may not always be indicative of rooting and therefore excessive callus

production should be avoided. Although callus was included as part of the root rating it was not indicative of root production as the callus occurred mainly on the cut ends and not by the bud where the adventitious roots were located. Achieving rooting success of a cutting, while critically important is only half the battle.

After root initiation, an easy and economical way to get the roots to acclimate to harsher conditions is of importance. None of the methods tried in this study worked with any great amount of success. A total of three cuttings from all of the cuttings used in the seven experiments survived and formed a plant. These cuttings were all 'Siskiyou' from different experiments and were potted in Sunshine #1 and left in the misting chamber in the greenhouse. It is not known why they survived and the multitudes of others did not and appeared to be random chance.

Although the results indicate that the success of rooting hardwood blackberry cuttings is cultivar dependent, more work still needs to be accomplished. Determining cultivar differences as well as differences between erect and trailing types should occur. Continued work should also occur to find the best, if any, auxin concentration and form of application. Before recommending this method as means of propagation or even suggesting the use of an annual production system, a more efficient and cost effective method needs to be discovered. As it currently stands, this method of blackberry propagation is not feasible for large scale production purposes and is possibly why it is not a method currently in use by nurseries.

Literature Cited

Blythe, E.K., J.L. Sibley, K.M. Tilt, and J.M. Ruter. 2007. Methods of auxin application in cutting propagation: a review of 70 years of scientific discovery and commercial practice. J.Environ. Hort. 25:166-185.

Bray, M.M., C.R. Rom, and J.R. Clark. 2003. Propagation of thorn less Arkansas blackberries by hardwood cuttings. Discovery (Univ. of Arkansas) 4:9-13.

Busby, A.L. and D.G. Himelrick. 1999. Propagation of blackberries (*Rubus* spp.) by stem cuttings using various IBA formulations. Acta Hort. 505:327-332.

Clark, J.R. 2013. 'Osage' thornless blackberry. HortScience. 48:909-912.

Clark, J.R. and J.N. Moore. 1999. 'Apache' thornless blackberry. HortScience. 34:1291-1293.

Clark, J.R. and J.N. Moore. 2005. 'Ouachita' thornless blackberry. HortScience. 40:258-260.

Caldwell, J.D. 1984. Blackberry propagation. HortScience 19:13-15.

Crandall, P.C. 1995. Bramble production: The management and marketing of raspberries and blackberries. Food Products Press. Binghamton, NY.

Finn, C.E., F.J. Lawrence, B.C. Strik, B. Yorgey, and J. DeFrancesco. 1999. 'Siskiyou' trailing blackberry. HortScience. 34:1288-1290.

Galletta, G.J., J.L. Maas, J.R. Clark, and C.E. Finn. 1998. 'Triple Crown' thornless blackberry. Fruit Varieties Journal. 52:124-127.

Gonclaves, D.M., C.M. Oliveira, L.Lopes-da-Fonseca, and P.B. Oliveira. 2012. Blackberry production by floricane stem cuttings. Acta Hort. 946:379-381.

Hambrick, C.E., F.T. Davies Jr., and H.B. Pemberton. 1991. Seasonal changes in carbohydrate/nitrogen levels during field rooting of *Rosa multiflora* 'Brooks 56' hardwood cuttings. Scientia Horticulturae 46:137-146.

Hartmann, H.T., D.E. Kester, F.T. Davies, Jr., and R.L. Geneve. 2011. Plant Propagation: Principles and practices. 8th ed. Prentice Hall, Upper Saddle River, NJ.

Lopez-Medina, J. and J.N. Moore. 1997. Propagation of erect blackberries by floricane stem cuttings. HortScience 32:602 (abstr.).

Moore, J.N. and J.R. Clark. 1993. ‘Arapaho’ erect thornless blackberry. HortScience. 28:861-862.

Moore, J.N. and J.R. Clark. 1996. ‘Kiowa’ blackberry. HortScience. 31:286-288.

Raven, P.H., R.F. Evert, and S.E. Eichhorn. 2005. Biology of plants. 7th ed. W.H. Freeman and Company Publishers, New York, NY.

Takeda, F., T. Tworkosi, C.E. Finn, and C.C. Boyd. 2011. Blackberry propagation by non-leafy floricane cuttings. HortTechnology 21:236-239.

Zimmerman, R.H., G.J. Galleta, and O.C. Broome. 1980. Propagation of thornless blackberries by one-node cuttings. J. Amer. Soc. Hort. Sci. 105:405-407.

CHAPTER 3. HIGH TUNNEL PRODUCTION OF PRIMOCANE BLACKBERRY IN A NORTHERN CLIMATE

Abstract

The recent introduction of primocane-fruiting blackberry cultivars may enable blackberry (*Rubus* L. subgenus *Rubus*, Watson) production in northern climates such as North Dakota, however, methods to increase yield need to be evaluated. Four primocane-fruiting cultivars, Prime-Jim®, Prime-Jan®, Prime-Ark® 45, and Prime-Ark® Freedom were evaluated in bare soil, silver plastic reflective mulch, and a high tunnel in 2015. Primocanes were subjected to no tipping, single soft-tipping and double soft-tipping treatments to determine the impact on growth and yield. Cultivar differences for yield were not found in any of the environments. Despite increasing the number of branches and inflorescences, tipping did not increase yield in the high tunnel or bare soil. Double-tipping decreased yield compared to single-tipping and no tipping in the silver mulch. Highest yield production occurred from 13 September –10 October in all the environments. Further research is needed to evaluate additional growing seasons as the plants continue to mature.

Introduction

Northern Use of Primocane-Fruiting Blackberry Cultivars

The recent introduction of primocane-fruiting blackberry cultivars from the University of Arkansas has provided the possibility of successful blackberry production in colder climates without having to use overwintering practices (Clark et al., 2005). The cultivars include Prime-Jan®, Prime-Jim®, Prime-Ark® 45, Prime-Ark® Freedom, and Prime-Ark® Traveler (Clark et al., 2005; Clark and Perkins-Veazie, 2011, Clark, 2014; Clark and Salgado, 2016). 'Prime-Ark® 45' and more recently 'Prime-Ark® Traveler' have been recommended for use in the

commercial market since they have firmer fruit. ‘Prime-Jan®’ has been noted to have higher primocane yields than ‘Prime-Jim®’ and ‘Prime-Ark® Freedom’. ‘Prime-Jan®’ also flowers and fruits earlier than ‘Prime-Ark® 45’ which is beneficial to obtain the maximum yield in a shorter growing season. ‘Prime-Ark® 45’ has higher primocane yields than the other cultivars; however, it flowers on average two weeks later than ‘Prime-Jim®’ and ‘Prime-Jan®’. Although these cultivars are rated for USDA Zone 4 hardiness, they produce fruit late into the season and early fall frosts can stop fruiting. Variable frost dates from year to year do not ensure that the fruit will have enough time to ripen each season and can detrimentally impact yield (Nennich, 2012).

It is currently not fully understood what triggers primocane-fruiting blackberries from the University of Arkansas to bloom. In primocane-fruiting raspberry it has been documented that they are independent of the normal triggers of day length and temperature and the same is thought to be true of primocane-fruiting blackberry (Lopez-Medina et al., 1999; Strik, 2012). Lopez-Medina et al. (1999) found that after a short period of growth, typically around 20 nodes in field studies, floral bud initiation begins to occur with bloom occurring about a month later. Additional heat via use of high tunnels applied early on in the season could provide an advantage in hastening bloom of primocane-fruiting blackberry, as plants could reach the point of 20 nodes earlier in the season.

High Tunnels

High tunnels have been around for many years to extend the growing season and vary widely in their structural design and whether or not they are fully enclosed (Lamont, 2008; Carey et al., 2008). They are most commonly used worldwide for annual vegetable production. More recently, interest in small fruit production to extend the season has been observed with strawberry as the main crop (Demchak, 2008). High tunnels have the potential to extend the

season as well as protect the crop from the elements and produce better quality fruit. Success has been documented with higher yields of floricane-fruiting blackberries in high tunnels in northern climates (Demchak, 2008; Pritts, 2016). Successful yields have also been realized in northern climates with primocane-fruiting raspberry (Demchak, 2008; Hanson et al., 2011; Yao and Rosen, 2011).

Some research using high tunnels to extend the fruiting season of primocane-fruiting blackberry to help increase yield has occurred in milder climates such as Oregon (Thompson et al., 2009). Thompson et al. (2009) reported longer harvest dates, and therefore higher yields, as a result of using a high tunnel compared to the open field. The main purpose of the use of high tunnels in this climate, however, was to protect against the fall rains that destroy the berries for harvest. Plastic is not kept on these high tunnels year round and so no spring extension capabilities are known. High tunnel production of blackberry has also been researched in some colder climates such as Minnesota (Nennich, 2012). It was reported that harvesting of berries occurred into October within the high tunnel; however, the yields obtained were less than desirable. According to Nennich (2012), growth begins earlier in the spring for blackberry when grown in a high tunnel, which can lead to early fruit production. In fall, the high tunnel extends the fruiting season by allowing the blackberries to continue to produce into October, whereas if they were grown outside, a September frost would stop production. It was noted by the author that in order to keep production going inside the high tunnel, supplemental heat was applied on a few of the unexpectedly cold nights during September.

Reflective Mulch

Various colors of plastic mulch have been used by fruit and vegetable growers in order to obtain higher yields and reduce pest problems on their crops. Hutton and Handley (2007) used silver plastic mulch to increase the yield on pepper (*Capsicum annuum*) plants by placing it in the plant rows. They found that the silver mulch significantly increased total marketable yield in comparison to black plastic mulch. Primocane-fruiting blackberry cultivar yields can be lower than floricane-fruiting blackberry cultivars (Clark et al., 2005). Thus growing them with in-row silver plastic mulch has the potential to increase yields.

Tipping

A pruning practice known as 'soft-tipping' can be used in primocane-fruiting blackberry to increase yield. This process removes around 2-5cm of the apical tip of the primocanes prior to flower bud development while the cane is still in a vegetative phase. Removing the apical tip encourages lateral branching to occur resulting in additional fruiting sites. Since primocane-fruiting blackberry cultivars do not yield as high as floricane-fruiting cultivars, tipping can be used as a means to increase yield (Clark et al., 2005). Strik et al. (2008) compared non-tipped to tipped plants and found that tipped plants produced three times the yield of non-tipped plants. A detriment of the tipping procedure, as reported by Thompson et al. (2009), is that it can delay the fruit harvest season by a couple of weeks, especially if plants are double-tipped. However, they also reported higher yields when combining double-tipping with the season extension of a high tunnel. Prior research on whether use of a high tunnel with tipping methods will increase yield in colder climates has not yet been documented.

Research Objective

The objective of the primocane-fruiting blackberry research is to evaluate the effectiveness of cultivar and tipping method on production in three different growing environments (high tunnel, silver plastic mulch and bare soil) in a cold climate. Specifically the following questions will seek to be answered. Which primocane-fruiting cultivar or tipping method produces the largest marketable yield in each environment? Does tipping or double-tipping delay fruit harvest to a level that it will decrease the yield? Do certain cultivars respond better to one tipping method over another with regard to yield and time of production?

Materials and Methods

Four cultivars of primocane-fruiting blackberry were evaluated in this study. These included the cultivars Prime-Jim®, Prime-Jan®, and Prime-Ark® 45, all of which are erect thorny types and the erect thornless cultivar Prime-Ark® Freedom. Thirty-six plants of each cultivar were planted in July 2014 and evaluated the following growing season within three different growing environments adjacent to one another at one location on the North Dakota State University campus in Fargo, ND (lat. 46°53’36”N, long. 96°48’36”W, USDA hardiness Zone 4a). The site was surrounded by windbreaks on all sides and consisted of a Fargo silty clay loam soil type with a pH of 7.1. The three environments consisted of two rows of blackberries planted in each of the following; a high tunnel, open field with bare soil, and open field with in-row 1.0 mil silver plastic reflective mulch (Johnny’s Selected Seeds, Winslow, ME).

The high tunnel was 6.7 m wide by 25.6 m long and covered year round with a single layer of clear 6 mm plastic with 88% light transmission (Rimol Greenhouse Systems, Inc., Hooksett, NH). No supplemental heat was provided to the high tunnel. The silver plastic reflective mulch extended the length of each row and was approximately 1 m wide. Plants were

spaced 1 m apart within rows and 2.4 m apart between rows. Row width was maintained at approximately 0.5 m for all environments by manually removing suckers. Primocanes outside of 0.5 m within the row were removed in order to differentiate between plants. A T-trellis with double sets of wires located at 1 m and 1.5 m was used to train the canes between, although they were not tied to the wires. Plants were irrigated as necessary with drip tape irrigation (AQ-TRXX 30 cm spacing, 1.02 lph 1.70 lpm/30 m, The Toro Company, Bloomington, MN). Plants were fertilized in May of 2015 at a rate of 56 kg/ha using a 46-0-0 urea granular fertilizer based on soil samples as recommended by Hart et al. (2006). Phosphorus and potassium were at acceptable levels for blackberries. Relative humidity and ambient temperatures were recorded in each environment at approximately 1 m high using sensors (Decagon VP-3 sensor, Decagon Devices, Pullman, WA) and data loggers (Decagon Em50R data logger, Decagon Devices, Pullman, WA). Soil moisture and soil temperature was recorded as well at approximately a 15 cm depth using sensors (Decagon 5TM sensor, Decagon Devices, Pullman, WA) and the same Em50R Decagon data loggers.

Three different tipping methods were applied to each of the four cultivars in all environments. The three tipping methods included a control (no tipping), single-tipping, and double-tipping. All of the tipping treatments were considered ‘soft-tip’ with 2-5 cm of the tip removed from the primocanes. The tipping treatments were similar to those used by Thompson, et al. (2009). The single-tipping occurred when the primocanes were at an average height of 0.5 m and the double-tipping also occurred when the primocanes were at an average height of 0.5 m and when the lateral branches reached a length of 0.5m. In order to catch the various flushes of cane growth at the proper height, a two-week window was used in which the plants were tipped. Plants were pruned to the ground after the growing season in November and covered with a 915

mg m^{-2} thermal blanket (DeWitt, Sikeston, MO) and mulched with 10-12 cm of straw to prevent root damage. Sides of the high tunnel were rolled up around 20 cm to allow venting on warm days as recommended by Heidenreich et al. (2012).

Data were collected to determine growth, yield, and berry characteristics as reported by Thompson et al., (2009) and Strik et al., (2012), but were collected on a per plant basis instead of averaged on a per plot basis. Additionally, growing degree days were calculated for each environment.

Data for growth and bloom per plant included: date of primocane emergence, tipping dates, bloom date of first fully open flower, date of fully ripe terminal fruit, and total primocane length at bloom. Bloom data were recorded throughout the season with the number of new inflorescences blooming per plant recorded every three days. The total number of floral structures (buds and blossoms) were counted at first open terminal flower on an inflorescence and summed per plant across the growing season. Days from bloom to first ripe terminal fruit were also determined. Primocane fresh weight per plant was recorded in November after the plants were cut to the ground. Primocane growth in terms of height was recorded weekly throughout the growing season on three canes per plant beginning 3 June and ending 30 September, as minimal growth was seen after this point. Primocane height included the length of the main cane plus the apical branch. Main cane length was measured from the ground to the tip of the plant and branch length was measured from the main cane to the tip of the branch. Data were collected per plant on the following variables at the end of the growing season, number of fruiting and non-fruiting canes, average fruiting and non-fruiting cane length, number of branches, and node location of branches. Three arbitrary reproductive primocanes were chosen and the following data collected, total number of nodes, total number of reproductive nodes, and

the total number of fruiting sites (included both evidence of where fruit had existed and current berries) per cane. Percent of reproductive nodes was calculated by taking the number of reproductive nodes divided by the total number of nodes.

Yield data collected per harvest time included the weight and number of berries per plant as well as the average berry weight, length, and width (n=10). Harvest occurred every three days and dates of fruit harvest were recorded. Berries were considered fully ripe when they achieved a glossy black appearance and separated easily from the stem when tipped to the side (Crandall, 1995). Total yield per plant and marketable yield per plant were also determined. Total and marketable yield included the number and weight of berries. Marketable berries were determined by the absence of visual blemishes. After data collection on size and weight, berries were frozen (-10 °C) for later analysis of berry characteristics.

Data collection for berry characteristics included berry soluble solids concentration (SSC), pH, and titratable acidity (TA). Due to small sample size for each harvest period, thawed berry samples were pureed using a polytron (Polytron®, Kinematica AG, Lucerne, Switzerland). SSC was measured using the berry puree with a digital refractometer (Pocket Refractometer PAL-1, Atago® U.S.A., Inc., Bellvue, Washington). The pH of the berry puree was measured using a calibrated pH meter (Orion Star A111, Thermo Fisher Scientific, Waltham, MA). Berry TA was determined using the method mentioned by P. Perkins-Veazie (personal communication) and calculated as percent citric acid. Three milliliters of berry puree was added to 40 ml of distilled water having a pH of 8.2, this mixture was then titrated back to a pH of 8.2 with 0.1 N NaOH.

