Effect of Harvesting Time on Berry Losses During Mechanical Harvesting of Wild Blueberries

by

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ABSTRACT

More than 90% of the total wild blueberry crop area in Canada is mechanically harvested. Only fields in rough terrain are still hand raked. Prior to this study, there were no identified protocols related to fruit maturity and time of harvest that could be used to minimize fruit losses and/or improve berry quality during harvesting. In this study, wild blueberry fields were selected in the Atlantic Provinces to examine the impact of different harvest times on the berry picking efficiency of a wild blueberry harvester. The results revealed that fruit losses of 17%, 21% and 23% were observed in early, middle and late season harvesting, respectively. The results also showed that higher ground speed in concomitance with higher header rpm resulted in substantially increased fruit losses in each harvesting season. These losses became more significant in late season due to the presence of over-ripened berries. Results of physico-chemical composition of wild blueberries suggested that total soluble solids and anthocyanin contents increased gradually from early to late season and the highest increase in total soluble solids were observed in middle season, while most pigment accumulation in blueberries took place in early and middle season. A significant decrease in acidity and an increase in TSS:TA were noticed in middle and late season harvesting. The maximum gain in moisture content, expansion in diameter and increase in weight were observed in middle season harvesting, while reduction in moisture, shrinkage of berries and loss of weight occurred in late season. This information would help the wild blueberry producers to develop a timely harvest plan and adjust machine parameters appropriately to reduce fruit loss during mechanical harvesting.

LIST OF ABBREVIATIONS AND SYMBOLS USED

$ – Canadian dollar

$\bar{O}$ – Mean of Observed values

μL – Microliter

^{0}C – Degree Centigrade

AC – Anthocyanin Content

AD – Anderson Darling

ANCOVA – Analysis of Covariance

ANOVA – Analysis of Variance

BGP – Blue Green Pixel

BL – Blower Loss

cm – Centimeter

CRBD – Completely Randomized Block Design

CV – Coefficient of Variance

CY – Collected Yield

d – Index of agreement

DF – Degree of Freedom

df – Dilution Factor

dM – Modified Index of agreement

dMP – Prime Modified Index of agreement

E – Coefficient of Efficiency

EM – Modified Coefficient of Efficiency

EMP – Prime Modified Coefficient of Efficiency

Fig. – Figure

g – Gram

gal – Gallon

GIS – Geographical Information System

GL – Ground Loss

GLM – General Linear Model

GPS – Global Positioning System

h – Hour

ha – Hectare

HCl – Hydrochloric acid

hp – Horse Power

HPLC – High Performance Liquid Chromatography

HSD – Honestly Significant Difference

kg – Kilograms

km – Kilometer

kW – Kilowatt

L – Liter

lb – Pound

LS – Least Squares

LSD – Least Significant Difference

m – Meter

M3GE – Malvidin-3-Glucoside

MAE – Mean Absolute Error

Max – Maximum

MC – Moisture Content

MEC – Molar Extinction Coefficient

meq – Milliequilents

mg – Milligram

Min – Minimum

min – Minute

ml – Milliliter

mm – Millimetre

MMC – Multiple Means Comparison

Mpixels – Mega pixels

MW – Molecular Weight

N – Newton

N – Normal

n – Number

NaOH – Sodium Hydroxide

nm – Nanometer

O_t – Observed values

O_{tm} – Mean of early, middle and late season

PGP – Percentage of Green Pixels

pH – Hydrogen-Ion concentration

P_t – Predicted values

R^2 – Coefficient of determination

RGB – Red-Ggreen-Blue

RMSE – Root Mean Square Error

rpm – Revolution per minute

RTK – Real Time Kinematics

r – Correlation coefficient

s – Second

SL – Shoot Loss

SAS – Statistical Analysis System

St Dev – Standard Deviation

TA – Titratable Acidity

TBL – Total Berry Loss

TFY – Total Fruit Yield

TSS – Total Soluble Solids

USDA – United States Department of Agriculture

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CHAPTER 1 INTRODUCTION

The wild blueberry (*Vaccinium angustifolium* Ait.) is an important horticultural crop in eastern Canada and the State of Maine, USA. Blueberry is the second largest fruit crop produced after apples in Canada (AAFC, 2013). These regions have 93,000 ha of wild blueberry crop under management, producing around 148 million kg of fruit, and contributing about $196 million annually to provincial and federal economies (Yarborough, 2015). Wild blueberry fields are established from naturally occurring native stands by clearing competing vegetation from forest farmland (Eaton, 1988). This crop is adjusted to well-drained acidic soils (pH 4.5-5.5) with low mineral nutrients (Trevett, 1962). Newly developed wild blueberry fields have gentle to severe topography, with significant proportion of bare spots and weed patches (Zaman et al., 2008). Wild blueberry is a biennial crop with the perennial shoots pruned in alternative years to maximize floral bud initiation, yield, fruit set, and ease of mechanical harvest (Eaton, 1988).

Hand-held metal rakes, initially designed as a cranberry scoop, have been used for manual harvesting of wild blueberry crop (Yarborough, 1992). The overall efficiency of hand-raking was observed to be 80% with an average loss of 20% (Kinsman, 1993). Short harvesting season, high labour cost, significantly higher yields, shortage and quality of labour over the past 20 years (Holbein, 1991) has pushed the wild blueberry industry towards mechanical harvesting. The research and development work on mechanical harvesters started in early 1950s, (Rhodes, 1961); however, a viable mechanical harvester was not commercialized until 1980s (Hall et al., 1983).

In the last three decades, wild blueberry fruit yield have significantly increased from 9 to 101 million kg in Atlantic Canada and Quebec, and from 8 to 47 million kg in the State of Maine due to improved management practices (fungicides, herbicides, fertilizers, pollination and pruning etc.,) (Yarborough and Ismail, 1985; Litten et al., 1997; Esau et al., 2013; Yarborough, 2015). Farooque et al. (2014) revealed that the plant height varied from 15 to 39 cm and the fruit zone ranged from 7 to 31 cm within selected wild blueberry fields. Fruit diameter for wild blueberry ranged from 0.5 cm to 1.5 cm (Hayden and Soule, 1969). Changes in crop characteristics, undulating terrain, environmental factors and time of harvesting have resulted in an increased fruit loss during mechanical harvesting. Farooque et al. (2014) suggested that the fruit losses during harvesting were directly proportional to the variation in fruit yield (higher fruit losses in high yielding areas and vice versa). The authors also narrated that the pre-harvest fruit losses were higher during late season when compared with the early season harvesting for selected wild blueberry fields. However, they did not quantify the impact of time of harvest on fruit losses during mechanical harvesting. Therefore, this present study is designed to identify the effect of harvesting time on picking efficiency of the commercial wild blueberry harvester.

Numerous studies have been centralized based on computer vision technology for assessing the food quality and agricultural products (Chen et al., 2002; Brosnan and Sun, 2004; Aguilera and Briones, 2005). Several researchers used digital photography technique to estimate fruit yield in wild blueberry fields (Zaman et al., 2008; Chang et al., 2012; Farooque et al., 2013). Zaman et al. (2008) used a cost effective 10 Mpixel digital color camera, acquired wild blueberry images, calculated blue pixels from the images, and correlated blue pixel ratios with manually harvested actual fruit yield from selected points within wild blueberry fields. Chang et al. (2012) developed an automated yield monitoring system using two μEye digital color cameras, custom software, a ruggedized laptop computer, and a real time kinematics global positioning system (RTK-GPS). This system was capable of calculating the blue pixel ratios in real-time to estimate wild blueberry fruit yield within selected fields. The digital photography techniques have been extensively used to estimate fruit yield for many cropping systems; however, its application to assess the ripening stages of the fruit have been very limited. This present study encompass the potential use of digital photography techniques in predicting the ripening stages of fruit at different times during harvesting. This information would identify the appropriate time of harvesting. Furthermore, this study will be helpful to quantify fruit losses due to harvesting inappropriate times.

Following researchers have investigated fruit characteristics at harvesting for different crops. Fruit ripening at the time of harvest is closely related to the amount and type of chemical contents (anthocyanin contents, total soluble solids, moisture contents) and physical nature (fruit color, hardness) of the fruit (Pantastico, 1975). Wills et al. (1989) used color, firmness, chemical composition, size, shape and time to ripen as a criterion to judge fruit maturity. Many researchers have used changes in color as an indication of maturity or ripening in the blueberry (Ballinger et al., 1973; Dekazos, 1980; El-Agamy et al., 1982). Hobson and Davies (1971) and Salunkhe et al. (1974) reported compositional changes in tomato fruit during maturation and ripening stages. Total solids and sugar contents increased gradually during maturaty and ripening of tomato fruit (Winsor et al., 1962a, b). Ripening of fruit is an indication for proper time of harvesting to reduce fruit loss. To date very limited research has been conducted to identify an optimum ripening time of wild blueberries. Harvesting of blueberries at proper ripening can assist to optimize the timing of harvest to increase berry recovery and quality.

The hypothesis of this study is that an optimum time of harvest in combination with appropriate ground speed and header revolution of the harvester will reduce fruit loss and increase berry quality.

1.1 Objectives

Some of wild blueberry producers harvest their crop by ignoring proper ripening and timing of harvest, which can result in an increased fruit losses and poor quality of berries. The objectives of this study are to:

1. Quantify fruit losses at different times of harvesting to evaluate the picking performance of the harvester;
2. Identify the proper fruit ripening levels using digital photographic technique to suggest proper time of harvest; and,
3. Evaluate the impact of fruit ripening parameters on harvesting efficiency of the wild blueberry harvester.

CHAPTER 2 LITERATURE REVIEW

2.1 Wild Blueberry Cropping System

Blueberries are the largest fruit export of Canada in terms of value (62.0% of total value) and volume (45% of total volume) (AAFC, 2013). The wild blueberry production in Canada was reported to be 101 million kg in 2014, which was significantly higher than the last five year's average. The State of Maine in the USA produced approximately 47 million kg of wild blueberry fruit in 2014 (USDA, 2014); which was an increase in fruit yield of 7 million kg when compared to the previous year (Yarborough, 2015). The diameter of wild blueberries ranging from 5 to 15 mm (Soule, 1969) with their rhizomatous shrub averaging 20 cm and this crop grows up to 50 cm in height (Hall et al., 1979). Wild blueberry fields are established from naturally occurring native stands by removing trees and keeping the fields to ground level every other year by pruning. Majority of the fields in Atlantic Provinces of Canada were established by invasion of wild blueberry into old pastures and abandoned farms (Baker et al., 1964). The wild blueberry clones are randomly distributed within fields with substantial variability in fruit yield and crop characteristics (Hepler and Yarborough, 1991). Blueberry clones spread slowly and the plant cover is dependent on the number of years a field has been in production (Hall et al., 1979). Blueberry fields that have been under production for more than 50 years may have nearly 100% cover but younger fields may have less than 50% cover (Yarborough and Bhowmik, 1988). Zaman et al. (2008) reported that a newly developed fields have significant proportion of bare spots and weed patches (ranging from 30 to 50% of the total field area). This crop has adapted to well drained, acidic (pH 4.5 to 5.5) and infertile soils that have well developed organic horizons (Trevett, 1962). Wild blueberry is compelled into biennial production by pruning in alternate years. First year in blueberry cropping system is for vegetative growth, followed by a year in which the fruit development occurs. Pruning of wild blueberry crop enhances floral bud initiation, fruit production, and ease of mechanical harvesting (Hall et al., 1979). Fruit ripening normally starts in late June and reaches full maturity with pollination in August of the crop year (Hall et al., 1979).

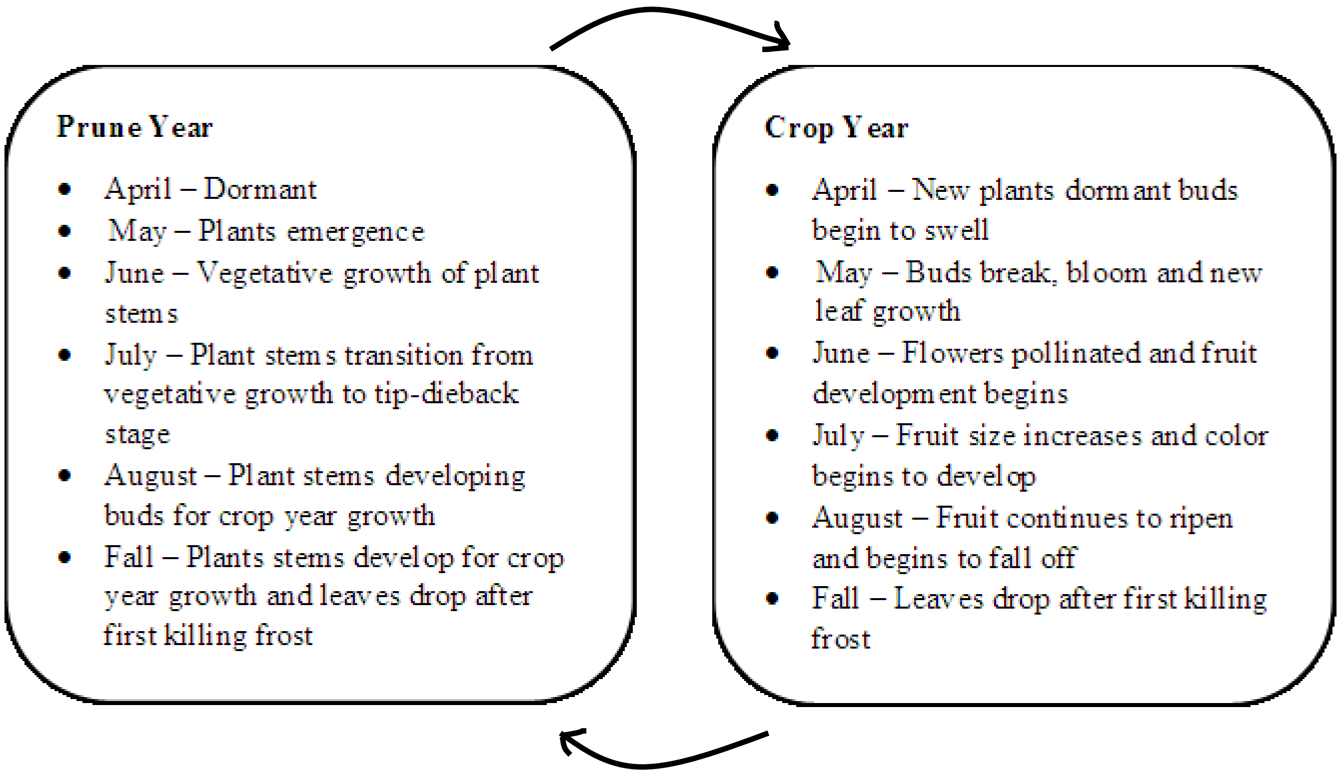


Figure 2-1. Two year growing cycle of wild blueberries [a]

[a] Adapted from http:// extension.umaine.edu/blueberries/factsheets/production/wild-blueberry-prune-management-schedule (Yarborough, 2010).

Blueberries have been hand raked for the past 100 years (Kinsman, 1993) and the design of the blueberry rake was adopted from cranberry scoop. The majority of wild blueberry fields are harvested mechanically using commercial harvesters; however, there are fields in rough terrain, which are still hand-raked.

2.2 Wild Blueberry Harvesting

2.2.1 Harvesting by Hand Raking

Blueberries have traditionally been harvested by hand rakers who walk along a row and rake through the bushes. Manual harvesting is tedious and back-breaking, as the bushes are shorter in height and the pickers are forced to work in a bent-over position. Since, harvesting of wild blueberries constitute the largest expense, there has always been an urge to reduce this cost by introducing mechanized harvesting. The short harvesting season also constrained the hand raking of blueberries at large scale (Yarborough, 1992). Efficient hand raking with better quality of fruit requires skilled rakers. The hand rakers are being paid by the box of berries picked and they often leave berries behind hanging on the bushes. This practice allows the hand rakers to concentrate on more lucrative areas, resulting in higher fruit losses at the owner's expense. Berry losses using hand raking differs from crew to crew, but it had been at a range of 15 to 40% with an overall average of 20% (Kinsman, 1993). The picking efficiency of hand rakers is reported to be 80% with 20% losses on an average (Yarborough, 1992). The low stature of the plant, uneven terrain and competing vegetation remained as obstacles on the way to the development of a mechanical harvester. The substantial increase in fruit yield over the past several decades has also pushed the wild blueberry growers towards sophisticated and reliable mechanical harvesting.

2.2.2 Mechanical Harvesting

Many researchers have evaluated the performance of different mechanical harvesters for fruit picking efficiency. Birger (2014) compared the mechanical harvesting of olives with manual picking, suggesting that the picking efficiency of the harvester was 80 to 95% with better quality of olives. Chen et al. (2012) compared the efficiency of vibratory shaker with an impact harvester. Results of their study revealed higher efficiency of fruit removal and less damage for sweet cherry

(*Prunusavium* L.) crop. Rabcewicz and Danek (2010) reported that the efficiency of a raspberry mechanical harvester was 60 to 80% with 1 to 5% raspberries left on the ground. Hall et al. (1983) evaluated a blueberry harvester made in Nova Scotia, reporting the picking efficiency of this machine was 68% (in weedy fields) to 75% (in weed free smooth fields).

Farooque et al. (2014) conducted an engineering assessment of this harvester and observed lower losses in low yielding fields and higher losses in high yielding fields. Results of their study indicated that the fruit losses ranged from 8 to 25% in selected wild blueberry fields. They recommended that a combination of 1.2 km h^{-1} and 26 rpm could result in significantly lower losses as compared to higher ground speed and header rpm in blueberry fields with yields over 3500 kg ha^{-1}. They found no significance effect of ground speed and header revolution on berry losses in low yielding fields.

The main drivers towards the development of a mechanical harvester were high labor cost, shortage and quality of labor, and short harvesting season (Yarborough, 1992). Agricultural Engineering Department, University of Maine, USA took an initiative to develop a mechanical harvester for wild blueberries in 1947. Rhodes (1961) developed the first experimental blueberry harvester, which was a modified design of a mechanical cranberry picker, consisting of a series of six raking combs. The developed harvester was able to pick blueberries in a direction opposite to the travel of machine. This machine resulted in higher fruit losses and digging of soil during harvesting. Gray (1969) developed a hollow reel raking mechanism from the concept of rotating picking head, which has served as the basis for the harvesters in use today. Gray (1969) also reported that the harvesting efficiency of this machine was 80 to 85% of the berries on the vine. However, this harvester was able to harvest only 30 to 35% of the fields due to limitations in field terrain. Towson (1969) evaluated CRCO-UM blueberry harvester and observed that the picking efficiency of this harvester fluctuated from 75 to 85% depending upon the field conditions. Soule (1969) defined the picking efficiency of harvester as the ratio of weight of harvested berries to the weight of berries on the plants before harvesting. They also reported that the blueberry harvester performed better on smooth ground with no weeds, but it really experienced challenge in rough and weedy fields. The Rhodes harvester's design was improved by installing a hydraulic control system for the head, head rotational speed, cleaning brush rotational speed, speed control of belts, and conveyors (Malay, 2000).

Doug Bragg Enterprises limited (DBE) is the largest manufacturer of wild blueberry harvesters. More than 1500 blueberry harvesters are working in Atlantic Canada, Quebec and the State of Maine, USA (Personal communication). Several researchers have made efforts, up to early 1990s, to evaluate the blueberry harvester for fruit losses (Rhodes, 1961; Abdalla, 1963; Hayden and Soule, 1969; Hall et al., 1983; Yarborough, 1992). In the last two decades, a significant increase in fruit yield has been observed. The wild blueberry industry is facing increased harvesting losses due to changes in crop condition and improper timing of harvest. Currently, there has been no protocol available regarding an appropriate time of harvesting for wild blueberry cropping system. There is an urgent need to identify the impact of timing on berry picking efficiency of the harvester. Harvesting of blueberries at proper maturity and an appropriate time can enhance berry recovery and quality, which can lead to farm profitability.

2.3 Factors Affecting Fruit Yield

2.3.1 Effect of Improved Management Practices on Fruit Yield

The improved management practices (selective fungicides, herbicides, fertilizers, pruning, etc.,) in last three decades have resulted in significant increase in fruit yield (Yarborough and Ismail, 1985; Eaton, 1993; Litten et al., 1997; Yarborough, 2004; Esau et al., 2013). Fruit yield observed to be significantly higher in 2014 in Atlantic Provinces, when compared to previous years. Fruit yield for the Province of Quebec, Canada was 35 million kg in 2014, which was significantly higher than the last five year's average. Similarly, the high berry yield approximately of 28, 27, and 10 million kg was reported in Nova Scotia, New Brunswick and Prince Edward Island, respectively. This substantial increase might be due to effective weed and disease controls, nutrition plans, favorable weather conditions, pruning, pollination, and growing number of acres coming into production (Yarborough, 2015).

Wild blueberry fields are being levelled using excavators. Removal of rocks and smoothing out knolls have resulted in an easier mechanical harvesting operation and pruning; thus, reducing the cost of production (Yarborough and Drummond, 2001). Yarborough (2004) developed and applied a land levelling procedure in the wild blueberry cropping system, which has resulted in an increased acreage in Atlantic Canada and the State of Maine, USA. Surface mulching is also being used to increase the soil productivity, reduce soil erosion, and increase rhizome spread in the rootzone (Degomez and Smagula, 1990).

Pruning by flail mowing or burning can be used to control weeds and this in turn helps the blueberry plants to remain dominant (Trevett, 1959). Ismail and Yarborough (1979) revealed that the mowing within a centimeter of soil would produce yield equivalent to burning. Flail mowing is more popular method for pruning and is utilized widely due to an increase in oil prices and its environment friendly aspects. Substantial reduction in cost of mowing compared to burning made production more efficient and profitable (Yarborough and Drummond, 2001).

The application of pre-emergence herbicide has resulted in an increased fruit yield up to two fold (Ismail et al., 1981). Herbicides are primarily used to control weeds, which results in an elevated fruit yield (Yarborough and Ismail, 1985; Yarborough and Bhowmik, 1988). The use of agrochemicals increases floral bud and harvestable fruit yield by reducing the disease and insect pressure (Percival and Dawson, 2009).

Esau et al. (2013) developed an automated prototype variable rate (VR) sprayer and applied three treatments of fungicide such as spot application (SA), uniform application (UA), and control application (CA). The authors evaluated the impact of fungicide on the crop and recorded the percentage of green pixel (PGP), floral buds and fruit yield from selected plots within selected fields. The PGP, floral bud and harvestable yield showed significant differences in SA and UA over the CA treatment. The use of fungicides and herbicides, both in sprout and crop years suppress competing weeds and control disease, to encourage plant health and fruit production (Yarborough, 2004).

The efficient use of herbicides and fertilizers has enhanced blueberry growth without nourishing weeds (Hepler and Ismail, 1985; Yarborough et al., 1986). A technique to determine the levels of nitrogen (N) and phosphorus (P) in leaves has been developed and is used by growers to optimize their fertilizer applications such as diammonium phosphate (DAP) or monoammonium phosphate (MAP) (Yarborough and Smagula, 1993; Smagula and Yarborough, 1999). The use of DAP fertilizer was found to be beneficial in phosphorus limited soil as it increased the flower buds and fruit yield from 4900 to 6235 kg ha^{-1}(Litten et al., 1997). Eaton (1993) observed an increasing fruit yield (1300 to 6000 kg ha^{-1}) after application of herbicides and fertilizers in blueberry fields. Saleem (2012) used a VR fertilizer spreader and applied fertilizer on site specific basis using slope based prescription map for selected blueberry fields. Results of this study suggested an increase in fruit yield using site specific fertilization, when compared to uniform fertilization in blueberry fields. This increase in fruit yield caused by improved management practices has an impact on picking performance of the harvester by increasing harvesting losses as it has been designed in early 1980's. The improved management practices also resulted in tall plants, high plant density, and stem thickness which may have an impact on fruit losses during mechanical harvesting. Time of harvest is also one of the most important factor which can influence fruit losses during mechanical harvesting. Fruit attached to the plants loses its grip with the plants as it over ripens, which can enhance the shattering losses during harvesting.

2.3.2 Effect of Time of Harvesting on Fruit Loss

Time of harvesting, pre-harvest growth and fruit development stages are considered as important parameters related to fruit yield and quality (Hewett, 2006). Thompson (2003) reported that the harvesting time, crop maturity, cultivar, climate, and soil structure influenced the fruit yield and quality. Moreover, the fruit yield was affected by the time of application of inputs such as irrigation or fertilizer, which can affect the fruit losses due to harvesting at different times (Thompson, 2003). Harvesting of fruit at proper time is a key factor in determining fruit quality since quality of some fruit cannot be raised but only maintained after harvest (Bachmann and Earless, 2000); it is important to harvest fruit at proper harvesting stage and size (Wills et al., 1989). Kader (2002) suggested that the poor decisions related to time of harvesting can influence the production environment and quality of the product, which reaches the consumer. Furthermore, Remorini et al. (2008) reported that time of harvest greatly influenced biochemical, physiological, and structural changes of peach. They also suggested that time of harvest must be taken into account along with quality characteristics for post-harvest losses as well as for consumer acceptance.

Testoni (2002) reported that persimmon fruit picked at proper harvest time can survive longer periods of time without loss of quality and decay. Salvador et al. (2004) pointed out that harvest time could have influential effect on chilling injury as well as storage of persimmon. Wills et al. (1989) defined the time of harvesting is a time at which the fruit has developed and reached its maximum desired eating quality. Burnett and Bakke (1930) reported that the impact of harvesting time on yield and length of harvesting period during which maximum yield may be secured have become burning issues of the last three quarters of a century. They also pointed out that harvesting time and duration of the harvest period are not only dependent upon soil and climatic factors but also harvesting practices as well as varieties of grain grown.

The stage at which crop is harvested greatly influence the yield and quality of seed and ease with which it is threshed and cured (Hyde et al., 1959). Sharrock and Parkes (1990) investigated that buttercup squash fruit harvested at an early stage of maturity showed a significantly lower chances of storage losses than fruit harvested at late. Harvesting of wild blueberry crop begins in early to mid-August when approximately 90% of the blueberries are ripened. The harvesting season has narrow window and lasts about three to four weeks and is probably the busiest time of the year for growers (Farooque et al., 2014).

The parameters such as fruit weight, fruit size and fruit color can be used as a guide for ripening and harvesting of fruit. The digital photographic technique can be employed to examine the fruit ripening stages in wild blueberry crop.

2.4 Estimation of Fruit Ripening Stages using Digital Photographic Technique

A number of studies have been centralized on camera-based, non-destructive fruit yield estimation and mapping techniques (Annamalai et al., 2004; Chinchuluum and Lee, 2006; Schumann et al., 2007). Zhang et al. (2010) used a cost effective and automated machine vision system to map bare spots in wild blueberry fields. Zaman et al. (2008) also executed a digital color camera for estimation of blueberry fruit yield, and concluded that the digital photographic technique was a viable technique for mapping blueberry yield. Zaman et al. (2010) developed an automated yield monitoring system using a digital color camera, custom software, a ruggedized laptop computer and a RTK-GPS. They successfully mapped and estimated fruit yield in wild blueberry fields. Esau et al. (2011) installed µEye color cameras on prototype VR sprayer to differentiate between bare spots, weeds and plants for targeted applications of agrochemicals in real-time.

Similar studies for fruit detection based on color were conducted for apple, citrus and tomatoes. A number of researchers used computer image analysis techniques (also known as computer vision system) which address the flaws of visual and instrumental techniques very well and provide a comprehensive measure for color and other physical factors (Paulus and Schrevens 1999; Shahin and Symons 2001; Chen et al., 2002). Richardson et al. (2007) used digital webcam images to examine the trajectory of spring green-up using red, green and blue color channel in a deciduous northern hardwood forest. They concluded that this technique can serve an inexpensive means by which phenological changes in canopy state can be quantified. Sakamoto et al. (2012) also explored the utility of an inexpensive camera system called crop phenology recording system for assessing the seasonal changes in crop growth. Yam and Papadakis (2004) described an inexpensive and more versatile method to examine the color of many foods using digital camera and image processing software than traditional color-measuring instruments.

Steddom et al. (2004) described the importance of image analysis by using low-quality joint photographer's expert group images in disease quantification and preferred to use it due to number of desirable qualities such as low-cost, commercially available and very robust. Parrish and Goksel (1977) used a method based on pictorial pattern recognition and artificial intelligence techniques for feasibility of apple harvesting. Whittaker et al. (1987) employed fruit shape instead of color information for tomato detection non-destructively. Slaughter and Harrell (1987) developed an image based on color information system for orange fruit detection. In present study, a digital color photographic technique using blue green pixel (BGP) ratio was used to examine fruit ripening stages for wild blueberry crop.

The fruit characteristics such as firmness, chemical composition, color, size, anthocyanin contents, and titratable acidity play an important role in ripening of fruit. Therefore, fruit ripening characteristics should also be monitored while studying fruit ripening during harvesting of wild blueberry crop.

2.5 Effect of Fruit Parameters on Harvesting Efficiency

Ripening is a critical phase in maturity of fruit that surrounds a range of physiological and biochemical changes in the tissue. The taste and flavor of fruits and vegetables are closely related to the amount and type of chemical constituents and physical nature of the crop at the time of harvest (Pantastico, 1975). Wills et al. (1989) suggested a criteria for judging the fruit maturity that includes color, firmness, chemical composition, size, shape and time to ripen. Many researchers have used changes in color as an indication of maturity or ripening in the blueberry cropping system (Ballinger et al., 1973; Dekazos, 1980; El-Agamy et al., 1982). El-Agamy et al. (1982) reported that blueberries are considered ready for eating when majority of the berries are blue or at least 75% are blue. Ceponis and Stretch (1983) found that the fruit color gradually changes from light-green to light-brown and then dark-brown as cranberry fruit matures. Bruhn (1995) reported that consumers prefer to purchase full red color fruit to less red color in peaches and nectarines. Crisosto et al. (2002) suggested skin color as simple and practical index to direct harvesters on when to harvest cherries. The authors further established a relationship between skin color and soluble solids concentration for harvesting of cherries to satisfy minimum consumer acceptance taste.

Kader (1999) considered color along with total soluble solids (TSS) and titratable acid (TA) as a maturity index for apricot, nectarine, peach, persimmon, plum, raspberry and strawberry fruits. High soluble solids and low titratable acidity in peaches have associated with high consumer acceptance (Testolini, 1995; hilaire, 2003). Postharvest life of fruit is dependent on flavor rather than physical appearance and end of flavor life comes as a result of losses in sugars, acids and aroma volatiles (Kader, 2008). Crisosto et al. (1995) suggested the attributes, such as soluble solids, titratable acidity and firmness as fruit maturity indices.

Fruit ripening encompasses physiological, biochemical and developmental changes arising through a coordinated and genetically regulated program (Stepanova and Alonso, 2005; Barry and Giovannoni, 2007; Bouzayen et al., 2010). Compositional changes in tomato fruits were observed during maturation and ripening (Hobson and Davies, 1971; Salunkhe et al., 1974). Total solids and sugar contents increased gradually during maturation and ripening of tomato fruits (Winsor et al., 1962a; Winsor et al., 1962b). Naczk and Shahidi (2006) described that anthocyanins are pigments that provide blue, violet and red colors in most fruits, vegetables and cereals. Ribereau-Gayon and Glories (1986) also revealed in their studies that anthocyanins are pigmented compounds accountable for color of red wine and grapes. Given et al. (1988) reported that anthocyanin reserves are one aspect of ripening in strawberry. Forney et al. (1998) revealed that as blueberries turned blue and continue to ripen, the total soluble solids increase and titratable acids decrease.

Firmness is one of the most attractable attribute influencing consumer appeal as well as marketing of fresh blueberries (NeSmith et al., 2002). Firmness level below retail standards can produce messy volumes of blueberries, causing rejection in marketplace (Prussia et al., 2006). Blueberries are harvested fully ripe (full blue) from the bush (Perkins-Veazie, 2004). The structure of blueberry softens with passage of time (Proctor and Miesle, 1991). Miller et al. (1993) suggested low levels of moisture helps blueberry firming rather than softening, whereas trend of more weight loss induce fruit softening (Forney et al., 1998). Moisture loss is considered to be related with blueberry firmness and it depends on the extent of dehydration (Paniagua et al., 2013). Moreover, decreased firmness has been associated with blueberry moisture loss in numerous studies (Miller et al., 1984; Tetteh et al., 2004; Angeletti et al., 2010; Cantin et al., 2012). Firmness decreases as fruit mature and there is a significant correlation (Knee and Smith., 1989) found between harvest firmness and firmness after storage in apples.

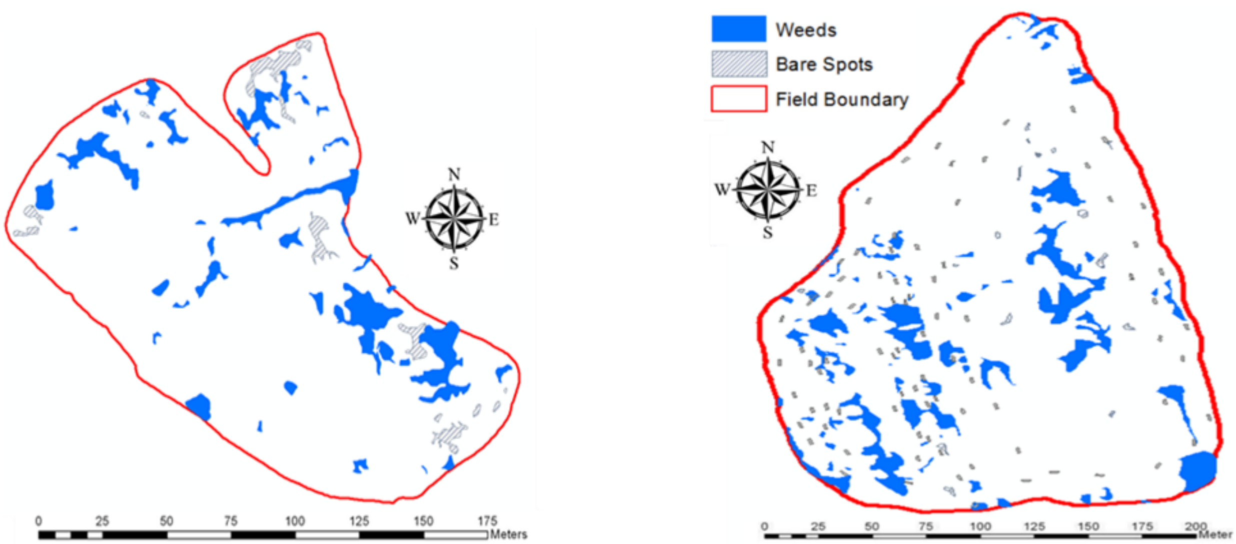
Limited research has been reported in the literature regarding the impact of fruit characteristics and ripening stages and their effect on harvestable yield and quality in relation with time of harvest. This situation emphasize the need to examine the above mentioned wild blueberry fruit characteristics at different times during harvesting of blueberry to assess fruit maturity and ripening.

