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High Tunnel Production Of Primocane Bearing Red Raspberries In Grow Bags

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HIGH TUNNEL PRODUCTION OF PRIMOCANE BEARING RED RASPBERRIES IN GROW BAGS

A Masters Thesis

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In Partial Fulfillment

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Masters of Science, Plant Science

By

Jennifer Sue Morganthaler

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ABSTRACT

Raspberries (*Rubus idaeus*) are a perennial crop with increasing consumer demand. While this highly perishable crop has not proven to be a commercially viable field grown crop in the Midwest, it does show increased yields when grown in a high tunnel. High tunnel construction in Missouri has increased partly due to the NRCS grant program. However, high tunnel production permanently utilizes that space. Bagged culture allows growers the ability to maximize high tunnel space and produce other annual crops, while testing the performance of the crop for their production. This 4 year trial evaluates 5 primocane bearing red raspberries cultivars in grow bags rotated in and out of the high tunnel with vegetable crops. The first 2 years of the trial are complete and all cultivars used in this production method were established and overwintered successfully. In 2014, all cultivars produced commercially acceptable yield with Polka bearing the most fruit and Crimson Giant producing the largest berry. In 2015, all cultivars produced commercially acceptable yield with Joan J. bearing the most fruit and Crimson Giant producing the largest berry. The results of this study provides breeders, growers and researchers an evaluation of these five cultivars in high tunnel bagged culture, and it will provide growers with an efficient system to test cultivars while maximizing high tunnel space, and the option to add a profitable crop to their high tunnel operation.

KEYWORDS:*Rubus idaeus*, primocane bearing red raspberry, high tunnel production, containerized production, Crimson Giant, Himbo Top, Joan J., Josephine, Polka,

This abstract is approved as to form and content

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William McClain, PhD
Chairperson, Advisory Committee
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INTRODUCTION

Raspberries (*Rubus idaeus*) rank as the third most popular berry in the United States for fresh use. Due to increased demand, interest in raspberry production is on the rise worldwide [U.S. Department of Agriculture (USDA), 2014]. The United States is the world's third-largest producer of raspberries, behind Russia and Serbia. Most of the United States production occurs in three states, Washington, Oregon, and California (Geisler, 2012). In 2010, the United States total production of raspberries was approximately 226 million pounds with the majority of those being produced in California (USDA, 2014). Raspberries favor moderate summer temperatures below 85° F and most cultivars are cold hardy to -20°F. Well-drained soil is needed to prevent root diseases. Missouri climatic conditions will allow raspberry production, however, raspberries grown in Missouri are often stunted and produce small berries due to the high summer and fall temperatures and heavy clay soils in some parts of Missouri. As a result, of summer and fall temperature and poor soil conditions, field grown raspberry production in Missouri is not a successful commercial crop (Warmund, 2009). A demonstration trial conducted at Missouri State University Fruit Experiment Station in Mountain Grove, Missouri indicated that high tunnel production of raspberries could be a viable option for commercial production and required further evaluation (Odneal, 2016).

The use of high tunnels began in the early 1950's at the University of Kentucky. E. M. Emmert realized the idea of using a high tunnel for manipulating and extending the growing season (Emmert, 1955). High tunnels consist of a structure covered in clear plastic. The sides and ends of the tunnel may be opened and closed to regulate

temperature. High tunnels are usually not heated although supplementary heat or row covers may be used in cold temperatures (Fig. 1) (Heidenreich et. al, 2012).

Most raspberry cultivars produce fruit in August, when the heat is the highest. Subsequently the berries can suffer sunburn as they are sensitive to intense heat. Missouri's high humidity and rainfall create a favorable environment for the development of fungal and root disease. Additional evaluation is needed to determine if protection from the heat and rain combined with growing season extension could offer growers the opportunity to have a viable commercial raspberry crop (Odneal, 2016). A survey conducted on Horticulture Crop Production in High Tunnel in the United States, concluded that high tunnel production has proven to be a successful alternative and is becoming an increasingly important production tool for commercial growers across the country. High tunnel production accomplishes this by allowing the grower the ability to extend the growing season by manipulation of the growing conditions. Manipulation of the growing season is achieved by growing cultivars that fruit earlier or later in the season. The protective environment of the high tunnel provides protection from frost, rainfall and excessive sunlight. Additional sunlight protection is controlled by the use of shade clothes that filter the light allowed into the high tunnel (Carey et. al, 2009). Off-season production of raspberries or season extension could potentially increase the supply of domestically grown fruit (Darnell et. al, 2006). According to Courtney Weber, Associate Professor at Cornell University, recent research has demonstrated advantages in high tunnel grown raspberries.

Despite the progress being made in high tunnel research, there is a lack of information on which raspberry cultivars that are suited for high tunnel production

(Weber, 2010). The construction and implementation of high tunnel production has increased in the United States in part due to the Natural Resources Conservation Service (NRCS) High Tunnel System Initiative. As part of the 2008 Farm Bill, the NRCS began offering financial assistance to growers with qualifying projects that research or observe improving plant, water, and soil quality, as well as reducing disease pressure in production operations (USDA, 2015).

The intention of this research trial is to evaluate the performance of five raspberry cultivars in grow bags rotated in and out of the high tunnel with vegetable crops. The experiment was designed to measure marketable yield, average berry weight, weight of fruiting canes and number of unharvested berries of each cultivar. This data will be used to determine if the five cultivars being tested will produce acceptable market yield for commercial production. Average marketable yield for raspberries is 5,500 pounds per acre for field production and 15,000 pounds per acre for high tunnel production (Demchak et. al, 2014). It is anticipated that all five cultivars will produce acceptable market yield for commercial production as a result of the benefits of the high tunnel environment combined with the use of grow bags. The results of this trial will add valuable cultivar performance information for breeders, growers and researchers. Additionally, results of this trial will provide beneficial information for containerized production of raspberries. Containerized production consists of plants that are not placed directly in the ground. Examples of containerized production are grow bags, any container, garden pot, soil bag or other product in which the plant is not directly planted in the ground. This type of production will allow growers the ability to test the addition of raspberries to their current operation without dedicating in ground high tunnel space.

LITERATURE REVIEW

Raspberry History

Red raspberries are native to the temperate region of Europe, Asia and North America (Jennings, 1988). Cultivated raspberries were first mentioned in human history dating back to the Ancient Greeks. Pliny the Elder wrote about the people of Troy at the base of Mount Ida that gathered 'ida' fruits. Raspberries were later given the name *Rubus idaeus* by Carl Linnaeus. Linnaeus used *idaeus* from 'ida' for the species name. The genus name *Rubus* was derived from the word rubra, meaning red in Latin (Hall et. al, 2009). Greek legend claims the Greek gods went searching for berries in Mount Ida, Turkey and returned with what are current day raspberries (Bushway et. al, 2008).

In 1771, the first raspberries from Europe were imported and sold in New York (Bushway et. al, 2008). Raspberries did not become a commercially important crop in North America until after 1865. The industry at that time was founded on the cultivar Cuthbert, a random seedling that was found in what is currently New York. The seedling was thought to be a cross between the European cultivar Hudson River Antwerp and the American wild red raspberry *Rubus strigosus* (Darrow, 1937). George Pyne, a private breeder from Topsham, Devon, England was successful in creating new cultivars by selecting parents from self-sown seedlings. Pyne's most successful cultivar was Pynes Royal (Hall and Kempler, 2011). Pynes Royal was a seedling raised by George Pyne in 1907 and introduced in 1913 (Darrow, 1937). Experiment stations in The United States of America (USA) began using controlled crossed to develop new cultivars. Latham and Chief red raspberries were released in 1918 and 1930 from the state experiment station in

St. Paul, Minnesota. Latham was derived from a cross between King and Louden, while Chief was from a self-seeded Latham (Darrow, 1937). Latham and Chief cultivars became important to breeders in developing new cultivars (Hall and Kempler, 2011). English cultivars continued to be brought to the USA and by the early 19^{th} Century over 20 cultivars were grown in England and the USA. Natural hybridization between the European species and the native North American species occurred, resulting in improved cultivars. There are more than 200 species of raspberry that have been identified in Europe, Asia and North America and only a few cultivars are commercially important. The European red raspberry (*Rubus idaeus* subsp. *vulgatus* Arrhen.) and the North American red raspberry (*Rubus idaeus* subsp. *Strigosus* Michx.) are among those cultivars (Pritts, 2006). As the cultivation of red raspberries continued, an important development was the discovery of primocane fruiting cultivars. Primocane fruiting cultivars bear fruit on the first year canes. Heritage, a cultivar released in 1969 from The New York Agriculture Experiment Station is the standard primocane producing cultivar in regions with cold winter temperatures (Hall and Kempler, 2011).