The experimental design for each environment was a randomized complete block design with four replications for each treatment arranged as a 4x3 factorial (four cultivars and three tipping methods). Data was analyzed using PROC MIXED (SAS® 9.3, Statistical Analysis Software, SAS Institute Inc., Cary, NC, USA). Primocane height and number of inflorescences blooming per plant were averaged monthly and analyzed by repeated measures. Yield harvest periods were summed biweekly and were also analyzed by repeated measures. Environments were not statistically compared as a result of lack of replication. Tests of simple effects were performed on interactions using the SLICE function in SAS® 9.3. Means were separated where appropriate using a pairwise t-test with a $P \leq 0.05$.

Results

Vegetative Growth Characteristics

Date of primocane emergence did not differ amongst cultivars in the bare soil and silver mulch environments (Table 3.1). 'Prime-Ark® Freedom' did emerge, on average, five days earlier than the other cultivars in the high tunnel. Although not statistically comparable, emergence was approximately a week earlier in the high tunnel than the outside environments.

Table 3.1 Cultivar differences for date of emergence in three different growing environments.

Cultivar	Date of Emergence (Julian)		
	High Tunnel	Silver Mulch	Bare Soil
Prime-Ark® 45	115 a[z]	120	127
Prime-Ark® Freedom	110 b	119	119
Prime-Jan®	117 a	123	125
Prime-Jim®	115 a	123	125
Significance[y]	*	NS	NS

[z]Means within the same environment followed by the same letter are not significantly different according to a pairwise t-test P>0.05.
[y]NS,*=not significant or significant, respectively, at P≤0.05.

The average date of single-tipping averaged across cultivars was 165, 174, and 182 Julian days in the high tunnel, silver mulch, and bare soil respectively (Figure 3.1). The average date of

double-tipping averaged across cultivars was 187, 195, and 201 Julian days in the high tunnel, silver mulch and bare soil respectively.

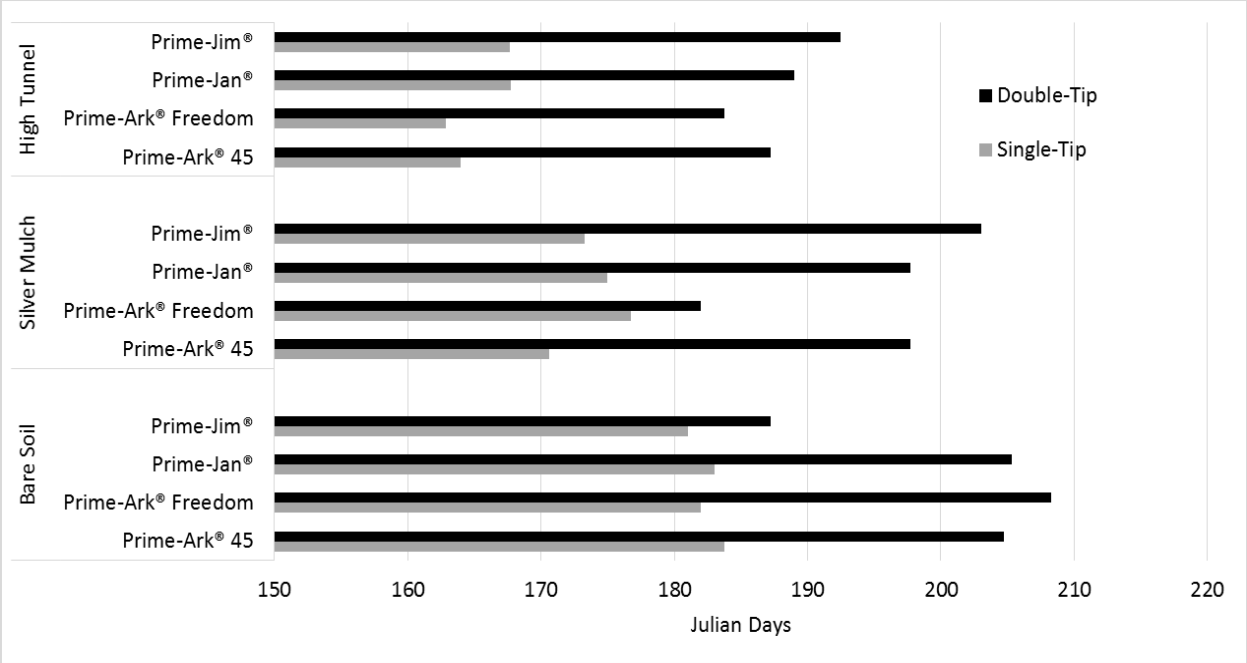

Figure 3.1. Average date of single-tipping and double-tipping for each cultivar in three different growing environments.

The interaction of tipping treatment by month was significant for plant height in all of the environments and tests of simple effects evaluated the variation among tipping treatments within certain months (Figure 3.2). It wasn't until July that control plants outgrew the single-tipped and double-tipped plants and were the tallest in the high tunnel. This did not occur until August in the silver mulch. In the bare soil, in August, the control plants were taller than both the single-tipped and double-tipped plants. Control plants were taller than double-tipped plants in September in all environments. 'Prime-Ark® Freedom' was taller than both 'Prime-Jan®' and 'Prime-Jim®' in the high tunnel but in the bare soil 'Prime-Jim®' was taller than both 'Prime-Jan®' and 'Prime-Ark® Freedom' (Table 3.2).

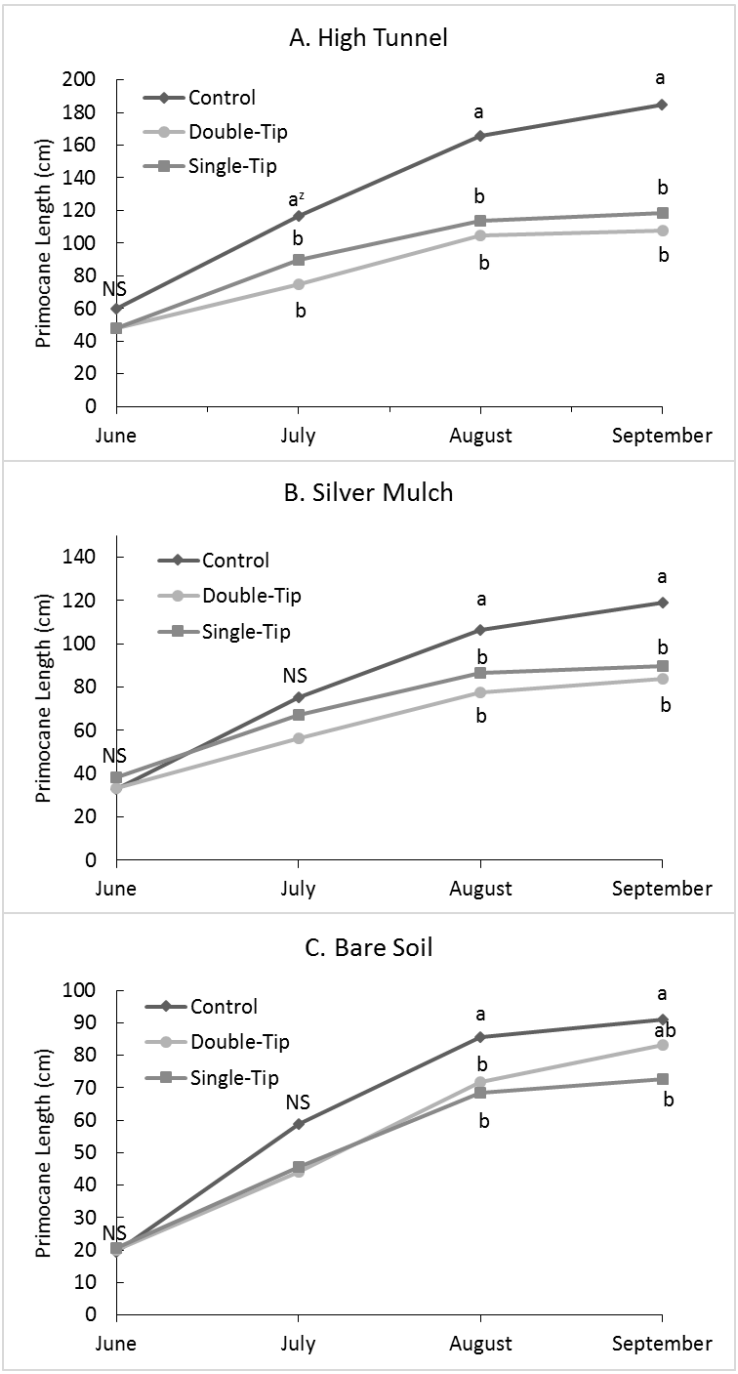

Figure 3.2. Effect of time and tipping treatment on primocane length in the high tunnel (A), silver mulch (B), and bare soil (C) throughout the growing season.
[z]Means within the same month in each environment followed by different letters are not significantly different according to a pairwise t-test, P>0.05. NS = not significant.

Table 3.2. Effect of cultivar on plant height measured during the growing season for the high tunnel and bare soil environments

Cultivar	Plant Height (cm)	
	High Tunnel	Bare Soil
Prime-Ark® 45	110.69 ab[z]	59.97 ab
Prime-Ark® Freedom	118.54 a	46.12 c
Prime-Jan®	85.66 c	51.34 bc
Prime-Jim®	95.65 bc	69.66 a
Significance[y]	*	*

[z]Means within the same environment followed by the same letter are not significantly different according to a pairwise t-test P>0.05.
[y]NS,*=Not significant or significant, respectively, at P≤0.05.

Cultivars performed similarly in the high tunnel and silver mulch with regard to number of non-flowering canes per plant (Table 3.3). ‘Prime-Jim®’ in the bare soil had the fewest non-flowering canes compared to the other cultivars. ‘Prime-Jim®’ in the high tunnel had shorter non-flowering canes than ‘Prime-Ark® 45’ and ‘Prime-Ark® Freedom’. Tipping treatments did not impact the number of non-flowering canes or non-flowering cane length in the silver mulch, but differences were found in the other environments. Single-tipped plants in the bare soil had the fewest non-flowering canes. Control plants in the high tunnel had the longest non-flowering canes. No differences amongst cultivars or tipping treatments for end-of-season fresh weight were found in the high tunnel or bare soil. However, ‘Prime-Jim®’ and ‘Prime-Ark® 45’ had a greater end-of-season fresh weight than the other cultivars in the silver mulch.

Table 3.3. Cultivar and tipping treatment effect on vegetative growth characteristics of primocane blackberry in three growing environments on a per plant basis.

	Fresh Weight (kg)	Non-flowering Canes (no./plant)	Non-flowering Cane Length (cm)
High Tunnel			
Cultivar			
Prime-Ark® 45	2.11	5.1	158.22 ab
Prime-Ark® Freedom	2.51	3.4	174.25 a
Prime-Jan®	2.03	4.1	111.62 bc
Prime-Jim®	1.95	5.0	99.08 c
Significance[y]	NS	NS	*
Tipping Method			
Control	2.12	3.5	184.40 a
Single-Tip	2.39	5.6	105.30 b
Double-Tip	1.94	4.7	117.60 b
Significance	NS	NS	*
Silver Mulch			
Cultivar			
Prime-Ark® 45	1.66 a	5.6	94.25
Prime-Ark® Freedom	1.26 b	6.7	94.98
Prime-Jan®	1.26 b	5.3	108.90
Prime-Jim®	1.76 a	6.3	125.35
Significance	*	NS	NS
Tipping Method			
Control	1.57	6.6	19.70
Single-Tip	1.57	3.9	19.20
Double-Tip	1.32	7.3	13.00
Significance	NS	NS	NS
Bare Soil			
Cultivar			
Prime-Ark® 45	1.18	13.0 ab	86.53
Prime-Ark® Freedom	1.05	14.2 a	65.56
Prime-Jan®	1.04	9.3 b	86.46
Prime-Jim®	1.24	2.4 c	96.26
Significance	NS	*	NS
Tipping Method			
Control	1.21	11.4 a	94.50
Single-Tip	1.09	6.7 b	76.50
Double-Tip	1.08	12.8 a	80.20
Significance	NS	*	NS

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test P>0.05.

[y]NS,*=Not significant or significant, respectively, at P≤0.05.

Average branch number per cane was significantly lower in the control plants compared to the other tipping treatments in all three environments (Table 3.4). Average branch length was not different for cultivars or tipping treatments in any of the environments. Control plants tended to produce branches more basally located, with the node number at which branches formed significantly lower in the high tunnel and bare soil for all cultivars. The interaction of cultivar and tipping treatment was significant in the silver mulch for branch location and tests of simple effects evaluated the differences between tipping treatments within each cultivar. All cultivars except 'Prime-Ark® 45' had control plants with lower branch node numbers compared to single-tipped plants (Table 3.5). Single-tipped plants in the silver mulch had the greatest number of nodes per cane compared to the other treatments while no differences were found between tipping treatments in the other environments. The amount of nodes did not differ amongst cultivars in any environment.

Table 3.4. Cultivar and tipping treatment effect on vegetative growth characteristics of primocane blackberry within three growing environments on a per cane basis.

	Branches (no./cane)	Average Branch Length (cm)	Location (node no.)[z]	Total Nodes
High Tunnel				
Cultivar				
Prime-Ark® 45	3.1	81.3	5.9	87.2
Prime-Ark® Freedom	3.4	103.7	8.0	105.0
Prime-Jan®	3.2	77.9	7.0	87.3
Prime-Jim®	3.7	81.0	7.2	97.1
Significance[y]	NS	NS	NS	NS
Tipping Method				
Control	2.4 b[y]	92.6	5.1 b	89.1
Single-Tip	3.8 a	89.1	8.3 a	103.1
Double-Tip	3.9 a	76.3	7.6 a	90.3
Significance	*	NS	*	NS
Silver Mulch				
Cultivar				
Prime-Ark® 45	3.4	65.2	--	77.7
Prime-Ark® Freedom	3.2	69.0	--	73.1
Prime-Jan®	3.5	50.0	--	66.1
Prime-Jim®	3.1	66.7	--	68.8
Significance	NS	NS		NS
Tipping Method				
Control	1.8 b	70.3	--	62.5 b
Single-Tipped	4.5 a	65.9	--	86.6 a
Double-Tip	3.7 a	51.8	--	65.2 b
Significance	*	NS		*
Bare Soil				
Cultivar				
Prime-Ark® 45	2.3	53.8	4.5	49.1
Prime-Ark® Freedom	2.8	65.5	4.5	53.3
Prime-Jan®	2.8	47.5	3.8	52.9
Prime-Jim®	3.2	57.8	5.0	65.2
Significance	NS	NS	NS	NS
Tipping Method				
Control	1.6 b	55.5	2.6 b	50.0
Single-Tip	3.6 a	52.6	5.8 a	54.4
Double-Tip	3.0 a	60.0	4.9 a	61.0
Significance	*	NS	*	NS

[z]From base of plant.

[y]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test $P>0.05$.

[x]NS,*= Not significant or significant, respectively, at $P\leq0.05$.

Table 3.5. Effect of cultivar and tipping treatment on average inflorescence length per cane, branch location, and number of flowering canes per plant in the silver mulch environment.

Treatment	Prime-Ark® 45	Prime-Jan®	Prime-Jim®	Prime-Ark® Freedom
		Location (node no.)		
Control	5.3	3.1 b	2.2 b	4.4 b
Single-Tip	7.6	6.3 a	8.5 a	10.0 a
Double-Tip	5.7	7.8 a	6.9 a	6.4 b
Significance[y]	NS	*	*	*
		Flowering Cane Length (cm)		
Control	160.5	112.5	234.2 a	187.7 a
Single-Tip	117.8	103.0	106.0 b	91.7 b
Double-Tip	93.5	107.0	89.5 b	109.3 b
Significance	NS	NS	*	*
		Average Inflorescence Length (cm)		
Control	17.0 a	10.6	19.9 a	8.6
Single-Tip	17.3 a	12.6	13.7 b	7.0
Double-Tip	11.7 b	12.6	10.8 b	10.3
Significance	*	NS	*	NS

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test P>0.05.
[y]NS,*= Not significant or significant, respectively, at P≤0.05.

Reproductive Growth Characteristics

The number of flowering canes per plant was not impacted by the tipping treatments but varied amongst the cultivars. A similar trend was found in all three environments, with 'Prime-Ark® Freedom' having fewer flowering canes than 'Prime-Ark® 45' and 'Prime-Jan®' (Table 3.6). In the high tunnel and bare soil, the control plants had longer flowering canes compared to the other tipping treatments for all cultivars. However, in the silver mulch, the interaction of cultivar by tipping treatment was significant for flowering cane length and tests of simple effects were used to evaluate the differences in tipping treatments within cultivars. Only within 'Prime-Ark® Freedom' and 'Prime-Jim®' did the control plants have longer flowering canes compared to the other tipping treatments (Table 3.5).

