RESEARCH REPORT

2007 - 2017

PRECISION AGRICULTURE TECHNOLOGIES:

Measure, Analyze, Take Action for Sustainable Smart Farming

DALHOUSIE UNIVERSITY 1818 2018

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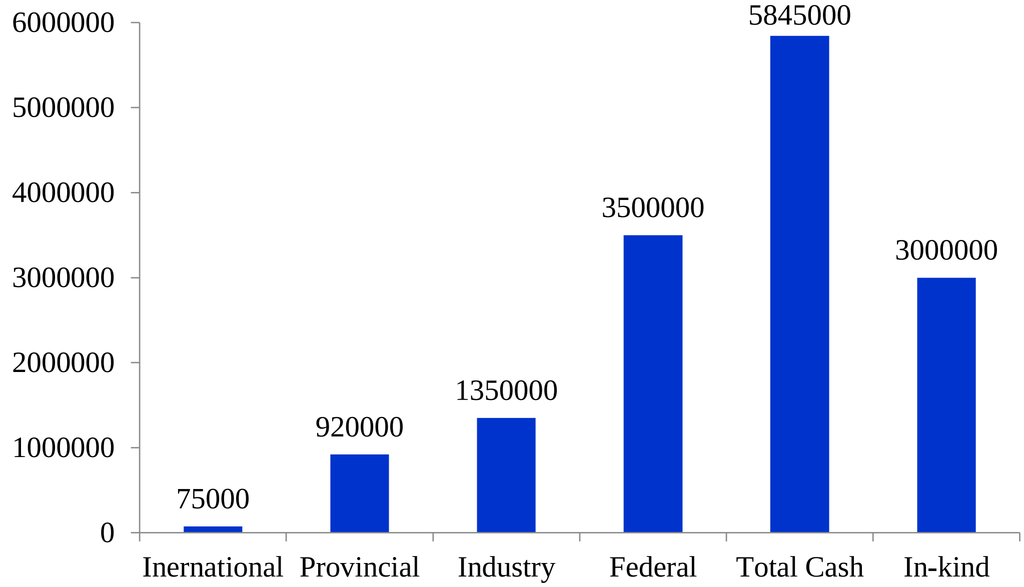
Precision Agriculture Research Program – Brief History

The Dal-AC is a comprehensive, tight-knit Faculty of Agricultural Sciences backed by strong programs in engineering, environmental sciences, plant sciences, food sciences, bioveterinary sciences, basic sciences, business management, social sciences, animal sciences and other technical programs. The programs are well integrated to promote education, basic and applied research and extension for agriculture and rural development.

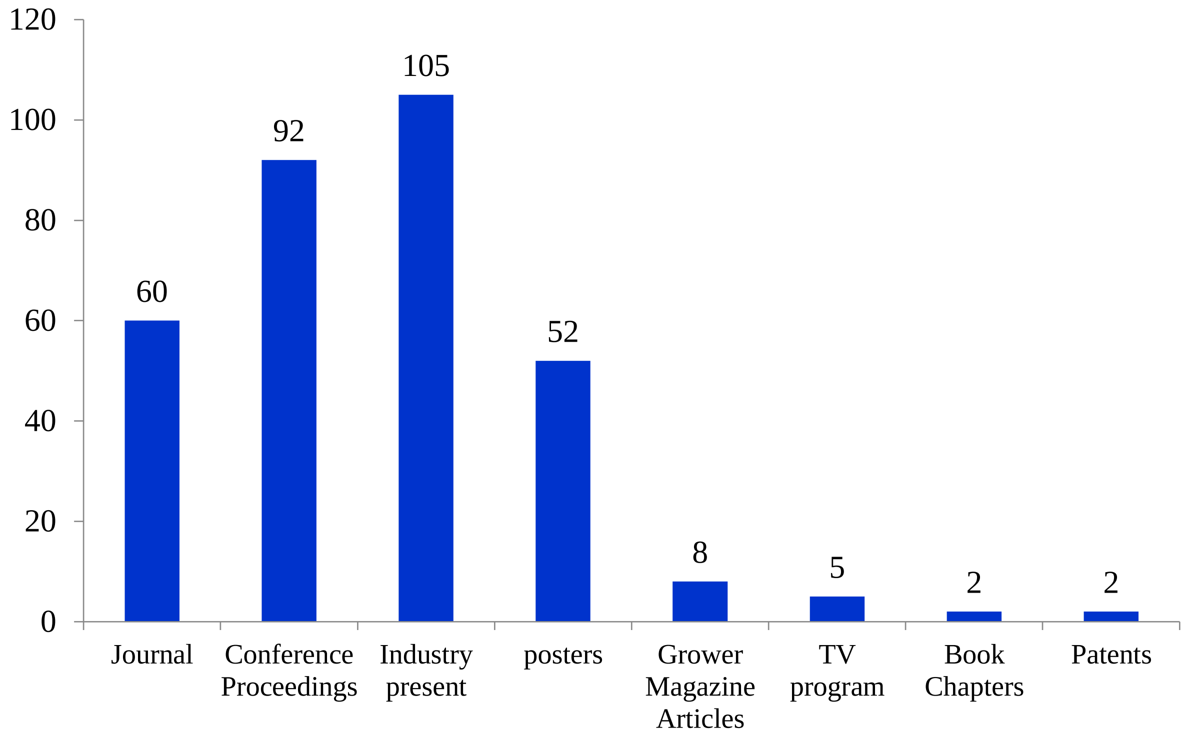
In 2007, Dr. Qamar Zaman established world-class Precision Agriculture Research Program (PARP) with an aim to automate the existing agricultural machinery for wild blueberry to substantially reduce the usage of agriculture inputs, improve land stewardship, increase profitability of the blueberry industry and enhance the sustainability of rural life in Atlantic Canada. This program have been extremely successful in securing research grants *(~**8.0 million dollars***) from the provincial and federal funding agencies, and industry. These grants have allowed this research team to establish state-of – the-art facilities for PA systems research.



Funding (CAD) from government and industry sources during last ten years

PA team is one of the pioneers in the field of PA and has invented cost-effective automated variable rate (VR) technologies for real-time spot application of pesticides and fertilizers. The team had two patents (*US Patent #* 8488874 B2 *and Canadian Patent #* 2740503 C) for the invention of "Variable Rate Sprayer System and Method of Variably Applying Agrochemicals". These innovative PA systems are affordable, reliable and user friendly and once implemented in North America are expected to significantly reduce agrochemical usage *(60-80% herbicide; 20-40% fungicide; 30-40% fertilizer),* as well as, increasing farm profitability *(~ 12 million dollars in NS alone)* and minimizing environmental impacts. PARP has been providing a number of economic benefits for Atlantic Canada including job creation *(industry research chairs, post-docs, research associates, graduate/undergraduate students)* and anticipated increases in private sector employment that would result from the development of new, value-added industries in the region. In 2012, the team actively initiated a collaborative research program to develop innovative harvesting technologies for Atlantic Canada to increase harvestable fruit yield. These technologies would allow innovative harvesting techniques to increase harvestable berry yield and quality, and will ultimately lead to a more sustainable wild blueberry industry in North America. The team was successful in attracting research grants for precision harvesting research programs from provincial and federal government funding agencies, in collaboration with industry *(Doug Bragg Enterprises and Wild Blueberry Producers' Associations in Atlantic Canada)* for five years. The preliminary results showed up to 6% increase in berry recovery using PA technologies, increasing farm profitability of NS farmers. Increased harvesting efficiency of the harvester *(say 5% only)* with no additional expenses contributes $5.5 million to the NS economy only and $31 million to Atlantic Provinces and Quebec every year.

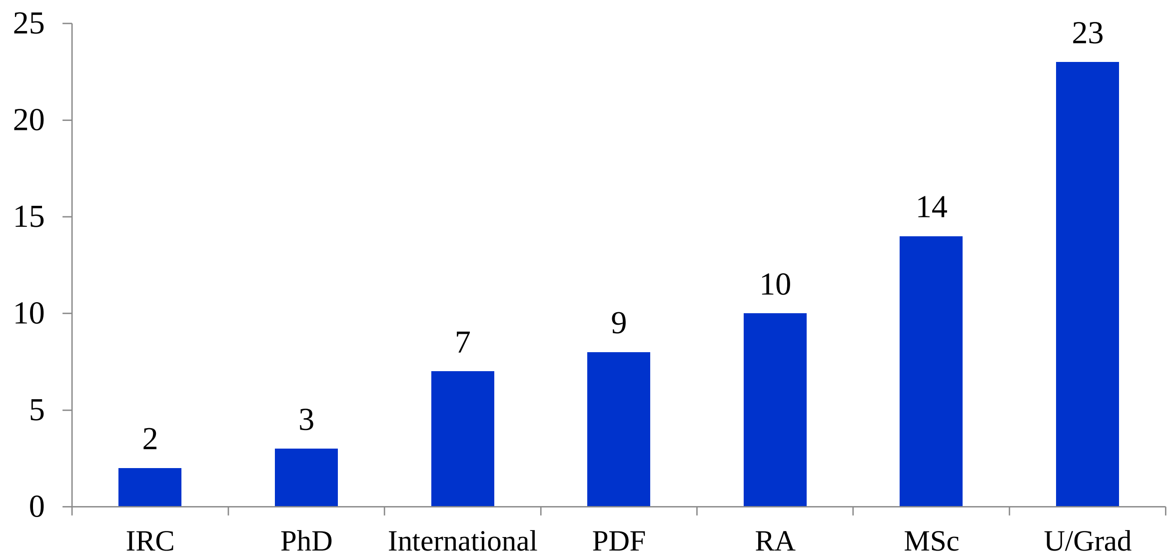
PA team has been very active in the technology transfer process presenting his results regional, national and international meetings and industry presentations and demonstrations throughout Atlantic Canada and Quebec.



Outreach/Technology transfer activities during last ten years

Over the last ten years, several HQPs (*undergraduate and graduate students, Industry research chairs, post-doctoral fellows, research assistants and international researchers*) were trained at the PA research laboratory. The training philosophy adopted constitutes hands-on-direct mentorship and hands-off with close supervision. All HQPs were provided an opportunity to apply their knowledge to the development of innovative PA systems to improve crop productivity and reduce environmental risks. HQPs are trained to publish research results in peer-reviewed scientific journals and also to present in regional, national and international conferences. HQPs are exposed to a wide variety of biological and engineering principles, basic scientific methods, and, production practices that are both specific to wild blueberries but also broadly applicable to other horticultural crops to prepare them for future employment opportunities including positions in academia, extension, research, industry, management, and private business in Canada.

Dr. Zaman has established ties with several North American, European and Asian academic institutions. He developed partnership with a research group to work on PA technologies for blueberries including researchers from various United States universities. These collaborations increased the ability to contribute to other research programs institutionally, regionally, nationally and internationally. One of his international collaborators Dr. Arnold Schumann, Professor, University of Florida is an adjunct professor in the Faculty of Agriculture, Dalhousie University. Dr. Schumann has been serving as a supervisory committee member for graduate students and is also actively involved in PA research projects.



HQPs trained at Precision Agriculture Research Program in last ten years

The PARP's contribution, in conformity with its concept, enlarged industrial scope, attitude and canvas of academic activity, has magnified several folds since its establishment. The strong ties of PA research team with government institutes (*Agriculture and Agri-Food Canada; Department of Agriculture and Aquaculture, NB; Department of Agriculture, Prince Edward Island; Natural Sciences and Engineering Research Council of Canada; NS Department of Agriculture; Mitacs; ACOA; Federation of Agriculture; Soil and Crop Improvement Association, NB; NS and NB Institute of Agrologists*) and industry (*Oxford Frozen Foods Limited, NS, Doug Bragg Enterprises, NS, Jasper Wyman's of PEI, McCain's group, New Brunswick, Wild Blueberry Producers Associations, NS, P.E.I., NB., NF, QC, Maine, NB Potato Board; Fruit Growers' association NS, Green Diamond, John Deere, Case IH, Chemical Containers, Florida, USA, Ag-Tronix, Inc, USA and Croplife- Atlantic Fertilizer Council, Canada*; *SkySquirrel Technologies Inc. Halifax NS*) will provide opportunities to receive research grants to develop PA technologies for different cropping systems in Atlantic Canada. The PARP will provide a number of economic benefits for Atlantic Canada including job creation and anticipated increases in private sector employment that would result from the development of new, value-added industries in the region.

1. Highly Qualified Personnel Training/Supervision

The HQPs are the foundation of research program. Dr. Zaman's HQPs *(undergraduate and graduate students, post-doctoral fellows, research assistants and international researchers)* are exposed to inter-disciplinary research, as my collaborators include colleagues from engineering, soils, water, agronomy, energy and atmospheric science disciplines. All HQPs were provided an opportunity to apply their knowledge to the development of innovative precision agriculture systems to improve crop productivity and reduce environmental risks. Students and post-doctoral fellows are being trained to design, analyze, and publish experimental results in scientific and technical publications. HQPs are also trained to publish research results in peer-reviewed scientific journals and also to present in regional, national and international conferences, growers' meetings, and farmers' field days. As an example, one of my graduate students published thirteen articles in peer-reviewed journals as an author and co-author and over twenty in national/international conference proceedings in past five years during his master and PhD program under my supervision. They have the opportunity to interact with researchers from multiple post-secondary institutions and various industrial partners including Doug Bragg Enterprises Ltd., Oxford Frozen Foods Group, and the Wild Blueberry Producers Associations. HQPs are exposed to a wide variety of biological and engineering principles, and, production practices that are both specific to blueberries but also broadly applicable to other horticultural crops to prepare them for future employment opportunities including positions in academia, extension, research, industry, management, and private business in Canada.

All the previous PDFs have gone on to successful faculty appointments in Canada, Asia, and Europe. During the past 11 years, nine of graduate students have completed their programs (M. Sc) under Dr. Zaman supervision. I supervised nine post-doc fellows and several research assistants in my research program. All have progressed into leadership roles. For the 15 M.Sc. students: three have successfully completed PhD programs *(T. Esau and A. Farooque being awarded NSERC-IPS);* four have moved into federal/provincial government/private sector positions. Producing 'degree holders' should not be the sole function of a university. During the 11 years, six international visiting researchers from Europe, Asia, *a*nd Middle East*)* completed research projects under his supervision. I assisted in creating a McCain Potato Research Chair with the financial support of industry partner and NBDA.

Dr. Zaman sees his HQPs as professionals and junior colleagues and treat them with respect, which they have also shown to him. He particularly emphasizes the value of collaboration/team work and showing respect in the work place. Consequently, the HQPs have always helped one another with their expertise and often share authorship credit in research publication. Dr. Zaman focuses more on the quality of work done and timeliness of execution than the physical presence of trainees in the lab during regular work hours. Indeed, PARP have attracted dedicated students, post-docs and researchers *(regionally, nationally and internationally)* to research team who always go beyond the expectations in rapidly learning and performing their work. Dr. Zaman received the prestigious *GLENN DOWNING AWARD* from the Canadian Society for Bio-engineering in recognition of his outstanding work in industry, teaching, research, and extension in the area of machinery systems. He also received *AWARD FROM UNIVERSITY OF FLORIDA* in recognition of outstanding contributions in the development of variable rate sprayer system and method of variably applying agrochemicals. Inspired by his teaching skills and mentorship, one of his PhD students (Dr. Farooque) received the *TEACHING IMPACT AWARD 2015*, CSBE Best Graduate (PhD) Thesis Award and Canadian Society of Hort Science Best Oral Presentation Award during his graduate studies. Now Dr. Farooque is serving as an Assistant Professor at the University of Prince Edward Island, PEI. He was one of the two recipients of this award from the entire university. Another, his graduate student Dr. Esau has received CSBE BEST Graduate (PhD) Thesis Award. The PA team has worked tirelessly during the last 11 years and made profound progress as a team in research, teaching and extension. In short, the energy exuded by PA research team invigorates Dr. Zaman, the learning process is certainly mutual. When everyone gets tired of work, they try to make time to get together in lab-only social events or holiday gatherings with family and friends.

1.2 Pedagogy through Undergraduate Research

1.2.1 Undergraduate (*Summer Students*) at Engineering Department, Faculty of Agriculture, Dalhousie University (Funding source in parenthesis)

Name	Status	Years' Supervised	Title of Project (Funding Source)	Present Position
Morgan Roberts	completed	2008-2009	Quantify soil and plant variability within wild blueberry fields (NSERC-IPS)	Mining Industry Employee
Travis Esau	completed	2007-2010	Development of automated fruit yield mapping system (NSERC-IPS)	PostDoc
Dainis Nams	completed	2008	Performance evaluation of automated slope measurement and mapping system (NSERC-USRA)	Graduate Student
Matthew Morrison	completed	2010	Quantification of nutrient losses in wild blueberry fields (HortCluster)	Undergraduate Student
Asena Yildiz	completed	2010	Mapping soil and plant parameters using PA technologies (HortCluster)	Graduate Student
Brittany Maclean	completed	2013	Improving harvesting efficiency of blue berry harvester using PA technologies (NSERC-IPS)	Undergraduate Student
Riley Giffen	completed	2013	Calculating the impact of header forces on berries during harvesting, (NSERC-IPS)	Undergraduate Student
Josiah McNutt	completed	2014	Capacity analysis of **a** commercial blueberry harvester (NSERC-IPS)	Undergraduate Student
Elizabeth Faulkner	completed	2014	Calculating impact of different diameter header forces on berries during harvesting (NSERC-IPS)	Undergraduate Student
Lucas Geldart	completed	2015	Design analysis of harvester head	Undergraduate Student
Samuel Creelman	completed	2015	Evaluating modified harvester head	Undergraduate Student
Karen Esau	completed	2016	Effective use of air from blower on the conveyor for cleaning berries	Graduate Student
Emily Merks	completed	2016	Smart hoop sprayer for tree crops	Undergraduate Student
Rachel Hirtle	Completed	2016	Implementation of precision agriculture system	Undergraduate Student
Scott Withrow	Completed	2017	Evaluating wild blueberry precision harvesting technologies	Undergraduate Student
Brooke MacLean	Completed	2017	Improving wild blueberry harvester efficiency	Undergraduate Student

1.2.2 Undergraduate Students (RESM 4000 and 4001 – Research Project) at Engineering Department, Faculty of Agriculture, Dalhousie University (Funding source in parenthesis)

Name	Status	Years' Supervised	Title of Project (Funding Source)	Present Position
Jason Withrow	completed	2012	A mathematical procedure to calculate impact forces exerted by blueberry harvester	Industry employee
Andrew Macewen	completed	2012	Identify the impact of tangential and radial forces on the picking efficiency of	Electrical work
Alex McDonald	completed	2012	Performance evaluation of commercial wild blueberry harvester to quantify fruit losses	unknown
Karen Esau	completed	2016	Improving harvesting berry picking and quality efficiency	Graduate student
Qi Li	Completed	2017	Digital photography technique to improve berry quality during harvesting	Undergraduate student

1.3 Pedagogy through Master Students Training (Funding source in parenthesis)

Name	Status	Years' Supervised	Title of Project (Funding Source)	Present Position
Aitazaz A. Farooque	completed	2010-11	Effect of soil variability on wild blueberry fruit yield, (NSDA-AIF)	Assistant Professor UPEI
Travis Esau	completed	2010-12	Development and evaluation of a prototype variable rate sprayer for spot-application of agrochemicals in wild blueberry fields (NSDA-AIF)	PostDoc
Fahad S. Khan	completed	2010-12	Mapping soil properties and water table depths using EMI methods (NSDA)	Industry Employee
Shoaib Rashid Saleem	completed	2010-12	Variable rate fertilization in wild blueberry fields to improve crop productivity and reduce environmental impacts (NSDA)	PhD Student Guelph
Shaun Sharpe	completed (committee member)	2007-10	Potential for hyperspectral technology in wild blueberry (Vaccinium angustifolium Ait.) production	Unknown
David Sampson	completed	2009-12	Evaluation of apple slice quality during convection drying using real-time image analysis	Provincial Govt. Employee
Hassan Shafqat	completed	2011-13	Evaluation of a modified variable rate granular fertilizer spreader for spot-specific fertilization in wild blueberry fields (NSDA)	Research Assistant at Dalhousie University

Asif Abbas	completed	2012-14	Impact of variable rate split fertilization on crop production and environmental contamination in wild blueberry (Self-Funded)	Provincial Govt. Employ
Muhammad W. Jameel	completed	2013-2015	Effect crop and machine parameters on wild blueberry harvester's efficiency (NSDA-Mitac)	Research Assistant at Dalhousie University
Salamat Ali	completed	2014-16	Effect of harvesting time on wild blueberry fruit loss during harvesting (NSDA)	M.Sc. Student
Tanzeel Rehman	In Progress	2015-present	Machine vision based weed detection system for spot-application of herbicide	M.Sc. Student
Muhammad H Farooq	In Progress Committee Member	2016-present	Management of Goldenrod	M.Sc. Student
Karen Esau	In Progress	2017-present	Improving berry quality during mechanical harvesting	MASc. Student
Liu Yu	In Progress	2016-present	Bioremediation of minkery wastewater and astaxanthin production by *haematococcus pluvialis*	M.Sc. Student
Arshdeep Grewal	In Progress Committee Member	2017-present	Haskap response to plastic mulch colour and fertility under irrigation	M. Sc Student

1.4. Pedagogy through Graduate (PhD) Training (Funding source in parenthesis)

Name	Status	Years' Supervised/ co-supervised	Title of Project/Funding Source
Aitazaz A. Farooque	Completed	2011-15	Performance evaluation of wild blueberry harvester to minimize fruit losses during mechanical harvesting (NSERC-IPS)
Travis Esau	Completed	2012-2016	Development of commercial VR sprayer for spot application of agrochemicals (NSERC-IPS)
M. Azhar Inam Baig	Completed	2010-2017	Development of a group built coupled physical – socio economic modelling framework for soil salinity management in agriculture (Pak. Govt.)
Rizwan Maqbool	Completed (Committee member)	2008-2014	Nitrogen cycling, optimization of plant nutrition and remote sensing of leaf nutrients in wild blueberries (Pakistan Government)
Wenfeng Zhu	In Progress (Committee member)	2012-present	Comparative study of agroecosystem services health between Fujian and Nova Scotia provinces

Wajid Ishaq GC University Pakistan	completed (External committee member)	2010-2016	Modeling water productivity in wheat (triticum aestivum l.) under irrigated and rain-fed conditions (Pakistan Government)

1.5 Pedagogy through Post-Doctoral Fellows Training

Name	Status	Years' Supervised	Title of Project	Present Position
Dr. Fangming Zhang	completed	2008	Development and evaluation of cost-effective automated vegetation mapping system	Assistant Professor, ZheJiang University, China
Dr. Kishore Swain	completed	2008-09	Development and testing of automated yield monitoring systems	Assistant Professor, Assam University, India
Dr. Muhammad Arshad	completed	2008-09	Development of VR technologies for fertilization/irrigation using EMI technologies	Professor, University of Agriculture, Faisalabad, Pakistan
Dr. Gashaw. A Gobizie	completed	2010-11	Software development for real-time spot-application of agrochemicals using discrete transformation technique	Unknown
Dr. Aitazaz Farooque	completed	2015-16	Integrated harvesting system	Assistant Professor University of PEI
Dr. Young K. Chang	completed	2010-2016	Image processing software development for real-time weed, plant and bare spot identification using textural analysis for real-time spot applications	Industry Research Chair Dalhousie University
Dr. Saima A Bharwana	Completed Co-Supervisor	2015	Farm Safety	Assistant Professor GC University Pak.
Dr. Travis Esau	In Progress	2016-present	Smart Sprayer and Precision Harvesting Technologies	Post-Doc Dalhousie University
Dr .Meftah Mohamed	In Progress	2017-present	Precision Harvesting Technologies	Post-Doc Dalhousie University

1.6 Pedagogy through Research Assistants/Technicians Training

Name	Status	Years' Supervised	Title of Project	Present Position
Kelsey Laking	completed	2009	Evaluating yield monitoring System	Govt. Employee
Rene Terriene	completed	2009	Application of GPS/GIS in Precision Agriculture	Govt. Employee
Travis Esau	completed	2011	Development of commercial prototype VR sprayer	PostDoc Dalhousie Univ.

Hafiz Nafees Ahmed	completed	2011	Ground Modelling to reduce ground water contamination	Federal Govt. Environment Canada
Shoaib Rashid Saleem	completed	2012-13	Developing algorithm for spot-applications	PhD Student University of Guelph, ON
Hassan Chattha	Completed	2013-15	Evaluation of wild blueberry harvester to minimize fruit losses	Research Assistant Dalhousie Univ.
M. Waqas Jameel	Completed	2015-2016		Research Assistant Dalhousie Univ.
Asif Abbas	Completed	2014-15	Evaluation of wild blueberry harvester to minimize fruit losses	Research Assistant Dalhousie Univ.
Salamat Ali	In Progress	2016 to present	Improving wild blueberry harvester efficiency to minimize fruit losses	Research Assistant Dalhousie Univ.
Negar S Mood	In progress	2018	Implementation of precision agric. technology	Research Assistant Dalhousie Univ.

1.7 Pedagogy through International Researchers Training

Name	Status	Years' Supervised	Title of Project	Country/Current position
Hou Weijun	completed	2008	Application of GPS and GIS in wild blueberry production	China/unknown
Lenka Priatkova	completed	2011	Physical and sensory evaluation of wild blueberries	Republic of Slovak/Post-doc
Dr. Mumtaz Cheema	completed	2011-12	To study the agronomic aspects of wild blueberry crop using PA technologies	Pakistan/Asso. Prof., Memorial Uni., NF
Dr. Muhammad Yaqoob	completed	2010	Application of PA technologies for livestock management	Pakistan/Professor
Dr. Muhamed Faruk	completed	2014	Evaluation of variable rate sprayer for spot-application	Egypt/Engineer in NSDA
Dr. Saima Aslam Bharwana	completed	2013 and 2015	Environmental impacts of variable rate technologies	Pakistan/Assistant Professor

2. Scholarships

In 2007, Dr. Zaman established the world-class Precision Agriculture Research Program (PARP) with objectives to improve the competitiveness and profitability of the blueberry industry and enhance the sustainability of rural life in Atlantic Canada. While building this program, he developed strong and effective partnerships with industry, government, and other institutions to support precision agriculture (PA) research needs. Dr. Zaman has been extremely successful in securing research grants from the Canada Foundation for Innovation, NSERC, AIF, Agriculture and Agri-Food Canada and Industry. These grants have allowed PA research team to establish state-of-the art facilities for PA systems research. The research program has also been funded, consistently and continuously, by federal and provincial governments, international funding agencies, industry partners, and grower's associations.
In 2012, PA team initiated a precision harvesting research program at Dal-AC with the collaboration of *Doug Bragg Enterprises and* the wild blueberry industry to develop innovative harvesting technologies for Atlantic Canada to increase harvestable fruit yield. These technologies would allow innovative harvesting techniques to increase harvestable berry yield and quality, and will ultimately lead to a more sustainable wild blueberry industry in North America.
PA team published more than sixty peer-reviewed articles in prestigious scientific journals. PA team members are highly sought out for national/international seminars and workshops and have made over one-hundred conference, industry and extension presentations over the past few years. They have also published articles in regional and national grower's magazines and newspapers, and developed fact sheets, operational manuals and custom software for growers and machinery manufacturers' use. PA research was promoted in a range of media, including national and international television channels such as CNN, MSNBC, Fox News, PBS, CTV, and Express and is available on Google Video, YouTube and CBC radio. They have received US Patent # 2012/0195496 A1 and Canadian Patent # 7231-1 for the invention of my "Variable Rate Sprayer System and Method of Variably Applying Agrochemicals". These innovative PA systems are affordable, reliable and user friendly and once implemented in North America are expected to significantly reduce agrochemical usage *(60-80% herbicide; 20-40% fungicide; 30-40% fertilizer),* as well as, increasing farm profitability *(~ 12 million dollars with VR spray in NS alone)* and minimizing environmental impacts. PARP has been providing a number of economic benefits for Atlantic Canada including job creation *(industry research chairs, post-docs, research associates, graduate and undergraduate students)* and anticipated increases in private sector employment that would result from the development of new, value-added industries in the region.

