CANADIAN AGRICULTURAL ADAPTATION PROGRAM (CAAP)

AGRI-FUTURES NOVA SCOTIA

Progress Report (July, 2012 - September, 2013)

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Improving Harvesting Efficiency of Wild Blueberry Harvester Using Precision Agriculture Technologies to Increase Farm Profitability

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Project Overview and Challenges:

Northeastern North America is the world's leading producer of wild blueberry with over 86,000 ha under management and producing 112 million kg of fruit valued at $470 million annually (Yarborough, 2009). Currently, the mechanically harvested blueberry area is more than 80 percent of the total wild blueberry area in Canada and only the fields in rough terrain are still hand raked (PMRA, 2005). In last two decades, increased management practices of wild blueberry fields using more fertilizers, pesticides and selective herbicides have resulted in healthy tall plants, high plant density, tall weeds and significant increase in fruit yield. Currently, there are 15 to 25% fruit yield losses during harvesting with existing commercial blueberry harvester due to changes in crop conditions and rough terrain. In other words, about 1/5th of the total revenue from wild blueberry production system is dumped in the fields each year because of the harvesting losses. This is an issue that has concerned recently due to changes in field and crop conditions. In a fact sheet published by Wild Blueberry Producers Association of Nova Scotia, it is reported that there are over 1000 wild blueberry producer with over 33,000 acres in production in Nova Scotia only. Each year wild blueberry industry contributes over $35,500,000 (5 years average) to the provincial economy (WBPANS, 2010). The economic importance of blueberries emphasizes the need to identify the factors resulting in harvesting losses in order to improve blueberry harvester efficiency. Increased harvesting efficiency of the harvester could reduce fruit losses and contribute $7,100,000 to NS economy only (WBPANS, 2010) and $31,200,000 to Atlantic provinces and Quebec every year.

Wild blueberry crop has been harvested with a hand rake that was originally designed as a cranberry scoop for the past 100 years. The increase in fruit yields over last few decades, shortage of labor and consequently the increase of wages have increased the demand for mechanized harvesting (Yarbrough, 1992). Challenges in developing a mechanical harvester have included: uneven field topography, low plant height and the presence of many weeds and other debris. Although research on the development of the mechanical harvester started in early 1950s, a viable mechanical harvester was not produced until the 1980s (Hall et al., 1983). After various stages of development, the hollow reel raking mechanism was developed by Gray (1969) as a continuation of the rotating picking head. This mechanism has served as the basis of harvesters today. The picking efficiency of this machine was 80 to 85% of the berries on the vine (Soule et al., 1969) although it could only pick 30 to 35% of the fields due to the limitations in field terrain. John MacAulay from Nova Scotia Agricultural College started to improve picking efficiency of the harvester in 1974 and found that the performance of the head could be greatly improved by replacing the garden tractor with a small farm tractor and by adding a support frame along one side of the tractor. Doug Bragg Enterprises Ltd. (DBE), Collingwood, Nova Scotia achieved a great success by further developing the Chisholm-Ryder machine. The hydraulic control systems for the head, head rotational speed, speed control of belts and conveyors, and the width of the picking head were all improved by DBE (Malay, 2000). Hall et al. (1983) estimated that the Bragg blueberry harvester attains 68% (in weedy fields) to 75% (smooth weed free fields) of total berry yields which is similar to manual raking.

Dr. Zaman and his team at Dalhousie Agricultural Campus developed innovative cost-effective precision agriculture (PA) technologies to measure and map soil variability (Farooque et al., 2012), topographic features (Zaman et al., 2010b), fruit yield (Zaman et al., 2010a and Chang et al., 2012), VRT for spot-application of pesticide and fertilizer (Zaman et al., 2011) in real-time within wild blueberry fields. PA technologies provide the tools that allow us to identify factors affecting harvesting efficiency in variable fields. Maps of fruit yield, quality, and canopies along with topography, soil characteristics, and bare spots are the basis for quantifying the harvest losses in wild blueberry fields. After this information has been mapped and the required sources of losses determined, feasible technology and equipment is required to modify the existing commercial harvester to increase berry picking efficiency. PA techniques generate vast quantities of information, but to be useful and profitable to the wild blueberry industry (manufacturer and producer), the most useful information must be gleaned, organized, and presented in a manner which they can understand and utilize in increasing picking efficiency of berries to maximize profit margins.

The **objectives** of the project were:

1. Develop sensor fusion system (hardware and software) to incorporate into a blueberry harvester to map variations in plant sizes, field conditions on-the-go in wild blueberry fields.
2. Characterize and quantify the variability in soil properties, topographic features, plant size and fruit yield to develop productivity zone.
3. Identify the factors affecting harvesting efficiency of wild blueberry harvester equipped with forward head rotation and reverse head rotation.

