ROTATING CROSS-ARM AND WINTER ROW COVERS FOR FLORICANE BLACKBERRY (*RUBUS* SUBGENUS *RUBUS* WATSON) PRODUCTION IN NORTH DAKOTA

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MASTER OF SCIENCE

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ABSTRACT

Blackberry (*Rubus* subgenus *Rubus* Watson) production has potential to expand into North Dakota, but this will only occur with the evaluation of new cultivars and overwintering protection methods. Ten cultivars under four row cover treatments were evaluated for hardiness, vegetative growth, yield, and factors affecting fruit quality. Thermo-couples monitored air temperature under each treatment. Results indicate that the treatments differed in their ability to moderate winter air temperatures. Row covers had little effect on growth but differences were found between cultivars. The thermal blanket with corn stover resulted in significantly higher yield and more berries, but row covers did not affect fruit quality. Differences were also found between cultivars for fruit quantity and quality. Although row covers enabled fruit production after winter temperatures reached -30 °C, further research is recommended to improve winter protection techniques and identify suitable floricane blackberry cultivars for production in North Dakota.

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DEDICATION

This thesis and all of the work that has gone into it is dedicated to my lovely wife Kelsie and our son Matthias. She has been completely supportive throughout this process and often helped me collect data and do other work directly related to this project.

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INTRODUCTION

In the book entitled "Growing fruit in the upper Midwest", the author Don Gordon (1991) discussed many fruit crops and the states in which he would recommend planting or trialing certain cultivars. Gordon neither recommended planting or trialing any blackberry cultivars in North Dakota. However, many homeowners have reported consistent blackberry production when plants were covered or sufficient snow was present to prevent canes from incurring winter injury (Hatterman-Valenti, personal communication).

Justification of Research

Research on blackberry production systems and the evaluation of new cultivars is needed to expand the industry into colder hardiness zones in the United States (Takeda et al., 2013). This would provide growers with the necessary knowledge to provide fresh, high quality fruit to consumers at a price that would be competitive with other production areas in the U.S. and abroad. Worldwide blackberry production increased 45% from 1995 to 2005 and is expected to continue to grow in many regions with a market geared toward local sales in the eastern and central U.S. (Strik et al., 2007). Most research in this area has been done in the eastern U.S., but there is also ongoing research in Michigan and Indiana (Takeda and Phillips, 2011). The objective of this research is to provide information on blackberry floricane production systems and cultivars in the northern Great Plains where there is currently no information for people interested in growing blackberries.

The research implemented in this study includes a rather new rotating cross-arm (RCA) technology that has a unique trellis design and cane training protocol with the potential to increase production efficiency and prevent winter injury (Takeda et al., 2013). In addition, different overwintering materials were utilized as row covers while a comparison was made between 10 blackberry cultivars for winter hardiness and yield.

The results of this project will help determine the effectiveness of using row covers for winter protection, along with the best suited floricane blackberry cultivars for the RCA trellis system and production in North Dakota. The goal of this research is to develop a rather simple method for growing blackberries in USDA Zones 3 and 4. This system has the potential to make blackberries widely available in local markets, allowing consumers to take advantage of the health benefits associated with blackberry consumption.

Literature Review

Blackberries, with high levels of vitamins and good flavor, have been a valued wild fruit for centuries around the world (Crandall, 1995). However, not until recent decades when improved cultivars and new methods of production have been developed, is the blackberry industry seeing great interest from growers and experiencing expansion around the world.

Plant Physiology

Blackberries belong to the family *Rosaceae* and are often referred to as brambles, denoting the thorny nature of the canes (Gordon, 1991). Blackberries are most often classified by growth habit as either erect, semi-erect, or trailing (Strik et al., 2007). Depending on the growth habit of the blackberry cultivar, canes are produced from vegetative buds on either the roots or the crown system (Crandall, 1995). The erect and semi-erect cultivars produce new canes, called primocanes, from buds on the roots while trailing cultivars produce primocanes from buds on the crown system and can produce new plants by forming adventitious roots as the tips of the canes bend down and touch the soil. The shallow fibrous root system of the blackberry plant is perennial while the aboveground canes are biennial with vegetative growth of the primocanes occurring in the first year. This cane growth generally continues well into the fall, when most canes lose the current year's foliage (Jennings, 1988). However, some cultivars with parentage from *Rubus ulmifolius* retain foliage during the winter. This vegetative growth is then followed by flowering and fruit set during the second year of growth when the canes are now known as floricanes (Crandall, 1995).

Like other members of the family *Rosaceae*, blackberries have flowers with five sepals and five petals. These flowers form on flowering shoot racemes produced from axillary buds (Takeda et al., 2003). The floricanes die after producing aggregate fruit composed of many small drupelets attached to a fleshy receptacle. This is typically how blackberry plants have produced fruit; however, in recent years, some cultivars have been developed to produce fruit on the first year of cane growth, as well as the second year (Strik et al., 2007). These primocane fruiting cultivars produce fruit on the top portion of the cane in the first year and then produce again the following year from the remaining basal portion (Crandall, 1995). This increases economic return and yield during the first year of growth and provides two harvests during a single year after establishment. Blackberry yield is also influenced by a variety of other factors, which can be controlled or moderated with good production practices and correct cultivar selection.

The yield of a blackberry plant is partially dependent on the number of reproductive bud nodes on the floricanes. However, if the plant is severely pruned, there may be increased bud break to compensate for that loss. Also, if the number of canes for a given plant is reduced, the remaining canes will produce longer laterals and have the potential for producing larger fruit (Crandall, 1995). Recently, blackberry yield has been decreased when fruit was rendered unmarketable due to insect damage, such as that caused by spotted wing drosophila. Yield can also be negatively impacted by environmental conditions such as a late frost during flower bud growth that may damage the flowers and reduce fruit set or more directly by sunburnt fruit.

Chilling and Acclimation

The formation of flower buds is dependent upon the *Rubus* cultivar's background and environmental factors (Jennings, 1988). Some cultivars begin to develop floral parts as early as October, while others remain vegetative throughout the winter and begin floral initiation as late as April (Takeda et al., 2002). The formation of flower buds also depends on temperature conditions and day length. Early in the season, while primocanes are developing, the axillary buds have the potential to form lateral branches. This is clearly demonstrated by the fact that growers generally tip primocanes to promote branching. However, later in the season these vegetative buds change into reproductive buds as the temperatures drop and the day length becomes shorter (Clark and Finn, 2008). This does not hold true for all cultivars as some cultivars appear to not need cooler temperatures to begin differentiation of floral organs. One study compared cultivar differences and found that shortening day lengths initiated flower bud development, but that temperatures below 2 ºC halted floral organ development (Takeda et al., 2002). In another study researching flower bud initiation, it was found that canes subjected to a cold treatment flowered after only 41 nodes of growth, while the non-cold treated canes flowered after 80 nodes of growth (Jennings, 1988). Since flower bud development is dependent on day length and temperature, the time of initiation will vary for different locations. Water stress can hasten flower bud initiation and some hormones, such as gibberellins and cytokinin, are also thought to impact flower initiation, but the effects of these hormones has not been conclusive.

Cultivars differ in the amount of chilling time required to remove endodormancy of the floral buds. 'Marion' needs as little as 300 hours of low temperatures compared to the 800 hours required by 'Chester Thornless' to remove bud dormancy (Takeda et al., 2002). This chilling requirement can be a limiting factor in blackberry production in regions with mild winters and may influence grower cultivar selection (Clark and Finn, 2008). Once the chilling requirement it met, the floricanes do not increase in length, but simply elongate the lateral buds to form bracts that will bear the flowers and fruit. The uniformity of this bud break can be affected by winter temperature (Takeda et al., 2002).

Cultivars also vary greatly in the ability of the canes to acclimate to winter temperatures (Jennings, 1988). The ability of a plant to acclimate is dependent upon the cessation of growth, the cane's water content, and the timing of dormancy. Elongation of canes begins to slow down and dormancy gradually sets in as a shortened photoperiod and lower temperatures occur, which are often associated with autumn (Takeda et al., 2002). Plants that begin 'shutting down' earlier in the fall are less prone to winter injury as the plants are able to transport water and nutrients from the canes and foliage into the root system (Jennings, 1988). Plants that have a reduced amount of water before the onset of winter also tend to have a reduced amount of winter damage. This movement of water can be reversed with warm spring days, which if followed by freezing temperatures could result in late winter damage. The intensity of dormancy that occurs can impact the response of cultivars to changes in winter temperatures. Cultivars with a shallow or low-intensity dormancy may respond to warmer temperatures in early spring and begin to move water from the root system to the canes. This movement of water is often detrimental to the canes if freezing temperatures occur after this water movement. Cultivars that have an earlier fruit set generally have a shallow dormancy type and are more likely to incur cane damage after fluctuating temperatures (Jennings, 1988). In addition, blackberry cultivars with an erect growth habit are generally more resistant to winter damage than cultivars with a trailing growth habit (Weber, 2013). Thornless cultivars also tend to be more susceptible to winter damage than thorny cultivars. Selection of appropriate cultivars for North Dakota must have reduced cane injury from low winter temperatures or late frosts that could damage flowers.

