Haskap (*Lonicera caerulea* L.) Response to Plastic Mulch Colours and Fertility Amendments

by

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Dedication

I dedicate this thesis to my late grandfather, Sh. Sadhu Singh who offered undying love and support

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ABSTRACT

Haskap (*Lonicera caerulea* L.) is a new berry crop in Canada. Crop growth and productivity largely depend on soil and plant microclimate conditions. Therefore, this study was conducted to determine the effect of plastic mulch colours (Black and White) and fertility amendments levels (Control, Low, High) on flowering, growth, yield, and total soluble solids (TSS) of three-year old haskap under irrigated conditions. Treatments had no significant effect on flower timing, flower number, fruit set, or yield after one year. However, delaying harvest for one week significantly increased 100-berry-weight and TSS, and reduced berry number per bush. The absence of significant response to fertility treatment likely due to adequate background soil fertility. Compared with White plastic, Black plastic had statistically higher mean soil temperature (during the growing season) and lower reflected photosynthetically active radiation but differences did not produce biologically significant changes in growth, flowering or yield. To have a better understanding of the effects of plastic mulch colours and fertility amendments on haskap under irrigation, further studies need to be performed beginning at haskap establishment on lower fertility sites and without wood mulch.

LIST OF ABBREVIATIONS AND SYMBOLS USED

ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
B	Boron
℃	Degree Celsius
C:N	Carbon to nitrogen ratio
Ca	Calcium
CEC	Cation exchange capacity
cm	Centimeter
CO_2	Carbon dioxide
Cu	Copper
CV	Coefficient of variance
cv.	Cultivar
Fe	Iron
Fv/Fm	Dark-adapted maximum quantum yield of photosystem II
g	Gram
GDD	Growing degree days
ha	Hectare
H_a	Alternate hypothesis
H_o	Null hypothesis
HBW	100-berry-weight
K	Potassium
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
L	Litre
m	Meter
meq	Milliequivalent
Mg	Milligram
MMC	Multiple means comparison

Mn	Manganese
N	Nitrogen
n.d	Not determined
NS	Nova Scotia
NSDA	Nova Scotia Department of Agriculture
OM	Organic matter
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
P	Phosphorous
PAR	Photosynthetic active radiation
ppm	Parts per million
PSII	Photosystem II
P-value	Probability>F
r^2	Coefficient of correlation
R^2	Coefficient of determination
RPA	Repeated measure analysis
S	Sulphur
s	Second
SAS	statistical analysis system
SDD	Soil degree days
SPAD	Soil-plant analysis development
TSS	Total soluble solids
VAM	Vesicular arbuscular mycorrhiza
Zn	Zinc
µmol	micromole
%	percentage
<	Less than
>	Greater than
≤	Less or equal
≥	Greater or equal

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CHAPTER 1. INTRODUCTION

1.1 Introduction

Consumers are increasingly looking for healthy nutritional and functional foods, which drive the growth of the fresh food market thereby driving the demand for berries (Invenire, 2008). Fruits in general are a valuable crop due to their nutritional values and health benefits associated with their consumption. Superfruits are especially rich in antioxidants, fiber, vitamins, and polyphenols, and have strong anti-inflammatory properties. Hence, the health food market is growing rapidly due to the increased demand for superfruits in the world. Haskap has been identified as a potential new superfruit in North America's market due to its high levels of antioxidants and phytochemicals (Rupasinghe et al., 2018) and has been used in traditional medicines to cure many degenerative disorders (Oyebode et al., 2014). However, its cultivation practices in North America have not yet been refined.

Haskap (*Lonicera caerulea* L.) is a perennial shrub indigenous to Siberia and northeastern Asia where commonly found in low-lying wet and mountainous regions (Bors et al., 2012). It was first reported as a horticultural plant in the 1890's in Russia (Hummer, 2006). *L. caerulea* is widely distributed over the Northern hemisphere (Bors, 2009), which has led to the adoption of several common names including: "Haskap", "Blue Berried Honeysuckle", "Blue Honeysuckle", "Sweet Berry Honeysuckle", and "Honeyberry" (Thompson, 2006; Bors, 2009). Haskap is a relatively new berry crop to the Canadian horticultural market (Bors et al., 2009). The round compact bushes of haskap are known for their winter hardiness (Plekhanova, 2000).

Haskap production did not begin in Nova Scotia until 2009 (Cheverie et al., 2013) after which it has gained rapid attention due to its early harvesting, ease of cultivation, nutritional values, and numerous other health benefits. In Atlantic Canada, the haskap industry is expected to become valued at approximately $500 million a year in the next five years (O'Connor, 2015). However, the major hindrance in achieving this goal can be attributed to slow plant establishment and growth which, in turn, affect fruit production and commercial supply. Plant establishment and productivity are mainly limited by soil conditions (e.g. nutrient availability and plant-microbial interactions) and plant micro-environment (i.e. light, temperature, humidity), which depend largely on crop management practices (Iheshiulo et al., 2018a). Soil chemical and biological processes affect plant root growth and microbial activity, which in turn affect nutrient uptake capacity and performance of the crop. Also, newly cleared forest for orchard establishment is likely to be at a higher risk of failure if adequate measures are not taken to enhance the soil and plant microenvironment. Therefore, there is a need to identify management practices to aid proper plant establishment and fruit production for the industry to thrive.

Fruit yield is dependent on genetic as well as external factors such as management practices, climatic and soil conditions (Salvo et al., 2012). Management practices of any crop should be aimed at increasing length and number of shoots to enhance vegetative growth and maximize commercial fruit harvest (McCarthy and Stoker, 1988). Fertilizer application is a standard practice (Plaster, 2009) with the aim of eliminating limitations to yield and quality (Hart et al., 2006) by supplying nutrients in sufficient quantities to sustain maximum crop productivity and profitability while minimizing environmental impacts of nutrient use (Havlin et al., 2014). The amount of nutrients required depends on plant characteristics, environmental conditions, soil characteristics, and management practices (Havlin et al., 2014). There is a need to understand the interaction between soil, plant, and microenvironment to ensure optimum plant response and support management decisions.

Soil fertility should be appropriate to support healthy growth, development, and berry yield for all crops including haskap. The essential macronutrients; nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) are required to complete the life cycle of any crop (Yadong and Shuang, 2009; Havlin et al., 2014). Excess or deficiency of any of these essential nutrients disrupt either the reproductive or vegetative growth cycles in crops and/or alter the composition of other nutrients (Marschner, 1995; Fageria, 2001; Fuqua et al., 2005). Therefore, an adequate supply of plant nutrients is essential for achieving potential haskap bush growth, development, and berry yield (Fageria, 2001; Pormale et al., 2009). Plant nutrient requirement is largely dependent on crop species, cultivar or genotypic variations within species (Kowalenko, 2005). In addition to this, soil factors such as type, nutrient composition, temperature, and moisture influence soil nutrient supply to the crop (Mylavarapu, 2010) and tissue nutrient status (Dresler et al., 2015). These factors also influence plant growth, productivity and fruit quality (Khan et al., 2011). Buskienė and Uselis (2008) stated that only fertile soils with a regulated pH and optimal mineral nutrient supply can ensure adequate yield and quality.

There has not been enough study done to examine what fertility regime is best for haskap production in North America (Bors, 2009). Berries of the Canadian haskap varieties are still relatively small and low quality, and bushes are low yielding as compared to Russian and Japanese varieties (Hummer, 2006). Soil fertility status may be a significant constraint in haskap production (Iheshiulo et al. 2018a). The crop performance and yield might also be increased by various management practices including modifying the crop growing environment. Plastic mulches have been used by farmers for weed control, early maturity, higher crop yields, higher water and fertilizer use efficiency, and to modify plant growing environment (Monette and Stewart, 1987; Lamont et al., 2004). Quality and yield of fruits can be influenced by the light environment which is determined by the amount of sunlight reaching crop surface and light reflected from coloured plastic mulches (Kasperbauer et al., 2001). Black plastic tends to have higher heating effects above and below the soil surface while white plastic reflects much of visible light to the environment and could provide lower soil and environmental temperature (Hammermeister, 2016). Therefore, white plastic is suitable for crops that require low temperature during hot summer periods and black plastic is popular for the cool season. The light reflected from coloured plastic mulches is involved in reproductive development such as formation of flower buds (Bernier and Périlleux, 2005; Yáñez et al., 2009). Shiukhy et al. (2015) found that size, weight, and phytochemical contents of strawberry under coloured plastic mulches were significantly higher compared to conventional practices (no mulch treatment). The use of proper types of plastic mulches is important for achieving potential crop growth, yield, and fruit quality. Although the effects of black (commercial) plastic mulch and soil amendments on fruit crops have been studied, the effects of different colours of plastic mulch and soil amendment on haskap have received less research attention, especially in Nova Scotia haskap orchards.

Cultivated haskap begins to produce commercial berry yields after four years of growth and reach maximum bearing after eight years (Plekhanova, 1992). There is a need of to maximize the haskap growth in the early years to get potential yield. There is a positive correlation between haskap berry yields and plant size (Plekhanova, 1992) which suggests that management practices that increase bush size might result in increased yield. In blackcurrant, improvement in vegetative growth resulted in a higher berry yield in the early years (Rhodes 1986; McCarthy and Stoker, 1988). However, the effect of plastic mulch colours and fertility amendments on haskap performance has not been optimized yet.

1.2 Project Goal

Haskap growers are facing increasing difficulties in achieving commercial profitability. Greater costs and reducing returns are forcing them to optimize their management operations. Higher yield and fruit quality are needed to address this situation. Therefore, the aim of this project is to identify optimal sustainable management practices for haskap production by determining the impacts of plastic mulch colours in combination with fertility amendments on haskap flowering, growth, yield and total soluble solids (TSS). This study will further help in understanding the best cultural practices for haskap production.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction to Haskap

The genus *Lonicera* belongs to fruiting shrubs found in temperate regions of the world, with the highest diversity occurring in Eastern and Central Asia. Haskap is also known as blue honeysuckle, honeyberry, or haskap in Canada and other countries like Poland, Japan, and Russia (Hummer et al., 2012). Haskap is an edible berry, native to Siberia and northeastern Asia and is generally found in low-lying wet areas or mountainous areas (Bors et al., 2012). Historically, the berries of haskap were harvested from wild plants where the edible form occurred, mainly in Hokkaido, Japan and Russia (Hummer et al., 2012). In these regions, these berries have long been attributed to have high medicinal and nutritional values. Haskap is well adapted for cultivation in northern areas of Canada as it is winter hardy, withstanding as low as -46°C (Imanishi et al., 2000; Plekhanova, 2000).

The first study which identified *L. caerulea* as a horticulture plant in Russia was made in 1894 and efforts to domesticate it started in 1913 (Hummer, 2006). Since the beginning of the 1950s, breeding programs have focused mainly on the development of new cultivars with characteristics of higher yield, larger berries, improved nutritional levels, and better berry quality. In North America, the breeding program started at Oregon State University in the late 1990s; at present, the largest breeding program is situated at the University of Saskatchewan, Canada (Bors, 2009) which uses several germplasms from within Canada as well as Japan and Russia (Bors et al., 2012).

Haskap has been gaining popularity in North America due to the health benefits of its berries which are a rich source of vitamins and antioxidants (Chaovanalikit et al., 2004; Rupasinghe et al., 2012). Haskap was considered "the elixir of life" in Japan (Thompson, 2006) due to its therapeutic properties. Haskap is a good source of phytochemicals like anthocyanins, vitamin C, ascorbic acid, polyphenolics, and other antioxidants which are two to three times higher than other berries known to have health benefits like wild blueberry (Arus and Kask, 2007; Rupasinghe et al., 2012). Experiments related to cancer prevention and cardiovascular benefits of haskap have started at Dalhousie University, Canada, as well as one looking at whether haskap can help manage Type 2 diabetes. Haskap is believed to have therapeutic properties and it has been used traditionally by Japanese Ainu aborigines to treat malaria, decrease the risk of heart attack and the effects of glaucoma and gastrointestinal diseases, inhibition of anemia and slowing the aging process (Thompson, 2006; Rupasinghe et al., 2018). Haskap berries have been used for confectionaries, beverages, baked goods, and jams. Also, the emergence of a whole industry extracting antioxidants from fruits to be used in cosmetics, food supplements and fortified foods (Castañeda-Ovando et al., 2009), has given the haskap industry a better grounding to thrive among other industries.

2.2 Morphology and Phenology of Haskap

Haskap is a deciduous shrub, growing up to 2 m or more in height with a diameter of up to 2 m when fully mature (Hummer et al., 2012). Leaves are opposite, simple, oval to elongate, and 3 to 5 cm in length (Hummer et al., 2012). A well-established haskap bush may have roots extending 1.5 m in diameter (Marková, 2001). There is great variability in wild genotypes of *L. caerulea* in terms of size and growth habit (Marková, 2001). There are different cultivars of haskap available in Canada (Berry Blue, Indigo Gem, Tundra, Borealis, Indigo Series, Indigo Treat, Indigo Yum, Honeybee, Aurora, Boreal Beast, Boreal Beauty, Boreal Blizzard) that vary according to bush size, growth rate, disease susceptibility, yield, ripening timing, and berry shape, size, and quality characteristics. Indigo Gem grows faster and upright as compared to most others.

Moreover, it is characterized by smaller and tangier berries and is relatively productive (Lauritzen, 2015).

Haskap inflorescence is unique in structure from other species of *Lonicera* (Rheder, 1909). Flowers are usually borne in pairs at the lowest one to four nodes of the shoots produced from the previous year's growth (Hummer et al., 2012). Haskap flowers are well-adapted to a temperature as low as -7° C (Hummer et al., 2012). Flowers are borne in two-flowered cymes (typical of *Lonicera*) but the ovaries of both flowers are surrounded by fused bracteoles creating what seems like an outer skin enclosing two interior berries. The ovaries and the fused bracteoles develop into a single fruit; thus, a haskap "berry" is a single compound fruit from the pollination of two flowers (Frier et al., 2016). Fruit set will occur even if only one of the two flowers of an inflorescence is pollinated, however, it results in smaller fruit with fewer seeds (Frier et al., 2016). Flowers are self-incompatible and need a compatible pollinator for fruit set (Plekhanova, 2000). In addition to this, flowers are perfect (five anthers and a single stigma), small, pale yellow to cream in colour, about 2 cm in length, tubular with flared lobes.

2.3 Management of Haskap

Documented information on management practices for haskap in Canada is scarce and growers are still exploring different techniques to get higher growth and yields. Site selection for haskap cultivation mostly follows general recommendations for small fruit crop production. Soil for haskap production should be well-drained and it can tolerate a wide range of soil pH (pH 5.0 – 8.0) (Ontario Ministry of Agriculture, Food and Rural Affairs - OMAFRA, 2012). While haskap is considered to be shade tolerant, it should be grown in full sun for maximum fruit production (Bors, 2009).

For optimum performance, haskap requires good soil moisture conditions and moderately warm summer temperatures. Spacing for planting should be one meter for a continuous hedge and 1.5m for individual uncrowded plants (Cheverie, 2013). The row spacing can be adjusted according to the farm machinery used for harvesting and weed management. Bors (2009) and OMAFRA (2012) recommended plant spacing of 1.3 m for haskap, which is suited for hand harvest of an individual bush. However, most research on haskap to date has focused on the breeding programme in North America. Very little is known about fertilizer needs, and existing studies have been entirely focused in Asia and Europe (Bożek, 2007; Thompson, 2006). Skupień et al. (2007) identified haskap as having “low” fertilizer requirements in Poland. In addition to this, Ochmian et al. (2010) reported that the nitrogen (N) fertilizer application of 40 kg ha^{-1} in a year is a normal practice for haskap production in Poland. It is noted that the plant does not have a heavy requirement for N, and excess application may hinder root growth (Belosohova and Belosohov, 2010; Tremblay et al., 2019). Currently, OMAFRA (2012) recommends yearly applications of 30-50 kg N ha^{-1} for haskap production in Ontario, however no information is supplied as to the basis for this recommendation. A recent study has been done in Nova Scotia by Iheshiulo et al. (2018a) to diagnose the variability in haskap plant characteristics with respect to leaf tissue and soil nutrient status. Furthermore, the study has examined soil nutrient sufficiency ranges and nutrient ratios for leaf tissue nutrients concentrations in haskap cv. Indigo Gem. In the same paper, the sufficiency ranges for haskap cv. Indigo Gem leaf tissues were estimated to be about 2.23%-2.96% for nitrogen (N), 0.22%-0.28% for phosphorous (P), 0.84%-1.32% for potassium (K), 1.63%-2.10% for calcium (Ca), 0.14%-0.50% for magnesium (Mg). The study found that 53% of Nova Scotia haskap fields are deficient in N and P, whereas 58% were deficient in K. However, 42% of fields were diagnosed with adequate leaf N content and many of the fields were diagnosed as having adequate leaf Ca and Mg (Iheshiulo et al., 2018a). Deficiency in leaf K and P were recognized as potentially important factors restricting haskap growth and development in Nova Scotia. In addition, it was observed that haskap could have higher Mg and Ca requirements than highbush blueberry and blackcurrant.

Haskap is self-incompatible requiring cross-pollination, however, insects may be scarce when it blooms due to early flowering (late April to May) (Bors et al., 2012; Hummer et al., 2012). Access of pollinators to flowers helps in higher fruit production while fruits of isolated haskap plants are lighter and smaller with a smaller number of seeds (Bożek, 2012). Pollinator plants may be placed within a row, usually one in every eight to ten plants, or as every third row in the orchard. Bumble bees are found to be the most efficient pollinators of haskap, but honeybees appear to be effective pollinators in Nova Scotia (Olmstead, 2019).

Haskap is reported in many research papers as resistant to pests and disease (Sabitov, 1986; Thompson and Barney, 2007; Korobkova, 2009). In Canada, a few pests and diseases are known to impact haskap bushes. Bushes can suffer powdery mildew in the regions of high relative humidity (OMAFRA, 2012). The leaves of haskap can get damaged from sun scald but usually after harvest. Small birds in the field are the major damaging pest to haskap berries, knocking the berries to the ground or eating them (Bors, 2012).

Weeds are a major problem in haskap production (annual and perennial). There are several weeds management trials going on at the Faculty of Agriculture, Dalhousie University, Nova Scotia and by fruit growers in Nova Scotia. Weed management strategies depend on many factors; soil fertility status and nature of the weeds might be most important. Other factors may include the availability of labor, size of the field to be managed, and whether the field is under organic or conventional production practices. There are several pre-emergent and post-emergent herbicides available for conventional fruit practice. Weed management practices in organic fruit production include tillage, dead organic mulches (straws, woodchips, compost, straw, and many others), manufactured synthetic mulches (plastic or fabric), living mulches, surface treatment as organic herbicides (acetic acid and plant oils) and heat (Hammermeister, 2016). Each weed control method has its advantages and disadvantages; it must nurture the soil biology while minimizing competition from other vegetation. The use of organic mulches to suppress weeds in fruit production is attracting more attention due to environmental issues and cost with regard to use of herbicides. Organic mulches minimize the evaporative water loss from the soil surface, thus conserving soil moisture and are known to buffer soil temperature (Forge et al., 2003). Hay and straw are known to increase organic matter and K levels in the soil (Hammermeister, 2016). Compost provides supplemental nutrients to the soil but requires routine weeding due to easy establishment of weeds under compost. However, organic weed practices are often time consuming and may be less effective than chemical herbicide control. Dead organic mulches, wood chips, sawdust, or straw, reduce the availability of other nutrients due to high carbon content (Hammermeister, 2016). Wood chips induced N deficiency in blackcurrant because of N immobilization (Larsson, 1997).

Manufactured mulches, such as plastic, fabric, woven or perforated, can be used in a wide range of conditions and can last for a longer period (plastic usually 5 to 10 years), providing the material is not damaged. However, manufactured mulches have a high initial cost. Manufactured mulches vary greatly in their properties including light reflectance, water infiltration, temperature effects, moisture conservation, and durability (Hammermeister, 2016). Plastic mulch covers are a relatively cheap investment in commercial fruit production and an effective tool for organic weed control (Hammermeister, 2016). Plastic mulches help in providing long-term soil cover at a minimal cost and lasting several years. It may be difficult to add fertility amendments under plastic mulches, except through the planting hole or by fertigation, over several years, soil may become impoverished if not amended (Forge et al., 2003). The application of plastic mulches is difficult after planting of the orchard. Plastic mulches may also be ineffective in controlling weeds in the planting hole. The plastic material can also get damaged due to weed growth, especially under reflective mulches. There has been no research investigated haskap response to different colours of plastic mulch yet.

At present, there are no recommended pruning regimes for haskap that are based on scientific research. However, pruning methods for other small fruit production might be applicable for haskap. Haskap Canada suggested the best time for pruning is late winter or early spring. It is also mentioned not to prune more than 25% of the bush in any year (Lauritzen et al., 2015).

Most of the varieties are ready to harvest from the last week of June to the last week of July or the first week of August depending on the cultivar, weather conditions, management practices and region (Bors, 2016). Productive orchards may begin producing commercially viable yields after three to four years of planting; this can also vary according to climate, soil fertility and management practices and be significantly delayed under poor growing conditions. Haskap berry yield starts from a few kg bush^{-1} in the third or fourth year to about 7 kg bush^{-1} after six or seven years, when the bush is well-established (Larson, 2009) but in the Maritime region of Canada, berry yields have been lower than 1 kg bush^{-1} for most plants up to four years old and sometimes older than that.

Haskap berries obtain full size four weeks after flowering when they start to turn purple and are bluish coloured when fully ripe after six or seven weeks (Bors, 2016). The average Growing Degree Days (GDD) required for full fruit development was 473.6 with a deviation of

67.5 at base temperature 5°C in Saskatchewan, Canada (Dawson, 2017). The shape of the fruit is variable from oval to long and thin with size ranges from 0.3 g to rarely over 2.0 g depending on the climatic conditions, genotype and management practices (Hummer et al., 2012).

2.4 Essential Nutrients for Fruit Production and Their Role

Plant nutrients are required in a balanced proportion for plants to grow and develop flowers and fruits. There are 17 essential nutrients required for plant growth and development. Plants cannot complete their life cycle when one or more essential element is deficient (Fuqua et al., 2005). Therefore, the amount of nutrients required by plants and the time of application of fertilizers are key components of an effective soil fertility management plan (Mattson and van Iersel, 2011). Crop nutrient requirements in fruit crops depend on new biomass production in reproductive and vegetative tissues, the amount of nutrients reallocated from existing plant tissues, and the nutrients required for the development of new tissue (Bañados et al., 2012). For instance, mature bushes of highbush blueberry (seven or eight years old plantings on the field) require 160-180 kg N ha^{-1}, while young bushes (three to four years old) need 60-68 kg N ha^{-1} (Hanson and Hancock 1996; Hart et al., 2006).

2.4.1 Macronutrients

Nitrogen is a predominant nutrient that stimulates plant and root growth, yield, and affects fruit quality (Yadong et al., 2009). It is an integral component of chlorophyll pigment and plant compounds like amino acids, proteins, flavins, nucleic acids and others. Nitrogen is very important for photosynthate use within plants. The highest demand of N for fruit production is in early spring and bloom at the growth and development stages (Patrick et al., 2004). Spring application of N in grapes enhances vegetative growth, while the application of N in summer enhances vegetative and reproductive growth the following year (Christensen et al., 1994). Nitrogen fertilization should be based on soil types, plant age, initial soil nutrient status, tissue N concentration, plant vigour and irrigation practices (Barney et al, 2007). Nitrogen may be absorbed more efficiently when its application matches with periods of high demand by crop (Patrick et al., 2004).

Nitrogen limitations can reduce crop growth, yield, and fruit quality by affecting berry size, fruit-set, and maturity of the crop (Bell and Robson 1999; Schreiner et al., 2013). Deficiency symptoms of N may include chlorosis of leaves, stunted growth, and reduction in flowering and crop yield. In highbush blueberry, applying 50 kg N ha^{-1} $year^{-1}$ resulted in more growth and yield than no N fertilizer during establishment (Bryla et al., 2012), while excessive supply, 100 kg N ha^{-1} $year^{-1}$ or greater, in young plants lead to salt stress and plant mortality (Bañados et al., 2012). The higher rates of N fertilizer than recommended can be unfavourable for crop yield and may stimulate vigorous vegetative growth which can cause lodging of the crop (Barney et al., 2007). Excessive N supply results in excessive grapevine vigour and poor berry quality due to increased shading of clusters, thus negatively affecting colour development (Spayd et al., 2002). In addition to this, an increased rate of N application increases the risk of insects and diseases attack on crop (Chen et al., 2007; Abro et al., 2012). Therefore, the appropriate amount of fertilizer applied is very important to support crop growth potential and yield. The sufficiency ranges for haskap leaf N concentration has been recommended in between 2.23 to 2.96% (Iheshiulo et al., 2018a).

Soil and plant status of N can be determined by several tools including nutrient analysis (e.g. soil, fruit, and leaf analysis) and observation of plant performance. Methods of nutrient analysis like Kjeldahl digestion are destructive and time consuming. Whereas assessment of plant N status in the field by optical properties of leaves (includes greenness of leaves and chlorophyll content) has been reported to be faster and non-destructive (Muñoz-Huerta et al., 2013). Chlorophyll content of haskap leaves has been found to have a strong linear relationship with leaf

N status (Iheshiulo et al., 2018a). However, plant growth stage, soil moisture, cultivars, diseases, position of sampled leaves and deficiency or imbalances of nutrients other than N can affect chlorophyll readings (Muñoz-Huerta et al., 2013).

Phosphorous (P), a key component of cellular compounds and is the second most important nutrient element after N (Holford, 1997). Phosphorous is an essential component of adenosine triphosphate (ATP) which helps in nutrients uptake and movement within the plants (Weil and Brady, 2017). Phosphorous is also important for seed germination, root development, and fruit maturity and quality (NSDA, 2010). Phosphorous nutrient helps to enhance several aspects of crop physiology, including photosynthesis, flowering, N fixation, fruiting, and maturation (Weil and Brady, 2017). In vines, P plays an important role in the transfer of energy as it is needed for photosynthesis and transferring of sugar to starch and vice-versa (Winkler et al., 1974; Spectrum Analytic, 2011a). An increase in P levels significantly increased berry weight, yield (in combination with high N), and shoot length of organic blackcurrant (Hobson, 2012).

Deficiency of P results in stunted plant growth and root system, reduced flower production, premature defoliation, and delayed maturity (NSDA, 2010; Winkler et al., 1974). Leaves with purplish-red margins indicating P deficiency were observed in apple and pear (Raese, 2002). Plants deficient in P are heavily stressed during drought (NSDA, 2010). Phosphorous deficiency in strawberry resulted in slow growth and reduction in fruit size (Domoto, 2011; Trejo-Téllez and Gómez-Merino, 2014). Deficiency in leaf P was identified as an important factor limiting haskap bush growth in Nova Scotia (Iheshiulo et al., 2018a). Iheshiulo et al. (2018b) suggested a soil sufficiency range of 232-360 kg ha^{-1} for P_2O_5 in haskap based on leaf tissue nutrient content. However, the rate of P applied to the crop is largely dependent on the soil test reports. Whereas the sufficiency range for haskap leaf P concentration has been recommended in between 0.22 to 0.28% (Iheshiulo et al., 2018a).

When P content is high in soil, it may reduce the availability of micro-nutrients like Zn, Cu, Fe or Mn in grapes (Skinner and Matthews, 1989). Phosphorous uptake by the plants is affected by soil pH as maximum availability of P is near to 6.5. However, it is also influenced by the availability of and interaction with other soil nutrients (May and Pritts 1993; Trejo-Téllez and Gómez-Merino 2014; Havlin et al., 2014; Iheshiulo et al., 2018a). Sometimes fertilizer P application results in a buildup of insoluble P due to fixation in the soil (Weil and Brady, 2017) and poor solubility of native P in soil (Dubey, 1997). Phosphorous is taken up in relatively small amounts by lowbush blueberry plants over time and had no significant effect on plant growth and yield components over the four years of study (Eaton et al., 1997); thus, low application of P fertilizer may be sufficient to meet the crop requirement (Townsend and Hall., 1970).