CHAPTER 3 MATERIALS AND METHODS

3.1 Quantification of Fruit Loss at Different Harvesting Times

3.1.1 Site Description

Eight wild blueberry fields, shown in Figures 3-1 to 3-3, were selected in Nova Scotia and New Brunswick to evaluate the impact of harvesting time in combination with machine operating parameters on berry losses during mechanical harvesting. The selected fields were Londonderry (Field A) (45.48°N, 63.57°W; 3.20 ha) and Earltown (Field B) (45.60°N, 63.09°W; 1.9 ha) in 2011, Tracadie (Field C) (47.28°N, 65.14°W; 1.6 ha) and Highland Village (Field D) (45.24°N, 63.40°W; 2.57 ha) in 2012, Debert-I (Field E) (45.45°N, 63.45°W; 1.01 ha) and Hardwood Hill (Field F) (45.42°N, 63.52°W; 2.05 ha) in 2013, and Debert-II (Field G) (45.44°N, 63.45°W; 1.01 ha) as well as East Mine-I (Field H) (45.43°N, 63.48°W; 3.88 ha) in 2014. These fields have been under commercial management of pest, disease, mowing, pollination and weed control.



(A) (B)

Figure 3-1. Field maps of wild blueberry fields (A) Londonderry (B) Earltown.

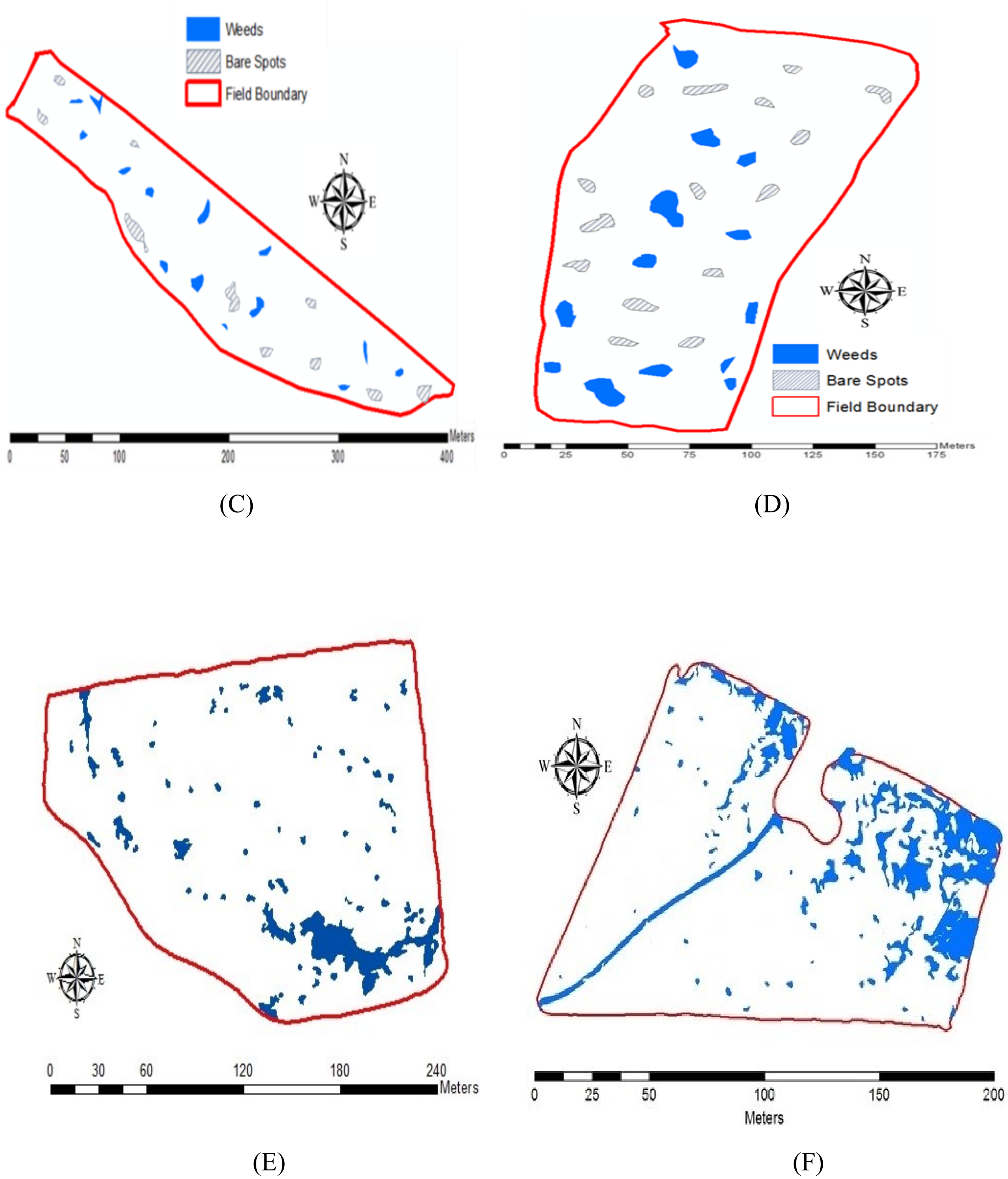
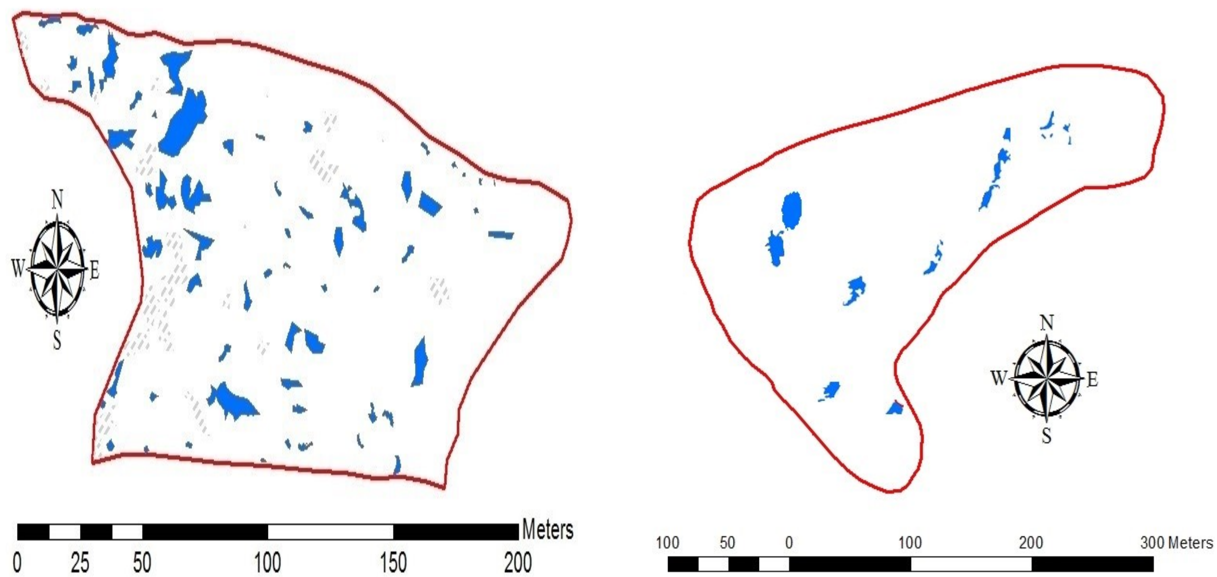


Figure 3-2. Fields maps of wild blueberry fields (C) Tracadie (D) Highland Village (E) Debert-I (F) Hardwood Hill.



(G) (H)

Figure 3-3. Field maps of wild blueberry sites (G) Debert-II (H) East Mine-I.

3.1.2 Experimental Design

Split plot designs are widely used in agricultural experiments. Split plot is a blocked experiment, where the blocks themselves act as experimental units for a subset of the factors. The blocks are served as whole plots, while the experimental units within blocks are referred split plots (subplots) (Fisher, 1925). Wild blueberry farmers operate their harvesters at ground speed of 1.6 km h^{-1} and header revolution of 28 rpm. Split plot factorial experiment was designed with three levels of ground speed, one ahead and one below to that of farmer's chosen level (1.2, 1.6 and 2.0 km h^{-1}) and header revolutions (26, 28 and 30 rpm), and three levels of harvesting time early: (1st week of August to mid-August); middle (mid-August to 25th of August); and late (25th to onwards). The year was considered as a block or replicate, as data were collected in four years from selected fields, in data analysis. Experimental plots were made randomly in the path of the operating harvester using a measuring tape. Each plot was 0.91 m wide (same as the width of harvester head) and 3 m long. Picker bars were cleaned of any foreign debris prior to harvest of each plot. The inside and side conveyors of the harvester head were also cleaned at each experimental plot within selected sites to allow storage of fruit yield in the bin from plots only. The plots were harvested at all nine treatment levels of ground speed and header rpm during each harvesting stage (early, middle and late) using a commercial wild blueberry harvester. Eighty one (each treatment combination replicated thrice) plots were constructed in each year in each field. The field boundaries, bare spots, weeds and experimental plots were mapped with RTK-GPS in each field.

3.2 Operating Mechanism

A commercially available single head wild blueberry harvester was mounted on a tractor (62.5 kW) to harvest the selected plots in each field and year (Fig. 3-4). Farooque et al. (2014) explained wild blueberry harvester's operating mechanism. A rotating head speed, direction of head rotation, head height, cleaning brush and conveyors are controlled hydraulically and the system is mounted inside the cabin of tractor. A sixty seven equally spaced bowed teeth are fixed on each bar of sixteen teeth bar's harvester head. These fixed teeth bars (picker bars) are attached with cam followers and rotate with cam. The picker bars pick blueberries at selected levels of ground speed and header rpm during harvesting. Operator can adjust or control the upward and downward movement of head and head rotational speed (rpm) by virtue of hydraulic control system.

The proper operating mechanism of harvester can be attained by changing the header rpm, which could offer gentle lift for effective berry recovery while reducing losses. The picking efficiency of the harvester is increased by removing debris and any foreign material stuck into teeth using a rotating cleaning brush at the top of the picking head. The picker bars dropped down the harvested berries onto the inside conveyor and then side conveyor transfer these collected berries into storage bin, attached behind the harvester. The blower, mounted at the end of side conveyor, is used to clean the berries from debris and plant leaves prior to dropping into storage bin. A guide wheel, in front of the harvester head, is used to maintain a constant height from the ground. The operator can change the height of the harvester's head according to plant height in fields manually to increase the berry picking efficiency of the harvester.

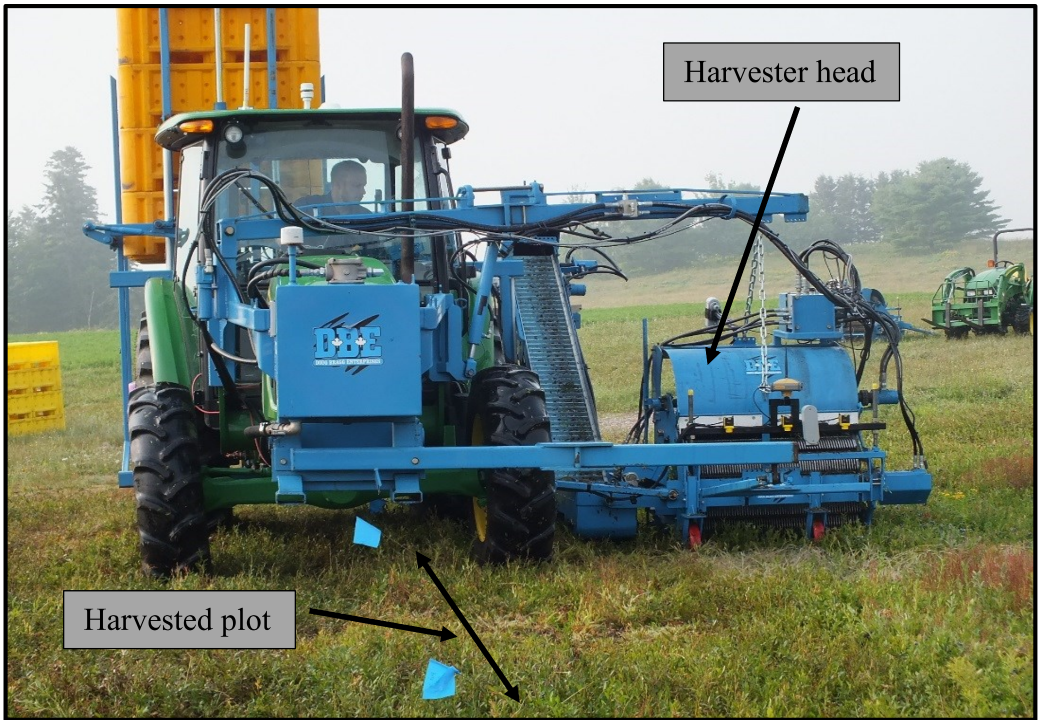


Figure 3-4. Single head wild blueberry harvester.

3.3 Data Collection

3.3.1 Pre-harvest Fruit Losses

The pre-harvest fruit losses were collected prior to harvesting of the plots in selected fields. A wooden quadrat (0.91 × 3 m) was placed at selected plot to collect pre-harvest fruit loss manually. The collected berries were placed in the labeled plastic bags and weighed using a balance. The percentage of pre-harvest fruit losses were calculated based on the fruit yield collected from each plot.

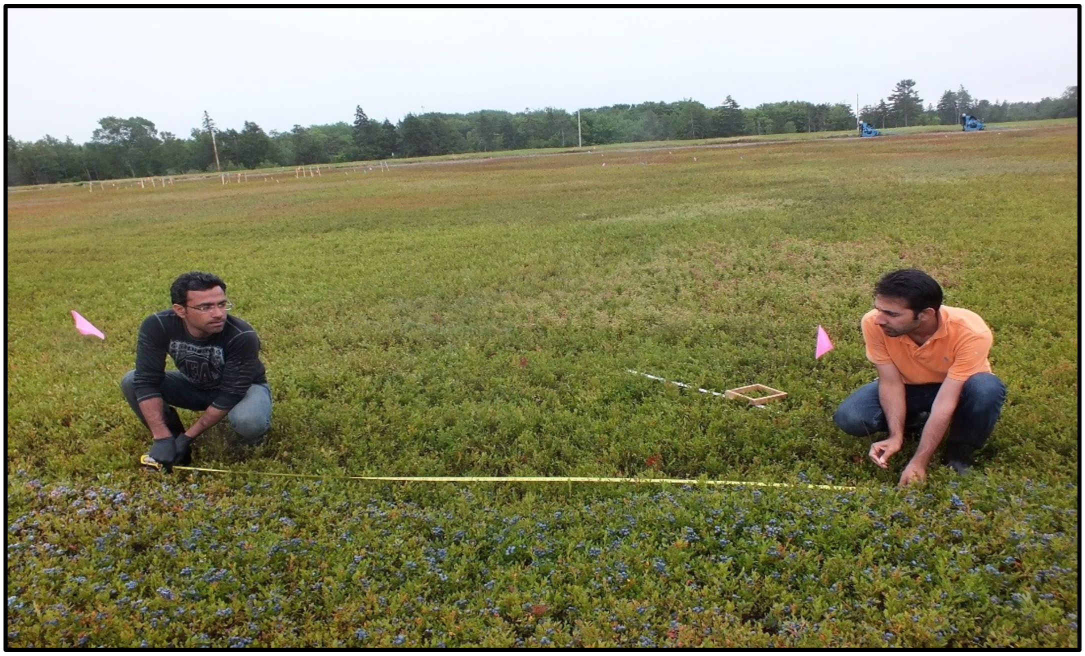


Figure 3-5. Constructing a plot before harvesting.

3.3.2 Fruit Losses during Harvesting

Prior to harvest of experimental plots, the harvester head was raised and moved back (approximately 3 m) to attain the selected levels of ground speed and header rpm. The harvester head was lowered at chosen combination of ground speed and header rpm to harvest the yield from each plot and was raised again at the end of each plot. The harvester was driven at all nine treatment combinations in early, middle and late season and fruit yield was collected from each plot by attaching a bucket to the harvester's conveyer belt. Three types of losses were collected from each harvested plot such as: un-harvested berries on the plants; berries knocked onto the ground due to the impact of the harvester head; and, losses through the blower. Loss through the blower was collected by attaching a bucket under the blower fan to collect any berries that were blown away (Fig. 3-6). Berries on the ground and un-harvested berries on the plants were picked manually from each plot within selected field (Fig. 3-7).

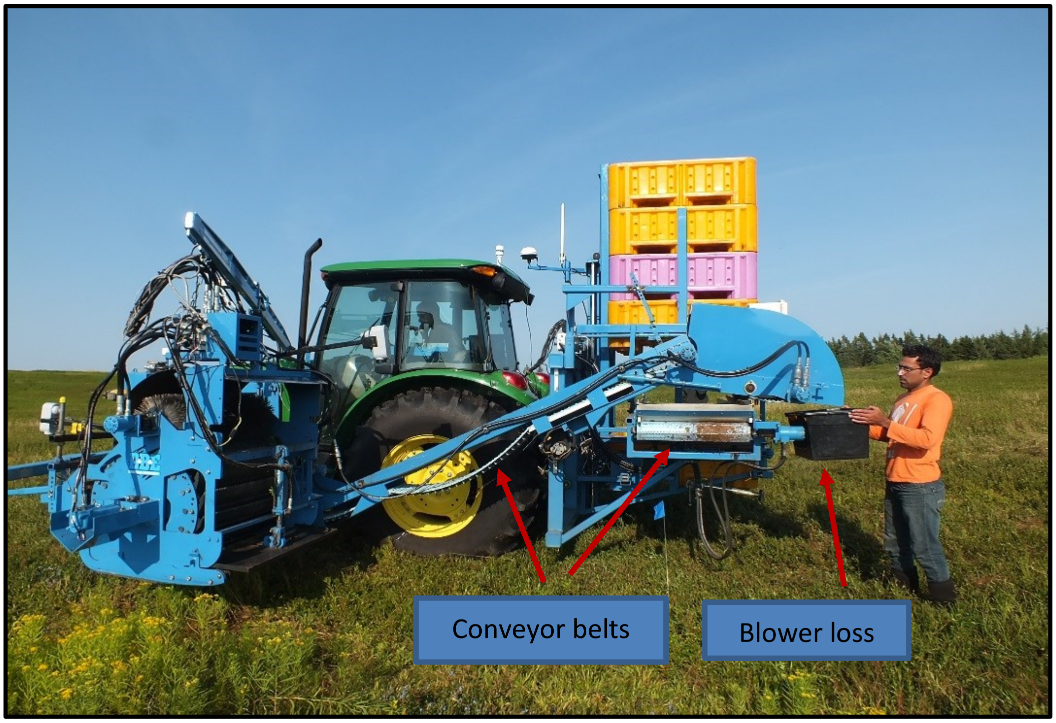


Figure 3-6. Collection of losses through the blower of the harvester.


Figure 3-7. Collection of after harvest losses from the selected plots.

The berries were separated from leaves and debris to record the actual weight of fruit yield and losses from each plot. The cleaned berries were placed in labeled plastic bags and were weighed using a balance (Denver Instruments Inc., NY, USA). The total fruit yield (TFY) and losses were recorded in kilograms (kg) and reported as (kg ha^{-1}). Total berry losses (TBL) were calculated by adding up ground loss (GL), un-harvested berries including shoot loss (SL) and blower loss (BL). Percentage berry losses were calculated by using following equations.

$$Shoot\ losses\ (\%) = \frac{\text{SL}}{\text{TFY}} \times 100 \quad -------(1)$$

$$\text{Ground Losses } (\%) = \frac{\text{GL}}{\text{TFY}} \times 100 \quad -------(2)$$

$$\text{Blower losses } (\%) = \frac{\text{BL}}{\text{TFY}} \times 100 \quad -------(3)$$

$$\text{Total losses } (\%) = \frac{\text{TBL}}{\text{TFY}} \times 100 \quad -------(4)$$

$$\text{TFY} = \text{CY} + \text{SL} + \text{GL} + \text{BL} \quad -------- (5)$$

$$\text{TBL} = \text{SL} + \text{GL} + \text{BL} \quad -------- (6)$$

Where,

TFY = Total fruit yield from harvested plot.

CY = Collected yield from harvested plot.

SL = Un-harvested berries or shoot losses from harvested plot.

GL = Ground losses from harvested plot.

BL = Blower losses from harvested plot.

TBL = Total berry losses.

3.4 Statistical Analysis

The analysis of collected data was performed using Minitab 17 (Minitab Inc., PA, USA) and SAS 9.3 (SAS Institute Inc., NC, USA) statistical software. A factorial analysis of co-variance using general linear model (GLM) procedure was performed to study the joint effect of the selected factors on fruit losses. The total variability in fruit losses can be due to main effects or/and interaction effects of ground speed, header rpm and time of harvesting. Fruit yield was used as covariate because it is an uncontrollable nuisance variable and it has a linear relationship with fruit losses (Farooque et al., 2014). Multiple means comparison were performed using least squares (LS) mean to determine which specific means significantly differed from each other in the treatment combinations. Classical statistics was utilized to calculate minimum, maximum, mean, standard deviation and coefficient of variation of the collected data.

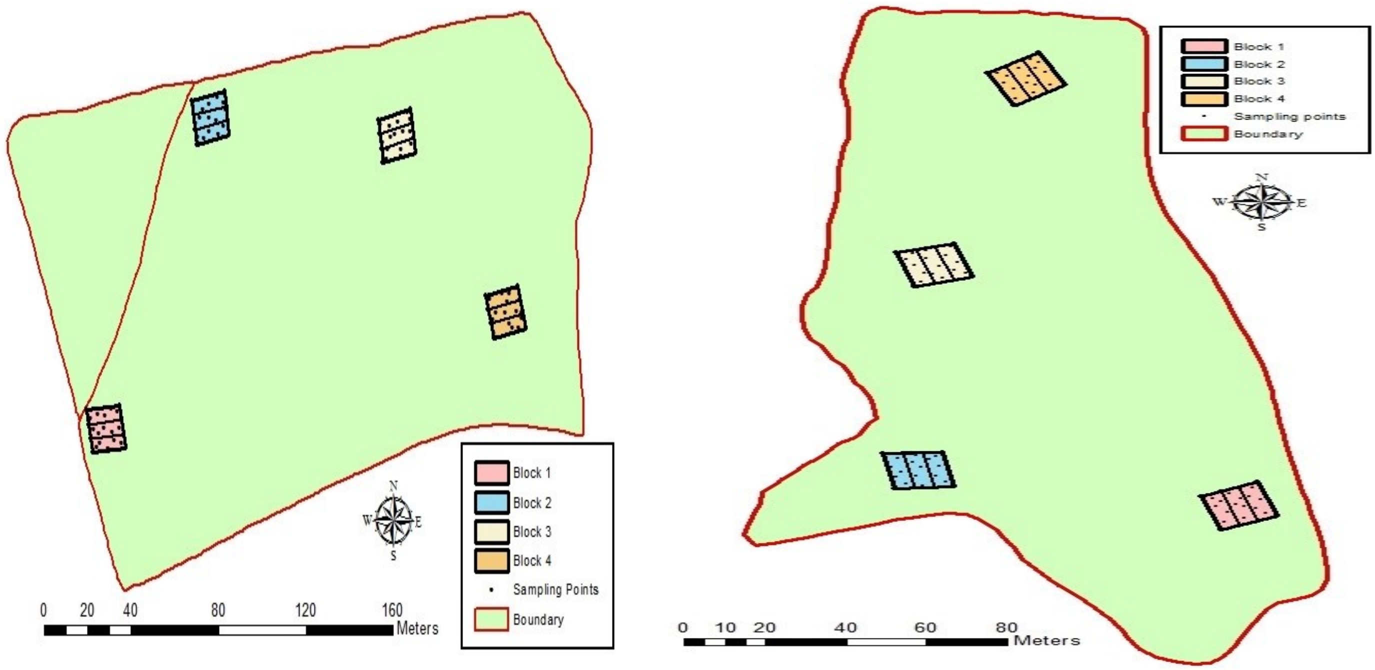
3.5 Digital Color Image Analysis to Asses Fruit Ripening

3.5.1 Site Selection

Two wild blueberry fields were selected in central Nova Scotia to evaluate a photographic method (Blue-Green pixels ratio) for estimation of fruit ripening. The fields were Highland Village-II (45.24°N, 63.40°W; 2.57 ha) and East Mine-II (45.43°N, 63.48°W; 3.88 ha). Both fields were in crop year of the biennial production cycle in 2015 (Fig.3-8). The selected fields were under commercial management, receiving biennial pruning by mowing for the past several years along with conventional management practices.

3.5.2 Experimental Design

Completely randomized block design (CRBD) is an important technique, dealing with nuisance factor and is widely used in agricultural experiments (Montgomery, 2008). There are two approaches to deal with nuisance factor. One could be, a nuisance factor is un-known and uncontrolled *i.e.* we don't know that the factor exists and it may even be changing levels while we are conducting experiment. In other cases, the nuisance factor is known but controllable. In this case, we can observe the value and can compensate for it in the statistical analysis by using analysis of covariance (Montgomery, 2008). In CRBD, treatments are divided into subgroups (blocks) in such a way that the variability within blocks is less than the variability between blocks. Then, treatments within blocks are randomly assigned and produce a better estimate of effects since this design decreases variability and possible confounding. CRBD was constructed and each field was divided into four blocks and each block was further divided into three levels of harvesting season (early, middle and late) randomly.



(a) (b)

Figure 3-8. Field maps of selected wild blueberry fields (a) East Mine-II (b) Highland Village-II.

3.5.3 Digital Color Image Collection and Processing

Sixty sampling points within four blocks were selected in each field to cover overall variability in fruit ripening. The sampling points and field boundary were marked using a RTK-GPS. The mapped data were imported in ArcView 10.1 GIS (ESRI, Redlands, CA, USA) for visual display. A 0.5 m × 0.5 m wooden quadrat frame was made and placed at marked points within each block in both fields to define the area of interest in the image (Fig. 3-9). A 16 megapixel 24-bit digital color camera (Fujifilm Canada, Inc., Mississauga, Ont.) was used to take photographs of the blueberry from a height of about 0.5-1.0 m (Fig. 3-10). Starting from early until the end of harvesting season, blueberry crop images were acquired at specified locations in each block within selected fields. The image exposure and other camera settings were automatic for this experiment. The images were imported into a laptop computer for further processing. Custom image processing software was developed (Precision Agriculture group) in C++ using Visual studio 2008 (Microsoft, Redmond, WA, USA) for a 32-bit Windows operating system to estimate the percentage of blue pixels representing ripe fruit in the field of view. The software was used to enhance and count the blue pixels in the quadrat region of each image, using red-green-blue (RGB) pixel ratio, and expressing the results as a percentage of total quadrat pixels.

Figure 3-9. Wooden quadrat frame for acquiring images from selected points.

The used ratio was (B*255)/(R+G+B) and a manually attained threshold (>80) effectively differentiated the apparent blueberry fruit pixels from remaining pixels in all images. Image analysis was confined to the quadrat by defining a rectangular polygon bounding region corresponding to the quadrat out line in the image and this was achieved by masking out the image.

Small clusters of pixels in the image were incorrectly identified as fruit due to specular reflection and deep shadows, but these were easily removed by applying one pass of an erosion filter. The final result of percentage of blue pixels in the quadrat region of each image was calculated automatically by running the software in batch mode and results were added to a comma-separated values (csv) file format.

Figure 3-10. Photograph of the selected point with camera.

3.5.4 Manual Fruit Yield Measurement

The same 0.5m × 0.5m wooden quadrat frame, used for acquiring images, was used to collect the fruit yield samples in early, middle and late season from each block in both fields. The fruit samples were harvested manually using hand rake and only ripe blueberries were included in the samples. Blueberries were separated from debris including grass, leaves and weeds for each sample.

3.5.5 Evaluation of Model Performance

The eight measures described below were used to evaluate the model performance in early, middle and late season. The various performance measures used by Legates and McCabe (1999) in the model were: observed values denoted by O_t; corresponding predicted values denoted by P_t and; the number of measures denoted by n.

3.5.5.1 Root mean square error

Root Mean Square Error (RMSE) is widely used absolute measure for assessing the model performance in time series as well as regression models. Its value is usually in terms of the unit of series or the variable being modeled. The RMSE is calculated using

$$RMSE = \sqrt{\frac{[\sum_{t=1}^{n}(O_t - P_t)^2]}{n}}$$

3.5.5.2 Mean absolute error

Mean Absolute Error (MAE) is another extensible used absolute measure that take the unit of the series or variable. It is calculated as

$$MAE = \frac{\sum_{t=1}^{n}|O_t - P_t|}{n}$$

Since RMSE are squared of the deviation, the inflating effect of outliers (extremely large or small values) is more pronounced in RMSE than in MAE. In general, RMSE ≥ MAE and the extent to which RMSE exceeds MAE shows the outliers in the data (Legates and McCabe, 1999).

3.5.5.3 Coefficient of efficiency

Nash and Sutcliffe, (1970) used coefficient of efficiency (E) as criteria for assessment of stream flow simulation models. It can be calculated as

$$E = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(O_t - \bar{O})^2}$$

Where $\bar{O}$ is mean of the observed values. E ranges from minus infinity to 1, with higher values representing better performance. If E > 0, the model gives better forecasts than forecasting all values by the mean ($\bar{O}$); E = 0 means the model forecasts are as good as the mean; and E < 0 means the model is worse than forecasting the values by the mean.

3.5.5.4 Baseline-modified coefficient of efficiency

Garrick et al. (1978) pointed out that even poor stream flow simulation models can give high values for E and use of the mean discharge as reference is unnecessarily primitive. Watt and Nozdryn-Plotnicki, (1982) argued a modified E, denoted by EM that uses the current observed stream flow instead of the mean. Using the means of early, middle and late, denoted by O_{tm}, instead of overall mean as reference did not require additional resources as it was available for forecast future values. It can be calculated using

$$EM = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(O_t - O_{tm})^2}$$

3.5.5.5 Baseline-modified prime coefficient of efficiency

Garrick et al. (1978) as well as Legates and McCabe (1999) suggested that squaring the differences increases the sensitivity of the measures to outliers and thus absolute values of the differences should also be considered. It is denoted by EMP and calculated using

$$EMP = 1 - \frac{\sum_{t=1}^{n}|O_t - P_t|}{\sum_{t=1}^{n}|O_t - O_{tm}|}$$

3.5.5.6 Index of agreement

The index of agreement (d), is also a relative measure that ranges between 0 and 1, with high values indicating better performance of model (Willmott, 1981). It can be calculated as

$$d = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(|P_t - \bar{O}| + |O_t - \bar{O}|)^2}$$

Where $\bar{O}$ is the mean of the observed values. Although both d and R^2 (coefficient of determination) range from 0 to 1, Legates and McCabe, (1999) caution against interpreting their values the same way because "a value of 0.5, for example, has substantially different meaning for R^2 and d." They also propose that d denotes a decided improvement over R^2, but is sensitive to extreme values (outliers).

3.5.5.7 Baseline-modified index of agreement

The baseline-modified index of agreement (dM) followed the same argument as in EM. It is calculated using

$$dM = 1 - \frac{\sum_{t=1}^{n}(O_t - P_t)^2}{\sum_{t=1}^{n}(|O_t - O_{tm}| + |P_t - O_{tm}|)^2}$$

3.5.5.8 Baseline-modified prime index of agreement

The absolute value of differences can be used in the baseline-modified index of agreement, denoted by dMP, to reduce its sensitivity to outliers like EMP.

$$dMP = 1 - \frac{\sum_{t=1}^{n}|O_t - P_t|}{\sum_{t=1}^{n}(|O_t - O_{tm}| + |P_t - O_{tm}|)}$$

RMSE and MAE are commonly used absolute error measures, in addition to this, a relative error measures, like E, EM and EMP are also used to give comparison of the errors in a physically meaningful way (a value of zero implying the model predicts as good as observed mean). The index of agreement d, dM and dMP are also used to see the correlation between the observed and the predicted values. Since these measures provide good idea about performance of the model, they do not give different weights for under- and over-predictions. The weight they give to (O_t – P_t) is the same regardless of the sign (negative for over- and positive for under-prediction) of the difference.

3.5.6 Statistical Analysis

Linear regression was used to calibrate the actual fruit yield with the percentage of blue pixels in each field separately. The calibration equation of Field A was used to predict fruit yield in Field B and calibration equation of Field B was used to predict fruit yield in Field A for validation. Calibration and validation of regression equations/models, coefficient of determination and root mean square error were calculated using Minitab 17 (Minitab Inc., PA, USA) software. Mean absolute error (MAE), coefficient of efficiency (E), modified coefficient of efficiency (EM), prime modified coefficient of efficiency (EMP), index of agreement (d), modified index of agreement (dM), prime modified index of agreement (dMP) were calculated using Microsoft Access (Microsoft Corp., Seattle, Wash). Analysis of variance (ANOVA) was used to evaluate the ripening of fruit at different stages of harvesting (early, middle and late) using Minitab 17 statistical software. The ripening of fruit was examined by calculating the percentage blue pixels at selected sampling locations. Normal probability plot of residuals using Anderson-Darling (AD) test at significance level of 5% was used to check the normality of the error terms. Residual versus fits plot was used to check the constant variance. The deviation from normality and constant variance assumptions required suitable transformation on collected data. Independence of error terms was achieved by applying treatments randomly. ANOVA using GLM procedure was utilized to examine the fruit ripening at different harvesting times. Multiple means comparison was performed using honestly significant difference (HSD) to determine which specific means significantly differ from each other in early, middle and late season.