Production Practices

Blackberries do well in warm temperate regions and prefer to grow in well-drained loam soils with 2-4 percent organic matter and a soil pH of 5.5 to 6.5 (Crandall, 1995). Plants established in a poorly drained soil will be more susceptible to disease and are more likely to be deficient in nutrients as root growth may be restricted. Blackberries do well in sites with full sun without strong winds that could cause problems with desiccation (Fernandez and Ballington, 1999). Blackberries need at least one inch of water every week under normal production practices to ensure optimal fruit development. Mulches can be used to help conserve moisture and reduce the need to irrigate, however this may be impractical with the cost of labor. Drip, overhead, or microjet irrigation systems are commonly used with all of the blackberry growth habits (Strik et al., 2007). Once established, blackberry crops require 67 to 90 kg/ha of nitrogen, while lower amounts are needed during establishment years. Potassium, phosphorus, calcium, and magnesium are also applied as needed.

Blackberry plantings are generally longer lived than raspberry plantings due to fewer disease problems. Depending on production practices, such as cultivar and region, plantings can be productive anywhere from 5 to 20 years (Strik et al., 2007). The establishment and care of a blackberry planting is very dependent on the type of cultivar grown, as well as the region.

Erect cultivars are similar in row spacing to semi-erect cultivars with 3.0 m between rows with plants 0.8 to 1.2 m apart (Strik et al., 2007). Erect cultivar primocanes are also tipped during the growing season, but the floricanes may be removed or left in the hedge row to decrease labor input. Most erect cultivars are used for fresh market production and are harvested twice weekly.

Semi-erect cultivars are generally planted in rows that are 2.5 to 3.6 m apart with 1.0 to 1.8 m between plants in most regions (Strik et al., 2007). However, China has a rather high planting density with only 1.0 m between rows and 0.3 to 0.4 m between plants. Semi-erect cultivar primocanes are often tipped during the growing season, with floricanes being removed during the winter. All semi-erect cultivars are hand-picked roughly twice a week for fresh market consumption.

Trailing cultivars are established with rows 3.0 meters apart and 0.8 to 1.2 meters between plants, very similar to erect type cultivar spacing (Strik et al., 2007). Trailing cultivar primocanes are generally left growing on the ground while the floricanes are wrapped around wires in the trellis system above (Hart et al., 2006). The floricanes are removed after harvest and the primocanes are then picked up are wrapped around the wires for production the following year. Production systems with trailing cultivars are most often harvested by machine and are marketed toward the processing industry.

Wild species are not managed like a typical production system. Although plantings may be established in evenly spaced rows, the plants are typically not pruned, fertilized, or irrigated (Strik et al., 2007). All wild type plantings are harvested by hand and contribute a significant amount to worldwide production.

Blackberry Production

A survey of blackberry production in 2005 revealed that more than 20,000 ha of blackberries were cultivated worldwide (Strik et al., 2007). This was almost a 50% increase from 1995, and production was projected to increase by another 35% by 2015. This survey also showed that Europe and North America were responsible for more than two-thirds of that total production with the greatest increases of production in Mexico and the United States.

In the United States, the majority of production occurred in Oregon, but approximately 30 other states have some degree of blackberry production (Strik et al., 2007). Most of the blackberry production, in states other than Oregon, was focused on the fresh fruit market, as well as on-farm sales and u-pick operations. Production in Oregon and California was focused on processed goods, where the cultivars ‘Marion’, ‘Boysen’, ‘Thornless Evergreen’, and ‘Silvan’ made up most of the acreage in blackberry production. Other states, such as Texas, Arkansas, and Georgia, only focus on erect cultivars such as ‘Arapaho’, ‘Navaho’, and ‘Kiowa’.

The United States led blackberry production in 2005 with over 31,000 Mg (Strik et al., 2007). Following the United States, production in Mexico, China, and Serbia were between 25,000 to 27,000 Mg. Serbia and Hungary were the largest producers in Europe with most of the crop processed and exported. Mexico was the second largest producer in North America with production focused on fresh export to the United States. Mexico’s acreage was primarily made up of ‘Brazos’, along with other erect cultivars. China was the only Asian country with reported blackberry production. The vast majority of the acreage was planted to semi-erect cultivars ‘Hull Thornless’ and ‘Chester Thornless’. Most of China’s production was geared toward processing along with a small amount for fresh export.

Based on growth habit, 50 percent of the blackberry production acreage worldwide, in 2005, was devoted to growing semi-erect plants, 25 percent to erect plants, and 25 percent to trailing plants. Of the semi-erect cultivars ‘Thornfree’, ‘Loch Ness’, and ‘Chester Thornless’ were the most important. ‘Brazos’ was the most important erect cultivar in 2005, but is being replaced in many production areas by ‘Tupy’. ‘Marion’ was the most important trailing blackberry grown worldwide followed by ‘Boysen’. These percentages do not include wild blackberries, which made up about 8000 ha of blackberries worldwide with most of that production occurring in Ecuador, Romania, and Chile (Strik et al., 2007).

In general, fruit used for processing was harvested with machines while fresh market fruit was harvested by hand. Fruit should be harvested in the morning while temperatures are low and are quickly cooled (Strik et al., 2007). Fresh market fruit should not be washed to reduce free moisture in the containers and enhance shelf life. Longer shelf life and better shipping quality are some of the many factors under consideration when breeding programs select for new cultivars.

Breeding and Cultivars

Blackberries belong to the family *Rosaceae* and share many characteristics with other members of this group. There are over 350 species of blackberries identified with most of the modern cultivars originating from either North America or Europe (Crandall, 1995).

Blackberry breeding programs have been around since the first program opened at Texas A&M University in 1909 (Clark and Finn, 2008). Some of the most important programs have been the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) programs in Carbondale, IL, Beltsville, MD, and Corvallis, OR (Finn, 2001). The University of Arkansas has also developed a blackberry breeding program with many thornless erect cultivars released in the last 20 years.

Important cultivars that have been developed to date are ‘Thornfree’, ‘Loch Ness’, ‘Chester Thornless’, ‘Brazos’, ‘Marion’, ‘Tupy’, ‘Thornless Evergreen’, and ‘Boysenberry’ (Strik et al., 2007). These cultivars were developed with many unique characteristics depending upon the native species used for the first selections. Many of the trailing blackberries have been developed from *Rubus ursinus* or *Rubus armeniacus* (Finn, 2001). *Rubus laciniatus* also served as a basis in early industry on the west coast and in breeding. Many of the current cultivars are the result of the hybridization that can occur easily between species within the genus *Rubus*. Blackberry research is seeing renewed interest and many of these newly released cultivars often have pedigrees with one or more of these older cultivars and aim to improve upon existing qualities (Moore and Clark, 1996).

Interest in blackberry breeding has recently increased as the nutritional value of blackberries has become better understood (Clark and Finn, 2008). Blackberries also have fewer problems with disease and insect pests than the very similar raspberry. Fruit flavor, shipping quality, and thornlessness have been a big focus in recent cultivar releases and make cultivars with these qualities more suitable for growers to produce and market to consumers. Current breeding programs are also focused on expanding the industry into varied environmental conditions. Major limitations include the chilling requirement of blackberries in areas such as Mexico or the lack of winter hardiness in much of North America. Extending the fruiting season is also a priority in breeding and has been one reason that the new primocane-fruiting types have received much attention.

The primocane-fruiting cultivars were developed by the University of Arkansas breeding program and have the potential to produce two crops within one season, if the floricanes are able to survive the winter. The primocane-crop yield is generally small compared to the yield potential of a floricane-crop. As such this research focuses on floricane blackberry cultivars that have the potential to do well in the northern Great Plains. Most of these cultivars have been developed from the University of Arkansas program, ('Apache', 'Arapaho', 'Kiowa', 'Natchez', 'Osage', and 'Ouachita'), the USDA ('Chester Thornless' and 'Triple Crown'), the University of Illinois, ('Illini Hardy'), and private breeders ('Doyle's Thornless Blackberry') (Weber, 2013).