Potassium (K) is the third essential element most likely to limit crop productivity. It is essential for protein synthesis, photosynthesis, starch formation, and translocation of sugars (Weil and Brady, 2017). It is required for crop growth, cell elongation, longevity, and over-wintering ability (NSDA, 2010; Trejo-Téllez and Gómez-Merino 2014). It activates the enzymes and helps in maintaining cell turgor pressure. Potassium is a mobile element in plants, thus important for the transport of assimilates, solutes, and synthesis of polyphenols (Fageria, 2001). Potassium is very important to increase the ability of the plants to tolerate stressful conditions (Weil and Brady, 2017). It also influences grape quality by affecting acid balance in juice, colour, and pH of the wine (Spectrum Analytic, 2011b). Hobson (2012) found that increased levels of leaf K concentration in organic blackcurrant increased berry weight and shoot length. The type of soil texture affects the movement of K in soils as its movement decreases with an increase in clay content, and it can easily leach out in sandy soils (Rosen and Eliason, 1996). The uptake of K appears to be proportional to vegetative growth and reaching its maximum in early summer (Johnson and Uriu, 1989). Potassium accumulates considerably in fruit tissues and appears to play an important role in fruit development since it has been shown that K deficient trees have dramatically reduced fruit size (Johnson and Uriu, 1989).

Iheshiulo et al. (2018a) found that haskap growth and leaf size are strongly related to soil and leaf K, suggesting it may be a key factor hindering bush growth and development in Nova Scotia haskap farms. Potassium deficiency in the fruit crops may be due to higher levels of Mg in the soils as Mg competes with K in plant uptake. On low K soils, a heavy crop load can induce deficiency symptoms (Johnson and Uriu, 1989). When there is an inadequate supply of K to plant, it is translocated from older tissues to younger ones. Therefore, its symptoms usually first appear on older leaves. Leaves margins become brown on the margins and spread inwards as scorch develops. Deficiency can also be characterized by cupping of leaves (Weil and Brady, 2017).

The deficiency of K decreased photosynthesis of leaves, which lowers carbohydrates content in fruits (Faust, 1989) and makes the plant more susceptible to disease pathogens (NSDA, 2010). In grapes, insufficient supply of K leads to low yield, poor vine growth, delayed ripening, and low concentration of K in fruits (Conradie and Saayman, 1989; Kudo et al., 1998; Schreiner et al., 2013). There may also be an antagonistic effect of excessive application of K because of nutrient imbalances as higher application of K may reduce the uptake of P, Ca, and Mg (Iheshiulo et al., 2018a). Iheshiulo et al. (2018b) suggested a soil sufficiency range of 270-580 kg ha^{-1} for K_2O in haskap based on leaf tissue nutrient content, whereas the sufficiency range for leaf K concentration has been recommended in between 0.84 to 1.32% (Iheshiulo et al., 2018a).

Calcium (Ca) is essential for cell elongation, division, protein synthesis, and carbohydrate movements in plants (Plaster, 2009; Havlin et al., 2014). It is a key nutrient for fruit firmness as it is needed for cell wall formation and thickness (Easterwood, 2002; Trejo-Téllez and Gómez-Merino, 2014). It also helps in absorbing other nutrients and their translocation into other parts of plants (Easterwood, 2002). Calcium has been found to improve post-harvest shelf life of fruits and significantly increases plant growth by activating growth regulating enzyme system (Motamedi et al., 2013). Calcium uptake is adversely affected by the factors inhibiting root growth because Ca is only taken by the region just behind the tip of a growing root. An increase in Ca levels may inhibit the availability and uptake of K and Mg (Iheshiulo et al., 2018a). Deficiency of Ca results in reduced shoot growth, twig dieback and defoliation. Deficiency symptoms first appear in young leaves due to its immobility (Johnson and Uriu, 1989). In apple and pear, low Ca concentration causes physiological disorders like biter pit and pre-mature fruit fall (Brunetto et al., 2015). Iheshiulo et al. (2018b) suggested sufficiency range of 2700-4000 kg ha^{-1} for Ca in haskap based on leaf tissue nutrient content. The sufficiency ranges for haskap leaf Ca concentration has been recommended in between 1.63 to 2.10% (Iheshiulo et al., 2018a).

Magnesium (Mg) is an important component of the chlorophyll molecule, thus it is required to collect solar energy for plant growth and production through photosynthesis (Trejo-Téllez and Gómez-Merino, 2014). Magnesium helps in protein formation and cell division. Magnesium is an essential nutrient for P metabolism, activation of several enzyme systems, and plant respiration (Marschner, 1995; Plaster, 2009; Trejo-Téllez and Gómez-Merino, 2014). Iheshiulo et al. (2018a) found a negative relationship of leaf Mg concentration with leaf Ca and K in haskap. High levels of Mg in leaf tissues may results in K deficiency, thus, affecting plant growth. Hall et al. (2011) reported Mg deficiency in grapes when high levels of exchangeable K are present in soil. The availability of Mg to plants is related to soil pH. Low pH values decrease Mg availability to plants and at high values, excessive Ca might have an overriding influence on Mg uptake by plant roots (Fageria, 2001). The higher concentration of Mg also decreases the uptake of K (Johnson and Uriu, 1989; Fageria, 2001; Iheshiulo et al., 2018a). Deficiency of Mg is usually caused by high K in soils rather than naturally low levels. Deficiency of Mg results in interveinal chlorosis, browning, premature leaf and fruit drops, and burning of leaf blades in apple (Trejo-Téllez and Gómez-Merino, 2014). Iheshiulo et al. (2018b) suggested sufficiency range of 245-380 kg ha^{-1} of soil Mg for haskap based on leaf tissue nutrient content. The sufficiency range for leaf Mg concentration has been recommended in between 0.14 to 0.50% (Iheshiulo et al., 2018a).

2.4.2 Micronutrients

The role of micronutrients in crop production has been increasing for a few years due to better nutrient analysis techniques and understanding of their function in the plants. These micronutrients are iron (Fe), chlorine (Cl), boron (B), zinc (Zn), copper (Cu), nickel (Ni), manganese (Mn), and molybdenum (Mo). Micronutrients also play an important role in crop growth and production. The micronutrients have important physiological roles in the synthesis of protein, photosynthesis, chlorophyll synthesis, transport of carbohydrates, reproduction process of some plants, and in the production of growth hormones (Trejo-Téllez and Gómez-Merino 2014). Iron is a key component of several enzymes associated with N reduction and fixation, energy transfer, and lignin formation. Boron is also important for crop root growth (Havlin et al., 2014) and flower pollination (Plaster, 2009). Boron deficiency leads to small fruits of poor quality due to declined pollen production and reduced flower size (Domoto, 2011).

2.5 Plastic Mulches and their Effects

Technologies have been developing to improve the efficiency of crop production since the beginning of civilization. The use of plastic mulch is one of these technologies that has been used since the 1950s to control weeds and alter plant microenvironment (Emmert, 1957; Lamont et al., 2004). Plastic mulch creates a favourable soil-water-plant relationship. The use of plastic mulches promotes earlier harvests, increases high-quality production, and is more efficient in the use of water and fertilizer nutrients (Lamont et al., 2004). Some other key benefits of plastic mulch in crop production include retaining soil moisture, minimizing erosion, reducing weed population, managing pest and disease incidence, altering thermodynamic environment, and ultimately improving fruit yields and quality (Bextine et al., 2001; Gough, 2001; Lamont, 2005).

Mulches modify the plant microenvironment by changing soil temperature, modifying soil energy balance, retaining soil moisture, and altering wavelengths and quantity of the light reflected to plant canopy which affects plant growth, development and yield (Voorhees et al., 1981; Csizinszky et al., 1995; Tarara, 2000). There are three basic non-radiative components to radiant energy at the soil surface: conduction of heat into the ground; the flux of latent heat in connection with evaporation from the soil; and convection of sensible heat into the layer of air between the soil surface and the mulch. Plant height, number and length of main roots, fresh and dry weights of roots as well as the number of flowers were significantly higher in tomatoes grown on mulch as compared to bare soil (Hasan et al., 2005). Gupta and Acharya (1993) observed increased root mass under black polyethylene mulch which was attributed to the resultant increase in soil temperature and nutrient uptake. Niu et al. (2004) concluded that improved productivity was related to increased root dry weight under mulches and larger rooting systems resulted in greater ability to take up water and nutrients that led to higher grain yield with mulched wheat. However, these above-mentioned benefits of plastic mulches depend on their thermal and optical properties, which are greatly affected by different colours. The colour of plastic can be associated with its energy trapping abilities. Dark bodies, such as black plastic mulches, absorb incident solar radiation and increases the soil temperature, and provides a warmer environment for crops due to its thermal and radiation properties (Lamont et al., 2004). Black plastic mulch may contribute to loss of heat to an aerial environment of a sparse crop due to convection as compared to white plastic mulch. White plastic mulches reflect much of the incident light and provide cooler soil and microenvironment as compared to black plastic mulch (Shinde, 1997).

Plants under plastic mulch have high relative growth and early harvesting than bare soil due to higher soil temperature (Lamont et al., 2004). The earlier a grower can produce a quality crop under plastic mulch system, the greater the chance the farmers will get higher price for his produce in the market due to less competitor. Earlier harvesting of the product is not only profitable in outperforming competitors, but it also helps to mature the crop before the outbreak of diseases and pests. The use of plastic mulch helped to bring earlier ripening in tomatoes (Decoteau et al., 1989; Brown et al., 1992). In addition to this, black plastic mulch also reduced the number of days for the eggplant to flower (Valdez-Fields et al., 2002). However, early flowering due to higher soil temperature by plastic mulches would not be economical in every crop. In early flowering crops like strawberry and haskap, increased soil temperature would result in early bud-break and reduces the number of days to flowers. But there will be lower fruit set and yield as pollinators would be less active at the earlier timing during cooler air temperature (Tuell and Isaacs, 2010; Kehrberger and Holzschuh, 2019).

However, there are some issues associated with the use of plastic mulches in crop production. Removing the plastic mulch from the field is the biggest disadvantage. The tucks or sides of the mulch buried in the soil remain intact and do not naturally degrade as plant materials mulches do. There would be emergence of weeds through the planting hole under plastic mulch which is difficult to control. The damage to the plastic mulch also results in weed growth. Plastic mulches reduce the ability to apply soil amendments and water application provided drip irrigation system installed under the mulch surface. The long term-use of plastic mulch deteriorates the soil quality by increasing the biological degradation of litter and soil organic matter (OM), which has recently been discussed as a trigger to rapid depletion of soil nutrients in general and carbon stocks in particular (Steinmetz et al., 2016).

2.5.1 Plant Aboveground Microenvironment

Modification of plant microenvironment with the uses of different coloured plastic mulches and their effects on crop growth and development are largely understudied. Plastic mulch has a direct influence on plant microclimate by changing the radiation budget (reflectivity versus absorption) of the soil surface and by decreasing evaporation (Shiukhy et al., 2015). The aboveground environment under plastic mulch is influenced by transpiration, radiation, and photobiology. Andris and Crisosto (1996) reported that reflective mulch materials reflected about 52% of the incident light, which resulted in significant increase in light in apples compared with no mulch. A reflected plastic surface results in an alteration in plant light environment and may change photosynthetic rate and/or light stimulus of morphogenic development. The use of reflective mulches increases photosynthetically active radiation (PAR) and absorption of photosynthetic photon flux in the lower part of apple canopy (Moreshet et al., 1975; Mancinelli, 1985; Miller and Greene, 2003). Reflected mulches stimulate the synthesis capacity of anthocyanin as anthocyanin biosynthesis in fruits is a light dependent process because enzymes involved in the biosynthetic pathway are light-inducible (Iglesias and Alegre, 2009). This technique improved fruit colouration and total soluble solids (TSS) in apples (Miller and Greene, 2003) and grapes (Todic et al., 2008). Reflective mulches have been found to increase fruit colour and yield of peach (Layne et al., 2001) and apples (Blanke, 2008; Iglesias and Alegre, 2009; Meinhold et al., 2011).

2.5.2 Soil Temperature

The heating properties of plastic "absorptivity, transmittance and reflectivity" have a direct influence on soil temperatures under the plastic mulch (Schales and Sheldrake, 1966). Increase in soil temperature increases crop productivity grown on plastic mulch (Grubinger et al., 1993; Davis, 1994). The uptake and translocation of soil nutrients are greatly influenced by the change in root zone temperature. The higher soil temperature under plastic mulch as compared to unmulched soil stimulates plant growth by increasing nutrient and water uptake as well as root growth and morphology (Tindall et al., 1990). At constant soil moisture, a decrease in temperature results in a decrease in uptake of nutrients and water by roots. Voth and Bringhurst (1962) found that strawberry yield is directly related to soil temperature. An increase in soil temperature under plastic mulch during the cold season might have increased sapota yield due to the increased microbial activity which transforms nutrients (Tiwari et al., 2014). An increase in soil temperature from minimum to optimum helps to stimulate root growth (Díaz-Pérez and Batal, 2002). No data are available for optimum root zone temperature for haskap production in North America till now.

The colour of plastic mulch creates many variations that have an effect on soil temperature. Black coloured plastic mulch is the most common to be used in fruit and vegetable production and can cause a significant increase in soil temperature (Wein et al., 1993). The unmulched soil loses its energy gained from solar radiation due to forced convection and radiation to the atmosphere. However, black coloured plastic mulches absorb most of the incoming solar radiation and prevent its loss to the atmosphere. The trapped thermal energy by black plastic mulches is transmitted to the soil by conduction, which increases the soil temperature. Black plastic mulches also reradiate some of the absorbed energy in the form of long wavelength infrared radiation and heats the atmosphere near the mulch surface. Soil temperature under black plastic mulch is generally 2.8°C higher at a 5 cm depth and 1.7°C higher at 10 cm depth compared to unmulched soil (Lamont, 1999). This increased soil temperature might help in early fruit maturing through early flower opening (Tarara, 2000).

White plastic is generally preferred during the summer growing period when the temperature is high because it can maintain soil moisture while having cooler soil temperatures. White mulches result in a slight decrease in soil temperature, about 0.4°C at a 10 cm depth as compared to bare soil (Ham et al., 1993) because they reflect most of the incident radiation into the atmosphere. This phenomenon leads to decrease in root-zone temperature that is at or below the temperature found on the bare soil surface (Decoteau et al., 1989; Ham et al., 1993). These mulches are useful when any reduction in soil temperature during summer periods is beneficial for the potential growth of the crop but too low soil temperature than optimum might have an adverse effect on the growth and development of plants: slower cell maturation and cell division, and reduced nutrient uptake and water uptake (Nielson, 1974).

Temperature rise under plastic mulch is also influenced by heat conductivity. There must be close contact between the soil surface and plastic mulch to raise soil temperature. If mulch has been laid down snugly, the space for air between soil and plastic is reduced and the heat is transferred by conduction, which leads to a rise in soil temperature (Tarara, 2000). If there is an air gap between plastic mulch and soil surface, most of the heat trapped will be lost to the atmosphere through planting hole. Other aspects to consider in the effectiveness of plastic mulches to heat soil are the amount of rainfall, the type of soil, the thickness and width of the mulch, soil moisture, intensity of the sunlight, humidity of the surrounding environment, and the plant canopy. However, the soil temperature is approximately equal among different mulch colours when the mulch surface is covered by plant canopy (Lamont et al., 2004).

2.5.3 Soil Moisture

Water is essential for any crop to get maximum yield potential. Plastic mulch has the ability to maintain soil moisture for improved crop growth and development (Lamont et al., 2004). Numerous studies have shown that soils under plastic mulch have higher moisture than unmulched soil (Gough, 2001; Alam and Zimmerman, 2003). Liakatas et al. (1986) documented that plastic mulches conserve soil moisture by restricting evaporation as mulches protect the soil from direct sun exposure. Plastic mulch stops raindrop splash and hence reducing soil crust formation. The mulch allows longer infiltration time by slowing surface runoff. Precipitation cannot penetrate the plastic, entering only by transfer from the branches down the stem and through the stem hole in the plastic. Thus, although plastic reduces water loss it also reduces precipitation benefits, drip irrigation is often necessary to maintain adequate soil moisture. As a result of increased and more consistent soil moisture under irrigated conditions, plants are less likely to suffer from water stress and plastic reduces water losses compared with irrigation without plastic. Tiwari et al. (1998) found a 40% reduction in water application requirement with the use of black plastic mulch in conjunction with drip irrigation. Besides this, conservation of soil moisture with the plastic mulch enhanced vegetative growth and yield components by improving the availability of N for plants (Kirknak et al., 2003), soil biological activity and, physical and chemical properties of the soil (Cooper, 1973; Chung, 1987; Aliudin, 1986).

2.5.4 Weed Control

Weeds in crops compete for nutrients, light, and moisture. Plastic mulch reduces the weed population in fruit crops in comparison to bare soil (Hammermeister, 2016). Plastic mulches have been widely used in organic crop production to reduce the use of chemical herbicides. Unlike bare soil, plastic mulch reduces the amount of light in the photosynthetically active range of 400-700 nm from reaching the soil beneath the plastic mulch. Reducing PAR beneath the plastic mulch helps to prevent the growth and limit the germination of weeds (Ngouajio and Ernest, 2005). Weed control with plastic mulch has been found by a wide array of researchers (Clarkson and Frazier, 1957; Rahman and Shadeque, 1999; Saikia et al., 1997; Lamont et al., 2004). It is this reduction in weeds that helps make the use of plastic mulch more economical for the grower by reducing fertilizer needs, water application, and use of chemical herbicides.

2.5.5 Fruit Quality

Fruit quality can be determined by several parameters, such as fruit size, berry size, titratable acidity, TSS, dry matter content, skin colour, taste, and nutritional value of fruits (Taylor, 2015). Coloured plastic mulch has been shown to have significant effects on fruit quality (Casierra-Posada et al., 2011). Coventry et al. (2005) found that reflective mulch increased soluble solids (Brix), total phenolics, flavanols, and anthocyanins content in grapes. Reflective mulch was also found to increase soluble solids in plums (Kim et al., 2008). Kasperbauer and Loughrin (2004) observed that altering the colour of plastic mulch can alter anthocyanin content in butterbeans. Strawberries that ripened over red plastic mulch were significantly higher in aroma and flavour compounds (Loughrin and Kasperbauer, 2002). Black plastic produces a better quality of fruits in strawberry as compare to other plastic colours (Bunty and Sharma, 2010). Soil temperature under raised beds, covered with plastic mulch, increases faster in the spring and excess water drains out from beds into row middles, thus keeping the plants drier. It helps in preventing deterioration in fruit quality from contact between harvestable portions of the plants and wet soil or standing water (Lamont et al., 2004).

2.6 Environmental Factors Affecting Crop Yield

Nova Scotia has a modified continental climate where the broad temperature range experienced over a year is moderated by ocean temperature. Fluctuations in crop yield have been linked to periodic weather events such as early warming followed by a cold period, frost damage in the spring, and prevailing weather conditions (Hall et al., 1979; Olson and Eaton, 2001). While unstable climate conditions were not a good predictor of provincial yields of lowbush blueberry, localized weather conditions were weakly correlated with regional yields (Hall et al., 1982). For example, in lowbush blueberry, heavy rainfall during bloom correlated with a decrease in yield in Newfoundland, while sunshine during pollination and warm temperatures in the month after pollination correlated with increased yield in Nova Scotia (Hall et al., 1982). This suggests a link between microclimate and yields in local fields.

2.7 Fruit Maturity

Haskap cultivars have not been adequately studied for growing in Nova Scotia. It is difficult to visually assess haskap fruit ripeness because there is no visual distinction between the early and late stages of fruit ripening. Identification and selection of a reliable maturity indicator are important for growers to determine optimum harvesting time. The TSS measurement is commonly used to facilitate the assessment of fruit maturity in many berry crops as it increases with fruit ripening. The TSS is an approximate estimate of sugar content (Simson and Straus, 2010) and it is measured using a refractometer (Thompson, 2003) as °Brix. There is no literature citing Brix ranges for haskap cultivars in Canada, but harvesting is not recommended below 12°Brix due to sour flavour. Although Brix increases with ripening, thereby improving flavour, berries become soft and easily damaged when ripened. Uneven ripening of berries results in some berries reaching full ripeness and dropping off the bush while others may not be ripe (Taiz and Zeiger, 2010). The TSS values vary among cultivars because of variations in the timing and uniformity of berry ripening. This means that the timing of berry harvest must be optimized considering the yield loss vs. quality trade-off. The haskap is commonly harvested between 12-14°Brix depending on post-harvest use. OMAFRA (2012) outlined that haskap berry with a reading above 13°Brix may have average to good flavour.

2.8 Conclusion

Plastic mulch colour may affect haskap by altering the timing of flowering and pollination success, affecting rooting environment, altering light reflectance into the canopy and canopy temperature. Optimum soil fertility management under plastic mulch with drip irrigation has not been studied for haskap in Canada till now. To achieve the optimum performance of haskap, efficient nutrient management is critical to stimulate not only plant growth and establishment, but also fruit production and responses to environmental indicators. Many recently established orchards are not achieving their growth and yield potential. Mechanisms of improving productivity in these established but still young orchards are needed using a systematic approach that integrates different practices under real growing conditions. Therefore, the aim of this research is to evaluate the combined effects of plastic mulch colour and fertility amendments on haskap growth and yield. A thorough study of different levels of fertilizers under white and black coloured plastic mulches would benefit growers by helping to refine management practices.

2.9 Objectives and Hypotheses

Objective 1: To assess haskap growth, yield, leaf nutrients, and total soluble solids in response to plastic mulch colours and fertility amendments.

Hypothesis: High fertility amendments with White plastic mulch will increase the vegetative growth, yield, and total soluble solids of haskap compared to low fertility amendments and Black plastic mulch.

Objective 2: To evaluate the effect of plastic mulch colours and fertility amendments on flowering and fruit set of haskap.

Hypothesis: High fertility amendments with White plastic mulch will delay flower initiation and have higher number of flower pairs and percentage fruit set.

Objective 3: To evaluate the effect of plastic mulch colours on the growing environment (soil temperature, soil moisture, canopy air temperature, and photosynthetically active radiation) of haskap.

Hypothesis: Soil temperature will be higher under Black plastic treatment than White plastic. Moreover, Black plastic will increase the canopy air temperature and decrease soil moisture status. The White plastic mulch will increase the reflection of photosynthetically active radiation towards the canopy.

CHAPTER 3. MATERIALS AND METHODS

The whole study was divided into two experiments. Experiment 1 addressed objective 1 and 2, and experiment 2 addressed objective 3. The site and treated bushes were the same for both the experiments, but the design of the experiment was different.

3.1 Experiment 1: Objective 1 and 2. Haskap Plant Performance

3.1.1 Site and Climate

The research was carried out from June 2017 to August 2018 on a commercial haskap farm in Belmont, Nova Scotia at approximately 45°25'54" N and 63°23'05" W. The site was hay land for several years before cultivation in 2013. The soil was mapped as an Orthic Humo-Feric Podzol with a well-drained sandy loam texture (Webb et al., 1991). The site was planted with several varieties of haskap arranged in rows with row spacing of about 4 m and plant spacing of 1 m in the row. The orchard was planted in 2014 with wood mulch applied for weed control and moisture conservation. There was no pruning of the haskap done before the beginning of this experiment. No further amendments were applied after the planting year. Baseline soil fertility samples were taken in June 2017 from four rows of cv. Indigo Gem and were sent to the Nova Scotia Agricultural Laboratory Services for standard soil test analysis including Mehlich III mineral nutrient concentrations (Mehlich, 1984) (Table 1). Mean monthly air temperature and rainfall were collected from the nearest available Environment Canada weather station located at Debert, Nova Scotia (45°26'12.9"N, 63°27'23.3"W, the elevation of 37.50 m) in 2018. Growing degree days (GDD_5) are the most common measure to link climate-influenced growing season temperature, to crop developmental processes such as flowering time, crop maturity, or berry ripeness (Carlson and Hancock, 1991). Growing degree days are the measure of heat accumulation over time, and were calculated using the Baskerville-Emin method in which base temperature is subtracted from the average of daily maximum and minimum air temperature (Baskerville-Emin, 1969). The GDD_5 were summed by total number of degree above a base temperature of 5°C from April 2018 through fruit development stages. The base temperature is the lowest temperature at which plants are physiologically active (Carlson and Hancock, 1991). A base temperature of 5°C was chosen as hakap is adapted to cool growing conditions (Dawson, 2017).

3.1.2 Experimental Design

In this experiment, a randomized two-factor split-plot design with three Blocks was applied. The whole-plot factor in design was fertility amendments with three levels (i.e. Control, Low and High) and the subplot factor was plastic mulch colour with two levels (i.e. White and Black). The mulches were selected due to differences in their optical (reflection) and thermal (absorption and transmission) effects on incoming radiation and thus, potentially resulting in a difference in soil temperature under the different mulches and change in light reflectance in bush canopy. The whole-plot consisted of one row that was randomly assigned to one of the three levels of fertilizer application and subplots within whole-plot were randomly assigned to plastic mulch colour. There was a total of 18 subplots, with each subplot having nine plants with two plants buffer between each subplot.

3.1.3 Treatments

To study the effects of plastic mulch colour and fertility amendment on haskap flowering, growth and yield; nine rows of three-year-old haskap cv. Indigo Gem were selected. The whole-plot factor included three levels of nitrogen, phosphorous, potassium (N-P-K, respectively) blend fertilizer: Control (unamended), Low and High. The Low treatment applied of 7.5 g N $bush^{-1}$ $year^{-1}$, 10 g P_2O_5 $bush^{-1}$ $year^{-1}$, 7.5 g K_2O $bush^{-1}$ $year^{-1}$ and High rate that was double the Low rate. In 2017, it was first assumed that the fertilizer nutrients would be applied through drip irrigation system (fertigation). However, the plan could not accomplish due to not fully installation of the system until the next year (2018). This delayed the fertilizer application of 2017. Then, plant based liquid fertilizers were applied in the second week of July 2017 as EZ-GRO's Nature's Nectar N, P, and K solutions which were organically permitted. Fertilizers were mixed in water and applied at the base of each bush by hand in mid-July 2017. Approximately 2 liters (L) of water per plant, was applied at a weekly interval starting from the second week of July to the second week of August in 2017.

In the second year of the experiment (2018), fertigation was done in June because there was no need for irrigation in April and May due to optimum rainfall. In nutshell, these reasons also pushed back the timing of fertilizer applications in 2018. The approximately same amount of nutrients (as rates of 2017), split over four weekly applications, were applied through weekly fertigation of synthetic fertilizer in the form of $20N:20P_2O_5:20K_2O$ (4% ammoniacal N, 6% nitrate N, 10% urea N, 20% available phosphate, and 20% soluble potash) in June. Fertigation was done once a week over the whole month of June. The bushes of Control treatment received only water by the drip irrigation system at the same amount of fertigation. The Low and High treatments both received the same fertilizer amounts by fertigation, but the High treatment received supplemental fertilizer nutrients by hand as follows. One barrel of about 166.4 L mixed with 33 kg of 20:20:20 fertilizer was injected to 3447 bushes each week. About 48.27 ml of fertilizer solution (as mixed in the barrel) was applied to each plant resulting in an additional 1.91 g of N, P_2O_5, and K_2O applied per plant weekly for four weeks (total of 7.64 g of N, P_2O_5, and K_2O over four weeks). The distribution of fertilizer level and water was controlled by gate valves that supplied each row, and the duration of flow was adjusted to ensure the correct amount of nutrients was applied.