2.1 Research Projects/Funding

Duration	Title	Funding Agency	Total Amount	Status of Award
2002 to 2005	Implementation of Precision Agriculture Techniques in Florida Citrus	USDA/NASA	$160,000	Completed
2005 to 2006	Application of Variable Rate Technologies –NIR soil sensor	Japan Society for Promotion of Science	$150,000	Completed
2007 to 2010	Precision Agriculture Technologies to Increase Profitability and Reduce Environmental Pollution	NS-Agri-Futures, ACAAF	$360, 000	Completed
2008 to 2010	Mapping Soil Properties in Wild Blueberry Fields, Using EMI to Enhance Water Quality and Conservation.	ND-Water Supply Expansion Program.	$36, 000	Completed
2008 to 2010	Development of An Automated Yield Monitoring System	NS-Dept. Agric. Tech. Dev. Program	$40, 000	Completed

2009 to 2011	Site-Specific Application of Agrochemicals using PA Technologies	NS- Dept. Agric.- Tech. Dev. Program	$40,000	Completed
2008 to 2013	Precision Agriculture Technologies to Increase, Farm Profitability and Reduce Environmental Impacts	Canadian Foundation for Innovation	$125,225	Completed
2010 to 2012	Development of Variable Rate Sprayer for Spot-Application in Wild Blueberries	NS- Dept. Agric.- Tech. Dev. Program	$40,000	Completed
2009 to 2011	Site-Specific Application of Agrochemicals Using PA Technologies	NS- Dept. Agric.- Tech. Dev. Program	$40,000	Completed
2011-2013	Prototype cost-effective automated variable rate sprayer for spot-application of agrochemicals	Early Stage Commercialization Fund, Innova Corp	$36,500	Completed
2012-2013	Prototype variable rate sprayer for real-time spot application of agrochemicals in wild blueberry fields	Growing Forward Enabl. Agri. Res. and Innov. Program NB	$40,000	Completed
2010 to 2012	Site-Specific Application of Agrochemicals Using EMI methods	NS- Dept. Agric.- Tech. Dev. Program	$40,000	Completed
2010 to 2013	Wild Blueberry Environment and Production Risk Mitigation System	Agriculture-Agri. Food Canada-Oxford Frozen Foods	$400,000	Completed
2012	Improving Harvesting Efficiency of Blueberry Harvester	NSERC-Engage, Dough Bragg Enterprises	$25,000	Completed
2012 to 2013	Improving harvesting efficiency of wild blueberry harvester using precision agri. tech. to increase farm profitability	Agri-Futures (CAAO)-Doug Bragg Enterprises Ltd	$2,32,000	Completed
2013 to 2015	Improving Berry Picking Efficiency during Harvesting Using Bio-Systems Modeling Approach	NS Department of Agriculture, G-2 Research Acceleration	$58,000	Completed
2014	Evaluation of Precision Agriculture Technologies for Spot-Applications	NSERC-Engage	$25,000	Completed
2014-15	Picking Efficiency during Harvesting Using Precision Agriculture Technologies and Bio-Systems modeling	Mitacs -DBE	$30,000	Completed
2014 to 2016	Develop accurate models and procedures for estimating and mapping wild blueberry yields, and for forecasting fruit maturity dates	Research Acceleration NS Dept. of Agriculture	$54,400	Completed
2013 to 2016	Improving Harvesting Efficiency of Blueberry Harvester Using Precision Agriculture Technologies	CRD, NSERC-Doug Bragg Enterprises Ltd	$1.2 million	Completed
2016	Integrated harvesting technologies to improve berry recovery and quality	Mitacs -DBE	$45000	Completed
2013 to 2017	Improving Berry Picking Efficiency during Harvesting Using Precision Agriculture Technologies and Bio-Systems modeling	NB-Dept. Agric. Growing Forward	$270, 000	In Progress

2016	Increase harvestable blueberry yield using PA technologies	Mitacs - DBE	$15000	Completed
2016	Evaluation of smart sprayer for spot application of agrochemical in wild blueberry fields	Mitacs-DBE	$15000	Completed
2016	Machine vision based weed detection system for spot-application of herbicide	NS-Provincial Scholarship	$10000	Completed
2017	Effective use of a variable speed blower fan on a wild blueberry harvester to improve quality	Mitac-WBPANS	$15000	Completed
2016 to 2021	Implementation of precision agriculture technologies to improve crop productivity	NSERC CRD Slack Farms	0.8 million dollars	In Progress
2016 to 2021	Automation of wild blueberry harvester to increase berry picking efficiency	NSERC CRD DBE	1.5 million dollars	In Progress
2016 to 2019	Variable rate agro-chemical application system in citrus orchards using on-the-go Sensors	USPCAS-AFS UNI.of Agri. FSD (Int. coordinator)	Rs. 300000	In Progress
2016 to 2019	Development of real-time weed detection system for spot application of herbicides in Maize	USPCAS-AFS UNI. of Agri. FSD (Int. coordinator)	Rs. 300000	In Progress

2.2 Publications

2.2.1 Patent

Zaman, Q. U., Y. K. Chang, A. W. Schumann. 2013. "Variable rate sprayer system and method of variably applying agrochemicals". US Patent Publication No. 8488874 B2.

Zaman, Q. U., Y. K. Chang, A. W. Schumann. 2014. "Variable rate sprayer system and method of variably applying agrochemicals". Canadian Patent No. 2,740,503 C.

2.2.2 Book Chapter

Swain, K. C. and **Q. U. Zaman.** 2012. Rice crop monitoring with unmanned helicopter remote sensing images, remote sensing of biomass - principles and applications, Dr. Lola Fatoyinbo (Ed.), ISBN: 978-953-51-0313-4, InTech, Available from: http://www.intechopen.com/books/remote-sensing-of-biomass-principles-and-applications/rice-crop-monitoring-with-unmanned-helicopter-remote-sensing-images

Farooque, A. A., **Q. U. Zaman** and Schumann A. W. 2017. *The Lime: Botany, Production and Uses*. Precision agriculture in lime. Centre for Agriculture and Biosciences International. (CABI publisher).

2.2.3 Peer-Reviewed Journal Papers

Submitted:

4. Karen, E., E. Travis, Q. U. Zaman, A.A Farooque, A. W. Schumann. 2018. Effective use of a variable speed blower fan on a mechanical wild blueberry harvester. Applied Engineering in Agricultute. In Review.

3. Maqbool R., D. Percival, Q. U. Zaman; S. Adl, D. Buszard. 2018. Remote sensing of leaf macro and micro nutrients in wild blueberry stands. Remote Sensing of Environment. In Review
2. Wajid. I., M. Zaman, M. H. Rahman, Q. U. Zaman, V. Shelia, S. Ali, R. M.d Ikram, F. Abbas. 2018. Water-yield relations and transpiration efficiency of wheat focusing on water scarce conditions using crop growth modeling approach. Agricultural Water Management. In Review
1. Rehman, T., Q. U. Zaman, Y. Chang, A. W. Schumann, K., Corscadden, T. Esau. 2018. A color co-occurrence matrix based algorithm: An analysis to minimize computational overheads. Bio-Systems Engineering. In Review

Published:

56. Ishaque, W., F. Abbas, S. Ali, K. Mahmood, Q.U. Zaman, M. Azam, I. Khan, and M. Zain. 2017. Yield response of wheat (*Triticum aestivum* L.) to deficit and regulated deficit irrigation under arid/semi-arid conditions. *Pak J. of Agric. Sci.* 54(1):135-144. *IF =1.24*
55. Maqbool, R., D. Percival, Q. U. Zaman, T. Astatkie, S. Adl and D. Buszard. 2017. Leaf nutrients ranges and berry yield optimization in response to soil-applied nitrogen, phosphorus and potassium in wild blueberry (*Vaccinium angustifolium* Ait.). Eur. J. Hortic. Sci. *82*(4), 166–179. *IF = 0.42*
54. Esau, T., Q. U. Zaman, D. Groulx, A. A Farooque, A. W. Schumann, Y. Chang. 2018. Machine vision smart sprayer for spot-application of agrochemical in wild blueberry fields. Precision Agriculture. DOI: 10.1007/s11119-017-9557-y *IF = 1.728*
53. Ali, S., Q. U., Zaman, A. A. Farooque, A. W. Schumann, C. C Udenigwe, Y. K.. Chang. (2017). Potential use of digital photographic technique to examine wild blueberry ripening in relation to time of harvest. Appl. Engg. Agric.. In Press *IF = 0.571*
52. Farooque A. A., Q. U. Zaman, A.W. Schumann, D. Groulx, T. Nguyen-Quang. 2017. Influence of wild blueberry fruit yield, plant height and ground slope on picking performance of a mechanical harvester: basis for automation. Appl. Engg. Agric.. 33(5): 655-666. *IF = 0.571*
51. Chattha, H. S., K. Corscadden, Q. U. Zaman. 2017. Hazard identification and risk assessment for improving farm safety on Canadian farms. J. of Agric. Safety and Health. 23(3): 155-174. *IF = 0.571*
50. Chang, Y. K., Q. U. Zaman, T. Rehman, A.A. Farooque, M.W. Jameel and T. J. Esau. 2017. A real time ultrasonic system to measure wild blueberry plant height during harvesting. Biosystems Engg. (157), 35-44.
49. Ishaque, W., F. Abbas, S. Ali, K Mahmood, Q. U. Zaman, M. Azam, I. Khan, and M. Zain. 2017. Yield response of wheat (triticum aestivum l.) to deficit and regulated deficit irrigation under arid/semi-arid conditions. Pak. J. Agri. Sci. 54(1): 135-144.
48. Maqbool, R., D. Percival, Q. U. Zaman, T. Astatkie, S. Adl, and D. Buszard .2016. Improved growth and harvestable yield through optimization of fertilizer rates of soil-applied nitrogen, phosphorus and potassium in wild blueberry (*Vaccinium angustifolium* Ait.). HortSci. 51(1):1092-1097.
47. Esau, T., Q. U. Zaman, D. Groulx, Y. Chang, A. W. Schumann and P. Havard. 2016. Supplementary light source development for camera-based smart spraying in low light conditions. Appl. Engg. Agric. 33(1): 5-14. *IF = 0.571*
46. Abbas. A., Q. U. Zaman, A. A. Farooque, A. W. Schuman, G.R. Brewster, and R. Donald. 2016. Effect of split variable rate fertilization on wild blueberry plant growth and berry yield. Appl. Engg. Agric. 32(6): 675-683. *IF = 0.571*
45. Farooque, A., Q. Zaman, Y. Chang, K. Corscadden, A. Schumann, H. Chattha and A. Madani. 2016. Influence of soil properties and topographic features on wild blueberry fruit yield. Appl. Engg. Agric. 32 (4) 379-388. *IF = 0.571*

44. Farooque, A. A., Q. U. Zaman, D. Groulx, A. W. Schumann and T. Nguyen-Quang. 2016. Response of spatial variation in crop characteristics and topographic features to the fruit losses for wild blueberry cropping system. Appl. Engg. Agric.. 32 (4) 493-504. *IF = 0.571*
43. Farooque, A. A., Q. U. Zaman, D. Groulx, A. W. Schuman and Y. K. Chang, T. Nguyen-Quang. 2016. Development of a predictive model for wild blueberry harvester fruit losses during harvesting using artificial neural network. Appl. Engg. Agric. 2(6): 725-738. *IF = 0.571*
42. Jameel, M. W., Q. U. Zaman, A. A. Farooque, A. W. Schumann, G. Brewster, T. Nguyen-Quang and H. S. Chattha. 2016. Effect of plant characteristics on the picking efficiency of wild blueberry harvester. Appl. Engg. Agric.. *32*(5), 589-598 *IF = 0.571*
41. Chang, Y., Q. Zaman, A. Farooque, H. Chattha, S. Read and A. W. Schumann. 2016. Sensing and control system for spot-specific fertilization in wild blueberry cropping system. Precision Agriculture. 1–14. DOI : 10.1007/s11119-016-9457-6. *IF = 1.728*
40. Esau, T., Q. Zaman, D. Groulx, K. Corscadden, Y. Chang, A. Schumann and P. Havard. 2016. Economic analysis for smart sprayer application in wild blueberry fields. Precision Agriculture. pp. 1-13. DOI 10.1007/s11119-016-9447-8.47. *IF = 1.728*
39. Khan, F. S., Q. U. Zaman, Y. K. Chang, A. W. Schumann, A. Madani, and A. A. Farooque. 2016. Identification of gravel layer below soil surface within field using electromagnetic induction method. Precision Agriculture. 17 (2):155-167. *IF = 1.728*
38. Abbas. A., Q. U. Zaman, A. W. Schuman, G.R. Brewster, and R. Donald. 2016. Effect of variable rate split fertilization on subsurface water quality in wild blueberry fields. Appl. Engg. Agric. 32(1): 79-88. *IF = 0.571*
37. Chattha, H. S., Q. U. Zaman, Y. K. Chang, A. A. Farooque, A. W. Schumann and G. R. Brewster. 2015. Effect of lighting conditions and ground speed on performance of intelligent fertilizer spreader for spot-application in wild blueberry. Precision Agriculture. 16: 654-667. *IF = 1.728*
36. Abbas, A., Q. U. Zaman, A. W. Schuman, G. R. Brewster, R. Donald, and H. S. Chattha. 2014. Effect of split variable rate fertilization on ammonia volatilization in wild blueberry cropping system. Appl. Engg. Agric. 30(4): 619-627. *IF = 0.571*
35. Chang, Y. K., Q. U. Zaman, T. J. Esau, and A. W. Schumann. 2014. Sensing system using digital photography technique for spot-application of herbicide in pruned wild blueberry fields. Appl. Engg. Agric. 30(2): 143-152. *IF = 0.571*
34. Chattha, H. S., Q. U. Zaman, Y. K. Chang, S. Read, A. W. Schumann, G. R. Brewster, and A. A. Farooque. 2014. Variable rate spreader for real-time spot-application of granular fertilizer in wild blueberry. Comp. and Elec. in Agri. 100: 70-78. *IF = 1.766*
33. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2014. Spot application of fungicide for wild blueberry using an automated prototype variable rate sprayer. Precision Agric. 15(2): 147-161. *IF = 1.728*
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31. Farooque, A. A., Q. U. Zaman, D. Groulx, A. W. Schumann, D. Yarborough, and T. Nguyen-Quang. 2014. Effect of ground speed and head revolutions on the picking efficiency of commercial wild blueberry harvester. Appl. Engg. Agric. 30(4): 535-546. *IF = 0.571*
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26. Farooque, A. A., Y. K. Chang, Q. U. Zaman, D. Groulx, A. W. Schumann, and T. J. Esau. 2013. Performance evaluation of multiple ground based sensors mounted on commercial wild blueberry harvester to sense plant height, fruit yield and topographic features in real-time. Comp. Elec. Agric. (91): 135-144. *IF = 1.766*
25. Maqbool, R., D. C. Percival, M. S. Adl, Q. U. Zaman, and D. Buszard. 2012. In situ estimation of foliar nitrogen in wild blueberry using reflectance spectra. Can. J. Plant Sci. 92(6): 1155-1161. *IF = 0.547*
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23. Chang, Y. K., Q. U. Zaman, A. A. Farooque, A. W. Schumann, and D. C. Percival. 2012. An automated yield monitoring system II for commercial wild blueberry double-head harvester. Comp. Elec. Agric. 81: 97-103. *IF = 0.571*
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21. Farooque, A. A., Q. U. Zaman, A. W. Schumann, A. Madani, and D. C. Percival. 2012. Delineating management zones for site-specific fertilization in wild blueberry fields. Appl. Engg. Agric. 28(1): 57-70. *IF = 0.571*
20. Farooque, A. A., Q. U. Zaman, A. Madani, F. Abbas, D. C. Percival, and T. J. Esau. 2011. Ecological impacts of the N-Viro biosolids land-application for wild blueberry (*Vaccinium angustifolium.*Ait) production in Nova Scotia. J. Envir. Sci. Health. Part B 46: 366-379. *IF = 1.10*
19. Farooque, A. A., F. Abbas, Q. U. Zaman, A. Madani, D. C. Percival, and M. Arshad. 2011. Soil nutrient availability, plant nutrients uptake, and wild blueberry (*Vaccinium angustifolium.* Ait) yield in response to N-Viro biosolids and irrigation applications. J. of Appl. & Envir. Soil Sci. 1-7. *IF = 0.74*
18. Zaman, Q. U., T. J. Esau, A. W. Schumann, D. C. Percival, Y. K. Chang, S. Read, and A. A. Farooque. 2011. Development of prototype automated variable rate sprayer for real-time spot-application of agrochemicals in wild blueberry fields. Comp. Elec. Agric. 76: 175-182. *IF = 1.766*
17. Zhang, F., Q. U. Zaman, D. C. Percival, and A. W. Schumann. 2010. Detecting bare spots in wild blueberry fields using digital color photography. Appl. Engg. Agric. 26(5): 723-728. *IF = 0.571*
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12. Zaman, Q. U., A. W. Schumann, and K. Hostler. 2007. Quantifying sources of error in ultrasonic measurements of citrus orchards. Appl. Engg. Agric. 23(4): 449-453. *IF = 0.571*
11. Zaman, Q. U. and A. W. Schumann. 2006. Nutrient management zones for citrus based on variation in soil properties and tree performance. Precision Agric. 7(1): 45-63. *IF = 1.728*

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2. Zaman, Q. U., R. S. Shiel, and A. W. Schumann. 2003. Variable lime application based on within-field variation in soil pH. Pak. J. Agri. Sci. 40(1-2): 1-6. *IF = 1.240*
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2.2.4 Research Presentations/Publications in International Conferences

2.2.4.1 Presentations and Papers Published in Int. Scientific Meetings

67. Esau, T., Q. U. Zaman, K. Esau, T. Rehman, & A. Farooque. 2017. Effective use of a variable speed blower fan on a mechanical wild blueberry harvester. Annual Meeting ASABE, Spokane, Washington. July 16-19.
66. Farooq, M. H., S.N. White, Q. U. Zaman and N.S. Boyd. 2016. Evaluation of summer broadcast and spot herbicide applications for goldenrod management in wild blueberry. Canadian Weed Science Society Annual Meeting. Moncton, New Brunswick.
65. Esau, T., Q. U. Zaman, D. Groulx, K. Corscadden, Y. Chang, A. Schumann and P. Havard. 2016. Smart sprayer economic analysis for application in wild blueberry fields. Annual International Meeting CSBE. Halifax, Canada. July 02-05, 2016.
64. Ali, S., Q. U. Zaman, A. W. Schumann, C. C. Udenigwe, and A. A. Farooque. 2016. Examining the fruit ripening levels using digital photographic technique to suggest proper time of harvest. Annual International Meeting CSBE, Halifax, NS, Canada. July 3-6, 2016.
63. Farooque, A. A., Q. U. Zaman, Y. Chang, T. J. Esau, A. W. Schumann, W. Jameel and S. Ali. 2016. Impact of Fruit Yield, Plant Height and Slope on Picking Performance of Mechanical Harvester:A Basis for Automation. Variation in harvesting losses in relation to fruit yield, plant height and slope: a basis for automation of harvester. Annual International Meeting CSBE., Halifax, Canada. July 02-05, 2016
62. Esau, T., Q. Zaman, D. Groulx, K. Corscadden, Y. Chang, A. Schumann and P. Havard. 2016. Smart Sprayer economic analysis for application in wild blueberry fields. Annual International Meeting CSBE. Halifax, Canada. July 02-05, 2016.
61. Jameel, Muhammad W., Q. U. Zaman, A. W. Schumann and A. A. Farooque. 2016. Impact of plant characteristics on berry losses during mechanical harvesting of wild blueberry. annual international. Meeting CSBE, Halifax, Canada. July 03-06, 2016.

60. Jameel M., Q.U. Zaman, A.W. Schumann; A. Farooque. 2016. Impact of plant characteristics on berry losses during mechanical harvesting of wild blueberry. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
59. Farooque, A.A., Q.U. Zaman, Y. K. Chang, T. J. Esau, A. W. Schuman, and M. W. Jameel. 2016. Variation in harvesting losses in relation to fruit yield, plant height and slope: a basis for automation of harvester. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
58. Esau, T., Q.U. Zaman; D. Groulx; Y. Chang; A.W. Schumann; P. Havard. 2016. Machine vision smart sprayer for spot-application of agrochemical in wild blueberry fields. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
57. Chang, Y. K., Q. U. Zaman, A. A. Farooque, H. S. Chattha., A.W. Schumann. 2015. Automated ultrasonic system to measure and map wild blueberry plant height in real-time during harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2188695.
56. Ali. S., Q. U. Zaman, A.W. Schumann, C. Udenigwe, A. Farooque. 2016. Impact of fruit ripening parameters on harvesting efficiency of the wild blueberry harvester. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
55. Rehman, T., Q. U, Zaman, A.W. Schuman,; Y. Chang. 2016. Development of an algorithm for goldenrod detection using digital image processing techniques. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
54. Chang, Y. K., Q. U. Zaman, A. A. Farooque, H. S. Chattha., A.W. Schumann. 2015. Automated ultrasonic system to measure and map wild blueberry plant height in real-time during harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2188695.
53. Esau. T., Q.U. Zaman, D. Groulx, K. Corscadden, Y. K. Chang, A. W. Schumann, P. Havard. 2015. Economic analysis for smart sprayer application in wild blueberry fields. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number: 152189076.
52. Farooque, A. A., Q. U. Zaman, D. Groulx, K. Corscadden, A. W. Schumann, T. Quang and T. J. Esau. 2015. Effect of spatial variability in crop characteristics and slope of the ground on wild blueberry fruit losses. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015.Paper Number: 2188653.
51. Chattha, H. S., Q. U. Zaman, and A. A. Farooque. 2015. Relationship of plant density and plant height with wild blueberry fruit yield. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2189148.
50. Abbas. A., Q. U. Zaman, A. W. Schuman, G.R. Brewster, and R. Donald. 2015. Effect of split variable rate fertilization on wild blueberry plant growth and berry yield. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2189139.
49. Nadeem, M., M. Iqbal, A. A. Farooque, A. Munir, M. Ahmad, and Q. U. Zaman. 2015. Design indigenization of self-propelled reaper for harvesting multi crops. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number: 2189141.
48. Jameel, M. W., Q. U. Zaman, A. W. Schumann, T. Nguyen-Quang, G. Brewster, and H. S. Chattha. 2015. Effect of fruit characteristics on berry losses during harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2189354.
47. Ali, S., Q. U. Zaman, A. W. Schumann, and A. A. Farooque. 2015. Quantification of wild blueberry fruit losses at different time intervals during mechanical harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015. Paper Number. 2189301.
46. Farooque, A. A., Q. U. Zaman, D. Groulx, T. Quang, A. W. Schumann, and Y. K. Chang. 2014. Predictive model for wild blueberry fruit losses during harvesting. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014. Paper Number: 1898444.

45. Chattha, H. S., Q. U. Zaman, Y. K. Chang, A. W. Schumann, G. R. Brewster, S. Read, and A. Abbas. 2014. Evaluation of intelligent fertilizer spreader for spot-application under sunny and cloudy conditions in wild blueberry fields. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014. Paper Number: 1910213.
44. Esau, T. J., Q. U. Zaman, D. Groulx, Y. K. Chang, A. W. Schumann, and P. Havard. 2014. Smart sprayer for spot-application of agrochemicals in wild blueberry fields. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014. Paper Number: 1913227.
43. Chang, Y. K., Q. U. Zaman, H. S. Chattha, S. Read, and A. W. Schumann. 2014. Sensing system using digital cameras for spot-application of fertilizer in wild blueberry fields. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014. Paper Number: 1913445.
42. Khan, F. S., Q. U. Zaman, A. W. Schuman, A. Madani, and A. A. Farooque. 2014. Estimation and mapping of soil properties using electromagnetic induction method in wild blueberry fields. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014.
41. Abbas, A., Q. U. Zaman, A. W. Schuman, G. R. Brewster, R. Donald, and H. S. Chattha. 2014. Effect of split fertilizer application on subsurface water quality in wild blueberry fields. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014. Paper Number: 1913294.
40. Farooque, A. A., Q. U. Zaman, and D. Groulx. 2013. Performance evaluation of commercial wild blueberry harvester to quantify fruit losses during harvesting. 6th Mechanical Engg. Research Conf. Halifax, NS, Canada. April 26, 2013.
39. Abbas, A., Q. U. Zaman, A. W. Schuman, R. Donald, G.R. Brewster, and S. R. Saleem. 2013. Effect of split fertilizer application on ammonia volatilization losses in wild blueberry fields. Annual Int. Meeting ASABE, Kansas City, MO, USA. July 21-24, 2013. Paper Number: 1598763.
38. Chattha, H. S., Q. U. Zaman, A. W. Schumann, G. R. Brewster, Y. K. Chang, and S. Read. 2013. Evaluation of modified variable rate granular fertilizer spreader for spot-specific fertilization in wild blueberry fields. Annual Int. Meeting ASABE, Kansas City, MO, USA. July 21-24, 2013. Paper Number: 1618578.
37. Esau, T. J., Q. U. Zaman, D. Groulx, Y. K. Chang, A. W. Schumann, P. Havard, and A. Farooque. 2013. Development and performance testing of a light source system on a smart sprayer for spot-application of agrochemical in wild blueberry fields. Annual Int. Meeting ASABE, Kansas City, MO, USA. July 21-24, 2013. Paper Number: 1594025.
36. Farooque, A. A., Q. U. Zaman, D. Groulx, T. Quang, D. Yarborough, A. W. Schumann, Y. K. Chang, and T. J. Esau. 2013. Effect of ground speed and header revolutions on the picking efficiency of wild blueberry harvester. Annual Int. Meeting ASABE, Kansas City, MO, USA. July 21-24, 2013. Paper Number: 1596449.
35. Zaman, Q. U., T. J. Esau, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2011. Development of commercial prototype variable rate sprayer for spot- application of agrochemicals in wild blueberry. Annual Int. Meeting ASABE, Louisville, KY, USA. August 7-10, 2011. Paper Number: 1111134.
34. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2011. Performance evaluation of a prototype variable rate sprayer for spot-specific application of Bravo® fungicide in wild blueberry. Annual Int. Meeting ASABE, Louisville, KY, USA. August 7-10, 2011. Paper Number: 1110707.
33. Gashaw, A. G., Q. U. Zaman, Y. K. Chang, A. W. Schumann, D C Percival, and T. J. Esau. 2011. Assessment of wavelet discrete technique for spot-application of pesticides in wild blueberry. Annual Int. Meeting ASABE, Louisville, KY,. August 7-10, 2011.
32. Chang, Y. K., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2011. Performance tests of g ratio index and color co-occurrence matrix based machine vision algorithms in the wild blueberry fields. Annual Int. Meeting ASABE, Louisville, KY,. August 7-10, 2011.
31. Saleem S. R., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, A. A. Farooque,

F. S. Khan, and S. Read. 2011. Impact of variable rate fertilization on ground water contamination in wild blueberry cropping system. Annual Int. Meeting ASABE, Louisville, KY,. August 7-10, 2011. Paper Number: 1110631.

30. Farooque, A. A., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, T. J. Esau, F. S. Khan, and S. R. Saleem. 2011. Delineation of management zones for site-specific fertilization in wild blueberry fields. Annual Int. Meeting ASABE, Louisville, KY,. August 7-10, 2011. Paper Number: 1110630.
29. Khan, F. S., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, A. A. Farooque, and S. R. Saleem. 2011. Mapping water table depths using electromagnetic induction methods to develop variable rate technologies. Annual Int. Meeting ASABE, Louisville, KY, USA. August 7-10, 2011. Paper Number: 1110632.
28. Farooque, A. A., Q. U. Zaman, A. Madani, D. C. Percival, A. W. Schumann, T. J. Esau, F. S. Khan, S. R. Saleem, and Y. K. Chang, 2011. Characterize and quantify soil variability to delineate management zones for variable rate fertilization in wild blueberry fields. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
27. Saleem, S. R., Q. U. Zaman, A. W. Schumann, D. C. Percival, A. Madani, A. A. Farooque and F. S. Khan 2011. Impact of variable rate fertilization on nutrients runoff losses in wild blueberry fields. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
26. Chang, Y. K., Q. U. Zaman, T. J. Esau, A. W. Schumann, and D. C. Percival. 2011. Development and evaluation of a green ratio based algorithm for the detection of weeds in mowed wild blueberry fields. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
25. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2011. Development of a prototype variable rate sprayer using digital color cameras for spot-specific application of agrochemicals in wild blueberry. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
24. Zaman, Q. U., Y. K. Chang, A. A. Farooque, A. W. Schumann, and D. C. Percival. 2011. An automated yield monitoring system for commercial wild blueberry harvester. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
23. Khan, F. S., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, A. A. Farooque, and S. R. Saleem. 2012. Mapping soil properties using electromagnetic induction methods in wild blueberry. Plant Canada Conf. August 16-21, Halifax, NS, Canada.
22. Zaman, Q. U., T. J. Esau, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2011. Development of a commercial prototype variable rate sprayer for spot-application of agrochemicals in wild blueberry. ASABE. St. Joseph, Michigan. Paper No. 1111134.
21. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. W. Schumann, D. C. Percival, and A. A. Farooque. 2011. Performance evaluation of a prototype variable rate sprayer for spot-specific application of bravo® fungicide in wild blueberry. ASABE. St. Joseph, Michigan. Paper No. 1110707.
20. Zaman, Q. U., A. W. Schumann, D. C. Percival, S. Read, and T. J. Esau. 2010. Development of cost-effective prototype variable rate sprayer for spot-specific application of agrochemicals in wild blueberry cropping systems. Annual Int. Meeting ASABE, Pittsburgh, PA, USA. June 20-23, 2010.
19. Chang, Y. K., Q. U. Zaman, A. W. Schuman, D. C. Percival. 2010. Development of real time based automated system for weeds and bare spot detection in the wild blueberry field. Annual Int. Meeting ASABE, Pittsburgh, PA, USA. June 20-23, 2010.
18. Zaman, Q. U., A. W. Schumann, D. C. Percival, S. Read, and T. J. Esau. 2010. Spot application of pesticide using variable rate sprayer in wild blueberry. CIGAR section III ASABE, QC, Canada. June 13-16.
17. Farooque, A. A., Q. U. Zaman, A. Madani, D. C. Percival, A. W. Schumann, and T. J. Esau. 2010. Mapping soil moisture variability using electromagnetic induction methods. 9th Int. Drain. Symposium, ASABE, QC, Canada. June 13-16.

16. Percival, D. C, S. Sharpe, R. Maqbool, and Q. U. Zaman. 2010. Narrow band reflectance measurements can be used to estimate leaf area index, flower number, fruit set and berry yield of the wild blueberry (*Vaccinium angustifolium Ait.*), 28th Int. Hort. Congress - Lisboa, August 22-22, 2010.
15. Zaman, Q. U., F. Zhang, A. W. Schumann, and D. C. Percival. 2009. Bare spot mapping in wild blueberry fields using digital photography. ASABE, St. Joseph, Michigan, USA. Paper No. 095582.
14. Zhang, F., Q. U. Zaman, A. W. Schumann, D. C. Percival, D. Nams, and T. J. Esau. 2009. Detecting weeds in wild blueberry field based on color images. ASABE, St. Joseph, Michigan, USA. Paper No. 096146.
13. Swain, C. K., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2009. Detecting weed and bare-spot in wild blueberry using ultrasonic sensor technology. ASABE, St. Joseph, Michigan, USA. Paper No. 096879.
12. Arshad, M., Q. U. Zaman, K. C. Swain, A. Madani, P. Harvard, and A.W. Schumann. 2009. Electromagnetic induction methods for water management enhancement. ASABE, St. Joseph, Michigan, USA. Paper No 095580.
11. Ahmad, H. N., P. Havard, R. Jamesen, A. Madani, and Q. U. Zaman. 2009. Evaluation of an assessment tool for a small watershed under eastern Canada conditions. ASABE, St. Joseph, Michigan, USA. Paper No. 080039.
10. Zaman, Q. U., A. W. Schumann, and D.C. Percival. 2008. Development of an automated slope measurement and mapping system. ASABE, St. Joseph, Michigan, USA. Paper No. 083702
9. Schumann, A. W. and Q. U. Zaman. 2008. Quantifying Wild Blueberry Yield with Image Processing. St. Joseph, Michigan, USA.
8. Zaman, Q. U. and A. W. Schumann. 2008. Evaluation of low-cost automated system for real-time slope measurement and mapping. CSBE Paper No. 08150.
7. Swain, K. C., Q. U. Zaman, H .P. W. Jayasuria, and F. Zhang. 2008. Estimation of rice yield and protein content using remote sensing images acquired by radio controlled unmanned helicopter. ASABE, St. Joseph, Michigan, USA. Paper No. 080038.
6. Arshad, M., Q. U. Zaman, and A. Madani. 2008. Modeling approach to stimulate water percolation in rice-wheat system. ASABE, St. Joseph, Michigan, USA. Paper No. 080039.
5. Arshad, M., Q. U. Zaman, and A. Madani. 2008. Lining impact on water losses in watercourses – a case study in indus basin, Pakistan. CSBE Paper No.08171.
4. Schumann, A.W., L. G. Albrigo, Q. U. Zaman, S. Bucanon, and M. Maliszewski. 2007. Feasibility of predicting citrus yield and canopy size with remote sensing imagery of different resolutions. ASABE, St. Joseph, Michigan, USA. Paper No. 051123.
3. Zaman, Q. U., A. W. Schumann, and K. H. Hostler. 2005. Quantifying sources of error in ultrasonic measurements of citrus orchards. ASABE, St. Joseph, Michigan, USA. Paper No. 051123.
2. Schumann A. W., K. H. Hostler, W. M. Miller, and Q. U. Zaman. 2004. Sensor –based automatic yield monitoring for manually harvested citrus. ASABE, St. Joseph, Michigan, USA. Paper No. 041098.
1. Zaman, Q. U. and M. Salyani, 2003. Effect of foliage density and ground speed on ultrasonic measurement of citrus tree volume. ASABE, St. Joseph, Michigan, Paper No. 011184.