Taxonomy

Raspberries are a diverse group of flowering plants that belong to the genus *Rubus*. Twelve subgenera are recognized within the *Rubus*, yet raspberries and blackberries are the only members of the subgenera that have commercial significance. The genus *Rubus* is a member of the rose family (Rosaceae). The rose family includes other fruit crops such as apples, blackberries, cherries, peaches, pears, plums, and strawberries (Pritts, 2006). Raspberries are additionally grouped by four main

characteristics: growth habit, fruiting habit, presence or absence of thorns, and fruit color (Fernandez et. al, 2014).

Botanical Characteristics

Red raspberries are a deciduous woody shrub with a perennial root system that produces biennial canes. Biennial canes take two years to complete a biological lifecycle. The perennial root system is fibrous with 70% of the roots located in the top 10 inches of the soil. The plant produces canes that emerge every year from crown buds or adventitious root buds during the spring and live for two growing seasons (Fernandez et. al, 2014). Growth habit can be erect, semi-erect, or trailing. Fruiting habit can be primocane which bears fruit in late summer to fall or floricane which bears fruit in early to late summer. Fruit color may be red, yellow, purple, or black (Fernandez et. al, 2014).

Primocanes arise the first year from crown buds and elongate rapidly in the spring. In optimal conditions the canes can reach upwards of 16 feet, which is excessive for normal production as it contributes to the difficulty of management and harvesting. Ideally managed canes are approximately 6.5 feet tall (Hall et. al, 2009). The canes produce nodes that vary in distance apart due by cultivar, plant vigor, and growing conditions. Located at each node is a pinnately compound leaf with 3-5 leaflets, followed by primary and secondary buds that form in the leaf axil (Galletta and Himelrick, 1990). Flower bud initiation in primocanes can occur when the cane reaches a certain height, even if day length and temperature requirements are not met (Koester and Pritts, 2003). Primocane advantages include an extended harvest season from a single plant, shorter duration to full harvest potential, higher density of plants, and minimal trellising is

required. Disadvantages of Primocane fruiting raspberries are reduced yields as a result of pruning back to the ground each year, difficult pest control attributed to pest build up during longer season, and reduction in pollinator activity as the growing season is extended (Koester and Pritts, 2003).

Floricanes produce flowers and fruit the second year after the dormant primocanes have overwintered. The canes arise from crown buds or root buds in early spring and elongate during the growing season. As day length shortens and temperatures decrease in the fall, fruit buds are formed in the axils of the leaves. The plant becomes dormant throughout the winter and the buds elongate the next growing season to form fruiting laterals. Fruit located at the distal end of the cane and the peripheral portion of the plant mature first, followed by the fruit located on the proximal portion of the cane and the interior of the plant (Pritts, 2006). Floricane advantages include a straightforward production schedule, shorter harvest season that produces high yields, a reduction in pest control requirements, a reduction in number of pollinators needed and the fruit has better size and flavor (Koester and Pritts, 2003). Disadvantages of floricanes are larger plants that utilize a greater amount of space, additional plant management and trellising are required, plants and canes require manipulation such as pruning and tipping the canes, increased chilling hours are required and extra time is needed to realize full harvest potential (Koester and Pritts, 2003).

Growing Conditions

Raspberry plants favor environments with moderate summer temperatures below 85° F and most cultivated varieties are cold hardy to -20°F. Winter temperatures that

fluctuating or drop below 30°F can cause damage to the plant (Warmund, 2009). The optimal leaf temperatures are between 65° to 70° F. Exceeding these temperatures can cause reduced photosynthesis which can lead to reductions in plant and fruit size, and stored carbohydrates (Fernandez et. al, 2014).

Raspberries grow best in well-drained loamy soil with organic matter greater than 3% and a pH of 5.5 to 6.5 (Nathan, et. al, 1999). Soil temperatures of 75° to 80°F are best for root performance. The root system mainly occupies the top 10 inches of the soil making them sensitive to high temperatures, drought stress or excessive water (Fernandez et. al, 2014). Raspberry roots are not salt tolerant (Nathan, et. al, 1999).

Light requirements for raspberry are full sun or a minimum of 6-8 hours of sunlight, plants will tolerate light shade while high light intensity can result in sun damage (Hall et. al, 2009). This can be controlled in high tunnel production by the use of a shade cloth. Shade clothes are rated by percentage which refers to the percentage of light that is filtered and not allowed to penetrate into the tunnel.

General water requirements for raspberry are approximately 1 inch of water a week per plant. This will differ by cultivar, growth stage, soil type, temperature and wind exposure (Fernandez et. al., 2014). The critical irrigation period for raspberry is during bloom and as berries are enlarging before harvest (Lamont et. al, 2015). Accurate quantities and timing of water for raspberry are important for proper growth and development. Excess water can lead to root disease, while a shortage of water can result in reduction of plant vigor and yield. Environmental monitoring equipment and good record keeping should be used as a guide for irrigation. Water should be applied before leaves show signs of wilting (Fernandez et. al., 2014). Technical advances in methods of

providing water have been developed, yet there is a lack of information for the optimum timing and dose of application applied at different levels of fertigation. Fertigation is the process in which nutrients are supplied at the same time as water usually by drip irrigation to the root zone of the plant (Koumanov, et. al, 2009).

Raspberries require a period of dormancy and chilling requirements annually. Chilling requirement refers to the number of hours the plant must be exposed to temperatures ranging from 32° F to 45°F before the plant breaks dormancy the following spring. Raspberry plants require approximately 800-1800 chilling hours at a temperature between 37° and 50° F to allow the plant to go dormant and complete a resting period in the winter before the plant resumes vegetative growth the next spring Throughout late summer and early fall the plant prepares by undergoing physiological changes that assist the plant with the ability to endure the cold winter temperatures. (Fernandez et. al, 2014).

Nutrient Requirements

A soil test is the first step to determine the needs of the planting site. The results of a soil test indicate what nutrients are available in the soil to be taken up by the plant and if any changes or recommendations are needed for the crop being produced (Pritts & Heidenreich, 2012). Factors that influence the availability of nutrients are temperature, soil aeration, nutrient concentration, rate of plant growth and soil moisture (Crandall, 1995). In contrast, a plant tissue analysis is used to measure the nutrients that have been taken up and are in various plant parts. Tissue analysis has the benefit of alerting the grower to nutrient levels that are approaching deficiency and if fertilizer is being over applied. Corrective action may be taken before symptoms are visible on the plant.

Tissue analysis provides the added benefit of reporting levels of thirteen essential nutrients in leaves at a time of collection. The standard collection time of leaf samples for tissue analysis is mid-summer, when nutrient levels fluctuate the least. Proper tissue collection for raspberry includes selecting fifty leaves from fully expanded primocanes in early August. Petioles, the stalk that joins the leaf to a stem, should be removed and the leaves washed in distilled water. When the leaves dry place them in a paper bag and send to a testing laboratory for tissue analysis (Pritts and Heidenreich, 2012).