Activities from July, 2012 to September, 2013

Hiring of Highly Qualified Personnel:

a) **PhD student:** Support has already been received for one PhD student stipend for three years through NSERC-IPS program. The PhD student has already been recruited and he is working on the proposed research project to quantify and characterize sources of harvest losses that will help to improve harvester berry picking efficiency using innovative precision agriculture technologies and mathematical modeling procedures.

b) **Summer Student:** Support for a summer student ($6500/year) attained through industry and NSERC-USRA and IRAP for three years. The summer student will help in data collection to improve harvester berry picking efficiency using innovative precision agriculture technologies.

c) **Postdoctoral Fellow**. The post-doctoral hired in April and he is assisting (100% of his time) in developing and testing the innovative integrated harvesting system (hardware and software) at commercial wild blueberry fields, collecting the soil, crop and machine data during growing season, setting up GIS databases, and processing and analyzing data to generate maps, reports, scientific papers, aid in the daily supervision of graduate students and recommendations for farmers and industry in a given area. All these services is being generating massive amounts of data, which requires skilled personnel with knowledge and experience to interpret, glean, organize, and present data in a manner which farmers and machinery manufacturer can understand and utilize in improving machine efficiency. Mid-year and annual progress reports are being delivered to the sponsors and cooperators. Manuscripts are being developed and published in prestigious scientific national and international journals.

d) **Technical/ Professional Assistant:** Technical support is vital to the success of this program. The proposed research requires extensive data collection, work with machinery, and travel to remote sites. The research assistant has already been hired to operate machines and provide a continuous knowledge base for graduate students on the location of sites and the operation of sensors, data loggers and other forms of technical equipment. The research assistant spends 100% of his time on this project. He is playing a vital role in the training and management of students and providing the wide range of support necessary for the smooth operation of the research program.

Development and Evaluation of Sensor Fusion System

An integrated automated sensing system including ultrasonic sensor, digital color camera, slope sensor, real-time kinematics global positioning system (RTK-GPS), custom image processing software and laptop computer was developed. The system was incorporated into a blueberry harvester (Fig. 1).

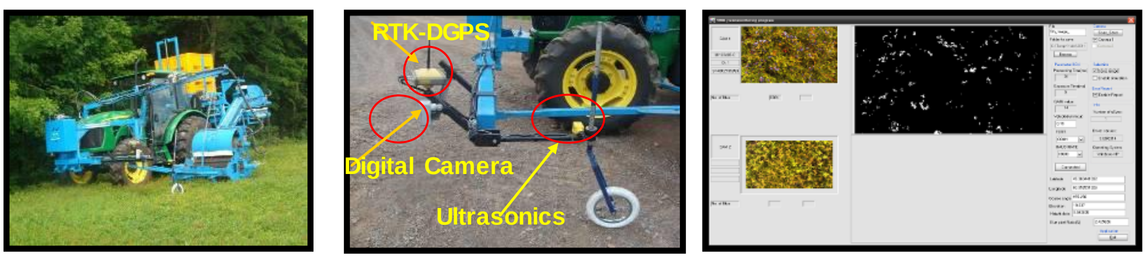

Figure 1: Sensor fusion system to map plant height, slope, elevation and fruit yield in real-time along with custom software.

The sensors mounted on the wild blueberry harvester were calibrated with the actual data prior to real-time performance. The ultrasonic sensor, digital color camera, slope sensor readings were significantly correlated with manually measured plant height, fruit yield and slope (R^2 = 0.91 to 0.95; $P < 0.001$) suggesting that the sensor fusion system was accurate enough to map plant height, fruit yield and topographic features in real-time.

The developed system was tested and evaluated in selected wild blueberry fields Frankweb, Nova Scotia (4.10 ha); Londonderry, Nova Scotia (3.2 ha); Small Scott, Nova Scotia (1.6 ha) and Tracadie, New Brunswick (1.9 ha) to map plant height, slope, elevation and fruit yield in real-time. Customized Windows-based software on a laptop computer was developed to merge the plant height, elevation, slope, and fruit yield data with corresponding RTK-GPS spatial coordinates through serial ports and save these data to the fixed disk as a Microsoft Access file.

Surveys were conducted to measure and map crop parameters and topographic features during July, 2012, and fruit yield was measured and mapped during harvesting season (August to mid September, 2012) in selected wild blueberry fields (Fig. 2). The integrated system took more than 30,000 data points for Small Scott and Tracadie fields; and more than 55,000 sampling points for Frankweb and Londonderry fields to estimate plant height, slope, elevation and fruit yield in real-time. Due to space constraint results of Cooper site are presented here.