2.2.4.2 Int. Conference Presentations and Publication in Proceedings

25. Khan, H. A., E. Yiridoe, T. Esau, Q. U. Zaman, A. A Farooque. 2018. Field efficiency comparison of traditional and semi-automated wild blueberry harvester handling systems. In Proceedings: 14th International Conference on Precision Agriculture, Montreal, QC, CA,. June 24-27, 2018.
24. Farooque, A.A., Q.U. Zaman. 2018. Delineating management zones for site-specific fertilization to improve crop productivity in potato cropping system. 14th International Conference on Precision Agriculture, Montreal, QC, CA,. June 24-27, 2018.

23. Esau, K., Q.U. Zaman, A. W. Schumann, A. A Farooque. 2018. Effective use of a debris cleaning brush for mechanical wild blueberry harvesting. 14th International Conference on Precision Agriculture, Montreal, QC, CA,. June 24-27, 2018.
22. Esau, T. J., Q. U. Zaman, D. Groulx, Y. K. Chang, A. W. Schumann, and P. Havard. 2018. Economic and management tool for assessing wild blueberry production costs and financial feasibility. 14th International Conference on Precision Agriculture, Montreal, QC, CA,. June 24-27, 2018. 67.
21. Esau, T., Q. U. Zaman, D. Groulx, Y. Chang, A. Schumann, & P. Havard. 2017. Machine vision for spot-application of agrochemical in wild blueberry fields. 11th European Conference on Precision Agriculture. Edinburgh, Europe. July 16-20, 2017.
20. Farooque, A. A., Q. U. Zaman, A. W. Schumann, and T. U. Rehman. 2016. Characterization of spatial variability: a first step to implement precision agriculture technologies. In Proceeding of a National Conference on Precision Agriculture, University of Agriculture Faisalabad, Pakistan. April 18, 2016
19. Farooque, A. A., Q. U. Zaman and D. Groulx. 2014. Development of accurate models to predict wild blueberry fruit losses using artificial neural network and multiple regression techniques. In Proc. of 7th Mechanical Engineering Research Conference, Halifax, Nova Scotia. April 30, 2014.
18. Farooque, A. A., Q. U. Zaman, and D. Groulx. 2013. Performance evaluation of commercial wild blueberry harvester to quantify fruit losses during harvesting. 6th Mechanical Engg. Research Conf. Halifax, NS, Canada. April 26, 2013.
17. Saleem, S. R., Q. U. Zaman, A. W. Schumann, D. C. Percival, A. Madani, S. Read, and H. N. Ahmad. 2012. Impact of variable rate fertilization on nutrient losses in surface runoff within wild blueberry fields. 11th Int. Conf. on Precision Agric. Indianapolis, Ind., USA. July 15-18, 2012.
16. Farooque, A. A., Q. U. Zaman, Y. K. Chang, D. C. Percival, A. W. Schumann, and T. J. Esau. 2012. Sensor fusion on blueberry harvester for fruit yield, plant height and topographic features mapping to improve crop productivity. 11th Int. Conf. on Precision Agric. Indianapolis, Ind., USA. July 15-18, 2012.
15. Chang, Y. K., Q. U. Zaman, T. J. Esau, A. A. Farooque, A. W. Schumann, and D. C. Percival. 2012. Development of sensing system using digital photography technique for spot-application of herbicide in wild blueberry fields. 11th Int. Conf. on Precision Agric. Indianapolis, Ind., USA. July 15-18, 2012.
14. Khan, F. S., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, A. A. Farooque, and S. R. Saleem. 2012. Relationship of soil properties to apparent ground conductivity. 11th International, Conference on Precision Agriculture, Indianapolis, Ind., USA. July 15-18, 2012.
13. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. A. Farooque, A. W. Schumann, D. C. Percival, and M. A. Cheema. 2012. Spot- application of herbicide using variable rate sprayer in wild blueberry. 11th Int. Conf. on Precision Agric. Indianapolis, Ind., USA. July 15-18, 2012.
12. Farooque, A. A., Q. U. Zaman, A. Madani, D. C. Percival, and A. W. Schumann. 2011. Characterization and quantification of spatial variability of soil properties and fruit yield in wild blueberry field. 8th European Conf. on Precision Agric. Prague. July 11-14, 2011.
11. Zaman, Q. U., A. W. Schumann, D. C. Percival, S. Read, and T. J. Esau. 2010. Performance evaluation of cost-effective prototype variable rate sprayer for spot-specific application of agrochemicals in wild blueberry cropping systems. 10th Int. Precision Agric. Conf. Denver, Colo., USA. July 21-23, 2010.
10. Farooque, A. A., Q. U. Zaman, A. W. Schumann, D. C. Percival, and T. J. Esau. 2010. Prediction of soil organic matter and clay content using electromagnetic induction methods. 10th Int. Precision Agric. Conf. Denver, Colo., USA. July 21-23, 2010.
9. Swain, K. C., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2009. Automated, low-cost yield

mapping of wild blueberry fruit. 7th European Conf. Precision Agric. Wageningen, Netherland. July 6-8.

8. Zaman, Q. U., A. W. Schumann, K. C. Swain, and D. C. Percival. 2009. Evaluation of low- cost automated system for real-time slope measurement and mapping. 7th European Conf. Precision Agric. Wageningen, Netherland. July 6-8.
7. Zaman, Q. U., A. W. Schumann, and S. Shibusawa. 2006. Variable rate fertilization based on ultrasonically-sensed tree canopy volume in citrus orchards. 3rd Int. Symposium Machinery and Mechatronics for Agric. and Biosystems Engg. (ISMAB) Seoul, Korea – November 23-25, 2006.
6. Zaman, Q. U., A. W. Schumann, and S. Shibusawa. 2006. Impact of variable rate fertilization on nitrate leaching in citrus orchards. 8th Int. Precision Agric. Conf. Minnesota. July 24-26, 2006.
5. Schumann, A. W., H. K. Hostler, S. Buchanon, and Q. U. Zaman. 2006. Relating citrus canopy size and yield to precision fertilization. Annual Meeting of the Florida State Horticultural Soc. Tampa, FL. June 4 - 6, 2006.
4. Schumann, A. W., Q. U. Zaman, and K. H. Hostler. 2006. Importance of soil organic matter in Florida citrus production. Annual Meeting of the Soil and Crop Sci. Soc. Florida, Tampa, FL. June 4-6, 2006.
3. Schumann, A. W., W. M. Miller, Q. U. Zaman, K. H. Hostler, S. Buchanon, G. Perkins, and S. Cugati. 2005. Variable rate granular fertilization of citrus groves: Spreader performance with single-tree prescription zones. 6th Europen Precision Agric. Conf. Sweden, June 2005.
2. Zaman, Q. U., A. W. Schumann, and W. M. Miller. 2004. Variable rate nitrogen application in Florida citrus based on ultrasonically-sensed tree size. 7th Int. Precision Agric. Conf. Minnesota. July 2004.
1. Schumann A.W. and Q. U. Zaman. 2004. Software for real-time ultrasonic mapping of tree canopy volume. 7th Int. Precision Agric. Conf. Minnesota. July 2004.

2.2.4.3 Posters and Abstracts in National, International and Industry Meetings

40. K. Esau, Q. Zaman, A. Farooque, A. Schumann. 2017. Effective use of a clean brush on a wild blueberry harvester. nova scotia wild blueberry producers of nova scotia Annual Fall Information Session. Truro, NS. November 17, 2017.
39. Ali, S., Q. U. Zaman, A. W. Schumann, C. Udenigwe and A. A. Farooque. 2016. Impact of fruit ripening parameters on harvesting efficiency of the wild blueberry harvester. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
38. Rehman, T., Q. U. Zaman, A. W. Schumann and Y. K. Chang. 2016. Development of an algorithm for detection of goldenrod using digital image processing techniques. Annual Int. Meeting ASABE, Orlando, Florida, USA. July 17-20, 2016.
37. Ali, S., Q. U. Zaman, A. W. Schumann, C. Udenigwe and A. A. Farooque. 2016. Impact of fruit ripening parameters on harvesting efficiency of the wild blueberry harvester. Annual meeting of Wild Blueberry Producers Association of NS and NB.
35. Esau, T., Q. U. Zaman, T. Rehman and W. Jameel. 2016. Effective use of a variable speed blower fan on a mechanical wild blueberry harvester. Annual meeting of Wild Blueberry Producers Association of NS and NB.
34. Ali, S., Q. U. Zaman, A. W. Schumann, C. Udenigwe and A. A. Farooque. 2015. Quantification of fruit losses at different harvesting time on picking efficiency of wild blueberry harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015.
33. Jameel, M. W., Q. U. Zaman, A. W. Schumann, T. Nguyen-Quang, G. Brewster and H. S. Chattha. 2015. Effect of fruit characteristics on berry losses during harvesting. Annual Int. Meeting ASABE, New Orleans, Louisana, USA. July 26-29, 2015.
32. Jameel, M. W., Q. U. Zaman, A. W. Schumann, T. Nguyen-Quang, G. Brewster and A. A. Farooque.

2015. Effect of plant characteristics on wild blueberry losses during mechanical harvesting. Annual International Meeting CSBE. Edmonton, Canada. July, 2015.

31. Ali, S., Q. U. Zaman, A. W. Schumann, C. Udenigwe and A. A. Farooque. 2015. Quantification of fruit losses at different harvesting time on picking efficiency of wild blueberry harvesting. Annual meeting of Wild Blueberry Producers Association of NS and NB.
30. Chang, Y. K., Q. U. Zaman, A. Farooque, T. Esau, H. Chattha and M. W. Jameel. 2015. On-the-go plant height measurement system for wild blueberry. Annual meeting of Wild Blueberry Producers Association of NS and NB.
29. Esau, T., Q. U. Zaman, D. Groulx, Y. Chang and A. Schumann. 2015. Economic analysis for smart sprayer application in wild blueberry fields. Annual meeting of Wild Blueberry Producers Association of NS and NB.
28. Esau, T., Q. U. Zaman, Y. Chang, D. Groulx and A. Schumann. 2015. Development and performance testing of a machine vision smart sprayer for spot-application of agrochemicals in wild blueberry fields Annual meeting of Wild Blueberry Producers Association of NS and NB.
27. Farooque, A. A., Q. U. Zaman, Y. Chang, T. J. Esau, A. W. Schumann, and W. Jameel. 2015. Variation in harvesting losses in relation to fruit yield, plant height and slope: A basis for automation of harvester. Annual meeting of Wild Blueberry Producers Association of NS and NB.
26. Jameel, M. W., Q. U. Zaman, A. W. Schumann, T. Nguyen-Quang, G. Brewster and H. S. Chattha. 2015. Effect of Plant Characteristics on the Picking Efficiency of the Wild Blueberry Harvester. Annual meeting of Wild Blueberry Producers Association of NS and NB.
25. Esau, T. J., A. A. Farooque, B. Mc Lean, R. Giffen, and Q. U. Zaman. 2014. Capacity analysis of wild blueberry harvester heads. WBPANS Annual Field Day, NS, and Wild Blueberry Producers Association Field Day NB.
24. Nadeem, M., H. S. Chattha, and Q. U. Zaman. 2014. Comparison of 16 Bars and 12 Bars Harvester Heads for Picking Efficiency. WBPANS Annual Field Day, NS and Wild Blueberry Producers Association Field Day NB.
23. Farooque, A. A. and Q. U. Zaman. 2014. Performance evaluation of commercial wild blueberry harvester for fruit loss. WBPANS Annual Field Day, NS and Wild Blueberry Producers Association Field Day NB.
22. Farooque, A. A., Q. U. Zaman, T. Quang, D. Groulx, and A.W. Schumann. 2014. Bio-systems modeling to improve berry picking efficiency. WBPANS Annual Field Day NS, and Wild Blueberry Producers Association Field Day NB.
21. Jameel, M. W., Q. U. Zaman, A.W. Schumann, T. Quang, and G. R. Brewster. 2014. Effect of plant height & density on wild blueberry fruit losses. WBPANS Annual Field Day. NS, and Wild Blueberry Producers Association Field Day NB.
20. Farooque, A. A., Y. K. Chang, Q. U. Zaman, T. Quang, D. Groulx, and A.W. Schumann. 2014. Sensor fusion to sense plant height, yield and topographic features in real-time. WBPANS Annual Field Day, NS, and Wild Blueberry Producers Association Field Day NB.
19. Jameel, M. W., M. Ahmad, Q. U. Zaman, A. Munir, and F. A. Warraich. 2014. Performance evaluation of photovoltaic module using aluminum reflectors. Annual Int. Meeting ASABE, Montreal, QC, Canada. July 13-16, 2014.
18. Chang, Y. K., Q. U. Zaman, A. W. Schumann, and T. J. Esau. 2013. Development of software for single boom smart sprayer using digital photography. WBPANS Annual Meeting, NS, and Wild Blueberry Producers Association Annual Meeting, NB.
17. Farooque, A. A., Q. U. Zaman, D. Groulx, A. W. Schumann, D. E. Yarborough, and T. Quang. 2013. Quantification of wild blueberry fruit losses at various combinations of machine operating parameters. WBPANS and Wild Blueberry Producers Association Annual Meeting, NB.

16. Chattha, H. S., Q. U. Zaman, Y. K. Chang, A. W. Schumann, and G. R. Brewster. 2013. Evaluation of intelligent fertilizer spreader for spot-application under sunny and cloudy conditions in wild blueberry fields. WBPANS and Wild Blueberry Producers Association Annual Meeting, NB.
15. Chattha, H. S., Q. U. Zaman, A. W. Schumann, G. R. Brewster, Y. K. Chang, and S. Read. 2012. Variable rate granular fertilizer spreader for spot specific fertilization. WBPANS Annual Meeting , NS, and Wild Blueberry Producers Association Annual Meeting, NB.
14. Chang, Y. K., Q. U. Zaman, A. A. Farooque, A. W. Schumann, and D. C. Percival. 2011. An automated yield monitoring system for commercial wild blueberry double-head harvester. Wild Blueberry Producers Association, NS, NB and P.E.I and WABANA annual meeting Maine.
13. Farooque, A. A., Q. U. Zaman, Y. K. Chang, D. C. Percival, A. W. Schumann, and T. J. Esau. 2011. Sensor fusion on blueberry harvester for fruit yield, plant height, and topographic features mapping to improve crop productivity. Wild Blueberry Producers Association Annual Meeting, NS, NB and P.E.I
12. Esau, T. J., Q. U. Zaman, Y. K. Chang, A. W. Schumann, and A. A. Farooque. 2011. Prototype variable rate sprayer for spot-application of fungicide in wild blueberry. Wild Blueberry Producers Association Annual Meeting, NS, NB and P.E.I.
11. Khan, F. S., Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival, A. A. Farooque, and S. R. Saleem. 2011. Mapping soil properties using electromagnetic induction methods in wild blueberry fields. WBPANS Annual Meeting, Truro, NS, Canada.
10. Ayalew, G., Y. K. Chang, Q. U. Zaman, D. C. Percival, and A. W. Schumann. 2010. Development of image processing software for automated variable sprayer. WBPANS Annual Meeting, Canada.
9. Chang, Y. K., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2009. Development of real time based automated system for weeds and bare spot detection in the wild blueberry field. WBPANS Annual Meeting, Truro, NS, Canada.
8. Zaman, Q. U. and A. W. Schumann. 2006. Variable rate technology reduces fertilizer use and limits nitrate leaching in citrus orchards. Abstract in 2006 ASA-CSSA-SSSA Annual Meetings, Indianapolis, November 12-16.
7. Zaman, Q. U., A. W. Schumann, and S. Shibusawa. 2006. Ground water mapping with electromagnetic induction method. International Workshop on Ecological Informatics of Chaos and Complex Systems. Tokyo University of Agric.and Tech., Tokyo, Japan, March 02-03, 2006.
6. Zaman, Q. U., A. W. Schumann, and S. Shibusawa. 2006. Impact of variable rate fertilization on nitrate leaching in citrus orchards. 8th Int. Precision Agric. Conf. Minnes. July, 2006.
5. Schumann A.W., Q. U. Zaman, and K. H. Hostler. 2005. Soil organic matter affects productivity of Florida citrus soils. Science to Secure Food and the Environ. 2004 ASA-CSSA-SSSA Int. Annual Meetings Canadian Soc. of Soil Sci. Seattle, Washington – Oct. 31 - Nov 4.
4. Zaman, Q. U., A. W Schumann, and W. M. Miller. 2004. Variable rate nitrogen application in Florida citrus based on ultrasonically-sensed tree size. 7th Int. Precision Agric. Conf. Minnesota. July, 2004.
3. Schumann, A.W. and Q. U. Zaman. 2004. Non-contact measurement of spatial variability in sandy hydromorphic soils. Abstract in “Int. Citrus Congress”: Agadir, Morocco Feb. 15-20.
2. Schumann A.W. and Q. U. Zaman. 2004. Software for real-time ultrasonic mapping of tree canopy volume. 7th Int. Precision Agric. Conf. Minnesota. July, 2004.
1. Zaman, Q. U. and A. W. Schumann. 2003. Spatial variability of soil properties and citrus tree performance. Abstract in “Changing Sciences for a Changing World: Building a Broader Vision" 2003 ASA-CSSA-SSSA Annual Meetings Denver, Colorado November 2-6.

2.2.4.4 Technical/Scientific Research Progress Reports

Routinely, quarterly and yearly progress reports have been developing in English and French and submitting to government and industry funding agencies, and collaborators.

3. Extension/Outreach/ Technology Transfer and Partnerships

3.1 Special Lecture Delivered

Invited Speaker **–** International Seminar on "Sustainable use of agricultural resources to minimize environmental risks**". Murray Darling Basin Authority, Canberra, Australia. August 03, 2016.**

Resource person– International workshop on "Implementation of PA technologies in Pakistan" **University of Agriculture Faisalabad, Pakistan, April 2015 and April/Nov. 2016.**

Keynote Speaker **– "Advanced agricultural techniques to reduce cost of production in Cotton Crop". University of Agriculture, Multan, Pakistan. March 2016.**

Invited Speaker - UK-Canada Symposium on "Smart Technologies for Agriculture – The Value of Precision Agriculture". **Canadian High Commission, London, UK, 18-19 January 2016.**

Special Lecture - Optimizing mechanical harvesting of wild blueberries using precision agriculture technologies. **Citrus Research and Education Center, University of Florida, January 07, 2016.**

Resource person– International workshop on PA technologies. **University of Agriculture Faisalabad, Pakistan, May 2015.**

Invited speaker – International Seminar on "Potential Use of Precision Agriculture Technologies for Vegetable Cropping Systems" **Gulf Coast Research and Education Centre, Wimauma, University of Florida, USA, December 16-20, 2013.**

Invited speaker – International Seminar on "Precision Agriculture Technologies for Wild Blueberry Cropping Systems" **Citrus Research and Education Centre, Lake Alfred, University of Florida, USA, December 16-20, 2013.**

Keynote speaker – International Seminar on "Innovative Technologies in Agriculture: Precision Agriculture, Renewable Energy and Bio-system Modeling" **University of Agriculture Faisalabad, Pakistan, June 21-23, 2013.**

Resource person – International Seminar on "Environmental Impact of Precision Agriculture Technologies" **GC University Faisalabad, Pakistan, July 02, 2013.**

Resource person - International Seminar on "Water Issues and Options; Precision Agriculture: Technology for Wise Use of Agricultural Resources" **University of Agriculture Faisalabad, Pakistan, December 12-13, 2011.**

Invited speaker – delivered lecture on "Machine Vision System for Precision Agriculture" in International Conference on Precision Agriculture and **July, 11-15, 2012. Indianapolis, Indiana.**

Invited speaker – New Brunswick Soil and Crop Improvement Association Annual Meeting and technical workshop and delivered seminar on "Innovative Technologies to Manage Soil and Crop Variability to Improve Crop Productivity" in. **March 16-17, 2011. New Brunswick, Canada.**

Resource Person - Annual Meeting of Nova Scotia Fruit Growers' Association and delivered lecture on "Precision Agriculture Technologies for Horticultural Crops to Increase Farm Profitability". **July 2011. Nova Scotia, Canada.**

Keynote speaker - International Seminar on "Crop Management: Issues and Options**" University of Agriculture Faisalabad, Pakistan, June 01, 2011.**

Resource person - International Seminar on "Environmental Issues and Options". **University of Agriculture Faisalabad, Pakistan June 07, 2011.**

Resource person - International Seminar "World Water Day" Precision Agriculture; Intelligent Use of Agricultural Resources" **University of Agriculture Faisalabad, Pakistan, March, 2011.**

Guest Speaker – Precision Agriculture Technologies for Horticultural Crops- Annual meeting- **Croplife-Atlantic Fertilizer Council. Sep-15-16 2010.**

Resource person - "Spatial Variability and Precision Agriculture: International Workshop, **University of Agriculture Faisalabad, Pakistan, August, 2010.**

Keynote speaker **-** Precision Agriculture Technologies to Increase Farm Profitability. Agricultural College, Multan University, Pakistan**. Sponsored by HEC, Ministry of Agriculture, Pakistan. March 2010.**

Guest speaker **-** "Precision Agriculture Research in Wild Blueberry Cropping Systems" **Citrus Research and Education Centre, Lake Alfred, University of Florida. December 07, 2008.**

Guest Speaker – "Application of Precision Agriculture Technologies in Horticultural/Agronomic Crops" **University of Agriculture Faisalabad, Pakistan, 2007.**

Observer – "Study Mission on Implementation of Precision Agriculture Technologies in Developing Countries" Organized by **Asian Productivity Organization in Taiwan, 2006.**

Invited Speaker – "Ground Water Mapping with Electromagnetic Induction Method" International Workshop on Ecological Informatics of Chaos and Complex Systems. **Tokyo University of Agriculture and Technology, Tokyo, Japan, 2006.**

Invited Speaker – "Spatial variability in soil properties and tree characteristics" 2nd Precision Agriculture Workshop for Florida Citrus, **Citrus Research and Education and Centre, University of Florida, January 21, 2004.**

3.2 International Visitors

2007	Hosted a research scientist from Northeast Agriculture University China with Chinese Govt. financial support for six months
2008	Hosted a research scientist from University of Agriculture, Faisalabad, with Pakistan Govt. financial support for nine months.
2011-12	Hosted a visiting professor from University of Agriculture, Faisalabad, with Pakistan Govt. financial support for six months
2011-12	Hosted a PhD student from Slovak University of Agric., Slovak Republic for six months
2013	Hosted a lecturer from GC University, Pakistan for one week
2014	Hosted scientist Dr. Muhamed Faruk, Minufiya University, Egypt
2007-2014	Hosted Dr. Arnold Schumann, Professor from University of Florida for one week every year from to work on collaborative research and academic programs.
2007-2017	Hosted international visitor from South America, Europe, Asia and US for short visits. Organized their seminars and shared ideas on PA technologies to develop collaborative research programs.

3.3 Training Courses, Conferences, Seminars, and Workshops

Seminars Organized: Internationally renowned professors *(Dr. John Schueller, University of Florida; Dr. Ian Yule, Professor and Director PA Research Centre, Massey University, New Zealand; Dr. Arnold Schumann, Professor, University of Florida)* were invited and organized seminars "PA technologies" at DAL-AC, Atlantic Agriculture Forum and Kentville Research Centre.

Panel Specialist: UK-Canada Symposium on Smart Technologies for Agriculture – The Value of Precision Agriculture. "Automation and Robotics – Fiction or reality?" 18-20 January, 2016. Canadian High Commission, London, UK. Researchers and industry related to precision agriculture technologies from both countries (UK and Canada) were participated in the workshop to share the activities and ideas for the development and implementation PA technologies.

3.3.1 International Training Workshops Organized

A two-day workshop for graduate students from December 14-15, 2011 in coordination with the Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan was organized. The purpose of this workshop was to train graduate students and the research community how to use DGPS and GIS for mapping soil, plant and yield variability to develop VR technologies to improve crop yield and reduce environmental impacts. Forty-three grad students attended the workshop.

Two days international workshop on Bio-systems modeling was organized in coordination with the GC University and University of Agriculture, Faisalabad, Pakistan June 22-23, 2013. More than 60 undergraduate and graduate students participated.
I organized four international workshops in 2015 and 2016 at University of Agriculture Faisalabad Pakistan for faculty and Graduate students.

3.3.2 Training Course at Faculty of Agriculture, Dalhousie University

We organized a two day short course for the Atlantic Canadian farmer's community on Feb 24-25, 2011 with the co-ordination of the Continuing and Distance Education Department, Faculty of Agriculture, Dalhousie University at Engineering Department, Dal-AC. Eighteen farmers from different cropping systems and industry personnel attended the course. The practical applications of DGPS and GIS for mapping soil, plant and yield variability to develop PA technologies and their use for precise or VR application of agricultural inputs within fields to improve crop yield and reduce environmental impact were demonstrated.

3.4 Extension Presentations/Innovative Demonstrations

The significant results were presented in Regional, National and International Scientific meetings:

- American Society of Agricultural and Biological Engineers (ASABE)
- Canadian Society for Bioengineering (CSBE)
- American Society of Horticulture Science (ASHS)
- International Society of Precision Agriculture (ISPA)
- International Society of Horticulture Science (ISHS)
- Canadian Society for Horticulture Sciences (CSHS)
- Plant Canada

We have made over 100 agricultural industry and extension presentations in annual meetings of Wild Blueberry Producers, Fruit Growers, Processors and Manufacturers over the last 6 years. I have also demonstrated Precision Agriculture Technologies in farmer's field days.

- Precision Agriculture Field Day
- Wild Blueberry Producers Associations of North America (WBANA)
- Wild Blueberry Producers Association of Nova Scotia (WBPANS)
- Wild Blueberry Producers Association of New Brunswick
- Wild Blueberry Producers Association of Prince Edward Island
- Wild Blueberry Producers Association of Quebec
- Nova Scotia Fruit Growers' Association
- Faculty of Agriculture, Dalhousie University Open Houses

- Engineering Department Open Houses
- Farm Mechanization Shows
- Soil and Crop Improvement Association, New Brunswick
- New Brunswick Institute of Agrologists
- Croplife- Atlantic Fertilizer Council

3.4.1 Demonstration of Technologies at Field Days

The Precision Agriculture Team led by me has been participating in Wild Blueberry Producers' Field Days organized throughout the North America. These field days included demonstrations and displays of innovative PA technologies for spot-application of agrochemicals. The key wild blueberry industry executives, producers association's representatives and growers attended the field days. Around 150-300 people representing different organizations and farming community attended the field days each year.

Precision Agriculture Field day

We organized PA field day at Wild Blueberry Research Institute, Debert during Fall, 2010 to demonstrate innovative cost-effective technologies developed by PARP at DAL-AC. The researchers from Agriculture Agri-Food Canada, NSDA representatives, University, key wild blueberry industry executives, producers association's representatives and growers attended the field day. Around 200 people representing different research and academic organizations, industry personnel and farming community attended the field day.

3.5 Articles in News Papers and Magazines

We have published several articles related to machinery development and precision agriculture in national/international newspapers and magazines.

- 2015. Dalhousie University Magazine. Field to fork
- Precision agriculture in wild blueberry fields. Agricola News, Volume 39, Number 1, 2013.
- Reducing herbicides – Saving $. Springboard. Highlights Report (Success Story) 2011-2012. .
- Precision variable-rate sprayer slays weeds – and costs. The Grower Magazine, February, 2011.
- Precision equipment being developed for wild blueberries. Fruit and Vegetables Magazine, March, 2011.
- Practical application of PA technologies for wild blueberries. Farm Focus Magazine, November, 2010.

3.6 Custom Software, Manuals, Broachers and Fact Sheets

Operational manuals for each precision agriculture system (developed by PARP research team at Faculty of Agriculture, Dalhousie University), brochures for precision agriculture systems and fact sheets were developed and supplied to producers through wild blueberry producers associations.

Operational manuals and software developed for:

1. Automated yield monitoring system
2. Cost-effective slope mapping system
3. DualEM for mapping soil properties, nutrients and water depth
4. Automated VR sprayer for spot application

3.6.1 Custom software (codes) and interface were developed for all precision agriculture systems.

3.6.2 Television Commercial/Programs and Radio Talk in Canada

T. J. Esau and Q.U. Zaman. 2009. Commercial mainly on Teaching and Research in Precision Agriculture Technologies for Wild Blueberries at Faculty of Agriculture, Dalhousie University, TV Commercial- Forty Times Aired on CNN, Fox, PBS channels, May, 2009. Available on Google Video and YouTube. With a potential reach of approximately 96 million people each day, the video is **an invaluable tool to the university**.
The video clip is available at http://www.dal.ca/sites/precision-agriculture.html

Zaman et al., (2009). TV program on Precision Agriculture Research Program at Faculty of Agriculture, Dalhousie University on CTV in Live @5. October, 29, 2009.
Another, our TV program on "Precision Agriculture Research Program at Faculty of Agriculture, Dalhousie University" was broadcasted in October, 2010 at CTV in Live@5 program.