3.6 Estimation of Fruit Ripening Characteristics

3.6.1 Site Selection

The same wild blueberry fields, used for objective 2 *i.e.* Highland Village-II (45.24°N, 63.40°W; 2.57 ha) and East Mine-II (45.43°N, 63.48°W; 3.88 ha), were selected to examine the impact of physical and chemical properties of blueberries on fruit ripening in central Nova Scotia. Both fields were in crop year of the biennial production cycle in 2015. The selected fields were under commercial management receiving biennial pruning by mowing for the past several years along with conventional management practices.

3.6.2 Experimental Design

Completely randomized block design (same blocks were used as for objective 2) was employed to collect fruit samples from each field. Fresh blueberries were harvested from blueberry plants during each harvesting time (early, middle and late) from selected plots within each block. Representative samples (harvested berries) from each block and each harvesting time was examined for firmness, total soluble solids (TSS), titratable acidity (TA), anthocyanin content (AC), moisture content (MC), weight and diameter. Triplicate from each block at each harvesting time were analyzed to improve statistical power for chemical assays.

3.7 Sample Collection

Blueberries were harvested with handrake (The Hubbard Rake Co. ME, USA) for physical and chemical analysis from start of harvesting season until end of the season. Blueberry samples (about 1 kg from each block), immediately after harvesting from selected sub blocks (early, middle and late), were cleaned from any debris and leaves. The samples were stored in plastic Ziploc ® bags (S.C. Johnson and Sons Ltd, ON, CA) and were kept on ice in a Coleman ® (Coleman Company Inc., Wichita, KS, USA) 62 quart hard cooler to preserve freshness and avoid from physical damage during transportation. The samples were transported from fields to Dalhousie Agricultural Campus, Truro, Nova Scotia for further analysis. The analysis were conducted in Product Lab (Haley Institute), Precision Agriculture Lab (Banting Building), and Health and Bio-products Lab (Cox Institute). Firmness, diameter, weight and MC were determined on fresh berries, immediately after reaching the samples on delivery points while rest of the samples were kept on -40°C in a Health and Bio-product Lab for later on anthocyanin, TSS and TA analysis.

3.7.1 Moisture Content and Physical Parameters

Blueberry samples were transferred into Precision Agriculture lab for determining moisture content (MC), weight and diameter. Average diameter of randomly selected 20 berries from each sample was made possible using vernier caliper and average weight was determined by randomly selected 25 berries from each sample, using an electronic balance (Denver Instrument Inc., NY, USA). MC was determined by oven dry method. An appropriate sample was put into weighed aluminum dish and weighed it (Fig.3-11a). The weighed sample was put into oven at temperature 105^0 C overnight until it dried and then again it weighed (Fig. 3-11b). Average diameter, average weight and percent MC were calculated by using following equations.

$$\text{Average Diameter} = \frac{\text{Sum diameter of berries}}{\text{No. of berries}}$$

$$\text{Average Weight} = \frac{\text{Sum weight of berries}}{\text{No. of berries}}$$

$$\text{MC (\%)} = \frac{(\text{Dish+Fresh beries}) - (\text{Dish+Oven dried berries})}{\text{Weight of fresh berries}} \times 100$$

(a) (b)

Figure 3-11. Moisture content determination (a) before oven dry (b) After oven dry.

3.7.2 Firmness

Firmness of fresh blueberries was determined in Product lab (Haley Institute) by using a TA.XTplus texture analyzer (Stable Micro System Ltd., GD, UK). Texture analyzer was calibrated for force by placing a weight of 2 kg loading cell on calibration hanger before conducting the compression firmness test. The compression firmness (N mm^{-1}) was determined by applying a force (N) through a cylindrical flat head stainless steel puncture probe with a diameter of 4 mm (TA-52) into berry flesh from the sagittal side. The probe height was calibrated to 10 mm above TA-90 base platform so that blueberry could be line up directly under the probe (Fig. 3-12). The other instrumental settings were: pre-test speed of 2 mm s^{-1}; test speed of 1 mm s^{-1}; post-test speed of 5 mm s^{-1}; auto force trigger of 5 g; and, test distance of 6 mm into the berries. The diameter and weight of each berry was determined before setting it for compression firmness. Blueberry samples were randomly selected for analysis and sample size was 10 berries (replicate thrice) from each block at each harvesting time (early, middle and late). The instrument was calibrated each time for force and height, when a new set of fruit was introduced.

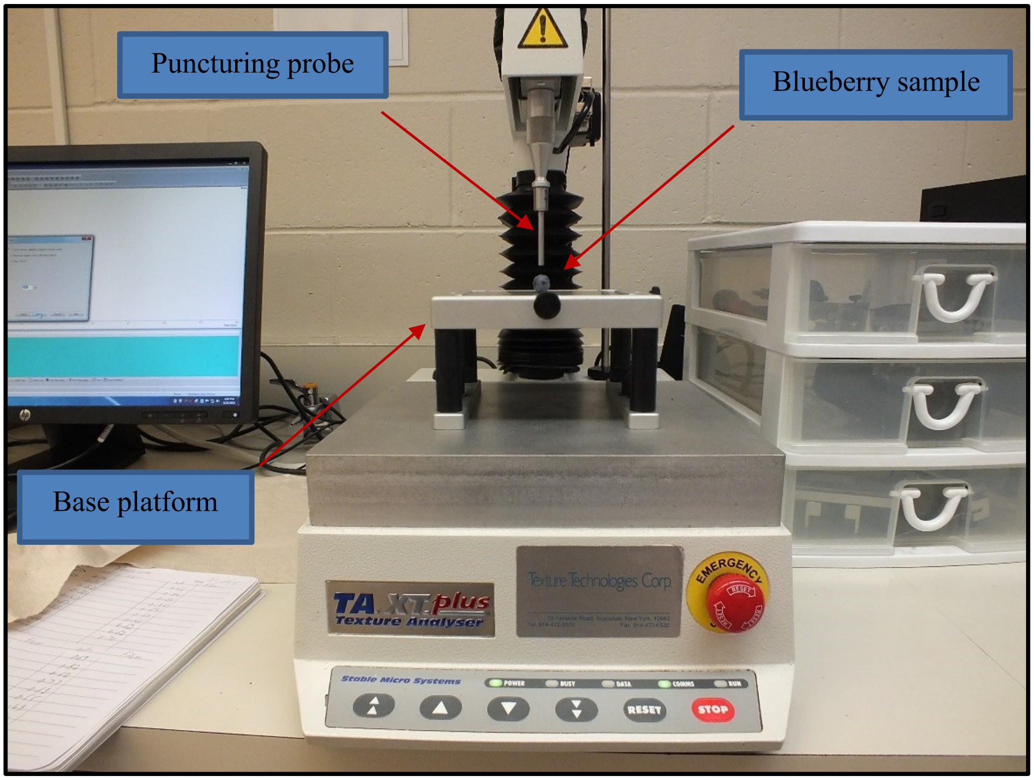
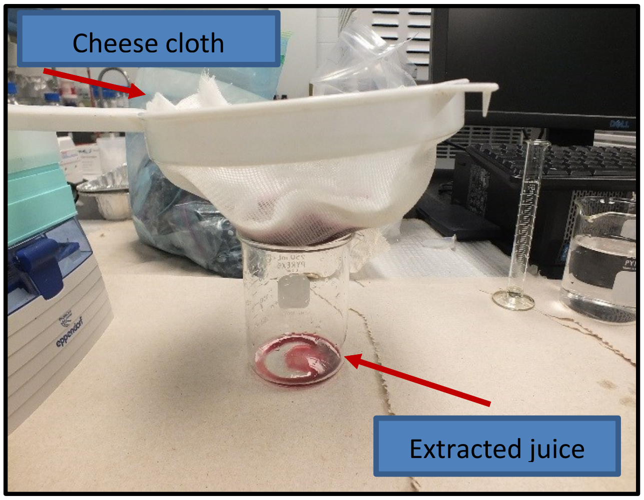


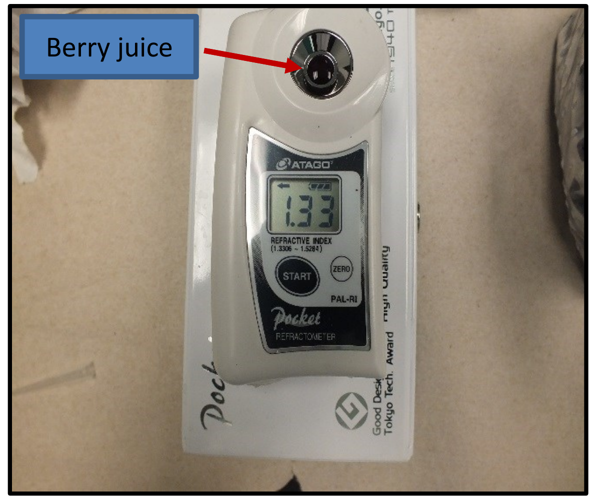
Figure 3-12. Texture analyzer for determination of firmness.

3.7.3 Total Soluble Solids and Titratable Acidity

Twenty grams of blueberries with equal amount of deionized water was added in a blender (Magic Bullet Single Shot, SH, CH) to extract juice. The extracted juice was filtered through four layers of cheesecloth (Everyday Essentials, TR, CA) (Fig. 3-13a). TSS were determined using handheld refractometer (Atago Co. Ltd., JP) and expressed as °Brix. Refractometer was calibrated by placing few drops of deionized water on refractometer's prism. If it shows zero value, then it is perfectly calibrated. Prism was wiped with tissue and then placed few drops of blueberry juice on it and noted the value (Fig. 3-13b).



(a)



(b)

Figure 3-13. TSS and TA determination (a) Blueberry juice extraction (b) Refractometer.

The remaining extracted juice was used to determine TA using pH meter method (Ronald et al., 1998). The electrode from deionized water in the storage beaker was removed and dried. The electrode was placed into a beaker containing a buffer solution of pH 7 and calibrated it. The electrode was rinsed with deionized water and placed into a beaker containing blueberry juice which was kept on hot plate magnetic stirrer (Isotemp® Fisher Scientific, ON, CA) with 300 rpm. The electrode should not have any contact with the sides and base of the beaker, otherwise it can affect the reading. The blueberry juice was titrated against 0.1N NaOH solution. NaOH was dropped directly into beaker with pipette and reading can be seen on digital readout (VWR SympHony B10P, CT, USA) until solution was reached to pH 8.2 (Fig. 3-14). The care must be taken that NaOH was not adhered to walls of beaker while it was pouring into beaker. The following equation was used to calculate TA, expressed as milliequivalents of citrus acid per gram of fresh weight.

$$\text{Percent Acid} = \frac{(\text{ml of NaOH used}) * (0.1\text{N NaOH}) * (\text{milliequivalent factor}) * 100}{\text{grams of sample}}$$

$$\text{Sugar Acid ratio} = \frac{°\text{Brix value}}{\text{Percentage acid}}$$

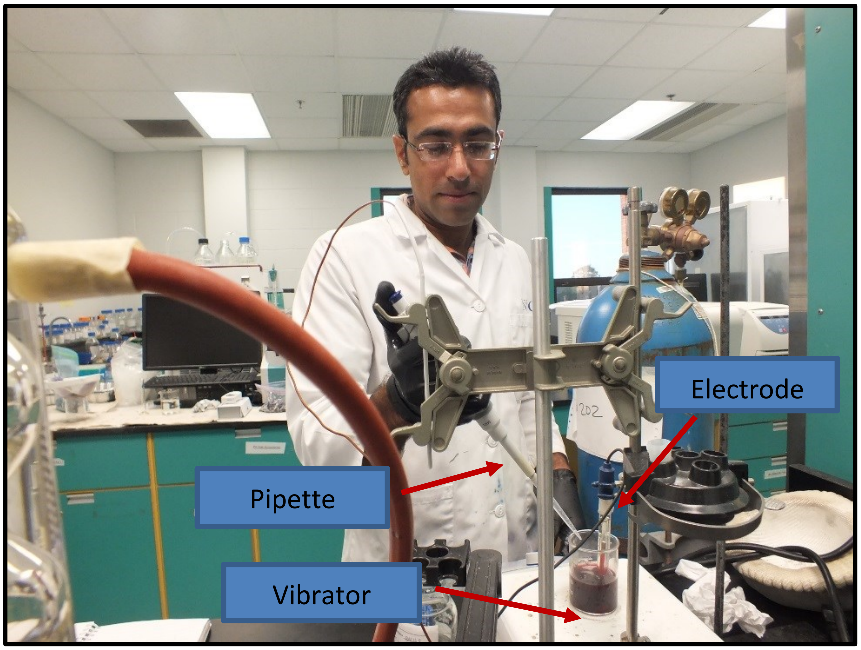


Figure 3-14. Titration process for determination of TA.

3.7.4 Anthocyanin Content

Wild blueberries samples were extracted in triplicate with acetonitrile (Fisher Scientific, Canada) for the analysis of anthocyanin content. A 10 g sample from each block at each harvesting time was added to 15 ml of acetonitrile containing 4% acetic acid and homogenized in a blender (Magic Bullet Single Shot, SH, CH) for 5 min. A 10 ml of acetonitrile containing 4% acetic acid was used to wash the blender after recovery of homogenate and pooled both homogenates. The pooled homogenate was kept in a water bath shaker (Thermo Fisher Scientific, GE, USA) at room temperature for 15 min and then centrifuged (Thermo Scientific, Sorvall ST16R, ON, CA) at 5000×g for 15 min at 4°C (Fig. 3-15). The pellets were washed with 5 ml of acetonitrile containing 4% acetic acid after centrifugation and again centrifuged. The resultant supernatant was combined with the initial extract.

Anthocyanin content (AC) can be measured with pH differential method using visible light spectrophotometry (Lee et al., 2005). Anthocyanin contents were measured between a colored oxonium salt at pH 1.0 and a colorless hemiketal at pH 4.5 (Fig. 3-16a). The difference in absorbance at the maximum absorbance wavelength (λmax 520 nm) associates with concentration of anthocyanin pigments in sample. The absorbance was also seen at a level where no color is absorbed (700 nm) and subtracted from maximum absorbance reading to correct for turbidity. Anthocyanin contents were calculated based on molecular weight and molar absorbance of the second prominent anthocyanin in wild blueberries *i.e.* malvidin-3-glucoside (Lee et al., 2005), instead of major anthocyanin *i.e.* delphinidin-3-glucoside, found in *Vacciniun angustifolium* blueberries due to low molar absorptivity of this pigment (Wrolstad, 1976). A potassium chloride buffer at pH 1.0 and sodium acetate buffer at pH 4.5 with concentrated HCl (Fisher Scientific, ON, CA) were prepared. A pipette was used to transfer 10 µL extracted wild blueberry sample followed by an additional 190 µL of pH 1.0 and pH 4.5 buffers to the respective wells of polypropylene 96-well microplate (VWR International, LLC, PA, USA)(Fig. 3-16a). The sample and reagent created a 1:19 of extract to buffer and samples were loaded in triplicate for each buffer. The plate was run in Synergy | H1 microplate reader (BioTek® ON, CA) and absorbance was read at 520 nm and 700 nm (Fig. 3-16b). The anthocyanin concentration was expressed as malvidin-3-glucoside equivalents (M3GE). The following equations were used to calculate anthocyanin contents.

Malvidin-3-glucoside molecular weight (MW) = 493.5 g mol^{-1}

Malvidin-3-glucoside molar extinction coefficient (MEC) = 28000 L $mol^{-1}cm^{-1}$

Extraction Volume = 30 ml

Dilution Factor = 19

Absorbance (A) = $(A_{520} - A_{700})$ pH 1.0 – $(A_{520} - A_{700})$ pH 4.5

Concentration (C)(mg L^{-1}) = (A* MW* df* 1000) / MEC

Final AC in mg M3GE / 100g fresh weight = (((C / 1000) * EV) / weight of sample (g)) * 100

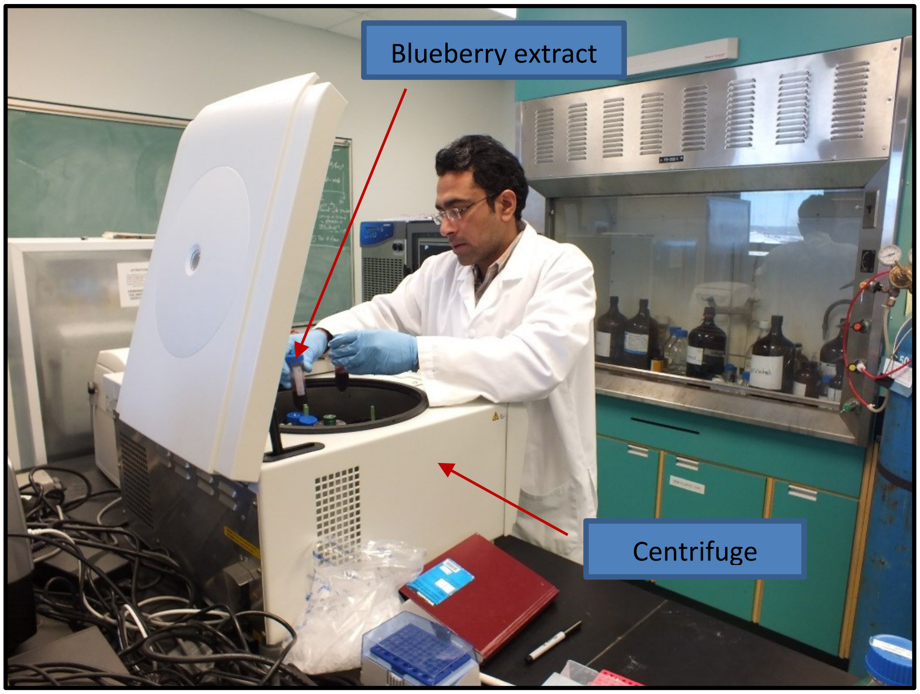
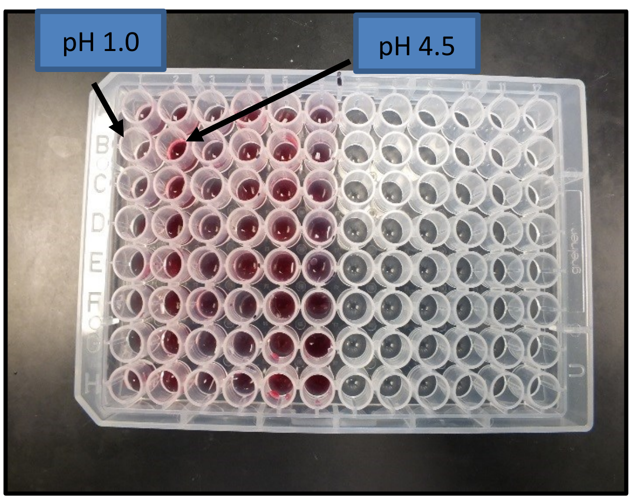


Figure 3-15. Centrifugation process for anthocyanin content.



(a) (b)

Figure 3-16. Spectophotometer process (a) extract at different pH in microplates (b) microplate reader for absorbance determination at 520 nm and 700 nm.

3.8 Statistical Analysis

Analysis of collected data was performed using Minitab 17 (Minitab Inc., PA, USA) and SAS 9.3 (SAS Institute Inc., NC, USA) statistical software. Normal probability plot of residuals at a significance level of 5% using Anderson-Darling (AD) was used to check the normality of the error terms in Minitab software. Assumption of constant variance was checked using residual versus fits plot and deviation from normality and constant variance required a suitable transformation on collected data. Independence of error terms were attained by applying treatments randomly. Analysis of variance was used to examine the fruit ripening characteristics such as anthocyanin contents, TSS, TTA, size and firmness etc. at each harvesting stage (early, middle and late). Multiple means comparison was performed using honestly significant difference (HSD) to determine which specific means significantly differ from each other in early, middle and late harvesting stage.

CHAPTER 4 QUANTIFY FRUIT LOSSES AT DIFFERENT HARVESTING TIMES TO EVALUATE THE PICKING PERFORMANCE OF THE HARVESTER

4.1 Introduction

Wild blueberry fields are established from the existing fields after removing of forest land to encourage development of natural stands (Eaton, 1988). It is managed on two year production cycle (Hall et al., 1979), with pruning above ground by fire or flail mowing to stimulate stem growth from rhizomes (Kinsman, 1993) and subsequent year pollination, fruit production and harvesting (Eaton, 1988). The harvesting of wild blueberry either manually or mechanically varies from early to mid-August of crop year (Yarborough, 1997).

Over the past 100 years, hand-held metal rakes, initially designed as a cranberry scoop, have been used for manual harvesting of wild blueberry crop (Yarborough, 1992). Harvesting losses varied from crew to crew but the overall efficiency of hand-raking was assessed to be 80% with an average loss of 20% (Kinsman, 1993). Short harvesting season, high labor cost, significantly higher yields, increased acreages, shortage and quality of labor over the past 20 years (Holbein, 1991) have thrust the wild blueberry industry towards mechanical harvesting. The research and development work on mechanical harvesters started in early 1950s, (Rhodes, 1961); however, a viable mechanical harvester was not commercialized until 1980s, (Hall et al., 1983).

In the last three decades, wild blueberry fruit yield have significantly increased due to improved management practices (selected fungicides, herbicides, fertilizers, pollination, pruning, etc.) (Yarborough and Ismail, 1985; Litten et al., 1997; Esau et al., 2013; Yarborough, 2015). Changes in crop characteristics, undulating terrain, environmental factors and time of harvesting have resulted in an increased fruit loss during mechanical harvesting. Past evaluations reveal that significant cost saving using mechanical harvester may be perceived but losses in yield, uproot of plants and quality of harvested berries may also be realized (Marra et al., 1989). The introduction of hydraulic control systems for head height aboveground, head rotational speed, cleaning brush rotational speed and speed control of belts and conveyors have made harvester more efficient with equivalent yields to hand-harvest while retaining high quality fruit (Hall et al., 1983; Roka et al., 2000). Farooque et al. (2014) described that the fruit losses during harvesting were directly proportional to the variation in fruit yield (higher fruit losses in high yielding areas and vice versa). The authors also narrated that the pre-harvest fruit losses were higher during late season when compared with the early season harvesting for selected wild blueberry fields.

Following researchers pinpointed the impact of harvesting time on crop yield and losses in different cropping systems. The optimum stage at which seed crop harvested greatly influences both yield and losses, if proper harvesting time is not known (Hyde et al., 1959). Sharrock and Parkes (1990) revealed that buttercup squash harvested at an early stage showed significantly lower losses compared to harvest at later stage. The time of harvesting has impacted on lettuce crop loss and quality during harvesting (Herner, 1989). It is immense important to harvest fruits, vegetables and flowers at proper harvesting time, proper size, and at peak quality (Wilson et al., 1995), because quality cannot be improved only maintained after harvest. They also narrated that produce, harvested at immature or over mature stage may not last long compared to that picked at proper maturity stage.

The influence of time of harvesting and length of harvest period at minimum losses and optimum yield may be secured have been problems of grain research throughout last three quarters of a century (Burnett and Bakke, 1930). Remorini et al. (2008) revealed that it is difficult to suggest harvesting time of peach that exhibit best compromise between optimal quality and nutritional attributes on one hand and minimum losses and resistance to handling damage on the other. It is of immense important to harvest fruit at proper harvesting time and stage because late harvest has resulted in more fruit losses from pre-harvest drop in oranges (Ali Dinar et al., 1976). Harvesting of wild blueberry crop normally starts in early to mid-August, approximately 90% of the blueberries turned blue, and the harvesting season lasts about three to four weeks (Farooque et al., 2014). However, limited research has been reported to examine the impact of time of harvesting on fruit losses during mechanical harvesting of wild blueberry. Therefore, this study was designed to identify the effect of harvesting time on picking performance in terms of harvesting losses of the commercial wild blueberry harvester.

4.2 Materials and Methods

Eight wild blueberry fields were selected to analyze the impact of time of harvesting on picking efficiency of wild blueberry harvester in Atlantic Canada. The selected fields were Londonderry (45.48°N, 63.57°W; 3.20 ha) and Earltown (45.60°N, 63.09°W; 1.9 ha) in 2011, Tracadie (47.28°N, 65.14°W; 1.6 ha) and Highland Village (45.24°N, 63.40°W; 2.57 ha) in 2012, Debert-I (45.45°N, 63.45°W; 1.01 ha) and Hardwood Hill (45.42°N, 63.52°W; 2.05 ha) in 2013 and Debert-II (45.44°N, 63.45°W; 1.01 ha) and East Mine-I (45.43°N, 63.48°W; 3.88 ha) in 2014. The selected fields had been under traditional management practices for the past several years. The experimental plots of 3.0 m x 0.91 m (same as the width of harvester head) were randomly selected in the path of operating harvester using a measuring tape. The field boundaries, bare spots, weeds patches and experimental plots of each field were mapped with a real-time kinematics global positioning system (RTK-GPS).

Split plot factorial design was used with three levels of ground speed (1.2, 1.6 and 2.0 km h^{-1}) and header revolutions (26, 28 and 30 rpm), and three levels of harvesting time (early, middle and late). The harvesting time was considered as whole plot and ground speed and header rpm were taken as sub-plots. All treatment combinations of sub-plots were randomized within whole plot and whole plots were also randomized with each other. All nine treatment combinations of ground speed and header rpm were allocated to each category of harvesting time. The combined effect of time of harvesting in combination with machine operating parameters on harvesting losses were evaluated by harvesting selected plots mechanically.

The selected experimental plots in each field were harvested mechanically using single head wild blueberry harvester. The harvester was run at chosen levels of ground speed and header rpm to collect fruit yield and berry losses. Prior to harvest, pre harvest losses were collected manually to differentiate any other losses than machine from the selected plots. The harvester head was raised and picker bars were cleaned of any debris before harvesting the selected plots. Then harvester head was lowered at selected levels of ground speed and rpm to harvest the plot and it was again raised at the end of each plot so that fruit harvested could be transferred to the storage bin. Immediately following the harvested plots, the berry losses such as ground losses, un-harvested berries on plants, and blower losses were collected. Total losses were acquired by accumulating the losses mentioned above. Detailed procedure about collection of berry losses can be seen in chapter 3. The picking performance of blueberry harvester was evaluated in relation with harvesting time and machine operating parameters.

4.3 Statistical Analysis

The analysis of collected data was performed using Minitab 17 (Minitab Inc., PA, USA) and SAS 9.3 (SAS Institute Inc., NC, USA) statistical software. Minimum, maximum, mean, standard deviation and coefficient of variation were determined on collected data using descriptive statistics. Normal probability plot of residuals using Anderson-Darling (AD) test at significance level of 5% was used to check the normality of the error terms. Residual versus fits plot was used to check the constant variance. The deviation from normality and constant variance assumptions required suitable transformation on collected data. Independence of error terms were achieved by applying treatments randomly. A factorial analysis of co-variance (ANCOVA) using general linear model (GLM) procedure was performed to study the joint effect of the selected factors on fruit losses. Fruit yield was used as covariate because it is an uncontrollable nuisance variable and it has a linear relationship with fruit losses (Farooque et al., 2014). Multiple means comparisons (MMC) were performed using least square (LS) means to determine which specific means significantly differ from each other in the treatment combinations.

4.4 Results and Discussion

The model assumptions normal distribution, constant variance and independence of error terms were tested by examining the residuals at 5% significance level. Non-normal data were normalized using square root transformation for analysis and were reported to original scale using back transformation. Summary table (basic statistics) revealed that variability in percent fruit losses in middle season is least (CV<15%), whereas in late season and early season variability is more (CV>15%) compared to middle season. Variability in fruit yield is moderate in early, middle and late season (CV<35%) (Table 4-1).

Table 4-1. Summary statistics of berry fruit losses and fruit yield for selected plots.

Fruit Losses (%)						
Season	Min	Max	Mean (%)	StDev	CV (%)	Skewness
Early	8.21	19.07	12.78	2.41	18.85	-0.03
Middle	12.31	21.83	17.21	2.20	12.78	0.13
Late	12.04	26.04	22.02	3.87	17.57	0.42
Fruit Yield (kg ha^{-1})						
Season	Min	Max	Mean	StDev	CV (%)	Skewness
Early	3182	11711	6746	1987	29.45	0.11
Middle	3024	9272	7207	2315	32.13	-0.44
Late	2809	7315	4822	1467	30.42	0.24

Factorial analysis of covariance (ANCOVA) results revealed that the main effects of time of harvesting (season), header rpm and ground speed of harvester were found to be significant. The interaction effect (Season × rpm) was found to be non-significant, while all other interaction effects were significant (Table 4-2). The higher order interaction effects are significant, then main effects and lower order interaction effects can be ignored in factorial experiments (Montgomery, 2008). Significance of three-way interaction effect suggested that a suitable combination of speed, season and rpm could result in better picking efficiency of blueberry harvester.

Table 4-2. Analysis of covariance of pooled data.

Effects	DF	F-value	P-value
Fruit Yield	1	1.74	0.2502
Season	2	9.63	<0.0001
Speed	2	6.94	<0.0001
RPM	2	11.94	<0.0001
Season*Speed	4	7.34	<0.0001
Season*RPM	4	1.37	0.3746
Speed*RPM	4	8.72	<0.0001
Season*Speed*RPM	8	5.96	<0.0001

Significance level is checked at $p = 0.05$.

Results of multiple means comparison (MMC) showed that losses were significantly higher in late season compared to early and middle season harvesting (Table 4-3). More berry losses in late season compared to early and middle season, in spite of having same impact force as in early and middle, might be due to loosening of berry grip with stem. The treatments 1, 2 and 3 were given the highest losses (losses >20%), while treatments 26 and 27 were found to generate the least losses *i.e.* 9.14% and 10.38%, respectively (Table 4-3). Results of MMC suggested that ground speed 2.0 km h^{-1} with 30 and 28 rpm generated 22.61% and 21.66% losses in late season, respectively, while minimum loss in early and middle season at ground speed of 1.2 km h^{-1} with 26 rpm suggesting the operating harvester at lower ground speed and rpm can minimize the harvesting losses. Results of (1-9) treatments suggested that either higher ground speed or faster rpm or combination of both induced more fruit losses at any harvesting time. The reason could be impact force due to higher tangential and radial forces applied by harvester during berry picking (Table A1, Appendix 'A'). Treatments (10-18) showed diversify trend of berry losses ranging 13 to 17 %. Treatments (10 & 11) and (11 & 12) were found to be non-significant to each other. Similarly, treatments 13, 14, 15, 16 and 17 were found to be non-significant with each other at selected levels of ground speed and header rpm at different harvesting times.

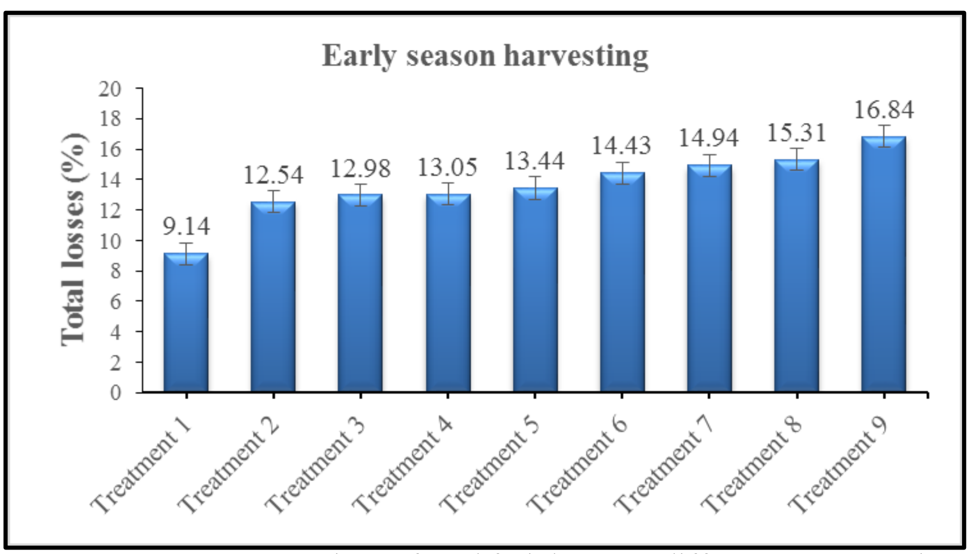
Table 4-3. Results of MMC of three-way interaction effect on fruit losses.

Treatments	Time of harvesting(season)	Speed (km h^{-1})	RPM	Loss (%)
1	Late	2.0	30	22.61 a
2	Late	2.0	28	21.66 ab
3	Middle	2.0	30	20.83 bc
4	Late	1.6	30	19.51 cd
5	Late	2.0	26	19.07 d
6	Middle	2.0	28	18.88 d
7	Middle	1.6	30	18.36 de
8	Late	1.6	28	17.06 ef
9	Early	2.0	30	16.84 f
10	Middle	2.0	26	16.77 fg
11	Early	2.0	28	15.31 gh
12	Late	1.2	30	15.10 h
13	Early	2.0	26	14.94 hi
14	Middle	1.6	28	14.92 hij
15	Middle	1.6	26	14.45 hijk
16	Early	1.6	30	14.43 hijk
17	Late	1.6	26	13.88 hijkl
18	Early	1.6	28	13.44 ijkl
19	Middle	1.2	30	13.42 jkl
20	Early	1.6	26	13.05 kl
21	Late	1.2	28	13.01 kl
22	Early	1.2	30	12.98 kl
23	Late	1.2	26	12.96 kl
24	Middle	1.2	28	12.72 l
25	Early	1.2	28	12.54 l
26	Middle	1.2	26	10.38 m
27	Early	1.2	26	9.14 m

Means with no letter shared are significantly different at p = 0.05

Fruit losses ranged from 9 to 13 % in treatments (19-27). Treatments 19 to 25 were non-significant to each other. The last two treatments (26 & 27) were found to be the best for producing least berry losses with ground speed of 1.2 km h^{-1} and 26 rpm.