The subplot factor included two colours of plastic mulch: White and Black. There was no uncovered treatment of plastic mulch. The plastic mulches (0.025 mm thick; Dubois Agrinovation Inc., St-Rémi, QC, Canada) were laid down in the third week of July 2017 after fertilization. Plastic was applied at the bushes by cutting a slit in the plastic and pulling it under the bushes. The plastic was 60-70 cm wide in total with edges buried 10-15 cm deep in tilled soil adjacent to the row. Weeds were removed by hand in between the bushes before plastic was laid down.

3.1.4 Data Collection

3.1.4.1 Objective 1: Haskap Growth, Yield, Leaf Nutrients, and Total Soluble Solids in Response to Plastic Mulch Colours and Fertility Amendments.

3.1.4.1.1 Plant Physiological Parameters and Observations

Bush volume was determined in the second week of August 2017 and 2018 as the cylindrical volume formula (3.142 × height × (width × 0.5) × (breadth × 0.5)) as per Erb et al. (1993), and modified by Hobson (2012) to estimate the bush volume of blackcurrant. The height of each bush was measured from the base of the bush to the highest tip, and the width was measured from one bush lateral branches ending to the opposite lateral branches' apex, using a meter stick. The change in growth was calculated as bush growth factor = $\frac{2018\ volume - 2017\ volume}{2017\ volume}$. The growth factor is an indication of a change in bush size with larger values representing a large proportional change in the volume of the bush.

Leaf chlorophyll content, a key indicator of plant health (Wood et al., 1993), was measured using a soil plant analysis development (SPAD) meter (SPAD 502 plus, Spectrum Technologies, Inc., USA) during the first week of July 2018. The leaves of a bush for SPAD readings were selected randomly but did not include leaves from the first and second nodes from the tip of the branch. Each reading consisted of measurements from five bushes from a subplot and five measurements were taken from each bush.

Leaf chlorophyll fluorescence, the maximum quantum yield of photosystem II (PSII) estimated by Fv/Fm ratio, was determined with chlorophyll fluorometer (OS30p+, Opti-Sciences, Inc., USA) after the leaves were dark-adapted for 20 minutes with dark adapting clips as mentioned by Schreiber et al. (1986) in sunny days. Four bushes were randomly selected for chlorophyll fluorescence in each subplot and 10 green leaves from different sides of each bush were clipped.

3.1.4.1.2 Leaf Sampling

Leaf samples were collected from each subplot in the last week of June 2018 for leaf size measurement and tissue analysis. Samples were selected from new stem growth, taking about 20 leaves from each bush two to three nodes down from the tip of the branch. The leaves were scanned to calculate average leaf size with the help of Compueye Leaf and Symptom Area software (Bakr, 2005). After measuring average leaf size, sampled leaves were collected in paper bags and oven-dried for 48 hours at 60ºC before submission to the Nova Scotia Analytical lab (Truro, NS) for leaf tissue analysis. The samples were digested with sulfuric-acid-hydrogen-peroxide (Wolf, 1982) and analyzed for macro and micro-nutrients by inductively coupled plasma spectrometer (ICP, Thermo Fisher Scientific Inc., Waltham, MA).

3.1.4.1.3 Yield and Yield Components

The yield was determined at two harvest times in 2018: Early (when approximately 90% of the berries had turned blue, July 4) and Late (seven days after Early harvest). Four out of the nine bushes in a subplot were harvested by hands at the Early harvest timing and the remaining five bushes were harvested at the Late timing. Yield and 100-berry-weight (HBW) were determined for an individual bush. All the berries including green berries were picked by hand at the Early harvest, and berries that had dropped on the ground before Late harvest time were not included in Late harvest picking. Berries were weighed immediately to have a total yield per bush.

Berry weight was determined by counting 300 random berries from the sample and weighing them to allow calculation of HBW ($\frac{weight\ of\ 300\ berries\ (g)}{3}$). The average berry weight was calculated from HBW and was used, in addition to total bush yield, to estimate the total number of berries per bush ($\frac{Yield\ (g)}{average\ berry\ weight\ (g)}$).

3.1.4.1.4 Total Soluble Solids

The total soluble solids (TSS) were measured at both harvest times. Samples of approximately 100 berries were placed in a freezer bag and stored in a cooler with cold packs for transport and were stored in a fridge (4°C) overnight. The TSS was determined the following day from fresh samples by handheld refractometer (Atago Co. Ltd., JP) and expressed as °Brix. Berries were squeezed and extracted juice was filtered through three layers of cheesecloth. The refractometer's prism was cleaned with deionized water and wiped with tissue and then two or three drops of haskap juice were placed on it and noted the value. The average of four readings per sample was recorded in °Brix.

3.1.4.2 Objective 2: Effect of Plastic Mulch Colours and Fertility Amendments on Flowering and Fruit Set of Haskap.

In the first week of March 2018, one branch was selected randomly from the top 1/3rd of each bush with length ranging from 13.0 to 19.8 cm and marked with flagging tape for detailed observations of the flowering parameters. Bushes of all 18 experimental units were marked for this study and average values were taken from each experimental unit for all flowering observations.

The total initial length of woody material (including secondary twigs) on the flagged branch was measured in the last week of March and again, the total length with new growth (final branch length) was measured in August 2018. The initial and final length of flagged branch consisted of length of main branch and its secondary branches. The change in the growth of flagged branch (growth factor) was calculated as growth factor = $\frac{final\ length - initial\ length}{initial\ length}$. The timing of flower initiation was recorded for each subplot as the first date that at least seven bushes out of nine had an open flower.

From the date of first flower initiation, the number of opened flower pairs were counted every three or four days until at least seven of the nine bushes, from each subplot, were without flowers. In the end, the total number of flower pairs was counted by adding flower numbers of each visit done after three days as Frier (2016) found that haskap flowers bloomed for an average of three days. The total number of flower pairs and green berries were standardized to 20 cm initial branch length for the analysis because the initial length was not consistent for flagged branch. The total duration of flowering was also recorded. The flower and berry number observations were counted on the main flagged branch as well as on its secondary branches.

The number of green berries on each branch was recorded on 15 June 2018 to determine the percentage fruit set = $\frac{total\ number\ of\ green\ berries}{total\ number\ of\ flower\ pairs} \times 100$. The percentage berry drop at Early harvest was assessed from the number of green berries. The four out of nine bushes of each subplot, which were assigned for yield analysis of objective 1, were accounted to calculate percentage berry drop from green berries to ripe berries at Early harvest.

3.1.5 Statistical Analysis

A split-plot design with three Blocks was conducted to examine the effects of the fertility amendments and plastic mulch colours on haskap performance. Fertility was considered as the whole-plot factor, with plastic mulch colour as a subplot factor. The two factors of interest were assigned as fixed factors, and Block (a combination of three Blocks) was considered as a random factor in the analysis. The initial bush size was used as covariates in the analysis of bush growth, berry yield, HBW, calculated number of berries per bush, and TSS. The yield data and TSS were taken at two different times, the most appropriate covariance structure among compound symmetry (CS), unstructured (UN) and auto-regressive order (1) (AR-1) was determined using the AIC and BIC values. Analysis of variance (ANOVA) was performed for each response variable using the Mixed Procedure of SAS (9.2, SAS Institute Inc, Cary, NC). The ANOVA without repeated measures was used for the analysis of leaf nutrient concentrations, leaf chlorophyll content and chlorophyll fluorescence, and flowering observations. Multiple means comparison (MMC) was done for significant (P-value $\leq$ 0.05) effects by comparing the least square means of the corresponding treatment combinations using the lsmeans statement of Proc Mixed with pdiff option to produce P-values for all pairwise differences. The validity of constant variance and normal distribution of the error terms for all response variables were verified by examining the residuals as mentioned in Montgomery (2017). Correlation analysis was conducted to determine the relationships between variables.

3.2 Experiment 2: Objective 3. Effect of Plastic Mulch Colours on Growing Environment of Haskap.

3.2.1 Site and Climate

The site and climate for this experiment were the same as described in experiment one.

3.2.2 Experimental design

The effects of plastic mulch colour on the growing environment were determined by measuring soil temperature and moisture, and canopy air temperature. The experiment was a randomized complete block design with two plastic mulch colour treatments (White and Black) applied in each of six Blocks resulting in a total of 12 experimental units. For soil temperature and moisture, six rows of haskap were selected from the plots prepared in experiment one with each row considered to be one Block; White and Black plots were randomly assigned within each Block. The fertility level for the Black and White treatment was controlled by blocking the experimental design and was not included as a dependent variable.

3.2.3 Data Collection

The decagon 5TM soil probes and Em50 ECH_2O data loggers (METER Group Inc., USA) were installed in the second week of August 2017 to measure soil temperature and moisture until August 2018 but only from spring 2018 to August 2018 data were analysed. One soil temperature/moisture probe was buried at the mid-point between two plants in each plot to a depth of 15 cm deep. Readings were taken at hourly intervals by the data loggers.

Soil degree days (SDD) were calculated by using the average method (Baskerville and Emin, 1969). The base temperature of 5°C was used in this experiment as haskap adapted to cool growing environment (Dawson, 2017).

In-canopy air temperature was recorded with Watchdog B-series Button Data loggers (Spectrum Technologies, Inc.). Data loggers were placed in a disposable foam cup, having holes to circulate the air, and attached to a branch of the bush at about 30 cm above the mulch surface. Due to equipment limitations, only one Block was measured at a time in only five Bocks; three probes were placed in each treatment plot to account for variability within a plot. The probes remained in the plot for one week with temperature data collected on an hourly basis. At the end of the week, data was downloaded, and the probes were transferred to the next Block. In this manner, data was collected over a five-week period beginning the first week of July and ending the first week of August, with one week of data for each Block.

The reflected photosynthetically active radiation (PAR) (μmol m^{-2} s^{-1}) from White and Black plastic mulch was measured using AccuPAR LP-80 ceptometer (METER Group, Inc. USA) attached with 86.5 cm long PAR sensors probe. Upwardly reflected PAR from plastic mulch was measured at a height of about 20 cm in the middle of canopy by facing probe PAR sensors downward. The length of probe sensors used for measuring PAR was adjusted according to the bush width. The measurement was taken on a clear sunny day at 11:00, 12:00, 13:00, and 14:00 hrs on five bushes from each coloured mulch with five replicates. The reflected PAR was also measured from Black and White plastic laying on the soil with no surrounding vegetation as a baseline measurement. The amount of PAR reflected by mulches was expressed as percentage of incident PAR.

3.2.4 Statistical Analysis

Since soil temperature and moisture were measured over a long time, the data were analyzed as repeated measures in a randomized complete block design with six Blocks. The ANOVA was completed using the Mixed Procedure of SAS (9.2, SAS Institute Inc, Cary, NC), and further multiple means comparison (MMC) was done for significant (P-value ≤ 0.05) effects by comparing the least square means of the corresponding treatment combinations using the lsmeans statement of Proc Mixed with pdiff option to produce P-values for all pairwise differences. Letter groupings were completed using 5% level of significance for the main effects, and 1% level of significance for interaction effects to reduce the over-inflation of Type 1 experiment wise error rate (large number of means is being compared). Independence assumption on error term is likely to be violated in RMA, so the appropriate covariance structure (a type of dependence) was examined by the Akaike Information Criterion and incorporated in the model.

However, analysis of variance of randomized complete block design with five Blocks was used to analyze the effect of plastic mulch colour on canopy air temperature in haskap. The statistical analysis was done in Minitab 18 (Minitab Inc., State College, PA). Since there are only two colours of plastic mulch, significant difference between treatments was detected by the ANOVA. The validity of constant variance and normal distribution of the error terms for all response variables were verified by examining the residuals as described in Montgomery (2017).

Table 1. Descriptive statistics of soil pH, soil organic matter (OM) and soil available nutrients taken in June 2017 from experiment site growing Indigo Gem at depth of 0-15 cm, and ranges of sufficient soil nutrients (P_2O_5, K_2O, Ca, Mg) status based on leaf tissue nutrient content suggested by Iheshiulo et al. (2018b).

Parameter(s)	Units	Mean	Sufficiency Range
OM	%	5.50	n.d.[1]
pH	-	6.33	n.d.
CEC	meq100 g^{-1}	14.13	n.d.
P_2O_5	kg ha^{-1}	1190.25	232-360
K_2O	kg ha^{-1}	478.00	270-580
Ca	kg ha^{-1}	3976.00	2700-4000
Mg	kg ha^{-1}	301.25	245-380
Na	kg ha^{-1}	22.00	n.d.
S	kg ha^{-1}	59.50	n.d.
Al	ppm	1477.50	n.d.
B	ppm	0.66	n.d.
Cu	ppm	2.00	n.d.
Fe	ppm	196.75	n.d.
Mn	ppm	28.75	n.d.
Zn	ppm	5.62	n.d.

[1]n.d. – not determined.

CHAPTER 4. RESULTS

4.1 Experiment 1: Objective 1. Haskap Growth, Yield, Leaf Nutrients, and Total Soluble Solids in Response to Plastic Mulch Colours and Fertility Amendments.

4.1.1 Climate

Total precipitation and air temperature relative to long-term averages (1996-2017) for the growing season (April-August) in 2017 and 2018 are displayed in Table **2**. Throughout the growing season, precipitation differed between years. In 2017, May had the highest precipitation, while June was the wettest month of 2018. The total precipitation from April to August in 2017 was lower than in 2018. In both years, July was the hottest month with an average temperature of 18.1°C in 2017 and 20.4°C in 2018.

April, June and July 2017 were notably drier than long-term averages. In 2018, the mean monthly temperature was lower than the long-term averages during flowering and fruit setting (April to June) and higher in July and August; mean monthly precipitation was considerably higher than long-term averages in April and June, but lower in July and August. The precipitation during flowering (May 2018) was slightly higher relative to long-term averages. In 2018, June was the coolest and the wettest month relative to long-term averages.

4.1.2 Yield and Yield Components

No statistically significant differences in the yield were detected among the fertility amendments (P=0.77), plastic mulches (P=0.21), and harvest times (P=0.58) (Table 3); no interaction effects were observed (P=0.41) (Table 3). The accumulation of GDD_5 from April 1, 2018 to Early harvest was 465 GDD_5 and 550 GDD_5 to Late harvest. However, the GDD_5 required for berry development from peak flowering (May 15, 2018) to Early harvest was 388 GDD_5 and to Late harvest was 454 GDD_5. The average yield by experimental unit ranged from 385.9 to 433.1

g bush^{-1} with the highest in the Low treatment and lowest in the Control treatment (Table 3), however, yield ranged from <100 to >700 g per individual bush. High variability in initial bush size in each plot was found to be a significant ($P<0.05$) source of variation for the analysis of harvested yield and yield components (Table 3). There was a significant positive linear relationship between Early harvest yield and initial bush size (R^2=0.55 P=0.001) (Figure 1) and calculated number of berries per bush (R^2=0.91; P=0.001) (Figure 2) but it was weakly negative with growth factor (R^2=0.17; P=0.002) (Figure 3).

The 100-berry-weight (HBW) was significantly influenced by plastic mulch colour (P=0.01) and harvest time ($P<0.01$) as shown in Table 3. The bushes with Black plastic had significantly higher average HBW (117.5 g 100 berries^{-1}) than White plastic (110.1 g 100 berries^{-1}). However, there was no significant difference in berry yield among plastic mulches. In the case of harvest time, mean HBW increased significantly from 70.7 g 100 berries^{-1} at Early harvest to 156.9 g 100 berries^{-1} at Late harvest. No significant correlation was found between HBW and yield (data not presented).

No significant difference was found in the calculated number of berries per bush among the fertilizer levels (P=0.52) and plastic mulch colours (P=0.55) treatments. However, the number was significantly influenced by harvest time ($P<0.01$). The mean berry number per bush decreased by 57% from Early harvest (594) to Late harvest (258). Bushes with larger initial size had the highest number of berries (R^2=0.50; $P<0.05$) (Figure 4).

4.1.3 Bush Growth and Leaf Size

The fertility amendments and plastic mulch colours had no significant effect (P=0.67 and P=0.65, respectively) on the final bush size (Table 4). Moreover, no significant interaction between the main effects was observed (P=0.20). Although means were not significantly different, bushes with High fertilizer application had about 12.5% larger bushes (0.45 m^3) than the Control (0.40 m^3) and Low (0.41 m^3) treatments. In terms of plastic mulch, the average bush size for Black and White was the same (0.42 m^3). The initial bush size was a significant covariate (P=0.007) in the final bush size analysis.

There was no significant effect of the plastic mulch (P=0.60) and fertilizer application (P=0.38) on the growth factor. However, the growth factor was highest in the High fertilizer treatment (1.98) and the lowest in Control (1.60). There was a negative significant correlation between the growth factor and initial bush size for individual bush (R^2=0.20; P<0.05) (Figure 5a).

Leaf size increased slightly with fertilizer levels from 11.14 cm^2 in the Control to 11.92 cm^2 in the High fertilizer treatment, but differences were not significant (P>0.05). There was also no significant difference observed in leaf size between White and Black plastic.

4.1.4 Leaf Chlorophyll Content and Chlorophyll Fluorescence

The chlorophyll content (SPAD) of leaves was significantly (P<0.01) affected by plastic mulch colours, whereas fertility amendments had no significant effect (P=0.23) on readings (Table 4). The SPAD readings in plots with White plastic were significantly higher than those for Black plastic (Table 5). There was no correlation found between SPAD readings and leaf N content (R^2=0.04, P=0.402) (data not shown).

Plastic mulch had significant (P=0.05) effect on leaf chlorophyll fluorescence (Fv/Fm) but no effect was observed for fertility amendments (P=0.92) or the interaction between main effects (Table 4). Bushes under Black plastic had a significantly higher Fv/Fm ratio than White plastic (Table 5).

4.1.5 Leaf Tissue Nutrients

Leaf nitrogen (N) content had a significant response to fertility amendments (P=0.05) and plastic mulch colours (P=0.02) (Table 6) but there was no significant interaction effect (P=0.59). Leaf N concentration was significantly greater in the High fertilizer treatment than the Control but not the Low treatment. Black plastic had significantly higher leaf N than White plastic (Table 7).

Black plastic had significantly higher leaf phosphorous (P) and iron (Fe) concentration than White plastic (Table 7). No statistically significant differences (P>0.05) were detected in leaf potassium (K), calcium (Ca), magnesium (Mg), boron (B), zinc (Zn), and manganese (Mn) contents of leaf tissues among levels of fertility amendment and between plastic mulch treatments.

4.1.6 Total Soluble Solids

The total soluble solids (TSS) content was significantly (P<0.01) affected by harvest time (Table 3). The TSS value increased significantly from 11.67°Brix at Early harvest to 13.63°Brix at Late harvest. The fertility amendments, plastic mulch colours, and their interaction with harvest time had no significant effect on TSS. In the context of yield and yield components, the concentration of TSS in the berry was found to be significantly (P=0.02) influenced by covariate initial bush size.

4.2 Experiment 1: Objective 2. Effect of Plastic Mulch Colours and Fertility Amendments on Flowering and Fruit Set of Haskap.

4.2.1 Flowering and Fruit Set

Based on phenological observations for this objective, bud break in haskap cv. Indigo Gem started on April 28 in 2018. There was no difference observed in the onset of flowering between fertility amendments and plastic mulch colour (Figure 6). The counting of open flowers lasted for almost 30 days, starting from 3 May (GDD_5 56) to 4 June (GDD_5 199) in all the treatments with no difference at the end of the flowering period (Figure 6). Fertility amendment and plastic mulch colour had no significant effect on the total duration of flowering period. The number of flower pairs started increasing after the first date of counting and peaked on 15 and 18 May followed by a gradual decline in all the treatments (Figure 6). The total GDD_5 reached 110 at the peak flowering period from the beginning of April 2018.

The standardized total number of flower pairs on the flagged branch was not significantly affected by fertility amendments and plastic mulch colour (Table 8). The average standardized number of flower pairs was highest in the Low fertilizer level and the lowest in Control treatment, however, there was no significant difference. In terms of plastic mulch colour, the difference in standardized total number of flower pairs was only 0.9 with high under Black plastic.

The standardized number of green berries on the flagged branch was not significantly affected by fertility amendments and plastic mulch colours (Table 8). However, the average standardized number of green berries in treatments was 17.5. The fertility amendments and plastic mulch colours also had no significant effect on the percentage fruit set (Table 8). The average percentage of fruit set was more than 50%, ranged from 54.3% to 81.6%.

There was no significant effect of fertility amendments and plastic mulch colours on the percentage berry drop of flagged branch at Early harvest (Table 8). The average drop of berries from flagged branches at the Early harvest was only 15.7%. In addition to this, it was observed that the maximum loss (about 30%) in berry number occurred during the fruit setting stage than fruit maturity.

Neither fertility amendments nor plastic mulch colours had a significant effect ($P>0.1$) on new growth of flagged branches (Table 8). For plastic mulch, the overall mean branch growth and growth factor were about 60 cm and 2.7, respectively. The High fertilizer treatment had slightly higher growth and the growth factor of flagged branch than the Control and Low treatments. However, the differences were not statistically significant (Table 8).

4.3 Experiment 2: Objective 3. Effect of Plastic Mulch Colours on Growing Environment of Haskap.

4.3.1 Soil Temperature and Moisture

A significant difference in average growing season soil temperature between Black and White plastic was observed where Black was 1.4°C warmer than White. The weekly mean soil temperature for Black and White plastic ranged from 1.1 to 24.8°C over the growing season 2018 (April – August) with a maximum of 24.8 and 24.1℃ in Black and White, respectively (Figure 7). In general, soil temperatures were lowest in the first week of April but steadily increased as the season progressed and reached a peak in the first week of August. The temperature remained steady from the second week of May to the second week of June. White plastic was found to be significantly ($P<0.05$) cooler through the spring to the third week of June, but after that, no significant differences were found. After the third week of August, soil temperature started declining in both plastics but the difference between Black and White began increasing (data not shown). Over the growing season, the difference in soil temperature between Black and White plastic was larger in April and May (about 2.15℃), whereas in June, July, and August, the difference was approximately 1.43℃. The soil degree days (SDD) was significantly ($P<0.01$) higher in Black (1679.6) than White (1515.8) plastic mulch (Figure 9). In addition to this, the weekly average air temperature remained lower than the soil temperature of both plastics throughout the growing season. The maximum and minimum soil temperature graph followed the same pattern of average soil temperature (Figure 8). The maximum temperature under Black and

White plastic reached in the first week of August. The average difference in maximum soil temperature between Black and White was 2.1℃.

There was no significant effect of plastic mulch on soil moisture under plastic mulches. The average soil moisture over the growing season was about the same in Black (0.21 m^3/m^3) and White plastic (0.20 m^3/m^3). The difference in soil moisture between Black and White plastic was larger (0.05 m^3/m^3) in April 2018, but it was negligible afterward (Figure 10).

4.3.2 Canopy Air Temperature and Photosynthetic Active Radiation

The canopy air temperature in haskap was not significantly (P=0.33) affected by the plastic mulch. The mean canopy temperature for Black and White treatments was 24.26 and 24.16°C, respectively.

As a baseline measure, it was determined that White and Black plastic laying flat on the soil with no surrounding vegetation, reflected about 53.3% and 6.4% of photosynthetically active radiation (PAR), respectively at a 20 cm height; bare soil reflected only 7.1% of PAR. In the haskap plantation, plastic mulch colour had a significant effect (P<0.01) on reflected PAR where Black plastic reflected the least PAR (4.9%) and White reflected the most (33.7%). In terms of time of day, 11:00 and 12:00 hrs reflected more amount of PAR than 13:00 and 14:00 hrs.

Table 2. Mean monthly air temperature (°C), total monthly precipitation (mm), and total monthly growing degree days with base temperature 18°C (GDD) relative to long-term mean for 1996-2017 from the nearest Environment Canada weather station.[1]

	Site Year 2017			Site Year 2018			Long-Term Mean	
Month	**Temperature**	**Precipitation**	**GDD**	**Temperature**	**Precipitation**	**GDD**	**Temperature**	**Precipitation**
April	4.9	31.7	100.9	3.4	104.0	77.1	4.1	82.2
May	10.1	135.0	185.6	9.5	93.9	185.3	10.2	86.1
June	14.6	62.0	293.6	12.5	175.7	241.0	14.9	100.6
July	18.1	66.1	402.4	20.4	47.4	478.9	18.8	84.3
August	17.6	109.0	390.4	20.1	64.8	467.6	18.3	94.6
Total	-	403.8	1372.9	-	485.8	1449.9	-	447.8

[1]Temperature, precipitation, and GDD were obtained from the nearby Environmental Canada weather station located at Debert, Nova Scotia (45°25'00.000"N, 63°28'00.000"W, elevation of 37.50 m). Data for year 2002 and 2003 in long-term means was missing.

Table 3. Mean yield (g bush^{-1}), 100-berry weight (g, HBW), calculated number of berries per bush (Berry Number), and total soluble solids (TSS, °Brix) obtained from the effects of fertility amendment, plastic mulch, and harvest time. Note: only main effects are shown in the table due to non-significant effect of treatment interactions.[1,2]

Source of Variation	Yield	HBW	Berry Number	TSS
Fertilizer level				
Control	385.9	113.5	396	12.8
Low	433.1	111.2	459	12.8
High	401.5	116.7	422	12.4
P-value	0.77	0.54	0.52	0.29
Plastic mulch				
Black	415.2	117.5a	413	12.6
White	398.5	110.1b	438	12.7
P-value	0.21	**0.01**	0.55	0.34
Harvest time				
Early	401.5	70.7b	594a	11.7b
Late	412.2	156.9a	258b	13.6a
P-value	0.58	**<0.01**	**<0.01**	**<0.01**
Initial bush size (Covariate)				
P-value	<0.01	0.04	<0.01	0.02

[1]For each factor, means within a column followed by the same letter are not significantly different at α=0.05.

[2]P-values of significant main effect (P-values ≤0.05) are shown in bold.

Table 4. Analysis of variance (ANOVA) P-values showing the significance of the main and the interaction effects of fertility amendment and plastic mulch on leaf chlorophyll content (SPAD), chlorophyll fluorescence (Fv/Fm), and final bush size. Note: Covariate was not used in the analysis of SPAD and chlorophyll fluorescence.

Source of Variation	SPAD	Fv/Fm	Final Bush Size
Fertilizer level (F)	0.23	0.92	0.67
Plastic mulch (P)	**<0.01**[1]	**0.05**	0.65
F X P	0.53	0.14	0.20
Initial bush size[2]	-	-	<0.01

[1]P-values of significant effect (P-values ≤0.05) that require multiple means comparison are shown in bold.

[2]P-value for the covariate "Initial bush size" in the analysis of Bush size.

Table 5. Mean leaf chlorophyll content (SPAD) and chlorophyll fluorescence (Fv/Fm) obtained from the effect of plastic mulch.[1]

Treatment	SPAD	Fv/Fm
Plastic mulch		
Black	38.5b	0.7967a
White	39.8a	0.7926b

[1]Means within a column followed by the same letter are not significantly different at α=0.05.

Table 6. Analysis of variance (ANOVA) P-values showing the significance of the main and the interaction effects of fertility amendment and plastic mulch on the leaf tissue nutrients.[1]

Source of Variation	N	P	K	Ca	Mg	B	Cu	Fe	Zn	Mn
Fertilizer level (F)	**0.05**	0.56	0.11	0.08	0.18	0.39	0.40	0.23	0.21	0.36
Plastic mulch (P)	**0.02**	**0.01**	0.07	0.88	0.22	0.27	0.06	**0.03**	0.57	0.55
F X P	0.59	0.18	0.77	0.94	0.53	0.66	0.06	0.91	0.91	0.51

[1]P-values of significant effect (P-values≤0.05) that require multiple means comparison are shown in bold.