Table 3.6. Cultivar and tipping treatment effect on reproductive characteristics in primocane blackberry within three growing environments on a per plant basis.

	Flowering Canes (no./plant)	Flowering Cane Length (cm)	Floral Structures (no./plant)
High Tunnel			
Cultivar			
Prime-Ark® 45	7.8 ab	145.23	166.8 ab
Prime-Ark® Freedom	5.2 c	155.96	59.8 b
Prime-Jan®	8.8 a	138.59	179.5 a
Prime-Jim®	5.8 bc	171.22	228.5 a
Significance[y]	*	NS	*
Tipping Method			
Control	5.5	207.10 a	145.9
Single-Tip	7.9	131.30 b	204.1
Double-Tip	7.3	119.90 b	126.1
Significance	NS	*	NS
Silver Mulch			
Cultivar			
Prime-Ark® 45	9.9 ab	--	156.9 a
Prime-Ark® Freedom	3.3 c	--	30.5 b
Prime-Jan®	10.9 a	--	149.1 a
Prime-Jim®	7.0 bc	--	106.8 a
Significance	*		*
Tipping Method			
Control	9.5	--	116.1
Single-Tip	7.0	--	155.0
Double-Tip	6.9	--	101.9
Significance	NS		NS
Bare Soil			
Cultivar			
Prime-Ark® 45	9.8 a	112.08 a	92.7 a
Prime-Ark® Freedom	4.3 c	107.96 a	33.1 b
Prime-Jan®	8.3 ab	86.86 b	130.9 a
Prime-Jim®	5.6 bc	124.78 a	109.6 a
Significance	NS	*	*
Tipping Method			
Control	8.3	136.10 a	94.5
Single-Tip	6.3	97.60 b	103.6
Double-Tip	6.4	90.00 b	76.6
Significance	NS	*	NS

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test $P>0.05$.

[y]NS,*= Not significant or significant, respectively, at $P\leq 0.05$.

Cultivars did not differ in the number of inflorescences per cane, but tipping treatments did have an impact in all three environments. Single-tipped plants in both the high tunnel and bare soil had more inflorescences than the control (Table 3.7). In the silver mulch, both double-tipped and single-tipped plants had a greater number of inflorescences than the control. The cultivars and tipping treatments in the high tunnel all had similar inflorescence lengths. The interaction of cultivar and tipping treatment in the silver mulch was significant for inflorescence length and tests of simple effects were used to evaluate differences in tipping treatments within cultivars. For 'Prime-Jim®' and 'Prime-Ark® 45,' control plants had longer inflorescences than the double-tipped plants (Table 3.5). In the bare soil, 'Prime-Ark® Freedom' had shorter inflorescences than 'Prime-Jim®' and 'Prime-Ark® 45'. Inflorescences did not vary in length for tipping treatments in the bare soil.

Tipping treatment did not have an effect on the number of fruiting sites per cane (Table 3.7). The number of fruiting sites per cane was different amongst cultivars only in the silver mulch with 'Prime-Ark® Freedom' having fewer than 'Prime-Ark® 45' and 'Prime-Jim®'. Tipping treatment did not have an effect on the percent of reproductive nodes per cane. 'Prime-Ark® Freedom' had a lower percent of reproductive nodes per cane in comparison to the other cultivars in all three of the environments.

Table 3.7. Cultivar and tipping treatment effect on reproductive characteristics in primocane blackberry within three growing environments on a per cane basis.

	Reproductive Nodes (% of total/cane)	Fruiting Sites (no./cane)	Inflorescences (no./cane)	Average Inflorescence Length (cm)
High Tunnel				
Cultivar				
Prime-Ark® 45	25.4 a[z]	27.6	2.9	17.1
Prime-Ark® Freedom	15.3 b	13.7	2.6	12.7
Prime-Jan®	24.9 a	27.9	3.3	13.4
Prime-Jim®	23.4 a	35.8	3.6	17
Significance[y]	*	NS	NS	NS
Tipping Method				
Control	21.0	25.4	2.4 b	15.0
Single-Tip	23.4	30.7	3.7 a	15.4
Double-Tip	22.4	22.7	3.2 ab	14.7
Significance	NS	NS	*	NS
Silver Mulch				
Cultivar				
Prime-Ark® 45	30.7 a	28.8 a	3.0	--
Prime-Ark® Freedom	13.5 b	10.2 b	2.0	--
Prime-Jan®	28.5 a	25.8 ab	2.8	--
Prime-Jim®	26.1 a	30.9 a	2.5	--
Significance	*	*	NS	
Tipping Method	23.8	20.5	1.8 b	--
Control	23.7	28.8	3.1 a	--
Single-Tip	26.7	22.4	2.8 a	--
Double-Tip	NS	NS	*	
Significance				
Bare Soil				
Cultivar	24.3 a	14.8	1.7	12.5 a
Prime-Ark® 45	8.6 b	6.3	1.6	6.1 b
Prime-Ark® Freedom	27.3 a	17.7	2.5	10 .0 ab
Prime-Jan®	22.9 a	19.1	2.1	12.9 a
Prime-Jim®	*	NS	NS	*
Significance				
Tipping Method	21.3	16.7	1.6 b	11.0
Control	21.4	14.9	2.4 a	10.3
Single-Tip	19.6	11.8	1.8 ab	9.9
Double-Tip	NS	NS	*	NS
Significance				

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test P>0.05.

[y]NS,*= Not significant or significant, respectively, at P≤0.05.

Bloom and Harvest

No differences were found between cultivars in any of the environments for the date of first bloom or the number of days it took to produce a ripe black fruit from bloom (Table 3.8). For the tipping treatments, however, control plants bloomed sooner than double-tipped plants by approximately two weeks in both the silver mulch and bare soil environments. In the silver mulch, single-tipped plants bloomed at the same time as the control, however, in the bare soil they bloomed later, around the same time as the double-tipped plants. No differences were found among tipping treatments in the high tunnel. Primocane height at bloom only differed in the high tunnel with the control plants being taller than both the single-tipped and double-tipped plants. 'Prime-Ark® 45' took longer to produce ripe fruit from bloom than both 'Prime-Ark® Freedom' and 'Prime-Jan®', but only in the silver mulch environment.

Table 3.8. Effect of cultivar and tipping treatment on days to bloom and fruit and height at bloom within three growing environments.

	Bloom (Julian Days)	Height (cm)	Fruit (Julian Days)	Bloom to Fruit (Julian Days)
High Tunnel				
Cultivar				
Prime-Ark® 45	221	85.3	262	43
Prime-Ark® Freedom	220	83.1	254	39
Prime-Jan®	212	62.7	256	46
Prime-Jim®	215	89.1	253	45
Significance[y]	NS	NS	NS	NS
Tipping Method				
Control	210	138.1 a	248	39
Single-Tip	217	104.8 b	253	44
Double-Tip	225	97.4 b	267	39
Significance	NS	*	NS	NS
Silver Mulch				
Cultivar				
Prime-Ark® 45	216	107.0	268	57 a
Prime-Ark® Freedom	230	94.6	265	40 b
Prime-Jan®	223	70.8	262	40 b
Prime-Jim®	221	93.8	257	45 ab
Significance	NS	NS	NS	*
Tipping Method				
Control	218 a	97.5	256	41
Single-Tip	217 a	96.4	258	42
Double-Tip	232 b	80.7	274	53
Significance	*	NS	NS	NS
Bare Soil				
Cultivar				
Prime-Ark® 45	234	113.5	273	39
Prime-Ark® Freedom	228	102.8	274	46
Prime-Jan®	217	106.8	258	45
Prime-Jim®	224	130.7	253	42
Significance	NS	NS	NS	NS
Tipping Method				
Control	217 a	82.0	259	45
Single-Tip	229 b	79.5	267	42
Double-Tip	231 b	78.7	268	42
Significance	*	NS	NS	NS

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test $P>0.05$.

[y]NS,*= Not significant or significant, respectively, at $P\leq 0.05$.

In the high tunnel, ‘Prime-Ark® Freedom’ had fewer floral structures per plant compared to ‘Prime-Jim®’ and ‘Prime-Jan®’ (Table 3.6). ‘Prime-Ark® Freedom’ had the fewest total floral structures for the season in the bare soil and silver mulch. Number of floral structures did not significantly differ amongst tipping treatments in any of the environments. Peak blossom, as measured by the number of inflorescences with an open terminal flower, occurred in August in the high tunnel (Table 3.9). The three-way interaction amongst tipping treatment, cultivar, and month for peak bloom in silver mulch was significant and tests of simple effects evaluated treatment differences within cultivars within each month (Figure 3.3). In July, double-tipped plants of ‘Prime-Jim®’ had fewer inflorescences blooming than single-tipped and control plants, while in August double-tipped plants had fewer inflorescences than the single-tipped plants. Single-tipped plants of ‘Prime-Ark® 45’ had more inflorescences open than double-tipped and control plants in August. The interactions of both tipping treatment and month as well as cultivar and month were significant in the bare soil and tests of simple effects evaluated differences within each month (Figure 3.4). In August, control and single-tipped plants had more inflorescences open than double-tipped plants. ‘Prime-Ark® 45’ had more inflorescences open than ‘Prime-Ark® Freedom’ and ‘Prime-Jim®’ in September.

Table 3.9. Number of inflorescences blooming per plant in a certain month in the high tunnel environment.

Month	Blooming Inflorescences (no./plant)
July	3.1 b
August	7.5 a[z]
September	4.2 b
October	0.6 c

[z]Means followed by the same letter are not significantly different according to a pairwise t-test P>0.05.

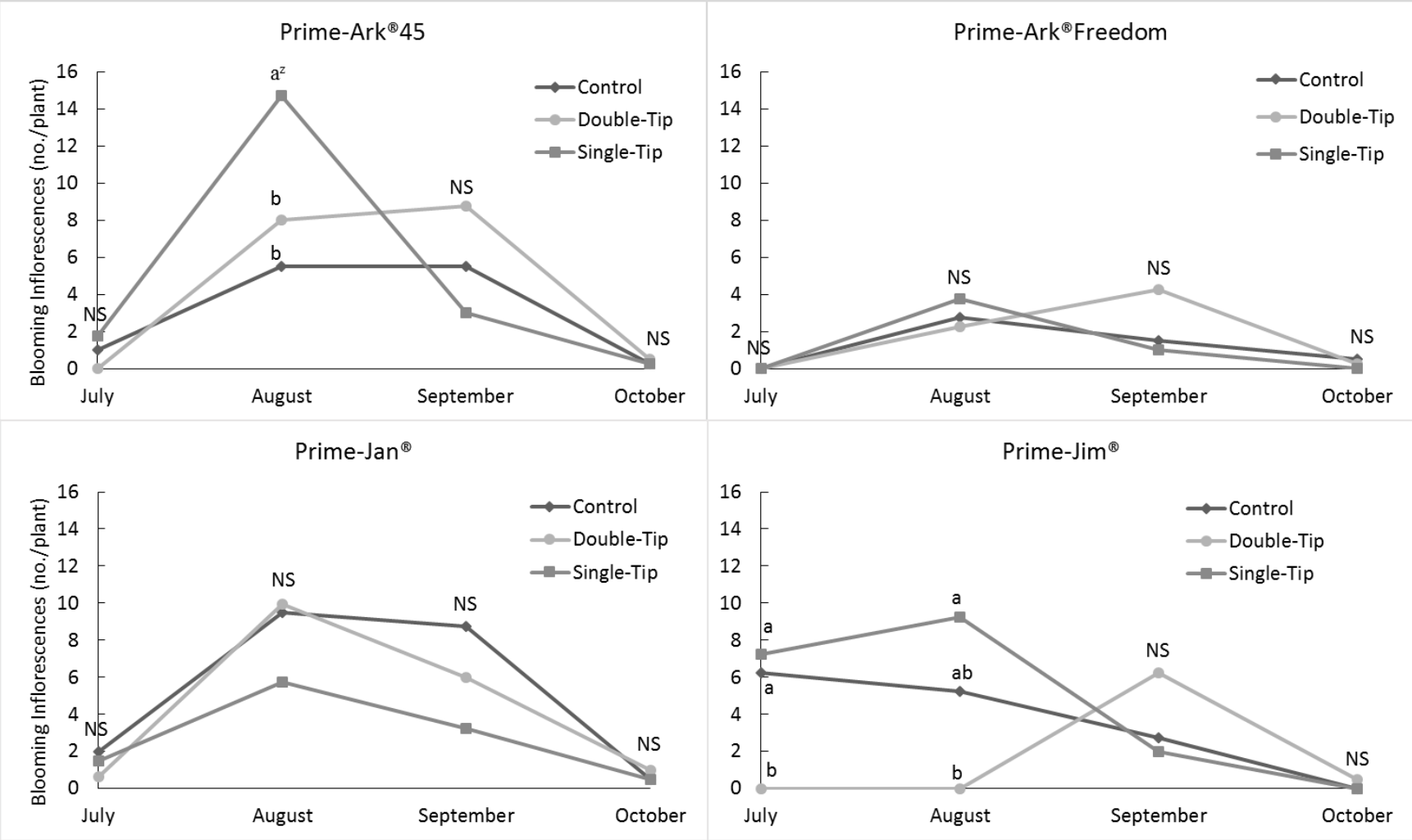

Figure 3.3. Effect of tipping treatment on the number of inflorescences blooming per plant for each cultivar in the silver mulch within a certain month.

[z]Means followed by the same letter within the same cultivar and time period are not significantly different according to a pairwise t-test, P>0.05. NS=not significant.

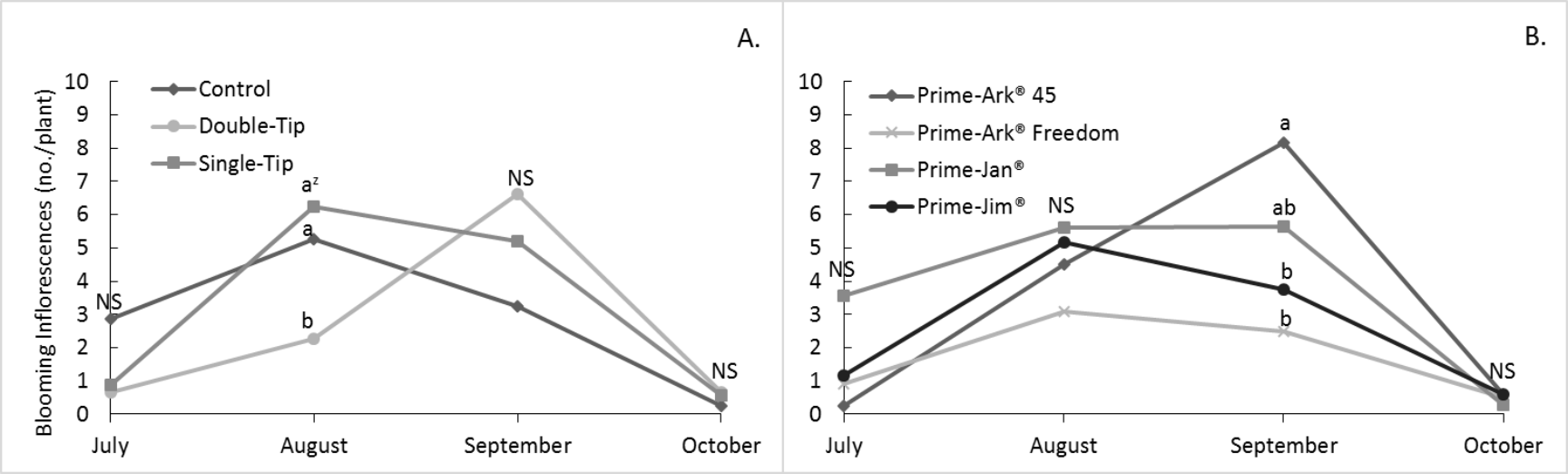

Figure 3.4. Effect of tipping treatment (A) and the effect of cultivar (B) on the number of blooming inflorescences per plant in the bare soil within a certain month.

[z]Means followed by the same letters within each month are not significantly different according to a pairwise t-test P>0.05. NS=not significance.

First harvest occurred on 3 August in the silver mulch and high tunnel and on 11 August in the bare soil. However, the average date of first ripe fruit was similar for the outside environments (262 Julian Days) and approximately one week earlier for the high tunnel (254 Julian Days), although not statistically comparable. Harvest occurred for a total of 11 weeks for the silver mulch and high tunnel and nine weeks for the bare soil. Harvest ended when a hard freeze (-2.0 °C) impacted both the outside and high tunnel environments and berries in all environments had considerable freeze damage.

Yield

The four cultivars did not exhibit significant yield differences in either the high tunnel or bare soil (Table 3.10). Yield differences were found in the silver mulch growing environment amongst cultivars with 'Prime-Jim®' having a greater number of total harvested berries, as well as more marketable berries than 'Prime-Ark® Freedom'. No differences amongst tipping treatments were observed in the high tunnel or bare soil. However, in the silver mulch, the double-tipped plants had significantly less total harvested berries, marketable berries, total weight, and marketable weight than the other treatments.