Primary macronutrients Nitrogen (N), Phosphorus (P) and Potassium (K) are the nutrients required in the highest quantity for raspberries. Secondary nutrients Calcium (Ca), Magnesium (Mg) and Sulfur (S) are essential nutrients. The requirements of raspberries for Ca and Mg is medium and requirement for S is low. Micronutrients Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo) and Zinc (Zn) are used in small quantities by the plant, nonetheless they play an important role in plant development. Requirements for B and Cu are medium, Fe and Mn are high and Mo and Zn requirements are low (Bushway et. al, 2008). It is important to have soil test results before application of these nutrients as over application of nutrients can be detrimental to the plant and environment (Sheavly et. al, 2011). Standard foliar nutrient ranges for raspberries have been determined by Cornell University (Table 1) (Pritts and Heidenreich, 2012).

Nitrogen (N) is the most important nutrient needed for plant growth and is generally needed in large amounts (Sheavly et. al, 2011). Nitrogen (N) is necessary for plant growth, the formation of amino acids and is directly involved in photosynthesis. Excess N at the time of planting can potentially lead to moderate vegetative growth of the

plant and consequently the root system will suffer. Nitrogen (N) should be applied based on the soil test recommendations and amount of organic matter in the soil (Nathan et. al, 1999). Organic matter is composed of living organisms, fresh and decomposed residues such as animal manures, cover crops and green manures. Animal manures add organic matter and nutrients directly to the soil. Cover crops add organic matter and N to the soil, reduce soil erosion, and provide habitat for beneficial insects. Green manures are cover crops that grow during the winter and spring and are plowed in during early spring (Gu, 2010).

Application rates and timing recommended by The University of Missouri Soil and Plant Testing Laboratory should be followed. As previously mentioned, application rates also depend upon organic matter percent in the soil. The recommendation rates are as follows, for soils containing organic matter of less than 2.5% N application rate is 60 pounds per acre, for soils containing organic matter of 2.5-4.5% N application rate is 50 pounds per acre and for soils containing organic matter greater than 4.5 % N application rate is 40 pounds per acre. For newly established plantings, N should be applied ½ at the time of planting and ½ side dressed in June. For established plantings N should be side dressed in the spring (Nathan et. al, 1999). Side dressed refers to a method in which the fertilizer is applied two to four inches from the side of the plant. After application, the soil is lightly raked and watered. Failure to disturb the roots help ensure reduction of root damage during application and safeguards against the fertilizer contacting the plant tissue. Direct contact to the plant tissue can result in damage associated with burning of the plant tissue. Nitrogen (N) is mobile in the soil and soil levels will fluctuate depending on biological activity and soil conditions (Sheavly et. al, 2011).

Phosphorus (P) is a major component of plant DNA and plays a key role in numerous plant functions. P is critical for root development, plant growth and maturity, seed production, energy transfer, photosynthesis, sugar and starch transformation, nutrient movement and transferring genetic traits. P is immobile in the soil, and should be mixed into the upper 4-6 inches of the soil (Ball, 2001). Recommended rates for P are 25 pounds of P_2O_5/acre. New plantings should receive a 25 percent greater recommendation than established plantings. The following equation has been recommended by The University of Missouri Soil and Plant Testing Laboratory to assist in determining P application rate: P_2O_5=95-1.25*PTest with a maximum application of 75 pounds per acre (Nathan et. al, 1999).

Potassium (K) is mandatory for the activation of eighty or more enzymes in the plant and is responsible for increasing water use efficiency and converting sugars to starch (Ball, 2001). Adequate levels of K improve fruit quality and increase stress tolerance (Sheavly et. al, 2011). Potassium (K) is immobile in the soil and should only be applied if the soil test indicates low levels (Ball, 2001). Recommended rates of K for all plantings are based on an equation and soil test recommendations. The University of Missouri Soil and Plant Testing Laboratory recommend the following application based upon the soil test K levels. For soil test results of less than 180 pounds of K_2O per acre application rate is determined by the equation K_2O=210-1.0*KTest-100 pound K_2O maximum. For soil test results of 180-220 pounds of K_2O per acre the application rate is 30 pounds per acre of K_2O. For soil test results of 220-260 pounds of K_2O per acre the application rate is 20 pounds per acre of K_2O. Soil that tests greater than 260 pounds per acre of K_2O no application should be made (Nathan et. al, 1999).

Fruit Development

Typical raspberry flower structure includes the sepal, petal, stamen and pistil. Five small sepals function to protect and support five small petals that surround the reproductive organs. The reproductive organs are the stamen (male part) and the pistil (female part). Pollen grains must be transferred from the stamen to the pistil for pollination to occur. Each flower contains 100 to 125 pistils that contain two ovules each. One ovule ripens to a mature seed and the other ovule ripens to form fruit approximately 30 days after pollination (Bushway et. al, 2008). The fruit is an aggregate fruit consisting of 75-125 drupelets attached to a central receptacle. The drupelets are held together by entangled epidermal hairs. The drupelet remains attached to the receptacle approximately 30-35 days after pollination at which time it is mature and separates easily leaving the receptacle behind (Crandall, 1995). The majority of raspberry cultivars are self-pollinating, meaning the pollen from the stamen is transferred to the pistil of the same flower or a different flower resulting in viable seed and drupelet formation. Pollen transfer is typically done by flying insects such as honeybees (Crandall, 1995). If natural pollinators are lacking incomplete pollination may occur. Incomplete pollination occurs when each individual drupelet fails to get pollinated, and contributes to compromised fruit structure, strength, and shape (Bolda, 2010). As a result of incomplete pollination and compromised fruit structure a reduction in fruit set can occur. Crumbly berry, a condition in which reduced development of the drupelets cause the berry to crumble apart before ripening or at harvest (Olcott-Reid and Reid, 2007). The fruit develops in three stages, with each stage lasting 10-12 days. The first stage of growth following pollination is a rapid stage of cell division. During the second stage growth occurs at a slower rate, as

cell division slows, the embryo develops and the seed coat hardens. Rapid growth occurs in the third stage of growth due to cell enlargement. The average fruit size is 1-5 grams and varies by cultivar (Pritts, 2006).

Fruit Composition And Quality

Raspberry fruit composition consists of 87% water. The remaining solids are 9% soluble with the rest insoluble. Pectins make up approximately 1.0% of the soluble portion. Glucose and fructose are the main sugars with minor amounts of sucrose. Typical ripe raspberry fruit includes 5-6% sugar. Citric acid accounts for another important part of the soluble portion of the fruit. Acid amount contained in the fruit is higher during the beginning of development and decreases as the fruit ripens. Proper balance between sugars and acid are important for a desirable flavor. Fruit with low sugar to acid ratio will be tart while fruit with a high sugar to acid ratio will be bland (Pritts, 2006). One cup or 123 grams of raspberries contains approximately 64 calories, 1 gram protein, 1 gram fat, 15 grams carbohydrates, 8 grams dietary fiber and 5 grams of sugar (USDA, 2016). Small amounts of vitamins are found in raspberries with Vitamin C considered significant at approximately 54 % (Bushway et. al, 2008).

Aspects of fruit quality that are important in the development of new cultivars are size, shape, color, firmness, skin strength, seed size, shelf life, flavor and nutritional content. Intended use for the berries determines the importance placed on the different traits. Quality of fruit that is intended for fresh market use is determined by large berry size, fresh flavor, strong skin strength and internal firmness, glossy appearance, a light red color, small seeds, low acidity, and high nutritional content. In contrast, quality of

fruit that is intended for processing is determined different since the fruit is harvested and frozen shortly afterwards. The berry does not need to be as large or firm. A good skin strength and powerful fruit flavor is still desired. The berry should be dark in color, high in soluble solids and titratable acidity and have a low pH (Hall et. al, 2009).

Annual Yield

Average marketable yield for raspberries are 5,500 pounds per acre for field production and 15,000 pounds per acre for high tunnel production (Demchak et. al, 201). Components that play a role in the yield other than environment are inherited traits that possess significant genetic interactions (Daubeny, 1996).