Table 7. Mean leaf N, P, K, Ca, Mg, Cu, and Fe obtained from the significant effect of fertility amendment, plastic mulch, and the combination of fertility amendment and plastic mulch.[1]

Source of Variation	N	P	K	Ca	Mg	Cu	Fe
	--------------------------------(%)--------------------------					-------(ppm)-------	
Fertilizer level							
Control	2.50b	0.20	0.83	1.83	0.30	7.89	62.12
Low	2.56ab	0.20	1.03	1.55	0.26	6.99	64.31
High	2.72a	0.20	1.01	1.54	0.20	7.13	68.00
Plastic mulch							
Black	2.65a	0.21a	1.00	1.64	0.27	7.56	66.44a
White	2.54b	0.19b	0.92	1.64	0.29	7.11	63.18b
Fertilizer level X Plastic mulch							
Control-black	2.58	0.21	0.89	1.82	0.29	8.24	63.81
Control-white	2.42	0.19	0.77	1.83	0.31	7.54	60.43
Low-black	2.59	0.21	1.07	1.55	0.24	7.65	65.62
Low-white	2.52	0.20	0.99	1.55	0.27	6.32	62.99
High-black	2.78	0.20	1.04	1.55	0.28	6.79	69.90
High-white	2.67	0.20	0.99	1.53	0.27	7.48	66.11
Sufficiency ranges[2]	2.2-3.0	0.22-0.28	0.8-1.3	1.6-2.1	0.14-0.50	-	-

[1]For each factor or combination, means within a column followed by the same letter are not significantly different at α=0.05.

[2]Sufficiency ranges for leaf N, P, K, Ca, Mg in haskap cv. Indigo Gem derived from Iheshiulo et al. (2018a).

Table 8. Mean total number of flower pairs and green berries per 20 per cm of initial branch length, percentage fruit set, percentage berry drop at Early harvest, net new branch growth (Final length–initial length, cm), and growth factor of flagged branch obtained from the effects of fertility amendment and plastic mulch. Note: only main effects are shown in the table due to non-significant effect of treatment interaction.[1]

Source of Variation	Total Flower Pairs	Green Berries	Fruit Set	Berry Drop at Early Harvest	Net New Branch Growth	Branch Growth Factor
	---Number per 20 cm of initial branch length---		-----------%-----------		cm	
Fertilizer level						
Control	24.2	16.7	70.4	16.4	42.5	2.5
Low	26.4	18.7	70.9	16.1	42.7	2.8
High	26.3	17.1	65.0	14.5	46.0	2.8
P-value	0.38	0.50	0.33	0.93	0.75	0.44
Plastic mulch						
Black	26.1	17.3	66.6	14.0	43.6	2.7
White	25.2	17.7	70.9	17.4	43.8	2.7
P-value	0.66	0.71	0.39	0.43	0.96	0.94

[1]There was no significant treatment effect on listed variables. The calculation of green berries was the average of all nine bushes in a subplot. However, percentage berry drop from green berries stage to ripe berries at Early harvest was calculated from only the four bushes per subplot that were harvested.

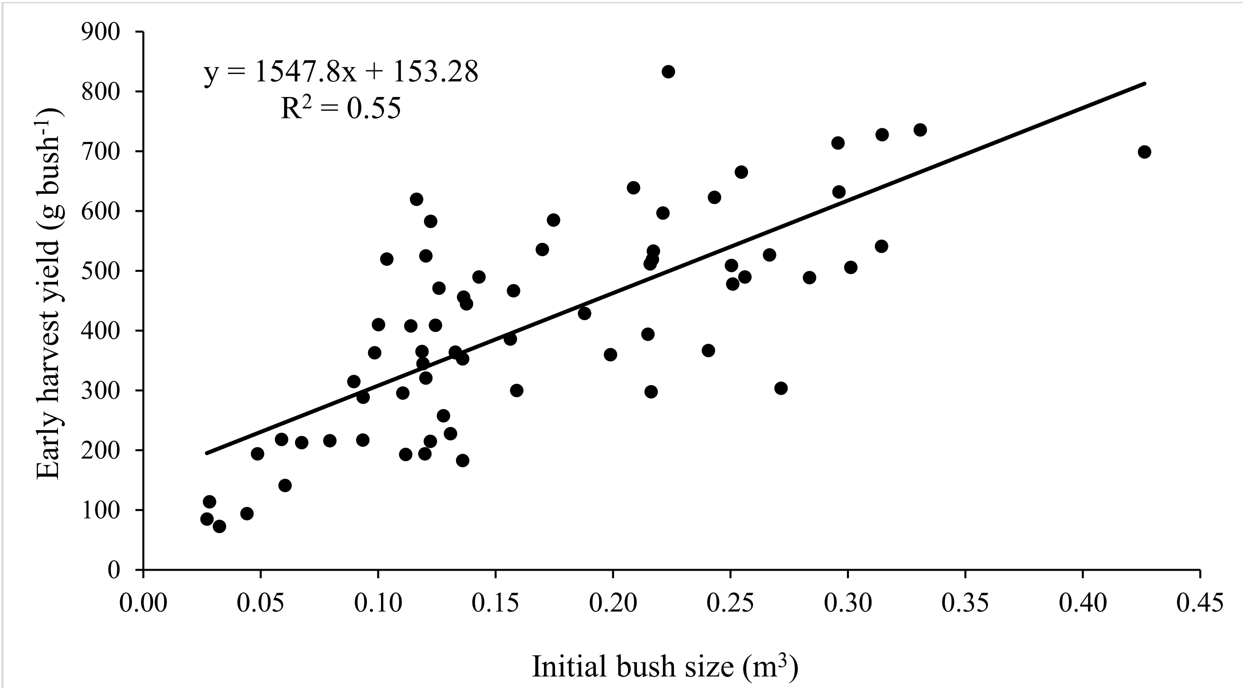

Figure 1. Relationship between Early harvest yield (g $bush^{-1}$) and initial bush size (m^3) for individual bushes in the experiment.

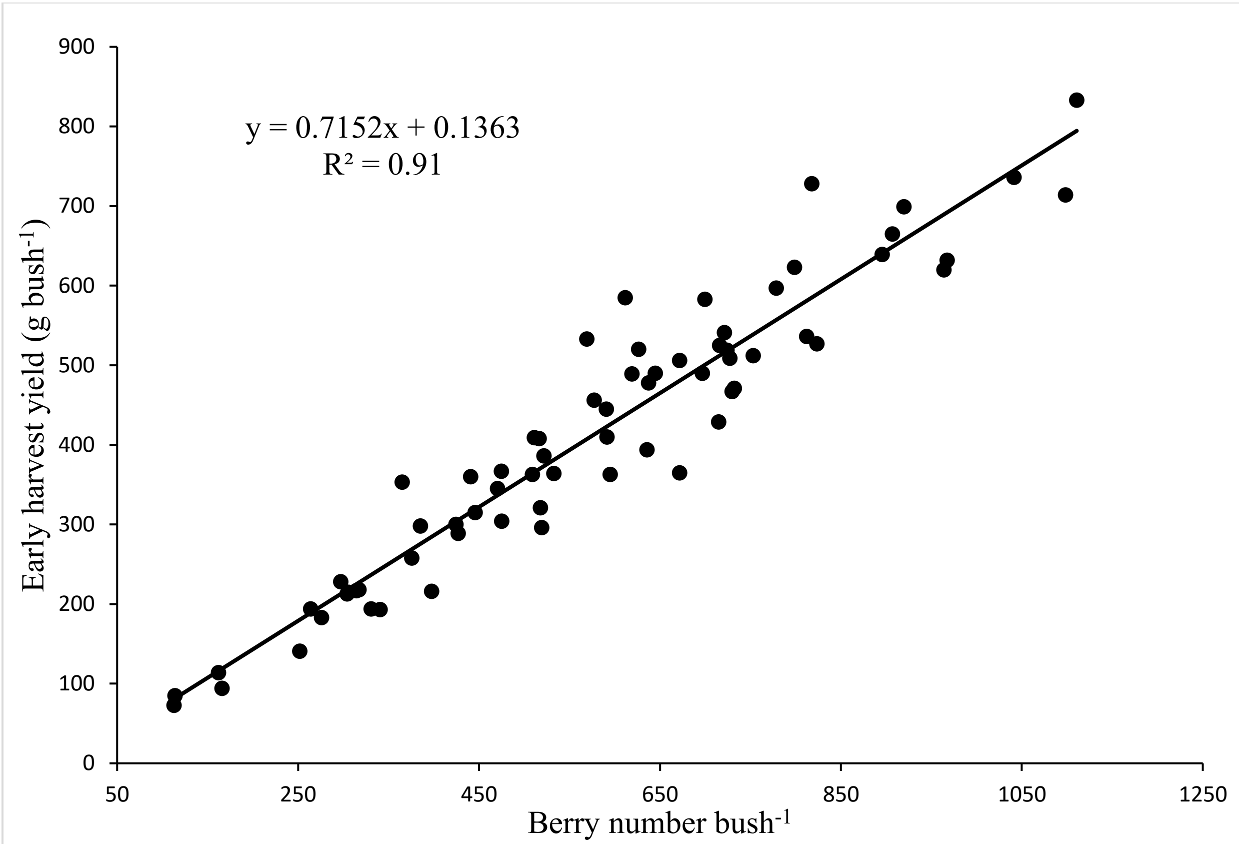

Figure 2. Relationship between Early harvest yield (g $bush^{-1}$) and calculated number of berries per bush for individual bushes.

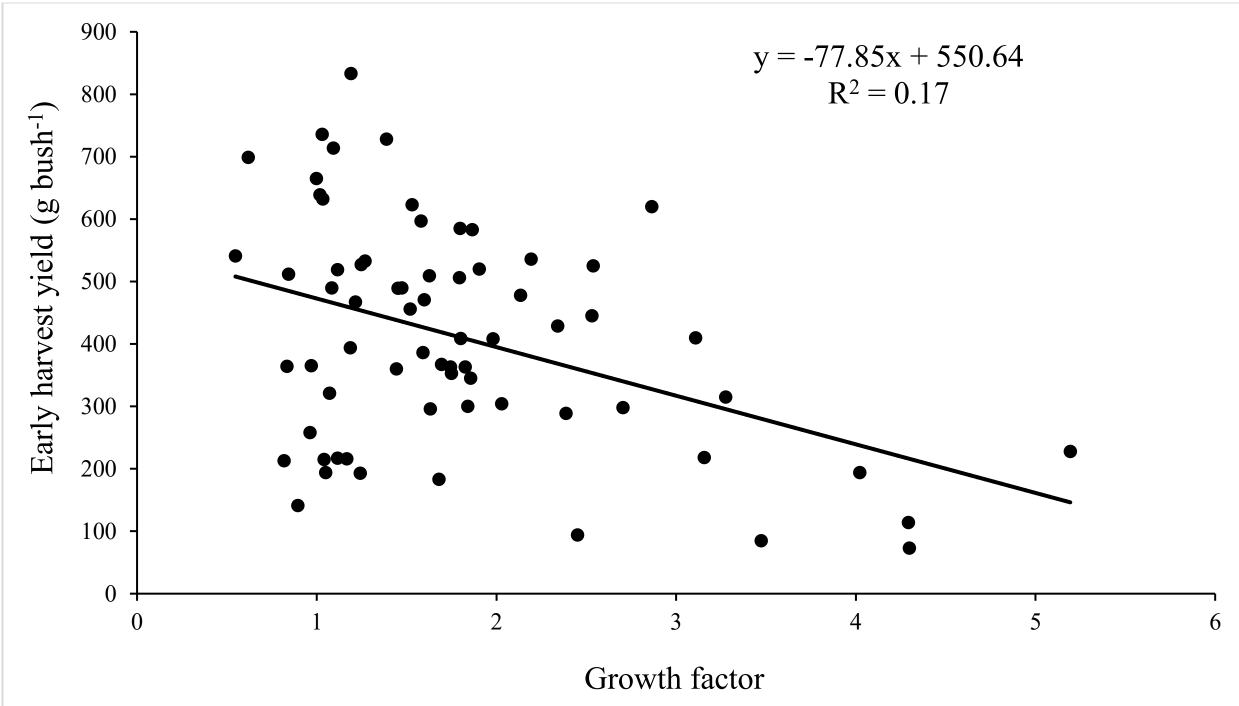

Figure 3. Relationship between Early harvest yield (g bush^{-1}) and bush growth factor for individual bushes.

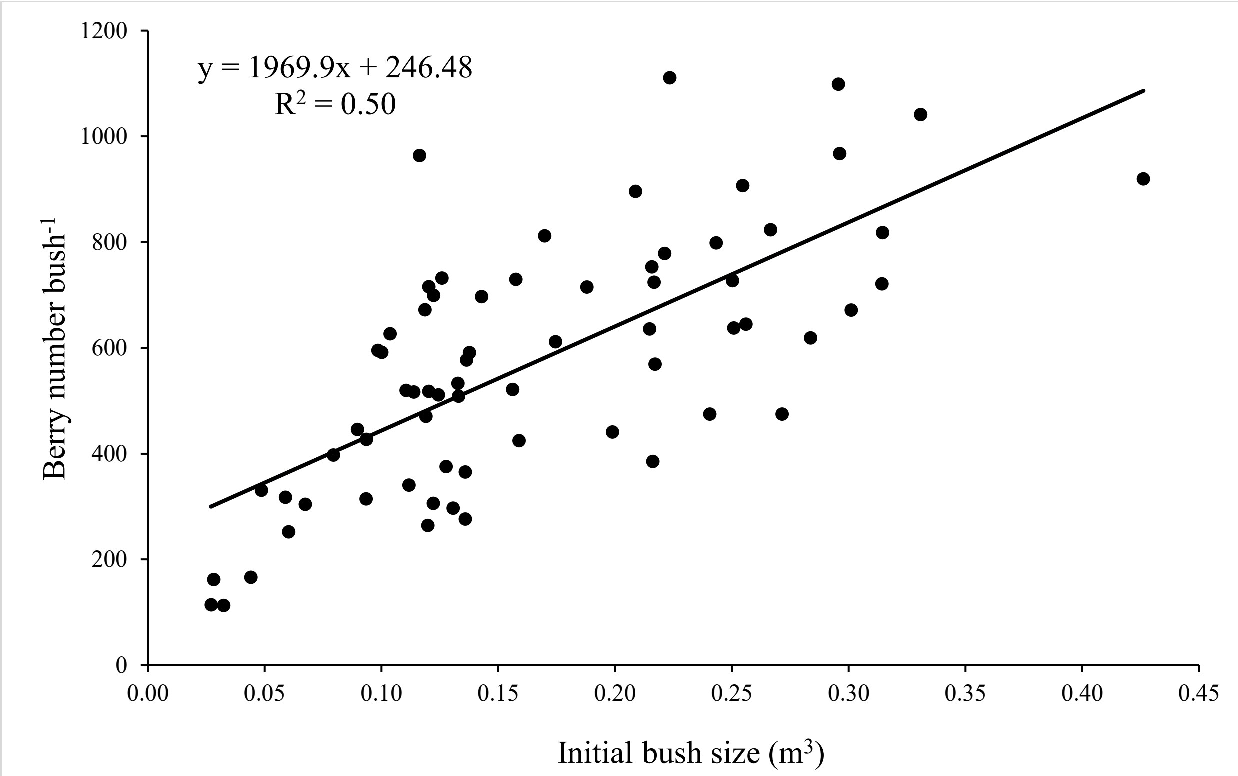

Figure 4. Relationship between calculated number of berries per bush (Early harvest) and initial bush size (m^3) for individual bushes.

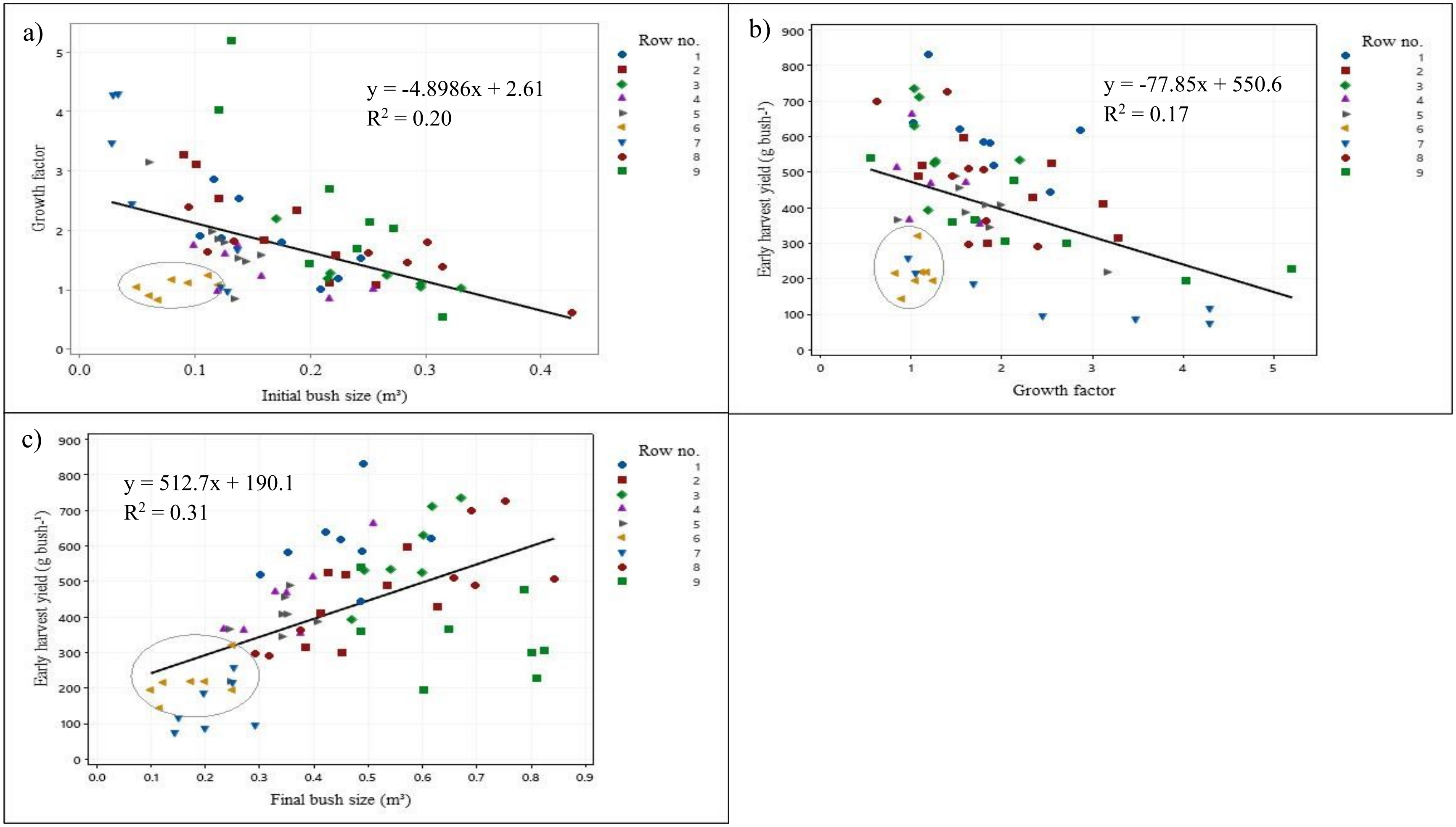

Figure 5. **(a)** Relationship between bush growth factor and initial bush size (m^3); **(b)** Early harvest yield (g $bush^{-1}$) and bush growth factor for individual bushes; and **(c)** Early harvest yield (g $bush^{-1}$) and final bush size for individual bushes. The panel consists of row number (1-9) used in the experiment: Block 1 consists of row 1 to 3, Block 2 consists of row 4 to 6, and Block 3 consists of row 7 to 9. Circle denoted stressed bushes of row number 6 and few of 7 having lower bush growth factor, Early harvest yield, and initial and final bush size. Block 3 had the largest variability in terms of bush growth factor, Early harvest yield, and initial and final bush size.

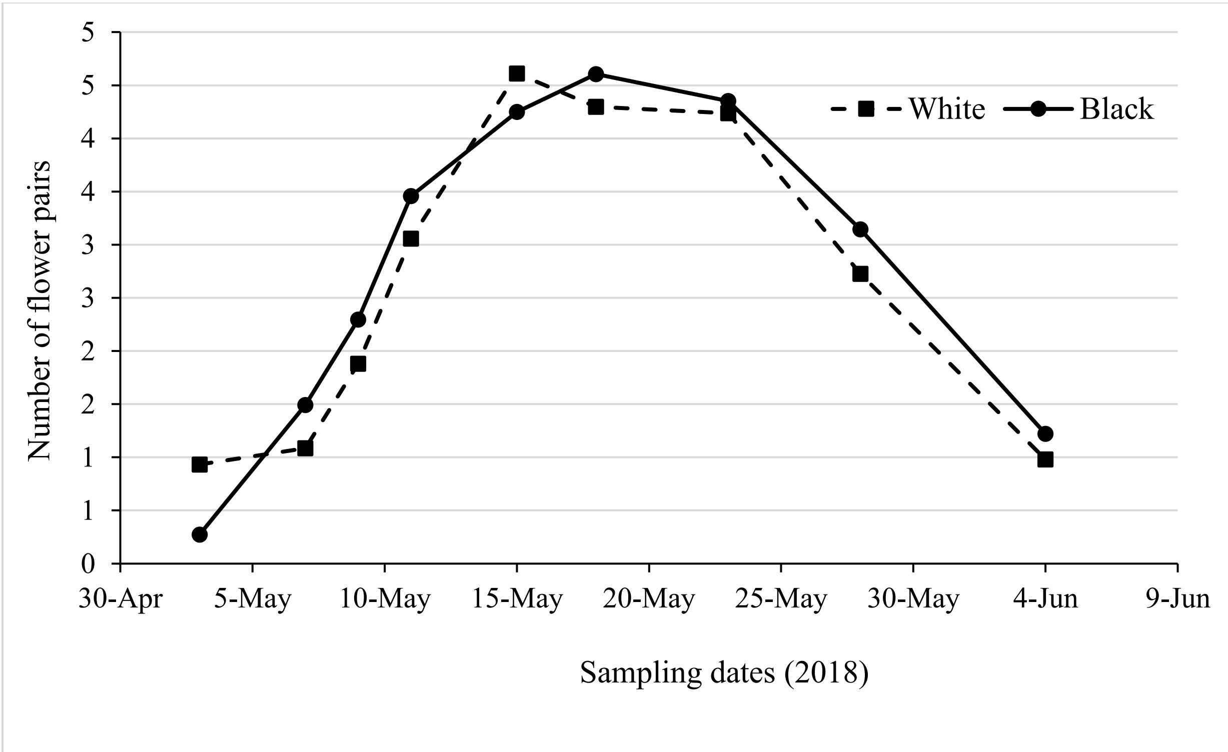

Figure 6. Mean number of haskap flower pairs present on marked branches (standardized to 20-cm length) over the flowering period (4 May – 4 June, 2018) with White and Black plastic mulch.

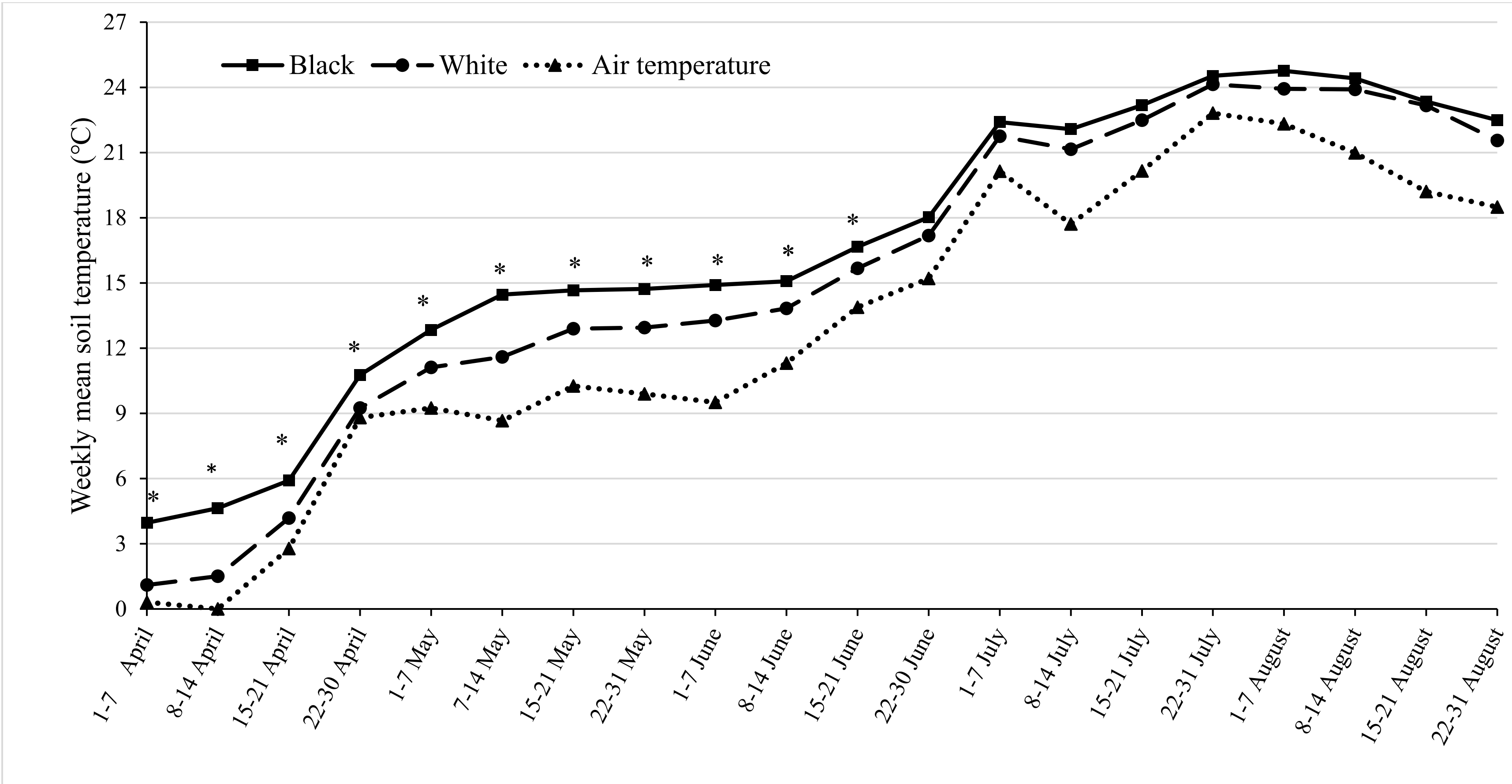

Figure 7. Weekly mean soil temperature under Black and White plastic mulch and air temperature throughout the 2018 growing season (April – August). Significant differences (*) were found between Black and White plastic until the third week of June and after which no significant differences were found. Overall growing season, Black had significantly higher soil temperature than White plastic.