Table 3.10. Cultivar and tipping treatment effect on cumulative yield per plant for primocane blackberry within three growing environments.

Environment	Total Berry Number (no./plant)	Marketable Berries (no./plant)	Total harvested weight (g/plant)	Marketable Weight (g/plant)
High Tunnel				
Cultivar				
Prime-Ark® 45	33.8	28.7	208.7	178.2
Prime-Ark® Freedom	32.0	28.5	260.2	231.5
Prime-Jan®	56.0	48.1	318.3	274.5
Prime-Jim®	82.3	69.7	431.9	366.4
Significance[y]	NS	NS	NS	NS
Tipping Method				
Control	53.6	46.4	309.3	269.4
Single-Tip	76.3	64.6	447.7	380.8
Double-Tip	23.1	20.2	157.3	137.7
Significance	NS	NS	NS	NS
Silver Mulch				
Cultivar				
Prime-Ark® 45	21.8 ab[z]	15.7 ab	131.0	106.9
Prime-Ark® Freedom	4.4 b	3.5 b	31.2	25.3
Prime-Jan®	24.4 ab	17.6 ab	110.6	71.8
Prime-Jim®	52.4 a	41.2 a	217.2	169.8
Significance	*	*	NS	NS
Tipping Method				
Control	36.1 a	28.6 a	172.6 a	136.6 a
Single-Tip	38.0 a	27.6 a	177.8 a	131.5 a
Double-Tip	3.3 b	2.3 b	17.1 b	12.2 b
Significance	*	*	*	*
Bare Soil				
Cultivar				
Prime-Ark® 45	5.0	4.0	23.3	18.8
Prime-Ark® Freedom	12.8	11.3	110.3	98.9
Prime-Jan®	28.9	21.9	127.4	96.9
Prime-Jim®	19.6	14.8	83.5	63.8
Significance	NS	NS	NS	NS
Tipping Method				
Control	26.2	20.5	122.6	96.6
Single-Tip	19.5	15.3	117.5	98.0
Double-Tip	4.0	3.2	18.3	14.3
Significance	NS	NS	NS	NS

[z]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test P>0.05.

[y]NS,*= Not significant or significant, respectively, at P≤0.05.

When yield by weight was analyzed across time, differences were found within time periods. Yields were summed biweekly with the time periods encompassing the weeks listed in Table 3.11. The most production occurred in the latter half of September and beginning of October in the high tunnel with time periods four and five having the highest total and marketable weight (Table 3.12). In the mulch, both the interactions of tipping treatment and time as well as cultivar and time were significant and tests of simple effects evaluated differences amongst tipping treatments and cultivars within time periods. For time period four, the control plants had higher total and marketable weight than the double-tipped plants (Figure 3.5). Also in time period four, 'Prime-Jim®' had the highest yield compared to the other cultivars. In time period five, single-tipped plants had the highest yield compared to the double-tipped plants for total weight. For marketable weight, single-tipped plants had the highest yield followed by control plants and then double-tipped plants. 'Prime-Ark® Freedom' had the lowest total weight in time period five out of all the cultivars and a lower marketable weight than 'Prime-Ark® 45' and 'Prime-Jim®'. In the bare soil, production was among the highest in late September and early October, which occurred during time periods four and five.

Table 3.11. The biweekly time periods and the equivalent harvest dates they encompassed.

Time Period	Equivalent Harvest Dates
1	2 August–15 August
2	16 August–29 August
3	30 August–12 September
4	15 September–26 September
5	27 September–10 October
6	11 October-17 October

Table 3.12. Differences in total yield and marketable yield for weight per plant between biweekly harvest periods.

Time	Total Weight (g/plant)		Marketable Weight (g/plant)	
	High Tunnel	Bare Soil	High Tunnel	Bare Soil
1[z]	0.95 c[y]	---[x]	0.86 c	---
2	9.51 c	1.90 c	9.18 c	1.67 bc
3	45.80 b	14.70 bc	43.75 b	13.21 ab
4	96.07 a	29.20 ab	82.77 a	25.89 a
5	99.60 a	29.95 a	84.92 a	22.35 a
6	55.83 b	11.98 c	43.22 b	8.72 bc

[z]Time 1= 2-15 August, Time 2= 16-29 August, Time 3= 30 August- 12 September, Time 4=13-26 September, Time 5= 27 September- 10 October, and Time 6= 11 October – 17 October.

[y]Means followed by the same letter are not significantly different according to a pairwise t-test P>0.05.

[x]Harvest did not start until time period two for the bare soil.

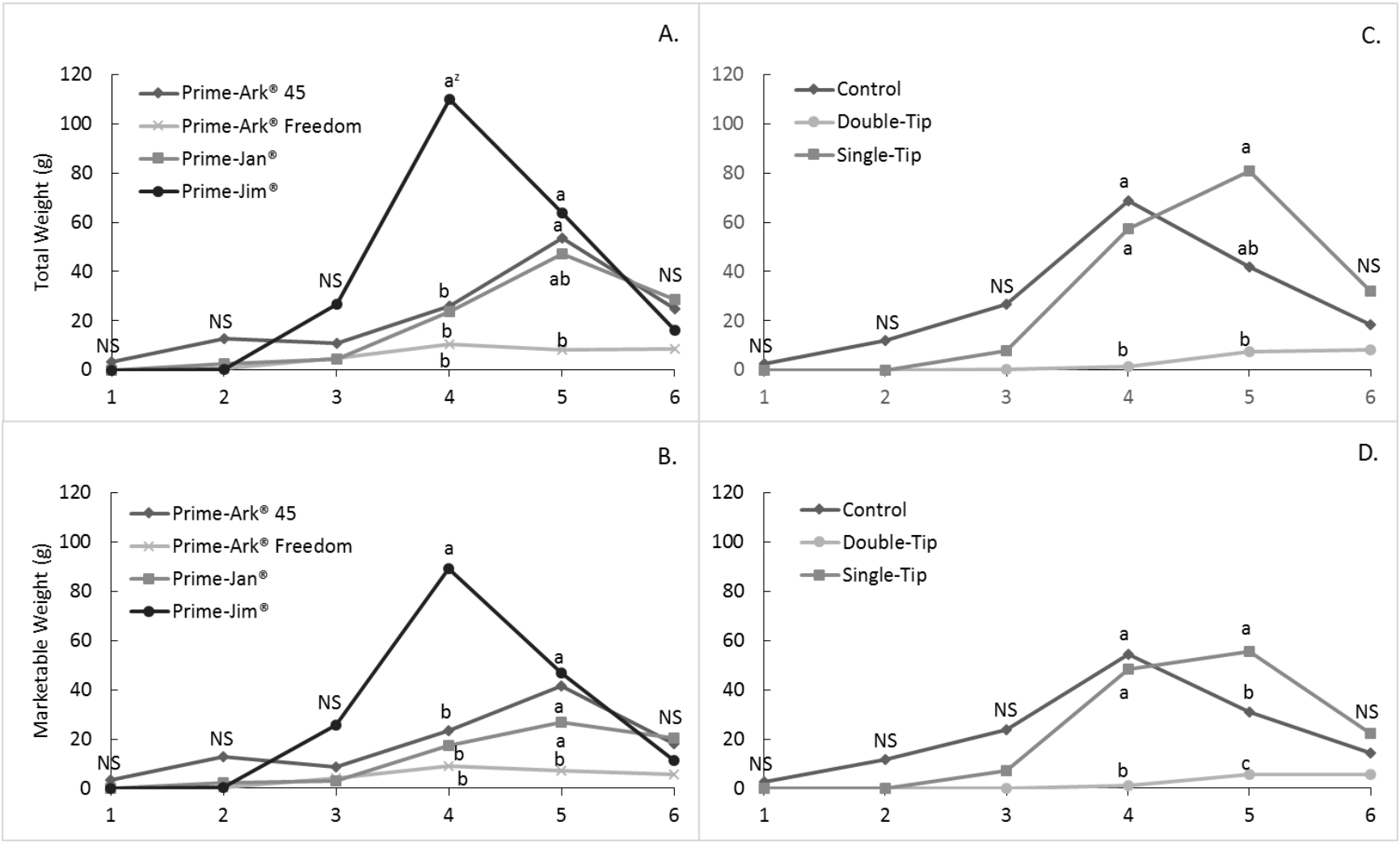

Figure 3.5. Effect of cultivar on total (A) and marketable (B) weight per plant and the effect of tipping treatment on total (C) and marketable (D) weight per plant in the silver mulch environment within a certain time period. Time 1= 2-15 August, Time 2= 16-29 August, Time 3= 30 August- 12 September, Time 4=13-26 September, Time 5= 27 September- 10 October, and Time 6= 11 October – 17 October.

[z]Means followed by different letters within the same time period are not significantly different P>0.05. NS = not significant.

Berry Characteristics

In the high tunnel, 'Prime-Ark® Freedom' had the greatest berry weight, length, and width in comparison to the other cultivars (Table 3.13). The silver mulch did not exhibit differences in berry size or weight for cultivars. The interaction between tipping treatment and cultivar in the bare soil found single-tipped plants of 'Prime-Ark® Freedom' had heavier berries than single-tipped plants of the other cultivars (Table 3.14). Tipping treatments did not have an effect on berry size in the high tunnel or silver mulch.

Berries from control and single-tipped plants in the high tunnel had a higher SSC and pH. The SSC was not different amongst the cultivars in the high tunnel (Table 3.13). 'Prime-Ark® Freedom' had the highest pH and a lower TA than 'Prime-Jim®' and 'Prime-Jan®'. 'Prime-Jan®' had the lowest pH in the high tunnel amongst all the cultivars. Tipping treatment had no effect on pH, SSC, or TA in the silver mulch. 'Prime-Jan®' had the lowest pH of the cultivars and a SSC that was lower than 'Prime-Ark® 45' and 'Prime-Jim®' in the silver mulch. 'Prime-Jan®' also had a significantly higher TA than 'Prime-Ark® 45' in the silver mulch. Tipping treatment did not affect SSC and pH in the bare soil, but double-tipped plants had the highest TA. 'Prime-Jan®' in the bare soil had the lowest and a lower pH than 'Prime-Ark® Freedom'.

Table 3.13. Cultivar and tipping treatment effect on berry characteristics for primocane blackberry within three growing environments.

	Weight (g)	Length (cm)	Width (cm)	SSC[z] (%)	pH	TA[y] (%)
High Tunnel						
Cultivar						
Prime-Ark® 45	5.98 b[x]	2.50 b	1.96 b	11.27	3.06 b	2.67 b
Prime-Ark® Freedom	9.19 a	3.11 a	2.26 a	10.84	3.22 a	2.18 bc
Prime-Jan®	5.41 b	2.47 b	1.99 b	11.25	2.91 c	3.32 a
Prime-Jim®	5.33 b	2.25 b	2.05 b	11.38	3.02 b	2.93 ab
Significance[w]	*	*	*	NS	*	*
Tipping Method						
Control	6.28	2.47	2.05	11.6 a	3.13 a	2.78
Double-Tip	6.62	2.64	2.09	10.3 b	2.95 b	3.01
Single-Tip	6.53	2.63	2.05	11.6 a	3.08 a	2.54
Significance	NS	NS	NS	*	*	NS
Silver Mulch						
Cultivar						
Prime-Ark® 45	5.46	2.23	1.89	12.96 a	3.08 a	2.19 b
Prime-Ark® Freedom	7.07	2.68	2.14	11.74 bc	3.10 a	2.69 ab
Prime-Jan®	4.52	2.15	1.84	10.72 c	2.87 b	3.13 a
Prime-Jim®	4.80	1.98	1.95	12.74 ab	3.06 a	2.82 a
Significance	NS	NS	NS	*	*	*
Tipping Method						
Control	2.30	2.21	1.94	12.06	3.04	2.58
Double-Tip	5.41	2.30	1.95	12.00	2.99	3.01
Single-Tip	5.68	2.27	1.96	12.06	3.05	2.53
Significance	NS	NS	NS	NS	NS	NS
Bare Soil						
Cultivar						
Prime-Ark® 45	--	2.39	1.91	13.04 a	2.97 ab	3.01 ab
Prime-Ark® Freedom	--	2.55	2.21	11.91 a	3.14 a	2.39 c
Prime-Jan®	--	2.36	1.87	10.21 b	2.85 b	3.39 a
Prime-Jim®	--	2.06	1.89	12.66 a	3.01 ab	2.67 bc
Significance		NS	NS	*	*	*
Tipping Method						
Control	--	2.32	2.02	12.06	3.05	2.58 b
Double-Tip	--	2.33	1.93	12.08	2.90	3.36 a
Single-Tip	--	2.38	1.96	11.83	3.03	2.67 b
Significance		NS	NS	NS	NS	*

[z]Soluble solids concentration expressed as a percent.
[y]Titratable acidity expressed as percent of citric acid.
[x]Means within the same category followed by the same letter are not significantly different according to a pairwise t-test P>0.05.
[w]NS,*= Not significant or significant, respectively, at P≤0.05.

Table 3.14. Cultivar and tipping treatment effect on average berry weight in the bare soil.

Cultivar	Control	Single-Tip	Double-Tip
Prime-Ark® 45	5.53	5.96 b	4.50
Prime-Ark® Freedom	4.84	9.19 a[z]	4.82
Prime-Jan®	5.58	4.00 b	4.40
Prime-Jim®	4.65	3.55 b	5.32
Significance[y]	NS	*	NS

[z]Means within the same column followed by the same letter are not significantly different according to a pairwise t-test P>0.05.
[y]NS,* = Not significant or significant, respectively, P≤0.05.

Discussion

High Tunnel

Cultivars

The performance of the cultivars inside the high tunnel was not completely expected based on previous reports. 'Prime-Ark® Freedom' proved to be a vigorous grower as exhibited by its earlier emergence than the other cultivars and greater non-flowering cane length and overall height compared to 'Prime-Jim®' and 'Prime-Jan®'. Clark (2014) noted that 'Prime-Ark® Freedom' had good cane vigor and non-tipped canes in this study were found to be in excess of 4 m on some plants (personal observation).This increased vigor would have thought to lead to earlier bloom and fruiting and even perhaps a greater yield, however, this was not the case.

Despite reports that 'Prime-Ark® 45' is a later bloomer, by around two weeks compared to the other cultivars, no differences in bloom time were found to exist in the high tunnel (Clark, 2014; Clark and Perkins-Veazie, 2011). This could be the result of the effects of the high tunnel as those reports were field based. When looking at the number of flowering canes, number of blossoms and percent of reproductive nodes, 'Prime-Ark® Freedom' tended to have the least amount out of all the cultivars, especially compared to 'Prime-Jan®'. Since 'Prime-Ark® Freedom' was not as vigorous reproductively, it most likely put all of its energy into vegetative growth, as seen by the heights it achieved, and less energy into fruit production. This could be a

potential downfall of this cultivar for commercial markets, which is likely why it is recommended for homeowner use (Clark, 2014).

With the increased reproductive vigor of 'Prime-Jim®' and 'Prime-Jan®' in comparison to 'Prime-Ark® Freedom', larger yields would be expected and have been reported in the literature; but no differences in yield for weight or berry number were found in this study (Finn and Strik, 2014). 'Prime-Ark® Freedom' did perform as expected with regard to berry characteristics, as berry weight and size differences were noted with 'Prime-Ark® Freedom' having larger fruit, which is typical for this cultivar (Clark, 2014). The increased pH and reduced TA of 'Prime-Ark® Freedom' compared to 'Prime-Jim®' and 'Prime-Jan®' can be attributed to inherent cultivar differences, with regards to flavor, that have been noted (Clark and Perkins-Veazie, 2011; Clark, 2014; Finn and Strik, 2014). As the berry continues to ripen, TA decreases and SSC increases making the berry more palatable, which is especially desirable for fresh market production (Perkins-Veazie et al., 1996; Walsh et al., 1983). The TA for 'Prime-Jan®' was higher than observed in Oregon but pH was similar (Thompson et al., 2009). These characteristics are dependent upon cultivar, climate, and fruit maturity so differences can be expected.

Tipping Treatments

Tipping treatments in the high tunnel also did not perform as expected from the literature with regard to yield, but did in terms of growth. Control plants were the tallest once tipping had occurred. They were also taller at bloom and had longer flowering canes. This was expected since the single-tipped and double-tipped plants were set back in growth by removal of the apical meristem. Excessive height is not necessarily a desired trait since too much energy could be going towards vegetative growth instead of fruit production. Although there is more potential for

inflorescences to form on longer flowering canes, unless they are tipped fewer inflorescences will be produced per cane (Thompson et al., 2007; Strik and Thompson, 2009; Strik et al., 2012). Despite having longer flowering canes, control plants did not have a greater percent of reproductive nodes or fruiting sites which was likely a response to the lower number of inflorescences compared to tipped plants.