‘Apache’ is a thornless erect cultivar first selected in 1991 from a cross between ‘Navaho’ and Ark. 1007 (Clark and Moore, 1999). Some of the original crosses can be traced back to ‘Merton Thornless’, ‘Eldorado’, ‘Thornfree’, ‘Darrow’, ‘Cherokee’, and ‘Brazos’. ‘Apache’ is moderately resistant to anthracnose and has no other documented disease problems. ‘Apache’ was also noted to have large, good quality fruit with high yields, large drupelets, and vigorous growth.

‘Arapaho’ is a thornless erect cultivar first selected in 1985 from a cross between Ark. 631 and Ark. 883 (Moore and Clark, 1993). Some of the original crosses can be traced back to ‘Thornfree’, ‘Darrow’, ‘Cherokee’, ‘Brazos’, and ‘Hillquist’. ‘Arapaho’ has several good characteristics including small seed size, early fruit ripening, and no recorded disease problems. ‘Arapaho’ also has self-supporting canes that bear firm, good quality fruit.

‘Kiowa’ is a thorny erect cultivar first selected in 1983 from a cross between Ark. 791 and Ark. 1058 (Moore and Clark, 1996). Some of the original crosses can be traced back to ‘Thornfree’, ‘Brazos’, ‘Comanche’, ‘Wells Beauty’, and ‘Rosborough’. ‘Kiowa’ is moderately resistant to anthracnose and has no other recorded disease problems. ‘Kiowa’s’ most notable characteristic is its large fruit size and a longer ripening period compared to other cultivars. ‘Kiowa’ has had fruit recorded as large as 23.9 grams (Personal observation).

‘Natchez’ is a thornless erect to semi-erect cultivar first selected in 2001 from a cross between Ark. 2005 and Ark. 1857 (Clark and Moore, 2008). Some of the original crosses can be traced back to ‘Thornfree’, ‘Darrow’, ‘Comanche’, ‘Brazos’, ‘Cherokee’, and ‘Raven’. ‘Natchez’ is moderately resistant to anthracnose. Other disease resistance has not been studied. ‘Natchez’ produces large, high quality fruit that ripen early in the season and has the potential to be good for shipping with excellent postharvest qualities.

‘Osage’ is a thornless erect cultivar first selected in 2003 from a cross between Ark. 1719 and Ark. 2108 (Clark, 2013). Some of the original crosses can be traced back to ‘Thornfree’, ‘Darrow’, ‘Brazos’, ‘Cherokee’, ‘Dallas’ and ‘Navaho’. ‘Osage’ is moderately resistant to anthracnose with no other diseases being evaluated. ‘Osage’ only has medium fruit size, however it has outstanding fruit flavor with excellent shipping qualities.

‘Ouachita’ is a thornless erect cultivar first selected in 1993 from a cross between ‘Navaho’ and Ark. 1506 (Clark and Moore, 2005). Some of the original crosses can be traced back to ‘Thornfree’, ‘Darrow’, ‘Brazos’, ‘Cherokee’, ‘Comanche’ and ‘Black Satin’. ‘Ouachita’ is moderately resistant to anthracnose and may have some susceptibility to powdery mildew. ‘Ouachita’ has good fruit size and quality, including very good shipping quality.

‘Chester Thornless’ is a thornless semi-erect cultivar released from the USDA program in Carbondale, IL in 1985 (Finn, 2001). ‘Chester Thornless’ produces medium sized fruit with average flavor and high storage quality (Weber, 2013). It is resistant to cane blight and considered winter hardy for a thornless cultivar.

‘Triple Crown’ is a thornless semi-erect cultivar released from the USDA program in Beltsville, MD in 1996 (Finn, 2001). The fruit of ‘Triple Crown’ is considered to be very sweet and flavorful, however this cultivar is not considered cold hardy (Weber, 2013).

‘Illini Hardy’ is a thorny erect cultivar released from the University of Illinois in 1988. ‘Illini Hardy’ is resistant to Phytophthora root rot and is considered very winter hardy (Weber, 2013). It produces medium sized fruit with good flavor.

‘Doyle’s Thornless Blackberry’ is a thornless trailing cultivar discovered by Thomas Doyle in Texas in the early 1970’s (Doyle, 2016). ‘Doyle’s Thornless Blackberry’ produces fruit that are average in quality and size but have the potential to produce high yields. It has no reported disease problems and is considered cold hardy.

The cultivars mentioned above are generally subjected to different production systems and management practices based upon the growth habit of the cultivar and the climate in which it was produced.

Trellising Systems

Many trellis systems have been developed over the past decades to help producers manage blackberry plants. Erect, semi-erect, and trailing cultivar types utilize different trellis systems as these growth habits require different amounts of training. A very common system used for erect type cultivars is a supported hedgerow. Canes are simply confined by two horizontal wires that also add some support. (Fernandez and Ballington, 1999). Trailing or semi-erect cultivars require more training and often employ a labor intensive trellis system. A common trellis system used for these cultivars is the two-wire trellis. In this system, the canes are tied together and trained upward until the canes reach the top wire. Then the canes are weaved around the wires horizontally. For less vigorous cultivars, the canes could simply be trained in a fan shape as the canes grow upward to the top wire. These are just a few examples of the numerous trellis systems used in blackberry production. The trellis system utilized in this study is the rotating cross-arm (RCA) trellis system recently developed by Dr. Fumiomi Takeda.

The RCA trellis system combines a shift type trellis system and a cane training protocol that has the potential to reduce winter injury, reduce fruit blemish, and increase harvest efficiency (Takeda et al., 2013). The RCA trellis consists of a short post with two arms that are rotatable between two plates attached to the post (Fig. 1). Two wires run through the plates and serve as the horizontal training wires. Additional wires run through both arms as attachment sites for the lateral canes. This system allows the horizontally trained canes to twist as the arms are rotated to the ground, avoiding the bending and breakage that would occur when trying to lay the canes down on the soil surface.

Fig. 1. The rotating cross-arm trellis (RCA).

The cane training protocol recommends training 3 to 4 primocanes horizontally along the bottom wire until the canes reach the adjacent plant, about 1.7 m (Takeda et al., 2013). The canes are then tipped to eliminate apical dominance, which results in the development of lateral canes from axillary buds. These lateral canes are trained vertically up the wires until the canes are tipped to induce further branching. Without the horizontal training, substantial damage could occur to upright canes when the trellis arm rotates close to the ground.

The ability of this trellis system to rotate close to the ground allows it to be easily covered, so that the blackberry plants can be provided with winter protection. In colder climates the use of a row cover and even mulch should allow growers to successfully overwinter cultivars that would otherwise suffer from winter damage. Growers could also utilize a high tunnel to moderate winter temperatures but the lower capital investment of the trellis system and row covers may make it a better option for many growers (Takeda et al., 2013).

This trellis system also has the added benefit of manipulating the canopy so that the majority of the fruit is located on one side of the trellis (Takeda et al., 2013). In the spring the trellis arm and canes are left parallel with the ground (20 cm above the soil surface) until the plants flower. After the plants flower, the rachis becomes woody and will not curve upward again. At this time, the trellis arm is moved to its summer position of 60º and all of the fruit will be located on that side of the trellis system. If the rows are oriented in the north-south direction the fruit will be in the shade most of the day and will avoid high solar radiation, which is attributed to causing white drupe formation. Having the fruit all on one side of the trellis system can increase harvest efficiency and reduce fruit blemishes such as white drupe and sunburn that can make the fruit unmarketable. Having a single plane of growth could also increase air flow and light penetration to the leaves in the canopy, which could reduce disease potential.

Row Covers

Cool temperatures at the beginning and end of the growing season can be a limiting factor for production of many fruits and vegetables in some areas. Untimely frosts can damage plants in the fall and spring reducing yield. Farmers have employed many methods in the past to protect plants: wax paper, boxes, Styrofoam cups, etc. (Hochmuth et al., 2015). It has not been until recent decades that row covers have become a common tool used by farmers to modify the environment around crops to increase vegetative growth and extend the growing season.

Commercial row covers were first used in California in 1958 using a polyethylene material (Hochmuth et al., 2015). However, the use of row covers did not become popular until the 1980s. Today there are two main variations of row covers: polyethylene and light-weight floating materials. Light-weight row covers, made of polyester or polypropylene, can be placed directly over plants without major reductions in the transmission of sunlight and moisture. One of the most important factors to consider in the use of row covers is the time of application and removal. Poor timing could result in frost damage or intolerably high temperatures for the plants that can be common under a polyethylene material on warmer days. However, if used correctly both types of row covers have been shown to increase growing degree days, prevent frost damage, and increase marketable yields (Gast and Pollard, 1991).