Primocane yield depends on cane number and amount of cane branching. Given that primocane cultivars have a shorter fruiting season, cultivars that bear fruit earlier play a significant role in the yield achieved before the onset of winter. The ideal number of canes for is 5-7 per plant. Floricane yield depends on cane number, fruiting laterals per cane, number of fruit per lateral and fruit weight. The number of canes for floricane cultivars will differ among the cultivars. Key management is to maintain an even balance between vegetative and reproductive portions. Fruit size is another important contributor to yield as cultivars vary in fruit size and shape. Current breeding goals include increasing drupelet size and number to improve overall fruit size, as well as thickness of the fruit in the middle. Both of these characteristics play an important role in increasing yield within the raspberry germplasm (Hall et. al, 2009).

Harvesting and Handling

High quality raspberry production is dependent upon both pre and post-harvest factors as well as the method of harvesting. Important factors that need to be considered pre-harvest include: cultivar selection, growing site, plant health, plant nutrition, and disease and pest management. Post-harvest consideration should be given to temperature, time of day harvested, amount of moisture on berry, and time between harvest and cooling (Heidenreich et. al, 2012). Harvesting once every two days is needed because the berries ripen quickly and are not uniform. Machine harvest is used for 75% of all field grown brambles in the United States that require further processing. There are various types of machines used. These machines provide quicker harvest, but there is risk of damaging the fruit. To cover the cost of the equipment, the grower would need to harvest a minimum of 25 acres. Hand harvest is used in high tunnel production and 8-10 trained workers are needed to harvest an acre (Olcott-Reid and Reid, 2007).

Differences exist between the cultivars, although the general rule is that raspberry fruit are ready to harvest when they first turn completely red. The fruit should easily separate from the receptacle. Raspberries are highly perishable and easily damaged. Once harvested, fruit should be placed directly in vented containers and forced-air cooled within 4 hours. Respiration is the process where the food reserves are converted to energy. This process begins after harvest and can result in shrinkage, reduced sugar and deterioration. The raspberry has a high respiration rate which increases as the temperature rises. The respiration rate for raspberry stored at 32°F is 24 mg of carbon dioxide per kg of raspberry per hour; the rate for 50° F is 92, and at 68° F the rate is 200. Therefore, it is

important to properly handle and cool the berries to ensure the best quality (Bushway et al., 2008)

Disease and Pest Management

There are numerous diseases and pests that can impact raspberry production. Management varies depending upon cultivar, geographical location, growing conditions and production method. It is important to establish pre plant and established plant management. Pre plant strategies include: selecting disease resistant cultivars, weed control, avoid planting near wild brambles, and proper site selection. Established plant management includes: maintaining plant health, prune and remove old fruiting canes, scout weekly, and obtain proper identification of the disease or pest. Diseases can be biotic or abiotic. Biotic diseases are caused by living things, while abiotic are caused by non-living things such as the environment (Bushway et al., 2008). Common diseases and pests include: Raspberry mosaic, Leaf curl, Anthracnose, Blight, Botrytis, Powdery Mildew, Sunscald, White Drupelet Disorder, Rust, Phytophthora Root Rot, Aphids, Mites, Japanese Beetles, Raspberry Cane Borer, Leaf Hopper, and Tarnished Plant Bug (Olcott-Reid and Reid, 2007). Spotted Wing Drosophila (SWD), is a new invasive pest that damages the fruit by using a serrated egg laying device to deposit eggs in firm fruit. SWD was first detected in Missouri in 2013 (Pinero and Byers, 2013). Sanitary growing conditions, proper scouting and good air movement are ways to reduce disease potential (Tepe and Hoover, 2012).

Commercial Production

World production of raspberries is 400,000 tons, with most of the production occurring in Russia, Europe and the Pacific Coast of North America. To meet the rising consumer demand of raspberry products, the United States must import. In 2015, the United States imported approximately 95,235 metric tons of fresh, frozen and processed raspberries valued at $567 million. An increasing trend has been present since 2009 (USDA, 2015).

Economic importance of raspberries worldwide has shifted over the last twenty years towards fresh market production. According to the USDA, 2015 imports of raspberries were valued at $492 million, up from the 2009 imports valued at $72 million. The first quarter of 2016 imports were at $187 million which is another increase from the first quarter of 2015 of $151 million. The exports for 2014 were valued at $175 million, an increase from 2009 exports of $94 million. Current export totals for 2015 and 2016 are not available (USDA, 2015).

High Tunnel Production

The typical growing season for raspberry is from June to August for floricane bearing cultivars and August to October for primocane bearing cultivars. Previous research has evaluated the benefits of high tunnel production for raspberries. The use of high tunnel production can extend that season from May to November or even December (Heidenreich et. al, 2012). Benefits of high tunnel raspberry production include an extended growing season, increased plant vigor, increased yield, increased berry size, and environmental control (Odneal, 2016). Protection from the environment can attribute to

the reduction of disease and insect pressure (Wien, 2009). Season extension using a high tunnel will allow growers to obtain a larger retail price for off season berries. High tunnel production has shown to yield more than three times that of field production (Heidenreich et. al, 2012).

In a study conducted by Cornell University at the New York State Agriculture Experiment Station in Geneva, New York the performance of eight primocane fruiting red raspberry cultivars were evaluating using standard production plots. The objective of the study was to compare newer primocane fruiting raspberry cultivars with the standard cultivar in the region, Heritage. Statistical analysis revealed significant differences among cultivars for total yield, marketable yield and fruit weight, but no year x cultivar interactions. In this trial six of the eight cultivars produced marketable yields that were equal to or greater than the standard cultivar Heritage and were determined to be suitable for growing in regions similar to western New York. Autumn Bliss produced the most overall marketable yield and had the largest fruit size. It is an early ripening cultivar, so further study is needed on other cultivars to lengthen the production season (Weber et. al, 2005).

In a study at Pennsylvania State University, raspberry cultivars grown in high tunnels were compared to those grown in the field. High tunnel yields were higher and the season was extended by three to four weeks in the fall and spring resulting in a 50% longer season when compared to field grown berries (Demchak, K., 2009).

A field versus high tunnel study at Southwest Michigan Research and Extension Center in Benton Harbor Michigan was conducted using four primocane fruiting and four floricane fruiting raspberry cultivars. This trial was conducted to evaluate berry yield,

berry size and harvest time variance between field and tunnel grown plants. The results indicated that high tunnels lengthened harvest periods and promoted plant vigor and increased yield. Fruit quality was also increased while the incidence of fruit, foliar and cane diseases were reduced (Hanson et. al, 2011).

North Central Research and Outreach Center, University of Minnesota at Grand Rapids, Minnesota conducted research on five primocane fruiting raspberry cultivars. The cultivars were evaluated in a high tunnel and in the field. The object of this study evaluation of the potential of primocane fruiting raspberry as a perennial crop in high tunnels. Results concluded that primocane fruiting raspberries will produce in high tunnel production in Grand Rapids, Minnesota and other areas with similar climatic conditions. The plants were taller, branched more, and produced higher yields than in the field (Yao and Rosen, 2011).

Seven primocane fruiting and fifteen floricane fruiting raspberry cultivars were compared for three seasons in adjacent plots on loamy sand soil at the Southwest Michigan Research and Extension Center in Benton Harbor, Michigan. This trial was conducted to determine the suitability of newer primocane and floricane fruiting raspberry cultivars for use in Michigan and areas with similar climatic conditions. The study concluded that Caroline was the highest yielding primocane fruiting cultivar and that Caroline, Autumn Bliss, and Autumn Britten produced larger berries than other cultivars included in this trial. Caroline showed promise as a primocane fruiting alternative to the standard Heritage, while Nova showed promise as an early season floricane fruiting variety. More research is needed to determine the role of cane and foliar

diseases in winter injury in cold climates and season extension for full harvest potential (Hanson et. al, 2005).