It has been reported, that tipping delays bloom and fruit production (Drake and Clark, 2003; Strik et al., 2012). In this study, no differences between tipping treatments were found for bloom time or harvest time, indicating that the high tunnel might have offset the delay caused by tipping. The purpose of tipping is to increase branch number which did occur in this study. The lower branch number in control plants can likely be attributed to apical dominance not being broken, which would have allowed the lateral branches to break. Control plants also produced branches more basally located. Strik et al. (2012) noticed similar branch location on untipped plants. According to Lopez-Medina et al. (2000), branching is correlated with the primocane-fruiting trait in blackberry and is therefore a normally occurring process regardless of tipping. These branches, for the most part, remained vegetative and was observed by Thompson et al. (2007) as well. Since apical dominance was asserted in the control plants, branches were likely formed later in the season attributing to the same average branch length as tipped plants.

The increased number of branches and resulting increase in inflorescences in single-tipped plants compared to control plants should have resulted in increased yield. However, yield was not impacted by tipping treatments, which was surprising since Strik et al. (2012) found correlation between the number of branches per cane and yield. Despite the increased number of inflorescences, the number of fruiting sites did not increase, which is likely what caused no significant differences in yield. The greater number of inflorescences with single-tipped plants

but not an increase in fruiting sites indicates that the inflorescences on tipped canes possessed a majority of flower buds that did not contribute to yield. Double-tipped plants had more branches than control plants, but the same number of inflorescences, which could indicate the additional branches were delayed in producing inflorescences. This is likely a result of tipping double-tipped plants in July, which did not allow enough time to produce inflorescences on each additional branch. Hanson (2012) commented on the likely detrimental effect on yield of tipping plants into July by delaying production. Strik and Buller (2012) also commented that tipping earlier maximized branch yield potential. Although Thompson et al. (2009) found higher yield with double-tipped plants in a high tunnel compared to single-tipped plants, it was not observed here.

It was not expected that the tipping treatments would have an effect on the quality of the berry. Berry characteristics are dependent upon ripeness of the berry with pH and SSC increasing and TA decreasing as the berry ripens. Thompson et al. (2007) found pH tended to decrease when measured early in the season compared to late in the season. More berries for double-tipped plants could have been included in the analysis from the later part of the season (Figure 3.6) when ripening slowed down thus contributing to the differences observed.

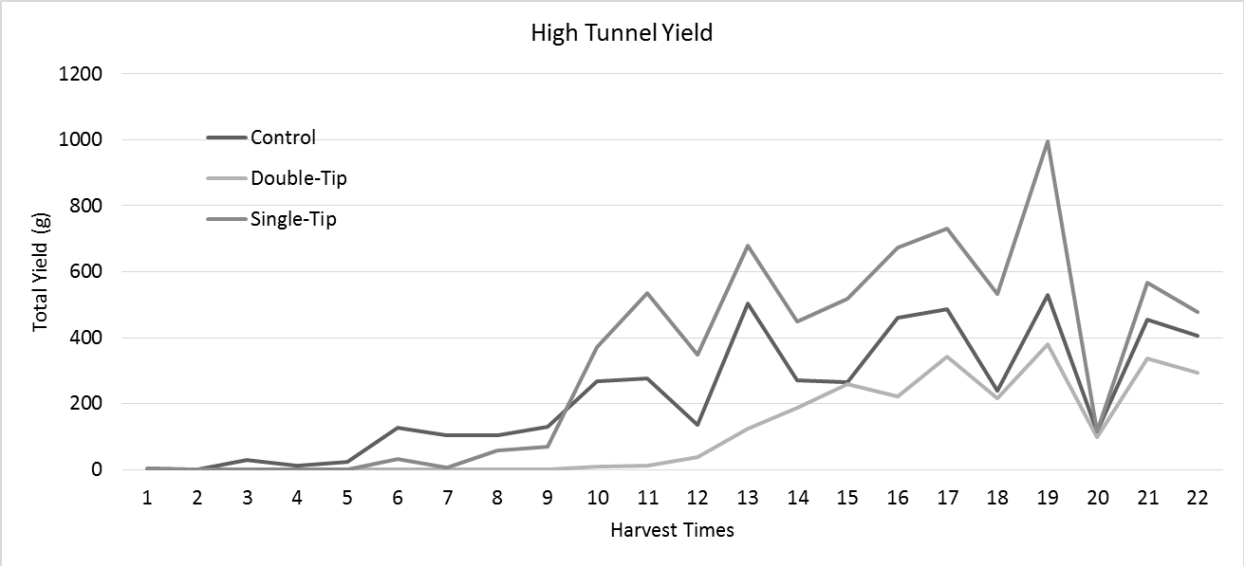

Figure 3.6. High tunnel total yield for double-tipped, single-tipped, and control plants across the harvest season starting 2 August – 17 October.

Yield and Observations

The greatest yield occurred from 13 September -10 October which is consistent with the length of time from bloom to fruit with the most bloom occurring in August. Yield for 'Prime-Jan®' was lower than that observed for double- and single-tipping in Oregon (Thompson et al., 2009). However, the yields for 'Prime-Jim®' and 'Prime-Jan®' were similar to yields reported by Hanson (2012) during the second year of establishment in Michigan, which has relatively similar climatic conditions. Clark (2008) has noted that with regard to yield of primocane blackberry it is very location specific with lower yields in Arkansas and higher yields in Oregon being reported.

As previously mentioned, Hanson (2012) noted that tipping into July led to lower yields for plants. Double-tipping of plants in this study occurred into July, however, no yield differences were found between treatments indicating that the high tunnel might have offset this problem at this location. Thompson et al. (2009) noted that 'Prime-Jan®' plants double-tipped inside a high tunnel had a higher yield compared to single-tipped plants, however, plastic was

not added to the high tunnel until harvest began. Although tipping did not increase yield in any of the cultivars, it did help maintain the vigorous cane growth experienced in the high tunnel.

It has been noted, especially with primocane-fruiting blackberries, that excessive heat (>35 °C) and humidity during bloom can detrimentally impact the flower, which in turn can decrease yield (Clark, 2014; Drake and Clark, 2003; Stanton et al., 2007). An indication of extreme temperatures can be found with the production of twin berries in 'Prime-Ark® Freedom'; this cultivar is known to produce twin fruit but it is exacerbated by high temperatures at pollination (Clark, 2008; Clark, 2014). A higher incidence of the twin berries was noted in the high tunnel indicating that excessive heat occurred on some occasions. Although maximum temperatures in the high tunnel got to be extreme, it is thought that the lower night temperatures allowed a reprieve and did not stop production like it did in Arkansas, as average temperatures were lower than those reported in Arkansas (Figure 1A, 2A) (Drake and Clark, 2003). The average relative humidity was also similar to outside environments and therefore most likely did not contribute to flower damage (Figure 3A).

Towards the end of the growing season, berry production slowed down due to the decrease in temperatures. It was observed that berry drupelets remained red and did not ripen as quickly. Thompson et. al (2009) and Strik and Buller (2012) also observed similar slowdown in production and red drupelets with cooler temperatures. However, plants were still blooming up until a killing frost indicating that these plants have the potential to produce longer if adequate supplemental heat were applied or floating row covers were used as this has been successfully done elsewhere (Heidenreich et al., 2012; Nennich, 2009; Yao and Rosen, 2011).

Silver Mulch

Cultivars

The effect of silver mulch on primocane blackberry plant growth amongst cultivars was more pronounced than in the high tunnel, although the environments cannot be compared statistically. 'Prime-Jim®' and 'Prime-Ark® 45' had a greater end-of-season fresh weight than 'Prime-Jan®' and 'Prime-Ark® Freedom'. It is not entirely understood what contributed to the greater weight as the number of non-flowering canes was the same for all the cultivars as well as primocane height throughout the growing season. 'Prime-Ark® Freedom' did have a lower number of flowering canes than 'Prime-Ark® 45' which may have contributed to the weight difference. The presence of more leaf matter on these cultivars may have also contributed to the weight, but leaf counts per plant were not taken.

'Prime-Ark® Freedom' had the fewest number of floral structures per plant, percent of reproductive nodes per cane, and fruiting sites per cane compared to the other cultivars. This was reflected in the yield differences for total and marketable number of berries. It is interesting that although 'Prime-Ark® Freedom' is a seemingly low producer, especially in terms of berry number, the total yield differences between cultivars for weight were not different. Berry size of 'Prime-Ark® Freedom' has been noted to be larger which would make up the weight difference in yield, however, they were not significantly larger for this particular environment in this study (Clark, 2014). 'Prime-Jim®' did have a greater yield than the other cultivars at approximately half-way through the harvest season, but this was not seen in the total yield indicating that the other cultivars caught up later in the season.

Since the time of bloom will generally dictate the time of harvest, earlier blooming cultivars are desirable in cooler regions for primocane-fruiting blackberry (Clark, 2008).

Previous reports about ‘Prime-Ark® 45’ indicated that it is the latest bloomer of these cultivars. However, no differences in bloom time were found in the silver mulch. ‘Prime-Ark® 45’ did take longer to produce ripe fruit from the time of bloom than ‘Prime-Ark® Freedom’ and ‘Prime-Jan®’, yet this did not impact the average date at which first black fruit was harvested. Days from bloom to ripe fruit for ‘Prime-Jim®’ and ‘Prime-Jan®’ were comparable to the number of days observed for these cultivars in Oregon, while ‘Prime-Ark® 45’ was outside of this range, which might have had an impact on yield (Strik et al., 2012; Thompson et al., 2009).

With regard to berry quality, ‘Prime-Jan®’ fruit had the lowest pH and one of the highest TA’s. Berry pH and TA have not been documented in the literature for all of these cultivars. However, TA affects berry taste and it has been noted that ‘Prime-Ark® 45’ and ‘Prime-Ark® Freedom’ taste better than ‘Prime-Jim®’ and ‘Prime-Jan®’ (Clark and Perkins-Veazie, 2011; Clark, 2014; Finn and Strik, 2014). Therefore, the higher TA of ‘Prime-Jan®’, especially in relation to ‘Prime-Ark® 45’, likely contributes to its low flavor rating.

Tipping Treatments

Plants in the silver mulch followed the same growing trend as observed in the high tunnel with control plants being the tallest and double-tipped plants the shortest at the end of the season. Since control plants were not tipped, apical dominance was not removed and plants could easily maintain their single cane growth habit. Control and single-tipped plants also bloomed sooner than the double-tipped plants, as expected, but this did not impact when the first ripe fruit was harvested. Despite the fact that control and double-tipped plants in ‘Prime-Ark® 45’ had a similar number of inflorescences that bloomed in August, double-tipped plants ended up having a lower yield.

Tipping did not impact the number of flowering canes, but in ‘Prime-Jim®’ and ‘Prime-Ark® Freedom’, the control plants had longer flowering canes than tipped plants. Single-tipped plants had the greatest number of total nodes, however, the percent of those nodes that were reproductive was similar to the other treatments and no real benefit was derived from the additional amount. Tipping increased the number of branches compared to control plants and control plants had branches that were more basally located compared to single-tipped plants in ‘Prime-Jim®’, ‘Prime-Jan®’, and ‘Prime-Ark® Freedom’. This was also observed in the high tunnel and is likely a characteristic trait of primocane-fruiting blackberry as previously mentioned.

The increase of branches on tipped plants resulted in an increased number of inflorescences per cane, however, this caused the inflorescences to be shorter in ‘Prime-Ark® 45’ and ‘Prime-Jim®’ for double-tipped plants. Since double-tipping took place in July (Figure 3.1), it may have set back inflorescence formation on each branch. As previously stated, Hanson (2012) noted detrimental effects on yield when tipping this late. An increased number of inflorescences does not guarantee that the number of fruiting sites will increase, as tipping did not increase the number of fruiting sites or reproductive nodes. Since inflorescences counted included buds, it is possible that the number of fruiting sites did not increase with the number of inflorescences because the majority of the inflorescence consisted of unopened buds in tipped plants.

Double-tipped plants had a lower yield in all the cultivars despite having similar inflorescence numbers and fruiting sites as the other tipping treatments. Although grown in different environments, this is opposite of what Thompson et al. (2009) found with ‘Prime-Jan®’ in field conditions. Since fruiting sites included berries still present on the cane, it is possible that

double-tipped plants had a higher proportion of fruit that would have been harvested had a freeze not occurred. This indicates that double-tipping has a detrimental impact on yield in the silver mulch as a result of the lateness of the season. It was expected that single-tipped primocanes would have a greater yield than control plants as Strik et al. (2012) noted in field conditions, but this was not observed in the current study. Although single-tipped plants had more branches and inflorescences per cane than the control plants, number of fruiting sites and reproductive nodes was the same indicating that the inflorescences were not as well-developed.

Yield and Observations

'Prime-Jim®' had a significantly higher yield than the other cultivars during the weeks of 13 September – 26 September, but returned to the same production levels as the other cultivars the following two weeks. Despite the lack of difference in end of season yield, the higher yield of 'Prime-Jim®' at an earlier time period is beneficial for production in cooler regions. The lower yield of double-tipped plants during the weeks of 13 September- 10 October is likely what caused the end-of-season yield to be lower as no differences were observed during the other time periods.

Although the use of silver mulch has not been reported in blackberry, the end-of season yield was significantly lower than field yields reported in Oregon and Arkansas (Clark, 2014; Clark and Perkins-Veazie, 2011; Drake and Clark, 2003; Thomspon et al., 2009; Strik et al., 2012). Instead of acting as a beneficial addition, the silver mulch may have hampered the growth of the primocanes, as plants were allowed a 30 cm square opening which may have reduced cane number. As Strik and Buller (2012) noted, yield is impacted not only by the number of branches but also by the number of flowering canes. A lot of sunburned berries were also observed in the

silver mulch, which reduced the amount of marketable yield. Similar production slow-down was also observed as in the high tunnel as the temperatures got cooler towards the end of the season.

Bare Soil

Cultivars

Cultivar differences were also observed in the bare soil but not as expected. 'Prime-Ark® 45' had more blooming inflorescences than 'Prime-Ark® Freedom' and 'Prime-Jim®' in September, which is consistent with the literature that it is a later bloomer (Clark and Perkins-Veazie, 2011; Clark, 2014). However, with the average time from bloom to ripe black fruit at approximately 43 days in bare soil, heavy flowering in September is not beneficial for production purposes in a colder climate. Even though 'Prime-Jim®' and 'Prime-Ark® Freedom' had among the fewest flowering canes these differences had no effect on yield as all cultivars had similar yields.

'Prime-Ark® Freedom' tended to produce shorter canes than 'Prime-Jim®' and had the lowest number of floral structures as well as reproductive nodes compared to the other cultivars. The number of inflorescences was the same for the cultivars but 'Prime-Ark® Freedom' had shorter inflorescences than 'Prime-Ark® 45' and 'Prime-Jim®'. It was observed that inflorescences for 'Prime-Ark® Freedom' often consisted of one flower bud which could account for the shorter length. Despite 'Prime-Ark® Freedom' having a lack of overall vigor and fewer reproductive aspects, the yield of 'Prime-Ark® Freedom' was not lower than the other cultivars. 'Prime-Jan®' had among the lowest SSC and pH readings with a high TA reading, which was consistent with values observed in the other environments and characteristic of the taste preference for this cultivar (Clark and Perkins-Veazie, 2011; Clark, 2014; Finn and Strik, 2014). The TA numbers were higher than those reported by Thompson et al. (2009) for 'Prime-

Jan®' but SSC was similar and pH was slightly lower, which could be a result of different environmental conditions.

Tipping Treatments

As observed in the other environments, control plants were generally taller, had longer fruiting cane length, fewer branches that were more basally located, and bloomed sooner than tipped plants, as expected. The fewer branches compared to the tipped plants explains the lower amount of inflorescences formed by the control plants compared to single-tipped plants. Double-tipped plants had a lower inflorescence number than single-tipped plants, but was similar to the control. Tipping most likely caused the laterals to break in the single-tipped plants which explains the increased amount of inflorescences over control plants. However, when plants were double-tipped it possibly set them back and fewer branches were able to form inflorescences. Regardless, no yield differences were found between tipping treatments. This was contrary to what Thompson et al. (2009) found where double-tipped plants had double the yield compared to single-tipped plants of 'Prime-Jan®'. Strik et al. (2012) also noted increased yield in tipped versus untipped plants of 'Prime-Jim®' and 'Prime-Jan®'. However, Drake and Clark (2003) also did not find significant yield differences between single-tipped and non-tipped plants of 'Prime-Jim®' and 'Prime-Jan®'.

Double-tipping appears to detrimentally impact fruit quality characteristics as fruit from these plants had a higher TA reading. However, these measurements were combined across the entire harvest season which included times with cooler night temperatures. Although not statistically proven, the majority of production for double-tipped plants occurred later in the season (Figure 3.7). Cooler night temperatures cause an increase in TA which might have occurred in this instance (P. Perkins-Veazie, personal communication). A more accurate measure

of TA would be to look at individual harvest dates, however, lack of sufficient fruit for testing prevented this. Additionally, TA samples were only run once because of small sample size, which may have resulted in discrepancies as well.