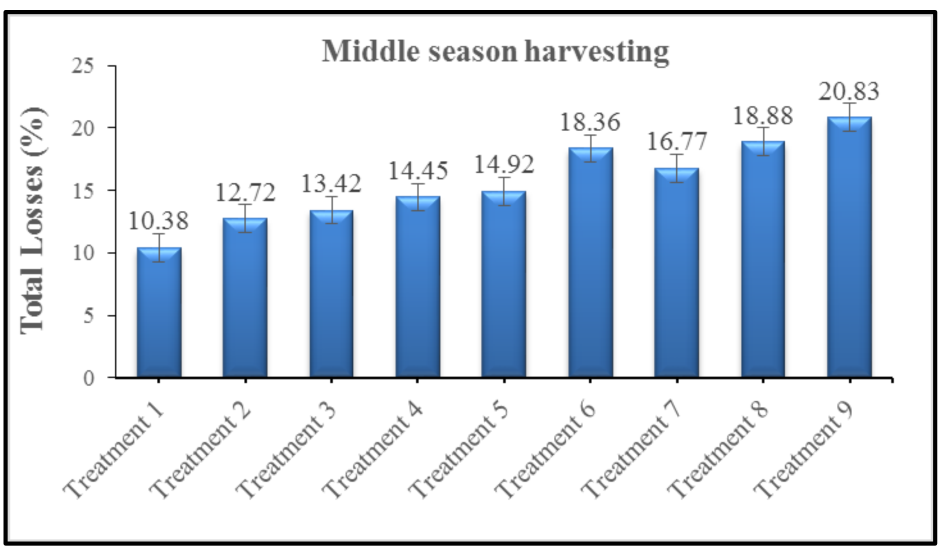
It is evident from results of this study, total losses are dependent upon time of harvesting, ground speed and header rpm of the harvester (Fig. 4-1). The overall losses ranging from 9-17% were observed during early season harvesting. The early season harvesting with less than 10% berry losses was found to be the best combination with treatment 1 (1.2 km h^{-1} and 26 rpm). The berry losses during early season harvesting increased, as ground speed and rpm of harvester were increased (Fig. 4-1). The treatment 2, 3, 4 and 5 were non-significant within each other in early season harvesting with less than 1% difference in berry losses. The treatment 7 was non-significant to treatment 8, but significantly different from treatment 9 (Fig. 4-1). The reason, in spite of having the same ground speed, could be higher rpm of the harvester head. The treatment 9 (2.0 km h^{-1} and 30 rpm) induced the highest fruit losses (> 16%). It might be due to high ground speed and higher rpm of the harvester.



Treatment 1: 1.2 km h^{-1} and 26 rpm
Treatment 2: 1.2 km h^{-1} and 28 rpm
Treatment 3: 1.2 km h^{-1} and 30 rpm
Treatment 4: 1.6 km h^{-1} and 26 rpm
Treatment 5: 1.6 km h^{-1} and 28 rpm
Treatment 6: 1.6 km h^{-1} and 30 rpm
Treatment 7: 2.0 km h^{-1} and 26 rpm
Treatment 8: 2.0 km h^{-1} and 28 rpm
Treatment 9: 2.0 km h^{-1} and 30 rpm

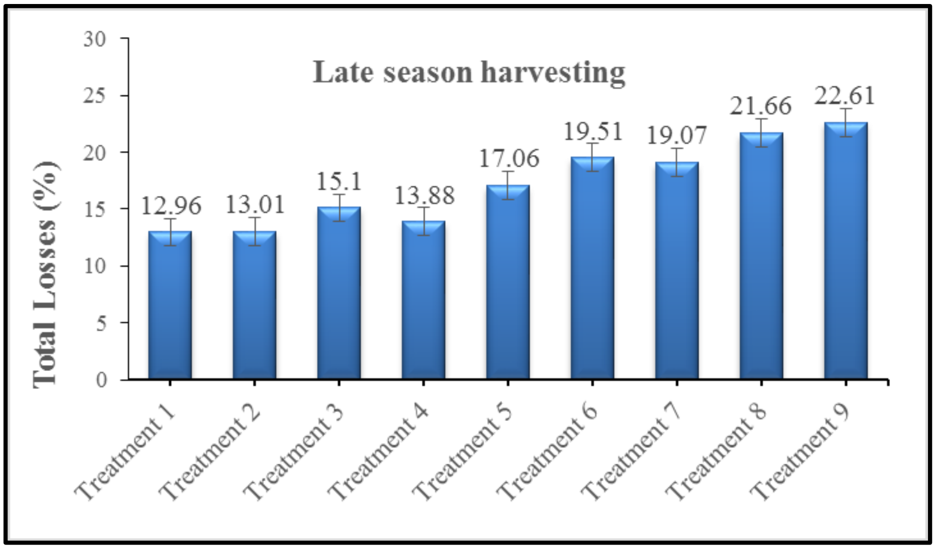
Figure 4-1. Mean comparison of total fruit losses at different treatments in early season harvesting.

The middle season harvesting with 1.2 km h^{-1} and 26 rpm (treatment 1) was found to be the best combination having < 11% fruit losses (Fig. 4-2). The inclusive losses during middle season harvesting ranging from 10-21% were observed. Fruit losses were observed more than 1% in middle season, when compared to early season harvesting with the treatment 1. It could be due to berry attached more firmly with stems in early season than middle season in spite of facing same impact force (Table A1, Appendix 'A'). The treatments 2 and 3 were non-significant, but significantly different from treatment 1 in middle season harvesting. The treatment 6 (1.6 km h^{-1} and 30 rpm) was significantly different from treatments 4 and 5, despite the fact, these treatments had same ground speed (Fig. 4-2). The more fruit losses in treatment 6 might be the result of higher rpm of the harvester. The other reason could be high impact force of the treatment 6 compared to treatment 4 and 5. The treatments 7, 8 and 9 were significantly different from each other and increasing trend of fruit losses were observed in them (Fig. 4-2). The combination 2.0 km h^{-1} and 30 rpm was the worst with fruit losses greater than 20%, suggesting the need to reduce the ground speed and header rpm for better berry recovery and picking efficiency in middle season harvesting.



Treatment 1: 1.2 km h^{-1} and 26 rpm
Treatment 2: 1.2 km h^{-1} and 28 rpm
Treatment 3: 1.2 km h^{-1} and 30 rpm
Treatment 4: 1.6 km h^{-1} and 26 rpm
Treatment 5: 1.6 km h^{-1} and 28 rpm
Treatment 6: 1.6 km h^{-1} and 30 rpm
Treatment 7: 2.0 km h^{-1} and 26 rpm
Treatment 8: 2.0 km h^{-1} and 28 rpm
Treatment 9: 2.0 km h^{-1} and 30 rpm

Figure 4-2. Mean comparison of fruit losses at different treatments in middle season harvesting.



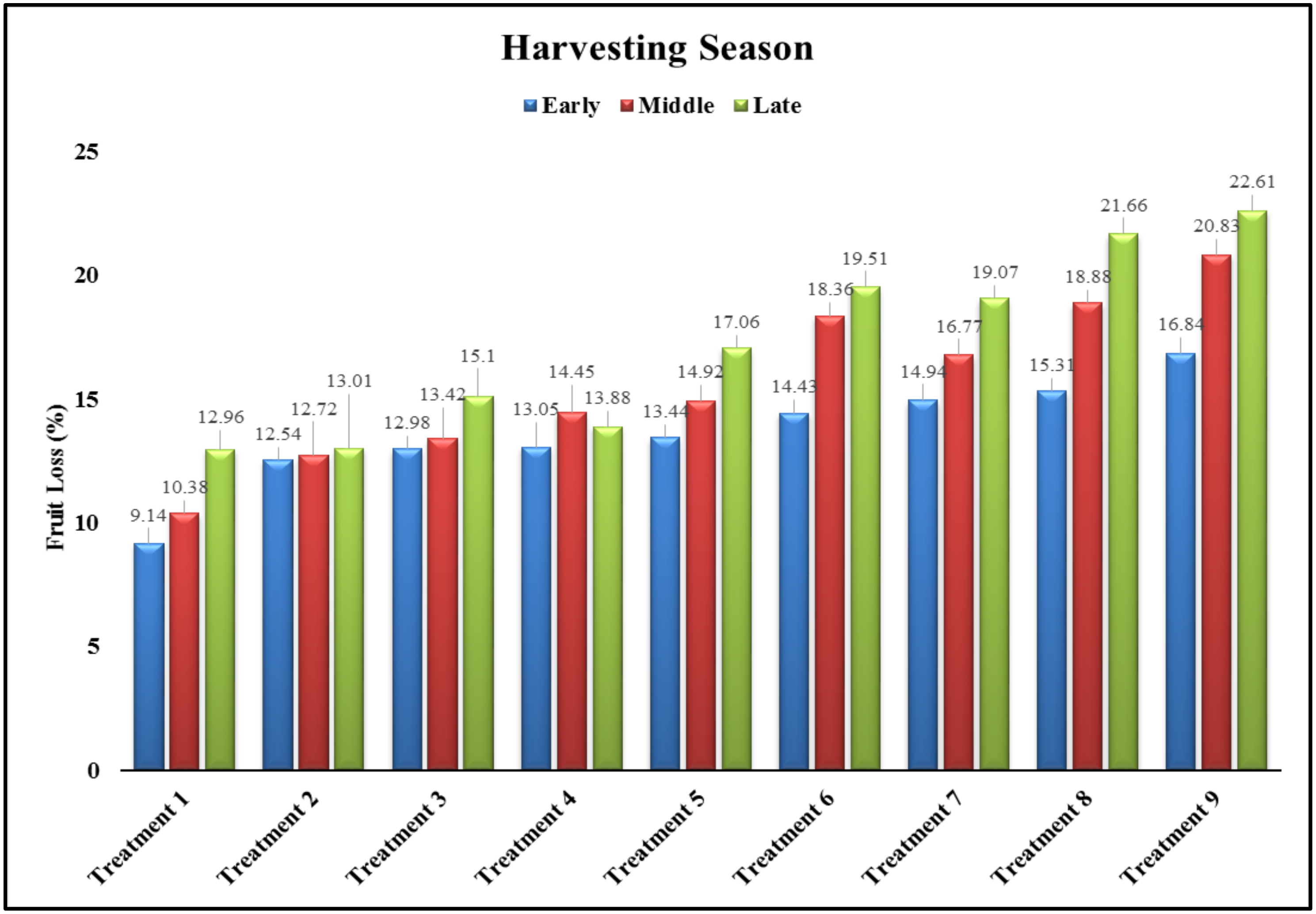
Treatment 1: 1.2 km h^{-1} and 26 rpm
Treatment 2: 1.2 km h^{-1} and 28 rpm
Treatment 3: 1.2 km h^{-1} and 30 rpm
Treatment 4: 1.6 km h^{-1} and 26 rpm
Treatment 5: 1.6 km h^{-1} and 28 rpm
Treatment 6: 1.6 km h^{-1} and 30 rpm
Treatment 7: 2.0 km h^{-1} and 26 rpm
Treatment 8: 2.0 km h^{-1} and 28 rpm
Treatment 9: 2.0 km h^{-1} and 30 rpm

Figure 4-3. Mean comparison of total fruit losses at different treatments in late season harvesting.

There was a fluctuating trend of fruit losses (%) with machine operating parameters in late season harvesting (Fig. 4-3). The treatment 1 was resulted more than 2% and 3% fruit losses in late season, when compared with middle and early season harvesting, respectively. It could be the reason of over ripeness and less firmly attached berries with plants, despite of having the same tip velocity and impact force (TableA1, Appendix 'A'). The treatment combinations 1 (1.2 km h^{-1} and 26), 2 (1.2 km h^{-1} and 28) and 4 (1.6 km h^{-1} and 26) were non-significant to each other, but significantly different from treatments 3 (1.2 km h^{-1} and 30) and 5 (1.6 km h^{-1} and 28) (Fig. 4-3). The treatment combinations 4, 5 and 6, in spite of having same speed, were significantly different, emphasizing the need to reduce header rpm as well to minimize berry losses in late season. The other reason could be different tip velocity and impact force were produced due to different rpm of the harvester. The treatment combinations 6 (1.6 km h^{-1} and 30) and 7 (2.0 km h^{-1} and 26) were non-significant, regardless of having different speed and rpm, suggesting that the combinations of machine parameters (low speed, high rpm and high speed, low rpm) can accommodate berry picking efficiency in late season harvesting. The treatment 7 was significantly different from treatment 8 and found to be more than 2% difference in fruit losses for over-ripened berries. There were 2%

and 6% more fruit losses with treatment 9 in late season as compared to same treatment in middle and early season, respectively. This could be due to berry attached with plant more firmly in early and middle season than over-ripened late season berries. The over-ripened berries required less force to remove from plants in late season due to loosely attached with plants compared to early and middle season.

Fruit losses ranging from (9-23)% were observed in entire harvesting season (early, middle and late season) (Fig. 4-4). There were noticed more fruit losses in late season compared to early and middle season in all treatment combinations. More than 4% fruit losses were observed in early, middle and late season with treatment 5 (grower's treatment), when compared with the least fruit loss producing treatment 1 (Fig. 4-4). The blueberry fruit losses increased gradually and reached at a level of 23% (6% more) after treatment 5 (1.6 km h^{-1} and 28 rpm). The middle and late season were more influenced with same level of ground speed and header rpm compared to early season harvesting (Fig. 4-4). The reason could be ripen or over-ripened berries were loosely attached to the plants and even with a small force, they can easily be removed from the plants. The results of this study suggested that less speed and lower rpm can contribute to reduce fruit losses in harvesting season. Operating the harvester at lower ground speed and header rpm will offer less impact force on plants (Table A1, Appendix 'A') and also provide a gentle upward movement of reel teeth bars through the plants to enhance harvesting efficiency by reducing the losses.



Treatment 1: 1.2 km h^{-1} and 26 rpm
Treatment 2: 1.2 km h^{-1} and 28 rpm
Treatment 3: 1.2 km h^{-1} and 30 rpm
Treatment 4: 1.6 km h^{-1} and 26 rpm
Treatment 5: 1.6 km h^{-1} and 28 rpm
Treatment 6: 1.6 km h^{-1} and 30 rpm
Treatment 7: 2.0 km h^{-1} and 26 rpm
Treatment 8: 2.0 km h^{-1} and 28 rpm
Treatment 9: 2.0 km h^{-1} and 30 rpm

Figure 4-4. Mean comparison of total fruit losses at different treatments in harvesting season.

4.5 Economic Analysis

The relative profitability of different treatment combinations can be best illustrated with yield and loss conclusions. The experimental results further describe as to which treatment combination is superior in wild blueberry fields. By knowing how much berries can be recovered from each treatment combination is meaningless without considering the time required to recover it and quality of harvested berries in economic analysis. The choices can be made through conclusion drawn from experimental results and from information on current prices and practices in blueberry industry. The underlying assumptions are maintained in determining the end results so that the reader can judge the results fairly.

1. The harvested fields are flat, smooth and free from rocks and other obstructions. It is an important assumption because much of the blueberry fields are rough and rocky.
2. The harvesting season is four weeks.
3. The allocated hectares for different treatment combinations are same.
4. We assume 62.5 kW (93 hp) tractor is operated with fuel consumption of 18.5 litter per hour (4.9 gal per hour) for all treatment combinations.
5. The operator and fuel cost is assumed to be \$15 per hour and \$1.03 per litter, respectively.
6. The average yield is assumed to be 4000 kg per hectare and middle season is taken for calculations.
7. All other parameters are assumed to be constant.

4.5.1 Calculations

Head width = 0.914 m (36”)

Chosen speed = 1.2 km h^{-1} = 1200 m h^{-1}

Area covered in 1 h = 1200*0.914 = 1096.8 m^2

$1096.8\ m^2$ area is harvested = 1 h

$10000\ m^2$ (1 hectare) is harvested = 9.12 h ha^{-1} = 9 h 8 min ha^{-1}

Similarly,

Time taken for speed of 1.6 km h^{-1}= 6.84 h ha^{-1} =6 h 51 min ha^{-1} and

Time taken for speed of 2.0 km h^{-1} = 5.47 h ha^{-1} = 5 h 28 min ha^{-1}

If,

Total yield = 4000 kg ha^{-1} and

Chosen ground speed is = 1.2 km h^{-1} with 26 rpm

Loss % = 10.38 % = 415.2 kg ha^{-1}

Remaining yield = 4000 – 415.2 = 3584.8 kg ha^{-1}

Let, the rate of berries = \$ 1.33 kg^{-1} = \$ 0.6 lb^{-1}

Blue berry growers get money = \$ 4767.78 ha^{-1}

Similarly,

With grower's speed of 1.6 km h^{-1} and 28 rpm

Loss % = 14.92 % = 596.8 kg ha^{-1}

Growers get money = \$ 4526.26 ha^{-1} and

With speed of 2.0 km h^{-1} and 26 rpm

Loss % = 16.77% = 670.8 kg ha^{-1}

Growers get money = \$ 4427.84 ha^{-1}

The difference in amount gets by farmer

1.2 km h^{-1} and 26 rpm with 1.6 km h^{-1} and 28 rpm = \$ 241.52 ha^{-1}

1.2 km h^{-1} and 26 rpm with 2.0 km h^{-1} and 26 rpm = \$ 339.94 ha^{-1}

1 ha is covered = 9.12 h

The yield harvested in 9.12 h = 4000 kg

The yield harvested in 1 h = 4000/9.12 = 438.60 kg

Similarly,

The yield harvested with 1.6 km h^{-1} = 4000/6.84 = 584.80 kg

The yield harvested with 2.0 km h^{-1} = 4000/5.47 = 731.26 kg

The time lag between each other

1.2 km h^{-1} with 26 rpm and 1.6 km h^{-1} with 28 rpm = 2.28 h

1.2 km h^{-1} with 26 rpm and 2.0 km h^{-1} with26 rpm = 3.65 h

When harvester with ground speed 1.6 km h^{-1} finishes job,

Then remaining kg with 1.2 km h^{-1} will be = (584.80 – 438.60)*2.28 = 333.34 kg

Similarly,

2.0 km h^{-1} with 1.2 km h^{-1} will be = (731.26 – 438.60)*3.65 = 1068.21 kg

4000 kg berries are harvested = 9.12 h

1 kg is harvested = 0.137 min

The additional time taken with speed 1.2 km h^{-1} compared to 1.6 km h^{-1} = 333.34*0.137

= 46 min ha^{-1}

And,

1.2 km h^{-1} compare to 2.0 km h^{-1} = 1068.21*0.137 = 146.34 min ha^{-1} = 2 h 26 min ha^{-1}

Operator cost = $ 15 h^{-1}

Fuel cost = 18.5 L h^{-1}

In our case, 46 min

Operator cost = $ 11.5

Fuel used = 14.18 L and cost of 1 L fuel = $ 1.03

Fuel cost = 14.18*1.03 = $ 14.61

Total expenditure = 11.5 + 14.61 = $ 26.11

The additional money gets when running harvester with 1.2 km h^{-1} and 26 rpm,

compared to 1.6 km h^{-1} and 28 rpm = 241.52 – 26.11 = $ 215.41 ha^{-1}

And,

With 1.2 km h^{-1} and 26 rpm compare to 2.0 km h^{-1} and 26 rpm = 339.94 – 83.07 = $ 256.87

To capture the profit potential among nine different harvest treatments, yield, loss, cost of harvesting a hectare and quality of berries were the considerations. The above results and appendix tables A2, A3 and A4 indicate that certain treatment combinations could be more profitable under certain circumstances, but, by and large, the treatment combination 1.2 km h^{-1} and 26 rpm could be optimal harvesting treatment to use on much of the blueberry fields under current future market and production conditions. The treatment combination 1.2 km h^{-1} and 26 rpm gives more $202.89, $215.41 and $192.25 compared to grower's treatment (1.6 km h^{-1} and 28 rpm) in early, middle and late season, when harvestable yield was 4000 kg ha^{-1}. As yield per hectare of blueberry fields increases, the profit margin for farmers also increases. The profit margin in early season harvesting ranges from $130 to $1043.71, when harvester ran with 1.2 km h^{-1} and 26 rpm compared to all other treatment combinations (Table A2, Appendix 'A'). The profitability in middle season harvesting for growers ranges from $93.37 to $1446.04 with treatment combination 1.2 km h^{-1} and 26 rpm compared to rest of the treatment combinations (Table A3, Appendix 'A'). The growers earn more money ranges from $2 to $1329 in late season with harvesting specification of 1.2 km h^{-1} and 26 rpm, when compared to all other treatment specifications in wild blueberry fields (Table A4, Appendix 'A').

In carrying out an economic evaluation between grower's treatment and all other treatments, we can see that the combination 1.2 km h^{-1} and 26 rpm turned out to be the most potential profit driven combination. This treatment combination in early season provided profit potential ranging $145.70 to $603.22 compared to grower's treatment 1.6 km h^{-1} and 28 rpm. Similarly, the grower's treatment (1.6 km h^{-1} and 28 rpm) was less profitable in middle and late season harvesting ranging $155.27 to $638.33 and $137.72 to $573.96, respectively, comparing to treatment combination 1.2 km h^{-1} and 26 rpm.

4.6 Conclusions

Based on the results of this study, it can be concluded that fruit losses during harvesting are not only a function of machine operating parameters (ground speed and header rpm) but also due to time of harvesting (season) in wild blueberry fields. Results showed that fruit losses were found to be higher in late season compared to early and middle season, emphasizing that early and middle season harvesting should be used in reducing fruit losses. The early season harvesting, regardless of having low berry losses, is not a wise decision due to existing of greener berries (not fully ripened) in fields. The better option at fully ripened, good quality berries and comparable berry losses occurred is middle season harvesting.

The economic evaluation between grower's treatment and all other treatment combination suggested that the combination 1.2 km h^{-1} and 26 rpm could be the most potential profit driven combination in different harvesting times. This treatment combination in early season provided profit ranging $145.70 to $603.22 per ha, compared to grower's treatment 1.6 km h^{-1} and 28 rpm. Similarly, the grower's treatment (1.6 km h^{-1} and 28 rpm) was less profitable in middle and late season harvesting ranging $155.27 to $638.33 and $137.72 to $573.96, respectively, comparing to treatment combination 1.2 km h^{-1} and 26 rpm.

Results indicated that ground speed, rpm, season and their higher order interaction were found to be significant for berry losses during mechanical harvesting of selected plots. The results of MMC revealed that a treatment combination of 1.2 km h^{-1} and 26 rpm can serve better in minimizing berry losses as compared to all other treatment combinations in early, middle and late season harvesting. The results also showed that higher ground speed in concomitance with higher header rpm resulted in substantial increased fruit losses in each harvesting season but these losses became more prominent in late season due to over-ripened berries. These over-ripened berries could not withstand the impact force of the harvester, in spite of facing the same impact force as in early and middle, due to loosely attached with stems suggesting the need to lower the speed and rpm of harvester. Selecting an appropriate combination of ground speed and header rpm is very important to enhance harvesting efficiency by reducing berry losses when dealing with early, middle and late season harvesting.

CHAPTER 5 EXAMINING THE FRUIT RIPENING STAGES USING DIGITAL PHOTOGRAPHIC TECHNIQUE

5.1 Introduction

Several researchers emphasized the importance of non-destructive and non-invasive computerized digital image analysis that can process and analyze information from images (Richardson et al., 2001; Díaz-Lago et al., 2003; Karcher and Richardson, 2003). Steddom et al. (2004) explained the attractiveness of digital image analysis, its low cost cameras, computers, and software packages. Lukina et al. (1999) employed digital image processing technique to calculate percent coverage and biomass of wheat using digital color, (RGB), images on crop canopies. Mirik et al. (2006) evaluated the importance of digital image analysis technique to quantify damage caused by green bugs on winter wheat. Richardson et al. (2007) concluded that phenological changes in canopy state of spring green-up in deciduous broadleaf forest can be quantified using digital webcam images. Furthermore, they also suggested that digital webcam technique can be used for regional or national phenological monitoring program. Mendoza and Aguilera (2004) investigated different ripening stages of bananas by acquiring images using computer vision system and characterized changes in color quantitatively. They also related brown spots and textural features of images with ripening stages.

Several researchers used computer image analysis techniques (also known as computer vision system), and encounter the deficiencies of visual and instrumental techniques and gave a complete measure for color and other physical factors for apple, citrus and tomatoes (Paulus and Schrevens, 1999; Shahin and Symons, 2001; Chen et al., 2002). Digital color camera and image processing software is more comprehensive and inexpensive method to investigate color of many foods over traditional color measuring instruments (Yam and Papadakis, 2004). Parrish and Goksel (1977) used a method based on pictorial pattern recognition and artificial intelligence techniques for feasibility of apple harvesting. Whittaker et al. (1987) used fruit shape instead of color information for tomato detection non-destructively. Slaughter and Harrell (1987) developed an image based on color information system for orange fruit detection.

A number of researchers used digital photographic technique to estimate fruit yield in wild blueberry fields (Zaman et al., 2008; Chang et al., 2012; Farooque et al., 2013). Zaman et al. (2008) used a cost effective 10 megapixel digital color camera, acquired wild blueberry images, calculated blue pixels from the images and correlated blue pixel ratios with manually harvested actual fruit yield from selected points to estimate fruit yield within wild blueberry fields. The digital photographic techniques have been extensively used to estimate fruit yield for many cropping systems; however, its application to assess the ripening stages of the fruit have been limited. This study encompass the potential of digital photographic techniques in predicting the ripening stages of fruit at different times of harvesting. In this study, digital color photographic technique using blue-green-pixel (BGP) ratio was used to examine fruit ripening stages in relation with fruit loss at different times of harvesting for wild blueberry crop.

5.2 Material and Methods

Two wild blueberry fields were selected in central Nova Scotia to evaluate a photographic method to examine blueberry ripening in relation with fruit loss. The selected fields were Field A (45.43°N, 63.48°W; 3.66 ha) and Field B (45.24°N, 63.40°W; 1.04 ha). Both fields were in crop year of the biennial production cycle in 2015. The selected fields had been under traditional uniform management practices.

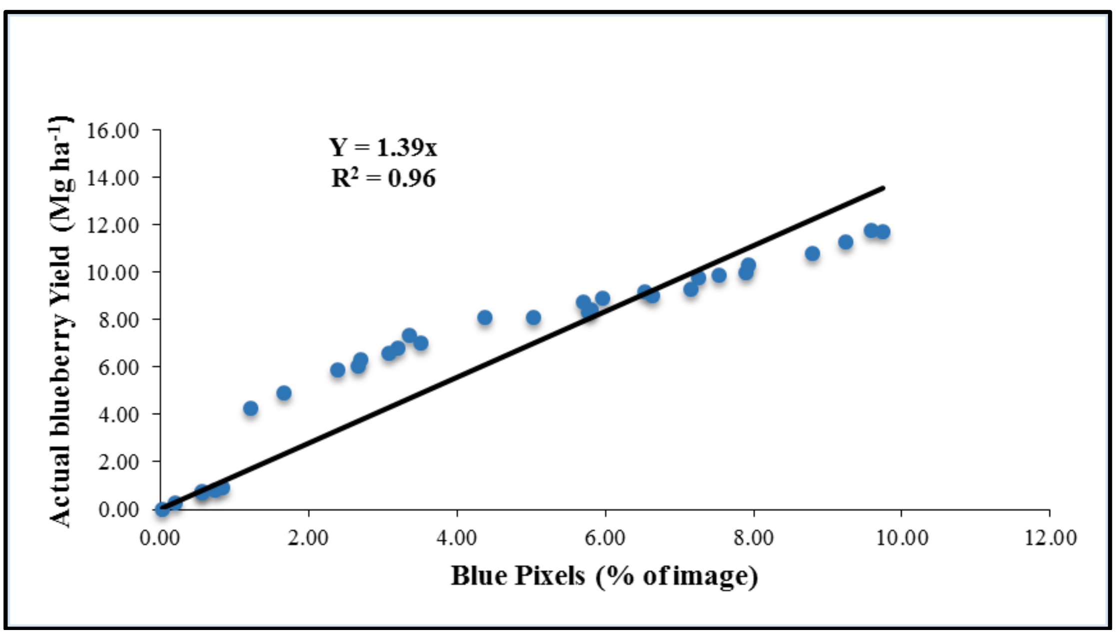
Completely randomized block design was used for data collection from each field. The selected fields were divided into four blocks and each block was further divided into three levels of harvesting season randomly. Sixty sampling points within four blocks were selected in each field to cover overall variability in fruit ripening. The experimental blocks, sampling points and field boundaries were marked using a RTK-GPS. The mapped data was imported in ArcView 10.1 GIS (ESRI, Redlands, CA, USA) software for visual display. A 0.5 m × 0.5 m wooden frame quadrat was constructed and placed at selected sampling points in both fields to define the area of interest in the image. A 16 megapixel 24-bit digital color camera (Fujifilm Canada, Inc., Mississauga, ON, Canada) was used to take photographs of the blueberry fruit from a height of about 0.5-1.0 m. The images were collected at specified locations in each block within the selected fields from early to end of the harvesting season. The images were imported into a computer for further processing. Detailed procedure about acquiring images can be seen in Chapter 3.

5.3 Statistical Analysis

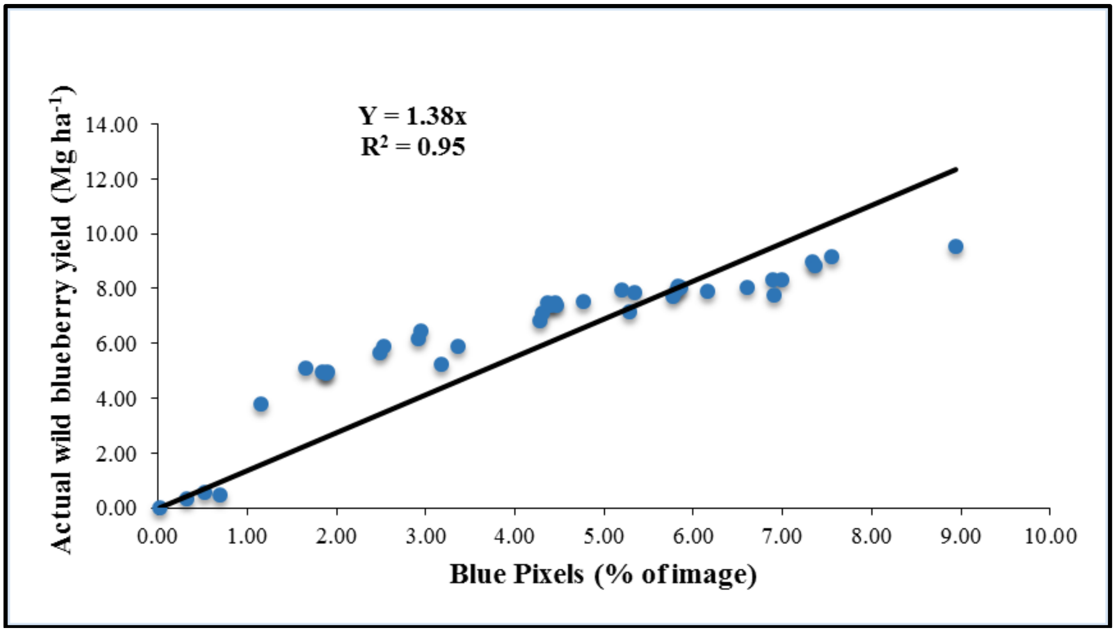
Linear regression was used to calibrate actual ripe fruit yield with percentage blue pixels separately in each field. The calibration equation of Field A was used to predict fruit yield in Field B and calibration equation of Field B was used to predict fruit yield in Field A for validation. Calibration and validation equations/models, coefficient of determination (R^2) and root mean square error (RMSE) were calculated in Minitab 17 (Minitab Inc., PA, USA). Mean absolute error (MAE), coefficient of efficiency (E), modified coefficient of efficiency (EM), prime modified coefficient of efficiency (EMP), index of agreement (d), modified index of agreement (dM), prime modified index of agreement (dMP) were calculated using Microsoft Access (Microsoft Corp., Seattle, Wash). Analysis of variance was used to evaluate the ripening of fruit at different stages of harvesting (early, middle and late) using Minitab. The ripening of fruit was examined by calculating the percentage blue pixels at selected sampling locations. Normal probability plot of residuals using Anderson-Darling (AD) test at significance level of 5% was used to check the normality of the error terms. Residual versus fits plot was used to check the constant variance. The deviation from normality and constant variance assumptions required suitable transformation on collected data. Independence of error terms was achieved by applying treatments randomly. ANOVA using GLM procedure was utilized to examine the fruit ripening at different harvesting times. Multiple means comparison was performed using honestly significant difference (HSD) to determine which specific means significantly differ from each other in early, middle and late season.

5.4 Results and Discussion

Custom image processing software was used to calculate and express the percentage of blue pixels in the quadrat region of the image in both fields. The zero percentages of blue pixels were due to the presence of greener berries (not ripened or absence of blue berries) within the selected blocks of wild blueberry fields. Images were also acquired, when all berries were green. The percentage of blue pixels significantly correlated the manually harvested yield in Field A (R^2 = 0.96; P < 0.001) and Field B (R^2 = 0.95; P < 0.001) (Fig. 5-1).