Radio Talk

Zaman, Q.U. (2014). Talk on CBC Radio "New pesticide technology sprays only weeds" http://www.cbc.ca/news/canada/prince-edward-island/new-pesticide-technology-sprays-only-weeds-1.2696146 (Jul 04, 2014)

Television Program in Pakistan June 09, 2011, 2016

Express Forum

Title "Importance of Research in Agriculture Development"

Participants:

Dr. Dr. Iqrar Khan Vice-Chancellor, Dr. Ashfaq, Dean, Faculty of Agriculture, Dr. Niaz, Dean Engineering, Dr. Noor-ul-Islam, Director General, Agriculture Research Institute, Chief scientist, Punjab Agricultural Research Board, Dr. Shahida Jamil, Pakistan Agricultural Research Council. **Canadian Scientist (Dr. Qamar Zaman).**

3.6.3 Additional Information (Web Site Development)

Precision Agriculture Web Pages:

PA website was developed for PA activities at Dal-AC. It would help us to attract national and international students, post-docs and to develop further industry and academic collaborations. It will also help to transfer technology. PA activities at website would recognize Faculty of Agriculture, Dalhousie University a prestigious university and would bring the Faculty of Agriculture, Dalhousie University closer to the other international academic and industry institutions to develop collaborations.
http://dal.ca/precisionag

3.7 Networking/Collaborations (Regional/National/International)

We established ties with several North American, European and Asian academic institutions including the, McGill University (Canada), University of Guelph, University of Florida (USA), University of Maine (USA), University of Agriculture, Faisalabad (Pakistan), Arid Agriculture University Rawalpindi (Pakistan), Slovak University of Agriculture (Slovak Republic), Northeast Agricultural University (China) and University of Sadat (Egypt) (Please see appendix B). One of my international collaborators Dr. Arnold Schumann, Professor, University of Florida is an adjunct professor at Faculty of Agriculture, Dalhousie University. He has been serving as a member of supervisory committee of my graduate students (M.Sc. and PhD). He is also actively involved in my research projects. Two PhD (Lenka and Hou) students from Slovak University of Agriculture, Slovak Republic and Northeast Agricultural University, China completed their research project under my supervision at Dalhousie University. Dr. Farouk from University of Sadat, Egypt also worked as visiting faculty in my research program.
We developed a research group to work on PA technologies for blueberries. This consortium consisted of researchers/professors from US universities including University of Florida, University of California,

Washington State University, Michigan State University, University of Wisconsin-Madison, New Jersey Agricultural Experiment Station and several industry (PA equipment manufacturers) partners.
We developed UK and Canadian researchers and industry group related to precision agriculture technologies to share/discuss the on-going activities for the development and implementation of PA technologies in both countries (UK and Canada).
We also established effective academic collaboration (MOUs signed) with the University of Agriculture, Faisalabad and Arid Agriculture University Rawalpindi, Pakistan. Agreements are being established to support HQP exchange and visiting faculty within the PARP.

3.8 Industry Partners

- Oxford Frozen Foods Limited, NS, Canada
- Wild Blueberry Producers Associations, NS, P.E.I., NB., NF, QC, Maine
- Doug Bragg Enterprises, NS Canada
- Chemical Containers, Florida, USA
- Ag-Tronix, Inc, USA
- McCain Foods ,Potato Industry
- NB Potato Board
- CaseIH
- Green Diamond
- Grape and Wine Industry
- Agromart
- Perennia
- NS Federation of Agriculture
- NS Farm Safety

4. Most Significant Research and Development Contributions

Precision Agriculture Technologies – Effective Use of Agriculture Resources (2007-2012)

Reduce Production Cost

...Protect The Environment

4.1 Executive Summary

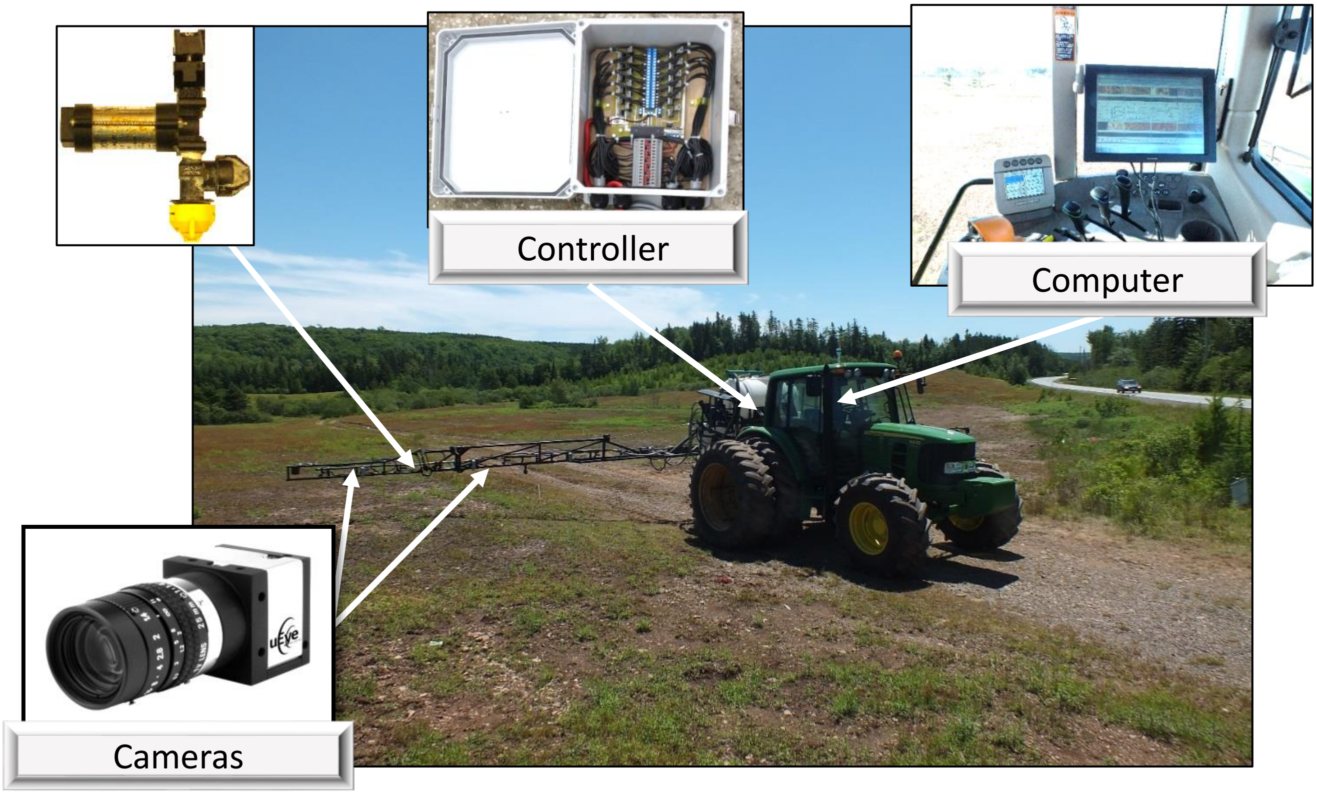
The story of surpluses and shortages go on and off for every crop. Rising fuel and agrochemicals price, water shortages, emerging disease and pests, climate change and environmental risks are diminishing the farmers and livestock dwellers. The cost of production is rising partly due to inefficient input use asking for innovative agriculture technologies. It is the duty of agriversitys' intelligentsia to foresee and be proactive. The leadership of the university must sensitize its faculty to the needs of farming community. They should feel the pain of small farmer and poor consumer alike. I developed precision agriculture research program (PARP) at Engineering Department (Faculty of Agriculture, Dalhousie University) with the partnership of Oxford Frozen Foods Limited (OFF) under the Atlantic Innovation Fund to develop variable rate technologies in wild blueberries. These technologies would allow corrective agricultural practices on an as-need basis to maximize profitability, minimize environmental impacts, and ultimately lead to a more sustainable industry with the following objectives:

- Development of cost-effective and reliable precision agriculture systems to map soil variability, weeds, bare spots, and fruit yield within wild blueberry fields.
- Sensor fusion to map soil and plant characteristics in real-time for wild blueberry fields.
- Development of VR applicators for real-time spot application of agrochemicals in wild blueberry fields to improve crop productivity and reduce environmental risks,
- Development of precision harvesting technologies to improve berry picking efficiency of the commercial wild blueberry harvester to improve profit margins.
- Training of HQPs (undergraduate and graduate students, post-doctoral research associates).
- Development of precision harvesting technologies to improve berry picking efficiency of the commercial wild blueberry harvester to improve profit margins.
- Dissemination of results to industry via participation at growers meetings, field days, and grower oriented publications.
- Dissemination of results to the scientific community via participation at conferences and publications in peer reviewed journals.
- Acquisition of additional sources of funding for research.

The following interconnected tasks accomplished in support of the above program.

4.2 Design, Development and Performance Evaluation of Cost-Effective Smart Sprayer for Spot-Application of Agrochemicals

One of the newest innovations in precision agriculture is automatic VR sprayer. Motivation for the development of this new VR sprayer is to assemble viable modern equipment which will perform significantly better than existing systems, at the lower cost. This type of VR sprayer does not use prescription maps, but relies on sensors/digital cameras to provide real-time weed detection information which is used to dispense correct agrochemical rates for the weeds. Most importantly, the herbicide is not applied where no weeds have been detected and fungicides/insecticides is applied only where blueberry plants have been detected. The precise spot-specific application of agrochemicals with automated variable rate sprayer in fields **saved significant amount of agrochemicals (herbicides 60-80% and fungicides (20-40%),** this improved profitability and protect the environment.



4.2.1 Farmer's Evaluation/Commercialization/Marketing

I received grant from Innovacorp for early commercialization of the prototype VR sprayer. We successfully tested/evaluated automated VR sprayer for spot application of herbicides and fungicides) at commercial farms during last few years.
We have been granted US and Canadian patent for commercialization.

Patent

Zaman, Q. U., Y. K. Chang, A. W. Schumann. 2013. "Variable rate sprayer system and method of variably applying agrochemicals". US Patent Publication No. 8488874 B2.

Zaman, Q. U., Y. K. Chang, A. W. Schumann. 2014. "Variable rate sprayer system and method of variably applying agrochemicals". Canadian Patent No. 2,740,503 C.

Please visit our website for details: http://www.dal.ca/sites/precision-agriculture.html

4.3 Modified VR Fertilizer Spreader for Spot-Application of Fertilizer Using Automated Sensing and Control System

We developed sensing and control system consisting of three way solenoid valves, return auger, programmable relay, air compressor, single acting cylinders, digital color cameras, custom image processing software and computerized controller. The boom was divided into six equal sections. Each section was controlled automatically and fertilizer will not be applied in the section where no plants have been detected, thus avoiding waste and environmental contamination. The principle components of modified VR spreader were tested in lab and also evaluated in the wild blueberry field to detect and dispense fertilizer at right targets in specific section of the boom where the targets were detected.

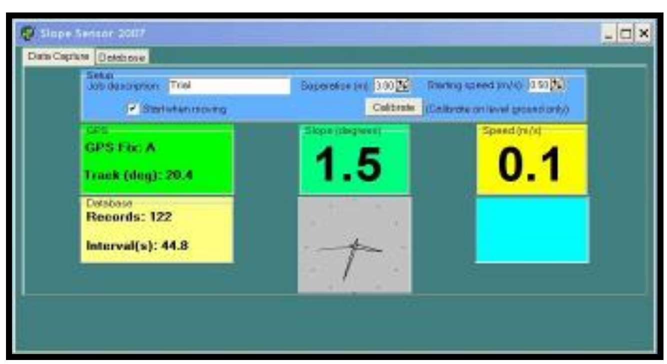
Modified VR fertilizer spreader for spot-application of fertilizer

VRT could Reduce Fertilizer Usage and Ground Water Contamination: Variable rate fertilization saved 40% fertilizer as compared to uniform application of fertilizer in a selected wild blueberry fields. Nitrate-Nitrogen concentrations in ground water were decreased with VRT and were below maximum contamination limit.
Please visit our website for details: http://www.dal.ca/sites/precision-agriculture.html

4.4 Development and Evaluation of an Automated Slope Sensing System

We developed an automated cost-effective slope mapping system (software and hardware) that consists of tilt sensors, DGPS and laptop to measure and map topographic features on-the-go within blueberry fields. The system performance for real-time slope measurement and mapping was tested in commercial fields with variable slopes. The use of low-cost and reliable accelerometers with DGPS is a better option to develop cost-effective system to quantify and map slopes (real-time) for planning site-specific management practices in commercial fields. The slope maps could also be used to adjust vehicle speed at particular slopes to avoid accidents in wild blueberry fields having highly variable slopes.


Cost-effective slope sensing system

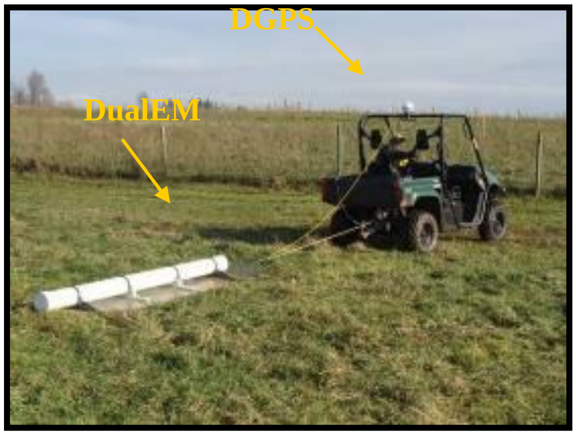


Software for ground speed and real-time slope

4.5 Development of Site-specific Technologies using DualEM

The EMI instruments are cost effective and are gaining wider use due to their non-destructive nature, rapid response, and ease of integration into a mobile platform, from which real-time measurements can be made.

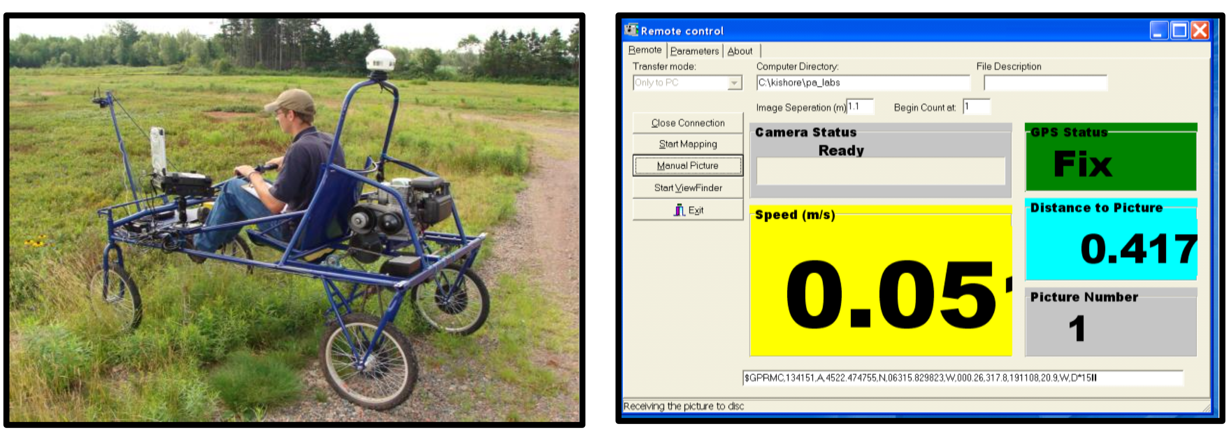
The spatial variations in soil properties, soil texture and soil moisture and water table depths were quantified and mapped using EMI technique. These maps were overlaid in GIS software to develop prescription maps for site-specific application of agrochemicals to reduce environmental contaminations and increase farm profitability. Results have been published in prestigious PA journals and also presented in growers meetings and at national/international meetings.



Dual EM to map soil properties and water table depth in real-time

4.6 Automated, Low-cost Yield Mapping of Wild Blueberry Fruit

The presence of weeds, bare spots, and variation in fruit yield within wild blueberry fields emphasizes the need for yield mapping for site-specific application of agrochemicals. An automated yield monitoring system (AYMS) consisting of a digital color camera, differential global positioning system, custom software, and a ruggedized laptop computer was developed and mounted on a specially designed Farm Motorized Vehicle (FMV) for real-time fruit yield mapping. Wild blueberry fields were selected to evaluate the performance of the AYMS. Real-time yield mapping was carried out with AYMS. Custom software was developed to acquire and process the images in real-time, and store the blue pixel ratio. The estimated yield per image along with geo-referenced coordinates was imported into ArcView 3.2 GIS software for mapping. Maps showed substantial variability in fruit yield in both fields. The bare spots coincided with no or low yielding areas in the fields. The yield maps could be used for site-specific fertilization in fields.



Configuration of automated yield monitoring system mounted on farm motorized vehicle.

4.7 Economic Benefits of PA Technologies

These technologies have 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.

4.7.1 Economic Benefits

4.7.2 Pesticides saving: chemical saved with spot-application was 60% - 80 % herbicide and 20% - 40% fungicide. Due to space constraint, only weed maps before and after of one field was shown as an example. Based on the results of this study, the VR sprayer proved very efficient for spot- application of herbicide on weeds and fungicide on foliage in wild blueberry fields. Following is the cost saving analysis for one chemical in one field using VR sprayer:

4.7.3 Cost/Benefit Analysis- Conventional vs Spot-Application (for one application only)

Target: Sheep Sorrel
Chemical: Kerb
Area sprayed = 300 acres
Weed cover = 25%
Application cost = $180/acre
Total cost (uniform application) = 300 X 180 = $54,000
Cost of spot- application = $13,500
Chemical cost saving with spot- application = **$40,500**

4.7.4 Additional cost of converting commercial to VR sprayer

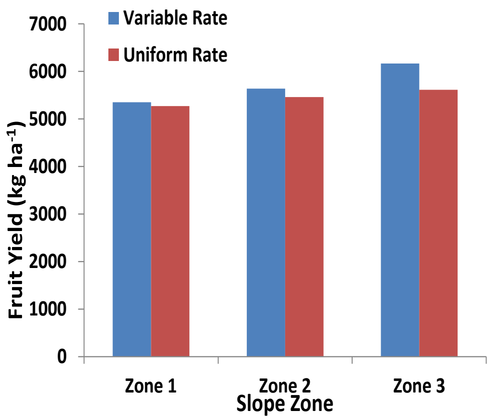
Computerized VR 8-channel controller
(Cameras + GPS + Dickey John controller) = $4,000.00
(Controller + GPS + linear flow control valve, flow meter) = $2,600.00
Wiring etc. = $400.00
Total initial cost: (Prototype Sprayer) = **$7,000.00**
Commercial Prototype Sprayer = **$14,000.00**

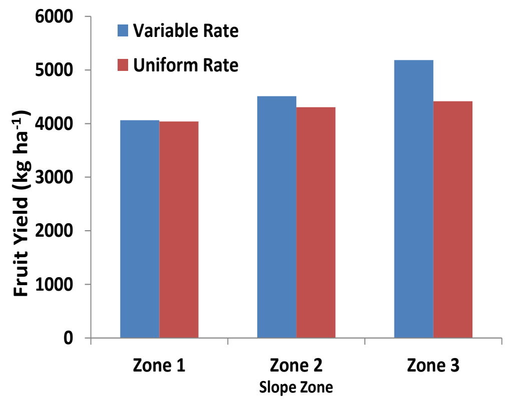
Cost/Benefit Analysis of VRT vs Uniform Application in Commercial Field

Chemical	Cost ($/ha)	Area (ha)	Application area needed (%)	Uniform cost ($)	SA cost ($)
Velpar	250	100	20	25,000	5,000
Sinbar	212	100	20	21,200	4,240
Venture	72	100	35	7,200	2,520
Callisto	72	100	35	7,200	2,520
Kerb	480	100	35	48,000	16,800
Bravo	90	100	80	9,000	7,200
Proline	50	100	80	5,000	4,000
Topas	48	100	80	4,800	3,840
Pristine	214	100	80	21,400	17,120
SA Saving = $84,760/two years production cycle				**$148,800**	**$63,240**

4.7.5 Fertilizer Saving with VRT

Variable rate (VR) fertilizer application has the potential to improve fertilizer use efficiency, reduce cost of production, and reduce environmental impacts. VR fertilization saved 39% and 41% fertilizer in Fields 1 and 2, respectively. Results of this study suggested that VR fertilization could increase fruit yield and reduce fertilizer usage in wild blueberry fields.



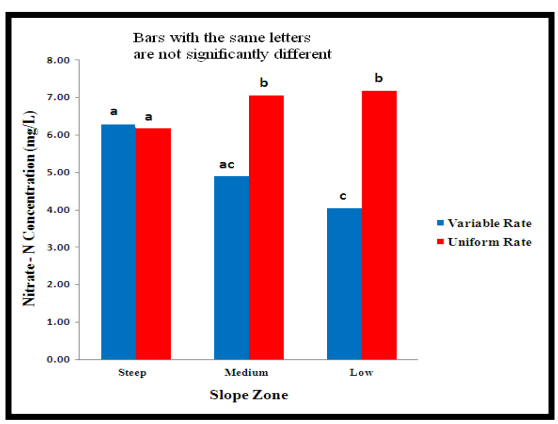


Comparison of fruit yield under VRT and uniform fertilization (Right side Field 1 and Left side Field 2)

4.8 Environmental Impact

4.8.1 Impact of VR Fertilization on Ground Water Contamination in Blueberry Fields

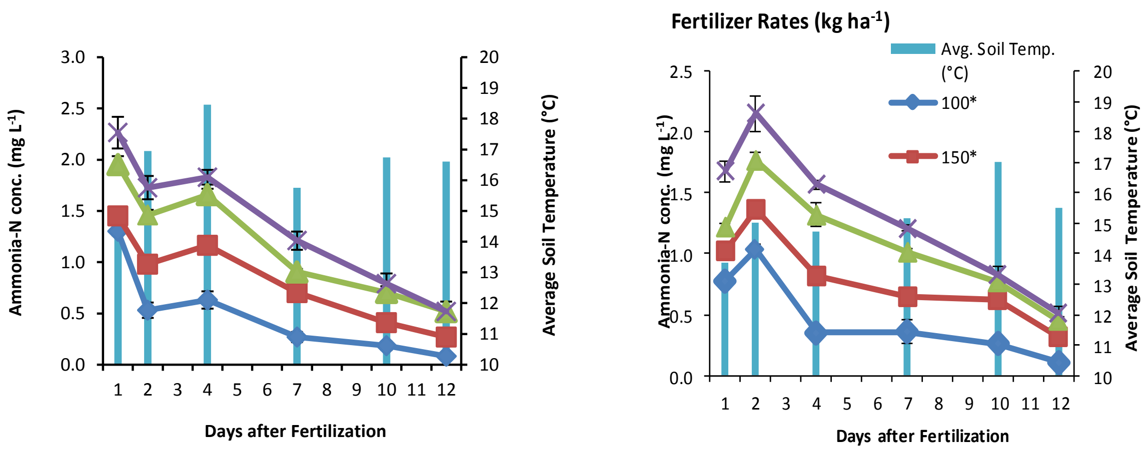
The overall environmental impact will be neutral/positive, as it is anticipated that the amount of current agrochemicals being used in the blueberry industry will be reduced. The intent of the proposed research is to develop site-specific management strategies for precise application of agrochemicals with minimal environmental impact. Mean leachate NO_3^--N concentrations for all VR treatments ranged from 2.71 to 3.84 mg L^{-1}, while those under uniformly fertilized in moderate slope and low lying areas were 7.72 and 8.52 mg L^{-1} , respectively.



Comparison of Nitrate-N concentration under VRT and uniform fertilization

4.8.2 Effect of Split VR Fertilization on Air Quality

Currently, fertilizer is applied uniformly in wild blueberry fields, once in a two year production cycle, without considering substantial variation in soil/plant characteristics, topographic features, and fruit yield. The heavy rainfall, gentle to severe topography with high proportion of bare spots, and weed patches in wild blueberry fields emphasizes the need for variable rate split (VRS) fertilization to avoid environmental contamination. The results of repeated measure analysis of variance showed ammonia volatilization losses were significantly ($p < 0.05$) lower in VRS sections as compared to uniformly fertilized sections of the selected fields.



Volatilization losses from different fertilizer rates at Field 1 (left) and Field 2 (right). Rates were divided into three equal amounts and applied three times in VRS section.

4.9 Conclusion: Precision Agriculture Technologies Advantages and Benefits

- Easy user-friendly setup on a touch screen monitor
- Automatic compensation for changing ground speed
- Manual speed input is possible in case there is GPS signal outage
- Adjustable front and back buffers for precise overlapping of agrochemical applications on targets
- Accurate placement of agrochemical reduces agrochemical use
- Cost effective
- Improve crop productivity
- Lowers pressure on environment
- Reduces operating costs to producers
- Help to expand to new markets from only spraying on the targeted location within the fields which can lower the residual levels on the harvested fruit
- Improve the competitiveness and profitability of the blueberry industry and enhance the sustainability of rural life.

Future Research

- Implementation and commercialization of Cost-effective, affordable and farmer's friendly precision agriculture technologies.

5. Most Significant Research and Development Contributions

Precision Harvesting Technologies – Increase Harvester Efficiency (2012-2017)

Increase Farm Profitability

...Improve Fruit yield and quality

5.1 Executive Summary

Dr. Zaman and his Precision Agriculture (PA) Research Team launched an initiative to develop innovative harvesting technologies in Atlantic wild blueberries. This proposal was a part of a multidisciplinary research effort at the Engineering Department, Faculty of Agriculture, Dalhousie University in collaboration with Doug Bragg Enterprises (DBE), Collingwood, Nova Scotia. This collaboration between industry and research scientist was initiated to develop innovative and viable techniques that should enhance berry picking efficiency, assist with the stabilization of yields over time and increase farm profitability. While this project is submitted with the collaboration of wild blueberry industry to increase harvestable berry yield and quality, the DBE harvester is being used to harvest 80% of the total acreage of wild blueberry in the Atlantic Provinces. 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 graduate students, post-doc fellows, wild blueberry producers and industry personnel, and a more competitive wild blueberry industry.

The research project “Improving efficiency of commercial wild blueberry harvester using precision agriculture technologies” was completed in September 2016. This research would help to ensure the long term stability of industry and make growers more profitable over time. The research contains training of HQPs component in the form of graduate and undergraduate student and postdoctoral fellow, and the continuing “lifelong” applied education of producers and industry representatives. Therefore, it is anticipated that this research would improve the current knowledge base of wild blueberry industry, potentially provide innovative technologies to reduce harvesting losses, and increase blueberry supply, and improve socio- and economic conditions in rural Atlantic Canada and Quebec. The PA team at Dalhousie Agricultural Campus is actively involved in transferring viable technologies including publications in scientific journals, growers’ magazines, radio and TV talks, presenting in national, international and industry meetings, and demonstrating the technologies in farmers’ field days. Results of current research project would increase harvestable berry yield and reduce operator stress.

5.2 Background

Northeastern North America is the world’s leading producer of wild blueberry *(Vaccinium angustifolium* Ait.) with over 93,000 ha under management and producing 145 million kg of fruit valued at $600 million annually. The crop is unique as it is native to North America and has never been cultivated. Fields are predominately managed on two-year cycles with the perennial shoots pruned in alternative years to maximize floral bud initiation, fruit set, yield, and ease of mechanical harvest. Wild blueberry crop has been harvested using 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). Although, the research on development of the mechanical harvester started in early 1950s, a viable mechanical harvester was not produced until the 1980s (Hall *et al*., 1983). 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.

Currently, the mechanically harvested blueberry area is more than 80% 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 using selective fertilizers and pesticides have resulted in healthy and tall plants, high plant density, tall weeds and significant increase in fruit yield. The increased harvesting losses of wild blueberry crop during harvesting due to change in crop and field conditions have pushed the growers and processors within the industry to set a goal, to increase the harvestable yields of wild blueberries by 33% to justify ever increasing cost of agrochemicals. Currently, there are 15 to 25% fruit yield losses during the harvesting with existing commercial blueberry harvester. Increased harvesting efficiency of the harvester would reduce fruit losses and contribute $31,200,000 to Atlantic Provinces and Quebec economy every year (WBPANS, 2010).

Improvements to the existing harvester using novel, automated and integrated precision agriculture (PA) systems to increase agricultural production will require; (i) identification of sources responsible for increased losses and reduced berry quality; (ii) improve harvestable berry recovery; (iii) replace old technology with innovative integrated harvesting system; (iv) find a suitable combination of ground speed and harvester head revolution with minimum losses after detailed evaluation of harvester using PA technologies and mathematical modeling procedures; (v) redesign the commercial blueberry harvester components to increase berry picking efficiency. The two primary objectives of this research initiative were to; (i) develop sensor fusion system for quantification of blueberry fruit yield losses; (ii) develop models for identification of sources of losses to improve harvesting efficiency in order to increase fruit yield; and (iii) train highly qualified personnel, producers and industry representatives.

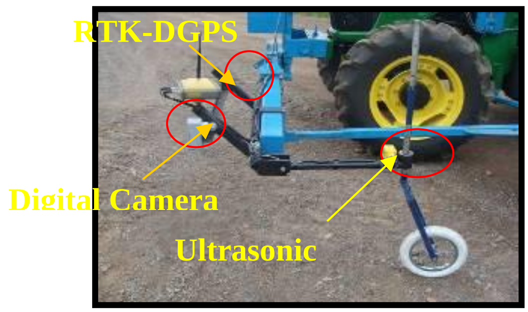
Optimizing Mechanical Harvester Efficiency: (2011-2015)

- ✓ Sensor Fusion System to Identify Sources of Error
- ✓ Quantification of Multiple Fruit Losses During Harvesting
- ✓ Design Analysis and Comparison of Different Harvester Heads (12 bar and 16 bar; 22” dia. 26” dia. and 26” wide teeth spacing)
- ✓ Impact of Relative Velocity and Different Header Forces on Fruit Picking Efficiency
- ✓ Effect of Crop Characteristics and Machine Parameters on Berry Losses
- ✓ Effect of Harvest Timings and Climatic Condition on Fruit Losses
- ✓ Development of Bio-System Modeling for Coupling of Biological, Environmental and Mechanical Processes
- ✓ On-Line Computer Program for Precise Berry Harvesting Recommendations
- ✓ Effective Use of Air from Variable Speed Blower to Separate Berries, Debris (leaves, shoots, dirt) – 26” head, 65 teeth and 26” head, 63 teeth
- ✓ Examine the fruit quality after harvesting with 26” head and 26” head (Quantification of fruit firmness at shoot, at the both sides of conveyors and in bin)
- ✓ Evaluate performance efficiency of debris cleaning brush on harvester head to improver berry yield and quality
- ✓ Economic analysis of small box and bin loader harvesters

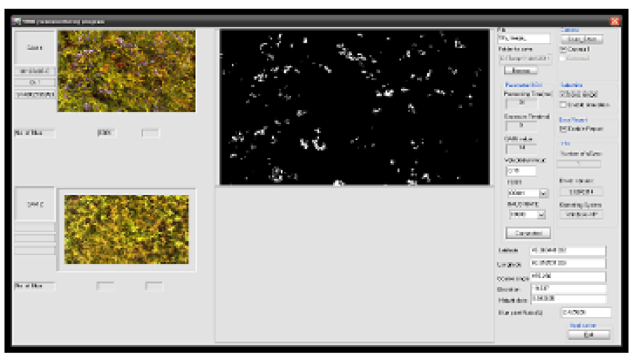
The following interconnected tasks accomplished in support of the above program.