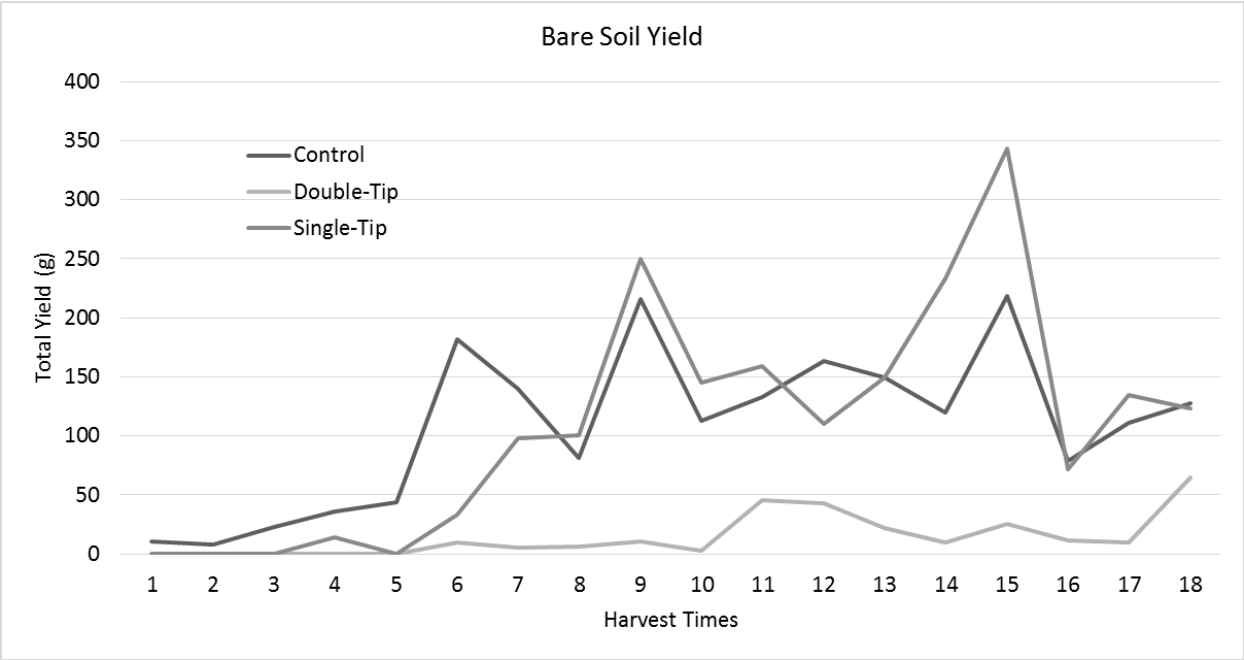

Figure 3.7. Bare soil total yield of double-tipped, single-tipped and control plants across the harvest season from 16 August–17 October.

Yield and Observations

Plants overall in the bare soil did not seem to perform well with regard to growth and production. Plants were relatively short and yields were much lower than reports for these cultivars (Thompson et al., 2009; Clark and Perkins-Veazie, 2011; Clark, 2014; Clark et al., 2005; Hanson, 2012; Strik et al., 2012). The greatest yield occurred from 13 September-10 October which may be too late for some years in northern climates.

All Environments

Although not statistically comparable, differences between environments were observed and are purely speculative. Average emergence in the high tunnel was sooner and is likely a

result of the warmer soil temperatures (Figure 4A). Date of tipping, bloom, and harvest were also sooner in the high tunnel and most likely a result of the warmer average temperatures and subsequent increase in growing degree days (GDD) (Figure 2A; Table 1A). Despite warmer average temperatures, the high tunnel was not able to extend the season longer than the outside environments when the freeze events occurred.

A general trend with regard to yield was noted with the bare soil having the lowest yield, followed by the silver mulch, and the high tunnel having the greatest yield. The greater yield in the high tunnel was likely a result of the increased GDD and warmer temperatures leading to a sooner harvest. However, peak yield occurred during the same time period for the high tunnel and bare soil. Double-tipped plants appeared to perform the worst in the silver mulch as it was the only environment where double-tipped plants had the lowest yield.

While all the cultivars appeared to perform better in the high tunnel with regard to growth and yield, 'Prime-Ark® Freedom' especially flourished. While the shortest cultivar in the bare soil, it was the tallest cultivar in the high tunnel. Berry size of 'Prime-Ark® Freedom' was also larger than the other cultivars in the high tunnel for all the treatments which is a cultivar characteristic noted by Clark (2014). Similarities in berry quality of cultivars with regard to SSC, pH and TA were noted in all three environments and are consistent with cultivar reports for flavor.

Conclusion

The recently introduced primocane-fruiting blackberry cultivars 'Prime-Jim®', 'Prime-Jan®', 'Prime-Ark® 45', and 'Prime-Ark® Freedom' can be successfully grown in North Dakota. Yield was not impacted by tipping except in the silver mulch in which double-tipped plants had lower yield. Therefore, tipping may not be a beneficial labor intensive process during

the second growing season in the field, but may become beneficial as plants mature. Tipping has become a general recommendation for primocane cultivars in other climates and single-tipping may be a practical procedure to control vigorous cane growth, especially in a high tunnel.

Cultivar yield production did not vary except in the silver mulch with 'Prime-Jim®' having more berries than 'Prime-Ark® Freedom'. Although yields were not similar to those from Arkansas or Oregon, Clark (2008) noted that yield can vary based on where the plants are grown and may increase with plant maturity. High tunnel cultivar yields, however, were similar for 'Prime-Jim®' and 'Prime-Jan®' to what Hanson et al. (2012) found in a high tunnel during the second year of establishment. Breeding work is being conducted for cultivars with earlier bloom time which would be better for production in northern climates as it would lead to earlier harvest (Clark, 2008). Plants were tipped at 0.5 m, similar to the height reported by Thompson et al. (2009). However, Strik et al. (2012) noted higher yields when plants in a similar environment were tipped at 1 m. It is not known whether tipping at a higher height would further delay the fruit production in this climate, as branches would be forming later in the season. Better yields might also be achieved if plants were allowed to grow in a hedgerow, which is common for erect-type blackberries, instead of maintaining individual plants.

Although not statistically comparable to outside environments, a high tunnel could be used to obtain higher yields, but economics would have to be taken into consideration for a grower to justify the added costs. Despite having warmer maximum temperatures, the high tunnel was not efficient at holding heat overnight. Plants did benefit from the additional GDD obtained throughout the season, but supplemental heat or a more efficient high tunnel covering system such as double poly would be required to effectively extend the growing season when freeze events occur.

These results are only from the second year of plant establishment in the field. Additional growing seasons will most likely see improved yield as well as possible yield differences with regards to tipping treatments. Although continued research is needed in our region, growing primocane-fruiting blackberries in North Dakota seems to have a promising future.

Literature Cited

Carey, E.E., L. Jett, W.J. Lamont, Jr., T.T. Nennich, M.D. Orzolek, and K.A. Williams. 2008. Horticultural crop production in high tunnels in the United States: a snapshot. HortTechnology. 19:37-43.

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

Clark, J.R. 2014. 'Prime-Ark® Freedom' Primocane-fruiting thornless blackberry. HortScience 49:1097-1101.

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

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

Clark, J.R. and A. Salgado. 2016. 'Prime-Ark® Traveler' Primocane-thornless blackberry for the commercial shipping market. HortScience. 51:1287-1293.

Crandall, P.C. 1995. Bramble production: The management and marketing of raspberries and blackberries. Food Products Press. Binghamton, NY.

Demchak, K. 2008. Small fruit production in high tunnels. HortTechnology. 19:44-49.

Drake, C. and Clark, J.R. 2003. Effects of pruning and cropping on field-grown primocane-fruiting blackberries. HortScience 38:260-262.

Finn, C.E. and B.C. Strik. 2014. Blackberry cultivars for Oregon. Oregon State University Extension Service. EC 1617.

Hanson, E. 2012. Primocane-fruiting blackberry performance in high tunnels in cold regions. Acta Hort. 946:397-401.

Hanson, E., M. Von Weihe, A.C. Schilder, A.M. Chanon, and J.C. Scheerens. 2011. High tunnel and open field production of floricane- and primocane- fruiting raspberry cultivars. HortTechnology. 21:412-418.

Hart, J., B. Strik, and H. Rempel. 2006. Caneberries. Oregon State University Extension Service. EM 8903-E.

Heidenreich, C.M., M. Pritts, K. Demchak, E. Hanson, C. Weber, and M.J. Kelly. 2012. High tunnel raspberries and blackberries. Dept. of Hort. Cornell Univ. Publication No. 47. 9 Dec. 2014. http://www.fruit.cornell.edu/berry/production/pdfs/hightunnelsrasp2012.pdf.

Hutton, M.G. and D.T. Handley. 2007. Effects of silver reflective mulch, white inter-row mulch, and plant density on yields of pepper in Maine. HortTechnology 17:214-219.

Lamont, W.J., Jr. 2008. Overview of the use of high tunnels worldwide. HortScience. 19:25-29.

Lopez-Medina, J., J.N. Moore, and R.W. McNew. 2000. A proposed model for inheritance of primocane fruiting in tetraploid erect blackberry. J. Amer. Soc. Hort. Sci. 125:217-221.

Lopez-Medina, J., J.N. Moore, and K.S. Kim. 1999. Flower bud initiation in primocane-fruiting blackberry germplasm. HortScience. 34:132-136.

Nennich, T. 2012. High tunnel primocane blackberry production in Minnesota. Greenbook 2012. Minnesota Department of Agriculture, St. Paul, MN.

Perkins-Veazie, P., J.K. Collins, and J.R. Clark. 1996. Cultivar and maturity affect postharvest quality of fruit from erect blackberries. HortScience. 31:258-261.

Pritts, M. 2016. Growing blackberries in a cold climate using high tunnels. Acta Hort. 1133:263-267.

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 regimes. HortScience. 42:508-513.

Strik, B. 2012. Flowering and fruiting on command in berry crops. Acta Hort. 926:197-214.

Strik, B. and Buller, G. 2012. The impact of severity and time of tipping and hedging on performance of primocane-fruiting blackberry in a tunnel. HortScience. 22:325-329.

Strik, B.C., J.R. Clark, C.E. Finn, and G. Buller. 2008. Management of primocane-fruiting blackberry to maximize yield and extend the fruiting season. Acta Hort. 777:423-438.

Thompson, E., B.C. Strik, C.E. Finn, Y. Zhao, and J.R. Clark. 2009. High tunnel versus open field: management of primocane-fruiting blackberry using pruning and tipping to increase yield and extend the fruiting season. HortScience 44:1581-1587.

Thompson, E., B.C. Strik, J.R. Clark, and C.E. Finn. 2007. Flowering and fruiting patterns of primocane-fruiting blackberries. HortScience. 42:1174-1176.

Walsh, C.S., J. Popenoe, J., and T. Solomos. 1983. Thornless blackberry is a climacteric fruit. HortScience. 18:482-483.

Yao, S. and C.J. Rosen. 2011. Primocane-fruiting raspberry production in high tunnels in a cold region of the upper Midwestern United States. HortScience. 21:429-434.

APPENDIX

Table A1. Number of growing degree days (GDD) from April 1, 2015 to October 31, 2015 using a base of 10 °C and an upper limit of 30 °C.

Month	High Tunnel	Silver Mulch and Bare Soil
April	166	111
May	420	273
June	745	581
July	1165	981
August	1542	1326
September	1863	1611
October	2072	1734

Table A2. ANOVA for root rating for two and four weeks after initiation in experiment one.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	1	1	28.26	1	1	0.07
Age	1	1	28.53	1	1	124.01
Treatment	1	1	0.14	1	1	1.63
Treatment*Cultivar	1	1	0.02	1	1	0.59
Cultivar*Age	1	1	4.46	1	1	0.07
Treatment*Age	1	1	2.61	1	1	0.87
Treatment*Cultivar*Age	1	1	1.87	1	1	0.01

Table A3. ANOVA for root number for two and four weeks after initiation in experiment one.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	1	1	46.77	1	1	46.18
Age	1	1	24.89	1	1	30.38
Treatment	1	1	0.36	1	1	0.18
Treatment*Cultivar	1	1	0.31	1	1	0.35
Cultivar*Age	1	1	24.47	1	1	32.17
Treatment*Age	1	1	1.89	1	1	3.12
Treatment*Cultivar*Age	1	1	1.78	1	1	1.15

Table A4. ANOVA for shoot length for two and four weeks after initiation in experiment one.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	1	1	3.05	1	1	9.19
Age	1	1	17.33	1	1	115.29
Treatment	1	1	9.08	1	1	1.80
Treatment*Cultivar	1	1	8.53	1	1	12.02
Cultivar*Age	1	1	1.81	1	1	23.45
Treatment*Age	1	1	0.62	1	1	0.31
Treatment*Cultivar*Age	1	1	0.4	1	1	0.46

Table A5. ANOVA for rooting percentage for two and four weeks after initiation in experiment one.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	1	1	40.03	1	1	19.69
Age	1	1	23.52	1	1	53.78
Treatment	1	1	0.37	1	1	7.11
Treatment*Cultivar	1	1	0.04	1	1	0.44
Cultivar*Age	1	1	19.02	1	1	28.44
Treatment*Age	1	1	9.12	1	1	16.00
Treatment*Cultivar*Age	1	1	5.51	1	1	0.44

Table A6. ANOVA for root length for two and four weeks after initiation in experiment one.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	1	1	35.75	1	1	23.55
Age	1	1	12.07	1	1	12.55
Treatment	1	1	1.03	1	1	0.00
Treatment*Cultivar	1	1	1.56	1	1	0.05
Cultivar*Age	1	1	10.57	1	1	11.44
Treatment*Age	1	1	0.02	1	1	0.19
Treatment*Cultivar*Age	1	1	0.01	1	1	0.01

Table A7. ANOVA for root rating for two weeks after initiation in experiment two.

Effect	Num DF	Den DF	F Value
Method	1	1	1.27
Auxin	4	4	0.50
Cultivar	1	1	3.78
Age	1	1	7.67
Auxin*Cultivar	4	4	1.20
Auxin*Age	4	4	0.19
Cultivar*Age	1	1	11.11
Auxin*Cultivar*Age	4	4	0.23
Method*Auxin	4	4	6.73*
Method*Cultivar	1	1	0.39
Method*Auxin*Cultivar	4	4	0.90
Method*Auxin*Age	4	4	0.80
Method*Cultivar*Age	1	1	0.20
Method*Auxin*Cultivar*Age	4	4	1.10

Table A8. ANOVA for root number for two weeks after initiation in experiment two.

Effect	Num DF	Den DF	F Value
Method	1	1	18.96
Auxin	4	4	34.37
Cultivar	1	1	2.05
Age	1	1	56.71
Auxin*Cultivar	4	4	0.42
Auxin*Age	4	4	0.41
Cultivar*Age	1	1	2.06
Auxin*Cultivar*Age	4	4	0.21
Method*Auxin	4	4	28.93*
Method*Cultivar	1	1	3.16
Method*Auxin*Cultivar	4	4	0.81
Method*Auxin*Age	4	4	1.40
Method*Cultivar*Age	1	1	3.13
Method*Auxin*Cultivar*Age	4	4	0.13

Table A9. ANOVA for shoot length for two weeks after initiation in experiment two.

Effect	Num DF	Den DF	F Value
Method	1	1	18.96
Auxin	4	4	34.37*
Cultivar	1	1	2.05
Age	1	1	56.71
Auxin*Cultivar	4	4	0.42
Auxin*Age	4	4	0.41
Cultivar*Age	1	1	2.06
Auxin*Cultivar*Age	4	4	0.21
Method*Auxin	4	4	28.93*
Method*Cultivar	1	1	3.16
Method*Auxin*Cultivar	4	4	0.81
Method*Auxin*Age	4	4	1.40
Method*Cultivar*Age	1	1	3.13
Method*Auxin*Cultivar*Age	4	4	0.13

Table A10. ANOVA for rooting percentage for two weeks after initiation in experiment two.

Effect	Num DF	Den DF	F Value
Method	1	1	0.34
Auxin	4	4	0.81
Cultivar	1	1	71.83
Age	1	1	1.75
Auxin*Cultivar	4	4	0.93
Auxin*Age	4	4	2.13
Cultivar*Age	1	1	1.19
Auxin*Cultivar*Age	4	4	1.82
Method*Auxin	4	4	0.34
Method*Cultivar	1	1	0.07
Method*Auxin*Cultivar	4	4	0.74
Method*Auxin*Age	4	4	2.13
Method*Cultivar*Age	1	1	3.77
Method*Auxin*Cultivar*Age	4	4	1.05

Table A11. ANOVA for root length for two weeks after initiation in experiment two.