Despite numerous benefits of high tunnel production, there are some cautions to consider. High tunnels production requires an increased amount of knowledge and time to grow the crop. Plants must be irrigated since no rain gets into the tunnel. The sides must be raised and lowered according to the temperature. High tunnels have a different microclimate and as a result some insects such as mites benefit and thrive (Koester and Pritts, 2003). As the season is extended into the winter the tunnel must be reinforced to withstand the load of snow or the snow must be removed from the structure. The climate and protection of the high tunnel environment may also be inviting to small animals such as rabbits, mice, and voles as well as birds (Heidenreich et. al, 2012).

Breeding Of Raspberries

Raspberry breeding methods encounter resistance due to the lack of information about the raspberry chromosome. The chromosomes vary in size from 1.8 to 3.1 μm in length. Due to the small size of the chromosome it is difficult to obtain complete information. Raspberry is a diploid, having two sets of the basic $7x$ chromosome genomic structure, $2x = 14$ (Hall and Kempler, 2011). Raspberries small chromosome size in combination with the plant being a highly heterozygous perennial with a long juvenility periods adds to the length of time required for the breeding. One way to advance the breeding process is by genetic linkage maps. A genetic linkage map would allow breeders to identify markers for polygenic traits and help in identifying genes that control the desired traits. Current construction of a genetic linkage map of raspberry was

successfully created from a cross between European cultivar Glen Moy and the North American cultivar Latham, which are two cultivars that are phenotypically different. Through the development of SSR markers and QTL analysis the traits were analyzed and linkage markers were found for thorny and thorn less groups (Graham, et. al, 2004).

Domestication of raspberries and the limitation of having five cultivars dominating the parentage, has led to a reduction in morphological and genetic diversity among raspberries Lloyd George and Pyne's Royal are the parents from European cultivars. The remaining three parents are European and North American crosses Preussen, Cuthbert and Newburgh (Graham, et. al, 2004). Natural hybridization occurred between European cultivars and North American cultivars until the early 1900's. It was during that time, that George Pyne, a private breeder from Topsham, Devon, England was successful in creating new cultivars by selecting parents from self-sown seedlings. Pyne's most successful cultivar was Pynes Royal (Hall and Kempler, 2011). Pynes Royal was a seedling raised by George Pyne in 1907 and introduced in 1913 (Darrow, 1937). Another cultivar found in the woods of Kent, England by J.J. Kettle was introduced in 1919. Kettle called this cultivar Lloyd George. The Pyne's Royal and the Lloyd George cultivars became the focus of at The East Malling research program (Hall and Kemper, 2011). East Malling was established in 1913 in Kent, England by the fruit growers of the area. The goals at that time were to address the current issues growers were encountering. Subsequently, by conducting applied research through genetics and crop improvement, pest and pathogen ecology, and resource efficiency for crop production, East Malling has contributed to the way of production and delivery of crops grown. Services currently offered include research, plant breeding, DNA fingerprinting, crop

protection trials, growing media trials, variety and novel crop trials, mushroom virus detection, and a viticulture consortium (NIAB EMR, 2016). Controlled crossed have been in use in North America since the mid 1900's. Two cultivars, Latham and Chief were derived from crosses between King and Louden and self-pollinated Latham and were released by the state extension program at The University of Minnesota, in St. Paul in 1918 and 1930. Latham and Chief cultivars were both successfully used for development of new cultivars and are important to the raspberry breeding program (Hall and Kempler, 2011).

As of 2011, there were 45 raspberry breeding programs in 22 countries. Breeding programs aim to develop new cultivars with improved characteristics. Focus has been placed on characteristics such as higher yield, improved fruit quality, and increased pest and disease resistance. Programs in the Pacific Northwest of North America at Washing State University (WSU), Agriculture and Agri-Foods Canada (AAFC) and the United States Department of Agriculture (USDA) have collaborated with each other and with breeding programs in England to release more floricane and primocane raspberries cultivars. The research and collaborations have produced a range of advanced selections. The most vital and productive program has been AAFC. North American breeding programs have placed an emphasis on cold hardiness, root rot resistance and primocane fruiting cultivars (Hall and Kempler, 2011). Heritage is the standard primocane bearing raspberry in North America and other parts of the world. Developed in Geneva, New York in 1969, it has parentage consisting of Milton X Cuthbert X Durham. A consistent producer that bears small flavorful fruit later in the fall. The fruit is firm and has a tolerance to Botrytis gray mold. The plant produces numerous erect canes with thorns.

Expanded breeding and the release of new cultivars is leading breeders and growers in the Midwestern United States to shift focus to cultivars that have an earlier ripening time and to cultivars that have larger berries. The industry is gradually starting to replace the standard 'Heritage' cultivar with improved cultivars (Hanson and Rytlewski, 2014).

Future Of Raspberries

Production of raspberry is changing towards fresh market use with an abundance of the production coming from protected growing environments, such as greenhouses and high tunnels. Breeding programs are continuing research focused on the development of cultivars with increased yields, improved fruit quality, larger fruit size, an increased number of fruit per lateral and increase in pest and disease resistance. Due to rising interest production of raspberries in protected growing environments, breeders and growers are focusing on a transition to increasing growing primocane fruiting cultivars and reducing floricane fruiting production. Furthermore focus is on improving the growth habit so the canes are stronger and more self-sufficient to reduce trellising needs, to develop a machine harvest method for fresh market use, incorporate wild relative traits to increase environmental stresses with the goal of year round production (Hall and Kempler, 2011).

MATERIALS AND METHODS

Location

This cultivar evaluation was conducted at Missouri State University State Fruit Experiment Station in Mountain Grove, Missouri. A high tunnel located at Latitude: 37° 9' 21.0996" and Longitude: -92° 15' 56.268" was used for production of the primocane red raspberry cultivars. Mountain Grove, Missouri is located in hardiness zone 6b with winter temperatures ranging from -5 °F to 0° F (USDA, 2012).

High Tunnel

The high tunnel used was a 30' Zimmerman Frame tunnel with drop down side curtains and a double door. The tunnel is 30' x 96' with a 36" drop down side curtain. The tunnel is oriented East to West, with a double door located on the West end and the drop down curtains located on the North and South sides (Fig. 2). The drop down curtains are controlled by an automated side venting system, which operates with an electrical 36" stroke curtain machine. Exterior covering of the tunnel consists of a double layer of 6 mil polyethylene plastic and a 47% shade cloth that is utilized from July through September. Polyethylene plastic covering for high tunnels is categorized by mil rating. A mil measurement equals one-thousandth of an inch or 0.001 inch. Shade cloth placed on the exterior of the tunnel will provide additional light filtration, the percentage of the shade cloth refers to the percent of light that is blocked from penetration. The high tunnel had no existing supplemental heat. Irrigation for the tunnel is provided by the irrigation

system connected to the well located on the property. A Dema Mixrite Proportioning Pump is connected to the irrigation system to provide fertigation as needed.

Each five foot section of row contained five individual 12 inch by 12 inch #5 High Caliper grow bags obtained from High Caliper Growing Systems, Oklahoma City, Oklahoma. This allows growers the ability to move the bags in and out of the tunnel. The grow bags offer the additional benefit of root pruning, aeration and reduction in tipping over.

Cultivars Used In This Evaluation

Raspberry cultivars Josephine, Himbo Top, Crimson Giant, Joan J., and Polka were the five primocane bearing red raspberry cultivars selected for this evaluation. (Fig. 3-7). Josephine was chosen to be the standard for this project based on previous demonstrated field production research at Missouri State Fruit Experiment Station. Cultivars Joan J, Polka, Himbo Top and Josephine were purchased as dormant bare root plants and Crimson Giant was purchased as plugs (rooted cuttings).