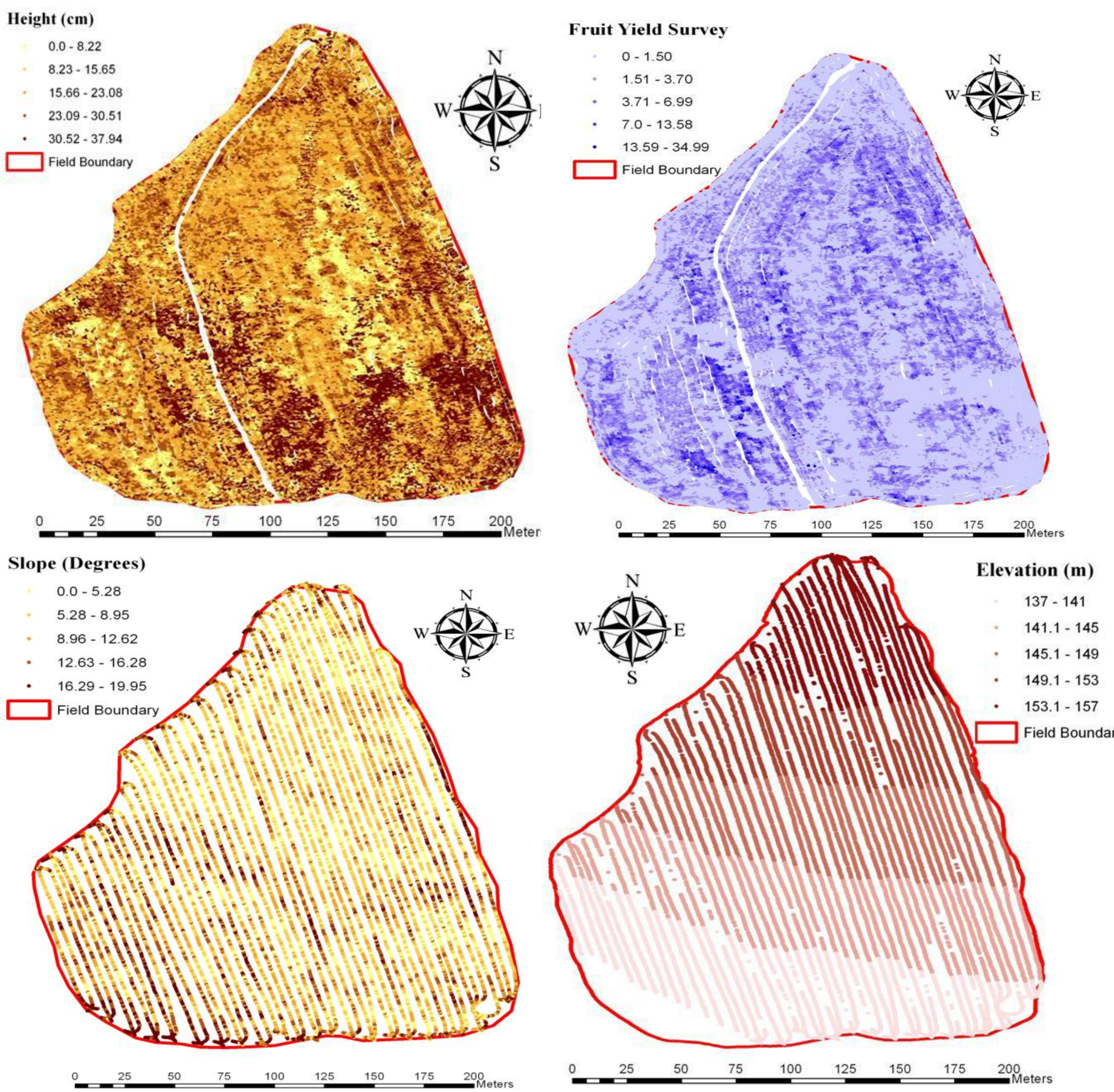

Figure 2: Raw data maps of fruit yield, plant height, slope and elevation obtained from sensor fusion system.

The μEye camera mounted on commercial wild blueberry harvester estimated fruit yield of 10,232 kg, while the actual yield collected in the harvester bin weighed at 9,100 kg for Cooper site suggesting 11.07% loss of berries during harvesting. The digital color camera indicated 8.74% pre-harvest loss of berries for Small Scott site. These results suggested that there is need to conduct research on the harvester picking efficiency in different yield (low, medium and high) areas to quantify the wild blueberry fruit losses during harvesting.