Effect	Num DF	Den DF	F Value
Method	1	1	8.24
Auxin	4	4	0.96
Cultivar	1	1	5.66
Age	1	1	0.89
Auxin*Cultivar	4	4	1.60
Auxin*Age	4	4	2.10
Cultivar*Age	1	1	0.75
Auxin*Cultivar*Age	4	4	1.59
Method*Auxin	4	4	0.35
Method*Cultivar	1	1	8.00
Method*Auxin*Cultivar	4	4	0.33
Method*Auxin*Age	4	4	1.91
Method*Cultivar*Age	1	1	0.97
Method*Auxin*Cultivar*Age	4	4	1.423

Table A12. ANOVA for root rating for two and four weeks after initiation in experiment three.

		Two Weeks			Four Weeks	
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	5	5	43.33*	5	5	14.17*
Method	1	1	6.70	1	1	24.45
Cultivar*Method	5	5	1.09	5	5	1.72
Auxin	4	4	28.54*	4	4	56.15*
Cultivar*Auxin	20	20	2.49*	20	20	3.71*
Method*Auxin	4	4	0.49	4	4	17.6*
Cultivar*Method*Auxin	20	20	1.52	20	20	1.43

Table A13. ANOVA for root number for two and four weeks after initiation in experiment three.

		Two Weeks			Four Weeks	
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	5	5	3.76	5	5	1.96
Method	1	1	3.46	1	1	3.8
Cultivar*Method	5	5	1.40	5	5	1.96
Auxin	4	4	2.18	4	4	2.48
Cultivar*Auxin	20	20	2.43*	20	20	2.15*
Method*Auxin	4	4	1.47	4	4	2.48
Cultivar*Method*Auxin	20	20	1.72	20	20	2.15*

Table A14. ANOVA for shoot length for two and four weeks after initiation in experiment three.

		Two Weeks			Four Weeks	
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	5	5	25.44*	5	5	17.5*
Method	1	1	1.02	1	1	18.65
Cultivar*Method	5	5	4.01	5	5	3.13
Auxin	4	4	13.78*	4	4	58.4*
Cultivar*Auxin	20	20	2.42*	20	20	6.19*
Method*Auxin	4	4	0.92	4	4	11.02*
Cultivar*Method*Auxin	20	20	1.40	20	20	1.89

Table A15. ANOVA for rooting percentage for two and four weeks after initiation in experiment three.

		Two Weeks			Four Weeks	
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	5	5	7.39*	5	5	1.22
Method	1	1	3.73	1	1	5.26
Cultivar*Method	5	5	1.5	5	5	1.22
Auxin	4	4	4.34	4	4	1.99
Cultivar*Auxin	20	20	3.34*	20	20	1.03
Method*Auxin	4	4	0.83	4	4	1.99
Cultivar*Method*Auxin	20	20	2.14*	20	20	1.03

Table A16. ANOVA for root length for two and four weeks after initiation in experiment three.

		Two Weeks			Four Weeks	
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Cultivar	5	5	3.24	5	5	1.67
Method	1	1	4.77	1	1	4.46
Cultivar*Method	5	5	1.82	5	5	1.67
Auxin	4	4	3.80	4	4	2.20
Cultivar*Auxin	20	20	3.22*	20	20	1.57
Method*Auxin	4	4	2.39	4	4	2.20
Cultivar*Method*Auxin	20	20	2.52*	20	20	1.57

Table A17. ANOVA for shoot length for two and four weeks after initiation in experiment four.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Node	1	1	1.68	1	1	3.80
Auxin	2	2	3.70	2	2	1.54
Node*Auxin	2	2	2.88	2	2	1.54

Table A18. ANOVA for root rating for two and four weeks after initiation in experiment four.

	Two Weeks			Four Weeks		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Node	1	1	1.42	1	1	3.79
Auxin	2	2	2.00	2	2	1.26
Node*Auxin	2	2	4.25	2	2	1.26

Table A19. ANOVA for root rating for two weeks after initiation in experiment five.

Effect	Num DF	Den DF	F Value
Method	3	3	0.36

Table A20. ANOVA for root number for two weeks after initiation in experiment five.

Effect	Num DF	Den DF	F Value
Method	3	3	3.25

Table A21. ANOVA for shoot length for two weeks after initiation in experiment five.

Effect	Num DF	Den DF	F Value
Method	3	3	0.39

Table A22. ANOVA for rooting percentage for two weeks after initiation in experiment five.

Effect	Num DF	Den DF	F Value
Method	3	3	0.38

Table A23. ANOVA for root length for two weeks after initiation in experiment five.

Effect	Num DF	Den DF	F Value
Method	3	3	2.68

Table A24. ANOVA for root rating for two weeks after initiation in experiment six.

Effect	Num DF	Den DF	F Value
Cultivar	1	1	0.00
Age	1	1	21.59
Cultivar*Age	1	1	0.00
Auxin	4	4	5.26
Cultivar*Auxin	4	4	0.40
Age*Auxin	4	4	6.34
Auxin*Cultivar*Age	4	4	2.02

Table A25. ANOVA for root number for two weeks after initiation in experiment six.

Effect	Num DF	Den DF	F Value
Cultivar	1	1	3.31
Age	1	1	0.07
Cultivar*Age	1	1	0.07
Auxin	4	4	1.37
Cultivar*Auxin	4	4	1.37
Age*Auxin	4	4	0.63
Auxin*Cultivar*Age	4	4	0.63

Table A26. ANOVA for shoot length for two weeks after initiation in experiment six.

Effect	Num DF	Den DF	F Value
Cultivar	1	1	3.05
Age	1	1	17.33
Cultivar*Age	1	1	9.08
Auxin	4	4	8.53
Cultivar*Auxin	4	4	1.81
Age*Auxin	4	4	0.62
Auxin*Cultivar*Age	4	4	0.40

Table A27. ANOVA for rooting percentage for two weeks after initiation in experiment six.

Effect	Num DF	Den DF	F Value
Cultivar	1	1	3.92
Age	1	1	0.17
Cultivar*Age	1	1	0.17
Auxin	4	4	1.10
Cultivar*Auxin	4	4	1.10
Age*Auxin	4	4	1.44
Auxin*Cultivar*Age	4	4	1.44

Table A28. ANOVA for root length for two weeks after initiation in experiment six.

Effect	Num DF	Den DF	F Value
Cultivar	1	1	4.39
Age	1	1	0.69
Cultivar*Age	4	4	0.69
Auxin	4	4	0.80
Cultivar*Auxin	1	1	0.80
Age*Auxin	4	4	1.38
Auxin*Cultivar*Age	4	4	1.38

Table A29. ANOVA for root rating for two weeks after initiation in experiment seven.

Effect	Num DF	Den DF	F Value
Age	1	1	0.43
Auxin	11	11	14.22*
Age*Auxin	11	11	1.12

Table A30. ANOVA for root number for two weeks after initiation in experiment seven.

Effect	Num DF	Den DF	F Value
Age	1	1	0.00
Auxin	11	11	1.70*
Age*Auxin	11	11	0.62

Table A31. ANOVA for shoot length for two weeks after initiation in experiment seven.

Effect	Num DF	Den DF	F Value
Age	1	1	7.35
Auxin	11	11	3.24*
Age*Auxin	11	11	0.71

Table A32. ANOVA for rooting percentage for two weeks after initiation in experiment seven.

Effect	Num DF	Den DF	F Value
Age	1	1	4.78*
Auxin	11	11	15.64*
Age*Auxin	11	11	0.95

Table A33. ANOVA for root length for two weeks after initiation in experiment seven.

Effect	Num DF	Den DF	F Value
Age	1	1	0.01
Auxin	11	11	7.22*
Age*Auxin	11	11	0.64

Table A34. ANOVA for date of primocane emergence in all three environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	0.22	2	32	1.28	2	32	0.08
Cultivar	3	33	5.37*	3	32	0.36	3	32	0.34
Cultivar*Treatment	6	33	0.95	6	32	0.95	6	32	0.85

Table A35. ANOVA for primocane height across time for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	36.1	6.91*	2	36.3	3.96*	2	28.6	2.39
Time	3	53	181.79*	3	56.6	143.11*	3	59.3	207.43*
Treatment*Time	6	63.5	6.75*	6	67.3	4.43*	6	70.2	4.07*
Cultivar	3	36.1	3.48*	3	36.3	2.82	3	28.6	4.93*
Treatment*Cultivar	6	36.1	0.49	6	36.3	1.46	6	28.6	1.93
Time*Cultivar	9	69.2	1.53	9	73	0.99	9	76	1.69
Treatment*Time*Cultivar	18	75.3	1.21	18	79	0.79	18	82	1.02

Table A36. ANOVA for end of season fresh weight per plant for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	1.01	2	32	1.51	2	32	0.88
Cultivar	3	33	0.97	3	32	3.83*	3	32	1.11
Treatment*Cultivar	6	33	0.75	6	32	1.93	6	32	1.92

Table A37. ANOVA for total number of non-flowering canes for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	1.03	2	32	1.71	2	32	4.41*
Cultivar	3	33	0.75	3	32	0.17	3	32	5.95*
Treatment*Cultivar	6	33	1.59	6	32	0.91	6	32	1.64

Table A38. ANOVA for average non-flowering cane length for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	6.53*	2	32	1.87	2	32	1.03
Cultivar	3	33	3.53*	3	32	1.31	3	32	1.46
Treatment*Cultivar	6	33	2.28	6	32	1.77	6	32	1.37

Table A39. ANOVA for number of branches per cane for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	6.3	2	30	23.06	2	32	18.92
Cultivar	3	32	0.54	3	30	0.28	3	32	1.94
Treatment*Cultivar	6	32	0.35	6	30	1.39	6	32	0.89

Table A40. ANOVA for average branch length for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	1.77	2	30	2.65	2	32	0.57
Cultivar	3	32	2.52	3	30	1.46	3	32	1.69
Treatment*Cultivar	6	32	2.25	6	30	0.87	6	32	0.59

Table A41. ANOVA for average branch node number for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	8.67*	2	30	32.56*	2	32	16.73*
Cultivar	3	32	1.65	3	30	1.2	3	32	1.08
Treatment*Cultivar	6	32	0.41	6	30	3.5*	6	32	1.78

Table A42. ANOVA for total node number per cane for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	0.52	2	30	4.62	2	32	1.07
Cultivar	3	32	0.46	3	30	0.58	3	32	1.28
Treatment*Cultivar	6	32	0.33	6	30	1.67	6	32	0.81

Table A43. ANOVA for total number of floral structures per plant for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	1.51	2	32	2.76	2	32	0.59
Cultivar	3	33	3.48*	3	32	11.05*	3	32	4.23*
Treatment*Cultivar	6	33	0.41	6	32	1.7	6	32	0.77

Table A44. ANOVA for total number of flowering canes per plant for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.84	2	32	1.21	2	32	1.43
Cultivar	3	33	3.87*	3	32	4.68*	3	32	5.72*
Treatment*Cultivar	6	33	2.38	6	32	0.88	6	32	2.05

Table A45. ANOVA for average flowering cane length per plant for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	19.05*	2	32	18.93*	2	32	10.05*
Cultivar	3	33	1.29	3	32	1.74	3	32	2.94*
Treatment*Cultivar	6	33	2.31	6	32	2.93*	6	32	1.04

Table A46. ANOVA for percent of reproductive nodes per cane for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	0.41	2	30	0.8	2	32	0.21
Cultivar	3	32	4.7*	3	30	11.46*	3	32	10.56*
Treatment*Cultivar	6	32	2.06	6	30	0.39	6	32	1.47

Table A47. ANOVA for number of fruiting sites per cane for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	0.57	2	30	1.66	2	32	0.09
Cultivar	3	32	0.91	3	30	4.06*	3	32	3.73*
Treatment*Cultivar	6	32	0.8	6	30	0.79	6	32	1.11

Table A48. ANOVA for average inflorescence length for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	0.05	2	30	2.52	2	32	0.19
Cultivar	3	32	1.8	3	30	9.27*	3	32	4.45*
Treatment*Cultivar	6	32	1.53	6	30	3.32*	6	32	1.38

Table A49. ANOVA for average number of inflorescences per cane for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	2.09	2	30	5.85	2	32	4.11*
Cultivar	3	32	0.73	3	30	1.55	3	32	2.57
Treatment*Cultivar	6	32	0.97	6	30	0.58	6	32	0.44

Table A50. ANOVA for date of bloom for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	2.76	2	31	6.3*	2	32	4.21*
Cultivar	3	32	0.67	3	31	2	3	32	2.38
Treatment*Cultivar	6	32	1.37	6	31	1.37	6	32	0.79

Table A51. ANOVA for height at bloom for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	32	7.52*	2	31	1.14	2	32	0.06
Cultivar	3	32	1.88	3	31	2.2	3	32	2.03
Treatment*Cultivar	6	32	0.88	6	31	0.32	6	32	1.33

Table A52. ANOVA for date of first fruit for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	24	2.85	2	20	1.92	2	16	1.15
Cultivar	3	24	0.37	3	20	0.44	3	16	2.67
Treatment*Cultivar	6	24	0.35	6	20	0.21	6	16	0.84

Table A53. ANOVA for number of days from bloom to fruit for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	24	1.31	2	20	1.81	2	16	0.18
Cultivar	3	24	0.52	3	20	3.1*	3	16	0.39
Treatment*Cultivar	6	24	0.93	6	20	1.03	6	16	0.95

Table A54. ANOVA for number of inflorescences blooming across time for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33.3	1.15	2	38.3	1.18	2	36.6	0.71
Time	3	55.6	38.15*	3	54.7	48.25*	3	56.4	39.09*
Treatment*Time	6	66.5	1.7	6	65.2	3.21*	6	66.9	3.26*
Cultivar	3	33.3	1.91	3	38.3	7.6*	3	36.6	3.78*
Treatment*Cultivar	6	33.3	0.92	6	38.3	1.26	6	36.6	2.09
Time*Cultivar	9	72.5	0.86	9	70.8	4.34*	9	72.5	2.69*
Treatment*Time*Cultivar	18	78.9	0.93	18	76.7	1.78*	18	78.2	0.94

Table A55. ANOVA for total berry number for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.69	2	32	4.05*	2	32	1.76
Cultivar	3	33	1.57	3	32	3.32*	3	32	2.96
Treatment*Cultivar	6	33	0.85	6	32	1.04	6	32	1.22

Table A56. ANOVA for marketable berries for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.53	2	32	3.72	2	32	2.73
Cultivar	3	33	1.46	3	32	3.27	3	32	1.43
Treatment*Cultivar	6	33	0.8	6	32	1.08	6	32	1.36

Table A57. ANOVA for total harvested weight for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.47	2	32	4.04*	2	32	2.29
Cultivar	3	33	0.81	3	32	2.24	3	32	1.06
Treatment*Cultivar	6	33	0.84	6	32	0.82	6	32	1.98

Table A58. ANOVA for total marketable weight for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.29	2	32	3.69*	2	32	1.95
Cultivar	3	33	0.74	3	32	2.18	3	32	0.93
Treatment*Cultivar	6	33	0.8	6	32	0.87	6	32	2

Table A59. ANOVA for total harvested yield across time for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.47	2	35.1	3.97*	2	35	2.35
Time	5	180	13.56*	5	175	11.23*	5	175	5.97*
Treatment*Time	10	180	1.33	10	175	3.48*	10	175	1.22
Cultivar	3	33	0.81	3	35.1	2.23	3	35	1.11
Treatment*Cultivar	6	33	0.84	6	35.1	0.8	6	35	2.14
Time*Cultivar	15	180	0.96	15	175	3.18*	15	175	0.73
Treatment*Time*Cultivar	30	180	1.28	30	175	1.2	30	175	1.24

Table A60. ANOVA for marketable yield across time for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	33	2.31	2	35.1	3.7*	2	35	2.05
Time	5	180	11.49*	5	175	9.43*	5	175	5.08*
Treatment*Time	10	180	1.21	10	175	2.82*	10	175	1.01
Cultivar	3	33	0.73	3	35.1	2.23	3	35	1
Treatment*Cultivar	6	33	0.8	6	35.1	0.88	6	35	2.17
Time*Cultivar	15	180	1.04	15	175	3.02*	15	175	0.71
Treatment*Time*Cultivar	30	180	1.26	30	175	1.33	30	175	1.21

Table A61. ANOVA for average berry weight for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	25	0.22	2	22	0.13	2	16	1.07
Cultivar	3	25	17.04*	3	22	2.59	3	16	2.73
Treatment*Cultivar	6	25	0.41	6	22	1.76	6	16	4.93*

Table A62. ANOVA for average berry length for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	25	0.51	2	22	0.09	2	16	0.07
Cultivar	3	25	5.1*	3	22	2.28	3	16	1.6
Treatment*Cultivar	6	25	0.43	6	22	1.78	6	16	2.17

Table A63. ANOVA for average berry width for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	25	0.15	2	22	0.02	2	16	0.26
Cultivar	3	25	5.44*	3	22	2.06	3	16	2.28
Treatment*Cultivar	6	25	0.37	6	22	1.42	6	16	0.62

Table A64. ANOVA for berry SSC for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	25	3.43*	2	21	0.13	2	16	0.14
Cultivar	3	25	0.29	3	21	2.59	3	16	8.67*
Treatment*Cultivar	6	25	1.2	6	21	1.76	6	16	0.99

Table A65. ANOVA for berry pH for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	25	8.00*	2	18	0.53	2	16	2.76
Cultivar	3	25	11.31*	3	18	3.94*	3	16	5.48*
Treatment*Cultivar	6	25	0.23	6	18	2.01	6	16	2.22

Table A66. ANOVA for berry TA for all environments.