5.2.1 Development of Sensor Fusion System

An integrated automated sensing system including ultrasonic sensor, digital color camera, slope sensor, RTK-GPS, custom software and laptop computer was developed. The system was incorporated into a blueberry harvester to map plant height, slope, elevation and fruit yield simultaneously. The information obtained from the system will be used to identify factors affecting harvesting efficiency of wild blueberry harvester. Commercial wild blueberry fields at different sites in Atlantic Provinces were surveyed to evaluate the performance of the system. Information obtained from the system could be used to increase berry picking efficiency of blueberry harvester. This information could also be used to optimize productivity while minimizing the environmental impact of farming operations in fields.

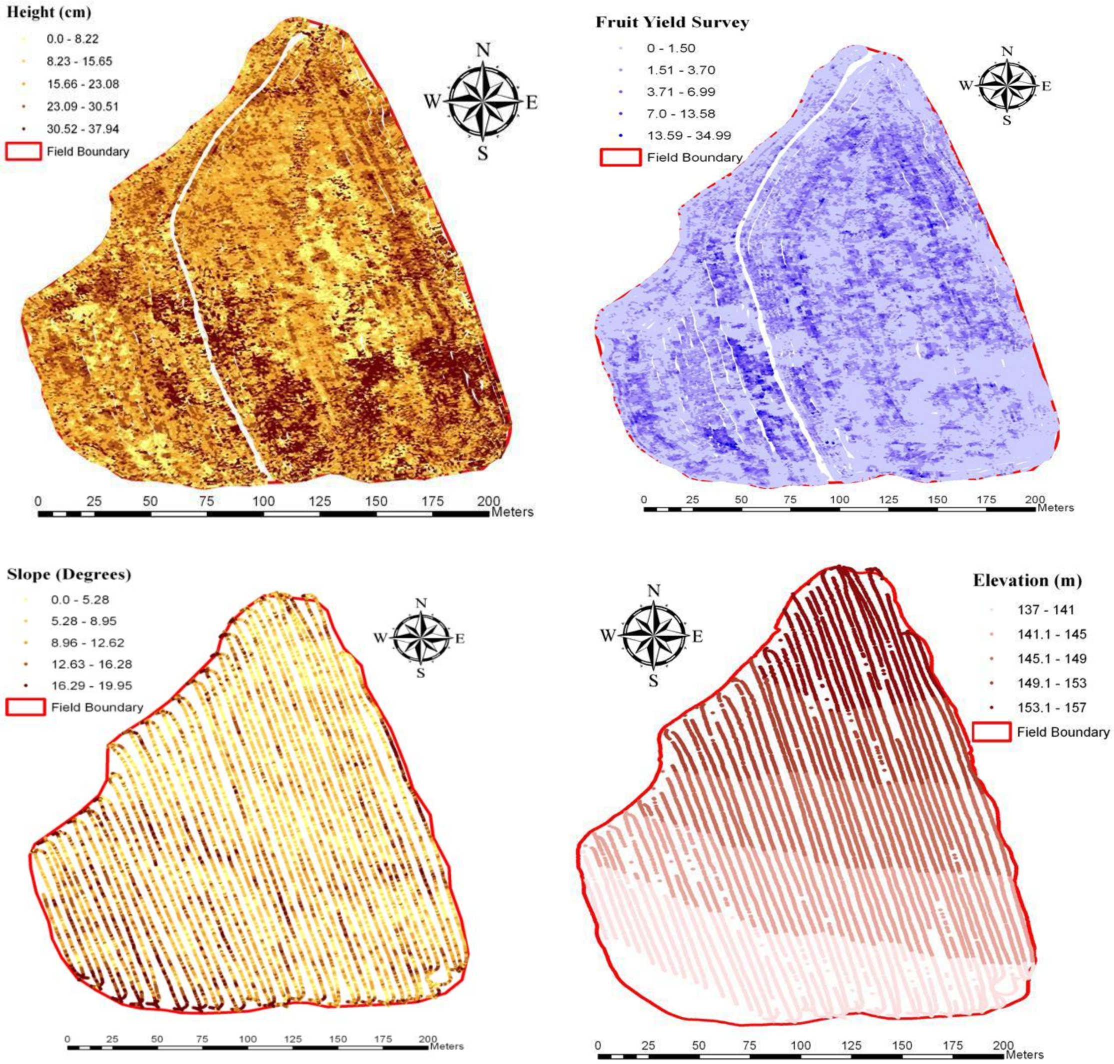


Yield monitoring system, ultrasonic sensor and RTK-GPS incorporated into harvester



Custom software to estimate fruit yield, plant height and topographic features

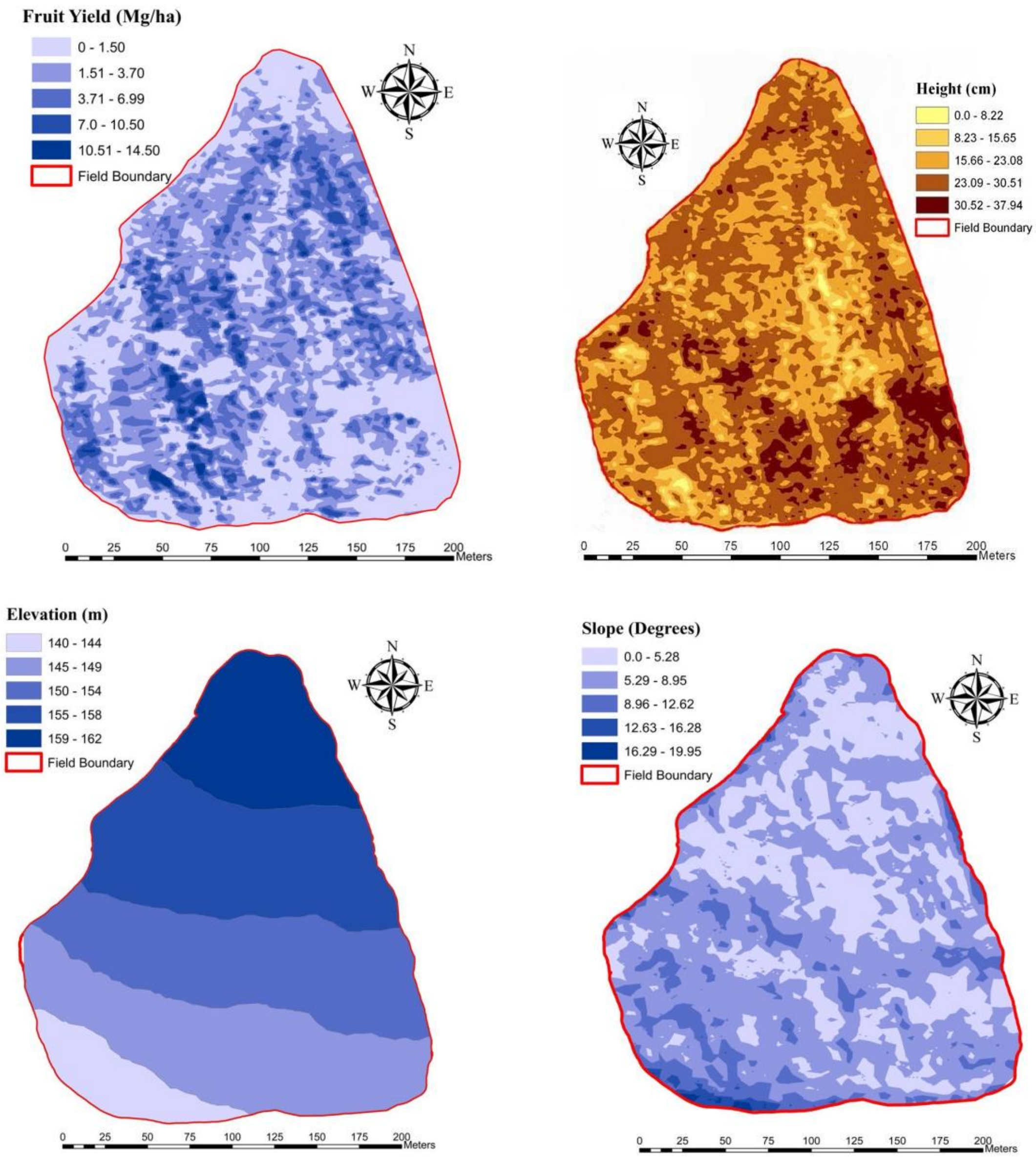
The developed system was tested and evaluated in selected wild blueberry fields i.e., Frankweb, Nova Scotia (4.10 ha); Londonderry, Nova Scotia (3.2 ha); Small Scott, Nova Scotia (1.6 ha) and Tracadie, New Brunswick (1.9 ha) to map plant height, slope, elevation and fruit yield in real-time. Customized 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.
Surveys were conducted to measure and map crop parameters and topographic features during July, 2013, and fruit yield was measured and mapped during harvesting season (August to mid-September, 2013) in selected wild blueberry fields. 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.



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.

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.



Kriged maps of fruit yield, plant height, elevation and slope with sensor fusion system.

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. 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 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.

The sensor fusion system (hardware and custom software; SFS) was developed and incorporated into wild blueberry harvester after lab testing and calibration of analog and digital sensors to map variability in plant height, fruit yield and topographic features in real-time. SFS mounted on harvester was evaluated in commercial blueberry fields in Atlantic Canada. Calibration and mapping results indicated that the developed system was an accurate, reliable and efficient to map plant height, fruit yield, slope and elevation in real-time. Results indicated that that there was a need to conduct research on harvester picking efficiency in different yield (low, medium and high) areas to quantify blueberry losses. This would help wild blueberry industry to generate more revenue and increase profitability. *Research results were published in scientific journal Computer and Electronics in Agriculture and presented in international conference and industry meetings. This research was part of PhD thesis research (completed).* These research results will directly support the automation of blueberry harvester to improve berry picking efficiency and reduce operator stress.

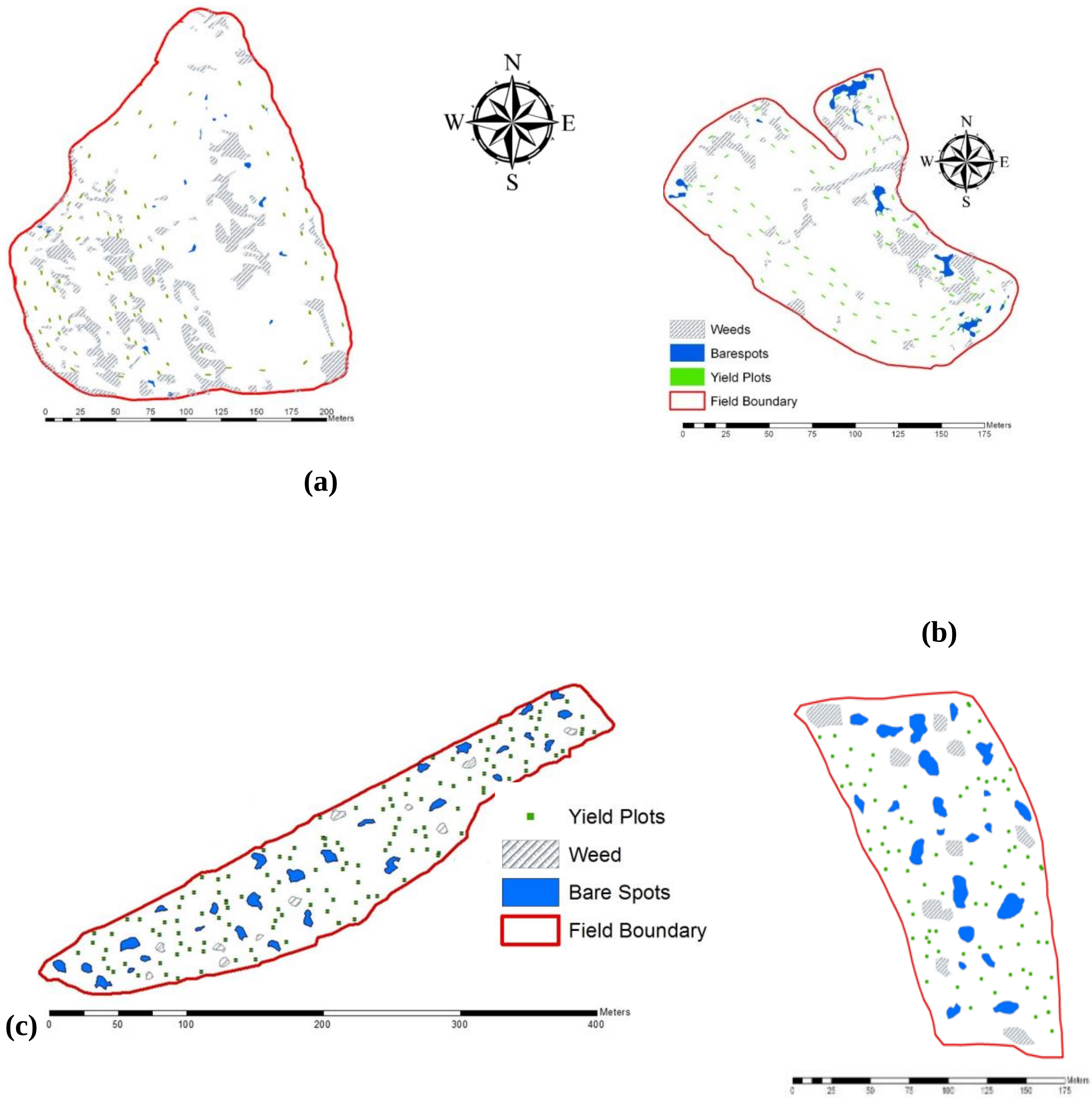
5.2.2 Quantification of Fruit Losses during Harvesting

Wild blueberry fields were selected to evaluate the berry picking efficiency of commercial wild blueberry harvester. The harvester was operated at specific levels of ground speed at 1.20, 1.6 and 2.0 km h^{-1} and header rpm 26, 28 and 30. The total fruit yield, un-harvested berries on the plants, berries on the ground, and berries through blower were collected from each plot within selected fields. The pre-harvest fruit losses were collected from each plot prior to harvest. The slope, plant height and fruit zone were also recorded manually from each plot. Results of this study 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 blueberry fields with yield over 3500 kg ha^{-1}. *Results were published in scientific journal Applied Engineering in Agriculture and presented in international conference and industry meetings. This research was part of PhD thesis research (completed).* This information will help to develop an automated system (hardware and software) to adjust ground speed and header rpm automatically according to the variation in fruit yield to increase harvestable berry yield.

5.2.2.1 Evaluation of Berry Picking Performance Efficiency of Harvester

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. Eighty one yield plots were selected randomly in each field. The harvester was operated at specific levels of ground speed at 1.20, 1.6 and 2.0 km h^{-1} and header rpm of 26, 28 and 30. The pre-harvest fruit losses were collected from each plot prior to harvest. The slope, plant height, and fruit zone were also recorded manually from each plot. 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.

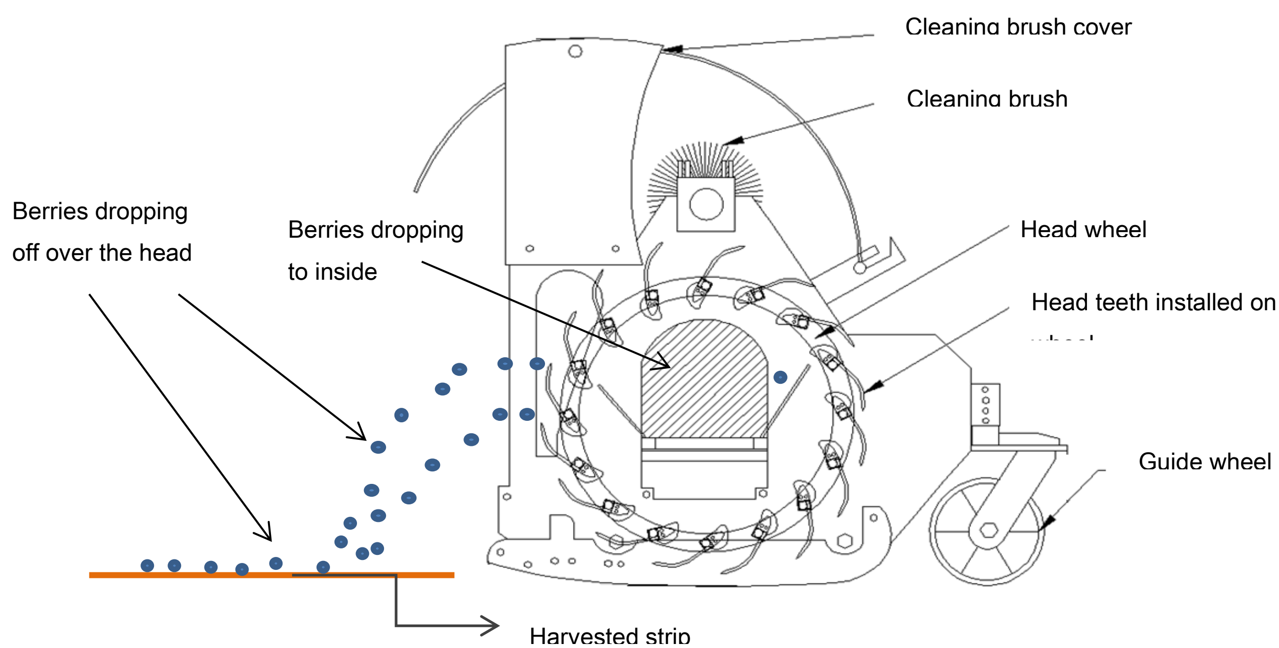
The data collected for fruit losses was analyzed using statistical; geo-statistical, bio-systems modeling and mapping tools to calculate the fruit losses at various combinations of ground speed and revolutions and to identify the factors responsible for losses.



Layouts of selected wild blueberry fields

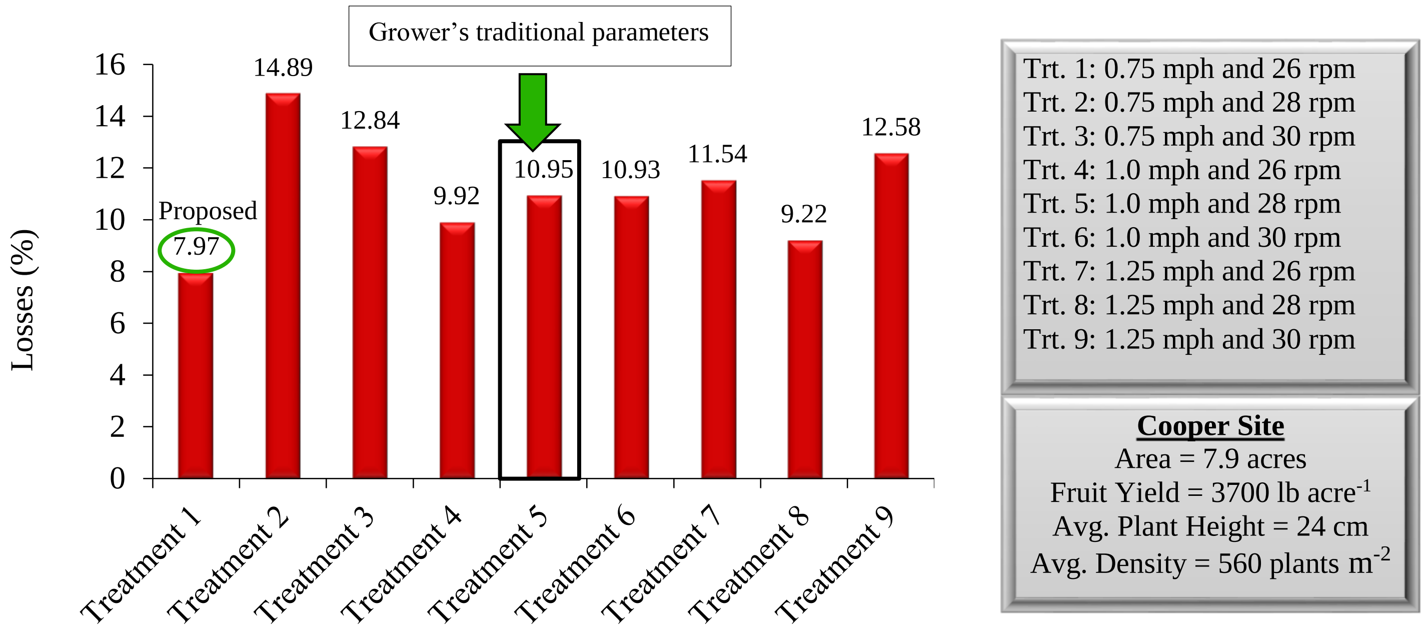
The results of this study suggest that the pre-harvest fruit losses are found to be higher during the late season suggesting that early season harvesting could be helpful in reducing pre-harvest fruit losses. Higher percentage of losses on the ground suggested that the berries were picked by the harvester but not effectively conveyed to the inside conveyer for transportation to the storage bin on the back of the harvester. The losses on the ground emphasized the need to operate the harvester at lower ground speed and header rpm to provide a gentle upward movement of reel teeth bars through the plants to enhance berry picking efficiency.

Collection of losses on the ground and un-harvested berries on the plants and fruit losses through blower and total fruit yield from the harvested plot.

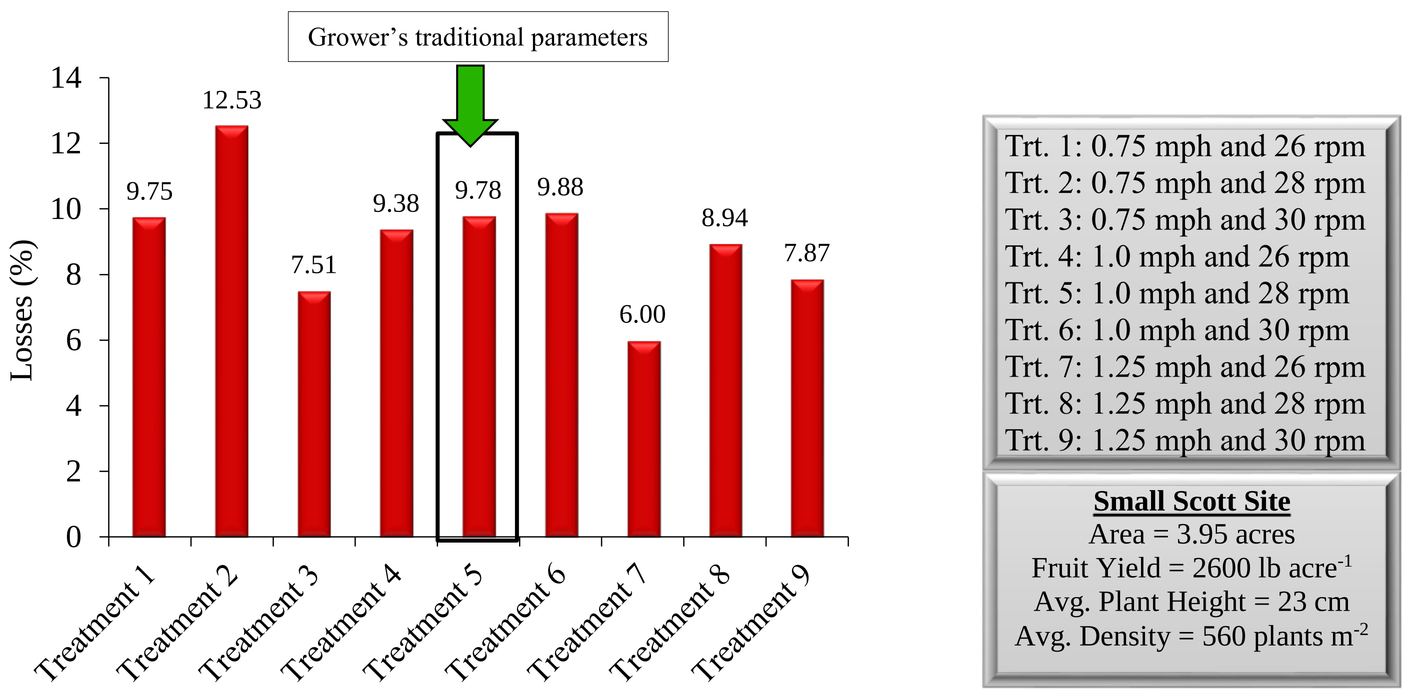


Berries dropped over the harvester strip after being picked by the harvester head during harvesting.

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.



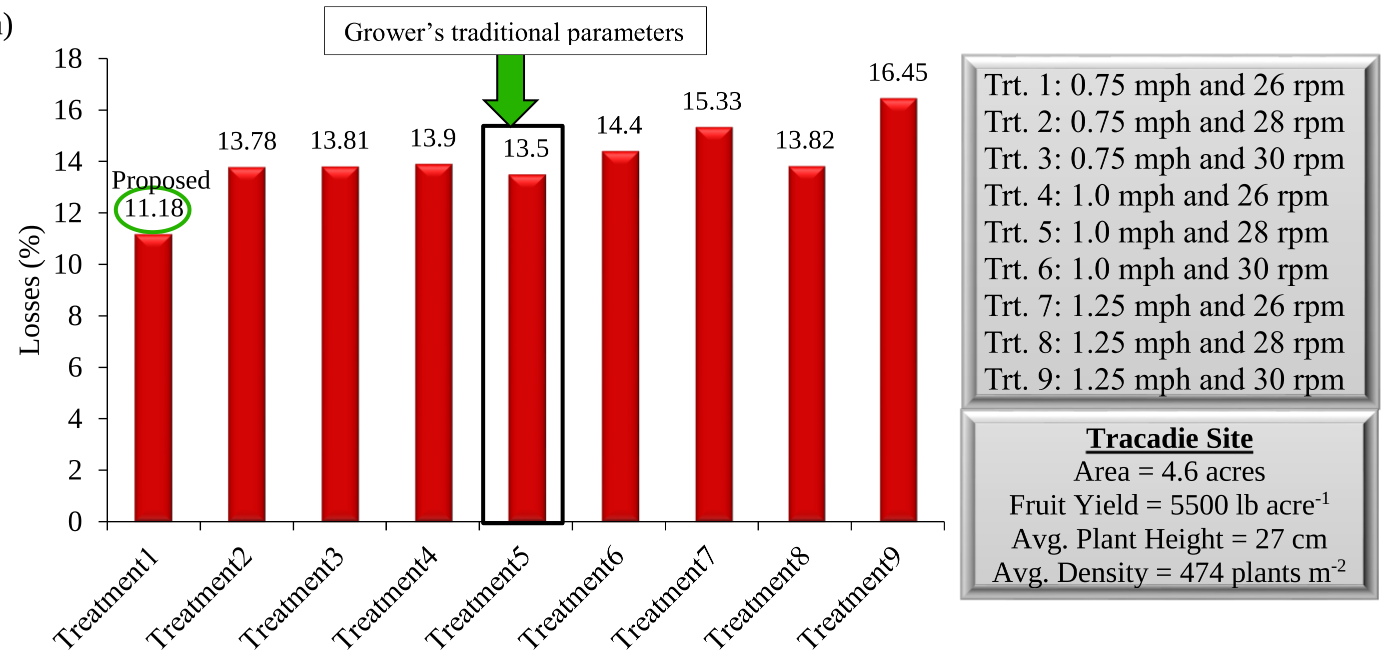
(a)

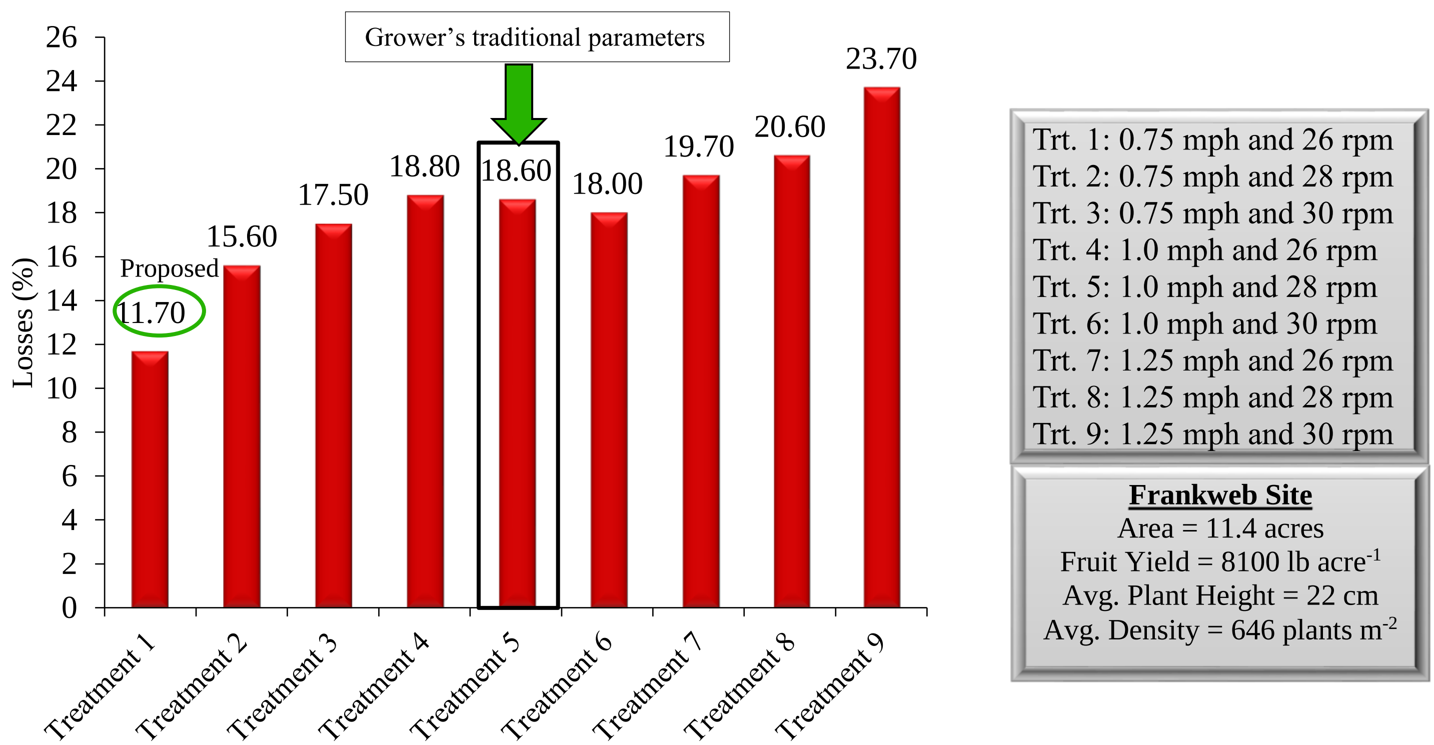


(b)

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

(a)





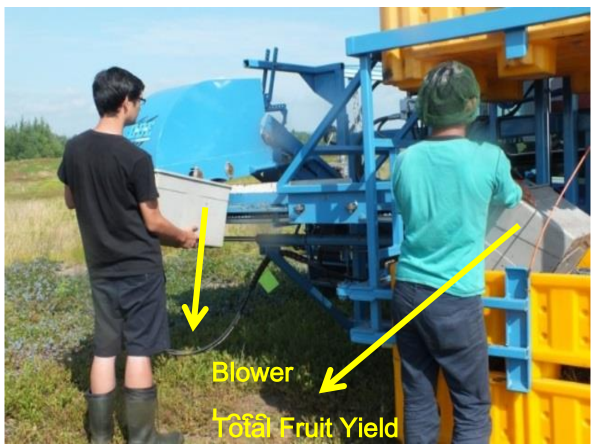
(b)

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

The results 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 harvester. Other factors including operator skills, field and weather conditions, time of harvesting, , 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.