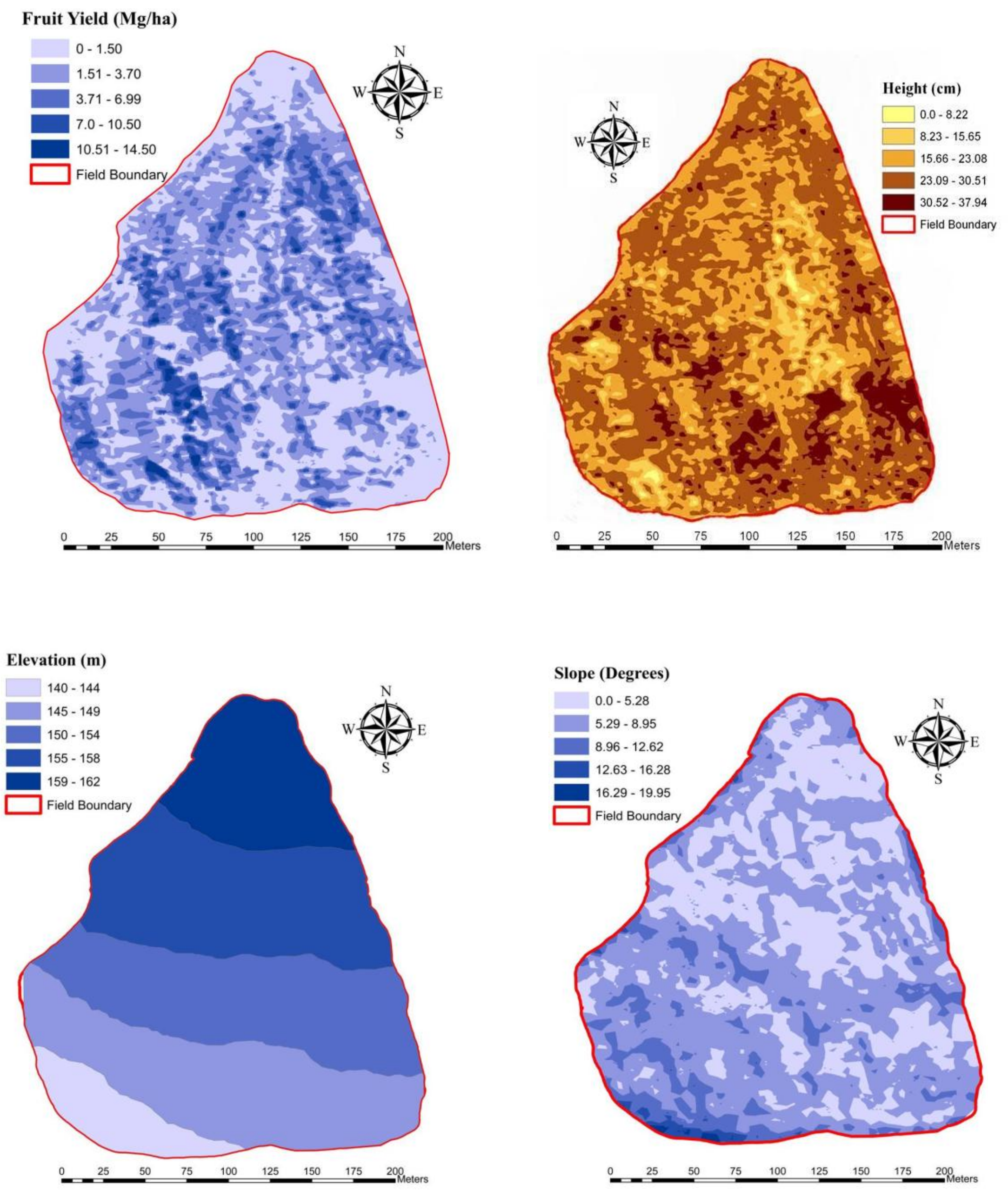

Figure 3: Kriged maps of fruit yield, plant height, elevation and slope data for Cooper site using sensor fusion system.

GIS was combined with the geo-statistics to generate detailed maps in ArcGIS 10 to analyze the spatial variability in measured parameters (Fig. 3). The characterization and quantification of the soil properties, topography (slope and elevation), fruit yield and plant parameters allows to generate zones, to identify if there is any effect of these parameters on the harvesting efficiency of the harvester. Variations in soil properties, plant characteristics and topographic features corresponding with the variability in fruit yield will provide strong evidence in determining the factors affecting localized yield and increasing yield losses during harvesting.

The map comparison of plant height with fruit yield suggested that in general fruit yield was lower in the areas where the plant height was higher (Fig. 3). The negative but non-significant relationship (r = -0.20) between the fruit yield and plant height also supported the correlation identified by the maps. The visual inspections also revealed the lower yield in the areas with more plant height suggesting more vegetative growth. The map analysis indicated the higher yield and lower plant height in low lying areas (mild slope) and vice versa (Fig. 3). The substantial variation in mapped parameters and presence of bare spots/weeds within blueberry fields suggested that these parameters could be playing a significant role in wild blueberry fruit losses during harvesting.

Evaluation of Berry Picking Performance Efficiency of Blueberry harvester

Four wild blueberry fields were selected (Frankweb, Nova Scotia; Londonderry, Nova Scotia; Small Scott, Nova Scotia and Tracadie, New Brunswick) to evaluate the berry picking efficiency of the commercial wild blueberry harvester. The experimental plots were set up in selected wild blueberry fields based on variations in slope (flat field, mild and steep slope), plant height (low, medium high) and fruit yield (low, average and high), to quantify the harvester berry picking losses. The field boundary, bare spots, weeds and yield plots were mapped with RTK-GPS (Fig. 4).

Eighty one experimental plots (0.91 x 3 m, same width as harvester head width) were randomly selected throughout the selected fields. The complete randomized block design was used for three combination of ground speed i.e. 0.75 mph, 1.0 mph and 1.25 mph, and head rotational speeds i.e. 26 rpm, 28 rpm and 30 rpm to collect fruit yield loss data in selected plots.

The total fruit yield from the each plot was collected by attaching a bucket to the harvester conveyer. Data for three types of losses were collected for the harvested plots i.e. yield loss through blower, un-harvested berries on the plant and berries knocked onto the ground due to the impact of the harvester head. The purpose of calculating these losses was to assess the picking efficiency of the commercial wild blueberry harvester and to find a suitable combination with minimum yield losses. This information would help to modify harvester components to improve berry picking efficiency (Fig. 5).