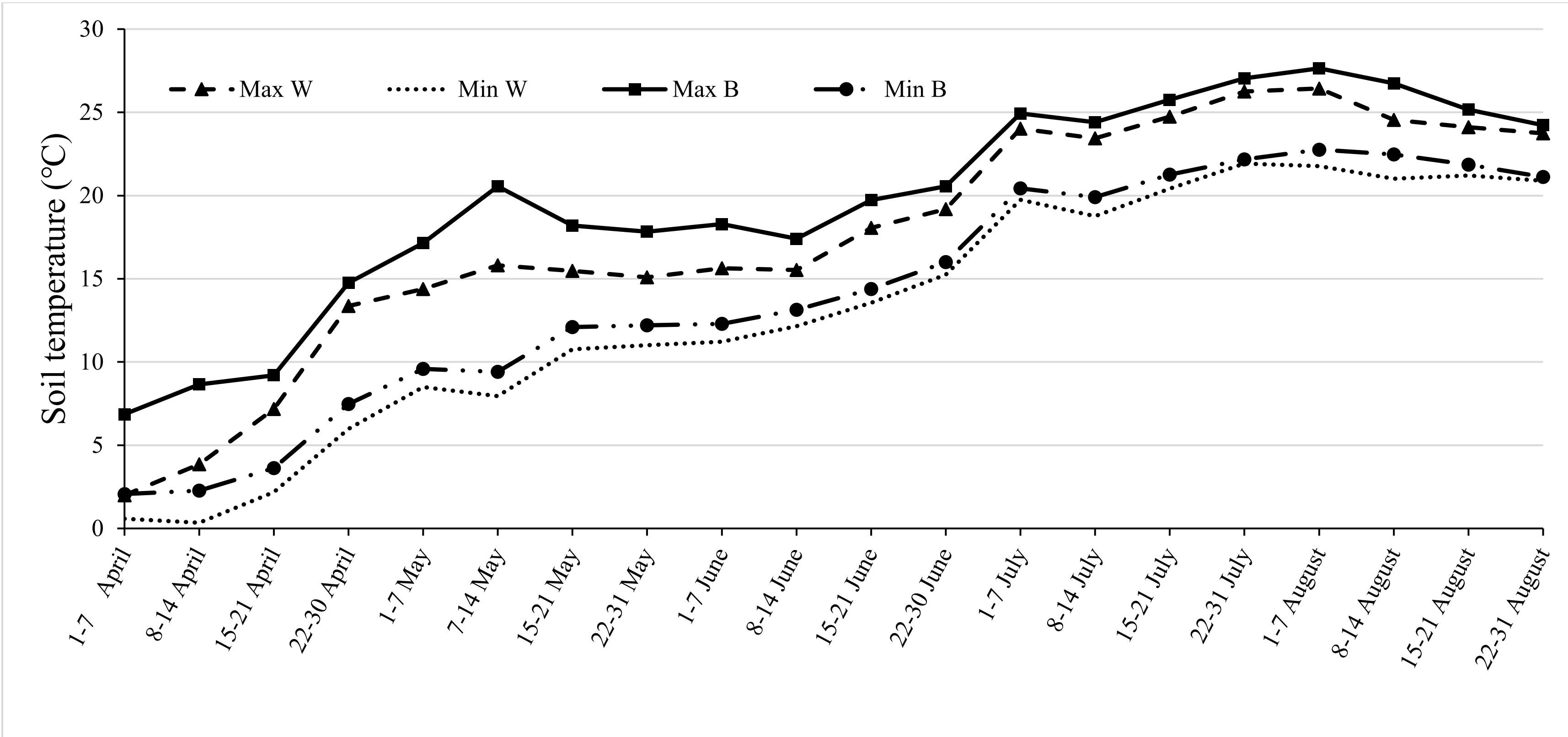

Figure 8. Weekly maximum and minimum soil temperature under Black and White plastic mulch throughout the 2018 growing season (April – August).

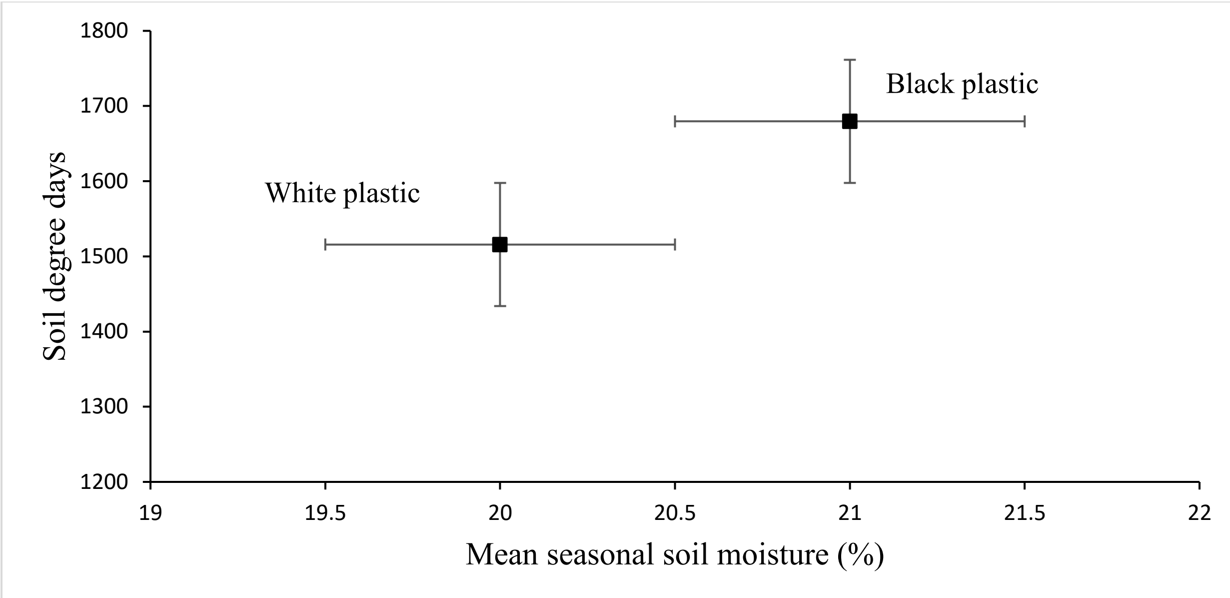

Figure 9. Soil degree days (base temperature 5℃) vs. mean seasonal soil moisture (%) from April to August 2018 as measured by data logger soil probes buried 15 cm deep in soil between two bushes. Bars represent standard error.

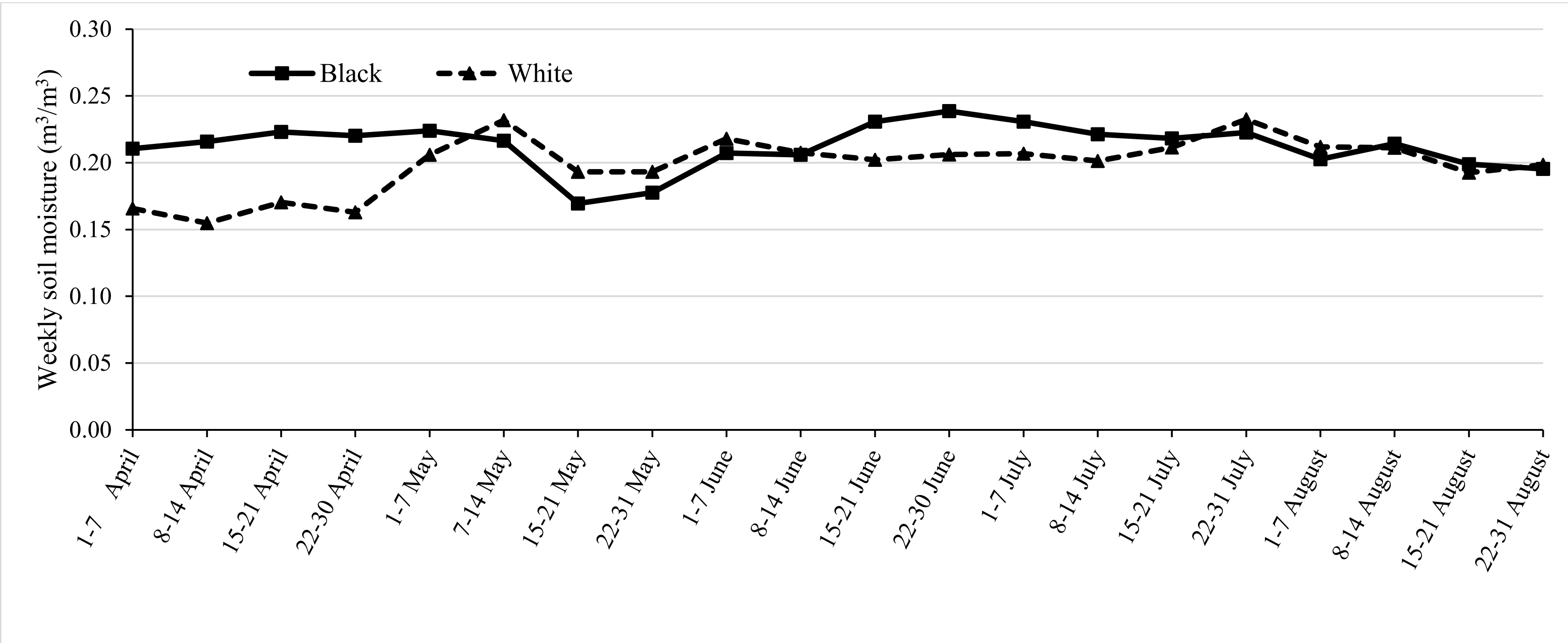

Figure 10. Weekly soil moisture (m^3/m^3) under White and Black plastic mulch throughout the 2018 growing season (April – August).

Figure 11. Berry drops at Late harvest

CHAPTER 5. DISCUSSION

5.1 Overall Treatment Effects

Based on current knowledge and previous literature report, it was hypothesized that the haskap would show a positive response to supplemental fertility and that white plastic might increase growth by reflecting more light into the plant canopy and producing a slightly cooler rooting environment which may reduce stress. The site was selected knowing that the plants in the orchard were not achieving optimum performance as compared to the potential seen in the same variety and age of plants at other haskap farms in Nova Scotia. As such treatment response was expected at the experiment site.

Overall, there were few statistically significant differences in haskap responses to the fertility amendments and plastic mulch treatments tested in this experiment. This may be due to a) the difference in treatments was too small to create a significant difference in haskap response, b) the variability (error) among experimental units within treatment was greater than the treatment effect, c) another factor limited plant response, and/or d) experimental error e) duration time of the experiment. The inconsistent initial bush size within subplots was identified as a major source of variability despite efforts to select rows with uniform growth. Another important reason for the absence of significant effects was the small difference in the growing environment created by the treatments.

5.1.1 Plastic Mulch Colour

The plastic mulch colour did not significantly affect haskap growth, fruiting parameters, and yield (Table 3 and Table 8). The absence of treatment effects might be due to the inability of the plastic mulch colours to create a large difference in the growing environment and on soil microbiology, nutrient cycling, or nutrient and water uptake (Li et al., 2014). The difference in soil temperature between Black and White plastics ranged from 1.4°C to 2.2°C in the growing season of 2018 (Figure 7), which might not be biologically large to result in a significant difference in crop response. MacDonald et al. (1995) reported that the rate of microbial respiration, net nitrogen (N) and sulphur (S) mineralization was more than double when soil temperature increased from 15° to 25°C. Many studies have reported the positive effects of warmer soil temperature on shoot growth, bud break, flowering onset, and fruit set are well known in grapes under controlled environment (Skene and Kerridge, 1967; Cooper, 1973; Zelleke and Kliewer, 1979), although the difference of soil temperature was large, ranged 10-15°C in these studies, as compared to the present study. No significant difference in strawberry yield and fruit numbers was found when average soil temperature under Black plastic was 2.9°C, on average, higher than White plastic (Shiukhy et al., 2015). Díaz-Pérez (2010) also found no significant differences in Black and White plastic based on plant height, leaf primary nutrients, number of fruits per plant and total fruit yield of bell pepper and related this to small soil temperature difference (0.54°C) between Black and White plastic.

The shade of canopy cover over the plastic mulch surface might have been reduced the biological effect of plastic on plant growing environment. The increase in canopy cover resulted in lower soil temperature due to more radiation interception and lower soil water content due to increased transpiration (Tanaka and Hashimoto, 2006). These combined effects resulted in lower soil respiration, an indication of biological activity including nutrient turnover in the soil. This study found that the difference in soil temperature between White and Black plastic was started decreasing after the second week of May 2018 and the difference becomes insignificant after mid-June (Figure 7). These results are similar to Privé et al. (2008) who confirmed that the difference in soil temperature between plastic mulch and bare soil in apples was the greatest earlier in the growing season but decreased with an increase in canopy cover. The increase in canopy cover might also reduced the percentage of photosynthetically active radiation (PAR) reflection from White plastic mulch as was observed in apple (Privé et al., 2008), cotton (Zhi et al., 2014), and vegetable crops (Csizinszky et al., 1995; Díaz-Pérez, 2010). The reduction in difference of soil temperature suggested that energy balance tends to be similar in both Black and White plastic under shading. Thus, the effect of plastic mulch colour would be expected to be more prominent immediately following orchard planting.

The interception and distribution of the reflected PAR within the canopy strongly influence the physiological response of the plant (Yáñez et al., 2009). In this study, the positive effect of PAR reflection from White plastic mulch might be decreased with an increase in canopy cover. The upper and exterior portion of canopy would get less benefit from reflected PAR than the area at base of canopy as found in other fruit crops (Iglesias and Alegre, 2009; Yáñez et al., 2009). The lower 20 cm of rabbiteye blueberry produced only 13.4% of total flower buds (Yáñez et al., 2009). The non-significant effect of White mulch reflectance on growth, flowering, yield and berry quality of haskap can partly be related to this phenomenon as the positive effect of reflective PAR might be limited to only lower part of the bush. Thus, the amount of leaf area and number of flower buds benefitting from the White mulch reflectance was not large enough to have an effect on haskap performance in terms of growth, flowering, yield and berry quality. Similar results were reported in apples (Andris and Crisosto, 1996; Layne et al., 2002; Iglesias and Alegre, 2009) and sweet cherry (Whiting et al., 2008) where the fruit numbers and yield were not significantly affected by reflective films due to inconsistent distribution of PAR reflation in the canopy.

The temperature increase under plastic mulch is greatly influenced by the heat conductivity and there must be close contact between plastic mulch and soil surface to create enough difference in temperature to have an effect on crop responses (Ham et al., 1993; Tarara, 2000). In this study, the presence of wood chips (applied at the timing of plantation) under the plastic mulch created a buffer zone between root systems and plastic mulch which might have reduced the direct effect of plastic mulch on soil temperature. Wood chip mulch applied at different thicknesses in *Penstemon digitalis* had the lowest soil temperature than unmulched soils due to the high soil water content and its effect decreased with an increase in thickness of mulch (van Donk et al., 2011), which confirms the results of the present study in haskap. Larsson (1997) also found that wood mulch resulting in cooling or moderating effect on soil temperature in blackcurrant.

5.1.2.Fertility Treatments

The fertilizer levels were established in this experiment because the crop at this site was not performing at full potential under dryland conditions. The recommended ranges for soil fertility status suggested by Iheshiulo et al. (2018b) had not yet been established at the time when the experiment was designed. This experiment was the first experiment in Nova Scotia intended to study the effects of fertility amendments and plastic mulch colours in combination with irrigation. The application of fertilizers to already nutrients rich soil can have adverse or no effect on crop growth and development. The absence of haskap response to fertility amendments in this experiment might be attributed to adequate soil fertility at the experiment site before applying treatments. Based on soil fertility recommendations provided by Iheshiulo et al. (2018b) (Table 1), soil potassium (K) and magnesium (Mg) were in the optimum range based on the 2017 soil test report (478 kg K_2O ha^{-1}, and 301 kg Mg ha^{-1}). Soil calcium (Ca) was found on the higher range (3976 kg Ca ha^{-1}) and soil phosphorous (P) was three times the recommended sufficiency range for haskap (1190 kg P_2O_5). Similarly, leaf tissue nutrient concentrations in the Control were all sufficient except for P according to the sufficiency levels provided by Iheshiulo et al. (2108b)

(Table 7). Based on these findings, background soil fertility was adequate, and at least not severely limiting plant growth or yield. The previous studies also found no significant effects of N and P fertilizer applications, applied when soil has sufficient nutrients, on number of flowers, growth, and yield in apples (Batjer et al., 1952), lowbush blueberry (Benoit et al. 1984), and red raspberry (Dean et al., 2000). The increase in dose of N, P, and K fertilizer treatments did not affect bush growth and yield of blackcurrant (Sako and Laurinen, 1979; Hobson, 2012) and a four-year trial of blackberry (Naraguma and Clark, 1997). Benoit et al. (1984) reported the same result that increasing N rates did not influence the number of flowers in lowbush blueberry.

The significant differences in plant responses can not be detected when there are small differences in the treatment levels and having a large variability of the crop (Opstad et al., 2007; Hobson, 2012). This rationale might partly explain the absence of positive effect of fertility amendments on haskap response variables. Opstad et al. (2007) found similar results with no significant increase in yield of blackcurrant with an increase in fertilizer rates and authors related this to having a small difference in the application rates and confounded with different fertilization strategies.

Haskap may also have a low response to N fertilizer as identified in blackcurrant (Opstad et al., 2007; Hobson, 2012). Studies from Russia and Canada suggested that haskap bushes do not have a high requirement for N (Belosohova and Belosohov, 2010), and excess N may impede root growth (Tremblay et al., 2019). The lack of response to the fertility amendment in this study can also be related to the low requirement of haskap for nutrients. This can be supported by results of leaf tissue nutrients which were found to be in recommended range established for haskap by (Iheshiulo et al., 2018a). There was no significant effect of different P fertilizer rates on total stem length, buds and flowers per stem, and yield of lowbush blueberry due to the low requirement of blueberry for nutrients (Hall, 1978; Eaton et al., 1997).

The non-significant effects of fertility amendments on haskap response might also be due to the presence of wood chips, which were initially applied for weed control at the time of haskap plantation and are known to have high carbon to nitrogen (C:N) ratio. The high C:N ratio of the organic materials causes low availability of soil nutrients, especially N, availability through immobilization (Idol et al., 2003; Homyak et al., 2008; Hammermeister, 2016). In the present study, the application of wood chips may have slowed the initial plant growth after the application in 2014. Besides this, the fertilizers were applied by hand in the first year (2017) at the base of the plants without the incorporation into the soil. This may have reduced the contact of the fertilizer nutrients with the soil and resulted in slow availability of nutrients to the haskap roots (Martínez-Alcántara et al., 2016).

5.1.3. Independent Effects

High variability in initial bush size among rows and bushes within a subplot was observed to be an important factor affecting haskap performance, thus difficult to measure crop responses. The criteria of Wilding et al. (1994) were used to calculate the magnitude of variability: coefficient of variation (CV) of 0-15% was low, 15-35% was medium and 35-100% was high. There was high variability in initial bush size ranging from 0.03 m^3 to 0.43 m^3 (51.0% CV) and growth factor ($\frac{Final\ bush\ growth - Initial\ bush\ growth}{Initial\ bush\ growth}$) 0.55 to 5.2 (52.4% CV) among the individual bushes, and (Figure 5a). Besides this, it was found that bushes of row number 6 and few of 7 in Block 2 and 3 underperformed because they had smaller initial bush size which resulted in the lowest yield and had a small increase in their size (lower growth factor) in 2018 (Figure 5). So, this suggested that some non-interest factors contributed to the variations in those bushes and inhibited their growth.

The largest variability in terms of growth factor and initial and final bush size was found only in one block (Figure 5).

As this study was carried out on three years old haskap bushes, there could be several explanations or factors that might have caused variability in bush size including quality of the planting stock, the history of planting and management, or field variabilities like moisture availability, improper seedling handling and planting techniques. To address the variability issues, a block design with four blocks was implemented to account for variability in the field, and treatments were randomly assigned to rows and within rows. It became apparent in 2018 that one block had substantial differences among rows that were not treatment related. This block was removed from the analysis. Variability within rows was accounted for by having a large subplot size of nine plants, trying to select a uniform grouping of 22 plants (including buffers), and randomly assigning a plastic colour to subplots. Despite this, variability among plants within subplots and hence among subplots began to become more apparent as the growing seasons progressed in 2017 and 2018. The variability had a large effect on the growth and ability of the plant to respond to nutrients and created large experimental errors in the analysis of haskap performance. It is hard to detect any treatment effects in the presence of variability given that the effect of any treatment is very subtle or modest. Similar results were found in blackcurrant where growth and yield were not significantly affected by different fertilizer rates due to the large variability in the initial bush size (Hobson, 2012).

The timing of fertilizer applications was seen to affect the vegetative growth, flowering, and yield of berry crops (Hansen and Retamales, 1992; Wang, 2000; Percival, 2002; Hobson, 2012). In this study, the late application of fertilizers in both 2017 and 2018 (as discussed above in section 3.1.3) left bushes with short time to respond to the fertilizer nutrients. The fertilizer application of 2017 may have had less effect on vegetative growth of haskap in the same year, which ultimately determined the reproductive buds and berry yield in the following year (2018). The absence of significant effect of the 2017 fertilizer application could be explained by the late application of fertilizers in 2017 as rapid growth of vegetative parts was more seen in late spring and early summer than late summer and fall in temperate regions (Abbott and Gough, 1987). The significant positive relationship of initial bush size with Early harvest berry yield and calculated number of berries per bush (Figure 1, Figure 2) suggests that the initial bush size can highly influence the yield of the following year. The significant effect of vigorous growth in the year before fruiting on the reproductive buds in haskap has been reported in several studies (Plekhanova, 1989; Kolasin and Pozdnyakov, 1991; Prischepina, 2000). A similar relationship has been found in blackcurrant where shoot growth, flower number, fruit set, and yield were determined by the growth of the year before fruiting (Bould, 1969).

5.2 Experiment 1: Objective 1. Haskap Growth, Yield, Leaf Nutrients, and Total Soluble Solids in Response to Plastic Mulch Colours and Fertility Amendments.

5.2.1 Yield and Yield Components

Plastic mulch colour and high fertilizer applications were expected to increase haskap yield in this study. The negative relationship between Early harvest yield and growth factor (Figure 3) suggests that the absence of berry yield response could be related to the tradeoff between vegetative growth and fruiting in establishment years. In this study, haskap bushes with smaller initial size had higher growth factor but lower berry numbers and yields as compared to large sized bushes (Figure 1, Figure 4, Figure 5a). This can be most likely due to either less vegetative surface to produce berries or fewer carbohydrate resources to support both biomass accumulation and fruit production. Previous studies in strawberry also found similar results where fruiting structures were seen to become dominant sink during the peak of fruit growth and strongly competing with vegetative growth (Forney, 1984; Reekie and Bazzaz, 1987). The growth of blackcurrant increased by deflowering in young plants and there was more growth and yield in the following year as compared to flowering plants as yield is more related to the previous year's growth (Hansen, 1985).

In this research, a strong relationship was found between Early harvest yield and calculated number of berries per bush (Figure 2). Whereas 100-berry-weight (HBW) had a weak non-significant relationship with berry yield (data not shown). Thus, the calculated number of berries per bush appeared to be more important in determining yield than berry weight in this experiment. A similar strong positive relationship between berry yield and berry number was found in highbush blueberry (Siefker and Hancock, 1986; Ehlenfeldt and Martin, 2010; Salvo et al., 2012; Palma et al., 2014) and pear (Einhorn et al., 2012). In these previous studies, a week relationship was also found between berry yield and berry weight. The lack of fertility amendments and plastic mulch effect on yield could also be explained by non-significant effect on calculated number of berries per bush.

The HBW and calculated number of berries did not show a significant response to plastic mulch colours and fertilizer amendments, but the harvest period had a significant effect on yield components (Table 3). Early harvest had higher calculated number of berries per bush than Late harvest. However, berry yield remained unaffected due to significantly increased berry weight at Late harvest (Table 3). The increase in berry weight from Early harvest to Late harvest may be attributed to the increase in GDD_5 (Growing Degree Days of base 5°C) and berry ripeness as similar results were found in previous studies of haskap (Ochmian et al., 2010; Dawson, 2017). The significant differences in berry numbers between Early and Late harvest (Table 3) might be due to the nonuniformity of berry ripening which resulted in berry drop (Figure 11) during the intervening period as berries become fully ripe. Haskap bushes produced flowers over a month (May 2018), but individual flowers pollinated and terminated within three to five days. This means that a wide range in ripening period of haskap occurred, and flowers that were pollinated early in May most likely dropped while the flowers that were pollinated later in May would not fully ripen at the time of harvesting. This suggests a trade-off effect between berry weight and numbers as the berries ripen. In haskap, the Late harvest period might allow berries to improve flavour but it also runs the risk of berry drop and loss of significant yields.

5.2.2 Bush Growth and Leaf Size

Haskap bush growth and leaf size did not respond significantly to the plastic mulch and fertilizer applications in this study (section 4.1.3). The average final bush volume (0.42 m^3) and leaf size (11.4 cm^2) in this study were more than the average bush volume (0.21 m^3) and leaf size (9.23 cm^2) of haskap found in Nova Scotia (2 to 5 years old plants) as reported by Iheshiulo et al. (2018a). The average yearly bush growth rate in this study (0.26 m^3 $year^{-1}$) was also more than the maximum range (0.19 m^3 $year^{-1}$) of the growth rate of haskap surveyed in Nova Scotia (Iheshiulo et al., 2018a). These results suggested that haskap bushes were performing well and were not under any physiological stress. The difference in soil temperature among Black and White plastic was not big enough throughout the growing season (Figure 7). Therefore, there might not be a big difference in soil nutrient transformation and their uptake particularly N, important for vegetative growth. Black plastic resulted in only 0.1% higher leaf tissue N than White plastic, which might not be a biologically large difference to show response in terms of vegetative growth. The canopy air temperature and increased PAR are also considered as one of the most important growth controlling factors in plants (Liu et al., 2013). In the present study, the shading of the canopy significantly reduced the amount of PAR reflected from the mulch towards middle and upper portion of canopy, which could have reduced the positive effect of reflectance on bush growth and leaf size. The canopy air temperature was the same for Black and White plastic that can also explain the lack of treatment effects on bush growth and leaf size (Granier and Tardieu, 1998; Lafarge et al., 1998). Medina et al. (2008) reported that the vegetative growth of strawberry was not affected by white and back plastic mulch grown under high tunnels. Similarly, Hammermeister (unpublished data) also found no significant effect of black plastic and white fabric on bush growth of organic blackcurrant.

No difference in bush growth and leaf size may also be attributed to no difference in concentration of leaf K, as K has a major role in cell expansion and enlargement (Elumalai et al., 2002; Iheshiulo et al., 2018b). Phosphorous and K are considered important macronutrients besides N for the growth of horticultural crops. Both nutrients were found to be strongly correlated with bush volume, growth rate, and leaf size parameters (Iheshiulo et al., 2018a). Background soil P was in excess, so adding more P nutrients might not have a significant effect on leaf P concentration. Tremblay et al. (2019) reported that adding N, P, K fertilizers to haskap did not increase vegetative growth and resulted in lower root development.

It was found that the initial bush size had significant influence on final bush size and growth factor (section 4.1.3). The growth factor was not similar among the treatments due to variability in initial bush size, even within a subplot. The maximum (5.19) and minimum (0.55) value of growth factor was found in bushes of the same subplot (Figure 5b). It can be concluded that the high variability in initial bush size was greater than the effect of the treatments, thus it is difficult to measure crop response in terms of final bush size or growth factor.

The small bushes had large changes in their final bush size (high growth factor) as compared to large bushes (Figure 5a). The small bushes likely allocated more energy to vegetative growth rather than berry production. However, large bushes may have utilized their resources for both higher berry production as well as growth, and therefore could not maintain the same level of proportionate growth as the small bushes. Moreover, small bushes allow more solar radiation to penetrate, hence more light is reflected towards the canopy which could stimulate more vegetative growth as compared to large bushes.

5.2.3 Total Soluble Solids

The total soluble solids (TSS), measured in °Brix, is the refractometer reading indicating the percentage dissolved solids contained in the juice being measured and an indication of sugar contents. In this study, TSS at Late harvest (13.6°Brix) was significantly higher than the Early harvest (11.7°Brix) (Table 3). The OMAFRA (2012) outlines that haskap berry with a reading above 13°Brix may have average to good flavour. An increase in sugar content with berry development or ripeness reveals the accumulation of monosaccharides such as fructose (Kader, 2008). The increased TSS at Late harvest in this study might be explained by an increase in sugar content due to berry ripeness. Similar results were found in haskap (Dawson, 2017) and blackcurrant (Rubinskienė et al., 2008; Taylot, 2015) where Brix level increased with an increase in berry ripeness or maturity at late harvest. In Poland, late harvested haskap berries had 24-33% higher TSS concentration than berries of early harvest (Ochmian et al., 2010). Higher TSS at Late harvest can also be correlated to larger berry weight as there is a direct linear relationship between berry weight and sugar content (Baeza et al., 2019). However, the TSS of berries at Late harvest was likely lower than what it would be because overripe berries (higher TSS) have dropped before harvest. It suggests that a long flowering period of haskap (Figure 6) might interfere in berry Brix level at Late harvest.