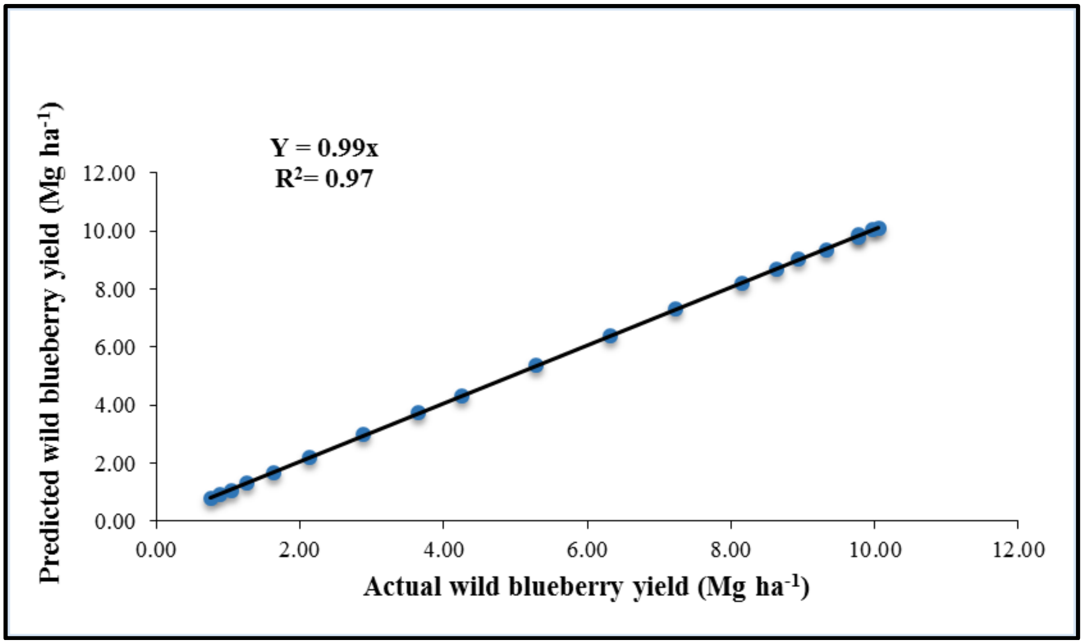
(a)



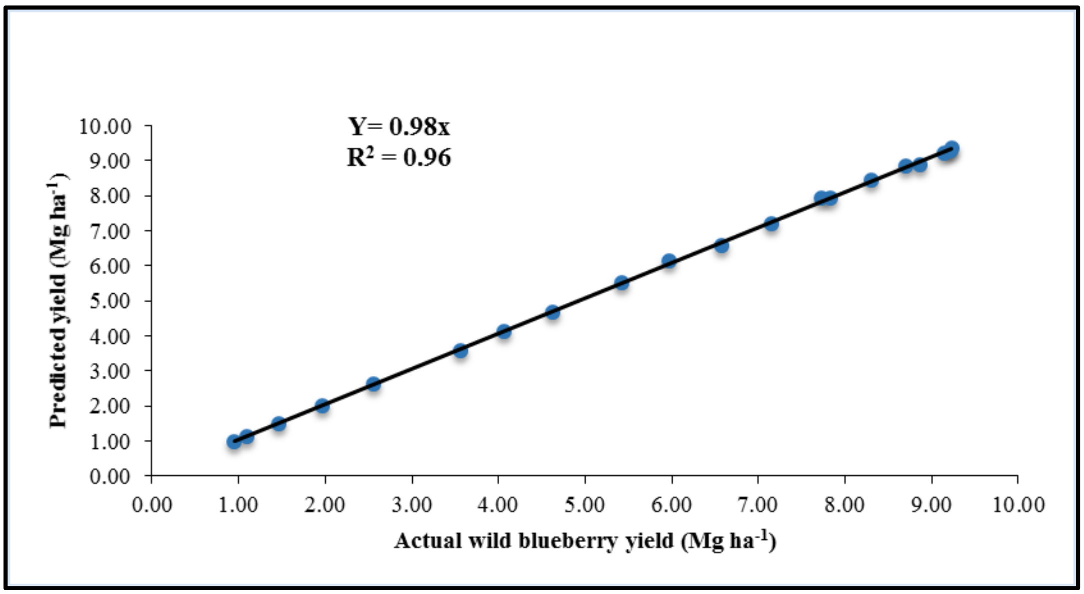
(b)

Figure 5-1. Calibration curve between percentage of blue pixels and actual fruit yield for (a) Field A and (b) Field B.

A slight deviation in mean values can be seen in both scatter plots, suggesting fruit yield was under- or over-estimated. A dense vegetation and hidden berries under leaves might be the reason of under-estimation. In addition, under-estimation could also be related to overlays (in a bunch, accompanying a few pixels in the image), which arose in in high yielding areas. Less or negligible vegetation and berries exposed to the camera could be the result of over-estimation. The correlation between actual and predicted fruit yield in Field A (validated using the equation of Field B) and Field B (validated using the equation of Field A) was also highly significant (Fig. 5-2).



(a)



(b)

Figure 5-2. Actual and predicted fruit yield (a) Field A (b) Field B.

5.4.1 Model Validation

RMSE and MAE are widely used absolute measures to compute the performance of models. Along with absolute measures, relative performance measures, such as: E; EM; EMP; d; dM, and dMP are also used to check model validity (Table 5-1).

Table 5-1. Overall performance evaluation of model in both fields.

	Field A				Field B			
Parameter	Overall	Early	Middle	Late	Overall	Early	Middle	Late
RMSE	0.103	0.100	0.122	**0.092**	0.136	**0.124**	0.158	0.142
MAE	0.090	0.090	0.111	**0.080**	0.112	**0.096**	0.141	0.126
E	0.999	**0.999**	0.998	**0.999**	0.998	**0.998**	0.996	**0.998**
EM	0.995	**0.997**	0.984	0.970	0.992	**0.996**	0.962	0.926
EMP	0.923	**0.946**	0.868	0.826	0.980	**0.944**	0.812	0.726
d	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
dM	0.999	**0.999**	0.996	0.992	0.998	**0.999**	0.991	0.982
dMP	0.961	**0.973**	0.934	0.911	0.954	**0.972**	0.907	0.865

RMSE and MAE are in Mg ha^{-1} and boldface values describe the best model performance.

Results showed that there was a large variability in model performance evaluation in early, middle and late season between the fields. The RMSE and MAE values (lower value is best) indicated that the model predicted well in late season in Field A, while the model forecasted good in early season in Field B. The relative performance measures of coefficient of efficiency (E) and index of agreement (d), as values were greater than 0 and approached 1, further strengthening the model prediction (Table 5-1). The model parameters, RMSE and MAE, were higher in Field B than in A. The reason could be that the cultivars' and clones' differences were present between the fields. The calculated values of MAE were less than RMSE values because, as Meade (2000) stated: "MAE does not give undue importance to large errors (as a RMSE would)."

The difference of E and EM values in the model is a strong indication that using the mean values of early, middle and late season as a reference, rather than using the overall mean (as in EM), raises performance of the model and gives more room for the measure before it reaches the maximum. Similarly, the values of EM for the three harvesting times were recognizably different from those of EMP. The same pattern existed in dM and dMP. The reason for the disparity between the modified and prime modified values could be that the model behaved differently because of the outliers and it showed different sensitivity to outliers in early, middle and late season harvesting.

Results indicated that the model behaved variably within, as well as between the blocks in Fields A and B. The model prediction was satisfactory during late season in blocks 1 and 2, as indicated by RMSE and MAE values, while the model forecasted well during early season in blocks 3 and 4 in Field A (Table 5-2). The values of coefficient of efficiency and index of agreement (closer to 1) suggested that the model prediction was equally good in early, middle and late season in Field A. When comparing EM and EMP, the modification in model parameters raised the standard during early season in blocks 2 and 4, while these changes were remarkable during late and early seasons in blocks 1 and 3 in Field A. The same trend was recurrent with dM and dMP in Field A (Table 5-2). When comparing the model performance between blocks, the predicted values agreed with the calculated values (highlighted values) in block 2. The changes in model parameters, as EM and dM, appeared reasonable in block 3, while in Field A, EMP and dMP were also good in block 2.

The model prediction and calculated values correlated during early season harvesting, as indicated by RMSE and MAE values, in blocks 2, 3 and 4, whereas the model forecasted good during middle season (RMSE value) and early season (MAE value) in Field B. The slight difference in model performance among early, middle and late season could be that some of the berries within a bunch were partly ripe in middle season and the software counted them as blue, whereas fully ripened berries were included in manually harvested berries. In addition, the software might have counted fewer pixels in bunches of ripened berries during middle and late season. The software might have differentiated clearly between blue and green berries due to the large number of greener berries in early season than in middle and late (Table 5-2). The magnitude of coefficient of efficiency and index of agreement were greater than 0.90, suggesting that the model performed equally well in early, middle and late season in Field B.

Table 5-2. Block wise performance evaluation of model in both fields.

Field A																
parameter	**Block 1**				**Block 2**				**Block 3**				**Block 4**			
	O	E	M	L	O	E	M	L	O	E	M	L	O	E	M	L
RMSE	0.121	0.123	0.143	**0.095**	0.079	0.092	0.070	**0.046**	0.085	**0.073**	0.120	0.076	0.120	**0.104**	0.142	0.131
MAE	0.110	0.115	0.134	**0.082**	0.063	0.073	0.061	**0.044**	0.077	**0.064**	0.115	0.074	0.109	**0.093**	0.136	0.125
E	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.998	0.999
EM	0.993	0.993	0.995	**0.971**	0.997	**0.998**	0.995	0.992	0.999	0.998	**0.999**	**0.999**	0.994	**0.997**	0.978	0.931
EMP	0.902	**0.926**	0.828	0.825	0.947	**0.955**	0.931	0.903	0.935	0.960	0.868	0.839	0.912	**0.947**	0.838	0.739
d	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
dM	0.998	**0.998**	0.994	0.992	0.999	0.999	0.999	0.998	0.999	**0.999**	0.996	0.995	0.998	**0.999**	0.994	0.981
dMP	0.951	**0.963**	0.915	0.908	0.973	**0.977**	0.965	0.952	0.967	**0.980**	0.933	0.923	0.956	**0.973**	0.919	0.857

Field B																
parameter	**Block 1**				**Block 2**				**Block 3**				**Block 4**			
	O	E	M	L	O	E	M	L	O	E	M	L	O	E	M	L
RMSE	0.170	0.176	**0.152**	0.171	0.103	**0.089**	0.142	0.096	0.120	**0.104**	0.154	0.121	0.143	**0.110**	0.183	0.167
MAE	0.144	**0.141**	0.146	0.151	0.086	**0.072**	0.123	0.089	0.097	**0.090**	0.114	0.098	0.121	**0.080**	0.180	0.165
E	0.998	**0.999**	0.997	0.911	0.999	**0.999**	0.997	**0.999**	0.999	0.999	0.999	0.999	0.998	**0.999**	0.995	0.997
EM	0.987	**0.992**	0.969	0.888	0.995	**0.998**	0.968	0.966	0.994	**0.997**	0.965	0.956	0.991	**0.997**	0.945	0.875
EMP	0.882	**0.919**	0.811	0.668	0.927	**0.957**	0.833	0.803	0.925	**0.949**	0.848	0.866	0.899	**0.953**	0.758	0.621
d	0.999	**0.999**	0.992	0.973	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
dM	0.998	**0.998**	0.991	0.971	0.999	**0.999**	0.993	0.993	0.999	**0.999**	0.991	0.988	0.998	**0.999**	0.987	0.971
dMP	0.940	**0.959**	0.903	0.830	0.964	**0.978**	0.919	0.910	0.961	**0.974**	0.925	0.904	0.949	**0.977**	0.880	0.808

RMSE and MAE were in Mg ha^{-1}.
Boldface values show the model performance within the blocks in early, middle and late season, while highlighted values show the model performance between the blocks.
The letter O, E, M and L represent overall, early, middle and late, respectively.

The modified versions of the model: EM; EMP; dM; and dMP performed well in early season in all four blocks, before it reached the highest standard in Field B. When comparing all modified versions of the model, they performed well, as indicated by magnitude greater than 0.50 in early, middle and late season. The reason for the better performance of the modified version in early season could be due to it having more data points in early, compared to middle and late season. When differentiating the model performance between blocks, as indicated by RMSE, MAE, E and d values, the model seemed to be good in block 2 in Field B. The reason could be that the different cultivars and clones were present among the blocks. Similarly, the modified versions, EM, EMP, dM, dMP were also found to be satisfactory in block 2 in Field B (Table 5-2).

5.4.2 Statistical Results

ANOVA results revealed that the effect of time of harvesting on blue pixels/wild blueberry yield was significant, but the effect of the blocks was non-significant with each other in Fields A and B. The results of MMC indicated that blue pixels/blueberry yield increased gradually in early harvesting and reached a maximum in late harvesting and then started decreasing in late harvesting in Field A (Table 5-3). The blue pixels/blueberry yield were non-significant to each other on imaging dates (14/7/15 and 17/7/15) and (17/7/15 and 20/7/15) during early season harvesting with an increase of 3 and 4 g 0.25 m^{-2} , respectively, in Field A. The blue pixels/blueberry yield increased significantly by 29%, 30% and 35% between imaging dates (23/7/15 and 26/7/15), (26/7/15 and 29/7/15) and (29/7/15 and 1/8/15), respectively, in early season (Table 5-3). Similarly, the blue pixels/blueberry yield were found to be significant with an increase of 16%, 24% and 20% between dates (4/8/15 and 7/8/15), (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), respectively during early season in Field A. A significant increase in blue pixels/blueberry yield continued in middle season with 13%, 10% and 9% increments between the dates

Table 5-3. Results of MMC of blue pixels/blueberry yield in both fields.

		Field A	Field B
Imaging Date	**Harvesting Time**	**Blueberry Yield (g 0.25 m^{-2})**	**Blueberry Yield (g 0.25 m^{-2})**
14/7/15	Early	18.67 q	23.84 p
17/7/15	Early	22.08 pq	27.38 p
20/7/15	Early	26.14 p	36.52 o
23/7/15	Early	31.55 o	49.09 n
26/7/15	Early	40.78 n	63.97 m
29/7/15	Early	53.10 m	89.05 l
1/8/15	Early	71.76 l	101.86 k
4/8/15	Early	91.20 k	115.73 j
7/8/15	Early	106.30 j	135.78 i
10/8/15	Early	131.75 i	149.42 h
13/8/15	Early	157.92 h	164.79 g
16/8/15	Middle	180.36 g	178.99 f
19/8/15	Middle	203.43 f	193.39 e
22/8/15	Middle	223.32 d	217.95 c
25/8/15	Middle	244.14 b	230.66 a
28/8/15	Late	249.13 a	231.08 a
31/8/15	Late	251.16 a	228.96 ab
3/9/15	Late	243.95 b	222.05 bc
6/9/15	Late	233.12 c	207.76 d
9/9/15	Late	215.77 e	196.21 e

Means that do not share a letter are statistically non-significant from each other (Tukey's HSD, $p \leq 0.05$).

(16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15) in Field A (Table 5-3). The blue pixels/blueberry yield increased, but non-significantly, between the first two dates (28/8/15 and 31/8/15) in late season. The decreasing trend in blue pixels/blueberry yield started at 3/9/15 in late season. The blue pixels/ blueberry yield decreased significantly between dates (31/8/15 and 3/9/15), (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15) with 3%, 4% and 7% decrement in late season, respectively. The decline in blue pixels/blueberry yield might be the result of ripe blueberries dropping from the plants in late season. A considerable increase in blue pixels/ blueberry yield of 746% and 35% were observed in early and middle season, respectively, whereas a 14% decrease was also noticed in late season in Field A.

A similar trend of increase and then decrease in blue pixels/blueberry yield was also noticed in Field B. An increase in blue pixels/blueberry yield was non-significant between the first two dates (14/7/15 and 17/7/15) during early season in Field B (Table 5-3). The increase in blue pixels/blueberry yield was found to be significant, with 34%, 30%, 39% and 14% increments between the dates (20/7/15 and 23/7/15), (23/7/15 and 26/7/15), (26/7/15 and 29/7/15) and (29/7/15 and 1/8/15) in early season, respectively. The increasing trend in blue pixels/blueberry yield continued significantly, with an increase of 17%, 10% and 10% between the dates (4/8/15 and 7/8/15), (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), respectively, during early season in Field B (Table 5-3). A significant rise in blue pixels/blueberry yield was observed between the dates (16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15) with an increment of 8%, 13% and 6% in middle season, respectively. A non-significant increase in blue pixels/blueberry yield was noticed on 28/8/15 of late season. A declining trend in blue pixels/blueberry yield was seen between the dates (28/8/15 and 31/8/15) and (31/8/15 and 3/9/15), with non-significant decrement during late season in Field B. A significant decrease in blue pixels/blueberry yield, with 6% and 6% decrements between the dates (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15) was depicted during late season in Field B, respectively (Table 5-3). Overall, a 591% and 29% increase in blue pixels/blueberry yield was seen in early and middle season, respectively, whereas a 15% decrease was also observed during late season in Field B.

A similar trend in blue pixels/blueberry yield, starting with the lowest magnitude, reaching the highest level and then declining in magnitude, was found in Fields A and B. A difference in the initial magnitude of 5.17 g 0.25 m^{-2} suggested that there were maturity differences between Fields A and B. An overall increase of 232.49 g 0.25 m^{-2} and 207.24 g 0.25 m^{-2} and a decrease of 35.39 g 0.25 m^{-2} and 34.87 g 0.25 m^{-2} in blue pixels/blueberry yield was observed in Fields A and B, respectively (Table 5-3). An increase in blue pixels/ blueberry yield was the outcome of green berries ripening, while a decrease was the consequence of berries dropping from plants due to microbial attack or decay in late season.

5.4.3 The comparison between blue and green berries at different harvesting times

The comparison between the number (no.) of green and blue berries revealed that green berries converted into blue gradually with passage of time. The number of green berries were dominant in early season and less than 10% blue berries were seen from 14/7/15 to 20/7/15 in Field A (Fig. 5-3). The berries gradually turned blue, with an increase of 30% from harvesting dates 23/7/15 to 7/8/15 during early season in Field A. The greatest increase in blue berries of 11% and 7% were observed between harvesting dates (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15) during early season, respectively. The conversion of greener to blue berries continued, with an increase of 8% and 7% between the harvesting dates (16/8/15 and 19/8/15) and (19/8/15 and 22/8/15), respectively, during middle season in Field A (Fig. 5-3). A total of 85% greener berries turned into blue by the end of middle season harvesting in Field A. A 6% of green berries converted into blue berries from the harvesting date 28/8/15 to 3/9/15 in late season.

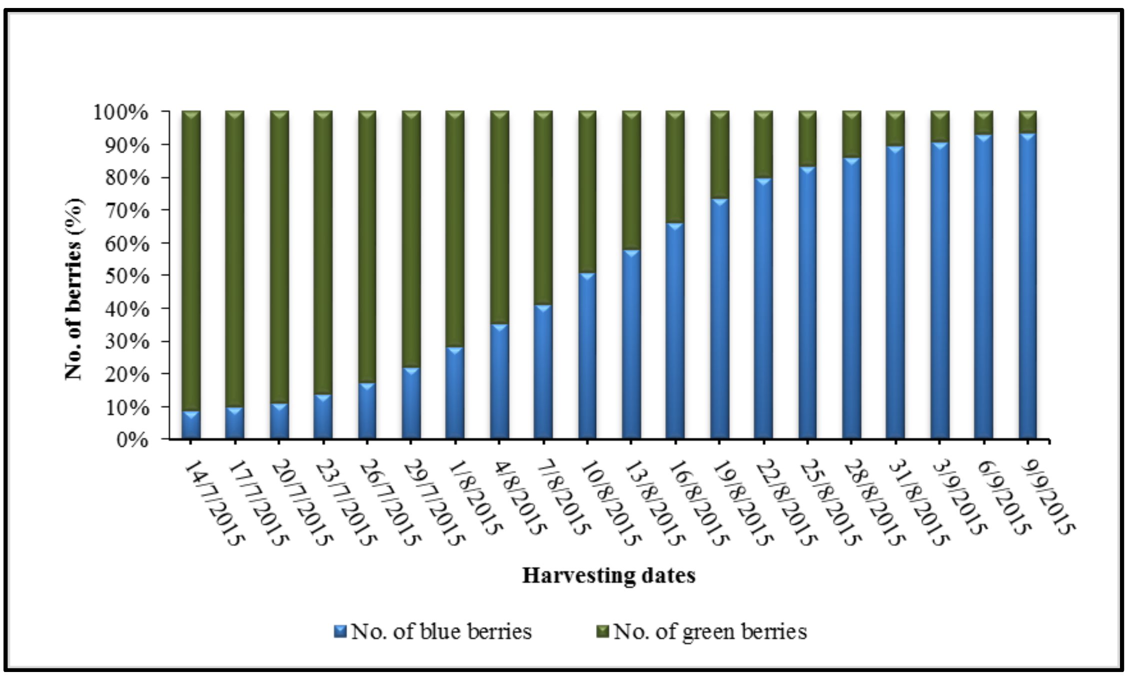


Figure 5-3. A comparison of green and blue berries at different harvesting dates in Field A.

There were still around 5% green berries at the termination of the experiment in Field A. The reason could be that some of the blueberries did not get maturity inadequate pollination or had fewer viable seeds. Aalders and Hall (1961) reported that every blueberry fruit should have at least 6 to 10 viable seeds and where there are less than 6 seeds, the fruit may remain small or unripe.

The number of blue berries were found less than 10% for the first two harvesting dates 14/7/15 and 17/7/15 of early season harvesting in Field B (Fig. 5-4). The trend of increasing blue and decreasing green berries continued from 20/7/15 to 4/7/15 with an addition of 30% blue berries during early season harvesting in Field B. The number of blue berries were of 50%, 56% and 60% at harvesting dates 7/8/15, 10/8/15 and 13/8/15, respectively, in early season harvesting in Field B. Since 40% of the berries were still green at the end of early season harvesting in Field B, early season harvesting would not be a wise decision. A 5% increase in blue berries was observed between harvesting dates 16/8/15 and 19/8/15 in middle season in Field B (Fig. 5-4).

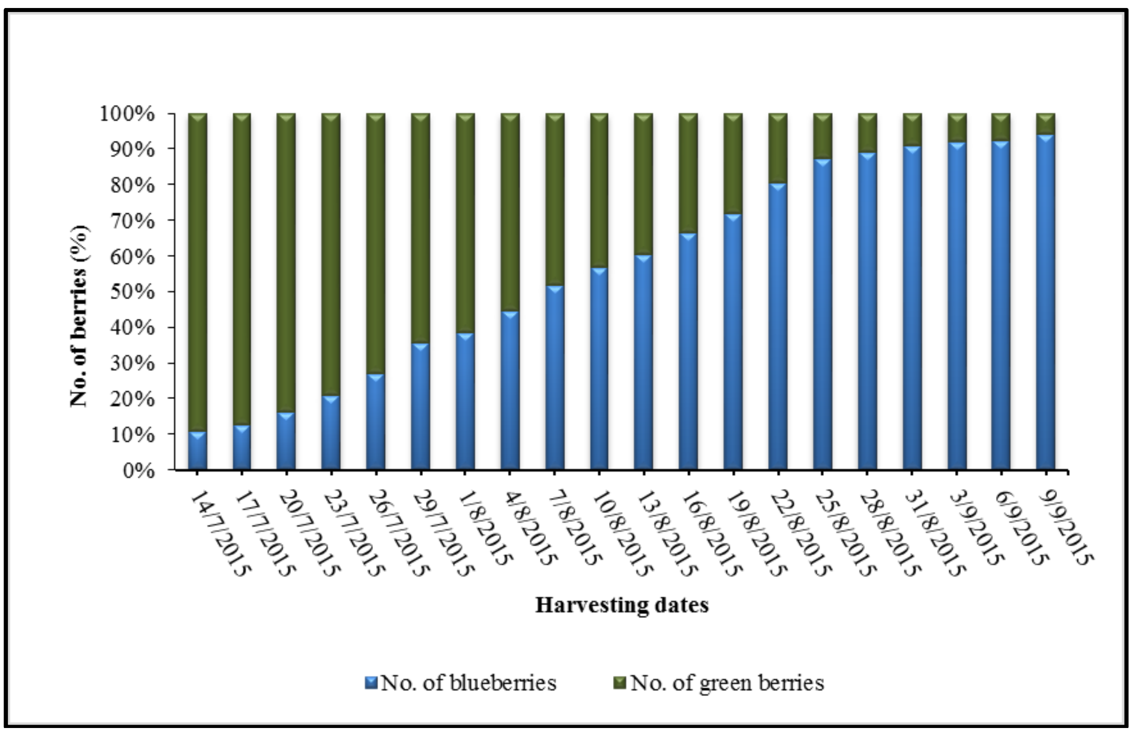


Figure 5-4. A comparison of green and blue berries at different harvesting dates in Field B.

A dramatic increase in blue berries was detected between the harvesting dates (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15), with an increase of 10% and 7% during middle season in Field B, respectively (Fig. 5-4). Results showed that approximately 90% of green berries turned blue at the end of middle season in Field B. A very small number of berries, around 5%, became blue in late season. There were still around 5% green berries at the termination of the experiment in Field B. An overall of 40%, 10% and 5% green berries were present at the end of early, middle and late season in Field B, respectively.

Results showed that 3% more blue berries were present in Field B, compared to Field A at initial harvesting date 14/7/15. The reason could be that the maturity differences of cultivars and clones existed between the fields. A rapid change of berries from green to blue, around 40%, was seen from the harvesting dates 7/8/15 to 22/8/15 in Field A, whereas the greatest change into blue berries, around 45%, was observed between the harvesting dates 4/8/15 and 25/8/15 in Field B. An overall of 55%, 30% and 10% of greener berries turned blue during early, middle and late season in Field A, respectively, whereas, 60%, 28% and 7% of green berries converted into blue berries during early, middle and late season in Field B, respectively.

5.4.4 Comparison between manually harvested (g 0.25 m^{-2}) and no. of blueberries

Results of comparison between manually harvested and no. of blueberries showed that manually harvested blueberries increased from 20 g 0.25 m^{-2} (800 kg ha^{-1}) to 45 g 0.25 m^{-2} (1800 kg ha^{-1}), while the no. of blueberries increased from 35 to 65 from harvesting dates 14/7/15 to 26/7/15 in early season in Field A. The manually harvested blueberries increased by 100 g and no. of blueberries rose by 135 from 29/7/15 to 13/8/15 in early season harvesting (Fig. 5-5). Manually harvested blueberries started with around180 g 0.25 m^{-2} (7200 kg ha^{-1}) and ended at 245 g 0.25 m^{-2} (9800 kg ha^{-1}) and no. of blueberries increased from 250 to 320 from 16/8/15 to 25/8/15 during middle season in Field A. The highest no. of blueberries, 330, and harvested berries, 250 g 0.25 m^{-2} (10000 kg ha^{-1}), were found on the harvesting date 31/8/15 in late season (Fig. 5-5). The decline in harvested and no. of blueberries were 30 g and 50, respectively, from 31/8/15 to 9/9/15 during late season harvesting. The reason of declining blueberries might be the result of microbial attack and berries dropping after decay.

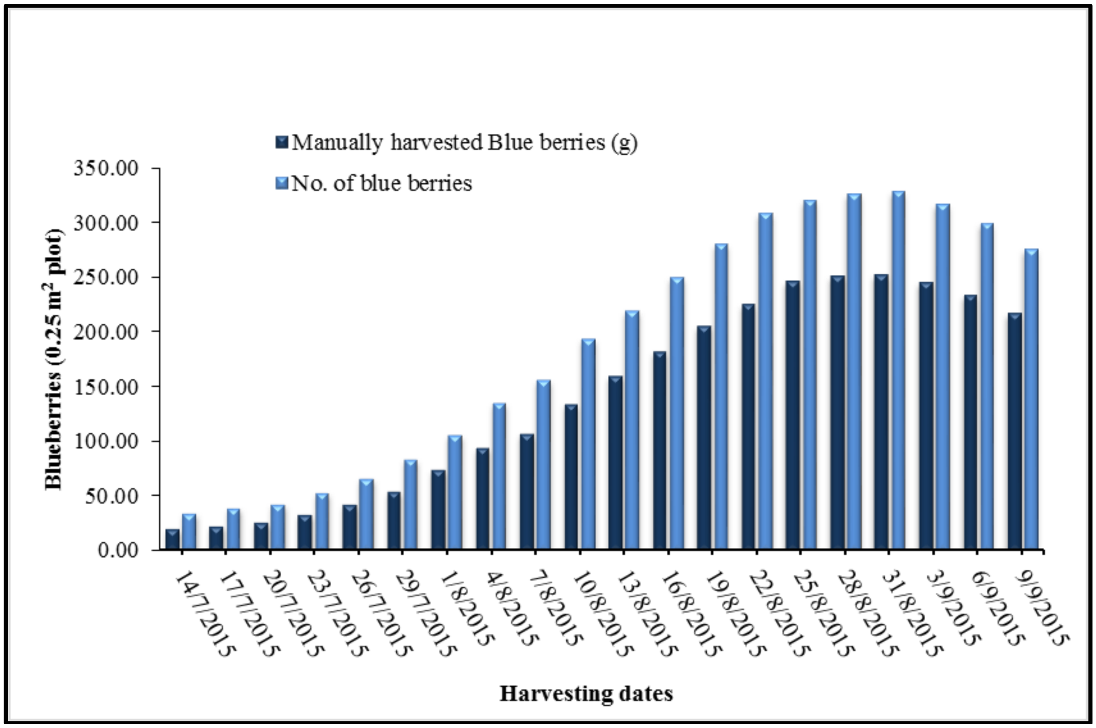


Figure 5-5. Comparison between manually harvested and no. of blueberries at different harvesting dates in Field A.

Results indicated that manually harvested blueberries increased from 25 g 0.25 m^{-2} (1000 kg ha^{-1}) to 65 g 0.25 m^{-2} (2600 kg ha^{-1}), while no. of blueberries increased from 40 to 100 from 14/7/15 to 26/7/15 during early season in Field B (Fig. 5-6). A gradual increase in harvested blueberries, approximately 74 g, and no. of blueberries, around 87, was observed from harvesting date 29/7/15 to 13/8/15 in early season. There were 180 g 0.25 m^{-2} (7200 kg ha^{-1}) and around 245 blueberries at harvesting date 16/8/15, whereas manually harvested blueberries and no. of blueberries were 230 g 0.25 m^{-2} (9200 kg ha^{-1}) and 300, respectively, at 25/8/15 during middle season in Field B

(Fig. 5-6). The manually harvested blueberries and no. of blueberries decreased by 35 g and 50, respectively, from 31/8/15 to 9/9/15 in late season harvesting in Field B.

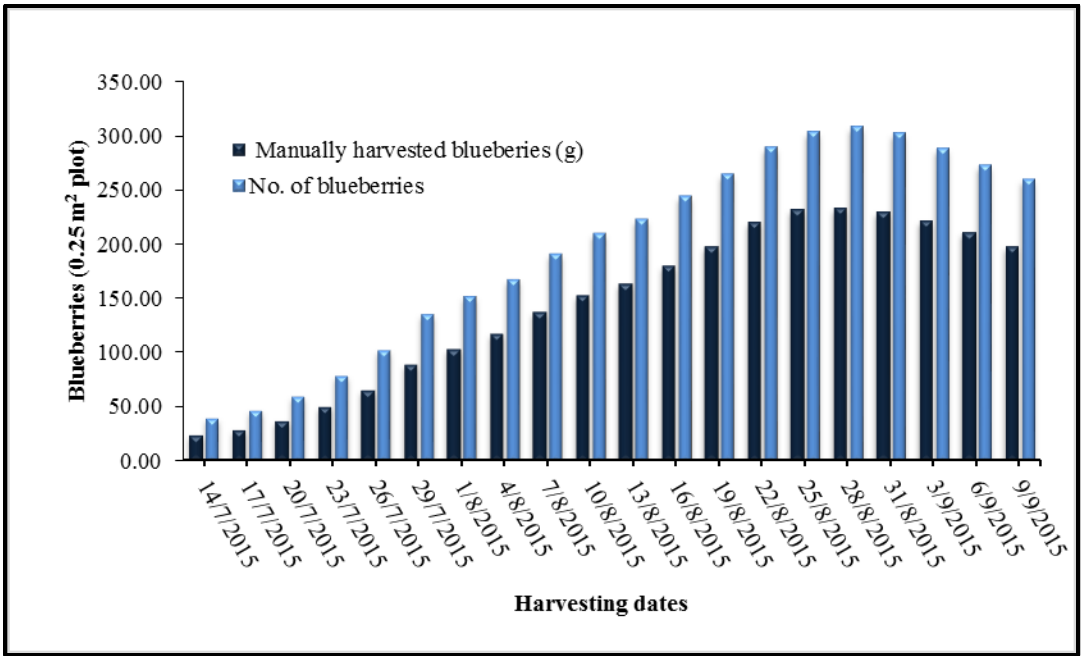


Figure 5-6. Comparison between manually harvested and no. of blueberries at different harvesting dates in Field B.

Results of comparison between manually harvested and no. of blueberries showed that blueberries increased gradually and reached a maximum and then a drop in berries was detected in both fields during the whole harvesting season. Manually harvested blueberries were, approximately 160 g 0.25 m^{-2} (6400 kg ha^{-1}) , 245 g 0.25 m^{-2} (9800 kg ha^{-1}) and 215 g 0.25 m^{-2} (8600 kg ha^{-1}) in Field A, while 165 g 0.25 m^{-2} (6600 kg ha^{-1}), 230 g 0.25 m^{-2} (9200 kg ha^{-1}) and 200 g 0.25 m^{-2} (8000 kg ha^{-1}) in Field B at the end of early, middle and late season, respectively. Moreover, no. of blueberries were, approximately 220, 320 and 275 in Field A, whereas 222, 300 and 260 were found in Field B at the end of early, middle and late season, respectively. The highest no. of blueberries and manually harvested blueberries were seen at 31/8/15 in Field A and 28/8/15 in Field B. A total increase of 252 g 0.25 m^{-2} (10080 kg ha^{-1}) and a decrease of 35 g 0.25 m^{-2} (1400 kg ha^{-1}) in Field A, while a total rise of 233 g 0.25 m^{-2} (9320 kg ha^{-1}) and a decline of 36 g 0.25

m^{-2} (1440 kg ha^{-1}) in Field B was observed during the whole harvesting season. Similarly, an increase and decrease in no. of blueberries were 329 and 53, respectively, in Field A, whereas an increase and decrease in blueberries were 308 and 49 in Field B, respectively.