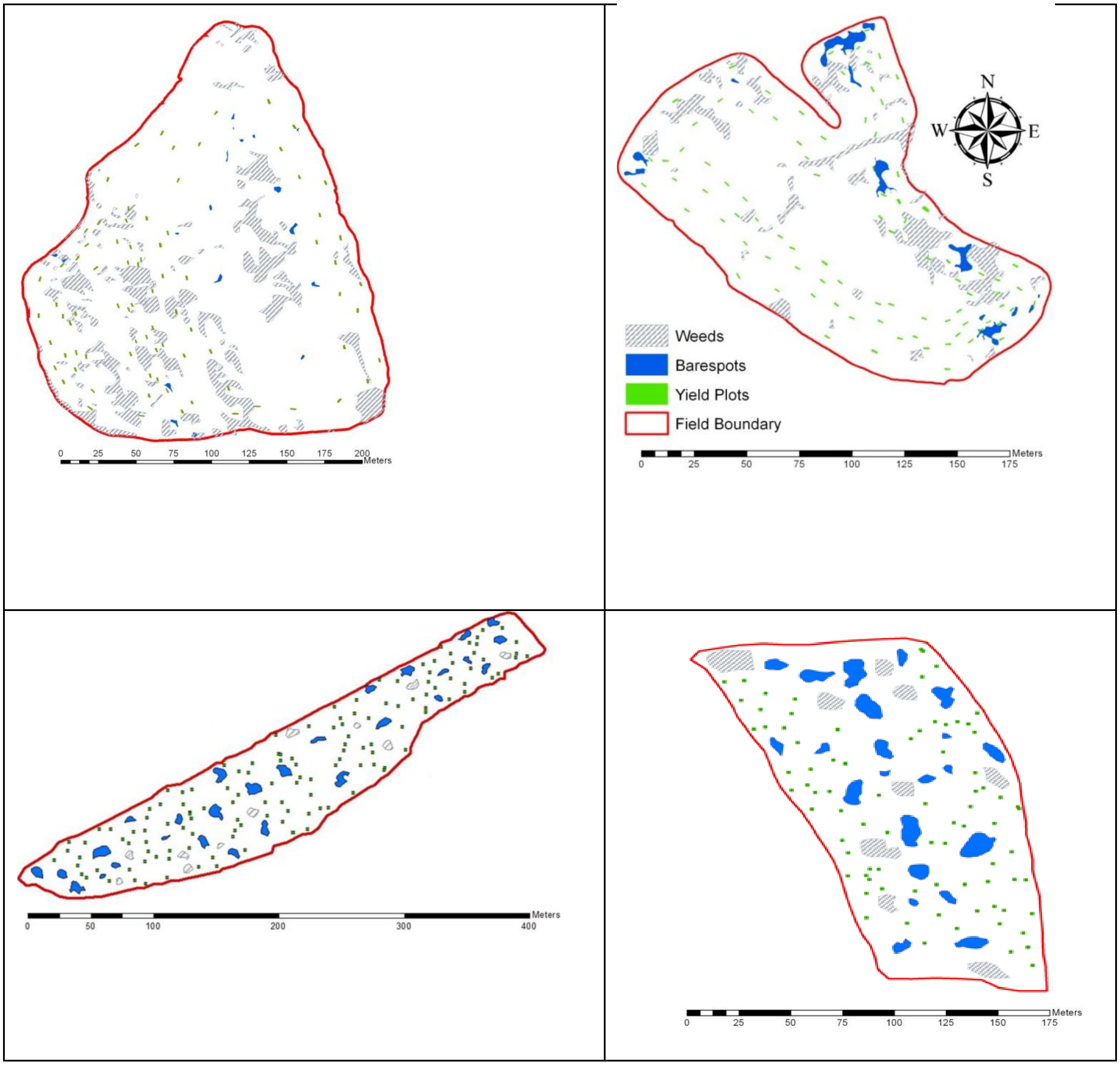

Figure 4: Layouts of selected wild blueberry fields (a) Cooper site (b) Small Scott site (c) Tracadie site and (d) Frankweb site

Five plant height, plant density, stem diameter, fruit diameter were recorded using a ruler to examine the impact of measured parameters on the picking efficiency of the harvester head at different ground speeds and header revolutions. Plant parameter readings were recorded using a 15 x 15 cm quadrant from each plot. The forward and reverse picking heads were compared side by side to examine the harvesting efficiency of the both heads.