5.3 Modification and Evaluation of Different Harvester Heads to Reduce berry Loss

Different components (number of teeth bars, spacing in bars, spacing in teeth, head diameter, inner conveyor width) of traditional harvester head (22” dia. and 16 teeth bars) were modified and evaluated in lab and field using innovative techniques to increase harvestable yield. Design analysis of different harvester heads (traditional and modified) was performed to calculate tip velocities, tangential and radial forces, patterns and paths of operating harvester along with the capacities of the internal and external conveyer of harvester, to examine their impact on picking efficiency and berry quality.



Collecting fruit sampling for berry quality analysis

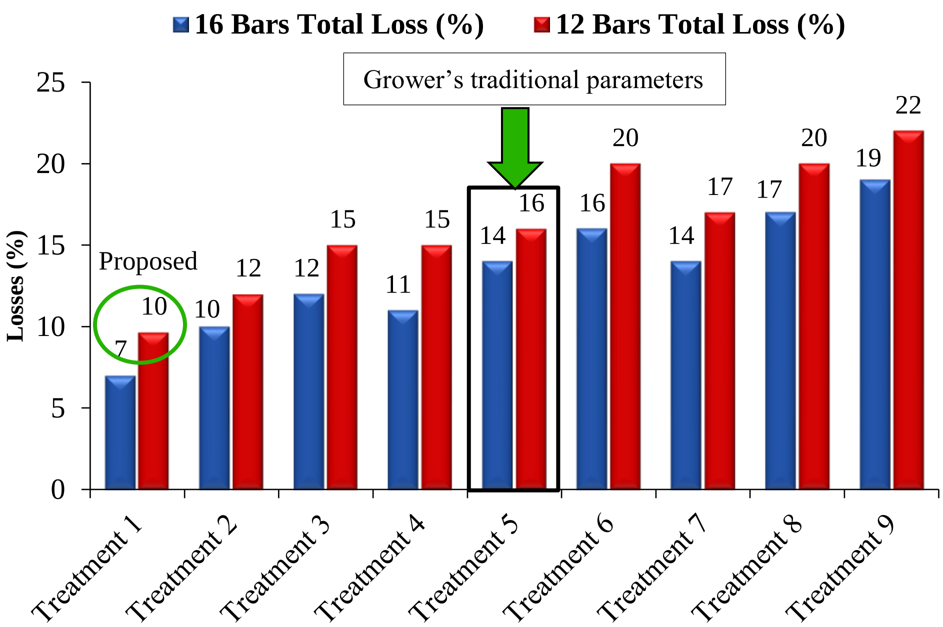
Wild blueberry fields were selected in Atlantic Provinces. Fruit losses (losses on the ground, losses on the leaves, blower losses, pan losses, and pre-harvest losses) and fruit yield were collected at different crop conditions (small and tall plants, low to high plant density, low and high yield, different fruit zone and dia.) from selected fields. Variation in plant height, fruit yield and slope were mapped with multiple sensors and related to field losses. The information obtained will help to develop integrated harvesting technologies and adjust machine parameters automatically in order to reduce fruit losses.

5.3.1 Comparison of Harvester Heads (12 bar and 16 bar)

Traditional blueberry harvester has sixteen bars head. The DBE has been trying to improve the design of harvester head in order to reduce fruit losses during harvesting. Based on the preliminary results of this project and design analysis of principle components of existing sixteen bars harvester, a twelve bars harvester head with more spacing between bars was developed to improve berry picking efficiency. Both harvester heads were operated at different combination of ground speeds (1.2, 1.6, and 2.0 km h^{-1}) and header rpm (26, 28, and 30 rpm).

Design analysis of harvester head components

Results indicated that twelve bars harvester head caused 15.18% and 28.82% higher losses (%) as compared to sixteen bars head. The 12 bar head provided more space for plants which causes the head to take bigger bites. The 12 bar head combed through each plant 6 times, while the 16 bar head combed through each plant 9 times. The capacity of the 12 bar head was 25% lower than 16 bar head. The 16 bar head kept the berries more securely inside the header. The 12 bar head pulled 12% and 39% more plants when compared with 16 bar head during dry and wet conditions, respectively. Field experimentation, visual observations and video clips proved that there were significantly higher losses with 12 bar head. *Presented in international conference and industry meetings.*

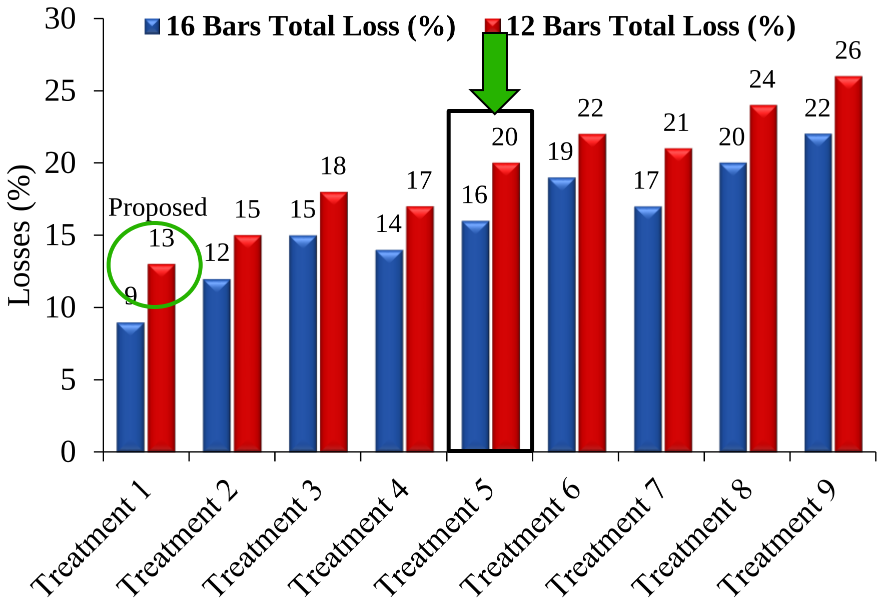


Trt. 1: 0.75 mph and 26 rpm
Trt. 2: 0.75 mph and 28 rpm
Trt. 3: 0.75 mph and 30 rpm
Trt. 4: 1.0 mph and 26 rpm
Trt. 5: 1.0 mph and 28 rpm
Trt. 6: 1.0 mph and 30 rpm
Trt. 7: 1.25 mph and 26 rpm
Trt. 8: 1.25 mph and 28 rpm
Trt. 9: 1.25 mph and 30 rpm

Robbie Glenn Site

Area = 8.0 acres
Fruit Yield = 3385 lb $acre^{-1}$
Avg. Plant Height = 23 cm
Avg. Density = 560 plants m^{-2}

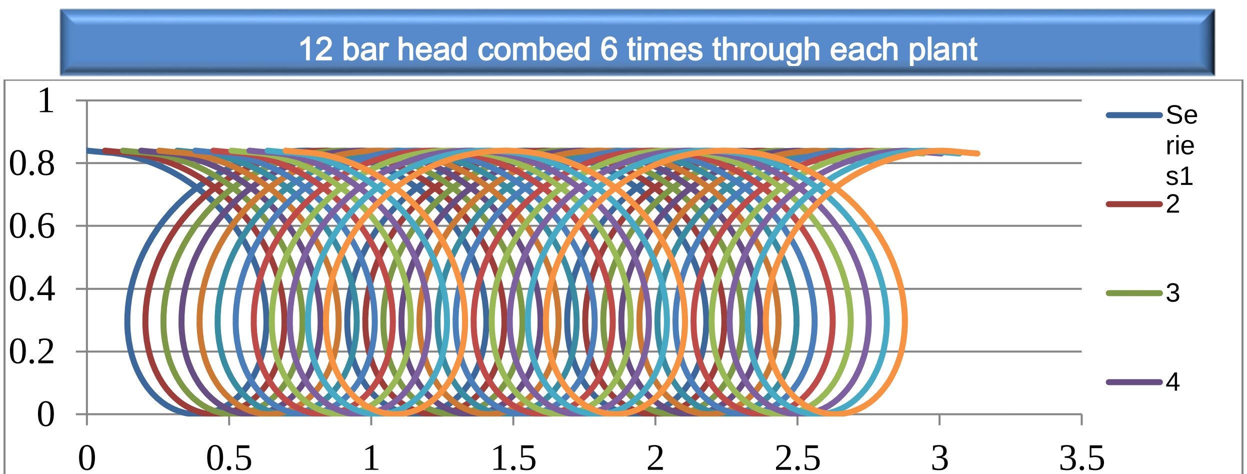
Mean comparison of total fruit losses (%) with 12 bars and 16 bars heads for Robbie Glenn Site.

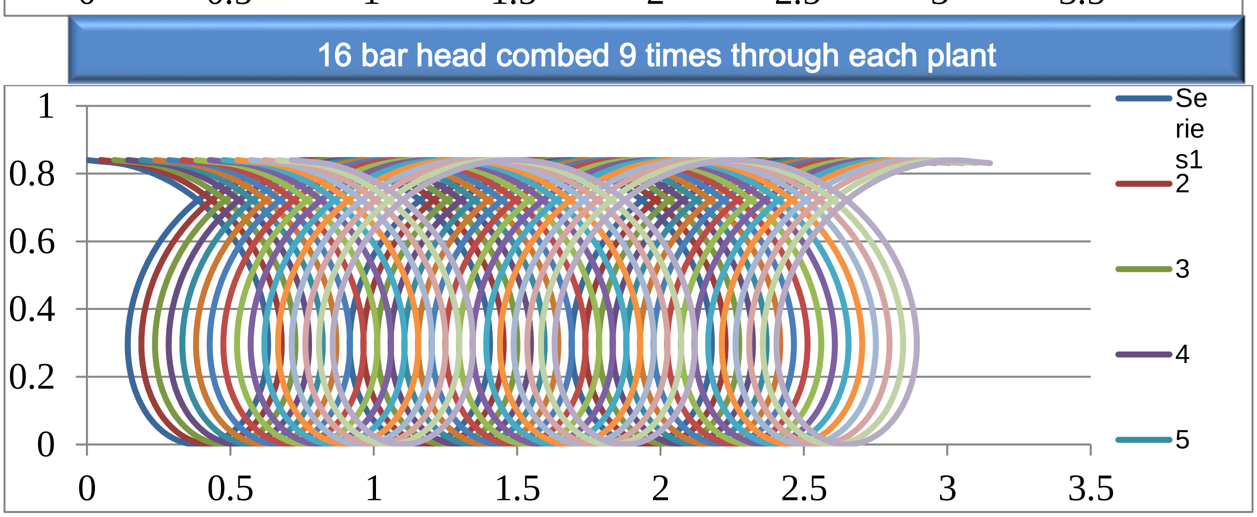


Trt. 1: 0.75 mph and 26 rpm
Trt. 2: 0.75 mph and 28 rpm
Trt. 3: 0.75 mph and 30 rpm
Trt. 4: 1.0 mph and 26 rpm
Trt. 5: 1.0 mph and 28 rpm
Trt. 6: 1.0 mph and 30 rpm
Trt. 7: 1.25 mph and 26 rpm
Trt. 8: 1.25 mph and 28 rpm
Trt. 9: 1.25 mph and 30 rpm

Hardwood Hill Site
Area = 5.1 acres
Fruit Yield = 6973 lb $acre^{-1}$
Avg. Plant Height = 19 cm
Avg. Density = 646 plants m^{-2}

Mean comparison of total fruit losses (%) with 12 bars and 16 bars heads for Hardwood Hill Site.





Head Capacity Comparison

16 Bar Head		12 Bar Head	
Max Yield Harvestable (Kg/ha)	25568	Max Yield Harvestable (Kg /ha)	19176
5% Leaves by Volume	24290	5% Leaves by Volume	18217
10% Leaves by Volume	23011	10% Leaves by Volume	17259
15% Leaves by Volume	21733	15% Leaves by Volume	16300

The capacity for the 12 bars head is 25% lower than 16 bars head

Results

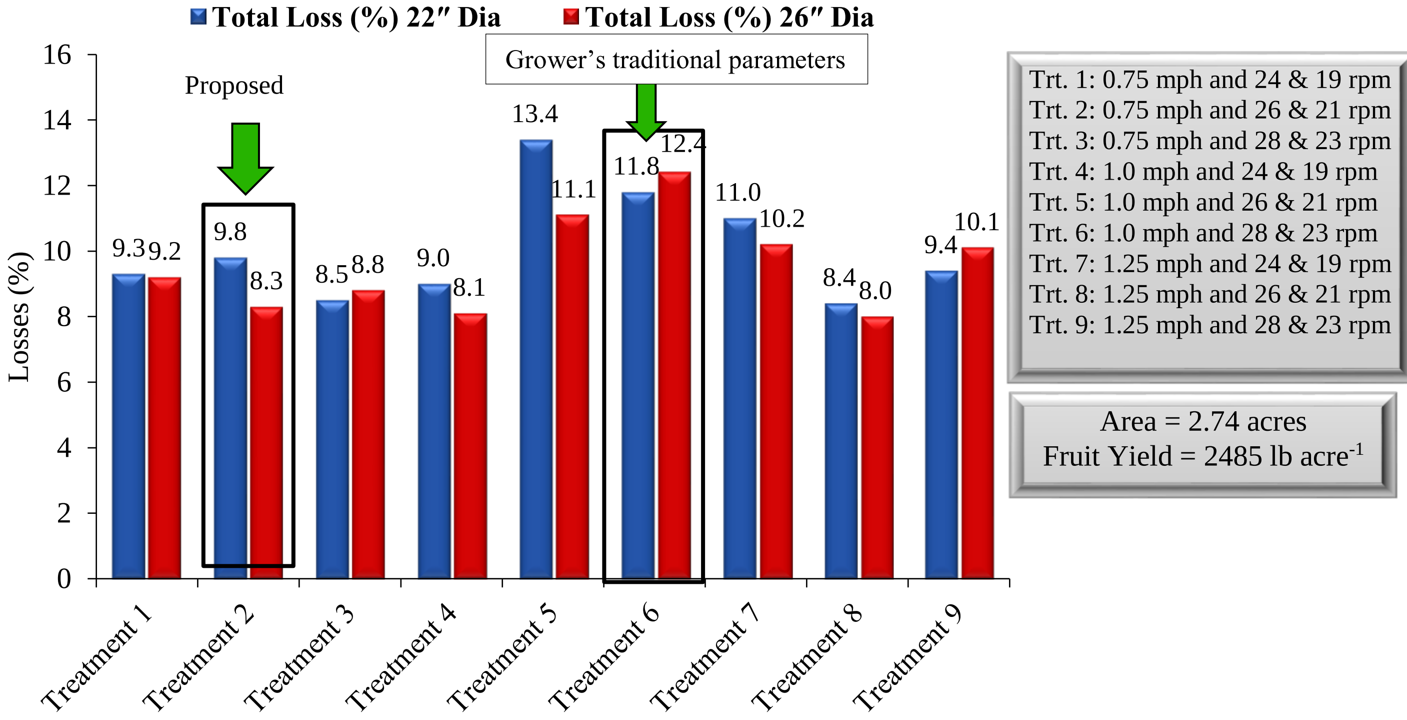
- ✓ The 12 bar head provides more space for plants which causes the head to take bigger bites
- ✓ The 12 bar head combed through each plant 6 times, while the 16 bar head combed through each plant 9 times
- ✓ The capacity of the 12 bar head is 25% lower than 16 bar head
- ✓ The 16 bar head keep the berries more securely inside the header
- ✓ The 12 bar head pulled 12% and 39% more plants when compared with 16 bar head during dry and wet conditions, respectively

We propose harvester should be operated at a combination of 0.75 mph and 26 rpm in wild blueberry fields with yield over 3000 kg ha^{-1} to reduce berry losses.

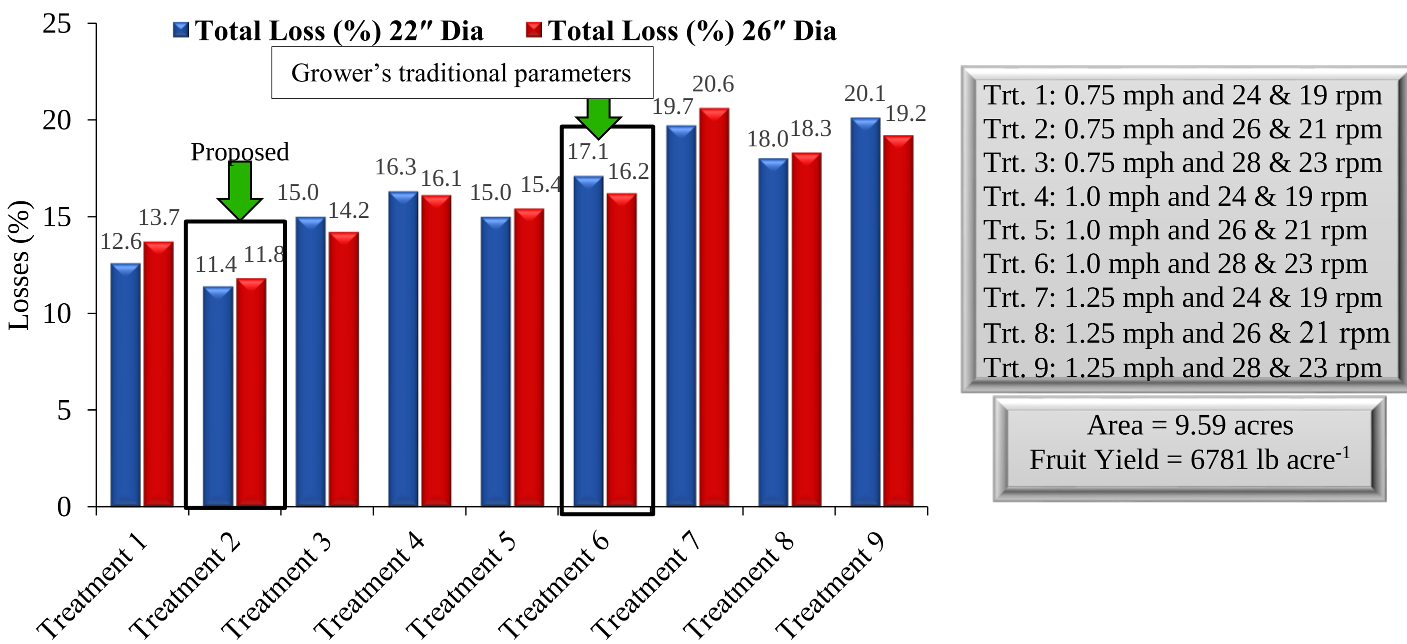
5.3.2 Comparison of Harvester Heads (22" dia. and 26" dia.)

Traditional harvester was modified, based on previous results of lab (design analysis) and field experiments using PA technologies to improve berry picking efficiency of harvester. Traditional head (22" dia) was modified by increasing the diameter of head and inner diameter of conveyer. Both harvester heads were operated at different combination of ground speeds (1.2, 1.6, and 2.0 km h^{-1}) and header rpm for 22 dia head (26, 28 and 30 rpm) and comparable head rpm (20, 22 and 24 rpm) for 26" head. Results indicted less fruit loss with 26' diameter head in traditional fields than 22" dia. head. The 26" diameter head pulled less plants than 22" head during harvesting.

Larger circumference with 26" head allowed for debris to be more thoroughly cleaned from picker teeth. (Stretched bar spacing on the 26" diameter head). Improved cam action resulted in a gradual picking action with 26" head. The inner head conveyor width was increased from 8" to 12" on 26" diameter head, allowing for a larger carrying capacity. The wider conveyor seems to allow for better berry handling when travelling on steep slopes (less dropped berries). The 26" dia head worked well on rough terrain and required less adjustment in head height without digging ground surface. *Results were presented in industry meetings and reported in routinely progress report.*



Mean comparison of total fruit losses (%) for 22" dia and 26" dia heads



Mean comparison of total fruit losses (%) for 22" dia and 26" dia heads at different treatment combination

Teeth Bar Spacing

22' Diameter Head

Spacing between the teeth bars - 1.37 inches

26' Diameter Head

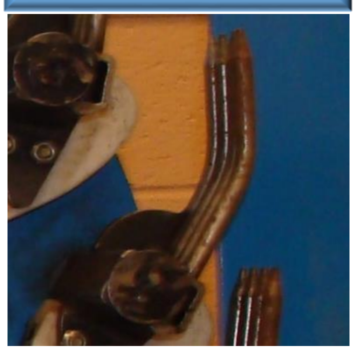
Spacing between the teeth bars - 1.63 inches

Head Capacity Comparison

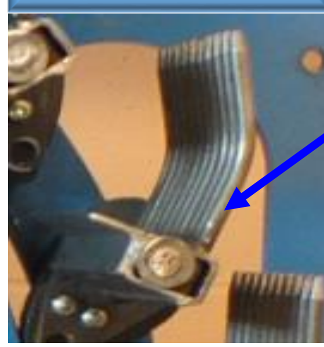
Part	26' Head	22' Head
Harvester Head (kg/ha)	218312.41	98602.43
Interior Conveyor (kg/ha)	34223.43	25164.17
Exterior Conveyor (kg/ha)	21426.52	21426.52
Overall Maximum (kg/ha)	21426.52	21426.52

The capacity for the 26' Head is **26% higher** than the 22' Head.

22' Diameter Head



26' Diameter Head



Extra Shelf

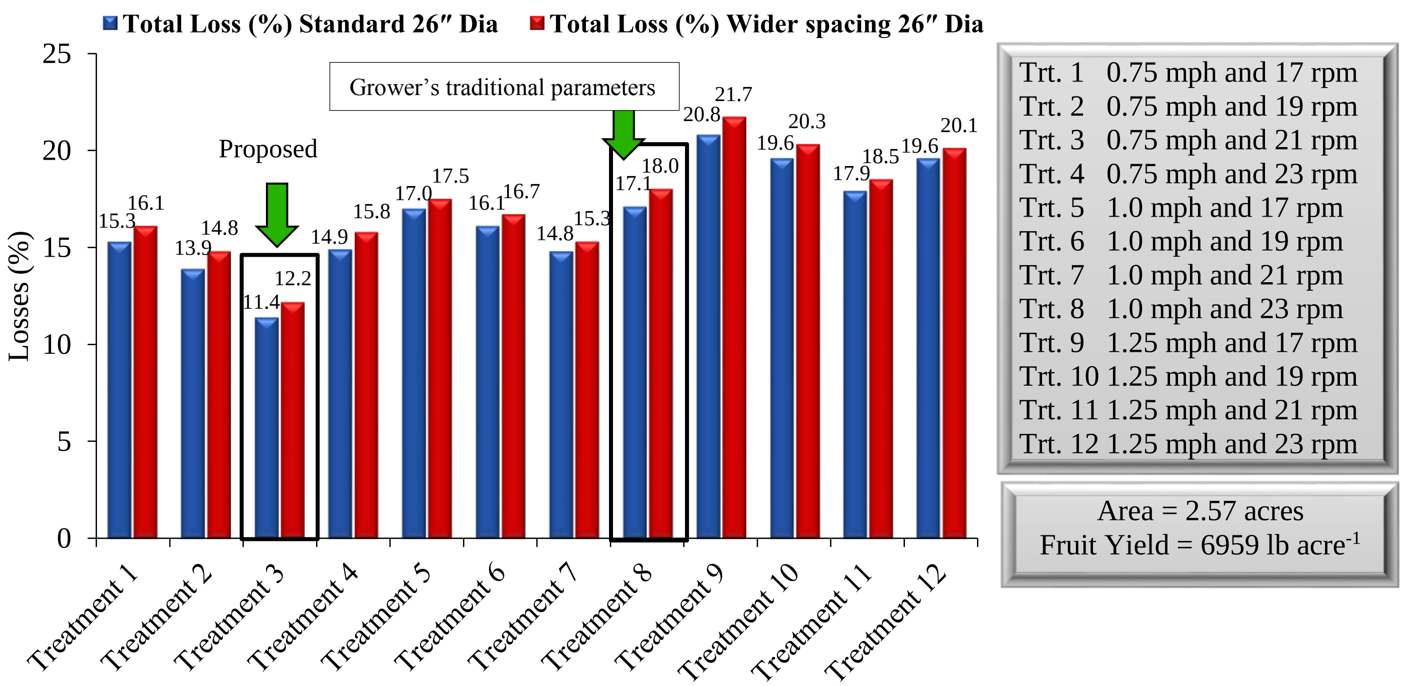
Results

- ✓ Less fruit loss with 26' diameter head in traditional fields than 22" dia. head.
- ✓ The 26" diameter head pulled less plants and debris than 22" head while harvesting.
- ✓ Larger circumference with the 26" head allowed for debris to be more thoroughly cleaned from the picker teeth. (Stretched bar spacing on the 26" diameter head).
- ✓ Improved cam action resulting in a gradual picking action from an increased diameter with the 26" head.
- ✓ The inner head conveyor has increased in width from 8" to 12" on the 26" diameter heads allowing for a larger carrying capacity.

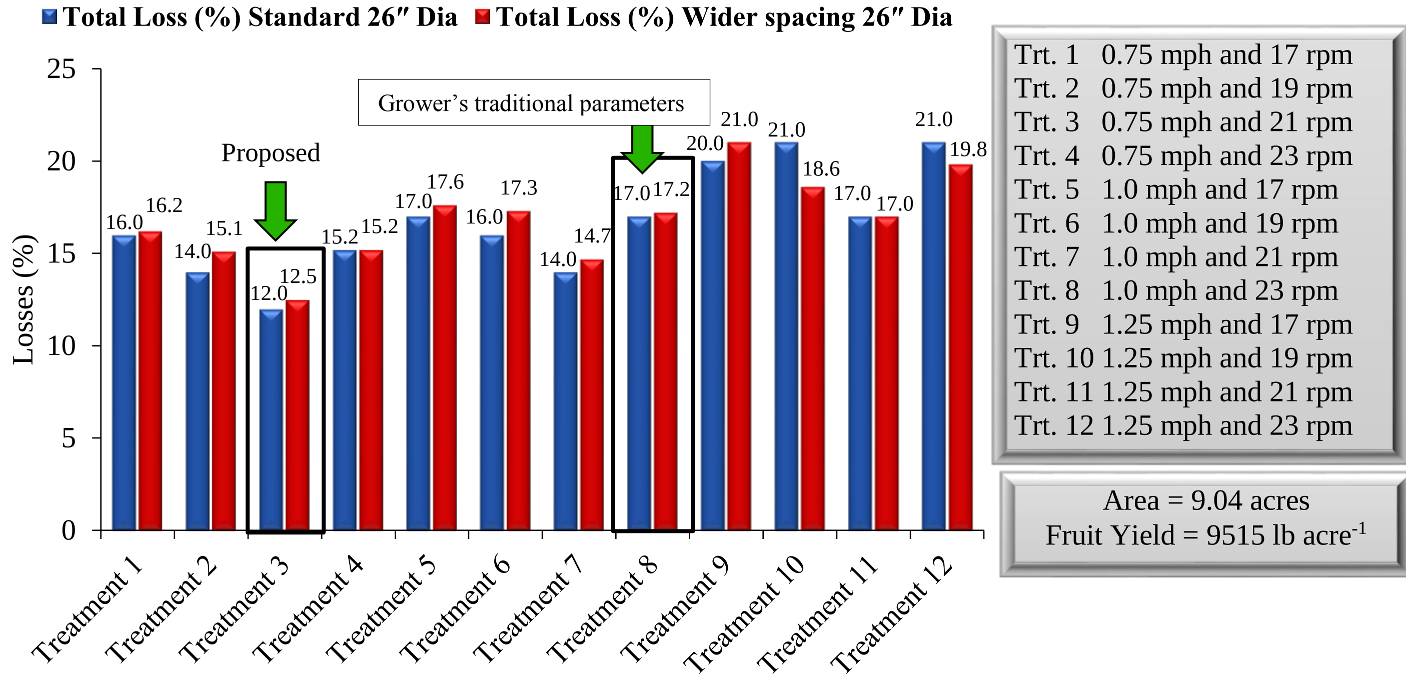
- ✓ The increased inner head conveyor has better debris handling (not as much an issue with the conveyor plugging with debris when wet).
- ✓ The wider conveyor seems to also allow for better berry handling when travelling on steep slopes (less dropped berries).
- ✓ The larger 26” diameter head seems to be easier to operate over rough terrain and required less adjustment in head height to successfully harvest the berries without digging into the ground surface.