The plastic mulch colours and fertility amendments had no significant effect on TSS in this study. These results are consistent with results in several studies of grapes, where fertilizer applications also had no significant effect on soluble solids (Bell et al., 1979; Conradie and Saayman, 1989; Neilsen et al., 2010). The use of reflective films had no significant effect on TSS concentration in apples (Li et al., 1994; Andris and Crisosto, 1996; Ju et al., 1999; Layne et al., 2002; Mathieu and D'Aure, 2000; Iglesias and Alegre, 2009). Farias-Larios and Orozco-Santos (1997) also reported that plastic mulch colours did not affect TSS in watermelon.

5.2.4 Leaf Nutrients

Among leaf tissue nutrients examined, N was significantly affected by fertility amendments and plastic mulch colours, whereas P was only influenced by plastic mulch colours (Table 6, Table 7). However, there was a small difference in response magnitude of leaf nutrients (Table 7). Leaf tissue nutrient content was compared with the available nutrient sufficiency range in haskap cv. Indigo Gem established by Iheshiulo et al. (2018a). These nutrient sufficiency ranges were derived from leaf tissue nutrient content and growth rate of cv. Indigo Gem (Table 7). Based on the sufficiency ranges, the average N, K, and Mg values were found to be within sufficiency ranges for the effects of fertility amendment and plastic mulch. Leaf P was slightly below the sufficiency range for both fertility amendment and plastic mulch treatments. There has been no study that examined the effect of fertilizer application on leaf tissue nutrients of haskap in North America. In this study, the absence of treatment effects may be attributed to the presence of sufficient background soil nutrients and thus, the site did not respond strongly to the application of additional fertilizers in terms of leaf nutrients. It was noted that bushes had established shallow roots in the presence of wood mulch, which might interfere in roots' ability to uptake sufficient nutrients and would have less soil surface for roots to explore for resources. This effect was also noted by Haynes (1987) in strawberry where K fertilizer application had no significant effect on leaf nutrients due to restricted root growth.

The significant effect of fertilizer applications and plastic mulch colours on leaf N may be due to the mobility of nitrate in soil, making it more available than P and K (Weil and Brady, 2017). The leaf N content in this study increased with an increase in fertilizer level. However, leaf N was not excessive in any treatment (>3% leaf N is considered high, Iheshiulo et al., 2018a) even at a high N level. Similar results were found in highbush blueberry where leaf N was increased with an increase in N fertigation rate, but leaf N concentrations were not excessive based on local fertilizer recommendations even when a higher rate than recommendation was applied (Bryla and Machado, 2011; Ehret et al., 2014). Sønsteby et al. (2004) found that high rate of NPK fertilizers resulted in the highest leaf N content in strawberry. The higher leaf N under Black plastic than White plastic might be associated with high ratio of leaf chlorophyll fluorescence. Increased leaf N under Black plastic can partly be explained by higher N mineralization due to warmer soil temperature and hence available N uptake. However, the increased Leaf N did not significantly affect leaf size, bush growth, leaf chlorophyll content, or berry yield. This might be due to small difference in fertilizer application levels which could not create a large biological difference in leaf N status. In this study, leaf N concentration under Black and White plastic was inversely proportional to leaf chlorophyll content (data not shown). However, there was no significant correlation found between them.

No significant effect of fertility amendment on leaf P (Table 6) might be attributed to less responsive of Indigo Gem to P fertility in the soil as compared to other varieties like Aurora, Berry Blue and Borealis (Iheshiulo et al., 2018b). Leaf P was the highest in bushes under Black plastic than White plastic (Table 7). The slight increase in soil temperature may increase the rate of mineralization of organic P and decomposition of insoluble inorganic forms of P (Eid et al., 1951; Power et al., 1964). Torres-Olivar et al. (2016) found higher activity of phosphate-solubilizing bacteria in soil under black plastic in cucumber which helps in mobilization of insoluble inorganic P from their mineral matrix to the soil. Higher soil temperature may increase vesicular-arbuscular mycorrhiza (VAM) formation through either direct effect of temperature on fungus germination and growth or an indirect effect via an increase in leakage of root metabolites necessary for mycorrhizal fungal activity, or both (Graham et al., 1982). Thus, the increase in VAM penetration and infection increases the supply of phosphate to the roots.

The leaf K concentration was not significantly affected by fertility amendment and plastic mulch (Table 6). The background soil nutrients test report in this study suggested a sufficient K level (Table 1). The crop response to applied K decreases as the level of background soil K increases (Barber, 1985). The application of K nutrients could be utilized by berries as berries are the dominant sink of K during development (Nes and Hageberg, 2002; Craighead et al., 2007). Hobson (2012) also reported the utilization of K for reproductive growth instead of vegetative growth when K was available to plants in blackcurrant.

5.2.5 Leaf Chlorophyll Content

The soil plant analysis development (SPAD) readings permit the rapid estimation of leaf chlorophyll (light collecting pigment within leaves) content by measuring leaf transmittance (Wood et al., 1993). The SPAD meter readings were found to be proportional to the amount of chlorophyll present in leaves of apple, grapes, peach (Singha and Townsend, 1989; Neilsen et al., 1995), Strawberry (Himelrick et al., 1992), and blackcurrant (Wójcik and Filipczak, 2015). The average leaf SPAD reading (39.1) in this study was found to be in the range of SPAD values (26.6 to 40.0) obtained from 19 haskap growing locations in Nova Scotia (Iheshiulo et al., 2018a), indicating relatively high leaf chlorophyll content. In this study, plastic mulch colour had a significant effect on leaf SPAD readings (Table 4), where bushes under White plastic (39.8) had higher value than Black plastic (38.5). The response magnitude of leaf SPAD readings between Black and White plastic might not be biologically large to create a significant difference in carbon assimilation as higher SPAD under White plastic did not stimulate haskap bush growth, flowering observations, leaf nutrients, and/or yield. The significantly higher SPAD reading under White plastic might be due to higher reflective PAR. Hammermeister (unpublished data) found the same results that haskap bushes under black plastic (approximately 33 SPAD value) had lower SPAD readings than White plastic (approximately 34 SPAD value), however, there was no significant difference. The plants grown on reflective film increased the concentration of chlorophyll '*a*' (an integral compound of light reaction of photosynthesis) to absorb the maximum amount of light reflected (Gosselin and Trudel, 1984). The higher leaf chlorophyll content, correspond to SPAD reading, was found in tomato plants grown under supplemented light than shaded plants (Gosselin and Trudel, 1984).

Fertilizer additions had no significant effect on leaf SPAD readings (Table 4) may be due to sufficient background soil fertility as leaf N being within sufficiency ranges of Iheshiulo et al. (2018a) (Table 7) and SPAD readings being at the upper range of their haskap survey. Another reason for the absence of significant effect of fertilizer application might be because fertilizer application levels were not sufficiently different from each other as discussed above. Naraguma and Clark (1997) found the same results that N fertilizer did not significantly increase leaf chlorophyll content in 'Arapaho' thornless blackberry and found leaf N content was in sufficient range. Tremblay et al. (2019) also found no significant effect of N fertilizers on haskap leaf SPAD readings due to the lower energy investment in root growth with high N application.

There was no correlation found between leaf N and SPAD readings in this study and values were contradict each other. However, previous studies found that leaf SPAD readings and/or chlorophyll content were positively correlated with leaf N status in grapefruit (Li et al., 1998), apple and grapes (Porro et al., 2001), and strawberry (Himelrick et al., 1993). The minimum content of leaf N required for functional photosynthetic efficiency in haskap remains largely unknown. Some researchers indicated that SPAD readings tend to approach a plateau when N availability is sufficient and that leaf N concentration no longer reflects the increase in N availability (Schepers et al., 1992; Shapiro et al., 2006). Similar results were found in blueberry cv. Bluecrop where higher rate of N results in decrease in leaf chlorophyll content due to inhibition of some enzymes in chlorophyll synthesis (Li et al., 2012). Sibley et al. 1996 found no correlation between SPAD readings and total leaf N content in red maple. The SPAD units of highbush blueberry increased with increase in N (applied as fertigation) application from 0 to half of the local N recommendation rate but SPAD reading (after reached maximum level) did not increase after application of full local recommendation rate (Ehret et al., 2014). About 50 to 60% of the total annual N requirement must be available during the flowering and fruit set stage for optimal concentration of leaf N and its relationship with SPAD readings in citrus (Tucker et al., 1995). The application of 2018 fertigation was applied at fruit set stage and leaf samples were taken about one week after the last fertigation application. Haskap leaves might not have sufficient time to respond to the fertility amendments. Thus, no relationship was found between leaf N and SPAD readings.

5.2.6 Leaf Chlorophyll Fluorescence

The leaf chlorophyll fluorescence (Fv/Fm) shows the potential maximum efficiency or photoactivation activity of photosystem II (PSII) and can be used as an indicator of plant photosynthetic activity. In general, it is a plant stress measurement. Lower values indicate plants have been exposed to environmental stress. No study has been reported the optimum value of Fv/Fm for haskap performance to my knowledge. In this study, White plastic had significant lower value (0.7926) of Fv/Fm as compared to Black plastic (0.7967), which were in the optimum range from 0.79 to 0.84 found for most of the plant species (Kitajima and Butler, 1975; Björkman and Demmig, 1987; Johnson et al., 1993; Maxwell and Johnson, 2000; Guidi and Degl'Innocenti, 2012). These Fv/Fm values under White and Black plastic were also lower than the optimum value for unstressed highbush blueberry (0.823) (Lobos et al., 2012). This suggests that haskap bushes in this study were not under any physiological stress.

The Fv/Fm values in this study were not too low under White plastic to establish measurable stress in response to bush growth, or berry yield. The significant lower Fv/Fm value of bushes under White plastic might indicate photoinhibition because higher absorbed light energy (reflected PAR) than the needed energy was hitting the reaction centers of photosynthesis (Yordanov and Velikova, 2000; Luciński and Jackowski, 2006). The photosynthetic light response curve is asymptotic for fruit species with a maximum rate at a certain level of light intensity and curve unchanged afterward (Flore and Lakso, 1989). When light intensity tends to increase above light saturation rates, photoinhibition can impair photosynthesis (Taiz and Zeiger, 2010). Pliakoni and Nanos (2011) found similar results to this study that the reflective mulch resulted in a lower value of Fv/Fm (0.798) in the leaves of olive plants compared to unmulched treatment (0.825). In highbush blueberry, the maximum PSII photochemical efficiency decreased with an increase in PAR (Lobos et al., 2012). Percival et al. (2008) found a quadratic relationship between Fv/Fm values and SPAD readings in *Acer pseudoplatanus, Quercus robur, and Fagus sylvatica*, where Fv/Fm ratio started to decrease after a specific SPAD value when extrapolated.

5.3 Experiment 1: Objective 2. Effect of Plastic Mulch Colours and Fertility Amendments on Flowering and Fruit Set of Haskap.

For this objective, haskap cv. Indigo Gem was managed by altering growth and environment through plastic mulch colours and fertility amendments to affect the flowering and fruit set. It was hypothesized that Black plastic would stimulate earlier flowering than White plastic due to higher soil temperature and resulted in earlier bud-break in bushes under Black plastic. The fruit set would be lower under Black plastic as pollinators would be less active at the earlier flowering time during cooler air temperature. The increasing availability of soil nutrients was hypothesized to increase number of flowers, percentage fruit set, berry retention by having positive effects on reproductive tissues (pollen, ovules, and developing embryos) (Wubs et al., 2009; Arrington and DeVetter, 2017). The statistical analysis showed no significant differences between the White and Black plastic mulches and among fertility amendments levels based on flowering observations, and growth factor ($\frac{Final\ branch\ length - Initial\ branch\ length}{Initial\ branch\ length}$) of flagged branch over the growing season of 2018 (Table 8).

The study of fruit set and factors affecting it in haskap have not been previously reported in Canada to my knowledge or at the timing of writing this document. The absence of treatment effects on flower onset, number of flower pairs, fruit set, and number of green berries, branch growth factor might be due to small differences in soil temperature between Black and White plastic in April (2.3°C), and May (2°C) during bud break and flower initiation in 2018, thus there might not be a biologically significant difference in supply of metabolites as stated earlier in section 5.1.1. Greer et al. (2005) reported that apple trees store carbohydrates predominantly in roots and it is likely that soil temperature influences the rate and extent of bud break and flower opening by affecting carbohydrates mobilization. The author found, in contrast to this study, that increased soil temperature from 7° to 15°C increased the proportion of apple plant bud break, reduced the number of days to bud break, and flower opening. However, the difference in soil temperature in this research was small relative to that in the Greer et al. (2005) study.

There was no significant difference in canopy air temperature which might also be attributed to the absence of significant treatment effects on flowering observations. Mills et al. (2015) found no significant difference in flower opening in highbush blueberry grown under 20°C and 23°C temperature in a greenhouse. The small difference in fertilizer application rates might also be a possible reason for non-significant effects of fertility amendments on flowering observation in this study as mentioned earlier in section 5.1.2. Arrington (2017) found no significant difference in fruit set of highbush blueberry due to small difference in fertilizer application rates of calcium and boron.

The loss of berries at Early harvest was less than the loss at fruit set. The possible reasons for berry drop at Early harvest may be due to predation (Martin et al., 2008), uneven maturation due to long flowering period (berries from the earliest flowers may have dropped even before the early berry harvest), cultivar characteristics, crop management or weather conditions like heavy rainfall or high windfall (Guardiola, 1997), although these factors have not been investigated in this study or any other study in North America until now.

The flowering period was lengthy (approximately one month) and peaked at the middle of the flowering period. This implies that early flowers had fruit set days if not weeks ahead of the last flowers to emerge. This wide and uneven flowering period is likely to result in an uneven ripening period of berries. At Early harvest times, there is higher likelihood that berries from late emerging flowers will be underripe. Whereas at Late harvest, reverse would be true; berries from early flowers are likely to have ripened earlier and are at a higher risk of dropping. Thus, at least this cultivar of haskap could benefit from a compressed flowering period. This may be achieved through breeding. Alternatively, flower removal during the first few days or week of the flowering period is hypothesized to result in fewer berries but larger berries and more uniform ripening.

5.4 Experiment 2: Objective 3. Effect of Plastic Mulch Colours on Growing Environment of Haskap.

5.4.1 Soil Temperature and Moisture

Black plastic mulch recorded with high soil temperature (16.7°C) over the growing season 2018 (April to August) compared with White plastic mulch (15.3°C). The effects of plastic mulch are associated with their optical properties of absorbance, transmittance, and reflectance of shortwave and longwave radiations. The mean soil temperature under plastic mulch decreased with an increase in reflected PAR. Black colour transmits and reflects more longwave radiation and absorbs more shortwave radiation than white colour which transforms into thermal energy. This thermal energy is transmitted to the soil by conduction, which increases soil temperature. Similar results have been found in a study of effects of different coloured plastic mulches on bell pepper (Díaz-Pérez, 2010). Black plastic mulch had higher soil temperature (on average, 2.9°C) than white mulch (Shiukhy et al., 2005). White plastic resulted in the lowest soil temperature until the third week of June (Figure 7). The effect of plastic mulch on soil temperature was more evident during the early season as discussed above in section 5.1.1. After the third week of June, no difference in soil temperature among White and Black plastic was found due to an increase in haskap canopy cover. Díaz-Pérez et al. (2005) found that the shading of mulch surface by full canopy cover of tomatillo resulted in decreasing soil temperature differences among different coloured mulches.

Plastic mulch had no significant effect on soil moisture. There was no relationship found between root zone temperature and soil water content. The same amount of water was applied to bushes under White and Black plastic and no difference in soil moisture content between Black and White plastic treatments suggests that transpiration rate and/or water uptake between bushes under White and Black plastic mulch was not different. It is important to note that plastic mulches that were used in this experiment were made of low-density polyethylene, thus presumably having the same water vapor transfer properties. Hammermeister (unpublished data) also found that the difference of average soil moisture through the growing season between white (26.2%) and black (30.4%) plastic mulch was not significantly different in haskap. The difference in soil moisture between black and white plastic was not statistically significant in bell pepper (Díaz-Pérez (2010).

5.4.2 Reflected Photosynthetic Active Radiation

Expectedly, White mulch reflected significantly higher PAR as compared with Black mulch. However, increased PAR under White plastic did not stimulate leaf size, bush growth, flowering and yield of haskap in this study. The light levels needed for the formation and induction of haskap flower buds, efficient photosynthetic activity, and carbon assimilation have not been published until the time of writing this document. Green et al. (1995) and Layne and Rushing (1999) have measured an increase in reflected PAR when they applied reflective foils in the apple orchard. The reflected PAR from White plastic was 262% higher than Black coloured plastic in bell pepper (Díaz-Pérez, 2010). In tomato, white mulch colour reflected more PAR (47% of direct sunlight) into the canopy, measured 10 cm above the plastic surface, than black mulch (6% of direct sunlight) (Decoteau et al., 1988).

The effect of mulch on light reflection would be much greater in the first two years of haskap growth and seasonally in the spring before the leaf canopy develops and intercepts incident PAR and prevents reflection. The amount of reflected PAR from coloured mulch surface was reduced as the leaf area grows and shades the mulch (Csizinszky et al., 1995; Díaz-Pérez, 2010).

5.4.3 Canopy Air Temperature

In this study, despite the greatest amount of reflected PAR from the White plastic into the canopy relative to Black plastic, the canopy air temperature was not significantly affected by plastic mulch colours. The results (section 4.3.2) suggest that canopy air temperature at a height of 20 cm may be considered independent of optical properties of plastic mulch. Turbulent mixing over the plastic mulch surface might have been enough to dissipate high temperature plumes developing from mulches surfaces. The absence of significant effect might also be attributed to large canopy volume mid to late in the season, which decreased the penetration of incident radiation and consequently reduced the effects of plastic mulch. Thus, shades of canopy minimize the difference in canopy temperature between plastic mulches. Tarara (2000) reviewed that the total amount of energy directed at plant canopy is similar between black and white plastics. Although the optical properties are very different, sensible heat flux (convection) is higher from black than from white plastics, whereas reflectance toward the canopy is higher from white than from black plastics. Therefore, it might be expected that the total energy directed at the canopy via radiation and convection would be similar between Black and White plastics. Ham et al. (1993) reported similar results that the near-surface air temperature was not significantly affected by white and black plastic mulches and concluded that canopy air temperature above 5 cm of plastic surface was independent of its colours. The use of reflective film had no significant effect on canopy air temperature of apple and pear crops compared with bare soil (Vangdal et al., 2007; Privé et al., 2008; Iglesias and Alegre, 2009).

CHAPTER 6. CONCLUSION

This study was conducted on three-year-old haskap bushes to identify optimal sustainable management practices for haskap production by determining the impact of plastic mulch colours in combination with fertility amendments on haskap flowering, growth, yield and total soluble solids (TSS) with supplemental watering. There was no significant effect of fertility amendments and plastic mulch colour, or their interactions on bush growth, berry yield, and TSS of haskap cv. Indigo Gem. However, harvest timing did influence the yield components (calculated number of berries and 100-berry-weight) and TSS. Early harvest (90% of berries had turned colour) had a higher calculated number of berries per bush, lower berry weight and lower TSS than Late harvest (one week after Early harvest). Most of the leaf tissue nutrient concentrations were in the optimum range and were not affected by plastic mulch and fertility amendments. The effect of plastic mulch and fertility amendments was not significant on flower onset, flower duration, fruit set, or berry retention at the Early harvest of haskap.

It was also concluded that the initial bush size was an important factor affecting haskap performance. The initial bush size was most likely influenced by planting and management history. The bushes with smaller initial size had lower final size, calculated number of berries, and yield but higher growth factor than bushes with larger initial size after one year. The smaller bushes might be allocated more carbohydrates resources to the vegetative growth than to the yield. The bushes with poor growth would have a lower ability to respond to the treatments applied in this study which created variability in the analysis.

There was a wide range of factors contributing to the lack of treatment effects. Despite efforts to select uniform bushes and to block treatments, the high variability of initial bush size within and among experimental units within treatment was an important source of error that may have limited statistical significance. The lack of fertility amendments effect was attributed to adequate background soil fertility coupled with relatively modest fertilizer application levels. The wood mulch beneath the plastic mulch reduced the effectiveness of the fertility amendments, likely due to nutrient immobilization and also reduced the contact of the fertility amendments with soil, causing interference in the movement and availability of nutrients released from the fertilizers to the haskap roots. The timing of fertilizer application was later than preferred which shortened the time for bushes to respond to the fertility amendments.

The absence of plastic mulch colour effects on haskap performance could be explained by minimal observed treatment effects on the haskap growing environment in terms of soil temperature, canopy air temperature and potentially the amount of useable photosynthetically active radiation (PAR) reflected into the bush canopy. In addition, the wood chips under the plastic mulch reduced the effect of plastic mulch by hindering heat transfer between the air and soil, thus reducing the direct effect of plastic mulch on mineral soil temperature.

Total soluble solids of haskap berry significantly increased from Early harvest to Late harvest. The average bush °Brix increased by 2 when harvesting of berries was delayed for a week due to maturity, however, substantial drop of ripe berries was observed between Early and Late harvest. There was no difference in yield between Early and Late harvest as yield with lower berry number at Late harvest was compensated for by an increase in berry weight. However, there would be a loss in yield if harvesting is delayed too long. Haskap farmers might consider a late harvest timing for fresh fruit market to allow berries to develop a sweeter flavour, and early harvest timing for freezing or processing fruit market, however, berry drop and softness at Late harvest are important considerations.

6.1 Future Research

The results obtained in this study are encouraging in terms of haskap production, however, further research still needs to be carried out to obtain better understanding of the effect of the fertilizer and plastic mulch in combination with irrigation on the microclimate and performance haskap. The limitations encountered in this study that can be addressed by the following ways:

1. Wood chips are known to have high C:N ratio and its presence under plastic mulch reduced the effect of plastic mulch and fertilizer application. The effects of treatments can be maximized without wood mulch and laying plastic directly on the soil surface.
2. The timing of fertilizer application, especially with irrigation, may plays an important role in increasing yield, nutrient use efficiency and reduces nutrients loss. Thus, the fertilizer application timing especially under irrigation on soil with lower fertility needs to be investigated to meet the need of crop for nutrients at the right time.
3. In this study, treatment effects were measured after one year of application on the three years old bushes. However, some studies state that perennial fruit crops showed treatment effects over the long term, so multiple years of study may be needed to see the potential of the crop to respond to treatments. This can also be achieved by applying treatments at the beginning of the orchard plantation to get maximum benefits from the reflection of plastic mulch. The heat transfer from plastic mulch to plant canopy through convection would be expected more in young plants due to less vegetative parts.
4. Environmental conditions play a crucial role in determining plant growth and development. A greenhouse or controlled environment study may show the potential physiological response of the crops to the treatments under controlled conditions with less environmental variability.

5. The roots are the lifeline of a plant, taking up moisture and dissolved minerals from the soil and moving them up to the aboveground canopy. Roots of haskap affected by treatments were not studied in this experiment. For the detailed observations, future research could also examine the effects of plastic mulch colours and fertility amendments on the root growth.

6. The long flowering period in haskap resulted in uneven ripening of the berries and caused berry drop, softer berries, and lower TSS. Thus, techniques for narrowing the flowering period of haskap need to be explored, potentially by using flower thinning agents at the beginning and end of the flowering period which may reduce berry number but increase berry size and uniformity of ripening.

The results should be interpreted cautiously and applied to a single cultivar of haskap (Indigo Gem) growing in a particular environment and soil conditions. To assure transferability to field conditions, a future study is needed to extrapolate these results involving multiple cultivars of haskap over a longer period under various field or soil conditions (multiple sites) and it would be ideal in developing robust recommendations for farmers.

REFERENCES

Abbott, J. D., & Gough, R. E. (1987). Seasonal development of highbush blueberry roots under sawdust mulch. *Journal of the American Society for Horticultural Science, 112*(1), 60-62.

Abro, M. A., Lecompte, F., Bryone, F., & Nicot, P. C. (2013). Nitrogen fertilization of the host plant influences production and pathogenicity of *Botrytis cinerea* secondary inoculum. *Phytopathology*, *103*(3), 261-267.

Alam, M., & Zimmerman, R. (2003). Plastic mulch and subsurface drip irrigation. Effects on yield and Brix levels of Kabocha squash. *International Water and Irrigation*, *23*(2), 37-40.

Aliudin, T. (1986). Effect of soil tillage and application of mulch on yield of field grown garlic. *Buletin Penelitian Hortikultura, 8*, 12-15.

Andris, H., & Crisosto, C. (1996). Reflective materials enhance 'Fuji' apple color. *California Agriculture, 50*(5), 27-30.

Arrington, M. A. (2017). *Optimization of pollination and fruit set in northern highbush blueberry*. (Doctoral dissertation, Washington State University, USA). Retrieved from http://hdl.handle.net/2376/13045.

Arrington, M., & DeVetter, L. W. (2017). Foliar applications of calcium and boron do not increase fruit set or yield in northern highbush blueberry (*Vaccinium corymbosum*). *HortScience, 52*(9), 1259-1264.

Arus, L., & Kask, K. (2007). Edible honeysuckle (*Lonicera caerulea* var. Edulis)–underutilized berry crop in Estonia. *NJF Report, 3*(1), 33-35.

Ashworth, S., & Harrison, H. (1983). Evaluation of mulches for use in the home garden. *HortScience, 18*(2), 180-182.

Bakr, E. M. (2005). A new software for measuring leaf area, and area damaged by *Tetranychus urticae* Koch. *Journal of Applied Entomology*, *129*(3), 173-175.

Baeza, P., Junquera, P., Peiro, E., Lissarrague, J. R., Uriarte, D., & Vilanova, M. (2019). Effects of vine water status on yield components, vegetative response and must and wine composition. In A. Morata & I. Loira, *Advances in grape and wine biotechnology* (pp.344-401). London, UK: IntechOpen.

Bañados, M. P., Strik, B. C., Bryla, D. R., & Righetti, T. L. (2012). Response of highbush blueberry to nitrogen fertilizer during field establishment, I: accumulation and allocation of fertilizer nitrogen and biomass. *HortScience*, *47*(5), 648-655.

Barney, D. L., Bristow, P., Cogger, C. G., Fitzpatrick, S. M., Hart, J. M., Kaufman, D., ... & Rempel, H. (2007). *Commercial red raspberry production in the Pacific Northwest*. Miles: Pacific Northwest Extension publications.

Basiouny, F. M., & Chen, Y. (1988). Effects of harvest date, maturity and storage intervals on postharvest quality of Rabbiteye blueberry (*Vaccinium ashei* Reade). *Proceedings of the Florida State Horticultural Society, FL, 101*, 281-284.

Baskerville, G. L., & Emin, P. (1969). Rapid estimation of heat accumulation from maximum and minimum temperatures. *Ecology, 50*(3), 514-517.

Batjer, L. P., Rogers, B. L., & Thompson, A. H. (1952). Fertilizer applications as related to nitrogen, phosphorus, potassium, calcium, and magnesium utilization by apple trees. *Proceedings of the American Society for Horticultural Science, Alexandria, VA, 60,* 1-6.

Bell, A. A., Ough, C. S., & Kliewer, W. M. (1979). Effects on must and wine composition, rates of fermentation, and wine quality of nitrogen fertilization of *Vitis vinifera* var. Thompson Seedless grapevines. *American Journal of Enology and Viticulture, 30*(2), 124-129.

Bell, S., & Robson, A. (1999). Effect of nitrogen fertilization on growth, canopy density, and yield of *Vitis vinifera* L. cv. Cabernet Sauvignon. *American Journal of Enology and Viticulture, 50*(3), 351-358.

Belosohova, O., & Belosohov, F. (2010). Research of morphological and physiological changes of sweet-berry honeysuckle under the influence of ammonium, nitrate, ammonium-nitrate and amide nitrogen forms. *Scientific Bulletin of Belgorod State University. Series: Natural Sciences*, *9*, 49-53.