5.4.5 Comparison between manually harvested green and blue berries

Results indicated that greener berries substantially decreased and were replaced by blue berries as harvesting season progressed in Field A. The green berries dominated, with approximately 154 g 0.25 m^{-2} (6160 kg ha^{-1}), while blue berries had approximately 20 g 0.25 m^{-2} (800 kg ha^{-1}) at the harvesting date 14/7/15 in early season (Fig. 5-7). The green berries reduced from 146 g 0.25 m^{-2} (5840 kg ha^{-1}) to 106 g 0.25 m^{-2} (4240 kg ha^{-1}), while blue berries increased from 23 g 0.25 m^{-2} (920 kg ha^{-1}) to 74 g 0.25 m^{-2} (2960 kg ha^{-1}) between 17/7/15 and 1/8/15 in early season harvesting. The decrease in green berries and an increase in blue berries were 34 g 0.25 m^{-2} (1360 kg ha^{-1}) and 65 g 0.25 m^{-2} (2600 kg ha^{-1}), respectively, from harvesting date 4/8/15 to 13/8/15 in early season. Green berries decreased from 56 g 0.25 m^{-2} (2240 kg ha^{-1}) to 23 g 0.25 m^{-2} (920 kg ha^{-1}), whereas blue berries increased from 182 g 0.25 m^{-2} (7280 kg ha^{-1}) to 246 g 0.25 m^{-2} (9840 kg ha^{-1}) between harvesting dates 16/8/15 and 25/8/15 in middle season in Field A (Fig. 5-7). A few green berries converted into blue berries between harvesting dates 28/9/15 and 31/8/15 and thereafter remained constant, while blue berries started decreasing from 3/9/15 to 9/9/15 during late season in Field A. The reason could be that over-ripened berries started to dropping due to decaying in late season.

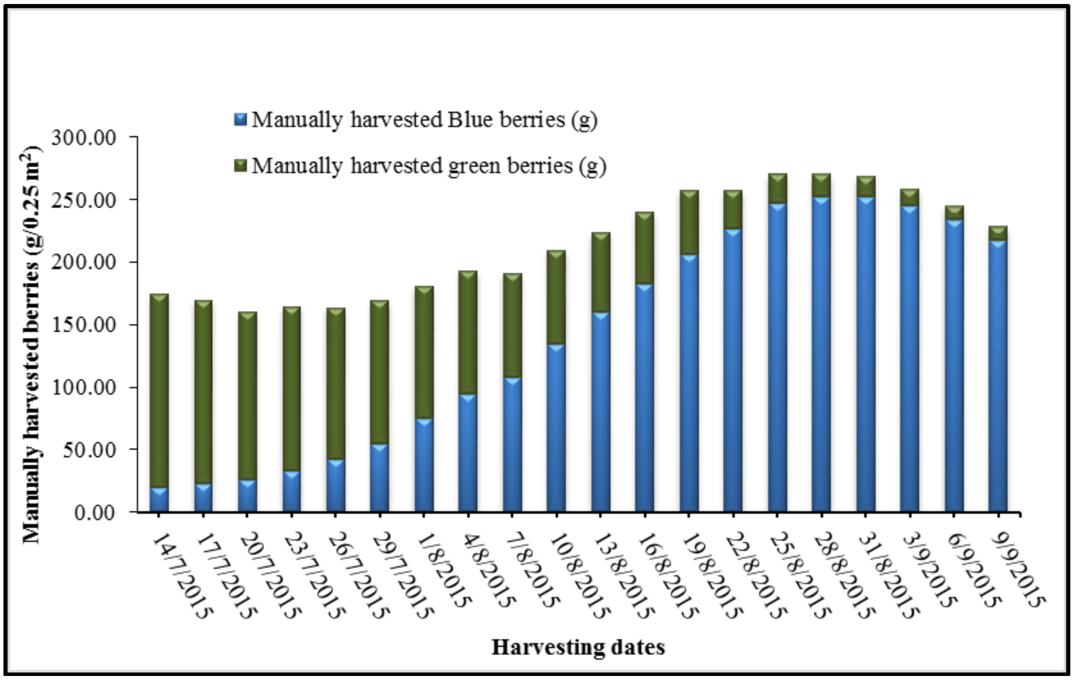


Figure 5-7. Comparison between manually harvested green and blueberries at different harvesting dates in Field A.

Results of comparison between manually harvested green and blueberries revealed that a total of 170 g 0.25 m^{-2} (6800 kg ha^{-1}) berries, 145 g 0.25 m^{-2} (5800 kg ha^{-1}) green berries and 25 g 0.25 m^{-2} (1000 kg ha^{-1}) blue berries, were present at the first harvesting date 14/7/15 in Field B (Fig. 5-8). The green berries gradually decreased from, approximately 138 g 0.25 m^{-2} (5520 kg ha^{-1}) to 60 g 0.25 m^{-2} (2400 kg ha^{-1}), whereas blue berries increased from, around 28 g 0.25 m^{-2} (1120 kg ha^{-1}) to 164 g 0.25 m^{-2} (6560 kg ha^{-1}) between the harvesting dates 17/7/15 and 13/8/15 during early season (Fig. 5-8). A decrease in green berries, approximately 52 g 0.25 m^{-2} (2080 kg ha^{-1}) to 18 g 0.25 m^{-2} (720 kg ha^{-1}), and an increase in blue berries, around 180 g 0.25 m^{-2} (7200 kg ha^{-1}) to 233 g 0.25 m^{-2} (9320 kg ha^{-1}), continued from 16/8/15 to 25/8/15 during middle season in Field B. The total amount of berries started declining, green berries almost remained constant but blue berries decreased by 30 g 0.25 m^{-2} (1200 kg ha^{-1}), from 31/8/15 until the termination of experiment in late season in Field B (Fig. 5-8).

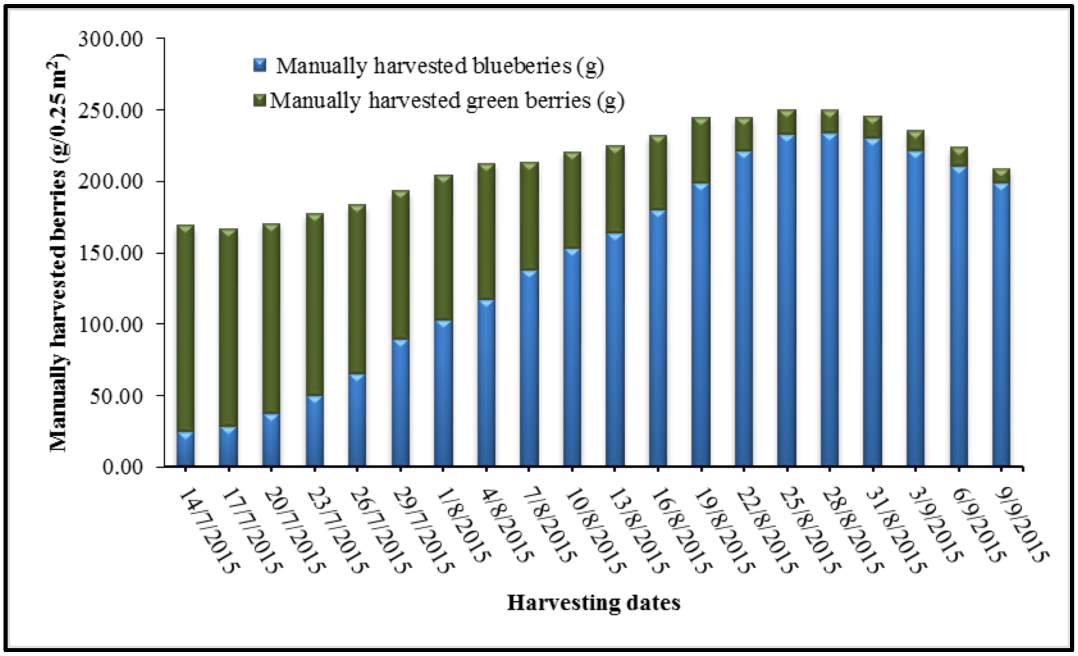


Figure 5-8. Comparison between manually harvested green and blueberries at different harvesting dates in Field B.

A comparison between manually harvested blue and green berries showed that green berries gradually decreased and blue berries increased during the whole harvesting season in both fields. More green berries and fewer blue berries were present at the start of the experiment in Field A compared to Field B, suggesting yield and maturity differences between the fields. The amount of green berries decreased by 90 g 0.25 m^{-2} (3600 kg ha^{-1}) and 84 g 0.25 m^{-2} (3360 kg ha^{-1}) and blue berries increased by 139 g 0.25 m^{-2} (5560 kg ha^{-1}) and 139 g 0.25 m^{-2} (5560 kg ha^{-1}) during early season in Fields A and B, respectively. The green berries decreased by 33 g 0.25 m^{-2} (1320 kg ha^{-1}) and 35 g 0.25 m^{-2} (1400 kg ha^{-1}) and blue berries increased by 64 g 0.25 m^{-2} (2560 kg ha^{-1}) and 52 g 0.25 m^{-2} (2080 kg ha^{-1}) during middle season in Fields A and B, respectively. The ripe blueberries gained 55% weight in Field A, compared to 48% in Field B from start of the harvesting to the date of the highest observed weight. The reason could be that the ripened berries had more volume and weight compared to green/unripen berries.

5.5 Conclusion

Digital photographic technique to estimate blueberry ripening and yield at different times of harvesting had a significant correlation between the percentage of blue pixels and actual fruit yield in Field A (R^2 = 0.96; P < 0.001) and Field B (R^2 = 0.97; P < 0.001). The correlation between actual and predicted fruit yield (validation) in Field A and B was also highly significant. The absolute measures of RMSE and MAE showed strong correlation between actual and predicted fruit yield. The relative performance measures of coefficient of efficiency and index of agreement further strengthened the model performance. The modified measures were lower than those of the unmodified. The results indicated that the modified versions use higher standards of model performance and differences between EM and EMP and between dM and dMP express the sensitiveness of model performance to outliers for different harvesting times. The results also indicated that the effect of time of harvesting on blue pixels/wild blueberry yield was significant and blue pixels/blueberry yield increased gradually during early harvesting, reached maximum in late harvesting and then started to decrease in late harvesting. Comparison results indicated that 90% of green berries turned blue at the end of middle season compared to early season (58%).

Based on the results of this study, it can be concluded that the digital photography is a viable technique to examine ripened blueberry fruit yield and can be used to estimate ripened fruit yield at different times of harvesting. It is suggested to include physico-chemical analysis, such as anthocyanin contents, total soluble solids, titratable acidity, moisture contents, weight and diameter as input variables in future studies to examine the ripening of wild blueberries, when dealing with time of harvesting and maturity. This information will help producers for timely blueberry harvesting decisions to improve crop productivity.

CHAPTER 6 EVALUATION OF THE IMPACTS OF FRUIT RIPENING PARAMETERS ON HARVESTING EFFICIENCY OF THE WILD BLUEBERRY HARVESTER

6.1 Introduction

Maturity indices are important decision making factors for any commodity in determining when it should be harvested to attain maximum desirable eating quality for the consumers (Kader, 1999). Most of the compositional changes associated with fruit ripening can occur during attachment of fruit to the mother plant and the attributes that most appealed to consumers were flavor and appearance, along with food quality and nutritional value (Cordenunsi et al., 2003). Robertson et al. (1991) revealed that harvest maturity of fruit can be judged using indices, such as fruit color, size, shape, firmness, concentration of soluble solids and titratable acidity. Fruit ripeness has been directly linked with changes in surface color arising from accumulation of pigments in many ripening fruits, including blueberries (Ballinger and Kushman, 1970). The correlation between surface color and other ripening attributes remained the same within a cultivar among location, season, harvest dates and berry size (Kushman and Ballinger, 1975). Kays (1999) reported that product appearance attributes, including color, size, shape and form were primary means of judging maturity of individual units of product. The study further pointed out that these appearance attributes changed with the development of the product and pre-harvest factors.

Many researchers have used changes in color as an indication of maturity or ripening in blueberry cropping systems (Ballinger et al., 1973; Dekazos, 1980; El-Agamy et al., 1982). El-Agamy et al. (1982) reported that blueberries were considered ready for eating when the majority of the berries were blue or at least 75% were blue. Ceponis and Stretch (1983) found that the fruit color gradually changed from light-green to light-brown and then dark-brown, as cranberry fruit matured. Naczk and Shahidi (2006) reported that anthocyanins were the pigments that provide blue, violet and red colors in most fruits, vegetables and cereals. Moreover, Ribereau-Gayon and Glories (1986) also showed that anthocyanins accounted for the red color of wine and grapes. Given et al. (1988) reported that anthocyanin reserves were one aspect of ripening in strawberry. Many ripening fruits, including blueberry, exhibit an increasing trend of anthocyanins and sugars contents (Ballinger and Kushman, 1970).

Physical appearance is not the sole deciding factors for the optimum harvestable stage and flavor quality of fruits; therefore, soluble solid concentration and titratable acidity have also been considered as fruit maturity indices (Kader, 1999). Forney et al. (1998) revealed that as blueberries turned blue and continued to ripen, the total soluble solids increased and titratable acids decreased. El-Nemr et al. (1990) reported that the fresh pomegranate held 85.4% moisture and a substantial amount of total solids, reducing sugars and anthocyanin content. Similarly, the main strawberry ripening attributes were soluble solids, organic acids and anthocyanin content (Cordenunsi et al., 2003). The soluble solids content was found to increase and titratable acids content decreased with time as bluberry changed to blue and continued to ripen (Forney, 2009). These characteristics, soluble solids concentration, titratable acidity and firmness, were associated with fruit maturity and are known to influence consumer' acceptance of fruits (Crisosto et al., 1995).

Firmness is one of the most influential attribute that attract consumer's appeal as well as marketing of fresh blueberries (NeSmith et al., 2002). Changes in firmness is a good and reliable way to reveal ripening behavior in fruit (Kader, 1999; Crisosto et al., 2001; Metheney et al., 2002). The decrease in firmness is a physiological process that takes place during fruit ripening on the tree and during cold storage (Delwiche, 1987; Chen, 1996; Abbott, 1999). A significant volume of blueberries are rejected due to decrease in firmness to below retail market standard (Prussia et al., 2006). In Salvador et al. (2004), firmness was considered an important characteristic in commercialization of persimmon. Firmness is associated with loss of moisture and it is dependent upon the amount of dehydration (Paniagua et al., 2013). Turgor loss was one of the most important causes of decreasing firmness in apples, potatoes and nectarines (Lin and Pitt, 1986; Heyes and Sealey, 1996). Blueberry firmness was also found to be related with moisture loss in number of studies (Miller et al., 1984; Tetteh et al., 2004; Angeletti et al., 2010; Cantin et al., 2012).

Therefore, the current study was carried out, with aim of determining the relationship between harvesting times and harvesting efficiency effected by fruit ripening characteristics (moisture content, firmness, total soluble solids, titratable acidity, and anthocyanin content) of wild blueberry.

6.2 Materials and Methods

Two wild blueberry fields were selected in central Nova Scotia to examine the impact of physical and chemical properties of blueberries on fruit ripening. The selected fields were East Mine-II (45.43°N, 63.48°W; 3.66 ha) (Field A) and Highland Village-II (45.24°N, 63.40°W; 1.04 ha) (Field B). Both fields were in the crop year of the biennial production cycle in 2015. The selected fields were under commercial management, receiving biennial pruning by mowing for the past several years along with conventional pest, disease and weed control management practices.

Completely randomized block design outlined in Chapter 3, with twelve sampling points within four blocks on each harvesting date, were employed to collect fruit samples from each field. Fresh blueberries from selected plots within each block were harvested from blueberry plants (about 1 kg) during each of three harvesting times: early (harvesting dates 4/8/15-mid-August); middle (harvesting dates 16/8/15-25/8/15); and late (harvesting dates 26/8/15-onwards). The harvested berries were transferred immediately to a laboratory in air tight cold containers for further analysis. Average berry weight was determined by dividing weight of berries to number of berries per sample. Diameters of berries were determined using digital Vernier calipers. Moisture content was determined by oven-drying berries at 105ºC for 24 hours. Firmness was measured using TA.XTplus texture analyzer, (Stable Micro systems, GD, UK). Total soluble solids (TSS) were determined using a refractometer on juice obtained from squeezing the blueberries. Titratable acidity (TA) was determined by homogenization of 20 g of berries with equal amount of water for 5 minutes. The prepared homogenate was titrated to pH 8.2 with 0.1 N NaOH and TA was calculated and expressed as milliequivalents of citric acid per gram of fresh weight (Ronald et al., 1998). A 10 g sample of blueberries was added to 15 ml of acetonitrile containing 4% acetic acid and was homogenized in a blender for 5 min. After the recovery of homogenate, 10 ml of acetonitrile containing 4% acetic acid was used to wash the blender and pooled with the first homogenate. The pooled homogenate was kept in a shaker at room temperature for 15 min and then centrifuged at 5000×g for 15 min at 4ºC. The pellets were washed with 5 ml of acetonitrile containing 4% acetic acid after centrifugation and again centrifuged. The resultant supernatant was combined with the initial extract. Total anthocyanin content was then estimated by a pH differential method (Lee et al., 2005). Detailed procedure can be seen in chapter 3.

6.3 Statistical Analysis

ANOVA was used to examine the fruit ripening characteristics including anthocyanin content, TSS, TA, moisture content, size and firmness at each harvesting stage (early, middle and late) using Minitab 17 (Minitab Inc., PA, USA) statistical software. The ripening of fruit was examined by calculating the amount of these chemical constituents at each harvesting date. A normal probability plot of residuals, using Anderson-Darling (AD) test at a significance level of 5%, was used to check the normality of the error terms in Minitab software. A residual versus fits plot was used to check the constant variance. The deviation from normality and constant variance assumptions required suitable transformation on collected data. Independence of error terms were achieved by applying treatments randomly. ANOVA using GLM procedure, was employed to examine the fruit ripening at different harvesting times. A multiple means comparison was performed using Tukey's honestly HSD to determine which specific means significantly differed from each other in early, middle and late seasons. Tukey's test was preferred for its control of the experiment-wise error rate in the face of pair-wise comparison among means (Ott and Longnecker, 2001). Pearson correlation was used to recognize the inner-variable relationship of physical characteristics and chemical composition.

6.4 Results and Discussion

The model assumptions normal distribution, constant variance and independence of error terms were tested by examining the residuals at a significance level of 5%. Non-normal data were normalized, using log transformation for analysis and were reported to original scale using back transformation. A descriptive statistics table revealed that there was a little difference in minimum, maximum and mean values of moisture content (%) in Field A and Field B, but there was a slight variation in minimum, maximum and mean values of all other quality parameters for both fields (Table 6-1). The variation of fruit quality parameters between blueberry fields could be due to natural variation in soil, different clones, field topography and crop management practices. ANOVA results indicated that the effect of time of harvesting on all quality parameters, including MC, firmness, TSS, TA, anthocyanin content, diameter, weight and TSS: TA in Field A and Field B were significant but the effect of blocks were found to be non-significant with each other in both fields.

Table 6-1. Summary statistics of blueberry fruit quality parameters for selected fields.

	Field A			Field B		
Variables	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
MC (%)	84.27	89.31	86.91	84.17	89.53	87.09
Firmness (N mm^{-1})	0.05	0.94	0.28	0.06	0.84	0.22
TSS (^{0}Brix)	5.28	12.90	9.31	5.40	13.20	9.82
TA	0.92	7.17	3.88	0.89	6.63	3.53
Anthocyanin content	32.05	118.84	80.28	33.90	125.84	90.73
Diameter (mm)	7.30	11.09	9.35	8.14	11.23	9.59
Weight (g)	0.43	0.73	0.60	0.49	0.77	0.64
TSS:TA	0.75	13.97	4.52	0.76	14.83	5.09

Anthocyanin were calculated as mg malvidin-3-glucoside per 100 g fresh weight and Titratable acidity was in meq g-1 fresh wt.

6.4.1 Moisture Content

Moisture content at different harvesting dates ranged approximately from 85-89% for Field A (Table 6-2), which agrees with the findings of Wu et al. (2006), who reported 89% moisture content in wild blueberries. The results of MMC also indicated that the percent moisture contents were low in early harvesting dates, then gradually increased to a level of 89% and thereafter, a decline in moisture content was observed (Table 6-2). Difference in moisture contents were non-significant for the first two early season harvesting dates, while the next two harvesting dates (10/8/15 and 13/8/15) of early season were found to be significantly different from each other. The percent moisture content at early season harvesting dates of 10/8/15 and 13/8/15 were also not significantly different from the late season harvesting dates of 9/9/15 and 6/9/15, respectively. The same non-significant trend was found in two middle season harvesting dates (16/8/15 and 19/8/15) with late season harvesting dates (3/9/15 and 28/8/15, 31/8/15, respectively) (Table 6-2). It could be that the early and middle season harvesting berries were still gaining water content, while late season harvesting berries were losing water content. Blueberries contained the greatest increase in water content, more than 89%, on 22/8/15 and 25/8/15 of middle season harvesting and the differences were also found to be non-significant to each other. The highest moisture contents, of more than 5% increase, were observed at harvesting date (22/8/15), compared to first harvesting

Table 6-2. Results of MMC of blueberry fruit quality parameters of East Mine-II field.

Harvesting Date	Moisture content (%)	Firmness (N mm^{-1})	Total soluble solids (^{0}Brix)	Titratable acidity (meq g^{-1} fresh wt.)	TSS:TA	Anthocyanin content (mg g^{-1} fresh wt.)	Diameter (mm)	Weight (g)
4/8/15	84.50 f	0.90 a	5.3 i	7.01 a	0.76 j	33.03 i	7.55 h	0.46 i
7/8/15	84.69 f	0.77 b	5.5 i	6.40 b	0.85 ij	33.83 i	7.76 gh	0.48 i
10/8/15	85.76 e	0.59 c	6.1 h	6.43 b	0.96 ij	60.90 h	8.11 g	0.51 h
13/8/15	86.43 d	0.37 d	6.3 h	5.90 c	1.06 i	70.46 g	8.62 f	0.55 g
16/8/15	87.14 c	0.22 e	7.5 g	5.03 d	1.49 h	75.94 f	8.93 f	0.58 f
19/8/15	88.11 b	0.16 f	8.3 f	4.96 d	1.68 h	76.57 f	9.42 e	0.62 e
22/8/15	89.13 a	0.13 g	9.5 e	3.66 e	2.58 g	82.89 e	10.07 cd	0.66 cd
25/8/15	89.02 a	0.10 gh	10.5 d	2.63 f	4.00 f	88.34 d	10.52 abc	0.69 ab
28/8/15	87.90 b	0.08 hi	11.7 c	2.59 f	4.53 e	89.96 d	10.93 a	0.72 a
31/8/15	87.85 b	0.05 i	12.3 b	2.13 g	5.78 d	95.01 c	10.75 ab	0.68 bc
3/9/15	87.34 c	0.06 i	12.5 b	1.78 h	7.01 c	102.18 b	10.33 bc	0.65 d
6/9/15	86.57 d	0.08 hi	12.7 a	1.05 i	12.17 b	116.20 a	9.70 de	0.59 ef
9/9/15	85.40 e	0.10 gh	12.8 a	0.93 i	13.87 a	118.28 a	8.87 f	0.55 g

Means that do not share a letter are statistically non-significant from each other (Tukey's HSD, $p \leq 0.05$).

Table 6-3. Results of MMC of blueberry fruit quality parameters of Highland Village-II field.

Harvesting Date	Moisture content (%)	Firmness (N mm^{-1})	Total soluble solids (^{0}Brix)	Titratable acidity (meq g^{-1} fresh wt.)	TSS:TA	Anthocyanin content (mg 100 g^{-1} fresh wt.)	Diameter (mm)	Weight (g)
4/8/15	85.19 g	0.81 a	5.5 j	6.54 a	0.84 j	35.63 i	8.17 h	0.50 h
7/8/15	85.10 g	0.58 b	5.6 j	5.96 b	0.95 j	51.80 h	8.24 h	0.52 h
10/8/15	85.79 f	0.39 c	6.7 i	5.65 c	1.18 j	65.30 g	8.46 gh	0.55 g
13/8/15	86.51 e	0.24 d	6.8 i	5.56 c	1.22 j	65.70 g	9.00 ef	0.60 f
16/8/15	87.17 d	0.16 e	8.4 h	4.81 d	1.74 i	82.74 f	9.37 de	0.63 e
19/8/15	88.17 b	0.12 f	9.2 g	4.12 e	2.23 h	88.63 e	9.67 d	0.67 d
22/8/15	89.34 a	0.10 fg	10.4 f	3.02 f	3.46 g	102 .45 d	10.52 b	0.71 c
25/8/15	89.44 a	0.08 ghi	11.6 e	2.94 f	3.95 f	102.99 d	10.93 a	0.74 b
28/8/15	88.02 bc	0.07 hi	12.1 d	2.39 g	5.06 e	107.10 c	11.16 a	0.77 a
31/8/15	87.87 bc	0.06 i	12.6 c	1.89 h	6.67 d	107.75 c	10.83 ab	0.72 bc
3/9/15	87.53 cd	0.08 ghi	12.9 b	1.11 i	11.57 c	118.19 b	10.07 c	0.68 d
6/9/15	86.55 e	0.09 gh	13.0 ab	1.00 ij	12.95 b	125.49 a	9.37 de	0.63 e
9/9/15	85.46 fg	0.12 f	13.1 a	0.91 j	14.45 a	125.72 a	8.83 fg	0.59 f

Means that do not share a letter are statistically non-significant from each other (Tukey's HSD, $p \leq 0.05$).

date (4/8/15). Similarly, there was a 4% decrease in moisture detected between harvesting dates 22/8/15 and 9/9/15 (Table 6-2).

The highest moisture contents of 89.44% and the least moisture contents of 85.19% were observed in Field B (Table 6-3). Moisture contents were non-significant between 4/8/15 and 7/8/15 harvesting dates, while significantly different between harvesting dates of 10/8/15 and 13/8/15 in early season harvesting. An increasing trend of moisture contents was observed from 16/8/15 to 25/8/15 harvesting dates and the peak value of moisture contents of 89.44% was found in middle season harvesting. There was a 5% increase in moisture content from first harvesting date 4/8/15 to 25/8/15. A decrease in moisture of 4% was detected from the peak moisture containing harvesting date (25/8/15) until the termination of the experiment (9/9/15) (Table 6-3). A significant amount of water loss observed in late season harvesting suggest the need to harvest the berries when they are at their peak moisture level. This is because moisture contents have marked effects on fruit texture and it may be at increased risk of physiological deterioration when too much water content is lost.

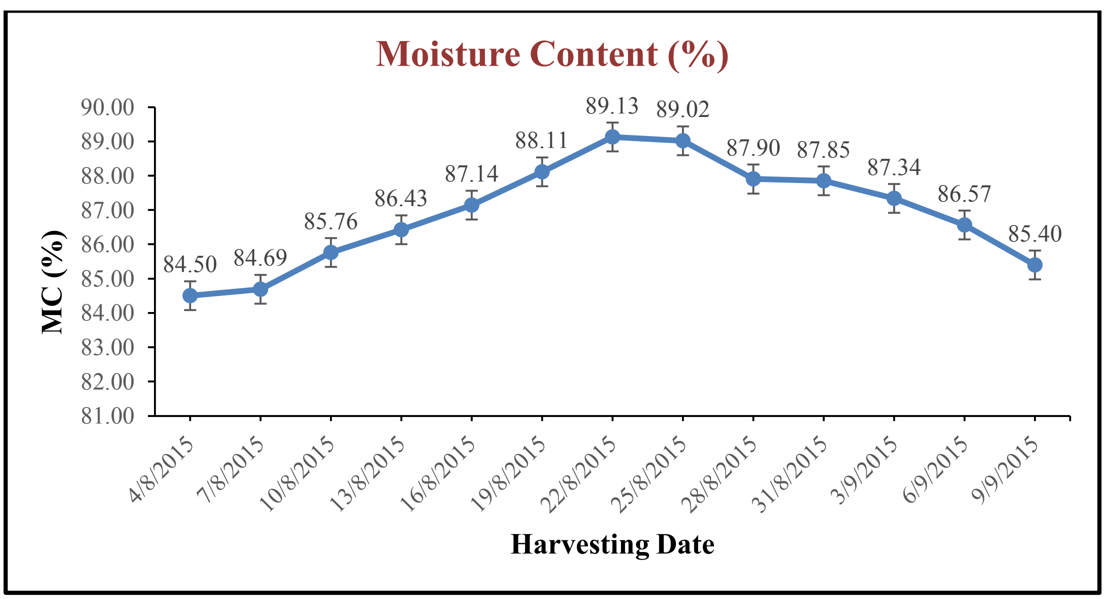


Figure 6-1. Wild blueberry fruit moisture content on different harvesting dates of field A.

The similar trend in moisture contents, starting with lowest moisture, gradually reaching a peak level and then a decline in moisture, was observed in both fields (Fig.6-1 and 6-2). A slight difference in moisture on each harvesting date was noticed between fields. The highest moisture contents were found on 22/8/15 in Field A, while the highest moisture contents in Field B were observed on 25/8/15 of the middle season harvesting. The moisture decline in wild blueberries started after 22/8/15 of middle season harvesting and reached the lowest level of moisture on 9/9/15 of late season harvesting in Field A, whereas the substantial loss of moisture began after 25/8/15 of the middle season harvesting and ended with the least moisture level on 9/9/15 of late season harvesting in Field B (Fig. 6-1 and 6-2). The general condition of blueberries was affected, with economic loss attributed to both decreased berry quality and weight, due to changes in moisture contents. Robinson et al. (1975) reported that a decrease of 5-10% moisture in most fruits and vegetables is sufficient to deteriorate their quality and would result in rejection of the product for sale. A loss of only 5% moisture could alter the quality of fresh fruit by causing it to shrivel (Wills et al., 2007).

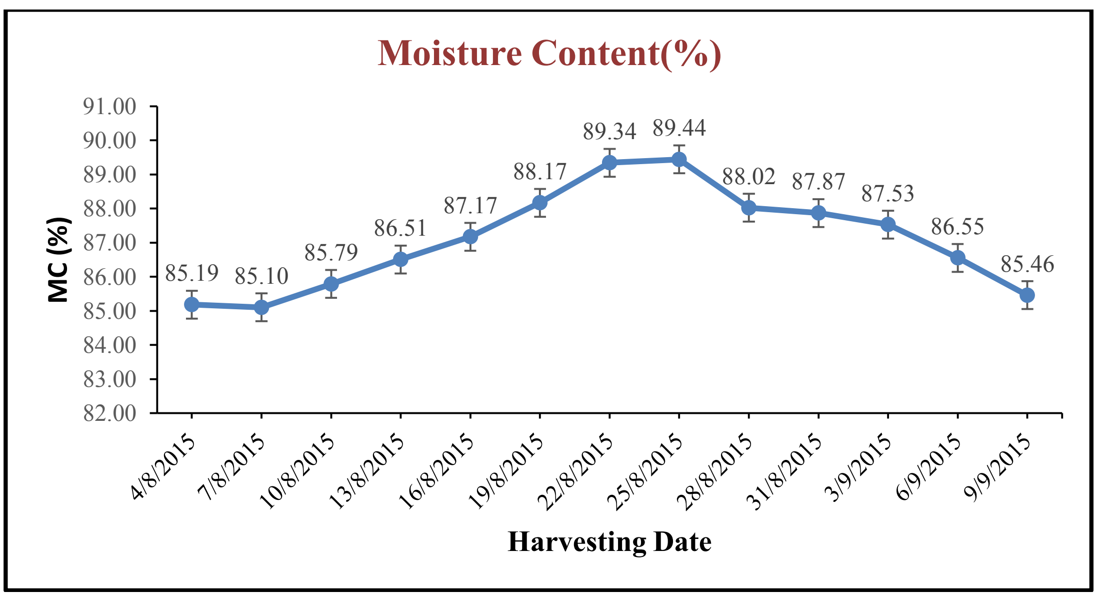


Figure 6-2. Wild blueberry fruit moisture content on different harvesting dates of field B.

6.4.2 Firmness

The decrease in firmness of wild blueberries at different harvesting dates ranged from 0.90-0.05 N mm^{-1} in Field A. The results of MMC revealed that berries at first harvest date (4/8/15) were significantly firmer (0.90 N mm^{-1}) than those at other harvesting dates (Table 6-2). Firmness decreased significantly on each consecutive harvesting dates from 4/8/15 to 13/8/15 of early season harvesting. This is possibly because the berries were in the ripening process, or not fully ripened, and more force was needed to rupture the outer skin of the berries. The results of the present study are consistent with those of Vicente et al. (2007), who reported that the greatest change in firmness was observed during ripening of blueberries and the decrease in firmness continued as the berries transitioned from 25% to 75% and 100% blue. In the present study, the decrease in firmness for the first two (16/8/15 and 19/8/15) middle season harvesting dates were significant, but the other two harvesting dates (22/8/15 and 25/8/15) of middle season harvesting were non-significantly different from each other (Table 6-2). An 88% decrease in firmness was observed from first harvesting date (4/8/15) of early season harvesting, compared to the last harvesting date (25/8/15) of middle season harvesting. The decreasing trend of firmness continued in the first two harvesting dates (28/8/15 and 31/8/15) of late season harvesting and reached its lowest level (0.05 N mm^{-1}) of firmness. A slight increase in firmness from harvesting date 3/9/15 was noticed until the end of harvesting date 9/9/15 (firmness value coincided with harvesting date 25/8/15) (Fig. 6-3). The increase in blueberry firmness could be due to elasticity or gumminess produced as excessive loss of internal water pressure (turgidity), which triggered enhanced resistance to the probe penetration. Overall, there was a 94% decrease in firmness exhibited from the first harvesting date (4/8/15) to the harvesting date (31/8/15) with the least decreasing firmness (Fig.6-3).

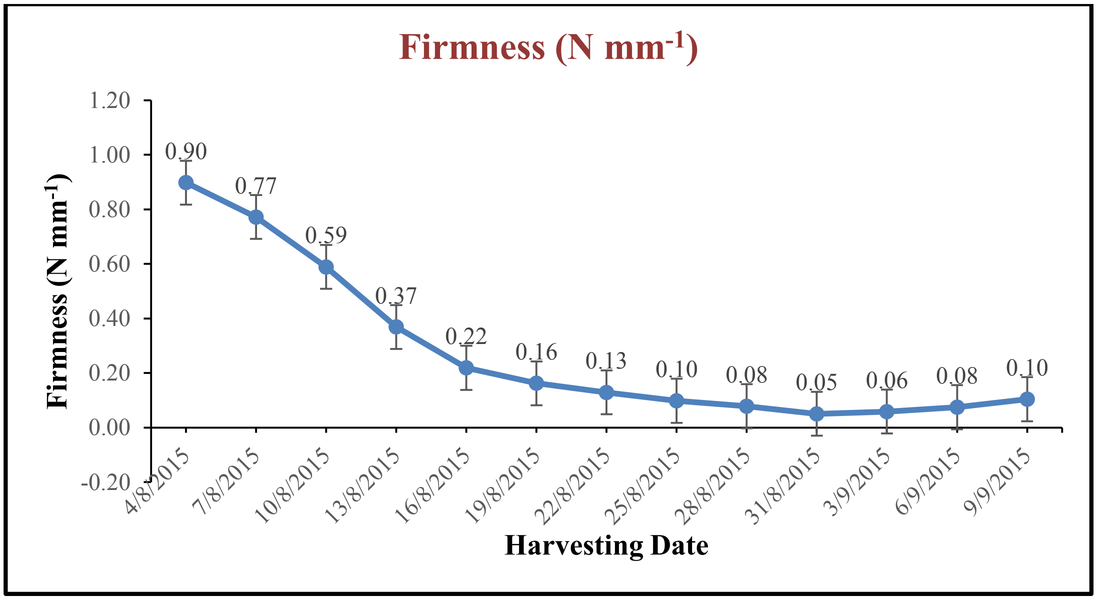


Figure 6-3. Wild blueberry fruit firmness on different harvesting dates of field A.