Josephine (Fig. 3) is a cultivar developed by the University of Maryland that ripens later in the season. The fruit are large with a good flavor, dark red color and a firm texture. The plants have an upright and vigorous growth habit and require a small amount of trellising. This cultivar is resistant to leaf hopper and Phytophthora root rot. Cornell University recommends this cultivar as a successful choice to extend the growing season in a high tunnel (Weber, 2012).

Himbo Top (Fig. 4) is a cultivar from Switzerland that produces large quality fruit. The fruit has good flavor and is a bright red color. The plant has an upright growth

habit with long vigorous fruiting laterals that may require additional trellising (Weber, 2012).

Crimson Giant (Fig. 5) is the latest release from the breeding program at New York State Agricultural Experiment Station - Cornell University. Released in 2011, this cultivar has large, bright red fruit with a conical shape. Fruit are firm and flavorful. Crimson Giant ripens later in the fall than the typical raspberry and has the potential to extend the harvest season until October in field production or until November or December utilizing high tunnel production. Frost damage may occur when grown in the field unless protection is provided by row covers (Weber, 2012).

Joan J (Fig. 6) is a cultivar from Great Britain that ripens early in the season. The fruit is very firm with a thick texture. The color of the fruit is dark red and will darken more with storage. The canes have an upright growth habit and are spineless which increases ease of hand harvest. The fruit is large in size, but has a thin skin and can be damaged easily (Weber, 2012).

Polka (Fig. 7) is a variety developed in Poland that ripens in the middle of the fall season. The fruit is softer with a shiny red appearance. This cultivar has a vigorous growth habit. Polka is susceptible to Potato Leaf Hopper, a pest that feeds on the vascular tissue causing damage to foliage (Weber, 2012).

Experimental Design

The experimental design for this evaluation is a randomized complete block with five treatments (cultivars) and four replications (blocks). Each treatment consisted of five raspberry plants of individual cultivars planted in grow bags (Fig 3-7). The four

replications consisted of Block A, B, C, and D (Fig 2.). Due to heterogeneity in initial plant size plants were stratified into the four replicate blocks. The grow bags are 1 foot in diameter, so each replication represents five linear foot of row. The four blocks were arranged in two rows eight feet apart orientated east to west and located on the south half of the high tunnel. Blocks A and C were located in row 1 near the middle of high tunnel. Blocks B and D were located in row 2 on the south side of the high tunnel. Block A, located on the north-west side of the high tunnel was assigned plants with the largest initial size. Block B, located on the south-east side of the high tunnel was assigned plants with large to moderate initial size. Block C, located on the north-east side of the high tunnel was assigned plants with moderate to small initial size. Block D, located on the south-west side of the high tunnel was assigned plants with small initial size (Fig 2).

Procedures

Five primocane raspberry cultivars were planted in the five gallon #5 High Caliber grow bags. All raspberry cultivars were planted in the grow bags on April 21-22, 2014 with 4 gallons of Fafard 52 potting media per bag with the exception of Crimson Giant which was planted on May 21, 2014. Fafard 52 potting media contains a mix of bark, peat moss, perlite, vermiculite, and dolomitic limestone. Plants were managed according to Cornell University Publication Number 47, High Tunnel and Raspberries and Blackberries (Heidenreich, et. al, 2012).

Early season vegetable crops such as beans, broccoli, cauliflower, cabbage, larkspur, lettuce, potato and onion were planted and harvested in the high tunnel in both 2014 and 2015. This demonstrated that annuals followed by perennial raspberries in grow

bags may be a suitable rotation option for high tunnel growers. The vegetable crop was harvested and the raspberry shoots were thinned to five per bag before the plants were placed in the high tunnel. In the establishment year, the plants remained in the center of the high tunnel from the time of planting in April until the vegetables were harvested. On June 9, 2014, the bags were moved into the blocks and arranged accordingly. After the plants were in place, a T-Trellis system and fertigation system were installed. Fertigation of plants supplied daily by drip irrigation for one hour with Peters 20-10-20 Peat Lite Special at the rate of 100 ppm Nitrogen (N), plus a fluid citric acid acidifier to ensure proper pH level.

The first harvest began on Polka on July 15, 2014. Raspberries were harvested three times a week beginning July 15, 2014 through October 31, 2014. Upon harvest termination, the plants remained in the high tunnel to allow canes to go dormant. On December 10, 2014, all plants were pruned back to 2" canes and the bags were removed from the high tunnel. The bags were stored outside surrounded and covered by straw and allowed to overwinter. In 2015, the second year of this trial, the straw was removed from the plants in early March and Osmocote fertilizer 14-14-14 was applied at the rate of 1 tablespoon per bag. April 21, 2015, each plant was thinned to 5 strong shoots and the bags were moved into the high tunnel. Drip irrigation supplied water and fertilizer using the same procedure as the previous year. Raspberries were harvested three times a week beginning on June 15, 2015 and ending on December 2, 2015. The raspberries were pruned on December 16, 2015 to 2" canes and moved out of the tunnel and surrounded and covered with straw to overwinter for the season.

Pest control during both growing seasons included scouting, trapping, salt and sugar float tests, and pesticide applications. Spotted Wing Drosophila (SWD) is a new invasive pest detected at the Missouri State Fruit Station in June of 2013. In 2014, a rotation of Assail, Malathion, FanFare, Danitol, and Delegate pesticide applications were applied weekly from July 2, 2014 to October 10, 2015 for a total of 10 applications. In 2015, to increase the effectiveness against SWD, different pesticides were selected. A rotation of Delegate, Mustang Max, Assail and Malathion were applied weekly from July 20, 2015 to September 28, 2015 for a total of 11 applications. Pesticide applications were applied at night to avoid pollinators and were for treatment of SWD, Spider mites, and Japanese Beetles. SWD was the major pest problem that occurred in this study.

Data Collection

Raspberries were harvested three times a week and marketable yield and berry weight were recorded in grams. At the time of harvest, the cull berries were separated and no data was recorded on cull yield. The interest of this trial was to evaluate total marketable yield not total production yield. Harvest was discontinued on October 31, 2014 and on December 2, 2015. Upon harvest discontinuation, the total number of unharvested berries was recorded. The plants remained in the high tunnel to allow the canes to go dormant and leaves to drop. At that time, the number of fruiting canes remaining were collected and the weight of those canes was recorded in pounds.

Statistical Analysis

The effects of cultivar on marketable yield, average berry weight and the weight of pruned dormant canes were assessed using a two-way analysis of variance. The effect of blocks was not tested because plants were stratified into blocks based on initial plant size instead of being randomly assigned, nor are they replicated. As such the block effect will be tested at a later date when subsequent annual data are collected allowing for enough degrees of freedom to test for this effect as well as any interactions in the model. The analyses were performed using the analysis of variance procedure of Number Cruncher Statistical System (NCSS) version 2007. All effects were considered significant when $P < 0.05$. When F test showed significance ($P < 0.05$), means were separated by cultivar within a year by the Tukey-Kramer procedure for multiple comparisons ($P < 0.05$). Individual years are presented separately due to insufficient degrees of freedom to include year in the model as a random factor.

RESULTS AND DISCUSSION

This project was funded by a Missouri Department of Agriculture Specialty Crop Block Grant program and the USDA. Funding has been awarded two additional years of evaluation. With four years of recorded data, statistical analysis can be ran using regression models to compare multiple years and account for any variances. Upon completion of this four year evaluation a recommendation of the best performing cultivars can be released with the most effective rotation schedule.

During the first two years of evaluation, all five cultivars that were observed successfully grew and overwintered in high tunnel bag production. All cultivars assessed were compared to the standard cultivar Josephine, base line data had been collected from a previous in-ground planting at the Missouri State Fruit Experiment Station in Mountain Grove, Missouri for Josephine. All five cultivars compared to Josephine exceeded the three year base line average of the standard cultivar Josephine, which was 8.6 pounds per 5 foot hedgerow.