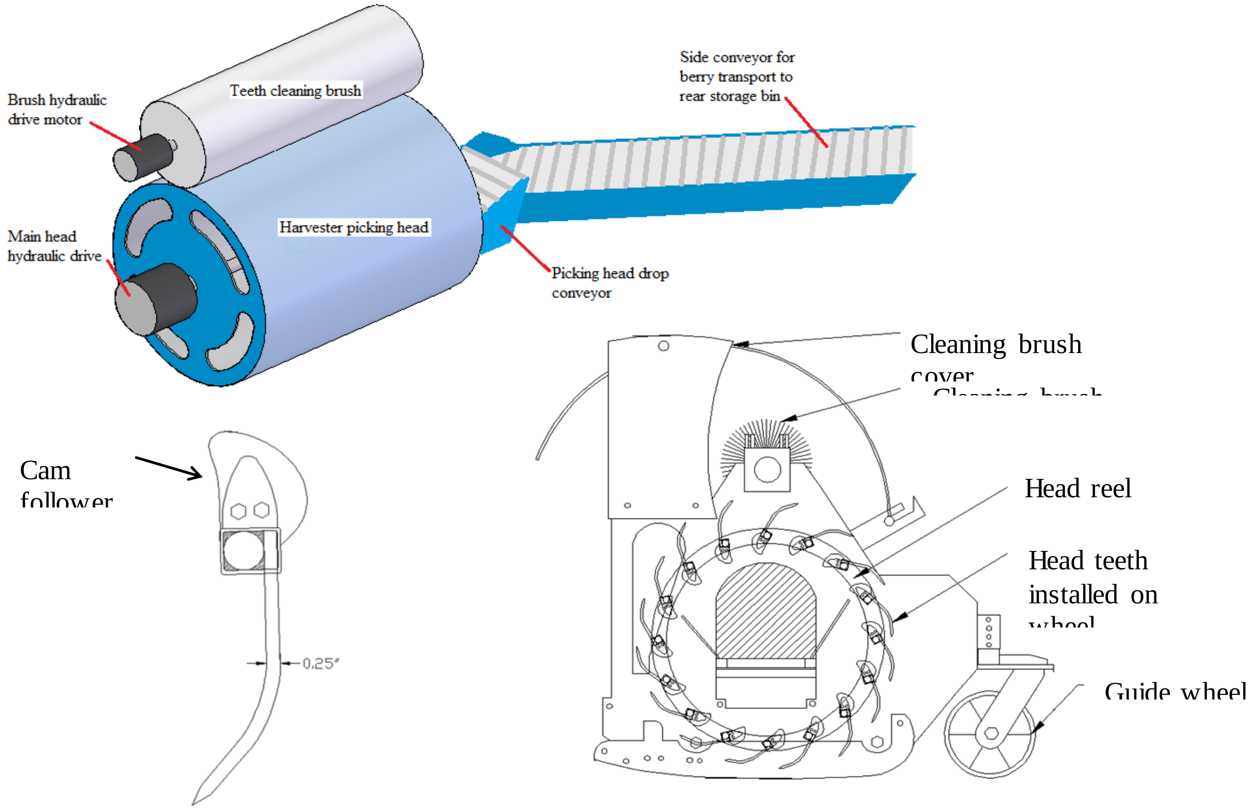

Figure 4: Berries dropped over the harvester strip after being picked by the harvester head during harvesting in selected sites.

The data collected for fruit losses was analyzed using statatistcal; geo-statistical, bio-systems modeling and mapping tools to calculate the fruit losses at various combinations of ground speed and revolutions and to identify the factors responsible for losses.

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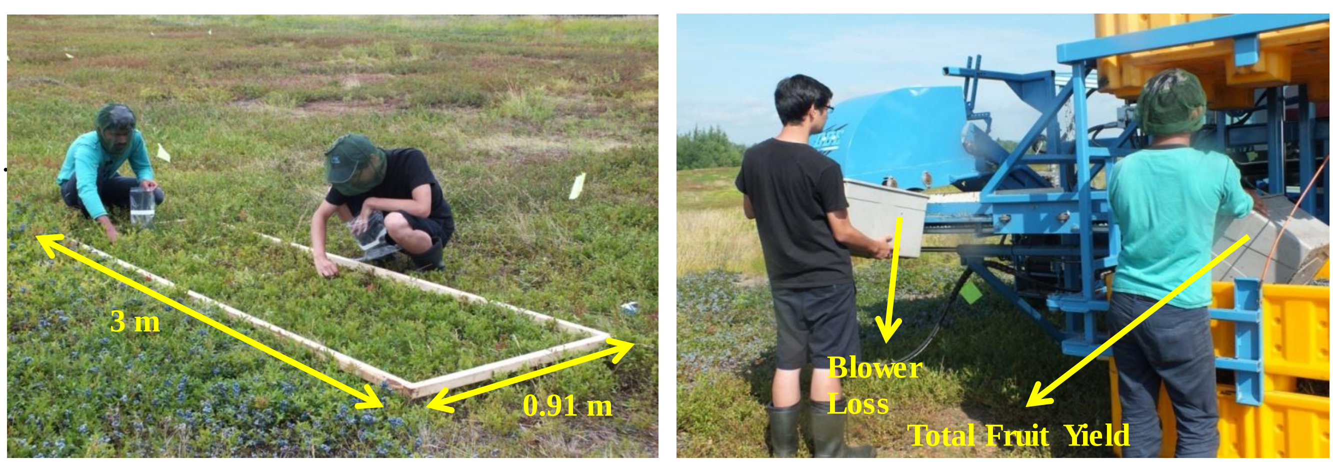
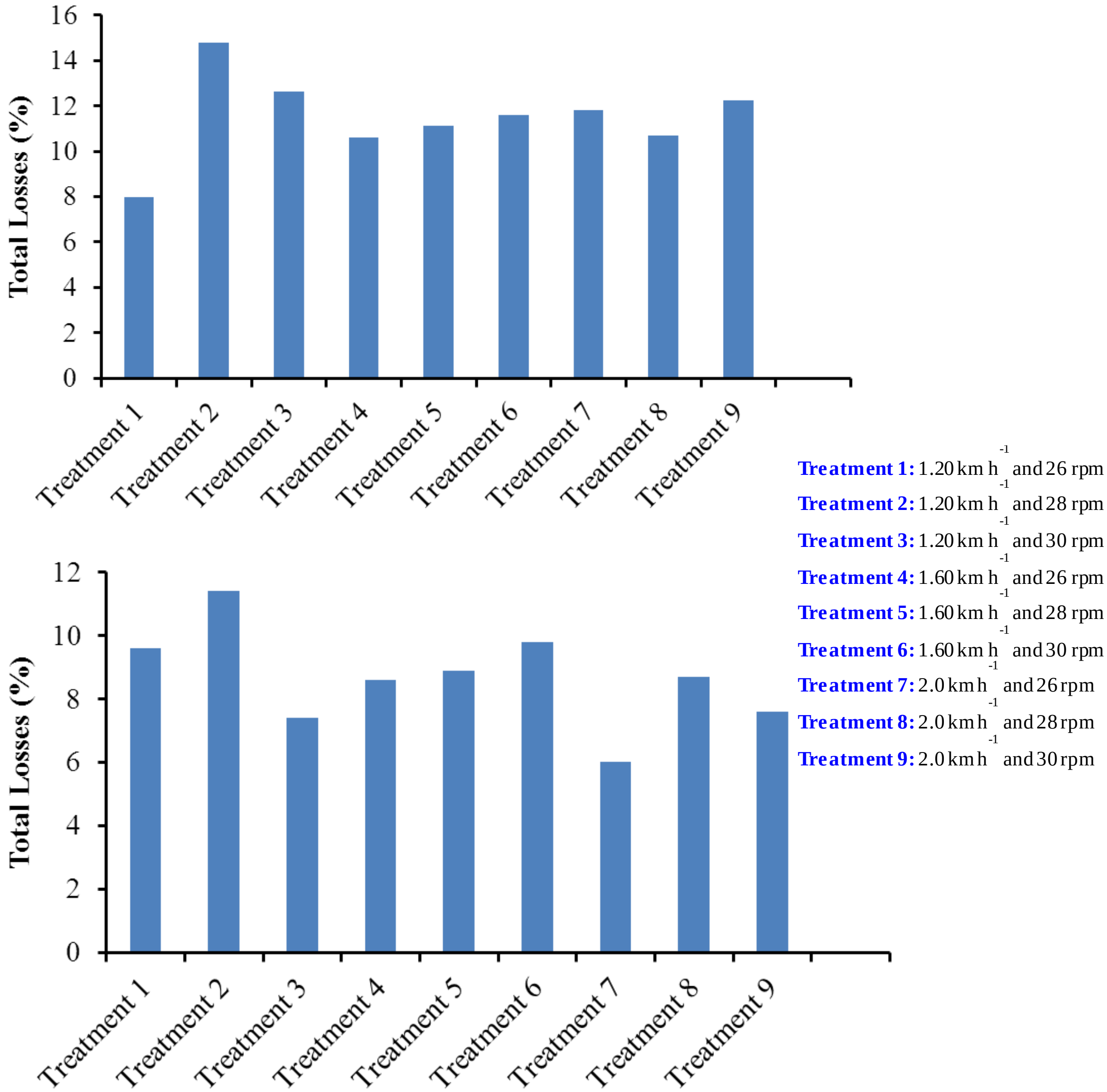