Firmness of wild blueberries was higher when they were harvested at an early stage of maturity in Field B. Berry flesh firmness was decreased significantly, in comparison to initial firmness (0.81 N mm^{-1}) and reached a minimum level of 0.06 N mm^{-1}, around 92% reduction in firmness during harvesting (Table 6-3). The decreasing firmness could be due to the metabolic process associated with the ripening process of fruit. Berry firmness decreased significantly with each other from harvesting dates 4/8/15 to 13/8/15 (overall 68% reduction in firmness) in early season harvesting. The first two harvesting dates (16/8/15 and 19/8/15) of middle season harvesting were found to be significant to each other, with 25% decrease in firmness, whereas the harvesting date 16/8/15 of middle season was non-significant in decreasing firmness for the rest of the middle season harvesting dates (19/8/15 to 25/8/15) (Table 6-3). The first three successive harvesting dates (28/8/15 to 3/9/15) of late season were non-significant to each other and reached a minimum level of firmness (0.06 N mm^{-1}) at 31/8/15 of late season harvesting. The increase in firmness was observed in the last three harvesting dates (3/9/15 to 9/9/15) of late season. The reason could be due to internal loss of water from fruit, which resulted in wrinkling and shriveling; thus, the fruit became soft and resisted penetration.

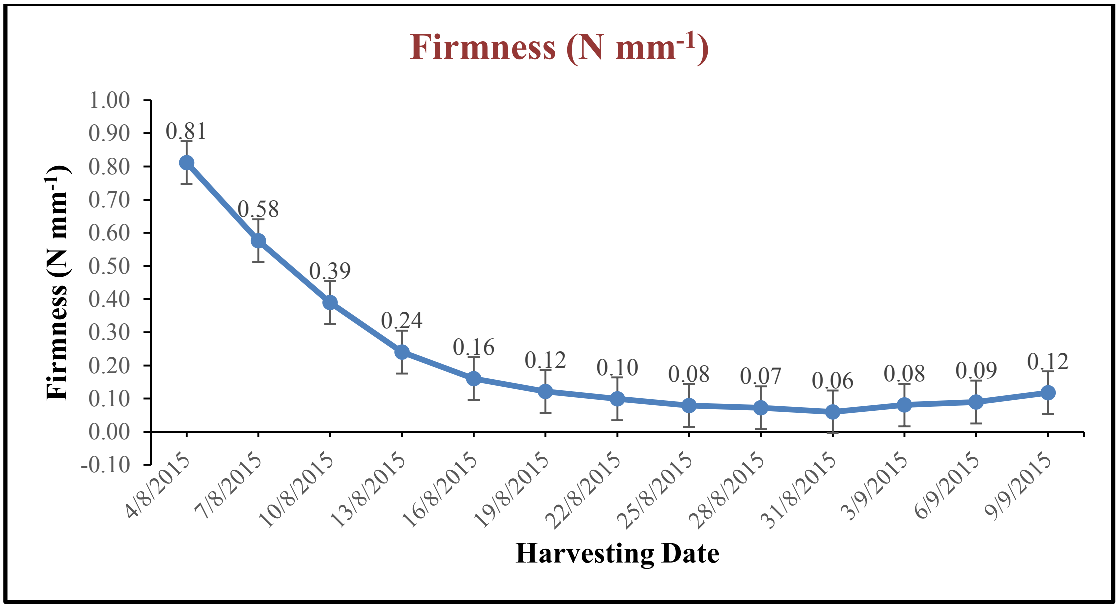


Figure 6-4. Wild blueberry fruit firmness on different harvesting dates of field B.

There were 0.09 N mm^{-1}, Field A berries were 10% firmer compared to berries in Field B, difference in initial firmness value at very first harvesting date (4/8/15) between both fields (Fig. 6-3 and 6-4). The reason could be that Field A had smaller berries compared to Field B, which agrees with the findings of Smagula et al. (1997) who reported that smaller blueberries tend to be slightly firmer compared to larger berries, confirming the negative relationship between size and firmness of blueberries. Field A and Field B showed significant decrease in firmness of 59% and 70%, respectively in early season harvesting (4/8/13 to 13/8/15) (Fig. 6-3 and 6-4). The decrease in firmness continued and were as 54% and 50% in Field A and Field B, respectively, in middle season (16/8/15 to 25/8/15). The decline in firmness reached a minimum level of 0.05 N mm^{-1} and 0.06 N mm^{-1} for Field A and Field B, respectively on harvesting date (31/8/15) in late season harvesting. Firmness diverted from decreasing trend to an increasing one on 3/9/15 and reached levels of 0.10 N mm^{-1} and 0.12 N mm^{-1} in Field A and Field B, respectively, on 9/9/15 in late season harvesting. This possibly because of internal loss of water resulted in resist penetration of probe.

6.4.3 Total Soluble Solids

Total soluble solids (TSS) values of wild blueberries ranged between 5.3ºBrix (%) and 12.8ºBrix in Field A at different harvesting dates. TSS values were found to be non-significant between the harvesting dates (4/8/15 and 7/8/15) and (10/8/15 and 13/8/15) in early season harvesting (Table 6-2). There was an 18% increase in sugar content from the first harvesting date (4/8/15) to the last harvesting date (13/8/15) in early season harvesting. TSS were found to be significant with each other for all harvesting dates (16/8/15 to 25/8/15) of middle season harvesting (Table 6-2). The gradual increase in sugar concentration between each consecutive harvesting dates from 16/8/15 to 25/8/15 were 11%, 14% and 10% in middle season harvesting. The substantial increase in sugar content was 40% in middle season and overall 98% from 4/8/15 to 25/8/15. The increase in sugar concentration is naturally attributed to the ripening process of attached blueberries with plants that indicates the biochemical reactions in the metabolism of the fruit (Basiouny and Chen, 1988). The increase in sugar concentration continued in late season harvesting but the percent increase was not as high as in early and middle season. The sugar concentration increased significantly between first harvesting date (28/8/15) and harvesting dates (31/8/15 and 3/9/15) of late season harvesting, while the harvesting dates (31/8/15 and 3/9/15) and (6/9/15 and 9/9/15) were non-significant to each other in late season (Table 6-2). There was only a 4% increase in sugar concentration for the last four harvesting dates of late season, suggesting a steady behavior in sugar concentration. Overall, 141% increase in sugar concentration was exhibited from the start of harvesting season (4/8/15) until the end of the harvesting season (9/9/15) in Field A.

TSS values at different harvesting dates of wild blueberry in Field B fluctuated between 5.5% and 13.1%. Difference in sugar concentration in wild blueberry was non-significant between initial two harvesting dates (4/8/15 and 7/8/15), with 2% increase in sweetness, and the last two harvesting dates (10/8/15 and 13/8/15), with 1.5% increase in sweetness, for early season harvesting (Table 6-3). The sugar concentrations increased significantly between harvesting dates 7/8/15 and 10/8/15, with 20% increment, in early season harvesting. The increase in TSS was found to be significant at all harvesting dates of middle season harvesting. The increases in sugar concentrations of 10%, 13% and 12% were observed between each consecutive harvesting dates from 16/8/15 to 25/8/15 in middle season harvesting (Table 6-3). The increasing trend in sugar concentrations continued at a steady rate in late season harvesting. TSS at the first three harvesting dates (28/8/15 to 3/9/15) were found to be significantly different from each other, with 4% and 2% increase in sugar concentrations, in late season. Increases in sugar concentrations were 24%, 38% and 8% in early, middle and late season, respectively, in Field B.

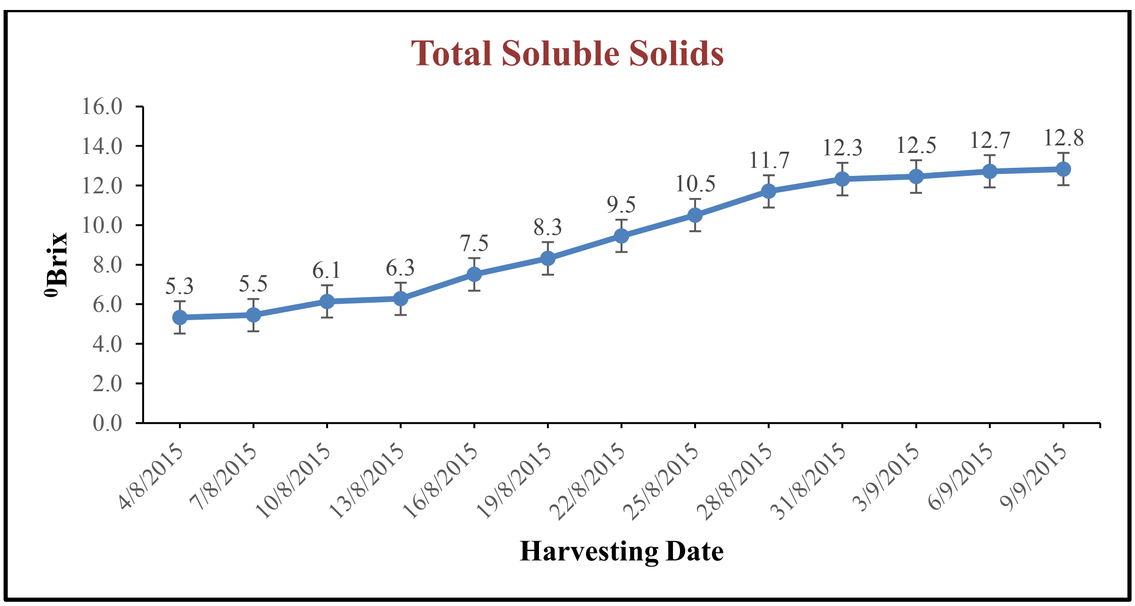


Figure 6-5. TSS at different harvesting dates in field A of wild blueberry.

The increasing trend in sugar concentrations (TSS) was observed in both fields (Fig. 6-5 and 6-6). An overall increase in sugar concentrations of 141% in Field A and 138% in Field B was noticed in the whole harvesting season. The initial and final concentrations of sugar were slightly lower (5.3% and 12.8%) in Field A, compared to Field B (5.5% and 13.1%), suggesting that there were ripening differences in both fields (Fig. 6-5 and 6-6). One common trait in TSS was an initial slow increase, then a dramatic increase in TSS and thereafter, in later stages, a consistent trend in both fields (Fig. 6-5 and 6-6). Kalt and McDonald (1996) reported sugar contents of 13.13% (Blomidon cultivar), 14.22% (Cumberland) and 11.92% (Fundy) and a mean of 13.09% for overripe wild blueberries. Our findings were slightly lower than this mean value. The reason could be that they measured TSS for each cultivar independently and in the present case, TSS was measured without distinction of cultivars.

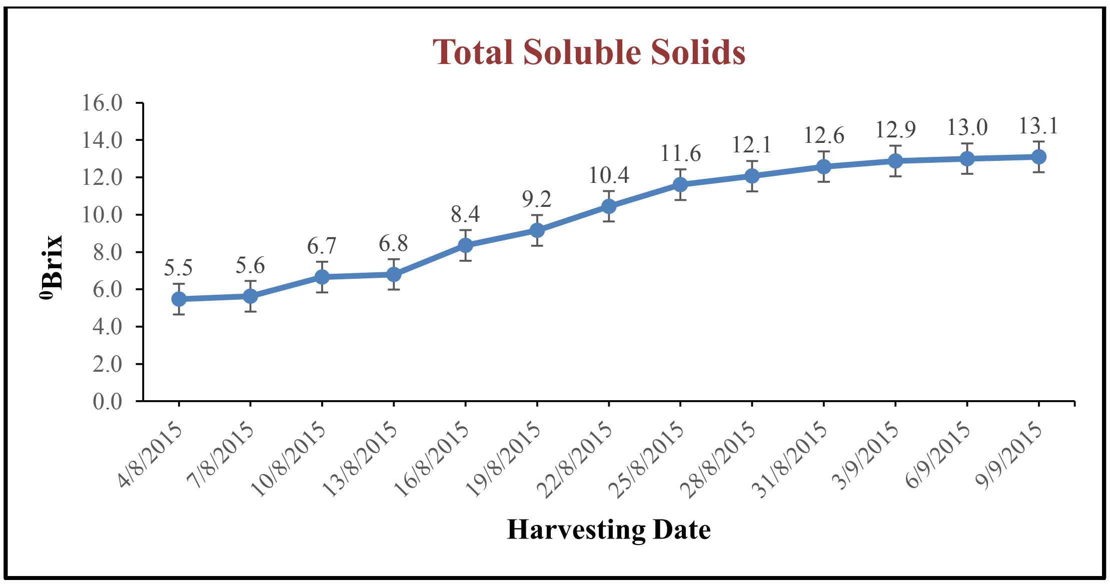


Figure 6-6. TSS at different harvesting dates in field B of wild blueberry.

6.4.4 Titratable Acidity

The decrease in acidity in wild blueberry has been shown from initial harvest (4/8/15) to final harvest (9/9/15) and was observed to be as high as from 7.01 meq g^{-1} fresh weight, to as low as 0.93 meq g^{-1} fresh weight in Field A (Table 6-2). The decrease in acidity was significant (9%

decrement) between the first two harvesting dates (4/8/15 and 7/8/15) and non-significant between harvesting dates (7/8/15 and 10/8/15) in early season harvesting. The decrease in acidity was also found to be significant between harvesting dates (10/8/15 and 13/8/15), with 9% decrease in early season harvesting. The decreasing trend in acidity became more prominent in middle season and 26% and 28% significant decline in acidity was observed on successive harvesting dates from 19/8/15 to 25/8/15 (Table 6-2). A gradual decrease in acidity is an intrinsic process in ripening of blueberries to impart the characteristic flavor. The significant drop in acidity continued at moderate rate of 21% and 16% from 28/8/15 to 3/9/15 in late season harvesting. The last two harvesting dates were non-significant to each other with 11% decrease in acidity. Decreases in acidity of 16%, 48% and 64% were noted in early, middle and late season harvesting in Field A, respectively.

Titratable acidity at different harvesting dates fluctuated between 6.54 meq g^{-1} fresh weight and 0.91 meq g^{-1} fresh weight in Field B. The results of the first three harvesting dates (4/8/15 to 10/8/15) showed significance to each other, with 9% and 5% decrease in acidity, in early season harvesting. The last two harvesting dates (10/8/15 and 13/8/15) were non-significant, with less than 2% decrease in acidity, in early season harvesting (Table 6-3). The sharp and significant decline in acidity was exhibited between harvesting dates (16/8/15 and 19/8/15) and (19/8/15 and 22/8/15), with 14% and 27% reduction in acidity, respectively, in middle season harvesting. The decline in acidity was non-significant, with less than 3% decrease in acidity, between harvesting dates (22/8/15 and 25/8/15) during middle season harvesting. The decline in acidity continued significantly with high decreasing rates of 21% and 41% in late season harvesting dates (28/8/15 and 31/8/15) and (31/8/15 and 3/9/15), respectively. The non-significant relation in decreasing

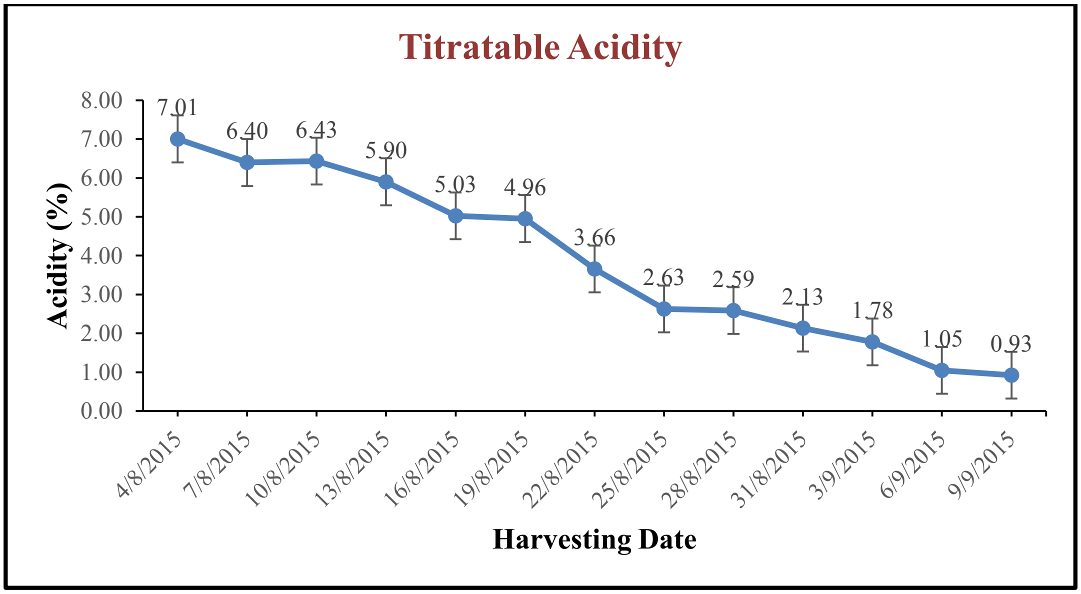


Figure 6-7. Wild blueberry fruit acidity at different harvesting dates in field A.

acidity was found between (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15) of the last three harvesting dates of late season (Table 6-3). There were of 15%, 39% and 62% decline in acidity observed in early, middle and late seasons, respectively, during wild blueberry harvesting in Field B.

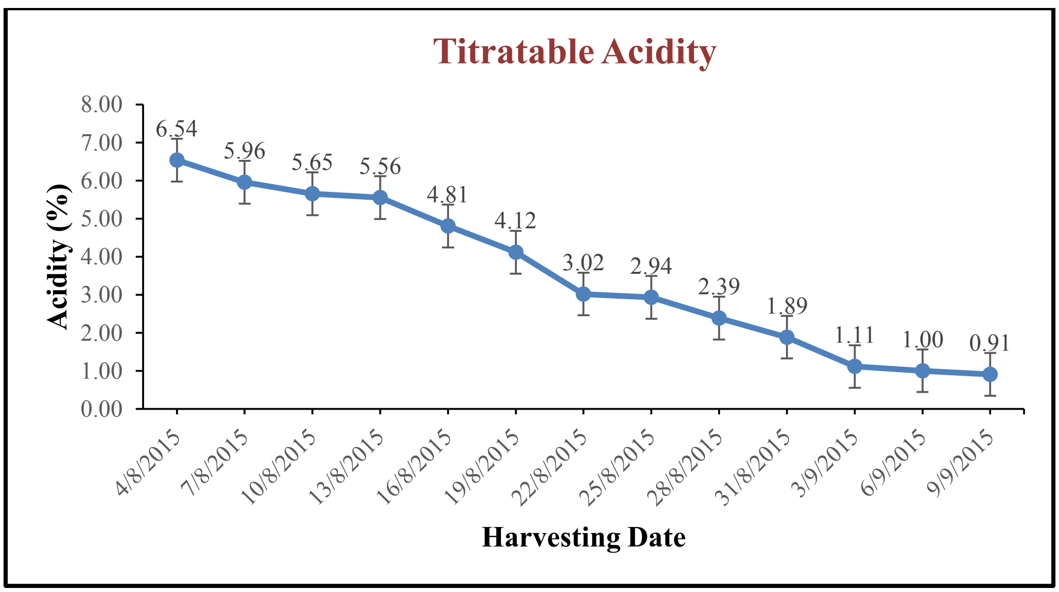


Figure 6-8. Wild blueberry fruit acidity at different harvesting dates in field B.

There was a 7% difference in initial acidity values between Field A and Field B, suggesting that there were ripening differences between the fields. The overall decrease in acidity for Field A and B were 87% and 86%, respectively, for the whole harvesting season (Fig. 6-7 and 6-8). The abrupt decline in acidity was noticed from harvesting dates (19/8/15 to 25/8/15) in Field A, but similar steep trend in decreasing acidity was found during harvesting dates (13/8/15 to 22/8/15) in Field B. The results indicated that there was a similar decline in acidity in early harvesting (16% and 15%) and late harvesting (64% and 62%), but noticeable change was quite significant in middle season, with 48% and 39% decrease in acidity, between Field A and B, respectively (Fig. 6-7 and 6-8). Kalt and McDonald (1996) reported 0.354 meq g^{-1} dry weight (Blomidon cultivar), 0.332 meq g^{-1} dry weight (Cumberland) and 0.652 meq g^{-1} dry weight (Fundy) and their mean was 0.446 meq g^{-1} dry weight for overripe blueberries. The present findings showed a slightly higher acidity values than the previously mentioned mean for overripe berries. This could be due to cultivars differences along with; moreover Kalt and McDonald (1996) measured TA on dry weight basis for each cultivar independently whereas, in present study TA was measured with composite samples of blueberries on fresh weight basis.

6.4.5 TSS:TA (Maturity Index)

TSS:TA values of wild blueberries at different harvesting dates varied from as low as 0.76 and to as high as 13.87 in Field A. The first four successive harvesting dates (4/8/15 to 13/8/15) were found to be non-significant to each other for maturity index in early season harvesting (Table 6-2). The maturity was not altered significantly between 16/8/15 and 19/8/15 of middle season but maturity differed significantly, with 55% increase in TSS:TA, between harvesting dates of 22/8/15 and 25/8/15. The increasing trend in TSS:TA during the course of ripening was the indication of a decline in acidity and increase in sweetness in ripe fruits compared to the immature fruits. TSS:TA measurements changed significantly between harvesting dates (28/8/15 and 31/8/15) and (31/8/15 and 3/9/15), with 28% and 21% increase in maturity, respectively. The greatest significant change in maturity was observed between 3/9/15 and 6/9/15, with a 74% increase, in TSS:TA (Table 6-

2). Decay was also attributed to fruits with low acidity and high TSS value (too high value of TSS:TA) (Basiouny and Chen, 1988). There were of 39%, 168% and 206% increase in TSS:TA in early, middle and late season, respectively, during the ripening process of blueberries.

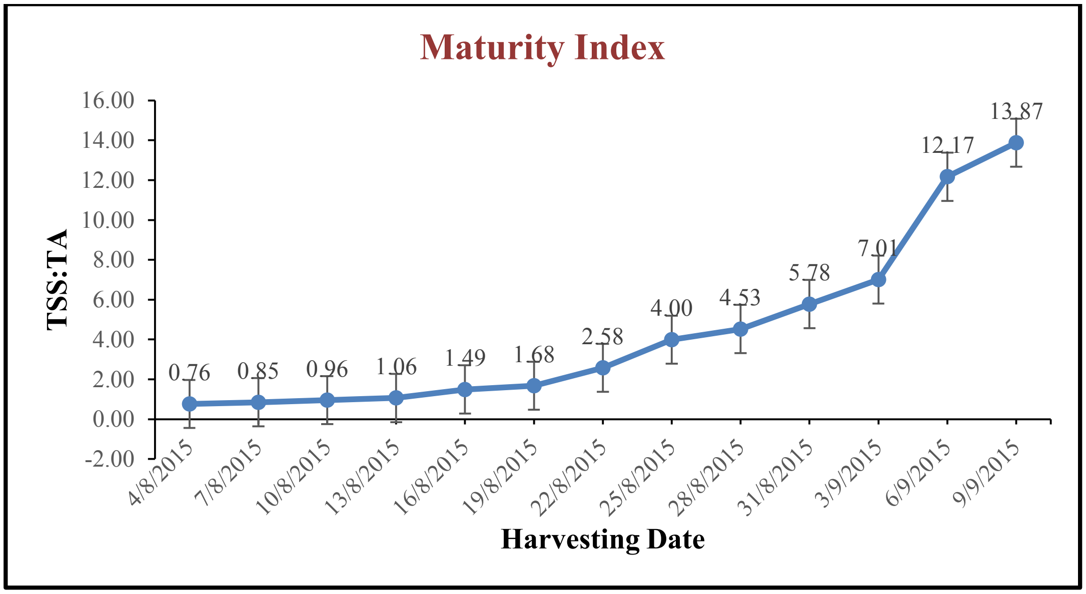


Figure 6-9. Wild blueberry fruit maturity at different harvesting dates in field A.

TSS:TA measurements fluctuated between 0.84 and 14.45 during the course of ripening in Field B. The maturity of blueberries did not change significantly from 4/8/15 to 13/8/15 in early season harvesting (Table 6-3). The significant increase in maturity was noticed between (16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15), with 28%, 55% and 14% increase, in TSS:TA, respectively, during middle season harvesting. The significant increase in TSS:TA measurements continued between harvesting dates (28/8/15 and 31/8/15), (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15), with 32%, 12% and 12% increase, in TSS:TA in late season harvesting, respectively (Table 6-3). The greatest change was observed between harvest (31/8/15 and 3/9/15), with 73% increase, in TSS:TA in late season harvesting. The considerable decrease in acidity and increase in sugar concentration (too high value of TSS:TA) during fruit ripening was the major cause of bad taste and microbial attack in fruit (Basiouny and Chen, 1988). The change in TSS:TA during early, middle and late season were of 45%, 127% and 186% in Field B, respectively.

Results indicated that the development of maturity in wild blueberry fruit continued to increase steadily in Fields A and B during harvesting until the termination of the experiment. There were approximately 1725% and 1620% increases in TSS:TA observed during the whole harvesting season in Fields A and B, respectively (Fig. 6-9 and 6-10). The greatest increases of 206% and 186% in TSS:TA were found during late season in Fields A and B, respectively. The rapid increase in TSS:TA, 74%, was noted between 3/9/15 and 6/9 15 in Field A, while the abrupt increase in TSS:TA, 73%, was noticed between 31/8/15 and 3/9/15 in Field B. Mitchell et al. (1991) reported that fruit harvested at too high a maturity might be susceptible of undesirable off flavors and attack of fruit decaying organisms along with short post-harvest life. The initial and final measurements of TSS:TA were lower in Field A (0.76 and 13.87, respectively) compared to Field B (0.84 and 14.45, respectively) (Fig. 6-9 and 6-10). A Similar trend in increasing TSS:TA measurements was reported in cherries (Crisosto et al., 2002) and plums (Crisosto et al., 2004).

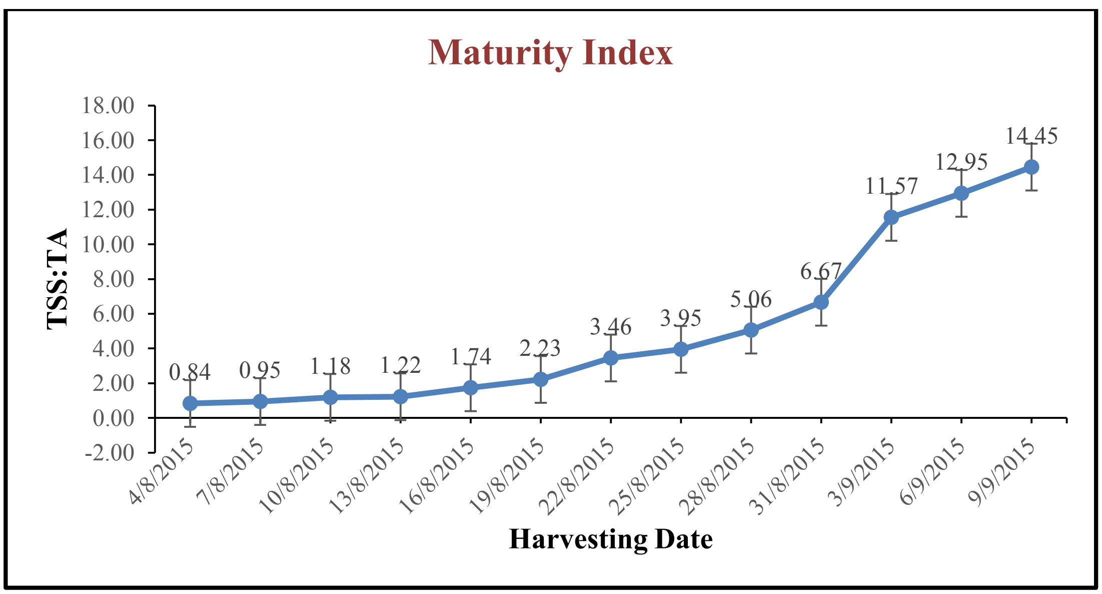


Figure 6-10. Wild blueberry fruit maturity at different harvesting dates in field B.

6.4.6 Anthocyanin Content

Anthocyanin contents varied significantly between different harvesting dates in Field A. The mean anthocyanin values at different harvesting dates ranged from 33.03 to 118.28 mg malvidin-3-glucoside equivalents (M3GE) per 100 g fresh weight (Table 6-2). Difference in the anthocyanin contents was non-significant between the first two harvesting dates (4/8/15 and 7/8/15), but significantly different for the next two harvesting dates (10/8/15 and 13/8/15) in early season harvesting. The reason could be that partly ripened berries did not impart characteristics pigments. Similarly, anthocyanin contents were similar between harvesting dates (16/8/15 and 19/8/15), but were significantly different at the harvesting dates (22/8/15 and 25/8/15), with a 7% increase in anthocyanin in middle season harvesting (Table 6-2). The anthocyanin accumulation continued significantly with 6%, 8% and 14% increase in pigments between harvesting dates (28/8/15 and 31/8/15), (31/8/15 and 3/9/15) and (3/9/15 and 6/9/15) in late season harvesting, respectively. The anthocyanin were non-significant between the last two harvesting dates (6/8/15 and 9/9/15), approximately 2% increase in pigments in over ripened berries, in late season harvesting. A considerable increase in pigments of 113%, 16% and 31% was noted in early, middle and late season in Field A, respectively.

The anthocyanin contents increased steadily ranging from 35.63 to 125.72 mg M3GE per 100 g fresh weight, during development of wild blueberries and continued to increase until the termination of the experiment in Field B. Results indicated that the anthocyanin were found to be significant between harvesting dates (4/8/15 and 7/8/15) with 45% increase in anthocyanin pigments, but the values at harvesting dates (10/8/15 and 13/8/15) were non-significant with less than 1% rise in pigments, in early season harvesting (Table 6-3). Similarly, the anthocyanin contents between harvesting dates (16/8/15 and 19/8/15) seemed to be significant, with a 7% rise in pigments, while the rise in pigments remained non-significant between harvesting dates (22/8/15 and 25/8/15) in middle season harvesting. The increasing trend of anthocyanin pigments continued significantly, with 10% and 6% increase in anthocyanin, between harvesting dates (31/8/15 and 3/9/15) and (3/9/15 and 6/9/15) in late season harvesting, respectively (Table 6-3). Since the increase in anthocyanin contents was a natural process during course of ripening of blueberries, however the continued increase in anthocyanin even after it stopped growing at the end of harvest required further examination. It was observed that there was of 84%, 24% and 17% increase in anthocyanin pigments during early, middle and late season harvesting in Field B, respectively (Table 6-3).

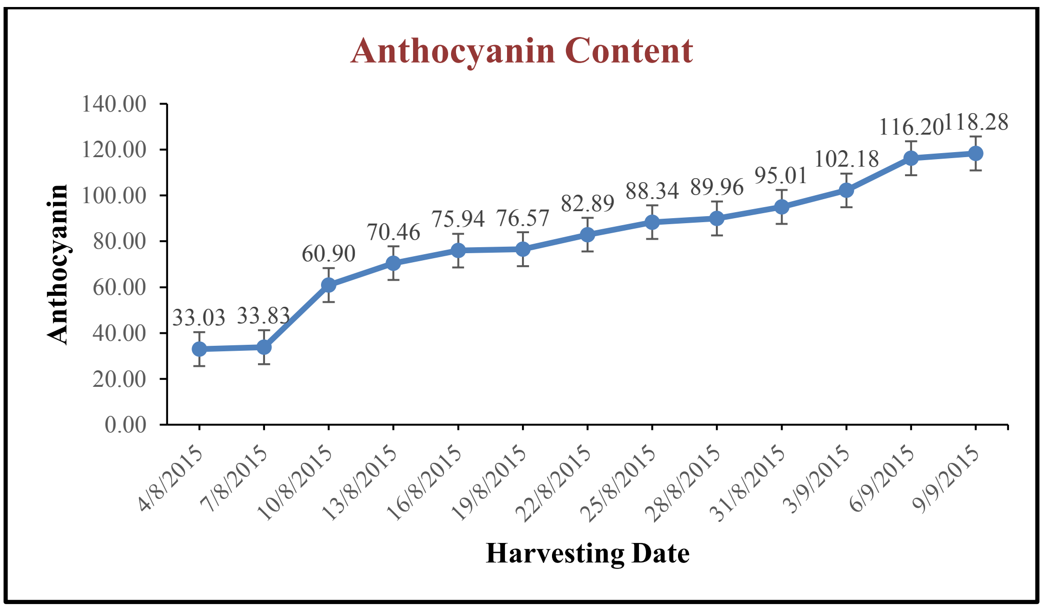


Figure 6-11. Anthocyanin content at different harvesting dates in field A.