5.3.3 Comparison of Harvester Heads (26” dia. head with standard teeth and increased spacings)

Another attempt was made to modify 26” dia. harvester head, based on the previous results of lab (design analysis) and field experiments. The 26” dia head was modified by increasing the spacing in between teeth on bars of head. The data was analyzed using statistical, geostatistical and GIS techniques and presented in meetings. The information obtained through detailed study of machine parameter related to field, crop and climatic conditions would improve harvestable fruit yield. The 26” dia head was modified by increasing the spacing in between teeth on bars of head performed better than 26” dia. harvester with standard teeth spacing bar.



Mean comparison of total losses (%) for 26” dia and 26” dia wider spacing heads at different combination.

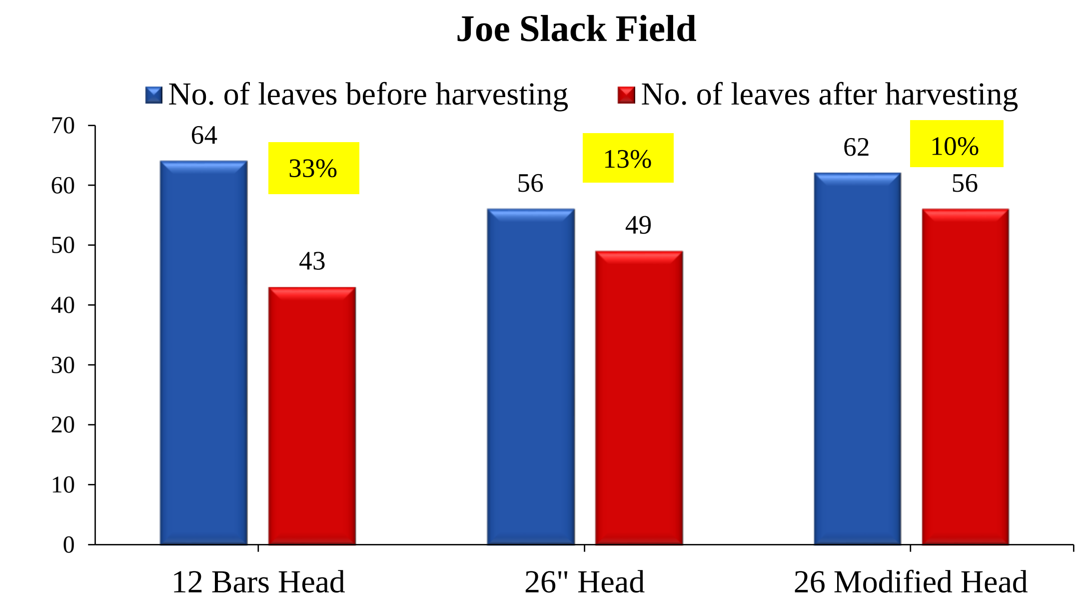


Comparison of total losses (%) for 26” dia and 26” dia wider spacing heads

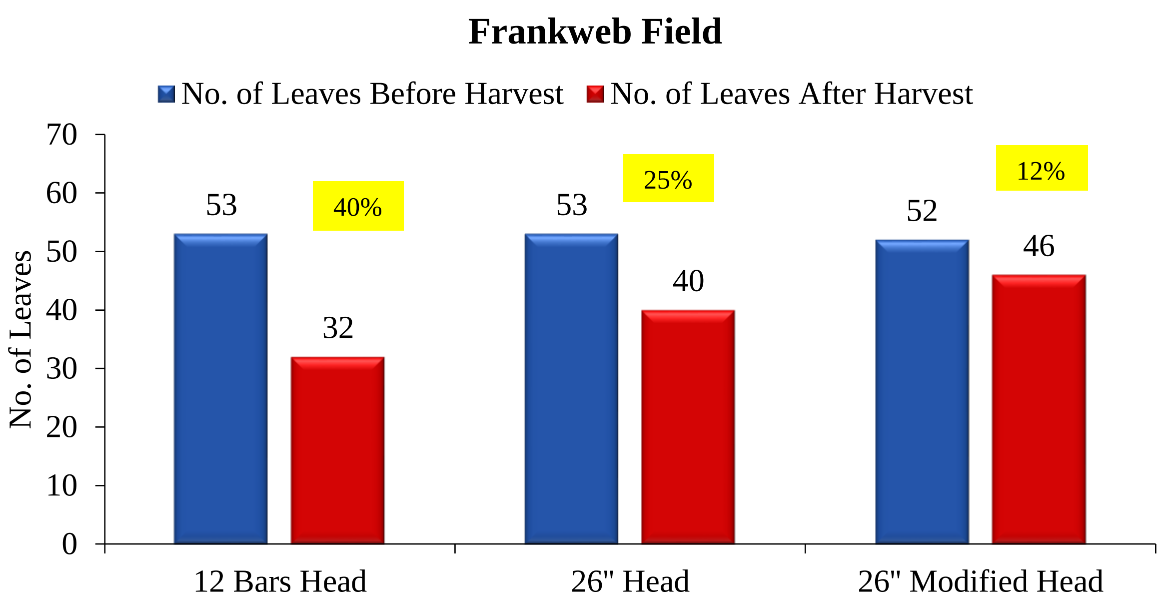
5.3.4 Three Wild Blueberry Harvester Heads (22” and 26” bars and 26” with Wider Teeth Spacing; 67, 65 and 63) for Plant Damage

Performance efficiency of different harvester heads was evaluated for plant damage during harvesting. Data was collected before rainfall and after rainfall for comparison. Results of preliminary comparison between 22”-12 bar and 22”-16bar heads indicated that 22”-12 bar head pulled more plants as compared to 22”-16 bar head. The 26-16 harvester head designed with increased diameter (26 in.) performed better as compared to 22”-16 bar head in both dry and wet conditions. The reason for better performance with increased diameter head could be the increased spacing between bars of 26”-16 bar head, which allowed relatively less aggressive action resulting in lesser plant pulling as compared to 22”-16 bar head.

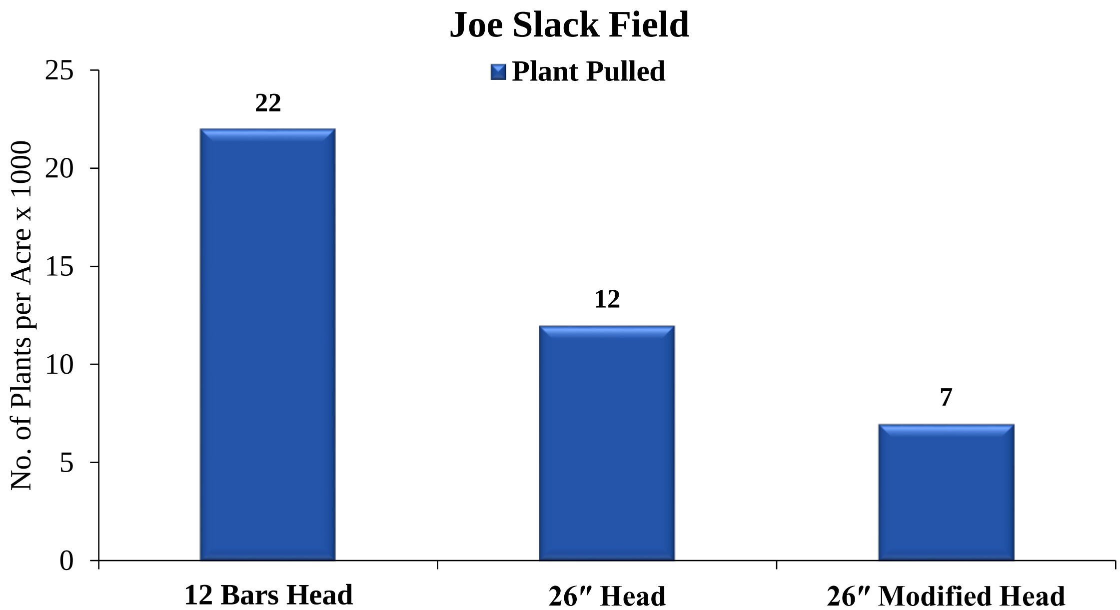
Data for 26” head with wider teeth spacing is being analyzed using statistical, geostatistical techniques and GIS software for comparison. The results of this study will help to improve berry picking efficiency and reduce plant damage during harvesting. The automated harvesting system will be developed using for real-time adjustment of head height and machine parameters to increase harvestable fruit yield.



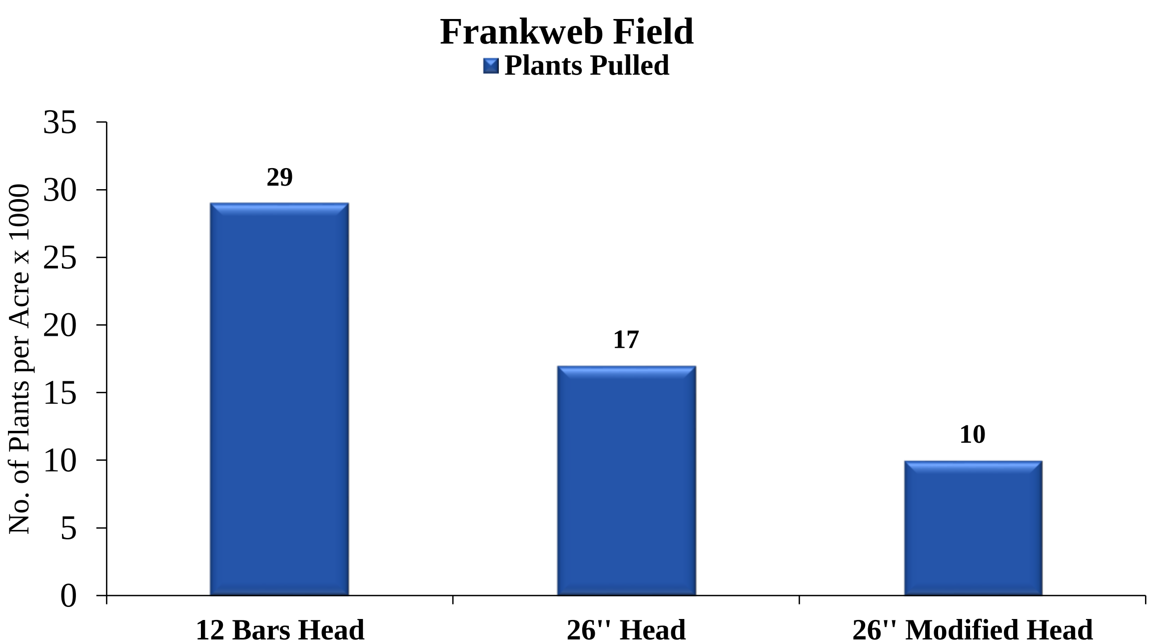
Defoliation of plants with three different heads for Joe Slack field.



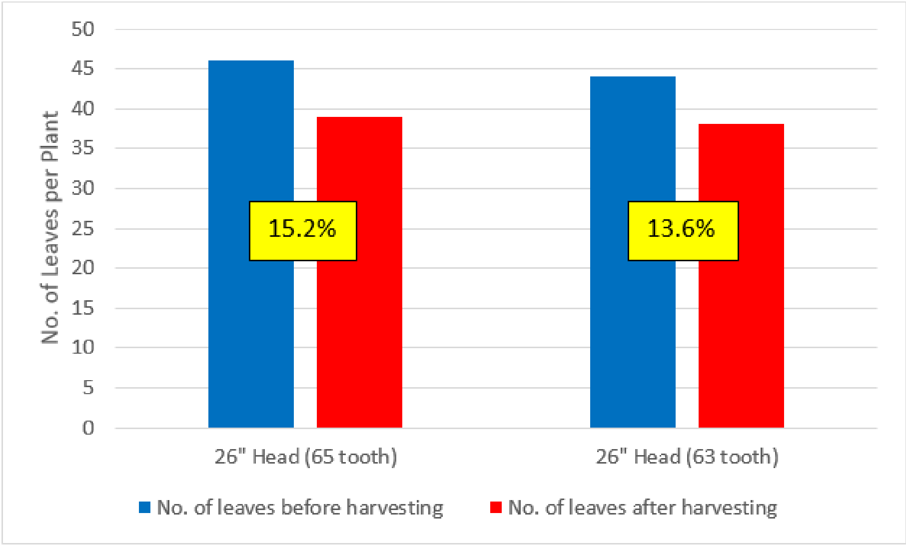
Defoliation of plants with three different heads for Frankweb field.



No. of plants pulled by three different heads for Joe Slack field.



No. of plants pulled by three different heads for Frankweb field.



The 26-16 harvester head with 65 and 63 tooth bar was designed and evaluated for berry quality improvement. Preliminary results indicated leaf loss was less with 63 tooth bar harvester head. However, visual observation revealed there was more small size berry loss with 63 than 65 tooth bar during harvesting.

Results

- ✓ Less "plant pulling" with wider teeth spacing 26" 16 bar head than 22" 12 bar head 26" 16 bar head.
- ✓ Less leaf loss with wider teeth spacing 26" head than 22" 12 bar head 26" dia. head.
- ✓ More small sized berries left on the stem and ground while with the wider teeth spacing.
- ✓ Potential for better debris cleaning from the brush with the wider teeth spacing.
- ✓ Potential for less fruit bud damage with wider teeth spacing.
- ✓ Larger circumference with the 26" head allowed for debris to be more thoroughly cleaned from the picker teeth. (Stretched bar spacing on the 26" diameter head).
- ✓ Improved cam action resulting in a gradual picking action from an increased diameter with the 26" head.
- ✓ The inner head conveyor has increased in width from 8" to 12" on the 26" diameter heads allowing for a larger carrying capacity.
- ✓ The increased inner head conveyor has better debris handling (not as much an issue with the conveyor plugging with debris when wet).
- ✓ The wider conveyor seems to also allow for better berry handling when travelling on steep slopes (less dropped berries).

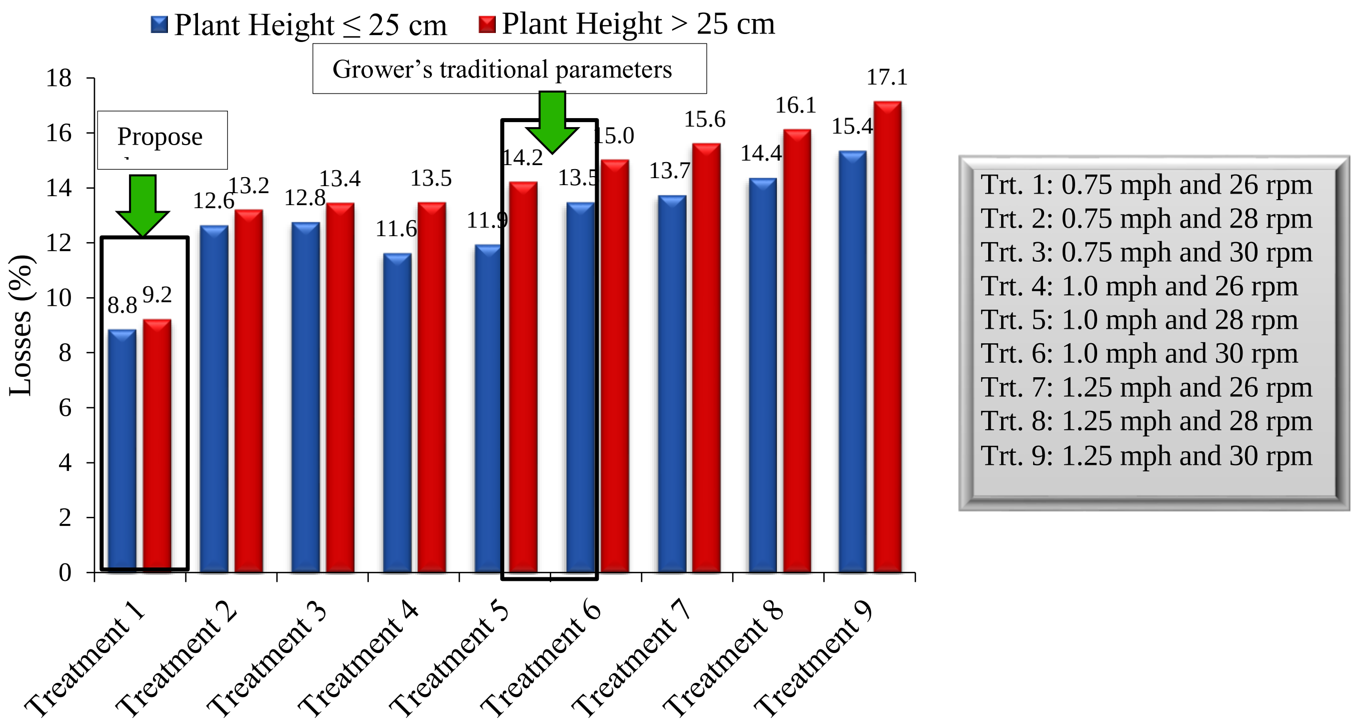
The larger 26" diameter head with 65 tooth bar seems to be easier to operate over rough terrain and required less adjustment in head height to successfully harvest the berries without digging into the ground surface.

5.4 Effect of Plant Characteristics on Berry Picking Efficiency of the Harvester

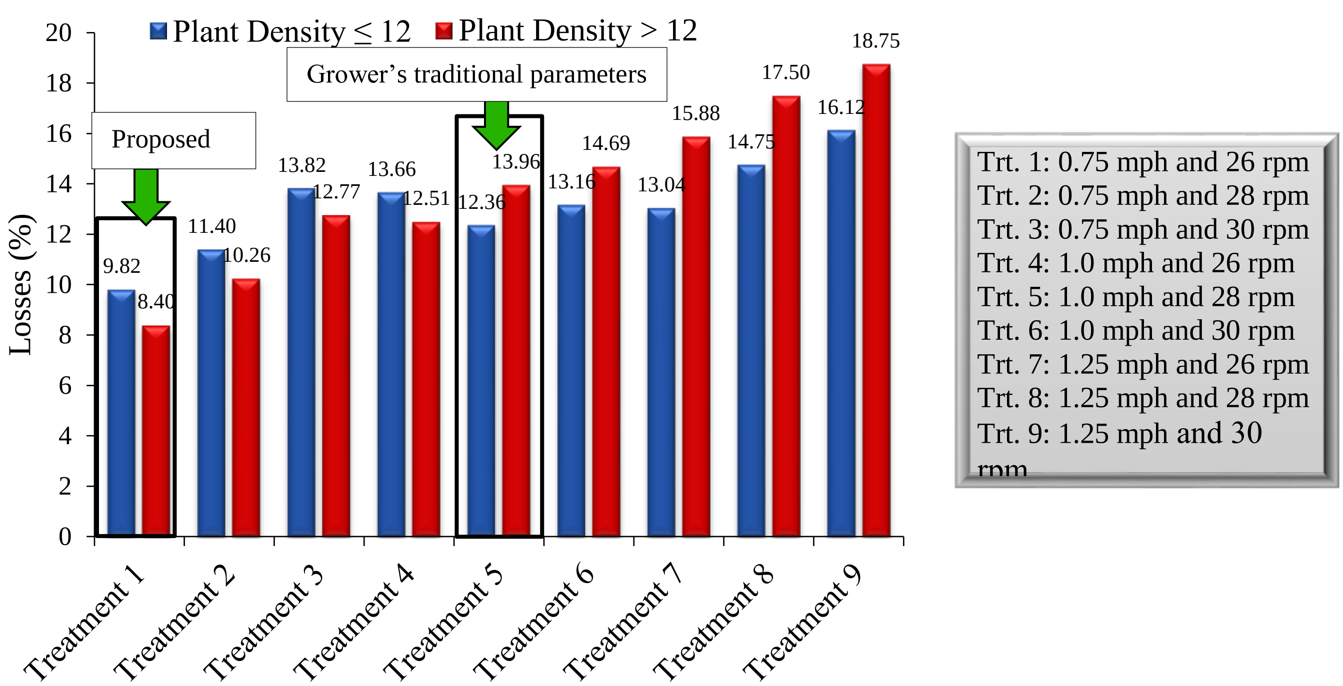
The effect of plant characteristics on picking efficiency of wild blueberry harvester was evaluated in wild blueberry fields in Atlantic Provinces. Plant height (PH) and plant density (PD) were classified into four different categories i.e. tall plant - low plant density, tall plant - high plant density, short plant - low plant density and short plant - high plant density. Combined effect of ground speed (1.2, 1.6 and 2.0 km h^{-1}) and header revolutions (26, 28 and 30 rpm) on berry losses at each category of PH and PD was identified. Berry losses were collected from each plot within the selected fields. Fruit losses were higher in taller (>25 cm) plants and low plant density (<12) than short plants and high plant density areas of the selected fields. A suitable combination of ground speed and header rpm in optimum plant characteristics at appropriate head height can minimize fruit losses.

The effect of fruit characteristics (fruit yield, fruit zone and fruit dia.) on berry losses at different machine parameters was examined in wild blueberry fields. Results indicated lower losses in high fruit zone areas of the field, while higher losses were observed in low fruit zone areas. This information will help to develop automated system to adjust head height on-the-go according to the variation in plant/fruit characteristics.

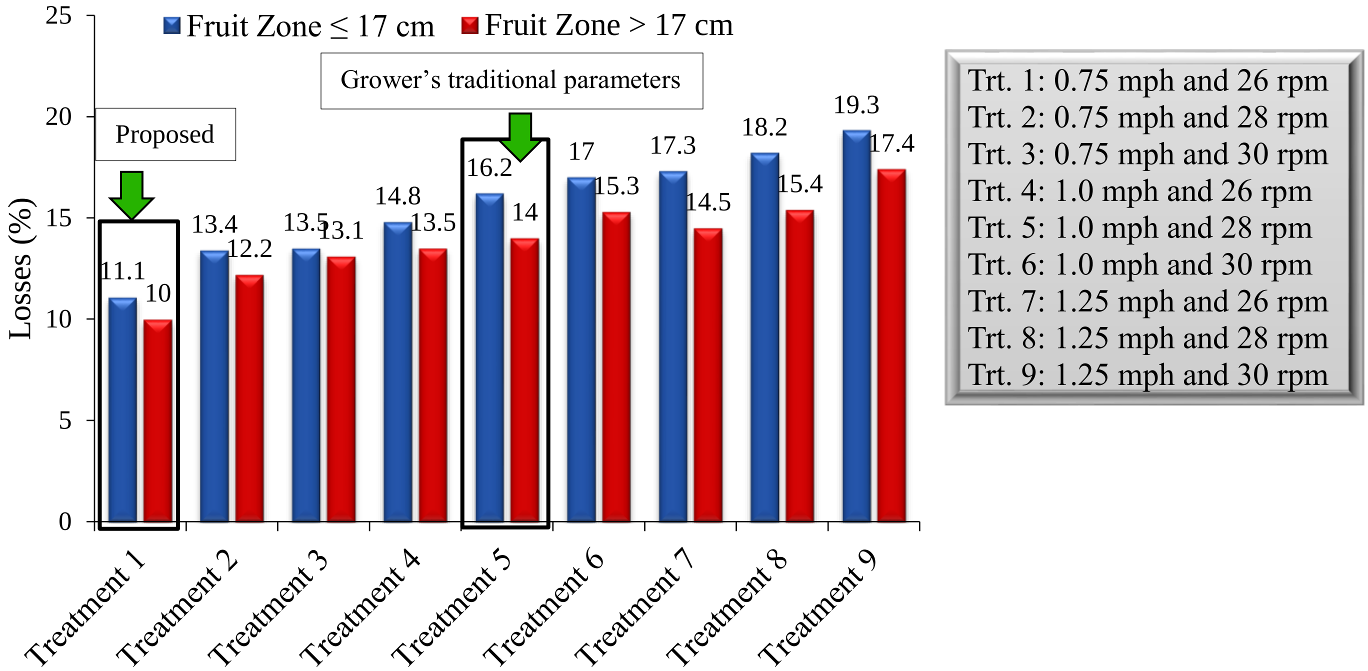
The combined effect of plant characteristics and machine parameters on picking performance of harvester was analyzed using accurate predictions of artificial neural network (ANN) model. Processed data were categorized into four classes of berry losses (<10%, 10-15%, 15-20% and >20%), to determine the optimum crop characteristics and machine parameters for effective berry picking during harvesting. Fruit losses were lower (<10%) in in high yield (FY > 3000 kg ha^{-1}), short plants (PH < 25 cm), high PD (PD > 12plants/0.0225 m^2) and higher FZ (FZ > 17cm) plots, within selected fields. The best operating combination for this category was 1.2 km h^{-1} and 26 header rpm. Berry losses increased with an increase in ground speed and head rpm in higher FY, PH and FZ plots. Higher berry losses (> 20%) were observed in high yielding plots with short plants and low plant density at 2 km h^{-1} and 30 header RPM. Results concluded that the picking efficiency can be increased by operating the harvester at a ground speed of 1.2 km h^{-1} and 26 header rpm of harvester in spatially variable plant characteristics (Table).



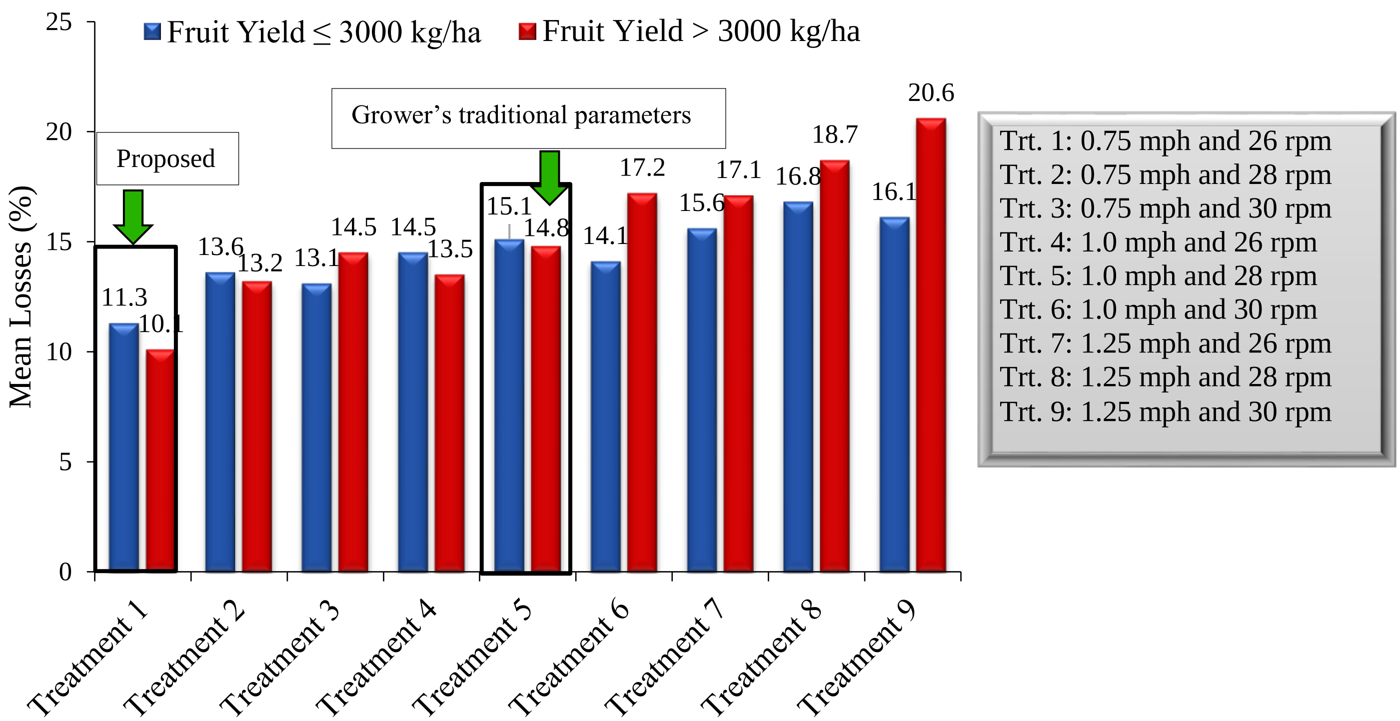
Mean comparison of fruit losses (%) for two plant heights at different treatment combinations.



Mean comparison of fruit losses (%) for two plant heights at different treatment combinations.



Mean comparison of fruit losses (%) for two fruit zones at different treatment combinations.



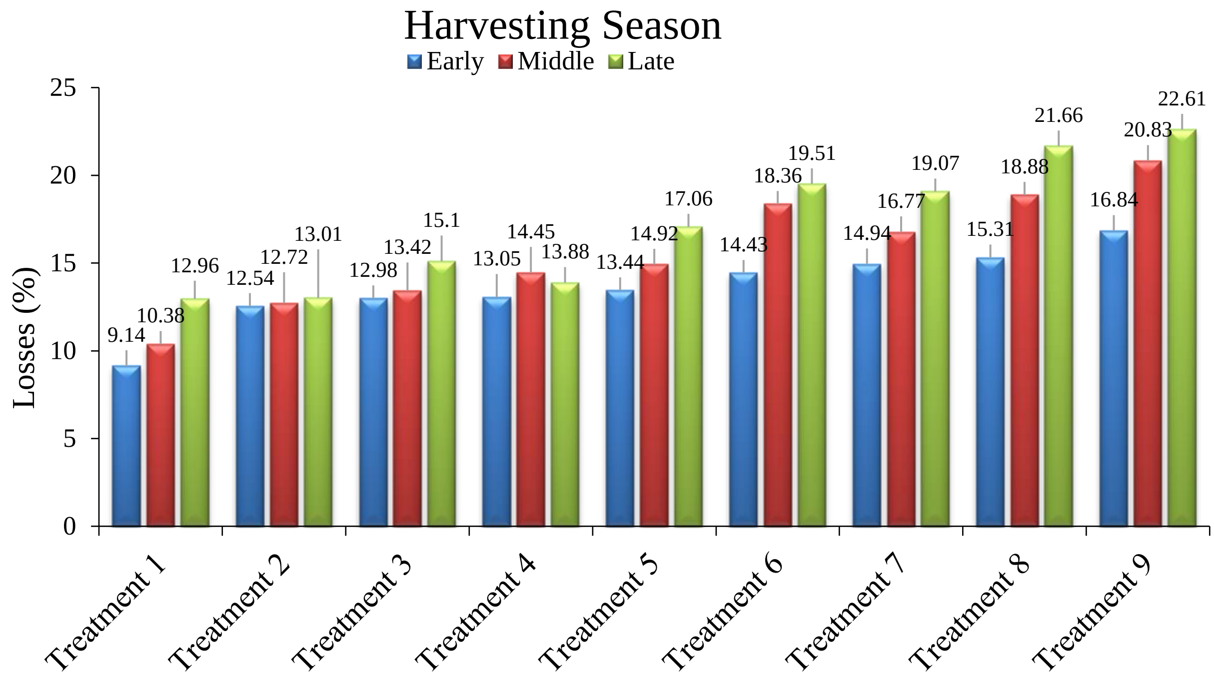
Mean comparison of fruit losses (%) for two fruit zones at different treatment combinations.