A study was conducted between 1986-1988 comparing the growth and yield of strawberry plants with and without row covers (Gast and Pollard, 1991). This study found that there were significantly higher mean air and soil temperatures when a row cover (polypropylene) was used compared to the control treatment (no row cover). This increase in temperature was most likely the reason that the strawberry plants in the row cover treatment had more flowers develop and had a higher marketable yield compared to the control treatment.

Other research conducted with blackberries and black raspberries has found that the use of floating row covers could jump-start growth earlier in the season and extend harvesting by protecting the plants from frost later in the season (Heidenreich et al., 2008). The Heidenreich study used row covers in a high tunnel to protect the plants during cool nights and removed the row covers during the day. The results of this study also indicated that the use of a high tunnel could greatly increase the yield of certain blackberry cultivars compared to open field plantings.

Researchers caution that the benefits of row covers may vary (Gast and Pollard, 1991). Depending on the weather conditions of a given year, crop or even cultivar differences, proper timing of row cover application and removal, and type of row cover; there may or may not be a significant benefit to the utilization of a row cover.

MATERIALS AND METHODS

This experiment was conducted as a randomized complete block design and arranged as a split plot. The row cover treatments were the whole plot factor and the blackberry cultivars were the subplot factor. This experiment was conducted over two years and contained two replications, four row cover treatments, and ten cultivars per treatment with two plants per experimental unit. The ten blackberry cultivars were chosen based on the potential for those cultivars to do well in North Dakota: ‘Kiowa’, ‘Osage’, ‘Ouachita’, ‘Illini Hardy’, ‘Arapaho’, ‘Chester Thornless’, ‘Triple Crown’, ‘Natchez’, ‘Apache’, and ‘Doyle’s Thornless’. These plants were established in a Swenoda fine sandy loam at the North Dakota State University Horticulture Research Farm and Arboretum near Absaraka, ND (Lat: 46º 59’ 22.0986” Long: -97º 21’ 22.2222”) in 2014. Plants were spaced 2.7 meters apart, in rows oriented north and south, with 3.3 meters between rows.

A metal trellis system was fabricated similar to the RCA trellis system previously discussed and was installed during Oct. 2014. All of the blackberry plants were trained using the same cane training protocol described by Takeda et al. (2013). This cane training protocol included the training of up to four primocanes per plant in the spring by forcing the canes to grow horizontally along the bottom wire after growth of more than 15 cm had occurred. Any primocanes over this amount were removed and treated as excessive plant growth. The canes were monitored and tied to the wire whenever the canes began to grow upward again. The primocanes were tipped after 1.2 m of growth occurred, which resulted in the development of many lateral shoots. All shoots found on the cane below the bottom wire were removed.

In the fall when temperatures dropped below -9 ^{0}C the arms of the RCA trellis were rotated close to the ground to facilitate the application of row covers would be relatively simple. In the spring the arm with the floricanes was raised parallel to the ground until flowering was complete (Takeda et al., 2013). The arm was then brought to the summer position of 60^0.

Four row cover treatments were applied in this experiment to moderate the temperature around the plants and thereby prevent winter damage. Treatment one was a 6mm thick polyethylene black plastic (Warp Bros, Chicago, IL.) with corn *(Zea mays* L.*)* stover mulch (BPC). Treatment two was the same black plastic but with wheat *(Triticum aestivum* L.*)* straw mulch (BPW). Treatments three and four both used a 915 g m^{-2} white polypropylene thermal blanket (DeWitt, Puyallup, WA) with and without corn stover mulch, respectively (TBC and TB). These mulch types were used as these are easily accessible in North Dakota and are inexpensive. Treatment mulches were applied over the black plastic and thermal blanket to a thickness of approximately 5 cm. No control (without row cover) treatment was used in this experiment as winter damage has been noted on blackberries without row covers in USDA hardiness zone 6 (Takeda and Phillips, 2011; Heidenreich et al., 2008). No canes were left in a vertical position during the winter for the same reason. All treatments were laid horizontally to the ground with a row cover. These treatments were applied on 19 Nov. in 2014 and on 9 Dec. in 2015, when temperatures below -9 ^{0}C were in the near forecast (Takeda et al., 2013). Treatments were removed on 8 May in 2015 and on 28 Apr. in 2016, when the threat of frost had passed.

Thermocouples and data loggers (Decagon Devices, Inc., Pullman, WA) were used to monitor the temperature at the soil surface underneath the row covers (Gast and Pollard, 1991). Plant dieback assessment included percentage of dead buds and dead cane length by checking for viable green phloem on 26 May in 2015 and 2016, after bud break had occurred (Takeda and Phillips, 2011).

Cultivars were compared and assessed using data collected on total yield, berry weight and size, percent soluble solids, pH, and plant vigor (Clark, 2013). Harvest began on 23 July in 2015 and ended on 15 Oct. During the 2016 growing season harvest began on 28 July and ended on 6 Oct. Not all plants had completed fruiting either year; however, frost damage and low temperatures prevented further fruit ripening. During both growing seasons fruit was harvested twice each week (Takeda et al., 2003a). Fruit was hand-harvested selecting for only ripe fruit.

Berry weight was calculated from an average of all fruit picked from the individual plant for each harvest date. The berry size was calculated by measuring the length and width of up to five randomly selected fruit from the individual plant. The percent soluble solids of fruit were measured using a handheld refractometer (Extech, Nashua, NH) from berries collected during each harvest. Berry pH was measured utilizing the same juice sample and a handheld pH meter (Oakton, Vernon Hills, IL.). All harvested blackberries used for data collection were refrigerated less than one day prior to measurements. Plant vigor was assessed using the measurements of total cane length for individual plants, total number of buds, and the weight of excess growth.

Creeping red fescue (*Festuca rubra*) was seeded between rows and was mowed as needed. Weeds were controlled via hand weeding near plants, weed whipping, and mowing. No irrigation or fertilizer was applied during the 2015 growing season. Results of a soil sample in the late summer of 2015 indicated that nitrogen was limited, although no deficiency symptoms were visible. Fertilizer was applied at a rate of 56 kg/ha of nitrogen, phosphorus, and potassium in a granular form of 19-19-19 in the spring of 2016. This was done to prevent any nutrient deficiencies and was based on recommendations made by Hart et al. (2006). Traps were used to monitor for spotted wing drosophila and insecticides (Asana, Malathion, and Mustang Max) were applied as needed. Netting was used to eliminate bird damage and was applied in early July before fruit ripening began each season.

Data were analyzed using PROC MIXED and PROC GLM in SAS 9.4 (SAS Institute Inc.; Cary, NC, USA). Data from both years were combined by conforming to the test of homogeneity of variance developed by Brown and Forsythe for temperature data. All other data were combined conforming to the Hartley test, when the ratio of larger mean square error/smaller mean square error was within a factor of 10. Temperature data were analyzed using repeated measures. All other data were analyzed as a split plot in time. All mean separations were done using a pairwise t-test with $\alpha \leq 0.05$. When a significant cultivar by row cover treatment effect was detected, the test of simple effects was used to analyze the significance of treatment effects within cultivars.

RESULTS

Temperature Moderation

Over the course of both winters there were significant differences in the ability of the row cover treatments to moderate the winter temperature. Differences occurred only seven out of the twenty-three weeks where temperature data were collected (Fig. 2). The differences in average temperature under the treatments occurred in weeks 12, 14, 15, 17,18, 19, and 20 (Table 1). This was roughly the time period between the middle of Feb. to the middle of May, when fluctuating temperatures were a more common occurrence compared to the other winter months.

In week 12, higher average temperatures occurred under the TB row cover compared to TBC and BPC (Table 1). Temperature under BPW was also significantly higher than under the TBC row cover, but was not different from temperatures under BPC or TB.

During weeks 14 and 15, the TB row cover had higher temperatures compared to all other row covers (Table 1). During weeks 17, 18, 19, and 20, temperatures under the TB were again significantly higher than temperatures under BPC and TBC, and similar to temperatures under BPW. There were no differences in the average temperatures under the row cover treatments in any of the other weeks where temperature data were collected.