The increasing trend in anthocyanin pigments was observed in both fields (A and B). An overall anthocyanin contents of 258% in Field A and 253% in Field B were extracted during the entire harvesting season. An increase of more than 29% in anthocyanin pigments in Field A, compared to Field B was observed in early season harvesting (Fig.6-11 and 6-12). The initial and final concentrations of anthocyanin were slightly higher in Field B (35.63 mg per 100 g fresh weight and 125.72 mg per 100 g fresh weight) than in Field A (33.03 mg per 100 g fresh weight and 118.28 mg per 100 g fresh weight). This could be due to the different clones and cultivars that were present in the two fields. Additionally, anthocyanin is concentrated in the skin of blueberry

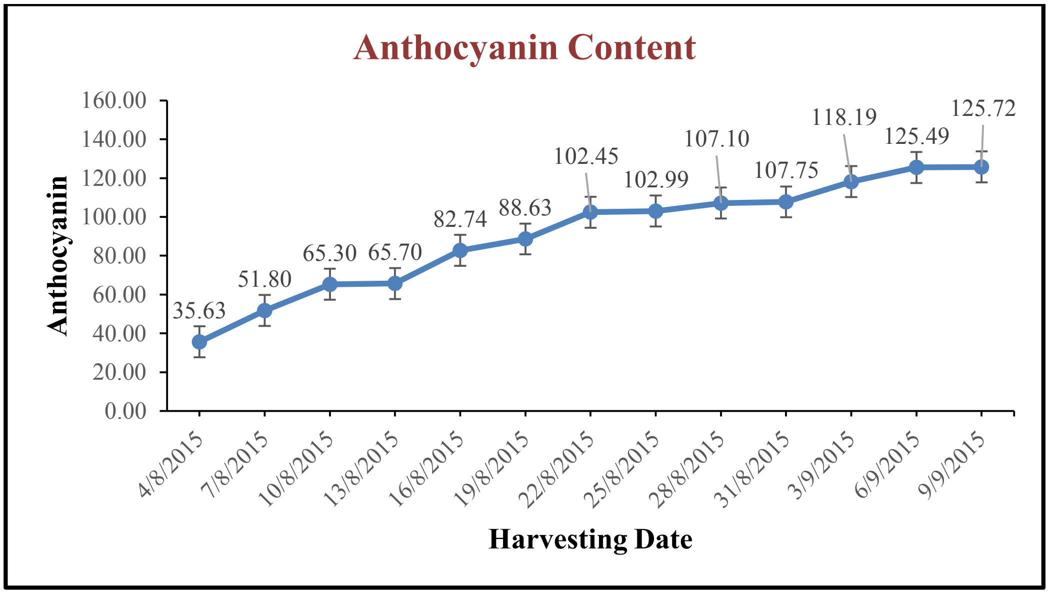


Figure 6-12. Anthocyanin content at different harvesting dates in field B.

and consequently, the fruit size can impact the quantity of anthocyanin in a given weight of sample (Prior et al., 1998). The present values of extracted anthocyanin were slightly lower than other values reported in the literature. Hosseinian and Beta (2007) reported a mean M3GE content of 139.6 mg per 100 g dry weight on extraction of *V. myrtilliods* blueberries. Moreover, Wu et al. (2006) reported 154.6 mg per 100 g fresh weight M3GE with HPLC. The results reported by Gibson et al. (2013), at different ripening conditions for M3GE, were 0.7 (green), 34 (red), 95 (blue) and 110 (over mature) in wild blueberry. These values agrees with findings from present study. When a particular anthocyanin compound used as a standard, its molar absorption can greatly influence the results. A large number of research studies for anthocyanin content, using cyanidin-3-glucoside, were conducted with the pH differential method, making the results difficult to compare with the present results (Kalt et al., 2001; Nicoue et al., 2007).

6.4.7 Diameter

Results of MMC revealed that the average diameter of wild blueberries at different harvesting dates fluctuated between 7.55 mm and 10.93 mm in Field A. The increase in diameter between harvesting dates (4/8/15 and 7/8/15) and (7/8/15 and 10/8/15) were non-significant, while the diameter increased significantly, by a 6% increment, between harvesting dates (10/8/15 and 13/8/15) in early season harvesting (Table 6-2). The diameter of blueberries enlarged significantly between harvesting dates (16/8/15 and 19/8/15) and (19/8/15 and 22/8/15) by 5% and 7% increments, respectively, in middle season harvesting. The increase in diameter, with 4% increment, was also observed but this was not significantly different during the last two harvesting dates (22/8/15 and 25/8/15) in middle season harvesting. The increasing trend in diameter continued in late season harvesting with the largest increase in diameter was 10.93 mm observed on 28/8/15. The decrease in diameter started from 31/8/15 until the termination of the experiment. The decrease in diameter between harvesting dates (28/8/15 and 31/8/15) and (31/8/15 and 3/9/15) were found to be non-significant to each other, with 2% and 4% decrements, respectively, in late season harvesting. The diameter decreased significantly, with 6% and 9% decrements, on harvesting dates (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15), respectively, in late season harvesting (Table 6-2). The increase in diameter of 14% in early, 18% in middle and the decrease in diameter of 19% during late season harvesting were observed in Field A.

The highest berry diameter of 11.16 mm and the lowest diameter of 8.17 mm were recorded during harvesting of wild blueberries in Field B (Table 6-3). The increase in diameter was non-significant among successive harvesting dates (4/8/15, 7/8/15 and 10/8/15), while diameter was found to be significant, with a 6% addition, between harvesting dates (10/8/15 and 13/8/15) in early season harvesting. The diameter increased non-significantly between the first two harvesting dates

(16/8/15 and 19/8/15), but increased significantly between the harvesting dates (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15), with 9% and 4% increments, respectively, in middle season harvesting (Table 6-3). The largest diameter of 11.16 mm was measured on 28/8/15 in late season harvesting. A decreasing trend in diameter was observed on 31/8/15, with a 3% decrement, compared to 28/8/15 in late season harvesting. The significant decrease in diameter was noted between harvesting dates (31/8/15 and 3/9/15), (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15), with 7%, 7% and 6% decreases in diameter, respectively, in late season harvesting (Table 6-3). The increase in diameter of 10% in early season, 17% in middle season and the decrease in diameter of 21% was measured in late season harvesting.

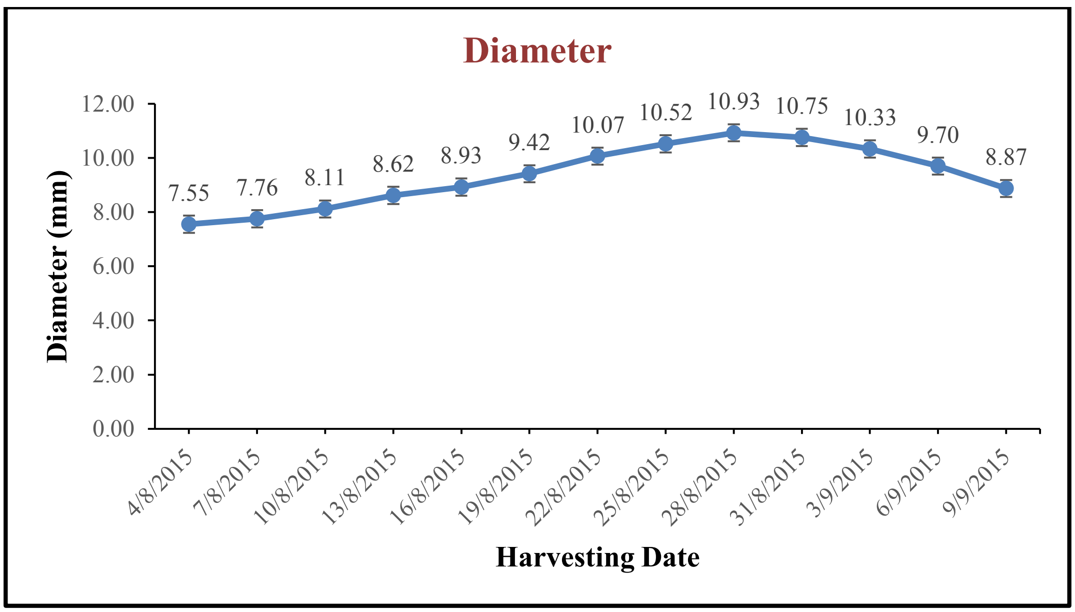


Figure 6-13. Average diameter of wild blueberries at different harvesting dates in field A.

A similar trend in diameter, starting with the lowest and reaching the highest level and then decreasing diameter, was found in both fields (Fig. 6-13 and 6-14). A difference of 8% in initial diameter values was observed on first harvesting date (4/8/15) between both fields. An increase in diameter of 45% and 37% and a decrease in diameter of 23% and 26% was measured in Fields A and B, respectively, during the whole harvesting season. An increase in diameter was the outcome of gaining moisture contents and total soluble solids during course of ripening, while a decrease in diameter of wild blueberries was the consequence of loss of moisture in late season harvesting. The greatest increase in diameters of 18% and 17% were measured at Fields A and B, respectively, in middle season harvesting. The initial value of diameter in Field B (8.17 mm) was slightly higher compared to Field A (7.55 mm), but the final recorded value of diameter was a little lower in Field B (8.83 mm) than Field A (8.87 mm). The present findings were remained a little lower (11.16 mm) than those reported by Kalt et al. (1995) (13.99 mm). It could be due to that the latter reported results were for specific cultivars and clones, but the present results had a composite sample of blueberries.

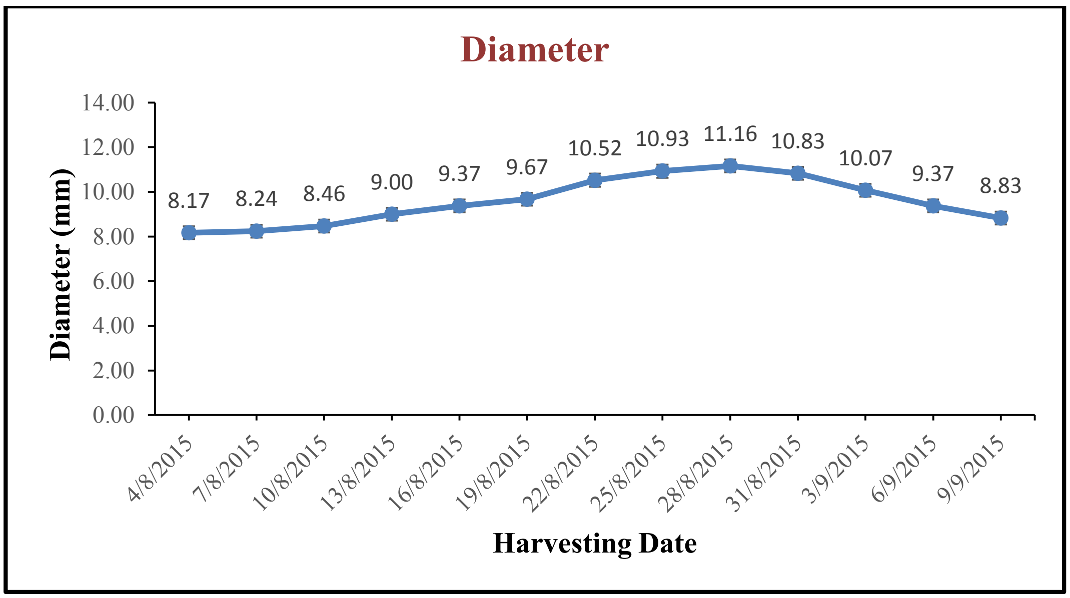


Figure 6-14. Average diameter of wild blueberries at different harvesting dates in field B.

6.4.8 Fresh Weight

Results indicated that the Average weight of wild blueberries ranged from 0.46 to 0.72 g in Field A. The weight did not change significantly between harvesting dates (4/8/15 and 7/8/15) in early season harvesting. The weight increased significantly between harvesting dates (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), with 6% and 8% increments, respectively, in early season harvesting. The increase in weight was significant in middle season harvesting (Table 6-2). All harvesting dates were found to be significant with 7%, 6% and 5% increases in weight between successive harvesting dates from 16/8/15 to 25/8/15 in middle season harvesting. The increase in weight is an inherent process undergoing in ripening fruit. The increasing trend in weight continued in late season and weighed the greatest increase in weight of 0.72 g on 28/8/15 and thereafter, a significant decrease in weight was observed. It could be due to the substantial loss of moisture in wild blueberries (Table 6-2). A significant decrease in weight of 6%, 4%, 9% and 7% was noted between each consecutive harvesting dates from 28/8/15 to 9/9/15 in late season harvesting. The wild blueberries gained a 20% weight in early season and a 19% in middle season, while the berries lost a 24 % weight during late season harvesting in Field A.

Wild blueberry fruit weight varied over a narrow range from 0.50 to 0.77 g in Field B. The increase in weight was non-significant between the harvesting dates of 4/8/15 and 7/8/15 in early season harvesting (Table 6-3). The gain in weight was significant between harvesting dates (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), with 6% and 9% increments in weight, in early season harvesting, respectively. An increase in weight continued significantly in middle season harvesting. The harvesting dates (16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15) were found to be significant to each other, with 6%, 6% and 4% increases in weight, in middle season harvesting, respectively. The greatest gain of 0.77 g was reported on harvesting date 28/8/15 and thereafter, the loss in weight was detected during late season harvesting in Field B (Table 6-3). The weight decreased significantly, with 6%, 6%, 7% and 6% decrements, on each consecutive harvesting dates from 28/8/15 to 9/9/15 in late season harvesting. The increase in weight of 20% and 17% were observed in early and middle season harvesting, respectively, while 23% reduction in weight was also noticed in late season harvesting.

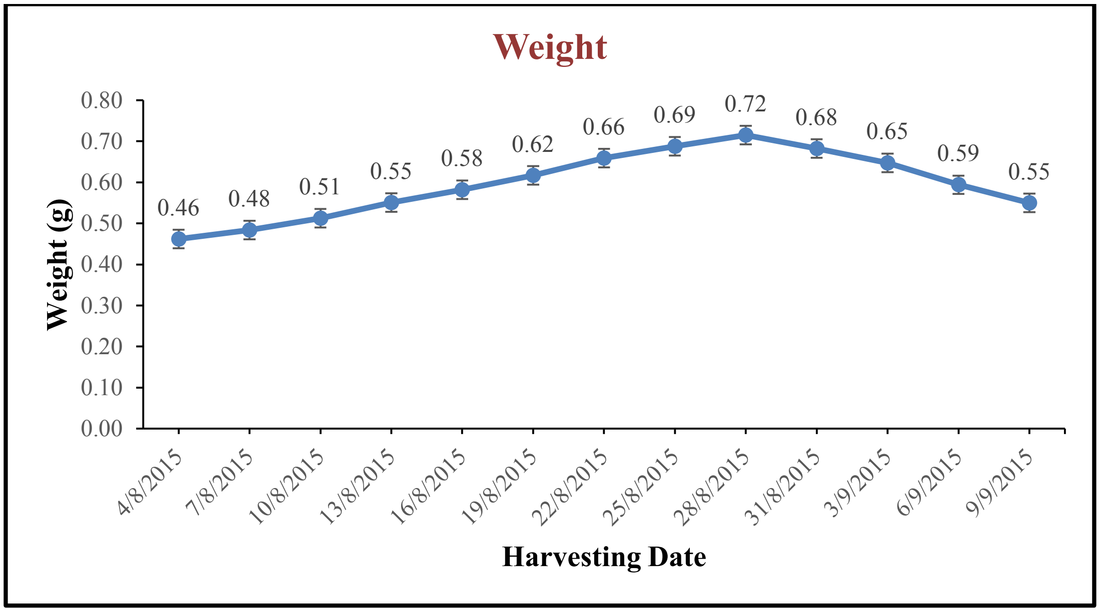


Figure 6-15. Average weight of wild blueberries at different harvesting dates in field A.

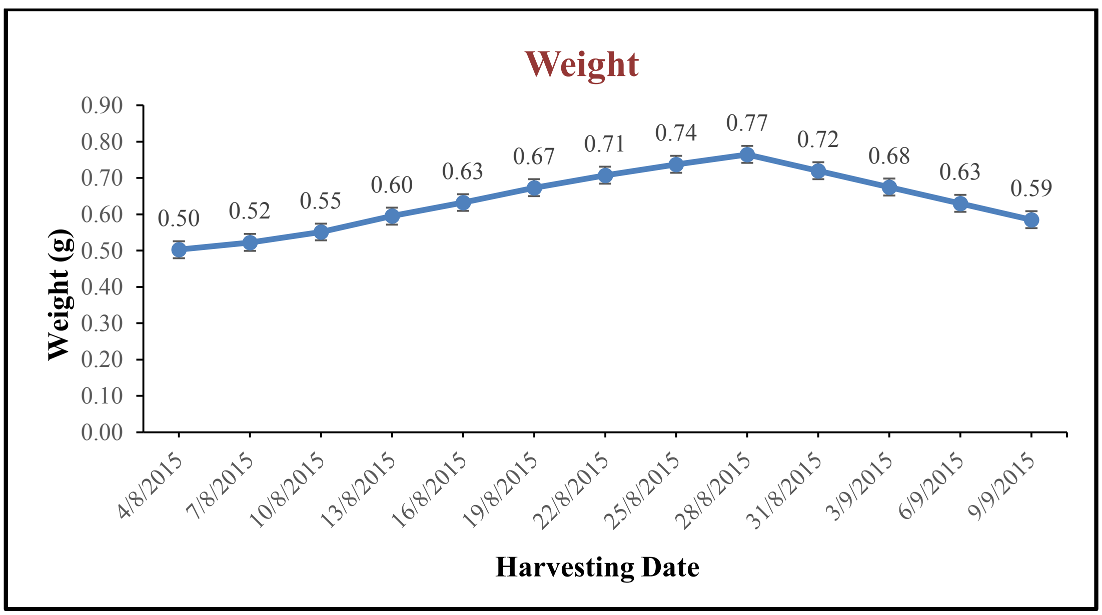


Figure 6-16. Average weight of wild blueberries at different harvesting dates in field B.

Results indicated that both Fields A and B had similar trends in gaining weight and then reached at peak level and thereafter, dropped off until termination of the experiment. The berries harvested in Field B were found to be 9% heavier than Field A berries on the first harvesting date (4/8/15) and this trend continued until the end of the experiment. The initial and final values of berry weights were slightly higher in Field B (0.50 g and 0.59 g) compared to Field A (0.46 g and 0.55

g). The differences could be due to genetic and environmental factors (e.g., pollination) as reported by Eck (1988). The present findings coincides with the results reported by Kalt and McDonald (1996) on different cultivars, Blomidon (0.63 g), Cumberland (0.60 g), Fundy (0.76 g) and their mean (0.66 g), of wild blueberries. The overall increase in weight was 57% and 54% and the decrease in weight was 24% and 23% in Fields A and B, respectively. Paniagua et al. (2013) reported that fruit shriveling begins after weight loss ≥ 8.7% in blueberries. Sanford et al. (1991) reported that wild blueberries turn out to be non-salable when they lose weight from 5% to 8%, emphasizing the importance of harvesting berries before they reach at this stage.

6.4.9 Correlation

Correlation coefficient, using Pearson correlation, was computed to assess the correlation among different quality parameters on the data collected from Fields A and B. All correlations were found to be significant with each other at 5% significant level. Results indicated that the firmness negatively correlated with moisture content (Table B1and B2, Appendix 'B'). It means that low turgidity (less MC) berries were firmer than the berries that had high turgidity. The firmness also showed a significant and high negative correlations with TSS (r = -0.85 and -0.82 for Fields A and B, respectively), anthocyanin content (r = -0.91 and -0.88 for Field A and B, respectively), diameter (r = -0.87 and -0.75 for Field A and B, respectively) and weight (r = -0.83 and -0.82 for Field A and B, respectively) in blueberries. Reported results (Table 6-2 and 6-3) indicated that as TSS and anthocyanin content increased, the firmness decreased. The diameter and weight both had strong positive correlation with MC (r = 0.84 and 0.87 for Field A and r = 0.87 and 0.89 for Field B, respectively), TSS (r = 0.79 and 0.69 for Field A and r = 0.69 and 0.70 for Field B, respectively) and anthocyanin content (r = 0.69 and 0.61 for Field A and r = 0.63 and 0.68 for Field B, respectively). This suggests that with increase in diameter and weight, MC, TSS and anthocyanin contents increase. The diameter and weight of berries could be a better indication of ripeness. A significant negative correlation existed between diameter and TA as well as weight and TA. A highly significant correlation between diameter and weight of the berries suggests a natural process of gaining weight is associated with increase in diameter. The relationship between anthocyanin content and TSS was 0.93 and 0.98 in Fields A and B and between anthocyanin and TA was -0.94 and -0.98 in Field A and B, respectively, indicating that a high anthocyanin pigments were linked with an increasing sweetness and decreasing acidity in wild blueberries. The increase in sweetness was highly correlated with a decrease in acidity ($r = -0.99$ for both fields). The sweetness was also correlated with increase in MC ($r = 0.45$ and 0.49 for Field A and B, respectively) and decrease in acidity was correlated with the increase in MC ($r = -0.43$ and -0.39 for Field A and B, respectively), showing that a high MC is an indication of less sour and sweeter berries.

6.5 Conclusion

Ensuring good quality berries is a distinct problem for wild blueberry growers and the industry. Therefore, the objective of this study was to investigate the effects of harvesting time on chemical composition and conducted with an aim to provide information and recommendations to blueberry growers, so that they can utilize the resources wisely, while maximizing output quality.

Results of the present study suggest that physico-chemical properties of wild blueberries during fruit maturation are the function of time of harvesting. Total soluble solids and anthocyanin contents, moisture contents, weight and diameter of wild blueberries increased, while titratable acidity and firmness decreased over time. Therefore, none of these measures can be used independently to assess fruit maturity. Total soluble solids and anthocyanin contents increased gradually from early to late season and the highest increases in total soluble solids were observed in middle season, while most pigment accumulation in blueberries took place in early and middle season. A significant decrease in acidity and an increase in TSS:TA was observed in middle and late season harvesting. A considerable decrease in acidity and an increase in TSS:TA may be the cause of fruit decay and microbial attack in late season which can affect harvesting efficiency of harvester. The maximum gain in moisture content, expansion in diameter and increase in weight were observed in middle season harvesting, while reduction in moisture, shrinkage of berries and loss of weight occurred in late season. More pre-harvest berry losses were observed in late season and berry detachment occurred due to excessive loss of moisture contents and weight that can affect harvesting efficiency by causing more berry loss and damage due to loosely attached with plants. Blueberries were firmer in early season, due to them being partial ripening, compared to middle and late season. Firmness decreased gradually from early to middle season; then an increase in firmness in late season was the consequence of gumminess, produced by loss of moisture and contraction of diameter. Fruit harvested at too high a maturity can result in decreasing harvesting efficiency due to loosely attached with plants and berries might be susceptible to undesirable off flavors and attack of fruit-decaying organisms, along with short post-harvest life. Similarly, fruit harvested at too low a maturity might be unable to achieve potential ripening flavor and textural qualities due to readily loss of internal water and increased risk of physiological deterioration. Therefore, optimum time to harvest wild blueberries would be in the middle season to ensure high quality blueberries. The increase in anthocyanin contents and total soluble solids were a natural process during the course of ripening blueberries. However, the continued increase in anthocyanin and total soluble solids, even after berries stopped growing at the end of harvest required further examination. These physico-chemical parameters greatly influenced the harvesting efficiency of harvester in late season. The decrease in moisture content, weight and contraction in diameter of blueberries in late season caused more fruit losses due high impact force of the harvester. It is also suggested that time of the day be included (early morning and afternoon harvesting) as an input variable, when dealing with firmness of wild blueberries. Required degree days are extremely important for maturation of crop; thus, in future research, degree days for maturing wild blueberries should be kept in mind, when dealing with time of harvesting. It is also suggested to include sensory evaluations in future studies to investigate the optimum level of physico-chemical characteristics, when dealing with time of harvesting and maturity in wild blueberries.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

This study was designed with an aim to identify the effect of harvesting time on picking performance of wild blueberry harvester and examining the fruit ripening characteristics using digital photography and chemical analysis. Harvesting time was divided into three categories (early, middle and late) and the harvester was operated on different combinations of ground speed (1.2, 1.6 and 2.0 km h^{-1}) and header revolutions (26, 28 and 30 rpm). Based on the results of this study, it can be deduced that fruit losses during harvesting are not only a function of machine operating parameters (ground speed and header rpm) but also due to time of harvesting (season) in wild blueberry fields. Results showed that fruit losses were found to be higher in late season compared to early and middle season emphasizing that early and middle season harvesting could be beneficial in reducing fruit losses. The early season harvesting, regardless of having low berry losses, is not a wise decision due to existing of greener berries (not fully ripened) at that time in fields. The option at which fully ripened, good quality berries and comparable berry losses occurred is middle season harvesting. The economic evaluation between grower's treatment and all other treatment combination at different times of harvesting suggested that the combination 1.2 km h^{-1} and 26 rpm could be the most potential profit driven combination. This treatment combination in early season provided profit ranging $145.70 to $603.22 compared to grower's treatment 1.6 km h^{-1} and 28 rpm. Similarly, the grower's treatment (1.6 km h^{-1} and 28 rpm) was less profitable in middle and late season harvesting ranging $155.27 to $638.33 and $137.72 to $573.96 comparing to treatment combination 1.2 km h^{-1} and 26 rpm, respectively. Results also indicated that ground speed, rpm, season and their higher order interaction were found to be significant for berry losses during mechanical harvesting of selected plots. The results of MMC revealed that a treatment combination of 1.2 km h^{-1} and 26 rpm can serve better in minimizing berry losses compared to all other treatment combinations in early, middle and late season harvesting. The results also showed that higher ground speed in concomitance with higher header rpm resulted in substantial increased fruit losses in each harvesting season but these losses were become more prominent in late season due to over-ripened berries. These over-ripened berries could not withstand the impact force, in spite of facing the same impact force as in early and middle, due to loosely attached with stems suggesting the need to lower the speed and rpm of harvester. Selecting an appropriate combination of ground speed and header rpm is very important to enhance harvesting efficiency by reducing berry losses when dealing with early, middle and late season harvesting.

Results of digital photographic technique to identify blueberry ripening levels and yield at different harvesting times revealed that there was a significant correlation between the percentage of blue pixels and actual fruit yield. The correlation between actual and predicted fruit yield was also highly significant. The absolute measures of RMSE and MAE showed strong correlation between actual and predicted fruit yield. The relative performance measures of coefficient of efficiency and index of agreement further strengthened the model performance. The results indicated that the modified measures were lower than those of the unmodified and modified versions use high standard of model performance and differences between EM and EMP and between dM and dMP express the sensitiveness of model performance to outliers on different harvesting times. The results also indicated that the effect of time of harvesting on blue pixels/wild blueberry yield was significant and blue pixels/blueberry yield increased gradually in early harvesting and reached maximum in late harvesting and then started decreasing in late harvesting. It can be concluded that the digital photography technique is a viable to examine ripened blueberry fruit yield and can be used to estimate ripened fruit yield at different harvesting times. This information could be used for timely harvesting decisions in blueberry fields to optimize productivity.

Results of the present study suggest that physico-chemical composition of wild blueberries, during fruit maturation, was the function of time of harvesting. Total soluble solids, anthocyanin contents, moisture contents, weight and diameter of wild blueberries increased, while titratable acidity and firmness decreased with passage of time. Total soluble solids and anthocyanin contents increased gradually from early to late season and the highest increase in total soluble solids was observed in middle season, while most pigment accumulation in blueberries took place in early and middle season. A significant decrease in acidity and an increase in TSS:TA were noticed in middle and late season harvesting. A considerable decrease in acidity and an increase in TSS:TA may be the cause of fruit decay and microbial attack in late season. The maximum gain in moisture content, expansion in diameter and increase in weight were observed in middle season harvesting, while reduction in moisture, shrinkage of berries and loss of weight occurred in late season. Blueberries were firmer in early season, due to them being partly ripened, compared to middle and late season. Firmness decreased gradually from early to middle season; then an increase in firmness in late season was the consequence of gumminess, produced by loss of moisture and contraction of diameter. Fruit harvested at too high a maturity might be susceptible to undesirable off flavors and attack of fruit-decaying organisms, along with short post-harvest life. Similarly, fruit harvested at too low a maturity might be unable to achieve potential ripening flavor and textural qualities due to readily loss of internal water and increased risk of physiological deterioration. The optimum time to harvest Nova Scotia wild blueberries would be in the middle season, to ensure high quality blueberries. The increase in anthocyanin contents and total soluble solids were a natural process during the course of ripening blueberries. However, the continued increase in anthocyanin and total soluble solids, even after berries stopped growing at the end of harvest required further examination. It is also suggested that time of the day be included (early morning and afternoon harvesting) as an input variable, when dealing with firmness of wild blueberries. Required degree days are extremely important for maturation of crop; thus, in future research, degree days for maturing wild blueberries should be kept in mind, when dealing with time of harvesting. It is also suggested to include sensory evaluations in future studies to investigate the optimum level of physico-chemical characteristics, when dealing with time of harvesting and maturity in wild blueberries.

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APPENDIX 'A'

Table A1. Impact force of the harvester at different treatments.

Treatments	Average tip velocity (m s^{-1})	F_{imp} (N)	F_{imp} (kg)
1.2 × 26	0.7586	809.17	82.48
1.2 × 28	0.7991	852.40	86.89
1.2 × 30	0.8490	905.65	92.32
1.6 × 26	0.7991	852.40	86.89
1.6 × 28	0.7838	836.06	85.22
1.6 × 30	0.8393	895.30	91.26
2.0 × 26	0.9137	974.65	99.35
2.0 × 28	0.7751	826.78	84.28
2.0 × 30	0.8285	883.74	90.09

Table A2. Economic analysis of yield at different treatments in early season.

Treatments	**3000 kg ha^{-1}**	**4000 kg ha^{-1}**	**5000 kg ha^{-1}**	**6000 kg ha^{-1}**	**7000 kg ha^{-1}**	**8000 kg ha^{-1}**	**9000 kg ha^{-1}**	**10000 kg ha^{-1}**	**11000 kg ha^{-1}**
1.2 × 26	The amount ($) gets, when running with 1.2 km h^{-1} and 26 rpm compared to others								
1.2 × 28	135.66	180.88	226.10	271.32	316.54	361.76	406.98	452.20	497.42
1.2 × 30	153.22	204.29	255.36	306.43	357.50	408.58	459.65	510.72	561.79
1.6 × 26	130.13	182.14	234.14	286.14	338.15	390.15	442.15	494.16	546.16
1.6 × 28	145.70	202.89	260.08	317.27	374.46	431.65	488.84	546.03	603.22
1.6 × 30	185.20	255.55	325.91	396.27	466.62	536.98	607.34	677.70	748.05
2.0 × 26	148.62	225.76	302.90	380.04	457.18	534.32	611.46	688.60	765.74
2.0 × 28	163.38	245.45	327.51	409.57	491.63	573.69	655.75	737.81	819.87
2.0 × 30	224.43	326.84	429.25	531.66	634.07	736.48	838.89	941.30	1043.71

Table A3. Economic analysis of yield at different treatments in middle season.

Treatments	**3000 kg ha^{-1}**	**4000 kg ha^{-1}**	**5000 kg ha^{-1}**	**6000 kg ha^{-1}**	**7000 kg ha^{-1}**	**8000 kg ha^{-1}**	**9000 kg ha^{-1}**	**10000 kg ha^{-1}**	**11000 kg ha^{-1}**
1.2 × 26	More amount ($) gets, when running with 1.2 km h^{-1} and 26 rpm compared to others								
1.2 × 28	93.37	124.49	155.61	186.73	217.85	248.98	280.10	311.22	342.34
1.2 × 30	121.30	161.73	202.16	242.59	283.02	323.46	363.89	404.32	444.75
1.6 × 26	136.52	190.65	244.78	298.91	353.04	407.17	461.30	515.44	569.57
1.6 × 28	155.27	215.65	276.04	336.42	396.80	457.18	517.56	577.95	638.33
1.6 × 30	292.53	398.66	504.80	610.93	717.06	823.20	929.33	1035.47	1141.60
2.0 × 26	172.16	257.15	342.14	427.12	512.11	597.10	682.08	767.07	852.06
2.0 × 28	256.35	369.40	482.45	595.50	708.55	821.60	934.65	1047.70	1160.75
2.0 × 30	334.16	473.14	612.13	751.11	890.10	1029.08	1168.07	1307.05	1446.04

Table A4. Economic analysis of yield at different treatments in late season.

Treatments	**3000 kg ha^{-1}**	**4000 kg ha^{-1}**	**5000 kg ha^{-1}**	**6000 kg ha^{-1}**	**7000 kg ha^{-1}**	**8000 kg ha^{-1}**	**9000 kg ha^{-1}**	**10000 kg ha^{-1}**	**11000 kg ha^{-1}**
1.2 × 26	More amount ($) gets, when running with 1.2 km h^{-1} and 26 rpm compared to others								
1.2 × 28	1.99	2.66	3.32	3.99	4.66	5.32	5.99	6.65	7.31
1.2 × 30	85.39	113.85	142.31	170.77	199.23	227.70	256.16	284.62	313.08
1.6 × 26	10.83	23.07	35.31	47.54	59.78	72.01	84.25	96.49	108.72
1.6 × 28	137.72	192.25	246.78	301.31	355.84	410.37	464.90	519.43	573.96
1.6 × 30	235.47	322.59	409.70	496.82	583.93	671.05	758.16	845.28	932.39
2.0 × 26	160.99	242.25	323.52	404.78	486.04	567.31	648.57	729.83	811.09
2.0 × 28	264.33	380.04	495.75	611.46	727.17	842.88	958.59	1074.30	1190.01
2.0 × 30	302.24	430.58	558.93	687.27	815.62	943.96	1072.31	1200.65	1329.00

APPENDIX ‘B’

Table B1. Correlation matrix for Field A.

	MC	Firmness	TSS	TA	Anthocyanin	Diameter
Firmness	-0.76					
TSS	0.45	-0.85				
TA	-0.43	0.85	-0.99			
Anthocyanin	0.46	-0.91	0.93	-0.94		
Diameter	0.84	-0.87	0.79	-0.75	0.69	
Weight	0.87	-0.83	0.69	-0.65	0.61	0.95

Table B2. Correlation matrix for Field B.

	MC	Firmness	TSS	TA	Anthocyanin	Diameter
Firmness	-0.69					
TSS	0.49	-0.82				
TA	-0.39	0.78	-0.99			
Anthocyanin	0.48	-0.88	0.98	-0.98		
Diameter	0.87	-0.75	0.69	-0.59	0.63	
Weight	0.89	-0.82	0.70	-0.61	0.68	0.98