	High Tunnel			Silver Mulch			Bare Soil		
Effect	Num DF	Den DF	F Value	Num DF	Den DF	F Value	Num DF	Den DF	F Value
Treatment	2	24	1.42	2	17	2.08	2	14	5.91*
Cultivar	3	24	4.75*	3	17	4.27*	3	14	5.99*
Treatment*Cultivar	6	24	1.25	6	17	2.4	6	14	2.71

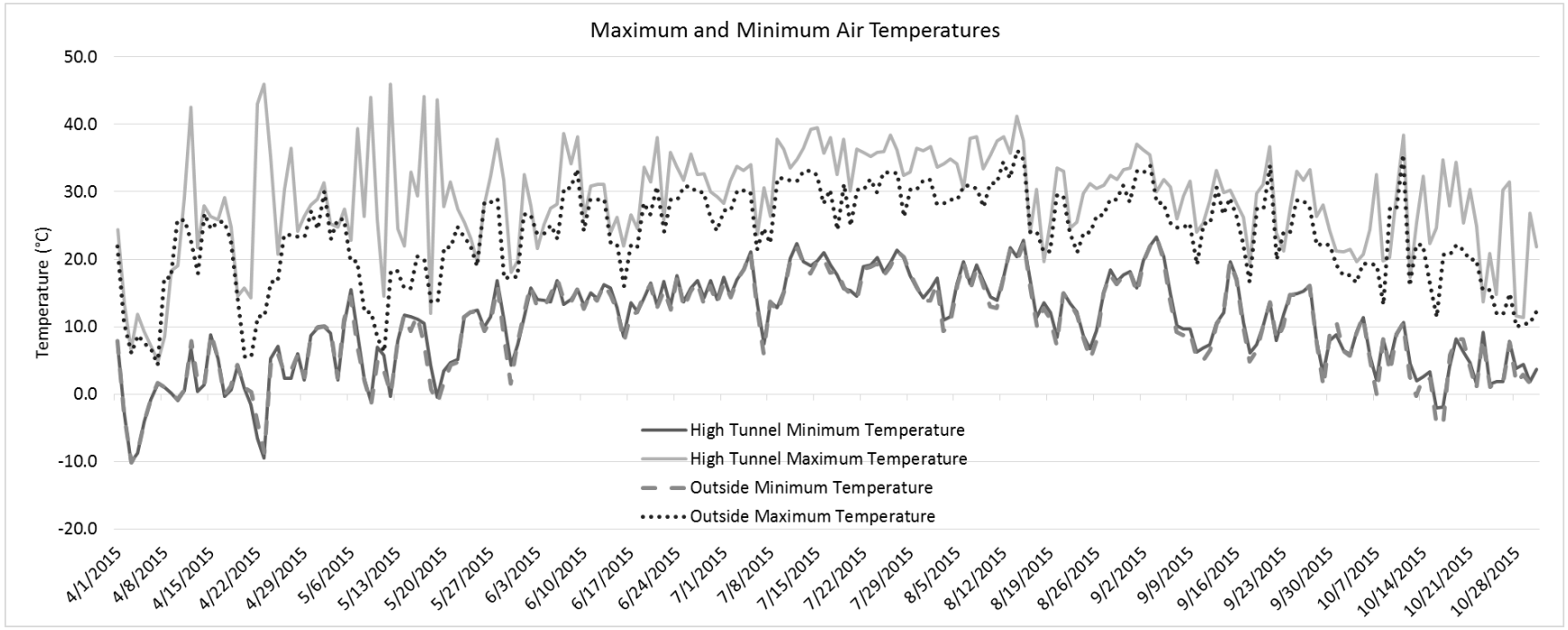

Figure A1. Maximum and minimum air temperatures for the high tunnel and outside environments (silver mulch and bare soil) throughout the growing season.

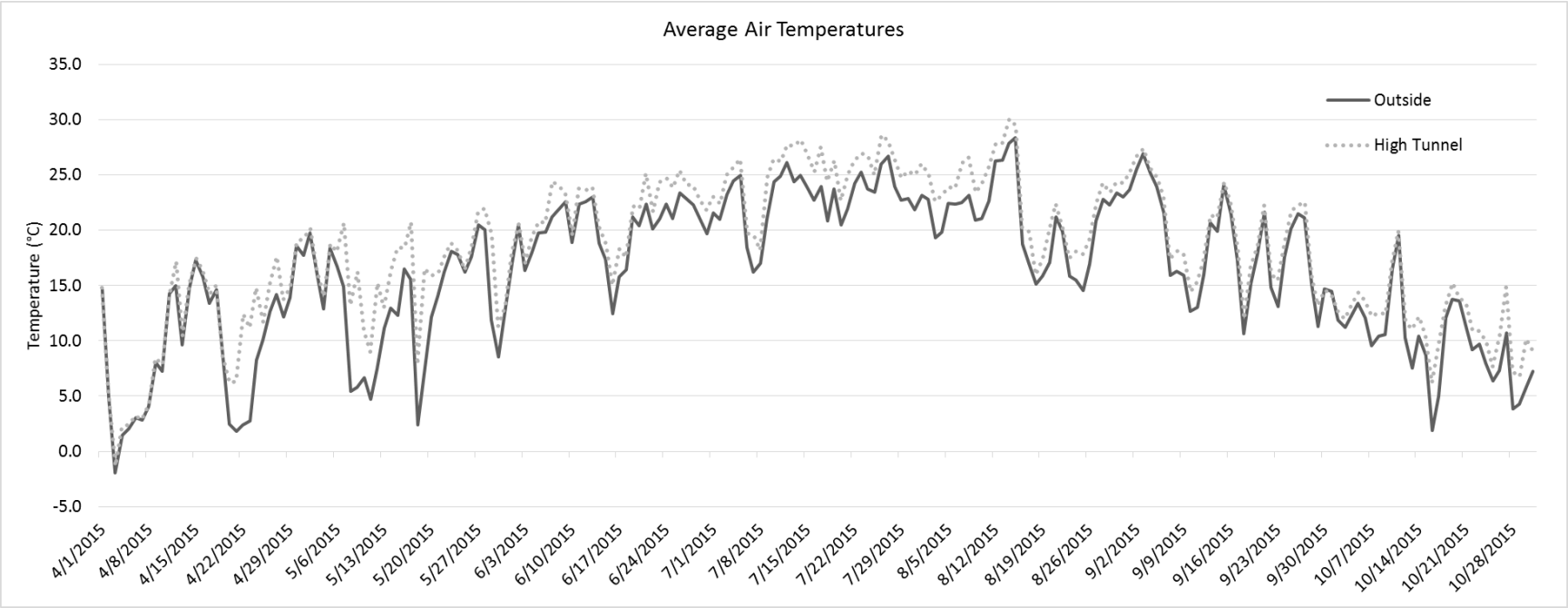

Figure A2. Average air temperatures for the high tunnel and outside (silver mulch and bare soil) environments throughout the growing season.

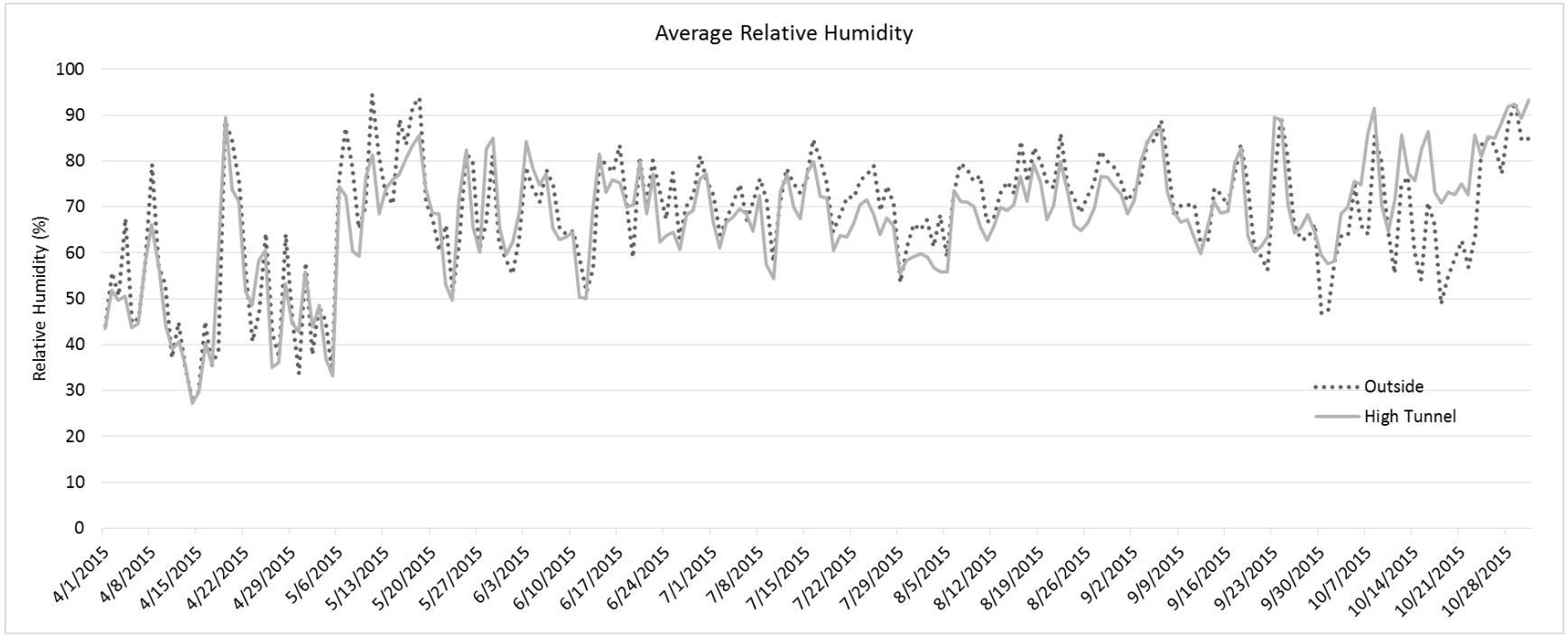

Figure A3. Average relative humidity for the high tunnel and outside (silver mulch and bare soil) environments throughout the growing season.

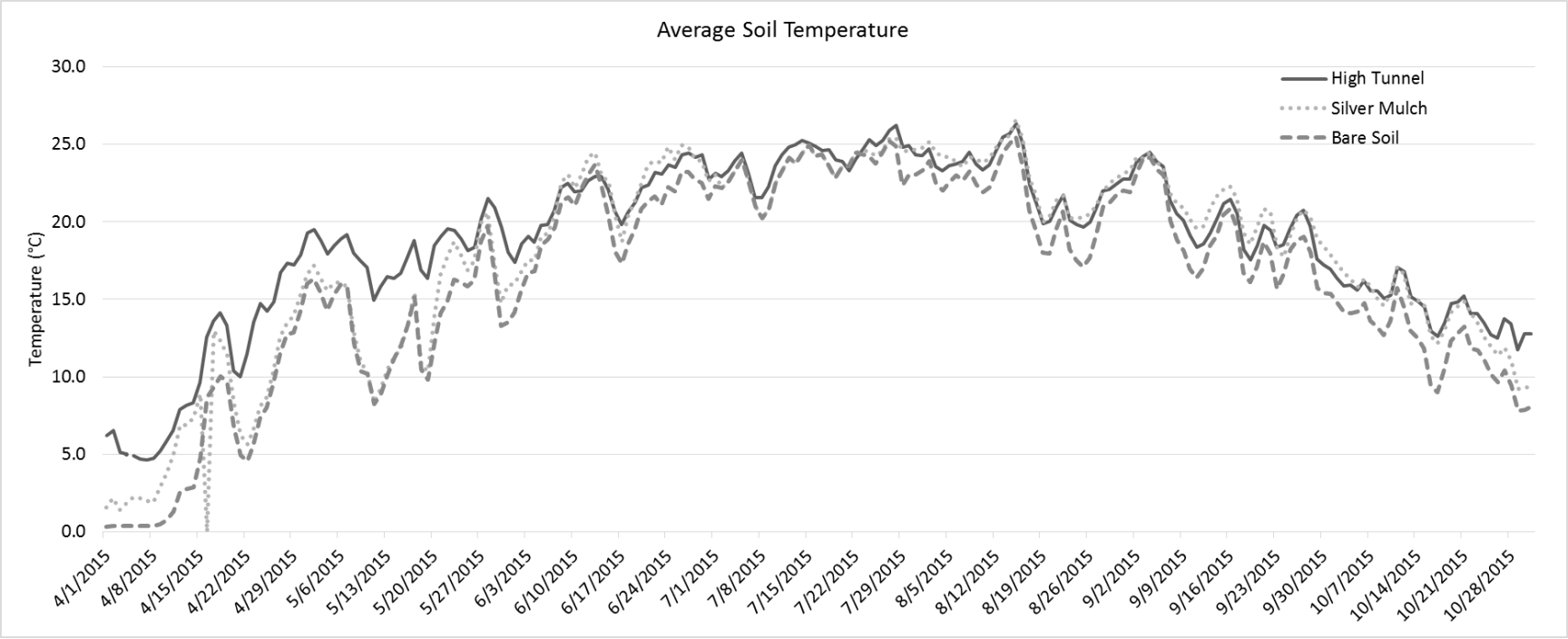

Figure A4. Average soil temperature at a depth of 15 cm in the high tunnel, silver mulch, and bare soil environments throughout the growing season.

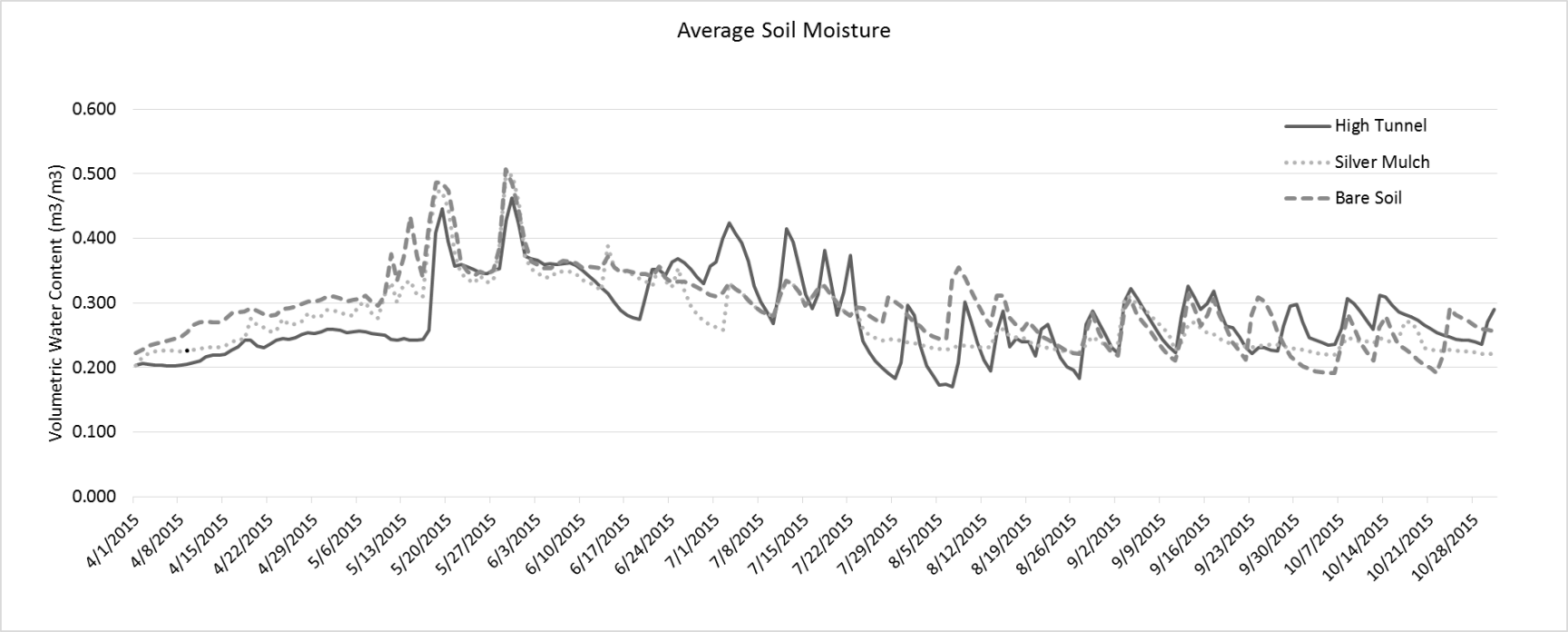

Figure A5. Average soil moisture at a depth of 15 cm in the high tunnel, silver mulch, and bare soil environments throughout the growing season.