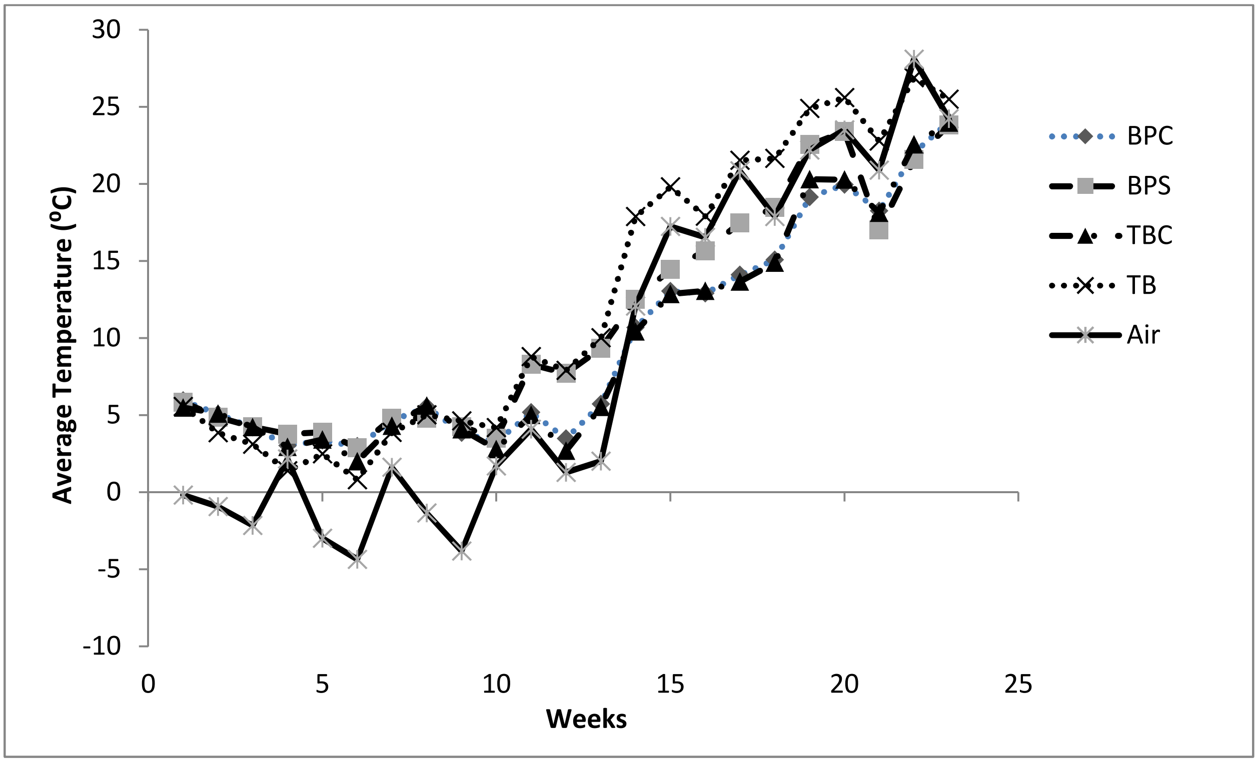

Fig. 2. Average temperature recorded under the four row cover treatments.
BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket. Air temperature was measured 1.52 m above the soil surface with a Temperature / Relative Humidity (RH) Sensor at the nearby Prosper NDAWN station and is for reference only.

Table 1. Average temperatures (^{0}C) under row covers each week where treatments differed.

Treatment	Week						
	12	14	15	17	18	19	20
BPC[Z]	3.48bc[Y]	10.69b	13.05b	14.11b	15.08b	19.14b	19.96b
BPW	7.71ab	12.50b	14.45b	17.48ab	18.46ab	22.55ab	23.39ab
TBC	2.70c	10.43b	12.86b	13.66b	14.89b	20.30b	20.29b
TB	7.90a	17.89a	19.80a	21.54a	21.66a	24.90a	25.60a

[Z]BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket.
[Y]Means with the same letter are not significant, within each week (column), based on a pairwise t-test at $\alpha \leq 0.05$.

Winter Dieback

Even though there were significant differences observed in average temperatures under row cover treatments, there were no differences in the percentage of dead buds (Fig. 3). However, data collected on length of dead cane revealed a significant interaction in the percentage of dead cane length between cultivar and row cover treatment (Fig. 4). 'Chester Thornless' was the only cultivar to vary in percentage of cane length dieback across the row cover treatments. The BPC treatment had a higher percentage of cane length dieback compared to the other row covers. While not significant, there was a general trend showing a lower percentage of dieback for most cultivars with the TBC row cover (Figs. 3 and 4).

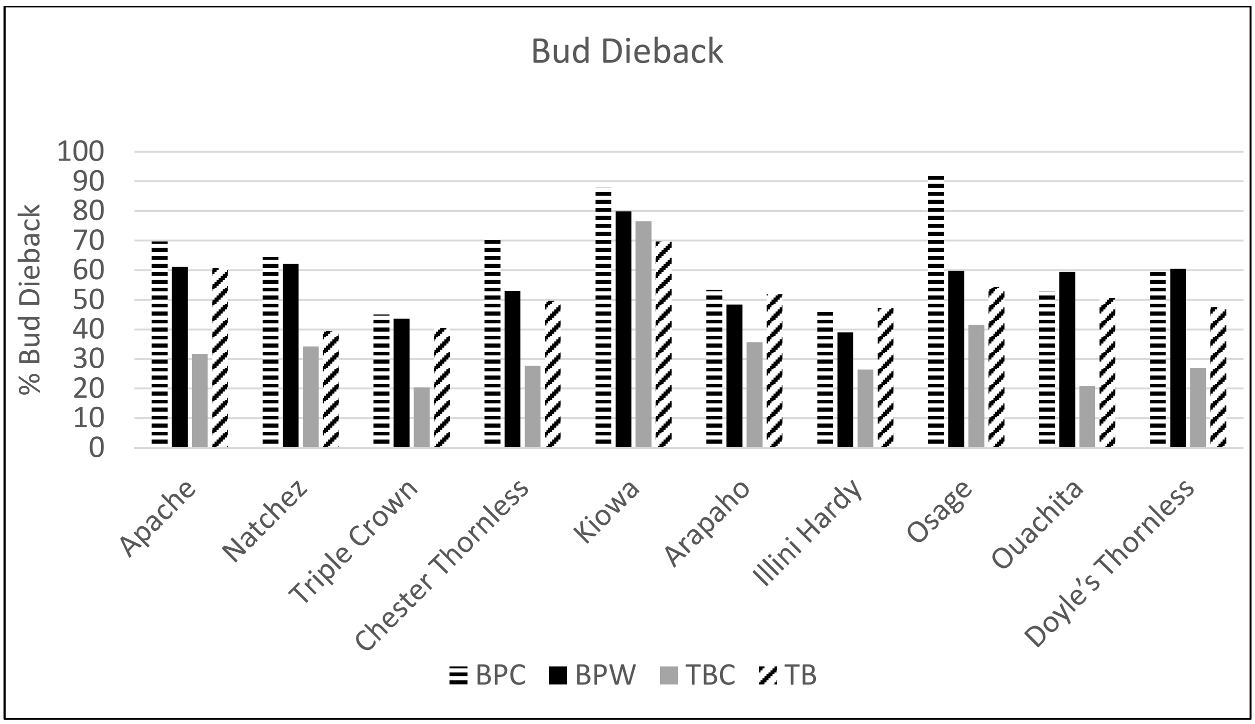

Fig. 3. Percentage of bud dieback in a nonsignificant interaction between cultivar and row cover. Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket.