Figure 5: (a) Manual collection of losses on the ground and un-harvested berries on the plants; (b) Collection of fruit losses through blower and total fruit yield from the harvested plot.

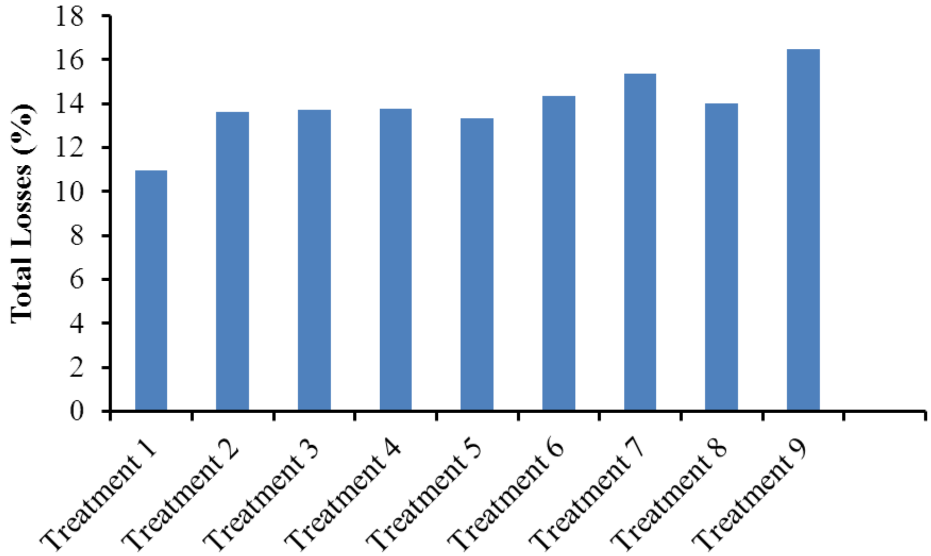
The results of this study suggest that the pre-harvest fruit losses are found to be higher during the late season suggesting that early season harvesting could be helpful in reducing pre-harvest fruit losses. Results indicate that fruit losses during harvesting are highly variable within selected fields. The major portion of the fruit losses during harvesting is on the ground when compared with the un-harvested berries on the plants and losses through blower. Fruit loss during harvesting is a linear function of the fruit yield, as fruit yield increases the fruit losses increases and vice versa. Based on the ANOVA results it can be concluded that ground speed, header rpm and their interaction can cause significant differences in the picking efficiency of the wild blueberry harvester (Figs 6 & 7).