Benoit, G. R., Grant, W. J., Ismail, A. A., & Yarborough, D. E. (1984). Effect of soil moisture and fertilizer on the potential and actual yield of lowbush blueberries. *Canadian Journal of Plant Science, 64*(3), 683-689.

Bernier, G., & Périlleux, C. (2005). A physiological overview of the genetics of flowering time control. *Plant Biotechnology Journal*, *3*(1), 3-16.

Bextine, B., Wayadande, A., Bruton, B. D., Pair, S. D., Mitchell, F., & Fletcher, J. (2001). Effect of insect exclusion on the incidence of yellow vine disease and of the associated bacterium in squash. *Plant Disease, 85*(8), 875-878.

Björkman, O., & Demmig, B. (1987). Photon yield of O_2 evolution and chlorophyll fluorescence characteristics at 77 K among vascular plants of diverse origins. *Planta, 170*(4), 489-504.

Blanke, M. M. (2008). Alternatives to reflective mulch cloth (Extenday™) for apple under hail net? *Scientia Horticulturae, 116*(2), 223-226.

Bors, B. (2009). Growing Haskap in Canada - University of Saskatchewan. Retrieved from https://research-groups.usask.ca/fruit/documents/haskap/growinghaskapinCanada.pdf.

Bors, B. (2016). Haskap compatibility, flowering and ripening charts for U of SK varieties. University of Saskatchewan, Canada. Retrieved from https://gardening.usask.ca/documents/Haskap-bloom-ripe-charts.pdf.

Bors, B., Thomson, J., Sander, T., Oster, V., Sawatzky, R., Matthews, L., … & Kalcits, L. (2009). Haskap breeding and production, Final report to Saskatchewan Agriculture, Agriculture Developmnet Fund, Regina, Canada. Retrieved from http://www.agriculture.gov.sk.ca/apps/adf/ADFAdminReport/20060140.pdf.

Bors, B., Thomson, J., Sawchuk, E., Reimer, P., Sawatzky, R., Sander, T., ... & Dawson, J. (2012). Haskap breeding and production, Final report to Saskatchewan Agriculture, Agriculture Development Fund, Regina, Canada. Retrieved from http://www.agriculture.gov.sk.ca/apps/adf/ADFAdminReport/20080042.pdf.

Bould, C. (1969). Leaf analysis as a guide to the nutrition of fruit crops: VIII.—Sand culture N, P, K, mg experiments with black currant (*Ribes nigrum* L.). *Journal of the Science of Food and Agriculture, 20*(3), 172-181.

Bożek, M. (2007). Pollen productivity and morphology of pollen grains in two cultivars of honeyberry (*Lonicera kamtschatica* (Sevast.) Pojark.). *Acta Agrobotanica, 60*(1), 73-77.

Bożek, M. (2012). The effect of pollinating insects on fruiting of two cultivars of *Lonicera caerulea* L. *Journal of Apicultural Science, 56*(2), 5-11.

Brown, J. E., Goff, W. D., Dangler, J. M., Gouge, W., & West, M. S. (1992). Plastic mulch color inconsistently affects yield and earliness of tomato. *HortScience*, *27*(10).

Brunetto, G., Melo, G. W., Toselli, M., Quartieri, M., & Tagliavini, M. (2015). The role of mineral nutrition on yields and fruit quality in grapevine, pear and apple. *Revista Brasileira de Fruticultura, 37*(4), 1089-1104.

Bryla, D. R., Strik, B. C., Banados, M. P., & Righetti, T. L. (2012). Response of highbush blueberry to nitrogen fertilizer during field establishment—II. Plant nutrient requirements in relation to nitrogen fertilizer supply. *HortScience*, *47*(7), 917-926.

Bryla, D., & Machado, R. A. (2011). Comparative effects of nitrogen fertigation and granular fertilizer application on growth and availability of soil nitrogen during establishment of highbush blueberry. *Frontiers in Plant Science*, *2*, 1-18.

Bunty, S., & Sharma, C. L. (2010). Evaluation of mulch colour for enhancing winter-strawberry production under polyhouse in mid-hills of Himachal Pradesh. *Journal of Horticultural Sciences, 5*(1), 34-37.

Buskienė, L., & Uselis, N. (2008). The influence of nitrogen and potassium fertilizers on the growth and yield of raspberries cv. 'Polana'. *Agronomy research*, *6*(1), 27-35.

Carlson, J. D., & Hancock, J. F. (1991). A methodology for determining suitable heat-unit requirements for harvest of highbush blueberry. *Journal of the American Society for Horticultural Science, 116*(5), 774-779.

Casierra-Posada, F., Fonseca, E., & Vaughan, G. (2011). Fruit quality in strawberry (Fragaria sp.) grown on colored plastic mulch. *Agronomía Colombiana*, *29*(3), 407-413.

Castañeda-Ovando, A., de Lourdes Pacheco-Hernández, M., Páez-Hernández, M. E., Rodríguez, J. A., & Galán-Vidal, C. A. (2009). Chemical studies of anthocyanins: A review. *Food Chemistry*, *113*(4), 859-871.

Celton, J. M., Kelner, J. J., Martinez, S., Bechti, A., Touhami, A. K., James, M. J., ... & Costes, E. (2014). Fruit self-thinning: a trait to consider for genetic improvement of apple tree. *PLoS ONE*, *9*(3), e91016.

Chaovanalikit, A., Thompson, M. M., & Wrolstad, R. E. (2004). Characterization and quantification of anthocyanins and polyphenolics in blue honeysuckle (*Lonicera caerulea* L.). *Journal of Agricultural and Food Chemistry, 52*(4), 848-852.

Chen, Y., Zhang, F., Tang, L., Zheng, Y., Li, Y., Christie, P., & Li, L. (2007). Wheat powdery mildew and foliar N concentrations as influenced by N fertilization and belowground interactions with intercropped faba bean. *Plant and Soil*, *291*(1-2), 1-13.

Cheverie, R., David., & Ernst, E. (2013). Haskap production and marketing. In *Report Hemp, Hops and Haskap: The Next Big Thing?*. Nova Scotia: Canada. Perennia Food and Agriculture Inc., Retrieved from https://www.novascotia.ca/agri/documents/thinkfarm/3h-workshop-notes.pdf.

Christensen, L. P., Bianchi, M. L., Peacock, W. L., & Hirschfelt, D. J. (1994). Effect of nitrogen fertilizer timing and rate on inorganic nitrogen status, fruit composition, and yield of grapevines. *American Journal of Enology and Viticulture, 45*(4), 377-387.

Chung, H. D. (1987). Effects of PE film mulching, sulphur application and different levels of nitrogen and potassium on growth, flower-stalk elongation, bulbing, and leaf tip yellowing of garlic, *Allium sativum* L. cv. Euisung. *Journal of the Korean Society for Horticultural Science 28(1), 1-8*.

Clarkson, V. A., & Frazier, W. A. (1957). Plastic mulches for horticultural crops. (Bulletin 562). Corvallis, OR: Oregon State University, Agricultural Experiment Station. Retrieved from https://ir.library.oregonstate.edu/downloads/sj1392257.

Conradie, W. J., & Saayman, D. (1989). Effects of long-term nitrogen, phosphorus, and potassium fertilization on chenin blanc vines. II. leaf analyses and grape composition. *American Journal of Enology and Viticulture, 40*(2), 91-98.

Cooper, A. J. (1973). *Root temperature and plant growth: A review*. London, UK: Commonwealth Agricultural Bureaux.

Coventry, J. M., Fisher, K. H., Strommer, J. N., & Reynolds, A. G. (2005). Reflective mulch to enhance berry quality in Ontario wine grapes. *Acta Hortculturae, 689,* 95-102.

Craighead, M. D., Langford, G., Braithwaite, B., HortResearch, L., Council, N. Z. B., & Grant, M. S. F. F. (2007). *Tools to aid with the nitrogen nutrition of blackcurrants and boysenberries*. Balcairn, New Zealand: RJ Hill Laboratories Ltd. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.552.1958&rep=rep1&type=pdf.

Csizinszky, A. A., Schuster, D. J., & Kring, J. B. (1995). Color mulches influence yield and insect pest populations in tomatoes. *Journal of the American Society for Horticultural Science, 120*(5), 778-784.

Davis, J. M. (1994). Comparison of mulches for fresh-market basil production. *HortScience*, *29*(4), 267-268.

Dawson, J. (2017). *Concentration and Content of Secondary Metabolites* (Doctoral dissertation, University of Saskatchewan). Retrieved from http://hdl.handle.net/10388/7819.

Dean, D. M., Zebarth, B. J., Kowalenko, C. G., Paul, J. W., & Chipperfield, K. (2000). Poultry manure effects on soil nitrogen processes and nitrogen accumulation in red raspberry. *Canadian Journal of Plant Science*, *80*(4), 849-860.

Decoteau, D. R., Kasperbauer, M. J., & Hunt, P. G. (1989). Mulch surface color affects yield of fresh-market tomatoes. *Journal of the American Society for Horticultural Science, 114*(2), 216-219.

Decoteau, D., Kasperbauer, M., Daniels, D., & Hunt, P. (1988). Plastic mulch color effects on reflected light and tomato plant growth. *Scientia Horticulturae, 34*(3-4), 169-175.

Díaz-Pérez, J. C. (2010). Bell pepper (*Capsicum annum* L.) grown on plastic film mulches: Effects on crop microenvironment, physiological attributes, and fruit yield. *HortScience, 45*(8), 1196-1204.1993

Díaz-Pérez, J. C., & Batal, K. D. (2002). Colored plastic film mulches affect tomato growth and yield via changes in root-zone temperature. *Journal of the American Society for Horticultural Science, 127*(1), 127-135.

Díaz-Pérez, J. C., Phatak, S. C., Giddings, D., Bertrand, D., & Mills, H. A. (2005). Root zone temperature, plant growth, and fruit yield of tomatillo as affected by plastic film mulch. *HortScience, 40*(5), 1312-1319.

Domoto, P. (2011). Recognizing and correcting nutrient deficiencies in strawberries. *Iowa State University Extension*.

Dresler, S., Bednarek, W., Tkaczyk, P., & Hawrylak-Nowak, B. (2015). Estimation of the macro- and micronutrient status of raspberries grown in the lublin region. *Folia Horticulturae, 27*(1), 53-62.

Dubey, S. K. (1997). Co-inoculation of phosphorus solubilizing bacteria with *Bradyrhizobium japonicum* to increase phosphate availability to rainfed soybean on Vertisol. *Journal of the Indian Society of Soil Science*, *45*(3), 506-509.

Easterwood, G. W. (2002). Calcium's role in plant nutrition. *Fluid Journal*, *10*(4), 1-3.

Eaton, L. J., Stratto, G. W., & Sanderson, K. R. (1996). Fertilizer phosphorus in lowbush blueberries: effects and fate. *Acta Horticulture, 446*, 477-486.

Ehlenfeldt, M. K., & Martin Jr, R. B. (2010). Seed set, berry weight, and yield interactions in the highbush blueberry cultivars (*Vaccinium corymbosum* L.) 'Bluecrop' and 'Duke'. *Journal of the American Pomological Society, 64*(3), 162-172.

Ehret, D. L., Frey, B., Forge, T., Helmer, T., Bryla, D. R., & Zebarth, B. J. (2014). Effects of nitrogen rate and application method on early production and fruit quality in highbush blueberry. *Canadian Journal of Plant Science*, *94*(7), 1165-1179.

Eid, M. T., Black, C. A., & Kempthorne, O. (1951). Importance of soil organic and inorganic phosphorus to plant growth at low and high soil temperatures. *Soil Science Society of America Journal*, *15*(C), 89-89.

Einhorn, T. C., Turner, J., & Laraway, D. (2012). Effect of reflective fabric on yield of mature 'd'Anjou' pear trees. *HortScience, 47*(11), 1580-1585.

Elumalai, R. P., Nagpal, P., & Reed, J. W. (2002). A mutation in the Arabidopsis KT2/KUP2 potassium transporter gene affects shoot cell expansion. *The Plant Cell*, *14*(1), 119-131.

Emmert, E. M. (1957). Black polyethylene for mulching vegetables. *Proceedings of the American Society for Horticultural Sciences, 69*, 464-469.

Erb, W. A., Draper, A. D., & Swartz, H. J. (1993). Relation between moisture stress and mineral soil tolerance in blueberries. *Journal of the American Society for Horticultural Science*, *118*(1), 130-134.

Fageria, V. D. (2001). Nutrient interactions in crop plants. *Journal of Plant Nutrition, 24*(8), 1269-1290.

Farias-Larios, J., & Orozco-Santos, M. (1997). Effect of polyethylene mulch colour on aphid populations, soil temperature, fruit quality, and yield of watermelon under tropical conditions. *New Zealand Journal of Crop and Horticultural Science, 25*(4), 369-374.

Faust, M. (1989). *Physiology of temperate zone fruit trees*. NY, USA: John Wiley & Sons, Inc.

Field, S. K., Smith, J. P., Holzapfel, B. P., Hardie, W. J., & Emery, R. N. (2009). Grapevine response to soil temperature: Xylem cytokinins and carbohydrate reserve mobilization from budbreak to anthesis. *American Journal of Enology and Viticulture, 60*(2), 164-172.

Flore, J. A., & Lakso, A. N. (1989). Environmental and Physiological Regulation of Photosynthesis in Fruit. *Horticultural Reviews*, *11*, 111-157.

Forge, T. A., Hogue, E., Neilsen, G., & Neilsen, D. (2003). Effects of organic mulches on soil microfauna in the root zone of apple: implications for nutrient fluxes and functional diversity of the soil food web. *Applied Soil Ecology*, *22*(1), 39-54.

Forney, C. (1984). *Sugar uptake, fruit growth and carbon partitioning in the strawberry.* (Doctoral dissertation, Oregon State University). Retrieved from http://hdl.handle.net/1957/23576.

Frank, A. B. (1981). Effect of leaf age and position on photosynthesis and stomatal conductance of forage grasses 1. *Agronomy Journal, 73*(1), 70-74.

Frier, S. D., Somers, C. M., & Sheffield, C. S. (2016). Comparing the performance of native and managed pollinators of haskap (*Lonicera caerulea*: Caprifoliaceae), an emerging fruit crop. *Agriculture, Ecosystems & Environment, 219*, 42-48.

Fuqua, B., Byers, P., Kaps, M., Kovacs, L., and Waldstein, D. (2005). Growing blueberries in Missouri (Bulletin). Missouri State University. Retrieved from https://ag.missouristate.edu/assets/MtnGrv/B44GrowingBlueberries.pdf.

Goldschmidt, E. E. (1997). Basic and practical aspects of citrus trees' carbohydrate economy. In S. H. Futch & W. J. Kender, *Citrus Flowering & Fruiting Short Course* (pp. 63-72). Lake Alfred, FL: IFAS, Citrus Research and Education Center, University of Florida.

Gosselin, A., & Trudel, M. J. (1984). Interactions between root-zone temperature and light levels on growth, development and photosynthesis of *Lycopersicon esculentum* Mill. cultivar 'Vendor'. *Scientia Horticulturae, 23*(4), 313-321.

Gough, R. E. (2001). Color of plastic mulch affects lateral root development but not root system architecture in pepper. *HortScience, 36*(1), 6-68.

Graham, J. H., Leonard, R. T., & Menge, J. A. (1982). Interaction of light intensity and soil temperature with phosphorus inhibition of vesicular-arbuscular mycorrhiza formation. *New Phytologist*, *91*(4), 683-690.

Granier, C., & Tardieu, F. (1998). Is thermal time adequate for expressing the effects of temperature on sunflower leaf development? *Plant, Cell & Environment, 21*(7), 695-703.

Green, S. R., McNaughton, K. G., Greer, D. H., & McLeod, D. J. (1995). Measurement of the increased PAR and net all-wave radiation absorption by an apple tree caused by applying a reflective ground covering. *Agricultural and Forest Meteorology, 76*(3-4), 163-183.

Greer, D. H., Wünsche, J. N., Norling, C. L., & Wiggins, H. N. (2005). Root-zone temperatures affect phenology of bud break, flower cluster development, shoot extension growth and gas exchange of 'Braeburn' (*Malus domestica*) apple trees. *Tree Physiology, 26*(1), 105-111.

Grubinger, V. P., Minotti, P. L., Wien, H. C., & Turneti, A. D. (1993). Tomato response to starter fertilizer, polyethylene mulch, and level of soil phosphorus. *Journal of the American Society for Horticultural Science*, *118*(2), 212-216.

Guardiola, J. L. (1997). Overview of flower bud induction, flowering and fruit set. In S. H. Futch & W. J. Kender, *Citrus Flowering & Fruiting Short Course* (pp. 5-21). Lake Alfred, FL: IFAS, Citrus Research and Education Center, University of Florida.

Guidi, L., & Degl'Innocenti, E. (2012). Chlorophyll a fluorescence in abiotic stress. In B. Venkateswarlu, A. Shanker, C. Shanker & M. Maheswari, *Crop stress and its management: Perspectives and strategies* (pp. 359-398). Dordrecht: NY, Springer.

Gupta, R., & Acharya, C. L. (1993). Effect of mulch induced hydrothermal regime on root growth, water use efficiency, yield and quality of strawberry. *Journal of the Indian Society of Soil Science, 41*(1), 17-25.

Hall, G. E., Bondada, B. R., & Keller, M. (2011). Loss of rachis cell viability is associated with ripening disorders in grapes. *Journal of Experimental Botany*, *62*(3), 1145-1153.

Hall, I. V. (1978). *Vaccinium* species of horticultural importance in Canada. *Horticultural Abstracts*, *48*, 441-445.

Hall, I. V., Aalders, L. E., & McRae, K. B. (1982). Lowbush blueberry production in eastern canada as related to certain weather data. *Canadian Journal of Plant Science, 62*(3), 809-812.

Hall, I. V., Aalders, L. E., & Nickerson, N. L. (1979). The biological flora of Canada. 1. *Vaccinium angustifolium* Ait., sweet lowbush blueberry. *The Canadian Field-Naturalist, 93*, 415–430.

Ham, J. M., Kluitenberg, G. J., & Lamont, W. J. (1993). Optical properties of plastic mulches affect the field temperature regime. *Journal of the American Society for Horticultural Science, 118*(2), 188-193.

Hammermeister, A. M. (2016). Organic weed management in perennial fruits. *Scientia Horticulturae*, *208*, 28-42.

Hansen, P. (1985). The effect of cropping on the growth and flowering of black currants. *Acta Horticulturae, 183,* 323-330.

Hanson, E. J., & Retamales, J. B. (1992). Effect of nitrogen source and timing on highbush blueberry performance. *HortScience*, *27*(12), 1265-1267.

Hanson, E., & Hancock, J. (1996). Managing the nutrition of highbush blueberries. (Bulletin E-2011). East Lansing, Mich: Michigan State University.

Hart, 1., Strik, B., White, L., & Yang, W. (2006). *Nutrient management for blueberries in Oregon.* Corvallis, Oregon: Extension Service, Oregon State University. Retrieved from https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8918.pdf.

Hasan, M. F., Ahmed, B., Rahman, M. A., Alam, M. M., & Khan, M. (2005). Environmental effect on growth and yield of tomato. *Journal of Biological Sciences, 5*(6), 759-767.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2014). *Soil fertility and fertilizers: An introduction to nutrient management*. New Jersey: PHI Learning.

Haynes, R. J., & Goh, K. M. (1987). Effects of nitrogen and potassium applications on strawberry growth, yield and quality. *Communications in Soil Science and Plant Analysis*, *18*(4), 457-471.

Hicklenton, P. R., Reekie, J. Y., Gordon, R. J., & Percival, D. C. (2000). Seasonal patterns of photosynthesis and stomatal conductance in lowbush blueberry plants managed in a two-year production cycle. *HortScience, 35*(1), 55-59.

Himelrick, D. G., Dozier Jr, W. A., Wood, C. W., & Sharpe, R. R. (1993). Determination of strawberry nitrogen status with SPAD chlorophyll meter. *Advances in Strawberry Research*. 12, 49-53.

Himelrick, D. G., Wood, C. W., & Dozier Jr, W. A. (1992). Relationship between SPAD-502 meter values and extractable chlorophyll in strawberry. *Advances in Strawberry Research,* 11*, 59-61.*

Hobson, D. W. (2012). *Establishing Organic Blackcurrants in Atlantic Canada*. (Master's dissertation, Dalhousie University, Canada). Retrieved from http://hdl.handle.net/10222/14804.

Holford, I. C. R. (1997). Soil phosphorus: its measurement, and its uptake by plants. *Soil Research*, *35*(2), 227-240.

Holzapfel, B. P., Smith, J. P., Field, S. K., & Hardie, W. J. (2010). 3 dynamics of carbohydrate reserves in cultivated grapevines. *Horticultural Reviews, 37*, 143.

Homyak, P. M., Yanai, R. D., Burns, D. A., Briggs, R. D., & Germain, R. H. (2008). Nitrogen immobilization by wood-chip application: Protecting water quality in a northern hardwood forest. *Forest Ecology and Management, 255*(7), 2589-2601.

Hummer, K. E. (2006). Blue honeysuckle: A new berry crop for North America. *Journal of the American Pomological Society*, *60*(1), 3-8.

Hummer, K. E., Pomper, K. W., Postman, J., Graham, C. J., Stover, E., Mercure, E. W., Aradhya, M., ... Zee, F. (2012). *Emerging fruit crops*. In M. L. Badenes & D. H. Byrne, *Fruit breeding* (pp. 97-147). Boston, MA: Springer.

Idol, T. W., Pope, P. E., & Ponder Jr, F. (2003). N mineralization, nitrification, and N uptake across a 100-year chronosequence of upland hardwood forests. *Forest Ecology and Management, 176*(1-3), 509-518.

Iglesias, I., & Alegre, S. (2009). The effects of reflective film on fruit color, quality, canopy light distribution, and profitability of 'Mondial Gala' apples. *HortTechnology, 19*(3), 488-498.

Iheshiulo, E. M. A., Abbey, L., & Hammermeister, A. M. (2018a). Nutrient sufficiency levels for haskap (Lonicera caerulea L.) using the boundary-line approach. *Canadian Journal of Plant Science*, *99*(2), 268-280.

Iheshiulo, E. M. A., Abbey, L., & Hammermeister, A. M. (2018b). Nutrient requirements of haskap in Nova Scotia (Pamphlet). Retrieved from https://www.perennia.ca/wp-content/uploads/2019/11/haskap.tech_.bulletin3.15aug20182280.pdf.

Imanishi, H., Suzuki, T., Masuda, K., & Harada, T. (2000). Changes in freezing tolerance and soluble sugar composition in plants and calli of *Lonicera caerulea* L. during cold acclimation. *Acta Horticulturae*, *515*, 179-184.

Johnson, G. N., Young, A. J., Scholes, J. D., & Horton, P. (1993). The dissipation of excess excitation energy in British plant species. *Plant, Cell & Environment, 16*(6), 673-679.

Johnson, R. S., & Uriu, K. (1989). Mineral Nutrition. In J. H. Larue, *Peaches, plums, and nectarines: Growing and handling for fresh market* (pp. 68-81). Oakland, California: University of California. Division of Agricultural Natural Resources.

Ju, Z., Duan, Y., & Ju, Z. (1999). Effects of covering the orchard floor with reflecting films on pigment accumulation and fruit coloration in 'Fuji' apples. *Scientia Horticulturae, 82*(1-2), 47-56.

Kader, A. A. (2008). Flavor quality of fruits and vegetables. *Journal of the Science of Food and Agriculture*, *88*(11), 1863-1868.

Kasperbauer, M. J., & Loughrin, J. H. (2004). Butterbean seed yield, color, and protein content are affected by photomorphogenesis. *Crop Science*, *44*(6), 2123-2126.

Kasperbauer, M. J., Loughrin, J. H., & Wang, S. Y. (2001). Light Reflected from Red Mulch to Ripening Strawberries Affects Aroma, Sugar and Organic Acid Concentrations. *Photochemistry and photobiology*, *74*(1), 103-107.

Kehrberger, S., & Holzschuh, A. (2019). Warmer temperatures advance flowering in a spring plant more strongly than emergence of two solitary spring bee species. *PloS ONE*, *14*(6), e0218824.

Khan, A. A., Jilani, M. S., Khan, M. Q., & Zubair, M. (2011). Effect of seasonal variation on tuber bulking rate of potato. *Journal of Animal & Plant Sciences, 21*(1), 31-37.

Kim, E. J., Choi, D. G., & Jin, S. N. (2008). Effect of pre-harvest reflective mulch on growth and fruit quality of plum (*Prunus domestica* L.). *Acta Horticulturae, 772*, 323-326.

Kirnak, H., Kaya, C., Higgs, D., & Tas, I. (2003). Responses of drip irrigated bell pepper to water stress and different nitrogen levels with or without mulch cover. *Journal of Plant Nutrition*, *26*(2), 263-277.

Kitajima, M., & Butler, W. L. (1975). Quenching of chlorophyll fluorescence and primary photochemistry in chloroplasts by dibromothymoquinone. *Biochimica et Biophysica Acta-Bioenergetics, 376*(1), 105-115.

Kolasin, E., & Pozdnyakov, A. (1991). Knowledge on medicinal fruit, knowledge. Moscow, 38-59.

Korobkova, T. S. (2009). Introduction of honeysuckle into central Yakutiya. *Proceedings of the 1st Virtual International Scientific Conference on Lonicera caerulea* L., Russia, 158-161.

Kowalenko, C. G. (2005). Accumulation and distribution of micronutrients in Willamette red raspberry plants. *Canadian Journal of Plant Science, 85*(1), 179-191.

Kudo, M., Vagnoli, P., & Bisson, L. F. (1998). Imbalance of pH and potassium concentration as a cause of stuck fermentations. *American Journal of Enology and Viticulture, 49*(3), 295-301.

Lafarge, T., de Raïssac, M., & Tardieu, F. (1998). Elongation rate of sorghum leaves has a common response to meristem temperature in diverse African and European environmental conditions. *Field Crops Research*, *58*(1), 69-79.

Lamont, W. J. (1999). *Vegetable production using plasticulture*. Tapei City, China: Food & Fertilizer Technology Center.

Lamont, W. J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. *HortTechnology*, *15*(3), 477-481.

Lamont, W. J., Bartok, J. W., Berghage, R. D., Bonanno, A. R., Fiola, J. A., Garrison, S. A., ... & Orzolek, M. D. (2004). *Production of vegetables, strawberries, and cut flowers using* plasticulture. Ithaca, N.Y.: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension. Retrieved from https://hdl.handle.net/1813/69448.

Larson, K. (2009). *Haskap: An Introduction to the Fruit, Its Health Benefits, and Marketing Possibilities.* Retrieved from http://www.brokentineorchard.ca/images/biotech_project_Larson_2009.pdf.

Larsson, L. (1997). *Evaluation of mulching in organically grown black currant (Ribes nigrum) in terms of its effects on the crop and the environment* (Doctoral dissertation, Swedish University of Agricultural Sciences, Sweden).

Lauritzen, E., Maughan, T., & Black, B. (2015). Haskap (blue honeysuckle) in the garden. Utah: Utah State University Extension. Retrieved from https://digitalcommons.usu.edu/extension_curall/752/.

Layne, D. R., Jiang, Z., & Rushing, J. W. (2001). Tree fruit reflective film improves red skin coloration and advances maturity in peach. *HortTechnology, 11*(2), 234-242.

Layne, D. R., Jiang, Z., & Rushing, J. W. (2002). The influence of reflective film and ReTain on red skin coloration and maturity of ‘Gala' Apples. *HortTechnology, 12*(4), 640-645.

Lechaudel, M., Joas, J., Caro, Y., Genard, M., & Jannoyer, M. (2005). Leaf: Fruit ratio and irrigation supply affect seasonal changes in minerals, organic acids and sugars of mango fruit. *Journal of the Science of Food and Agriculture, 85*(2), 251-260.