The first producers in 2014 were Josephine and Joan J. with first harvest July 15, 2014 and July 18, 2014 respectively. The remaining cultivars continued to produce until harvest was discontinued on October 31, 2014. Figure 9 shows 2014 peak production by month for all cultivars. Joan J., Polka and Himbo Top production peaked in September while Josephine and Crimson Giant had peak production in October. First harvest in 2015 was on June 15, 2015 for all cultivars with the exception of Crimson Giant which ripens later. The last day of harvest for all cultivars was December 2, 2015. Figure 10 shows 2015 peak production by month for all cultivars. Joan J. and Polka production

peaked in July, Himbo Top and Josephine production peaked in August and Crimson Giant production peaked in November (Fig. 9 and 10).

Marketable Yield in for 2014 results concluded that Polka produced the most fruit with total marketable yield of 4104.25 grams and was not significantly different from Joan J at 3719.75 grams. Josephine and Himbo Top produced significantly different yields from Polka and Joan J. at 2420.25 and 2300.50 grams respectively. While Crimson Giant was significantly less at 957.25 grams (Table 2). In 2014, the establishment year Crimson Giant produced significantly less than the other cultivars due to early termination of harvest. Harvest was discontinued in October 31, 2014 and it was later realized that Crimson Giant was bred to produce in late November. As a result of early harvest was termination, Crimson Giant was not allowed to realize its full harvest potential in 2014. Based upon the number of unharvested berries taken at that time from Crimson Giant, it appears that the cultivar would have produced an acceptable yield had it been harvested into November. In 2015, harvest was discontinued on December 2, 2015 and Crimson Giant production increased significantly to 4796.75 grams.

Marketable Yield in 2015, results concluded that Joan J. produced the most fruit with a total marketable yield of 7365.25 grams and was not significantly different from Polka and Himbo Top with 6436.50 and 6246.25 grams respectively. Crimson Giant produced 4796.75 and was not significantly different from Himbo Top and Josephine. All cultivars had an increase in production and Crimson Giant indicated that production potential was realized in the second year when harvest was extended (Table 2). The marketable yield in 2015 for all cultivars in the grow bags (including Josephine) exceeded the highest yield of Josephine from the previous in-ground trial.

The evaluation of these five cultivars demonstrated that all five cultivars produced commercially acceptable Marketable Yield in 2014 and 2015 with the exception of Crimson Giant in the establishment year, however adjusted yield indicates that Crimson Giant would also have produced acceptable Marketable Yield. All five cultivars could be recommend for high tunnel production in a grow bag based on acceptable marketable yield production. Economic consideration for acceptable marketable yield in raspberry changes with prices and yields. A summary of returns has been determined by Penn State Extension. Approximately 1875 half pints or 3 lbs. yield per foot for high tunnel production at a price of $3.00 per half pint results in $3442.00 profit (Demchak, et. al, 2014).

Average berry weight for all cultivars were similar to the standard Josephine. Crimson Giant exceeded the standard as well as all other cultivars in the trial (Table 3 and Fig. 5). In 2014 the average berry weight for each cultivar ranged from 3.17 grams to 4.46 grams in 2014 with Crimson Giant producing the largest berry at 4.46 grams. In 2015 average berry weight for each cultivar ranged from 3.06 to 4.31 grams with Crimson Giant producing the largest berry in the second year as well (Table 3). According to Dr. Marvin Pritts, a professor at Cornell University, the average raspberry size is 1-5 grams. All five of the cultivars evaluated produced in the mid to top range with a combined average berry size of 3.65 grams in 2014 and 3.45 grams in 2015. Again, all five cultivars could be recommended for high tunnel production in a grow bags based on acceptable berry size.

Pruning weight data of dormant canes was recorded to assess plant size and vigor. In 2014, Himbo Top had the lowest pruning weight with 1.19 lbs. and Joan J. had the

most at 2.20 lbs. The plants ranged from 1.19 to 2.20 lbs. with the combined overall average of 1.80 lbs. In 2015, the plants ranged from 2.05 to 3.64 lbs. with a combined overall average of 2.69 lbs. Joan J. had the lowest at 2.05 lbs. and Crimson Giant had the highest at 3.64 lbs. The pattern observed was that the cultivars that ripened early had lower dormant cane weight and the cultivars that ripened later had a higher dormant cane weight (Table 4). The weight of the dormant canes did not appear to have an impact on yield, however, there was an overall increase in pruning weight from 2014 to 2015. This can be attributed to 2014 being the establishment year and 2015 being the first year that the plants overwintered and produced. Pruning weight increase indicated that the plants are overwintering and producing successful, therefore all cultivars could be recommended for high tunnel production in grow bags based on overall plant health and success.

Additional observation made during this evaluation included trellising issues, cultivar preference and further evaluation needed, disease symptoms and pest pressure reduction. Trellising issues presented with Himbo Top as it was vigorous with top heavy canes that can reach back down to the ground unless extra trellising or tying is implemented. Cultivar preference was shown for Joan J. cultivar among the crew for harvesting as it did not have thorns. Late season disease symptoms presented on Polka that looked like virus symptoms. Conversations with Dr. Courtney Weber, Associate Professor at Cornell University determined that this is typical on Polka and that it is only an esthetics issue that does not affect the long term performance of the plant. Pest pressure in 2014 was limited to mites until the arrival of Spotted Wing Drosophila (SWD). SWD is a new invasive pest that arrived in Missouri in 2013. The pest population

number was not enough to have an effect in 2014. In 2015, pesticide application changes were implemented to target SWD. The applications were discontinued in late September and harvest continued until early December. Weekly testing was still conducted to observe SWD. No observation of SWD was detected during that time, which suggests that the production of late season cultivars such as Crimson Giant may avoid some SWD pressure in this region.

Limitations of this study included establishment year and second year differences in yield, variance in initial plant size of the dormant bare root plants, and two different types of starting plant material. To obtain statistics from a production standpoint, the data from 2014 and 2015 were analyzed separately. The difference in starting plant material and different initial plant size, was accounted for by a placing the plants in stratified blocks based on initial size. As a result of questions posed during presentations at grower meetings a changes to this evaluation included the time the raspberries were moved inside the tunnel. In 2015 the decision was made to wait until the raspberries started to flower to move them inside the tunnel. This will extend the time the producer has to grow other crops inside the tunnel. In 2014 the raspberries were moved inside the tunnel in early April which added restrictions to the annual crops being produced and in 2015 the raspberries were moved inside the tunnel in late May allowing the annual crops to reach full harvest potential.

Evaluation examined high tunnel production of five primocane bearing raspberries in grow bags rotated with annual vegetable crops. A rotation method such as this will allow the grower to utilize the high tunnel space for other crops while the raspberries are removed and overwinter outside of the tunnel. The current evaluation of

these five cultivars in grow bags has shown that growing these cultivars in a grow bag in the high tunnel is a suitable option for high tunnel growers that want to maximize valuable high tunnel ground space by rotation of raspberries with annual crops grown in the same growing space. To date, results are that all five cultivars are suitable for the high tunnel production in grow bags and will survive overwinter rotation outside of the tunnel in locations with similar climatic conditions as southern Missouri.

The results from this trial will benefit growers by offering them the ability to test the addition of a value added crop to current operations. The difference in yield through time will offer growers diversity in production and the ability of including raspberries into the high tunnel production schedule. Results will be available to assist extension staff and educators by offering cultivar information that was not currently available for this high tunnel bag production. Collaboration between educators and growers will contribute to sustainable farming operations by increasing efficiency and economics.

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Table 1. Standard Foliar Nutrient Range for Raspberries

Nutrient	Deficient Below	Sufficient
Nitrogen	1.90 %	2.00-2.80%
Phosphorus	0.20	0.25-0.40
Potassium	1.30	1.50-2.50
Calcium	0.50	0.60-2.00
Magnesium	0.25	0.60-0.90
Boron	23 ppm	30-70 ppm
Manganese	35	50-200
Iron	40	60-250
Copper	3	6-20
Zinc	10	20-50

Table 2. Means (±SE) of Marketable Yield for Each Raspberry Cultivar in Grams per 5 ft. row, in 2014 and 2015.