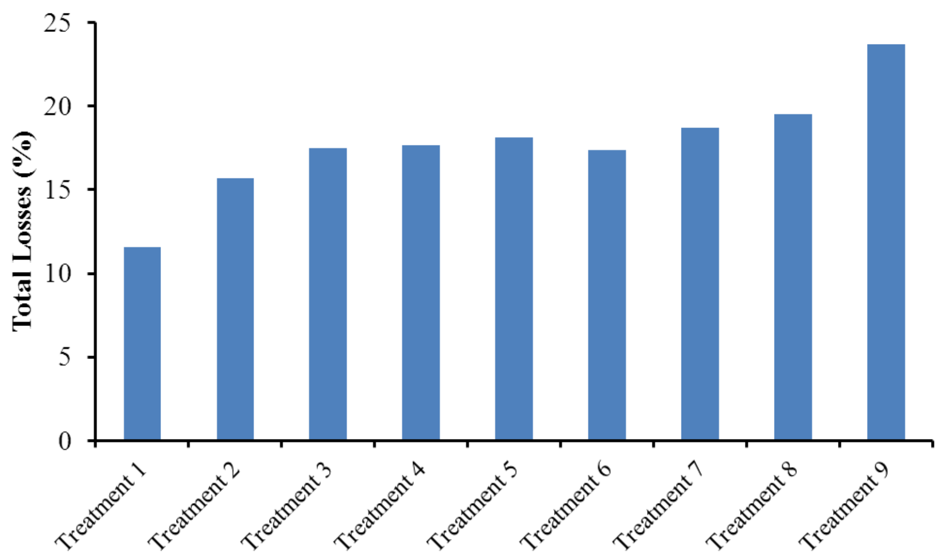


Means with no letter shared are significantly different at $p = 0.05$.

Figure 6. Mean comparison for total fruit losses (%) at different treatment combination for (a) Cooper site, and (b) Small Scott site.

The results of means comparison showed a treatment combination of 1.2 km h^{-1} and 26 rpm can result in significantly lower losses as compare to higher ground speed and header rpm in wild blueberry fields with yield over 3500 kg ha^{-1}. In low yielding fields (<3500 kg ha^{-1}) a combination of 2.0 km h^{-1} and 26 rpm can do a better job to increase the berry picking efficiency of the commercial wild blueberry harvester. Other factors including operator skills, field conditions, time of harvesting, weather conditions, bare spots and weed coverage, crop maturity, crop characteristics and improper maintenance of the harvester can change the picking efficiency and berry recovery of the harvester. By choosing an ideal combination of ground speed and header rpm can minimize the fruit losses to increase farm profitability.





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

Figure 7. Mean comparison for total fruit losses (%) at different treatment combination for (a) Tracadie site, and (b) Frankweb site.

Benefits to the Blueberry Industry

The research project has the potential to improve the competitiveness, and profitability of the blueberry industry, reduce the environmental impact of current wild blueberry production practices, and enhance the long-term sustainability of the industry. Through the development of an integrated harvesting program, blueberry producers will have the resources available to make better and efficient harvesting schedule. The improved blueberry harvester will increase fruit yield, and also increase farm profitability. This increased productivity is of paramount importance with an escalating demand for wild blueberries, the need to remain competitive with the bilberry and cultivated blueberry industries (i.e., northern and southern highbush and rabbiteye industries).

Communication Plan

The communication plan for the project involves dissemination of results at the scientific community, industry specialists, and producer level. We have already published one manuscript in a prestigious international scientific peer reviewed journal and another manuscript is under review. We are in the process to submit one more paper in scientific peer reviewed journal of the ASBAE. Significant results were presented in ASABE annual meeting and International Precision Agriculture Conference. In addition, results from the project will be posted on the Wild Blueberry Information Network and Wild Blueberry Precision Research Program websites. We provided reports to Doug Bragg Enterprises on the research. Results and updates are being made available to producers in Atlantic Canada through the participation in wild blueberry producer meetings (e.g., WBPANS) and field days, and publication of producer newsletters and bulletins. We are training four graduate students, one post-doctoral fellow, a research assistant to develop innovative, cost-effective and viable harvesting technologies.

Research progress meetings within the Wild Blueberry Precision Research Program occur on a bi-weekly basis. During these meetings, the progress of the various experiments is being monitored and discussed. The research staff, and students involved in the research activities are present and attempts are being made to facilitate constructive criticism, and enhance the quality of research being conducted. The research staff also meets regularly with the industry partners involved to discuss the progress of the experiments and dissemination of results.

Intended Benefits

Resource optimization, production sustainability and yield enhancement are all critical research priorities to the blueberry industry. It is anticipated that the project results will have a positive impact on the rural economy and employment. Wild blueberries are the most important commodity in Northeastern North America with over 86,000 ha under management, producing

112 million kg of fruit valued at $412 million annually. The research, producer awareness, and training components contained within the project will result in the development of a more efficient, productive, and sustainable production system resulting in the continued development of a more profitable Canadian blueberry industry. This will in turn continue to enhance the rural economy, increase employment opportunities, and expand the marketing opportunities for wild blueberry production.

The research project will address these research priorities through the development of an integrated program for improving harvesting efficiency of commercial harvester. The development of innovative techniques will increase wild blueberry fruit yield.

Project Summary

The project consists of a combination of research and extension activities that are structured around developing/adopting the technologies to increase wild blueberry production. The collaborators for this project consist of the Doug Bragg Enterprises, Wild Blueberry Producers Association of Nova Scotia, the Precision Agriculture Research Program Dalhousie Agricultural Campus, Dalhousie University, and University of Florida. The objectives of the project continue to be to *develop and evaluate technologies to improve berry picking efficiency of commercial wild blueberry harvest*. The combination of research and technology transfer activities situated within the project are in the process of resulting in the continued development of more efficient, sustainable, and environmentally friendly harvesting technologies, the continued training of wild blueberry producers and industry personnel, and a more competitive wild blueberry industry.

Acknowledgements

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