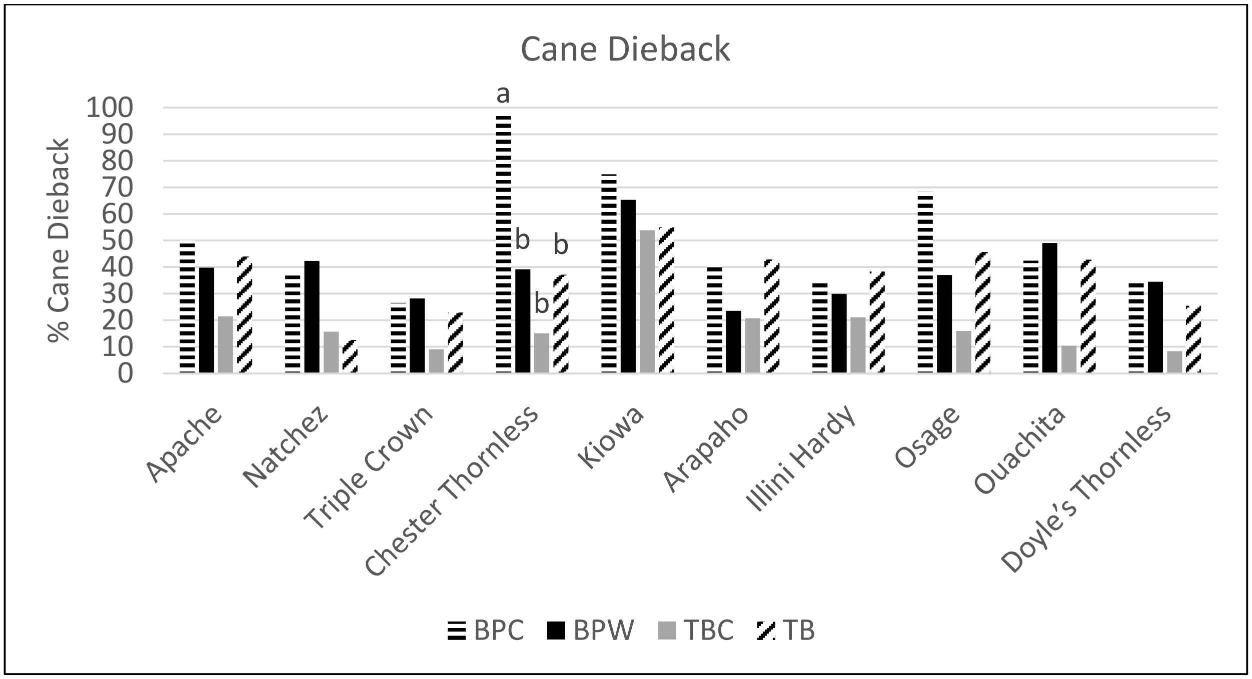

Fig. 4. Percentage of cane dieback observed in an interaction between cultivar and row cover. Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket. Means with the same letter are not significant based on a pairwise t-test at $\alpha \leq 0.05$. Mean separation only shown for cultivars with significant differences between the row cover treatments.

Plant Vigor and Growth

Plant vigor and growth were evaluated using total buds, total cane length, and excessive cane growth for the cultivars used in this study. The total number of buds and the total cane length for an individual plant was collected at the same time as the dieback analysis for each year. A significant interaction affecting the total number of buds was observed between the row cover treatments and the blackberry cultivars (Fig. 5).

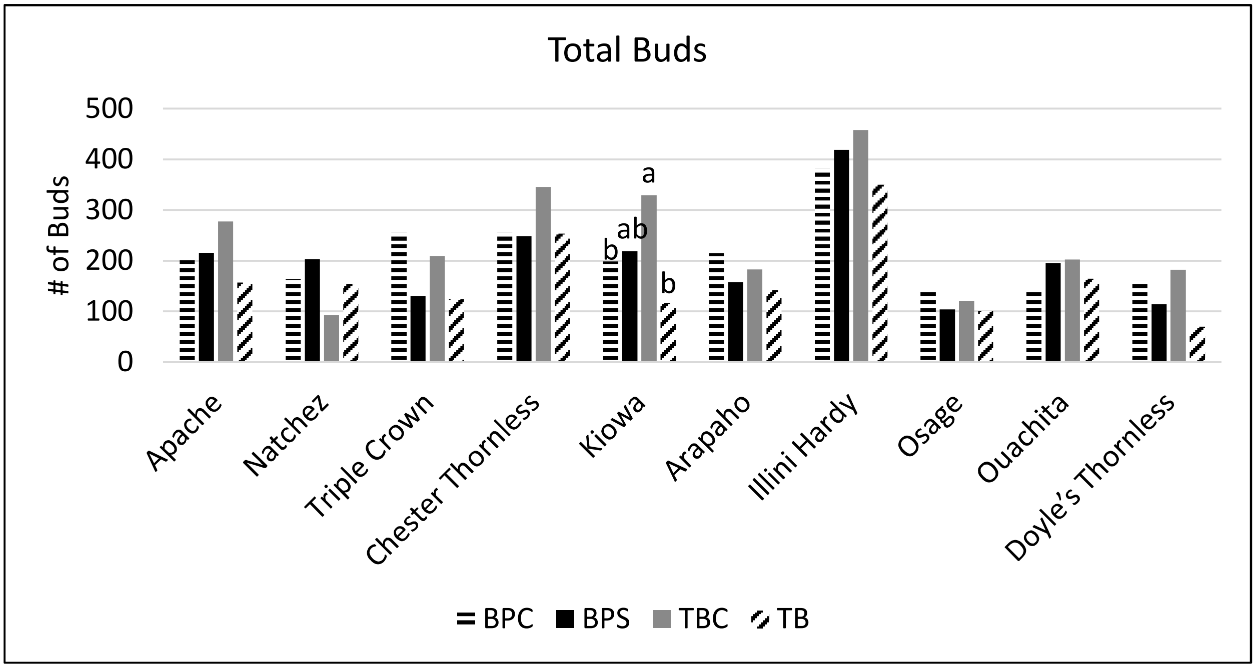

Fig. 5. Total number of buds observed in an interaction between cultivar and row cover. Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket. Means with the same letter are not significant based on a pairwise t-test at $\alpha \leq 0.05$. Mean separation only shown for cultivars with significant differences between the row cover treatments.

'Kiowa' was the only cultivar to vary in the amount of total buds across the row cover treatments. 'Kiowa' under the TBC row cover had more buds than 'Kiowa' under the TB and BPC row covers, while 'Kiowa' under the TBC and BPW row covers had similar total buds. The total amount of buds for 'Kiowa' under the BPW, TB, and BPC row covers were also similar. While not significant, there was a general trend showing that most cultivars performed better with the TBC row cover (Fig. 5).

No interaction was found between cultivars and row covers so main effects were analyzed. Cultivars differed in total cane length produced (Table 2). The differences between cultivars for total cane length followed a similar trend between cultivars for the total number of buds. 'Illini Hardy' had higher total cane length than all other cultivars except 'Triple Crown' and 'Chester

Thornless'. 'Chester Thornless' only differed significantly in total cane length when compared to 'Osage'.

Table 2. Total cane length observed for each blackberry cultivar across treatments.

Cultivar	--- cm ---	
Apache	1158.71	bc[Z]
Natchez	842.8	bc
Triple Crown	1377.09	abc
Chester Thornless	1682.42	ab
Kiowa	937.6	bc
Arapaho	845.1	bc
Illini Hardy	2190.39	a
Osage	541.16	c
Ouachita	950.7	bc
Doyle's Thornless	852.18	bc

[Z]Means with the same lower-case letter are not significant based on a pairwise t-test at $\alpha \leq 0.05$.

From the data collected, while training the blackberry plants, an interaction was observed in the weight of excess growth between the row cover treatments and the cultivars (Fig. 6). 'Triple Crown' and 'Illini Hardy' were the only cultivars to vary in excess weight of growth across row cover treatments. 'Triple Crown' had significantly more excess weight when in the BPW row cover than the TBC or the TB row covers, but was similar when in the BPC row cover. 'Illini Hardy' had more excess weight removed when in the BPC row cover than the BPW or TB row covers, but was similar when in the TBC row cover.

The number of excess primocanes removed followed a similar trend for cultivars in the weight of excess primocanes removed. However, there was no observed interaction between row cover treatments and blackberry cultivars. Significance was only observed between cultivars for the number of excess primocanes (Table 3). 'Illini Hardy' and 'Apache' had a higher number of excess primocanes removed compared to all other cultivars except 'Arapaho' and 'Ouachita'.