Cultivar	Yield 2014		Yield 2015	
Crimson Giant	957.25 ± 52.09	c	4796.75 ± 710.85	b
Himbo Top	2300.50 ± 169.43	b	6246.25 ± 551.87	ab
Josephine	2420.25 ± 163.42	b	4954.00 ± 537.97	b
Joan J.	3719.75 ± 113.89	a	7365.25 ± 216.79	a
Polka	4104.25 ± 217.45	a	6436.50 ± 404.87	ab

Means with in a column that are not followed by the same letter are significantly different ($p<0.05$, Tukey's pairwise comparisons).

Table 3. Means (± SE) of Average Berry Weight for Each Raspberry Cultivar in Grams per 5 ft. row, in 2014 and 2015.

Cultivar	Average Berry Weight 2014	Average Berry Weight 2015
Crimson Giant	4.46 ± 0.08 a	4.31 ± 0.26 a
Himbo Top	3.17 ± 0.09 c	3.06 ± 0.06 b
Josephine	3.79 ± 0.07 b	3.30 ± 0.05 b
Joan J.	3.25 ± 0.08 c	3.38 ± 0.04 b
Polka	3.56 ± 0.10 bc	3.20 ± 0.06 b

Means with in a column that are not followed by the same letter are significantly different ($p<0.05$, Tukey's pairwise comparisons).

Table 4. Means (±SE) of Pruning Weight of Dormant Canes in lbs. for Each Raspberry Cultivar per 5 ft. row, in 2014 and 2015.

Cultivar	Pruning Weight 2014	Pruning Weight 2015
Crimson Giant	2.00 ± 0.26 a	3.64 ± 0.24 a
Himbo Top	1.19 ± 0.06 b	2.60 ± 0.11 b
Josephine	2.14 ± 0.15 a	2.57 ± 0.26 b
Joan J.	2.20 ± 0.18 a	2.05 ± 0.03 c
Polka	1.47 ± 0.12 b	2.59 ± 0.15 b

Means with in a column that are not followed by the same letter are significantly different ($p<0.05$, Tukey's pairwise comparisons).


Fig 1. High Tunnel

East End of High Tunnel	
Block C	Block B
Polka	Polka
Himbo Top	Himbo Top
Joan J	Josephine
Crimson Giant	Crimson Giant
Josephine	Joan J
Block A	Block D
Polka	Crimson Giant
Himbo Top	Joan J
Josephine	Himbo Top
Joan J	Josephine
Crimson Giant	Polka
West End of High Tunnel	

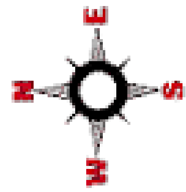

Fig. 2. High Tunnel 30’ x 96’ and Planting Map for Years 2014 and 2015.

Fig. 3. Treatment Josephine, the standard cultivar for this study.

Fig. 4. Treatment Himbo Top.

Fig. 5. Treatment Crimson Giant.

Fig. 6. Treatment Joan J.

Fig. 7. Treatment Polka.

Fig. 8. Berry Size by Treatment. Top Row Right to Left: Crimson Giant, Josephine, Polka. Bottom Row Right to Left: Joan J., Himbo Top. Photo Credits: Eric Hanson Michigan State University.

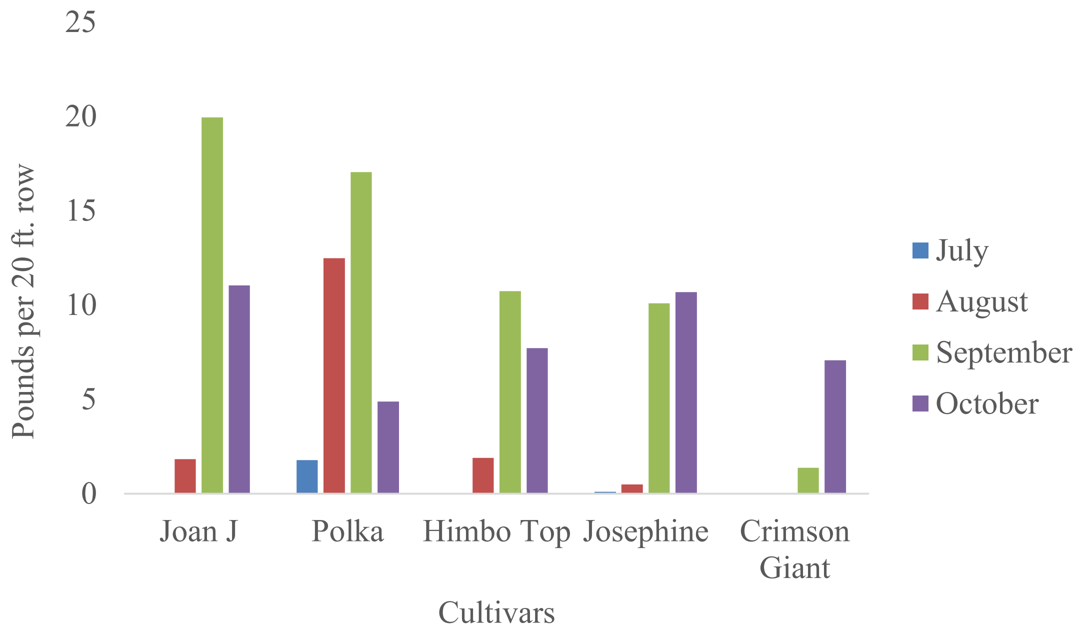

Fig. 9. 2014 Yield by Month.

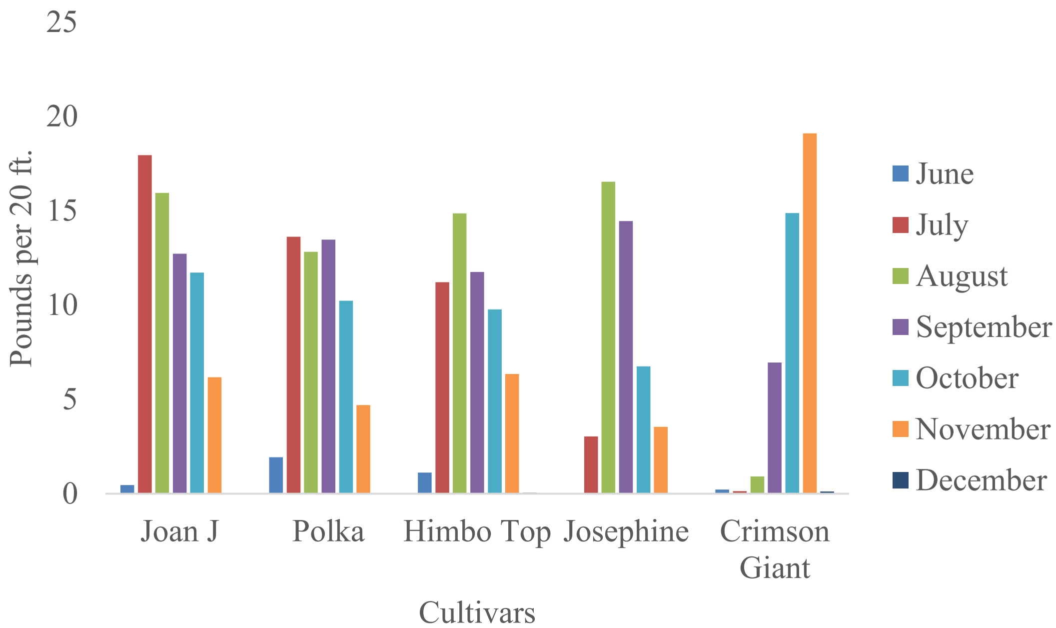

Fig. 10. 2015 Yield by Month.