Li, X., Wei, J., & Li, Y. (2012b). Physiological effects of nitrogen, phosphorus and potassium on blueberry 'Bluecrop'. *Acta Horticulturae, 926*, 347-351.

Li, Y. C., Alva, A. K., Calvert, D. V., & Zhang, M. (1998). A rapid nondestructive technique to predict leaf nitrogen status of grapefruit tree with various nitrogen fertilization practices. *HortTechnology*, *8*(1), 81-86.

Li, Y. D., Zhao, C., YN, L., GS, Z., YN, L., & GS, Z. (1994). Improving fruit quality of ‘Starking’ apple with silvery reflector film mulching. *Journal of Agricultural Science and Technology*, *6*, 19-21.

Li, Y., Liu, Y., Wang, Y., Niu, L., Xu, X., & Tian, Y. (2014). Interactive effects of soil temperature and moisture on soil N mineralization in a *Stipa krylovii* grassland in Inner Mongolia, China. *Journal of Arid Land*, *6*(5), 571-580.

Liakatas, A., Clark, J. A., & Monteith, J. L. (1986). Measurements of the heat balance under plastic mulches. Part I. Radiation balance and soil heat flux. *Agricultural and Forest Meteorology*, *36*(3), 227-239.

Lobos, G. A., Retamales, J. B., Hancock, J. F., Flore, J. A., Cobo, N., & del Pozo, A. (2012). Spectral irradiance, gas exchange characteristics and leaf traits of *Vaccinium corymbosum* L. ‘Elliott’ grown under photo-selective nets. *Environmental and Experimental Botany, 75*, 142-149.

Loughrin, J. H., & Kasperbauer, M. J. (2002). Aroma of fresh strawberries is enhanced by ripening over red versus black mulch. *Journal of agricultural and food chemistry*, *50*(1), 161-165.

Luciński, R., & Jackowski, G. (2006). The structure, functions and degradation of pigment-binding proteins of photosystem II. *Acta Biochimica Polonica, 53*(4), 693-708.

MacDonald, N. W., Zak, D. R., & Pregitzer, K. S. (1995). Temperature effects on kinetics of microbial respiration and net nitrogen and sulfur mineralization. *Soil Science Society of America Journal*, *59*(1), 233-240.

Maib, K. M. (1996). *Tree fruit physiology: Growth and development: a comprehensive manual for regulating deciduous tree fruit growth and development*. Yakima, Washington: Good Fruit Grower.

Mancinelli, A. L. (1985). Light-dependent anthocyanin synthesis: a model system for the study of plant photomorphogenesis. *The Botanical Review*, *51*(1), 107-157.

Marková, R. (2001). Study of vegetative, growing and economic character of genus *Lonicera* subsect. *caerulea*. *Proceedings of 9th international conference of horticulture, Lednice. Czech Republic, 1,* 130-135.

Marschner, H. (1995). *Mineral nutrition of higher plants*. London, UK: Academic press.

Martin, R. R., Tzanetakis, I. E., Caruso, F. L., & Polashock, J. J. (2008). Emerging and reemerging virus diseases of blueberry and cranberry. *Acta Horticulturae*, *810,* 299-304.

Martínez-Alcántara, B., Martínez-Cuenca, M., Bermejo, A., Legaz, F., & Quinones, A. (2016). Liquid organic fertilizers for sustainable agriculture: Nutrient uptake of organic versus mineral fertilizers in citrus trees. *PLoS ONE, 11*(10).

Mathieu, V., & D'Aure, R. (2000). Apple, a reflective film for improving colour. *Infos Paris, 160*, 37-41.

Mattson, N. S., & Van Iersel, M. W. (2011). Application of the "4R" nutrient stewardship concept to horticultural crops: Applying nutrients at the "right time". *HortTechnology*, *21*(6), 667-673.

Maxwell, K., & Johnson, G. N. (2000). Chlorophyll fluorescence - a practical guide. *Journal of Experimental Botany, 51*(345), 659-668.

May, G. M., & Pritts, M. P. (1993). Phosphorus, zinc, and boron influence yield components in 'Earliglow' strawberry. *Journal of the American Society for Horticultural Science, 118*(1), 43-49.

McCarthy, T. P., & Stoker, R. (1988). Effect of irrigation on yield, berry weight, and sugar content of blackcurrants. *New Zealand Journal of Experimental Agriculture, 16*(4), 321-327.

Medina, Y., Gosselin, A., Desjardins, Y., Gauthier, L., Harnois, R., & Khanizadeh, S. (2008). Effect of plastic mulches on microclimate conditions, growth and yields of strawberry plants grown under high tunnels in northern Canadian climate. *Acta Horticulturae*, *842,* 139-142.

Mehdi, K., Reza, M. M., Reza, K. A., & Soheila, R. (2008). EvaluatioSHAH of manganese, boron, potassium, calcium and zinc effects on yield and fruit quality of barberry (*Berberis vulgaris* L.) plants. *Horticulture Environment and Biotechnology, 49*(5), 293-297.

Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in soil science and plant analysis*, *15*(12), 1409-1416.

Meinhold, T., Damerow, L., & Blanke, M. (2011). Reflective materials under hailnet improve orchard light utilisation, fruit quality and particularly fruit colouration. *Scientia Horticulturae, 127*(3), 447-451.

Miller, S. S., & Greene, G. M. (2003). The use of reflective film and ethephon to improve red skin color of apples in the Mid-Atlantic region of the United States. *HortTechnology*, *13*(1), 90-99.

Mills, S. A., Park, S., Park, Y. L., & Waterland, N. L. (2015). Effect of Temperature on the Floral Development of Blueberries (*Vaccinium corymbosum* L.). West Virginia University.

Monette, S., & Stewart, K. A. (1987). The effect of a windbreak and mulch on the growth and yield of pepper (*Capsicum annuum* L.). *Canadian Journal of Plant Science*, *67*(1), 315-320.

Montgomery, D. C. (2017). *Design and analysis of experiments* (9th ed.). Hoboken, NY: John Wiley & Sons.

Moreshet, S., Stanhill, G., & Fuchs, M. (1975). Aluminum mulch increases quality and yield of 'Orleans' apples. *HortScience*, *10*, 390-391.

Motamedi, S., Jafarpour, M., & Shams, J. (2013). Evaluation of nutrition on flower number and yield of strawberry in greenhouse. *International Journal of Agriculture and Crop Sciences, 5*(18), 2091-2095.

Muñoz-Huerta, R. F., Guevara-Gonzalez, R. G., Contreras-Medina, L. M., Torres-Pacheco, I., Prado-Olivarez, J., & Ocampo-Velazquez, R. V. (2013). A review of methods for sensing the nitrogen status in plants: Advantages, disadvantages and recent advances. *Sensors, 13*(8), 10823-10843.

Mylavarapu, R. S. (2010). Diagnostic nutrient testing. *HortTechnology*, *20*(1), 19-22.

Naraguma, J., & Clark, J. R. (1997). Effect of N fertilization on 'Arapaho' Thornless blackberry. *HortScience*, *32*(4), 596.

Neilsen, D., Hogue, E. J., Neilsen, G. H., & Parchomchuk, P. (1995). Using SPAD-502 values to assess the nitrogen status of apple trees. *HortScience*, *30*(3), 508-512.

Neilsen, G. H., Neilsen, D., Bowen, P., Bogdanoff, C., & Usher, K. (2010). Effect of timing, rate, and form of N fertilization on nutrition, vigor, yield, and berry yeast-assimilable N of grape. *American journal of enology and viticulture*, *61*(3), 327-336.

Ngouajio, M., & Ernest, J. (2005). Changes in the physical, optical, and thermal properties of polyethylene mulches during double cropping. *HortScience, 40*(1), 94-97.

Niskanen, R. (2002). Nutritional status in commercial currant fields. *Agricultural and Food Science in Finland*, 11, 301-310.

Niu, J. Y., Gan, Y. T., & Huang, G. B. (2004). Dynamics of root growth in spring wheat mulched with plastic film. *Crop Science, 44*(5), 1682-1688.

Nova Scotia Department of Agriculture (NSDA). (2010). Soil test interpretation ratings for Nova Scotia crops. Retrieved from https://novascotia.ca/agri/documents/lab-services/analytical-lab-soil-interpretation.pdf.

Ochmian, I., Grajkowski, J., & Skupien, K. (2010). Yield and chemical composition of blue honeysuckle fruit depending on ripening time. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture, 67*(1), 138-147.

O'Connor, J. (2015, September 18). Better than blueberries? Introducing Canada's new super food - the haskap berry. *National Post*. Retrieved from https://nationalpost.com/news/canada/better-than-blueberries-introducing-canadas-new-super-food-the-haskap-berry.

Olmstead, S. (2019). *Pollinators and pollination of Haskap (Lonicera caerulea* L.*) in Southern Nova Scotia* (Master's dissertation, Dalhousie University, Canada). Retrieved from http://hdl.handle.net/10222/75245.

Olson, A. R., & Eaton, L. J. (2001). Spring frost damage to placental tissues in lowbush blueberry flower buds. *Canadian Journal of Plant Science*, *81*(4), 779-781.

Ontario Ministry of Agriculture, Food & Rural Affairs (OMAFRA). (2012). Haskap. Retrieved from http://www.omafra.gov.on.ca/CropOp/en/spec_fruit/berries/hask.html.

Opstad, N., Nes, A., Måge, F., & Hageberg, B. (2007). Effects of fertilization and climatic factors in a long-term experiment with blackcurrant (*Ribes nigrum* L.) cv. Ben Tron. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science, 57*(4), 313-321.

Oyebode, O., Gordon-Dseagu, V., Walker, A., & Mindell, J. S. (2014). Fruit and vegetable consumption and all-cause, cancer and CVD mortality: Analysis of health survey for England data. *J Epidemiol Community Health, 68*(9), 856-862.

Palma, M. J., Retamales, J. B., Sánchez, S., & Maldonado, G. (2014). Yield components and fruit quality of highbush blueberries (*Vaccinium corymbosum* L.) in three production areas in the Maule region, chile. *Acta Horticulturae, 1117,* 125-132.

Patrick, A. E., Smith, R., Keck, K., & Berry, A. M. (2004). Grapevine uptake of 15N-labeled nitrogen derived from a winter-annual leguminous cover-crop mix. *American Journal of Enology and Viticulture, 55*(2), 187-190.

Percival, D. C., Janes, D. E., Stevens, D. E., & Sanderson, K. (2002). Impact of multiple fertilizer applications on plant growth, development, and yield of wild lowbush blueberry (*Vaccinium angustifolium* Aiton). *Acta Horticulturae*, *626,* pp. 415-421.

Percival, G. C., Keary, I. P., & Noviss, K. (2008). The potential of a chlorophyll content SPAD meter to quantify nutrient stress in foliar tissue of sycamore (*Acer pseudoplatanus*), English oak, (*Quercus robur*), and European beech (*Fagus sylvatica*). *Arboriculture and Urban Forestry, 34*(2), 89.

Plaster, E. J. (2009). *Soil science and management.* NY: Delmar, Cengage Learning Inc.

Plekhanova, M. N. (1989). Actinidia, Schizandra, and blue honeysuckle. *Agropromizdat*, *88*.

Plekhanova, M. N. (1992). Blue honeysuckle: a new berry crop in Russia. *Pomona 29*(1), 46–48.

Plekhanova, M. N. (2000). Blue honeysuckle (*Lonicera caerulea* L.)-a new commercial berry crop for temperate climate: genetic resources and breeding. *Acta Horticulturae, 538*, 159-164.

Pliakoni, E. D., & Nanos, G. D. (2011). Influence of deficit irrigation and reflective mulch on 'konservolea' olive leaf physiology during the growing period. *Acta Horticulturae, 888*, 199-204.

Porro, D., Dorigatti, C., Stefanini, M., & Ceschini, A. (2001). Use of SPAD meter in diagnosis of nutritional status in apple and grapevine. *Acta Horticulturae*, *564*, 243-252.

Power, J. F., Grunes, D. L., Reichman, G. A., & Willis, W. O. (1964). Soil Temperature Effects on Phosphorus Availability. *Agronomy Journal*, *56*(6), 545-548.

Prischepina, G. (2000). *Culture of Altai honeysuckle (Lonicera altaica* Pall.*) in the forest-steppe zone of the Altai territory* (Doctoral dissertation, Altai State Agrarian University, Russia).

Privé, J. P., Russell, L., & Leblanc, A. (2008). Use of Extenday reflective groundcover in production of ‘Gala’ apples (*Malus domestica*) in New Brunswick, Canada: 1. Impact on canopy microclimate and leaf gas exchange. *New Zealand Journal of Crop and Horticultural Science*, *36*(4), 221-231.

Quartieri, M., Millard, P., & Tagliavini, M. (2002). Storage and remobilisation of nitrogen by pear (Pyrus communis L.) trees as affected by timing of N supply. *European Journal of Agronomy*, *17*(2), 105-110.

Raese, J. T. (2002). Phosphorus deficiency symptoms in leaves of apple and pear trees as influenced by available soil phosphorus. *Communications in Soil Science and Plant Analysis, 33*(3-4), 461-477.

Rahman, N., & Shadeque, A. (1999). Comparative efficacy of mulches with or without an herbicide on growth and yield of lady’s finger [*Abelmoschus esculentus* (L.) Moench (var. Vijaya)]. *Journal of the Agricultural Science Society of North East India, 12*, 123-127.

Reekie, E. G., & Bazzaz, F. A. (1987). Reproductive effort in plants. 1. carbon allocation to reproduction. *The American Naturalist, 129*(6), 876-896.

Rhodes, P. J. (1986). Growth and yield of black currant (*Ribes nigrum*) established from cuttings. *New Zealand Journal of Experimental Agriculture, 14*(1), 63-69.

Rosen, C. J., & Eliason, R. (1996). Nutrient Management for Commercial Fruit & Vegetable Crops in Minnesota (Bulletin). University of Minnesota Extension Service. Retrieved from https://conservancy.umn.edu/bitstream/handle/11299/197955/nutrient-management-commercial-fruit-vegetable-2005.pdf?sequence=1.

Rubinskienė, M., Viškelis, P., Stanys, V., Šikšnianas, T., & Sasnauskas, A. (2008). Quality changes in black currant berries during ripening. *Sodininkystė Ir Daržininkystė, 27*(2), 235-243.

Rupasinghe, H. V., Arumuggam, N., Amararathna, M., & De Silva, A. B. K. H. (2018). The potential health benefits of haskap (*Lonicera caerulea* L.): Role of cyanidin-3-O-glucoside. *Journal of Functional Foods*, *44*, 24-39.

Rupasinghe, H. V., Yu, L. J., Bhullar, K. S., & Bors, B. (2012). Haskap (*Lonicera caerulea*): A new berry crop with high antioxidant capacity. *Canadian Journal of Plant Science*, *92*(7), 1311-1317.

Sabitov, A., Chebukin, P., & Hummer, K. E. (2006). Plant exploration for fruit genetic resources in sakhalin territory. *Acta Horticulturae*, *760,* 381-388.

Saikia, S., Saikia, A., Shadeque, A., & Gogoi, S. (1997). Field performance of okra as influenced by low density plastic mulches. *Annals of Biology, 13*, 253-258.

Sako, J., & Laurinen, E. (1979). The effect of fertilization on the black currant in two soils. *Annales Agriculturae Fenniae, 18*, 96-105.

Salvo, S., Muñoz, C., Ávila, J., Bustos, J., Ramírez-Valdivia, M., Silva, C., & Vivallo, G. (2012). An estimate of potential blueberry yield using regression models that relate the number of fruits to the number of flower buds and to climatic variables. *Scientia horticulturae*, *133*, 56-63.

Schales, F. D., & Sheldrake Jr, R. (1966). Mulch effects on soil conditions and muskmelon response. *Proceedings of the American Society for Horticultural Sciences, 88*, 425-430.

Schepers, J. S., Francis, D. D., Vigil, M., & Below, F. E. (1992). Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. *Communications in Soil Science and Plant Analysis, 23*(17-20), 2173-2187.

Schreiber, U., Schliwa, U., & Bilger, W. 1. (1986). Continuous recording of photochemical and non-photochemical chlorophyll fluorescence quenching with a new type of modulation fluorometer. *Photosynthesis Research, 10*, 51-62.

Schreiner, R. P., Lee, J., & Skinkis, P. A. (2013). N, P, and K supply to pinot noir grapevines: impact on vine nutrient status, growth, physiology, and yield. *American Journal of Enology and Viticulture, 64*(1), 26-38.

Shahrokhi, M., Eshghi, S., Tafazoli, E., & Tehranifar, A. (2008). Interaction of foliar application of paclobutrazol and manganese sulfate on vegetative and reproductive growth of strawberry cv. Paros. *Advances in Natural and Applied Sciences*, *2*(1), 21-26.

Shapiro, C. A., Schepers, J. S., Francis, D. D., & Shanahan, J. F. (2006). Using a chlorophyll meter to improve N management. NebGuide G1632. Lincoln, NE: Cooperative Extension Service, University of Nebraska. Retrieved from https://efotg.sc.egov.usda.gov/references/public/MI/Chlorophyll_Meter_N.pdf.

Shinde, D. (1997). *Modeling coupled water-heat flow and impacts upon chemical transport in mulched soil beds*. (Doctoral dissertation, University of Florida). Retrieved from http://ufdc.ufl.edu/AA00012978/00001.

Shiukhy, S., Raeini-Sarjaz, M., & Chalavi, V. (2015). Colored plastic mulch microclimates affect strawberry fruit yield and quality. *International journal of biometeorology*, *59*(8), 1061-1066.

Sibley, J. L., Eakes, D. J., Gilliam, C. H., Keever, G. J., Dozier, W. A., & Himelrick, D. G. (1996). Foliar SPAD-502 meter values, nitrogen levels, and extractable chlorophyll for red maple selections. *HortScience, 31*(3), 468-470.

Siefker, J. H., & Hancock, J. F. (1986). Yield component interactions in cultivars of the highbush blueberry. *Journal of the American Society for Horticultural Science*, *111*(4), 606-608.

Siegelman, H. W., & Hendricks, S. B. (1958). Photocontrol of anthocyanin synthesis in apple skin. *Plant Physiology*, *33*(3), 185.

Simson, S. P., & Straus, M. C. (2010). *Post-harvest technology of horticultural crops*. Jaipur, India: Oxford Book Co.

Sivak, M. N., & Walker, D. A. (1986). Photosynthesis in vivo can be limited by phosphate supply. *New Phytologist, 102*(4), 499-512.

Skene, K., & Kerridge, G. H. (1967). Effect of root temperature on cytokinin activity in root exudate of *Vitis vinifera* L. *Plant Physiology, 42*(8), 1131-1139.

Skinner, P. W., & Matthews, M. A. (1989). Reproductive development in grape (*Vitis vinifera* L.) under phosphorus-limited conditions. *Scientia Horticulturae*, *38*(1-2), 49-60.

Sønsteby, A., Nes, A., & Måge, F. (2004). Effects of bark mulch and NPK fertilizer on yield, leaf nutrient status and soil mineral nitrogen during three years of strawberry production. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science, 54*(3), 128-134.

Spayd, S. E., Tarara, J. M., Mee, D. L., & Ferguson, J. C. (2002). Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. *American Journal of Enology and Viticulture*, *53*(3), 171-182.

Spectrum Analytic. (2011a). Agronomic Library: Phosphorous basics. Retrieved from https://spectrumanalytic.com/support/library/ff/P_Basics.htm.

Spectrum Analytic. (2011b). Agronomic Library: Potassium basics. Retrieved from https://www.spectrumanalytic.com/support/library/ff/Potassium_basics.htm.

Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., ... & Schaumann, G. E. (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?. *Science of the Total Environment*, *550*, 690-705.

Strik, B. C., Brun, C., & Oregon State University. (1993). *Highbush blueberry production*. Corvallis, Or: Oregon State University Extension Service.

Taiz, L., & Zeiger, E. (2010). *Plant Physiology.* (5th ed.). Sunderland, Massachusetts: Sinauer Associates Inc.

Tanaka, K., & Hashimoto, S. (2006). Plant canopy effects on soil thermal and hydrological properties and soil respiration. *Ecological Modelling*, *196*(1-2), 32-44.

Tarara, J. M. (2000). Microclimate modification with plastic mulch. *HortScience*, *35*(2), 169-180.

Taylor, N. (2015). *Characterization of Ribes nigrum* L. *fruit quality in relation to fruit maturity, genotype and growing location* (Master's dissertation, Dalhousie University, Canada). Retrieved from http://hdl.handle.net/10222/56760.

Thompson, A. K. (2003). *Fruit and vegetables: Harvesting, handling and storage*. Hoboken, New Jersey: Willey-Blackwell.

Thompson, M. M. (2006). Introducing haskap, Japanese blue honeysuckle. *Journal of the American Pomological Society, 60*(4), 164.

Thompson, M. M., & Barney, D. L. (2007). Evaluation and breeding of haskap in north America. *Journal of the American Pomological Society, 61*(1), 25-32.

Tindall, J. A., Mills, H. A., & Radcliffe, D. E. (1990). The effect of root zone temperature on nutrient uptake of tomato. *Journal of Plant Nutrition, 13*(8), 939-956.

Tiwari, K. N., Mal, P. K., Singh, R. M., & Chattopadhyay, A. (1998). Response of okra (*Abelmoschus esculentus* L.) Moench.) to drip irrigation under mulch and non-mulch conditions. *Agricultural Water Management, 38*(2), 91-102.

Todic, S., Beslic, Z., Vajic, A., & Tesic, D. (2008). The effect of reflective plastic foils on berry quality of Cabernet Sauvignon. *Bulletin in 30th International Organisation of Vine and Wine*, *81*, 165-175.

Torres-Olivar, V., Valdez-Aguilar, L. A., Crdenas-Flores, A., Lira-Saldivar, H., Hernndez-Surez, M., & Ibarra-Jimnez, L. (2016). Effect of colored plastic mulch on growth, yield and nutrient status in cucumber under shade house and open field conditions. *Journal of Plant Nutrition, 39*(14), 2144-2152.

Townsend, L. R., & I. V. Hall. (1970). Trends in nutrient levels of lowbush blueberry leaves during four consecutive years of sampling. *Naturaliste Canadien*, 97, 461-466.

Trejo-Téllez, L. I., & Gómez-Merino, F. C. (2014). Nutrient management in strawberry: Effects on yield, quality and plant health. *Strawberries,* 239-267.

Tremblay, C., Deslauriers, A., Lafond, J., Lajeunesse, J., & Paré, M. C. (2019). Effects of soil pH and fertilizers on haskap (*Lonicera caerulea* L.) vegetative growth. *Agriculture*, *9*(3), 56.

Tucker, D. P., Alva, A. K., Jackson, L. K., & Wheaton, T. A. (1995). *Nutrition of Florida citrus trees*. Gainesville, FL: Cooperative Extension Service, University of Florida, Institute of Food and Agricultural Sciences.

Tuell, J. K., & Isaacs, R. (2010). Weather during bloom affects pollination and yield of highbush blueberry. *Journal of Economic Entomology*, *103*(3), 557-562.

Valdez-Fields, F., Radillo-Juarez, F., & Farias-Larios, J. (2002). Effects of colored plastic on the growth and yield of two cultivars of eggplant (*Solanum melongena* L.) in West Mexico. *American Society for Plasticulture, 30,* 155-159.

van Donk, S. J., Lindgren, D. T., Schaaf, D. M., Petersen, J. L., & Tarkalson, D. D. (2011). Wood chip mulch thickness effects on soil water, soil temperature, weed growth and landscape plant growth. *Journal of Applied Horticulture, 13*(2), 91-95.

Vangdal, E., Meland, M., & Hjeltnes, S. (2007). Reflective Mulch (Extenday^{TM}) in fruit orchards - preliminary results. *Acta Horticulturae, 732*, 665-668.

Voorhees, W. B., Allmaras, R. R., & Johnson, C. E. (1981). Alleviating temperature stress. In G. F. Arkin & H. M. Taylor, *Modifying the root environment to reduce crop stress* (pp. 217-266). St. Joseph, Mich: American Society of Agricultural Engineers.

Voth, V., & Bringhurst, R. (1962). Early mulched strawberries: Early mulching of winter-planted strawberries with clear polyethylene gives gross yield increases. *California Agriculture*, *16*(2), 14-15.

Wang, S. Y., & Camp, M. J. (2000). Temperatures after bloom affect plant growth and fruit quality of strawberry. *Scientia Horticulturae, 85*(3), 183-199.

Webb, K.T., Thompson, R.L., Beke, G.J., Nowland, J.L. (1991). *Soils of Colchester county Nova Scotia report. no. 19*. Retrieved from http://sis.agr.gc.ca/cansis/publications/surveys/ns/ns19b/index.html.

Weil, R. & Brady, N. (2017). *The nature and properties of soils* (15th ed.). Columbus, Ohio: Pearson.

Whiting, M. D., Toye, J., & Rodriguez, C. (2008). Preliminary testing of a reflective ground cover: sweet cherry growth, yield and fruit quality. *Acta Horticulturae*, *795*, 557-560.

Wien, H. C., Minotti, P. L., & Grubinger, V. P. (1993). Polyethylene mulch stimulates early root growth and nutrient uptake of transplanted tomatoes. *Journal of the American Society for Horticultural Science*, *118*(2), 207-211.

Wilding, L. P., Bouma, J., & Goss, D. W. (1994). Impact of spatial variability on interpretive modeling. *Quantitative Modeling of Soil Forming Processes, 39*, 61-75.

Wilding, L. P., Bouma, J., & Goss, D. W. (1994). Impact of spatial variability on interpretive modeling. In R. B. Bryant & R. W. Arnold (39th ed.), *Quantitative modeling of soil forming processes* (pp. 61-75). Madison, WI: SSSA, Inc.

Winkler, A. J., Cook, J. A., Kliewer, W. M., & Lider, L. A. (1974). *General viticulture*. Berkeley: University of California Press.

Wójcik, P., & Filipczak, J. (2015). Growth and early fruit production of 'Tiben' blackcurrants fertilised with pre-and post-planting applications of mineral fertilisers and swine manure. *Scientia Horticulturae*, *185*, 90-97.

Wolf, B. (1982). A comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. *Communications in Soil Science and Plant Analysis*, *13*(12), 1035-1059.

Wood, C. W., Reeves, D. W., & Himelrick, D. G. (1993). Relationships between chlorophyll meter readings and leaf chlorophyll concentration, N status, and crop yield: a review. *Proceedings of the Agronomy Society of New Zealand*, *23*, 1-9.

Wubs, A. M., Ma, Y., Hemerik, L., & Heuvelink, E. (2009). Fruit set and yield patterns in six *Capsicum* cultivars. *HortScience, 44*(5), 1296-1301.

Yadong, L., Shuang, Z., Hanping, D., Xiuwu, G., Hummer, K., Strik, B., et al. (2009). Effects of nitrogen, phosphorus and potassium on growth, fruit production and leaf physiology in blueberry. *Acta Horticulturae, 810*, 759-764.

Yáñez, P., Retamales, J. B., Lobos, G. A., & Del Pozo, A. (2009). Light environment within mature rabbiteye blueberry canopies influences flower bud formation. *Acta Horticulturae, 810*, 471-473.

Yordanov, I., & Velikova, V. (2000). Photoinhibition of photosystem 1. *Bulgarian Journal of Plant Physiology, 26*(1-2), 70-92.

Zelleke, A., & Kliewer, W. M. (1979). Influence of root temperature and rootstock on budbreak, shoot growth, and fruit composition of cabernet sauvignon grapevines grown under controlled conditions. *American Journal of Enology and Viticulture, 30*(4), 312-317.

Zhi, X., Han, Y., Mao, S., Wang, G., Feng, L., Yang, B., ... & Li, Y. (2014). Light spatial distribution in the canopy and crop development in cotton. *PLoS ONE*, *9*(11), e113409.