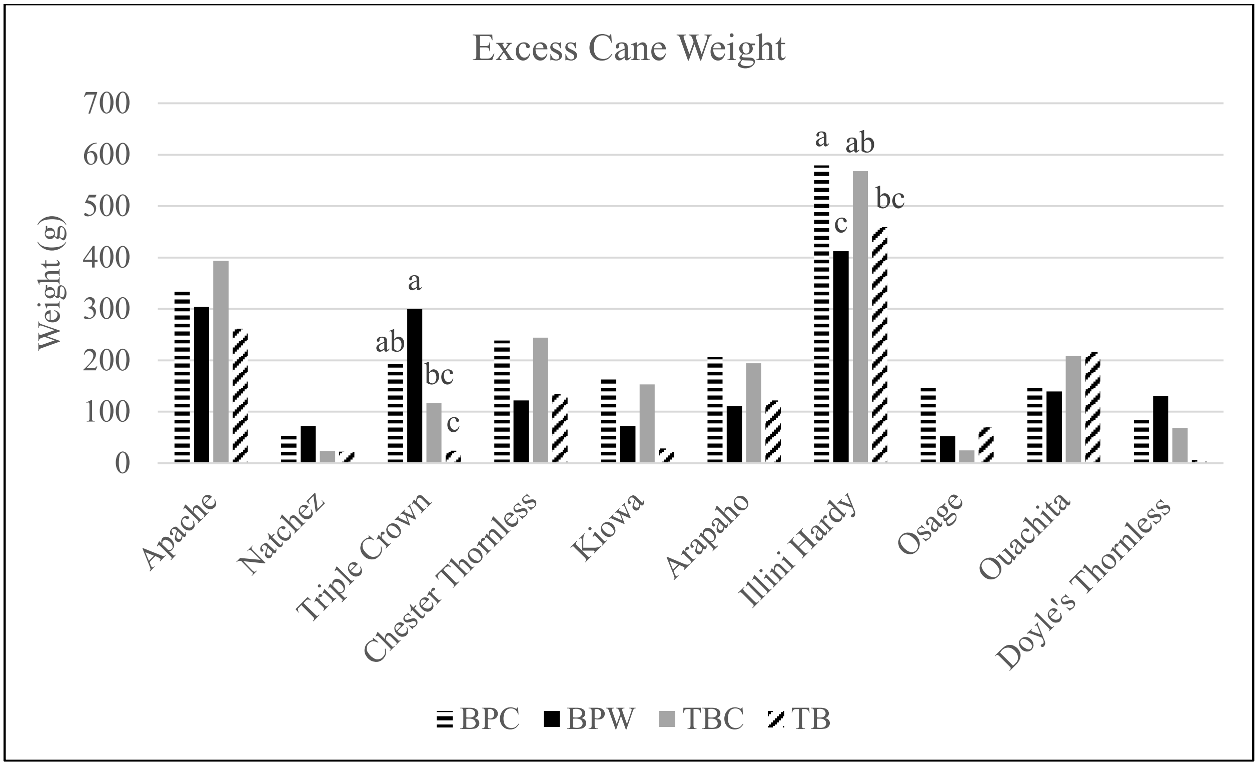

Fig. 6. Weight of excess growth removed (primocanes) in an interaction between row cover treatments and blackberry cultivars. Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket. Means with the same letter are not significant based on a pairwise t-test at α ≤0.05. Mean separation only shown for cultivars with significant differences between the row cover treatments.

Table 3. Number of excess primocanes removed per cultivar according to the training system used in this experiment.

Cultivar	---#---	
Apache	24.1	a[Z]
Natchez	0.8	d
Triple Crown	3.6	cd
Chester Thornless	8.0	bcd
Kiowa	9.7	bcd
Arapaho	15.4	abc
Illini Hardy	24.9	a
Osage	11.0	bcd
Ouachita	19.2	ab
Doyle's Thornless	3.7	cd

[Z]Means with the same lower-case letter are not significant based on a pairwise t-test at α≤0.05.

Fruit Quantity and Quality

Significant differences in total yield, number of fruit, average weight of the fruit, percent soluble solids, and pH occurred between cultivars and between row cover treatments. There were no significant interactions found between cultivars and row cover treatments for any of these factors, therefore main effects were analyzed.

Regarding fruit quantity, ‘Illini Hardy’ had a higher total fruit yield and number of berries compared to all the other cultivars except ‘Chester Thornless’ (Table 4). ‘Chester Thornless’ in turn had a higher yield than all the other cultivars except for ‘Triple Crown’, ‘Kiowa’, and ‘Ouachita’. ‘Chester Thornless’ also produced more berries compared to all other cultivars, with the exception of ‘Triple Crown’.

While ‘Illini Hardy’ and ‘Chester Thornless’ may have ranked at the top for quantity, these cultivars did not stand out in fruit quality characteristics. ‘Ouachita’ fruit had the highest percentage of soluble solids, but did not differ significantly from ‘Natchez’ or ‘Osage’. ‘Illini Hardy’ fruit had the lowest percentage of soluble solids, but was not significantly lower than ‘Doyle’s Thornless’. ‘Arapaho’ fruit had higher pH than all other cultivars. Following ‘Arapaho’, ‘Triple Crown’ fruit had the next highest pH, but did not differ from ‘Natchez’, ‘Kiowa’, ‘Illini Hardy’, or ‘Ouachita’ fruit pH. ‘Doyle’s Thornless’ fruit pH was lower than all other cultivars. ‘Natchez’ and ‘Kiowa’ had the highest average fruit weight, but did not differ from ‘Apache’, ‘Triple Crown’, ‘Osage’, or ‘Ouachita’ average fruit weight.

Significant differences were also found between row cover treatments in total fruit yield, number of berries, and average berry weight (Table 5). Blackberries under the TBC row cover had significantly higher fruit yields and number of berries compared to blackberries under the other row cover treatments. However, plants under the BPC row cover produced fruit that had a higher average berry weight compared to plants under the other row covers.

Table 4. The total yield, number of berries, average berry weight, soluble solids, and pH for the blackberry cultivars.

Cultivar	Yield		Berries		Weight		SS[Z]		pH[Y]	
	------ g ------		----- # -----		----- g ------		------ % ------		--- -log[H+] ---	
Apache	58.25	c[X]	13.9	c	3.47	ab	9.74	b	2.61	d
Natchez	63.76	c	13.8	c	3.83	a	10.28	ab	2.70	bcd
Triple Crown	134.52	bc	36.9	bc	3.07	abc	9.63	bc	2.75	b
Chester Thornless	262.20	ab	87.4	ab	2.96	bc	9.65	bc	2.64	cd
Kiowa	109.99	bc	17.5	c	3.88	a	8.81	cd	2.66	bcd
Arapaho	68.10	c	24.6	c	2.12	d	9.84	b	2.87	a
Illini Hardy	383.18	a	116.2	a	2.75	c	7.93	e	2.68	bcd
Osage	6.55	c	2.3	c	2.99	abc	10.22	ab	n/a[W]	
Ouachita	85.51	bc	23.1	c	3.14	abc	10.60	a	2.72	bc
Doyle's Thornless	27.18	c	12.7	c	2.03	d	8.70	de	2.46	e

[Z] Concentration of total soluble solids.

[Y] A logarithmic measure of hydrogen ion concentration.

[X] Means with the same lower-case letter are not significant between cultivars (column) based on a pairwise t-test at $\alpha \leq 0.05$.

[W] n/a= not applicable, not enough fruit harvested to run pH sample.

Table 5. The total yield, number of berries, average berry weight, soluble solids, and pH for the blackberry cultivars under the four row cover treatments.

Treatment	Yield		Berries		Weight		SS[Z]		pH[Y]	
	------- g ------		----- # ------		----- g ------		------ % ------		-- -log[H+] ---	
BPC[X]	65.71	b[W]	16.9	b	3.50	a	9.40	a	n/a [V]	
BPW	43.98	b	15.5	b	2.86	b	9.58	a	2.66	a
TBC	305.08	a	85.2	a	3.06	b	9.51	a	2.71	a
TB	64.93	b	21.7	b	2.68	b	9.68	a	2.70	a

[Z] Concentration of total soluble solids.

[Y] A logarithmic measure of hydrogen ion concentration.

[X] Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket.

[W] Means with the same lower-case letter are not significant between treatments (column) based on a pairwise t-test at $\alpha \leq 0.05$.

[V] n/a= not applicable, too many missing data points to produce estimate.

Measurements collected for fruit length and width indicated a significant interaction between cultivars and row cover treatments. A test of simple effects was used to analyze individual cultivars across treatments. Only three cultivars varied significantly in fruit width across treatments; ‘Natchez’, ‘Triple Crown’, and ‘Kiowa’ (Fig. 7). ‘Natchez’ and ‘Triple Crown’ also differed in fruit length across the four row cover treatments. ‘Natchez’ had longer fruit under the BPC row cover than the other row cover treatments. ‘Triple Crown’ also had the longer fruit under the BPC row cover.

‘Natchez’ also had wider fruit under the BPC row cover when compared to fruit width with all other row cover treatments. The width of fruit for ‘Triple Crown’ was significantly smaller under the TB row cover than the other three row covers. ‘Kiowa’ had wider fruit under the BPC and TB row covers.

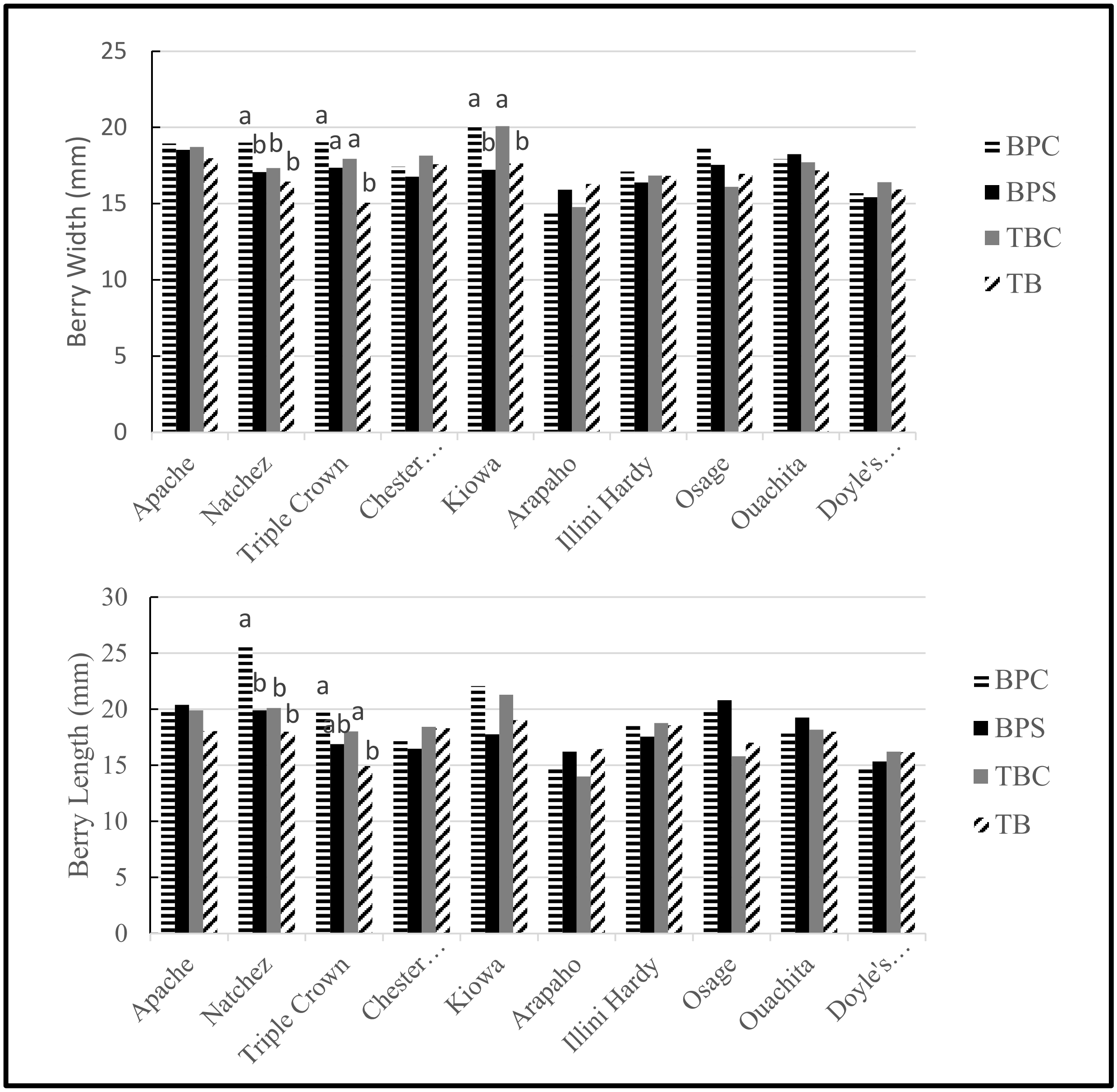

Fig. 7. Length and width of fruit analyzed for individual cultivars across row cover treatments. Abbreviations for the row cover treatments: BPC = black plastic with corn stover, BPW = black plastic with wheat straw, TBC = thermal blanket with corn stover, and TB = thermal blanket. Means with the same letter are not significant based on a pairwise t-test at $\alpha \leq 0.05$. Mean separation only shown for cultivars with significant differences between the row cover treatments.

DISCUSSION

Temperature Moderation

Differences in average temperature under row cover treatments may have been influenced by the type of material used for the row cover, type or absence of mulch, and the depth of snow cover. The black plastic used for treatments BPC and BPW is impermeable to moisture and air. The thermal blanket used in treatments TBC and TB is a polypropylene material that is permeable to moisture, air, and sunlight. However, no difference in average temperatures were observed between BPC and TBC. These treatments utilized different row cover materials but contained the same mulch materials. BPC and BPW employed the same black plastic but had different mulches, corn stover and wheat straw, respectively. These two treatments never differed significantly in the average temperatures under the row covers. So, no differences were observed between mulch types used. The largest differences were observed when comparing a row cover with no mulch, such as TB, to treatments that contained a mulch. The TB row cover was different from BPC and TBC row covers, which contained corn stover, more often than it was different from the BPW row cover, which contained wheat straw. A trend observed was that the TB treatment had lower temperatures in the early winter before snow cover and higher temperatures in the spring after snow melt (Fig. 1). The addition of a mulch over a row cover added the ability to moderate the temperature under the row cover.

Plant Vigor and Growth

The row cover treatments did not have a significant effect on the vegetative growth for most of the cultivars. The significant difference in growth that occurred between row covers may have been the result of damage to the root system during the winter prior to recorded growth. Further research that would include quantifying winter damage to the root system could also reveal why there were differences in the plant vigor and growth in the row cover treatments. There were however many differences between cultivars. 'Illini Hardy' had more vigorous growth than all other cultivars across a variety of factors. This is not surprising as 'Illini Hardy' is a thorny, erect cultivar and is known for being vigorous and generally winter hardy (Weber, 2013). Following 'Illini Hardy', 'Apache' was the next most vigorous cultivar and is also known for being very prolific. After 'Illini Hardy' and 'Apache', 'Chester Thornless' performed well in terms of plant growth. It is considered one of the hardiest thornless cultivars, which may have helped it survive and produce more vegetative growth than other thornless cultivars in this study.

Having a healthy and vigorous plant is good for most production practices. However, in the rotating cross-arm trellis system only four canes need to be trained onto the wires. Excess canes become troublesome and require more labor to remove. Thorny, erect, or even some semi-erect cultivars can take more time to train as the canes are not as pliable as trailing cultivars. These erect canes also tend to break more easily, which can make erect cultivars, such as 'Illini Hardy' and 'Apache', difficult to have in a rotating cross-arm trellis system and could reduce yield. Overall, trailing or some semi-erect cultivars, such as 'Triple Crown' or 'Chester Thornless', would be the most compatible for planting with a rotating cross-arm trellis system. Unfortunately, trailing cultivars tend to be more susceptible to winter injury when compared to other growth types (Crandall, 1995).

Fruit Quantity and Quality

Considering that 'Illini Hardy' and 'Chester Thornless' had more total cane length and buds than most other cultivars, it is not surprising that these cultivars had a higher yield and number of berries compared to the other cultivars. These two cultivars are currently considered the hardiest cultivars on the market (Clark and Finn, 2008).

The higher yield and number of berries in the TBC row cover compared to the other row cover treatments could be due to several factors. While not significant, there was a general trend for cultivars to have less dieback under the TBC treatment. Unlike the BPC and BPW row covers, the TBC and TB row covers have a porous material that allows for more air and water movement. With the impermeability of the black plastic, an increase in the spread of disease may occur with decreased air flow in the spring. Etiolation due to the exclusion of sunlight could also have a negative impact on yield. Frost damage was observed during both years in late May and appeared to be more damaging to weak etiolated buds under the BPC and BPW treatments. The floral buds and primocanes under the TBC and TB treatments appeared to be more acclimated to the spring temperature when the row covers were removed, but this was not a quantified factor.

‘Ouachita’, ‘Natchez’, ‘Arapaho’ and ‘Osage’ had good fruit quality characteristics with a high percentage of soluble solids and high pH. However, these cultivars had poor yields, which has been typical for cultivars with good flavor when attempts have been made to produce these blackberries in USDA hardiness zones 5 or lower (Heidenreich et al., 2008). ‘Natchez’ also had a high average fruit weight in this study. However, the average fruit size was much smaller across all cultivars compared to other production areas in the United States (Clark, 2013; Heidenreich et al., 2008; Strang et al., 2006).

Use of irrigation in this study may have increased overall average fruit weight, size, and yield as insufficient rainfall can inhibit fruit development (Crandall, 1995). Rainfall totaled 45.6 cm in 2015 and 33.8 cm in 2016 at the nearby Prosper station (NDAWN, 2016).

CONCLUSION

Differences in the ability of row cover treatments to moderate winter temperature and differences between the effects of row cover material had a significant effect on the yield of the blackberry cultivars. The TBC row cover increased plant productivity in USDA Hardiness Zone 4a. The average yield of plants under the TBC row cover was only 305 g/plant, but this average includes cultivars that performed poorly. The plants in this study were only 2 and 3 years old with minimal input regarding irrigation and fertilizer. With a mature blackberry stand and increased input, commercial blackberry production could be possible in North Dakota. Further research for the best row cover treatment, as well as continued cultivar selection, is needed to fully recommend the best winter protection technique and best suited floricane blackberry for production in North Dakota.

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