Optimum combination of machine and crop parameters.to reduce fruit loss using ANN model

Class	Speed ($km\ h^{-1}$)	RPM	FY ($kg\ ha^{-1}$)	PH (cm)	PD (*)	FZ (cm)	Mean Loss (%)
Training							
<10%	**1.2**	**26**	4326	23.46	13.53	21.13	7.8
10-15%	1.2	28	5918	23.92	10.78	22.28	12.47
15-20%	1.6	28	6546	29.23	12.70	27.81	17.26
>20%	2	30	5521	17.24	9.92	15.43	23.13
Validation							
Class	**Speed ($km\ h^{-1}$)**	**RPM**	**FY ($kg\ ha^{-1}$)**	**PH (cm)**	**PD (*)**	**FZ (cm)**	**Mean Loss (%)**
<10%	1.2	26	4543	22.85	12.90	21.16	8.29
10-15%	1.2	28	5879	21.11	10.91	20.27	12.06
15-20%	1.6	28	6477	28.65	12.22	26.92	17.02
>20%	2	30	5436	17.93	11.79	14.08	22.56

5.5 Quantification of Fruit Losses at Different Harvesting Times

Wild blueberry fields were selected in Atlantic Provinces to examine the impact of different harvest timings on berry picking efficiency of harvester. Fruit losses data were collected at three different levels of ground speed (1.2, 1.6 and 2.0 km h^{-1}) and header revolution (26, 28 and 30 rpm) for each category of season (early, middle and late season from each field. Results revealed fruit losses were higher in late season compared to early and middle season harvesting. Results also showed that higher ground speed in concomitance with higher header rpm resulted in substantial increase in fruit losses in each harvesting season, but these losses were more prominent in late season due to over-ripened berries. 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. *Presented in international conference and industry meetings. This research is part of Master thesis research).*



Mean comparison of fruit losses (%) for different time of harvesting season.

5.6 Coupling Biological, Mechanical and Environmental Data to Develop Integrated Harvesting Techniques Using Bio-system Modeling

Bio-system modeling (ANN) to couple mechanical, biological and environmental processes enabled us to identify the senstive factors responsible for increased losses. This approach implemented various aspects of harvesting, *i.e.*, quantification, prediction, classification, optimization of efficiency and quality damage during harvesting. Processed ANN modeling data comprising of soil, plant, fruit and environmental characteristics, and fruit losses is ready for the development of a farmer's friendly small computer program by considering spatial and temporal variations to enhance berry recovery. Peltarion Synapse software was used to develop WorkArea0.dll file. This file served as brain to recommend efficient harvesting settings (ground speed and header rpm).

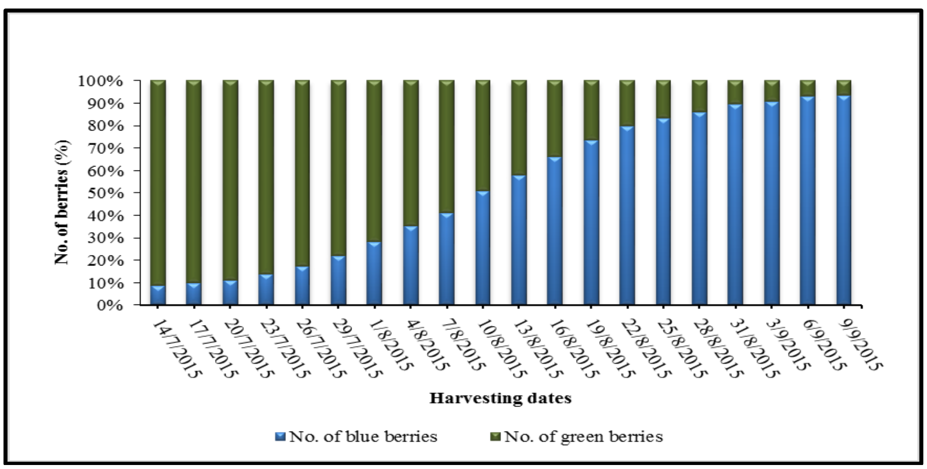
The collected data were normalized, and 70% of the data were utilized for training, and 30% for validation of the developed models using ANN and MR techniques. Results of mean square error (MSE) and root mean square error (RMSE) suggested that the tanh-sigmoid transfer function between the hidden layer and output layer was the best fit for this study. The developed models were validated internally and externally and the best performing configuration/architecture was identified based on MSE, RMSE, CE and coefficient of determination (R^2). The optimum number of iterative steps (epoch) to process data and predict fruit losses was examined by plotting the error rate against epoch number. Results suggested that the iterative steps of 15000 was enough to predict fruit losses during mechanical harvesting. Results suggested that tanh sigmoid mathematical function was the best to process the data collected. The optimal configurations of the model to predict fruit losses were selected based on MSE, RMSE, CE and R2.

Overall, the results of the study suggested that the ANN model was able to predict fruit losses during harvesting accurately and reliably. This study can help to identify the factors responsible for fruit losses and to suggest optimal harvesting scenarios to improve berry picking efficiency and recovery.

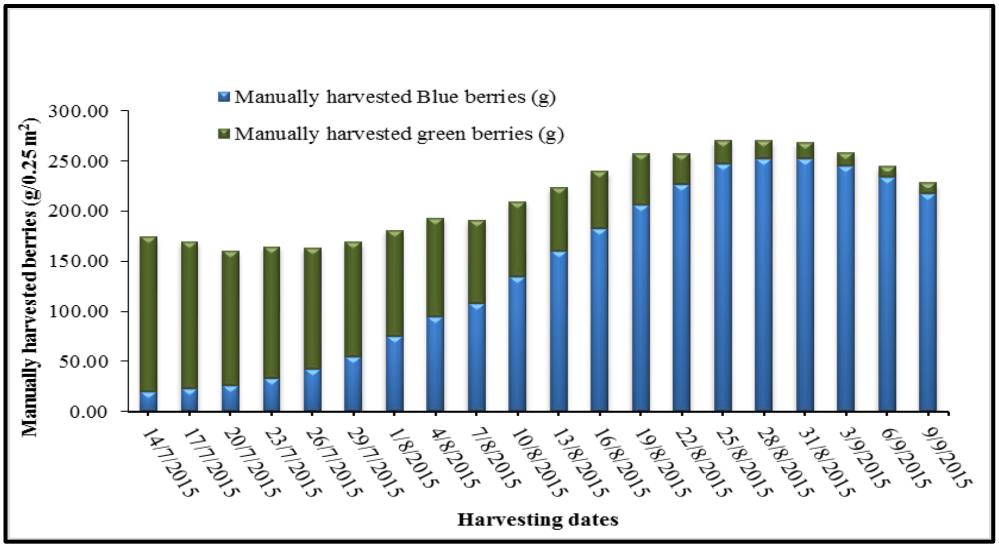
Results suggested that the ANN model could thus effectively be used for predictive modeling and optimization of fruit losses during mechanical harvesting of wild blueberries. Based on the results of this study, it is suggested to include environmental factors, time of harvest, soil properties, plant densities, fruit diameters and stem thickness to input variables in future studies while modeling the harvesting dynamics of the wild blueberry cropping system. We developed a C# (Microsoft, Redmond, Wash.) program for wild blueberry industry. The farmers are able to login, add their inputs (yield, PH, PD), and software will suggest best settings of machine to reduce fruit loss. *This research is a part of PhD and Master thesis research. Manuscript was published in Applied Engineering in Agriculture Journal and presented in international conference and industry meetings.*

5.7 Fruit Ripening in Relation to Harvesting Time Using Digital Photographic Technique

Ripening of wild blueberry at the time of harvest is the leading factor for fruit quality. Currently, there are no protocols available for the farming community related to wild blueberry fruit ripening and maturity. Two wild blueberry fields were selected to examine the berry ripening levels using digital photographic technique on different harvesting times (early, middle and late). Completely randomized block design with four blocks and each block was further divided into three classes of early, middle and late. Fruit images from each block at early, middle and late seasons were acquired and processed to count blue pixels from each image, using image processing software. A significant correlation was found between 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 were also highly significant. The absolute and relative measures further strengthened the model. The results also indicated that the effect of time of harvesting on wild blueberry yield was significant and 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 had turned blue at the end of middle season compared to early season (58%).



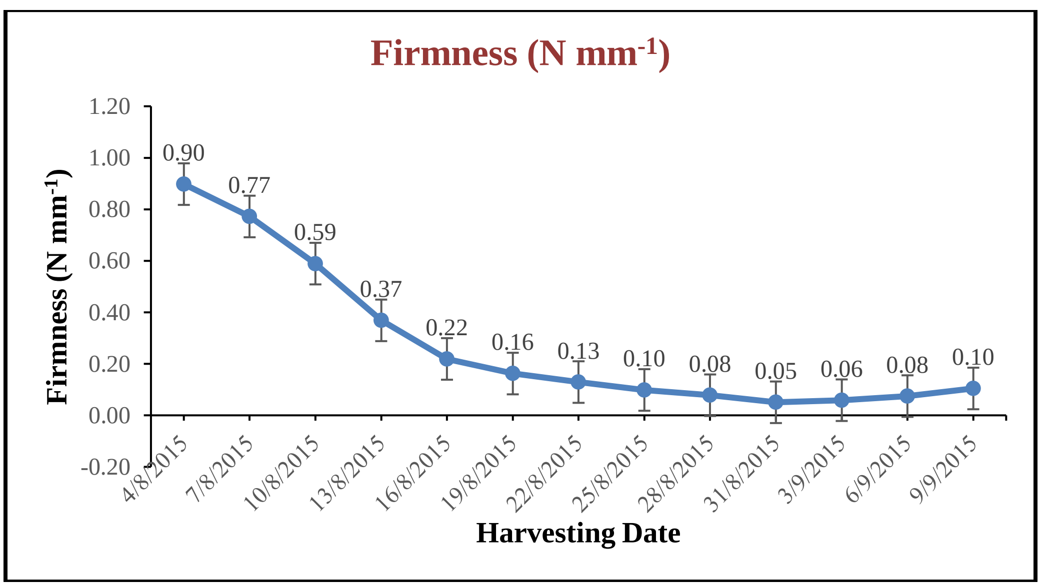
Comparison of green and blue berries at different harvesting dates



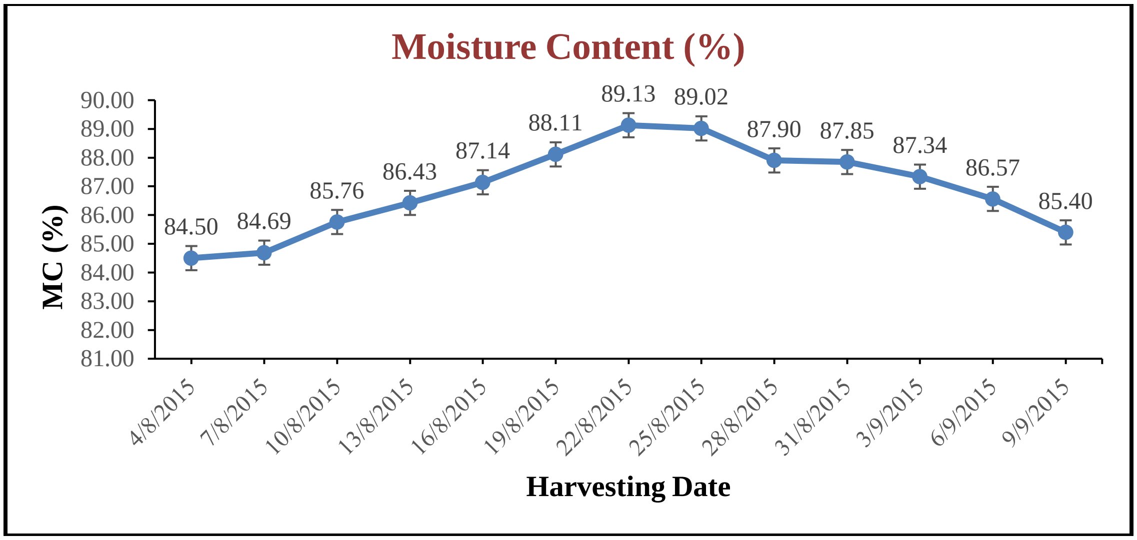
Comparison between manually harvested green and blueberries at different harvesting dates

5.8 Impact of Time of Harvesting on Physical and Chemical Characteristics of Wild Blueberry Ripening

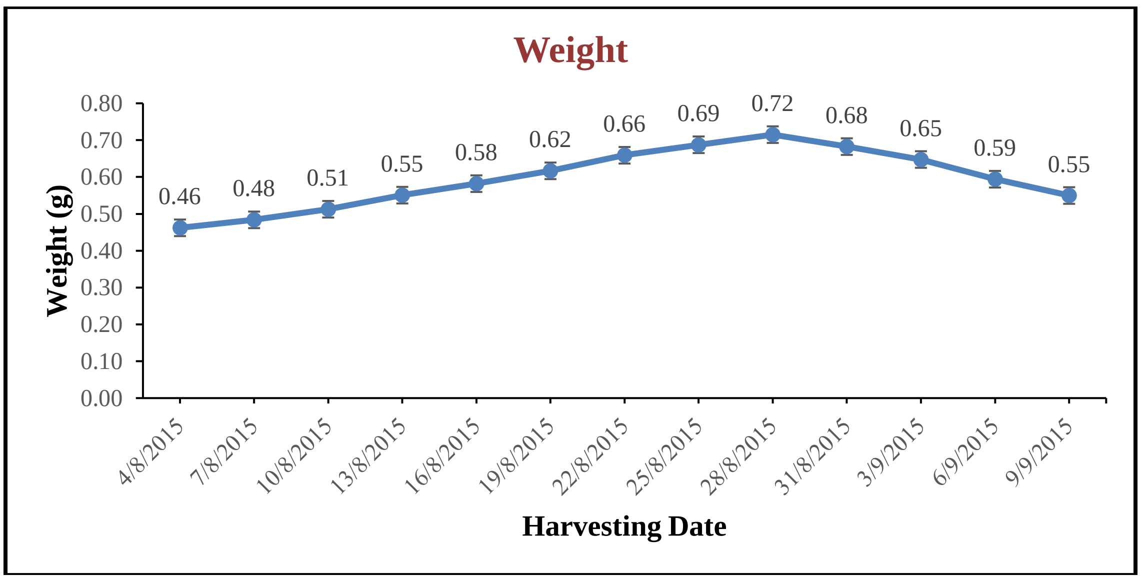
Maturity of wild blueberry at the time of harvest is the leading factor for fruit quality. Prior to this study, there were no identified protocols related to wild blueberry maturity and time of harvest that could be used to minimize fruit loss and /or improve fruit quality. Two wild blueberry fields were selected in Atlantic Provinces to examine the impact of different harvesting times (early, middle and late) on berry ripening characteristics (anthocyanin content, firmness, total soluble solids, total titratable acidity and moisture content). Completely randomized block design with four blocks and each block was further divided into three classes of early, middle and late was used to collect the data from two fields.



Wild blueberry fruit firmness on different harvesting dates



Wild blueberry fruit moisture content on different harvesting dates



Average weight of wild blueberries at different harvesting dates

The highest increase in total soluble solids (40%) were observed in middle season, whereas most pigment accumulation in blueberries took place in early and middle season. A significant decrease in acidity (54%) and an increase in TSS:TA (74%) were found in middle and late season harvesting. The maximum gain in moisture content (89%), expansion in diameter (12%) and increase in weight (19%) were observed in middle season harvesting, whereas reduction in moisture (to a level of 84%), shrinkage of berries and loss of weight occurred in late season. Firmness decreased gradually from early to middle season (88%); then an increase in firmness in late season was the consequence of gumminess, produced by loss of moisture and contraction of diameter. Therefore, optimum time to harvest wild blueberries would be in the middle season to ensure better quality blueberries.

5.9 Effective Use of Variable Speed Blower Fan for Improvement of Berry Quality

The management of wild blueberry fields is continuously improving and plant density/leaf foliage have increased. The result of improved management practices has led to an increased amount of debris being collected while harvesting. When operating the mechanical harvesters during periods of high moisture the debris is more difficult to remove as compared to dry conditions. Many commercial harvester units contain a single speed blower fan to remove debris before the fruit enters the storage bins. The wild blueberry processing facilities are suggesting that producers should lower the amount of debris that is being collected in the bins.

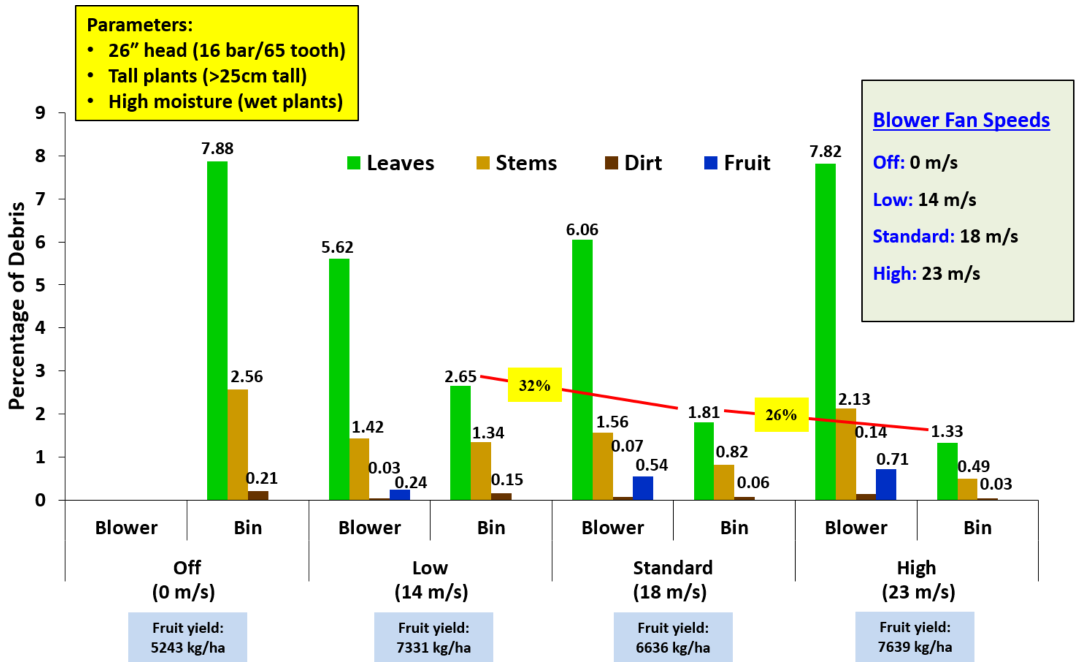
The study was designed to examine the effective use of variable speed blower fan on wild blueberry harvester for improving berry quality. A new dual fan plenum was designed and tested that allowed for uniform air distribution to help separate debris away from the wild blueberries. The two fans installed on the mechanical harvester were controlled using a handheld speed controller from the driver's seat of the tractor. A dielectric leaf wetness sensor was used to determine the moisture of the debris that is being handled on the harvester conveyors.

A commercial DBE mechanical harvester was tested with two style of picker bars (63 and 65 tooth configuration). Four different blower fan speeds (B_1=0 m/s, B_2=14 m/s, B_3=18 m/s & B_4=23 m/s) were tested for berry cleaning performance. The effectiveness of the blower fan speed for debris separation was tested at two different leaf wetness conditions (LW_1=high moisture & LW_2=low moisture) within selected wild blueberry fields.

New dual fan plenum & controller for fan speed adjustment.

The picking heads in conjunction with different blower fan speeds and moisture conditions was tested at two levels of wild blueberry plant heights (PH_1 < 25cm & PH_2 > 25cm) within selected fields. The results of this experiment can be used to suggest an ideal combination of blower fan speeds for minimal debris during mechanical harvesting.

The harvester operating with a low fan speed (14 m/s) was able to remove 63.1% of the debris in high moisture conditions using the 26" head with and 65 tooth bars in tall plants (Fig 5). Under similar operating conditions, a fan speed of 18 m/s removed 74.1% debris while a fan speed of 23 m/s removed 84.5% debris. This data showed that the higher moisture conditions and taller plants led to an increased amount of debris in the harvested collection bin as compared to dry conditions or low plant height.



Percentage of debris found under high moisture conditions (26" head, 65 tooth bar, tall plants)

Results from this study have shown a significant improvement with the debris separation using the developed variable speed blower fan system. Data suggests that operating the fan at a speed of 23 m/s resulted in the best debris cleaning performance with insignificant berry loss in both wet and dry conditions. A fan speed of 23 m/s leads to a 11% increase in debris separation using a 65 tooth head as compared to the standard operating speed of 18 m/s under high moisture field conditions without any significant loss in berry yield. Recommendations from this study have recently allowed new commercial systems to be developed with the new fan system incorporated into the design. The results proved to be an important step for the low bush blueberry industry to improve their harvested product to better compete with the highbush blueberry market on the global scale.

Increase in berry cleanliness with increase in blower fan speed.

5.10 Conclusion

The research project "Improving efficiency of commercial wild blueberry harvester using precision agriculture technologies" was completed in October 2017. This research would help to ensure the long term stability of industry and make growers more profitable over time. The intensive data collected during last four years have been gleaning, organizing and analyzing using innovative technologies. Proposed research would result in delivery of peer reviewed scientific publications and producer factsheets associated with improved harvesting techniques, environmental stewardship, food safety, and renewal and risk management. Several articles have been published/publishing in peer-reviewed scientific journals and presented in industry, national and international conferences. In addition, it is anticipated that results from this research are being posted on the PA Website, and also be disseminated to growers and industry representatives at field days, twilight meetings, and oral and poster contributions at grower and scientific meetings. Broachers/factsheets are being published for producers.

The HQPs (post-doctoral fellows, PhD/master students, undergraduate students, research assistants were trained to publish research results in peer-reviewed scientific journals and also present in regional, national and international conferences, growers' meetings, and farmers' field days. They have an opportunity to interact with researchers from multiple post-secondary institutions and various industrial partners including DBE, Oxford Frozen Foods Group (OFF), and Wild Blueberry Producers Associations. HQPs should feel the pain of farmer and poor consumer alike. They should wear dirty shoes while being cutting edge scientists. Both, research and extension will then flow from them, simultaneously! Producing 'degree holders' should not be the sole function of a university.

This collaboration between industry and research scientist was initiated to develop innovative and viable techniques that should enhance berry picking efficiency, assist with the stabilization of yields over time and increase farm profitability. While this project is submitted with the collaboration of wild blueberry industry to increase harvestable berry yield and quality, the DBE harvester is being used to harvest 80% of the total acreage of wild blueberry in the Atlantic Provinces. 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 graduate students, post-doc fellows, wild blueberry producers and industry personnel, and a more competitive wild blueberry industry.The results of this research project showed up to 6% increase in berry recovery using PA technologies, increasing farm profitability of NS farmers. Increased harvesting efficiency *(say 5% only) can* contribute $5.5 million to NS economy with no additional expenses and $31 million to Atlantic Provinces and Quebec every year.

Future Research: This information obtained during last five years will directly support to develop an automated system (hardware and software) to adjust machine parameters automatically according to the variation in field and crop conditions to increase harvester and operator efficiency during harvesting in order increase berry yield and quality.

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WILD BLUEBERRY FACT SHEET

Precision Harvesting Technologies - Improve Berry Yield and Quality

Background:

Dr. Zaman and his Precision Agriculture Research Team launched an initiative to develop innovative harvesting technologies in wild blueberries. This project was part of a multidisciplinary research effort at the Engineering Department, Faculty of Agriculture, Dalhousie University in collaboration with Doug Bragg Enterprises, Collingwood, Nova Scotia and wild blueberry producer associations. 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 graduate and undergraduate students, post-doc fellows, wild blueberry producers and industry personnel, and a more competitive wild blueberry industry. The PA team at Dalhousie Agricultural Campus is actively involved in transferring viable technologies including publications in scientific journals, growers' magazines, manuals, factsheets, radio and TV talks, presenting in national, international and industry meetings, and demonstrating the technologies at farmers' field days. Results of current research projects would increase harvestable berry yield (up to 6%) and quality with existing mechanical harvester in order to increase farm profitability.

Recommendations:

✓ **Optimum harvester settings in high yielding fields (>3500 lbs/acre):**
- 22" diameter head - ground speed of 0.7 mph and head rotational speed of 26 rpm.
- 26" diameter head - ground speed of 0.7 mph and head rotational speed of 19 rpm.

✓ **Optimum plant characteristics:**
- Plant height ≤ 10"
- Plant density = 55 per ft^2
- Fruit zone = 7.5"
- Fruit Loss < 10%

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- ✓ **Optimum Harvesting time (know your field condition):**
  - Early harvest – more green berries
  - Late harvest – over ripened berries (up to 4% fruit loss and quality deterioration)
- ✓ **16 bar with 65 teeth improves fruit yield and quality:**
  - Less plant pulling with wider teeth spacing 26" 16 bar head than 22" 12 bar head.
  - Less leaf loss with wider teeth spacing 26" head than 22" 12 bar head.
  - More small sized berries left on the stem and ground with the wider teeth (63 tooth bar) spacing.
  - Potential for better debris cleaning from the brush with the wider teeth spacing.
  - Potential for less fruit bud damage with wider teeth spacing.
- ✓ **In high yielding fields, 26" harvester head and wider conveyer has improved berry handling capacity:**
  - Larger circumference with the 26" head allowed for debris to be more thoroughly cleaned from the picker teeth (stretched bar spacing on the 26" diameter head).
  - Improved cam action resulting in a gradual picking action from an increased diameter with the 26" head.
  - The inner head conveyor has increased in width from 8" to 12" on the 26" diameter heads allowing for a larger carrying capacity.
  - The increased inner head conveyor has better debris handling (not as much an issue with the conveyor plugging with debris when wet).
  - The wider conveyor also allows for better berry handling when travelling on steep slopes (less dropped berries).
- ✓ **New dual fan plenum has improved berry quality:**
  - 50 mph fan speed improves berry quality (both for single head and double head harvesters as well as for bin loaders and small box machines).
- ✓ **Cleaning brush is essential for debris removal:**
  - Wore brushes increase the harvesting time.
  - Improper adjustment of brush can lead to poor debris removal or excess brush and picker teeth wear.
  - Replacement of brush when bristle length is less than 4.3" (11cm).
- ✓ **Economic analysis of small box and bin loader harvesters:**
  - Bin loader systems allow for a major time savings as compared to small box harvesters.
  - Small box machines take additional labor.

Prepared by:

Dalhousie University
Precision Agric. Research Program

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6. Long Term Precision Agriculture Research Plan

ESTABLISHMENT OF PRECISION AGRICULTURE CENTRE (DAL-AC)

Increase Farm Profitability

… Enhance The Sustainability of Rural Life

PRECISION AGRICULTURE CENTRE

6.1 SUMMARY OF RESEARCH PLAN

The objective of the Precision Agriculture Research Program, led by Dr. Zaman, at Dalhousie Agricultural Campus is to develop and implement novel, automated and integrated field operations system for site-specific application of agricultural resources. It allows farmers, machinery manufacturers and processors at all levels, ranging from small family-run operations to large agri-businesses, to achieve significant improvements in farming efficiency. Benefits include increased yields, savings in time, higher productivity, high profitability, reduced pollution, lower water use and cost savings from precise applications of nutrients, seeds, feeds and water.

One of my primary goals has been the teaching and training of highly qualified personnel (industry research chairs, post-docs, research associates, graduate and undergraduate students). The HQPs are the foundation for my research program. I thoroughly enjoy working with students and I appreciate the important role that we play in supporting their development. I firmly believe that my most important role is that of a mentor, teacher and leader in the research that is undertaken by my HQPs. The HQPs are being trained to develop innovative technologies, publish research results in peer-reviewed scientific journals and also present in regional, national and international conferences, growers' meetings, and farmers' field days.

To achieve this, next five year precision agriculture research program was developed with the collaboration of national and international academic collaborators, industry partners and research proposals were approved/ submitted (more than 10 million dollars) to provincial and federal funding agencies.

The overall goal of my research plan is to develop **PRECISION AGRICULTURE CENTRE (PAC)** at Faculty of Agriculture, Dalhousie University**.** The Dal-AC is a comprehensive Faculty of Agricultural Sciences backed by strong programs in basic and social sciences, and technologies. The programs are well integrated to promote education, basic and applied research and extension for agriculture and rural development. The Centre of Excellence for Precision Agriculture is envisaged to cater the inter-disciplinary needs in Agricultural Automation and Robotics, Variable Rate Technologies, Remote Sensing, GPS/GIS and Climatic Changes in Canada to **make Canada a world leader in innovation, environmental stewardship, food production and food safety**.

VISION

To lead change through outstanding achievements in learning, discovery and community service with a clear focus on programs of significance to agriculture and rural development.

The PAC will contribute to solving national and global challenges related to food, agriculture, and environment faced by the next generation through excellence in education, research, outreach and policy support. PAC envisions 9.8 billion thriving, well-fed people by 2050.

MISSION

Inspired by the global phenomenon known as the "internet of everything" PAC exists to advance the commercialization of PRECISION AGRICULTURE technologies. Working with our academic and industry partners we are unparalleled platform for research and innovation. We strive to enable the creation of a more efficient global food production and processing system through the advanced use of sensors, networking, data analytics and information communication technologies in connected agricultural systems.

In working to feed the world we educate and train students in the theory, use and application of these new precision agriculture technologies to ensure economic and environmental sustainability.

In this way we support the growth of high-tech jobs in Atlantic Canada while contributing to Canada's reputation as a global producer of safe, high quality food.

6.2 GENERAL OBJECTIVE OF PAC

Building infrastructure and human resource capacity for developing competitive manpower, undertaking cutting edge research and framing of policies for food security and economic growth.

SPECIFIC OBJECTIVES

1. To develop high quality human resource in agricultural sciences through internationally compatible curriculum and research.
2. To enhance institutional capacity to provide leadership in the development process.
3. To cultivate entrepreneurial skills in the students for generating businesses and employment.
4. To develop and commercialize innovative precision agriculture technologies.
5. To develop data banks for policy input and guidelines.
6. Outreach for technology transfer, skill development, and community service.
7. To strengthen networking with national and international organizations.
8. To develop industrial linkages for object oriented development of Agriculture sector.

ELEVATOR PITCH

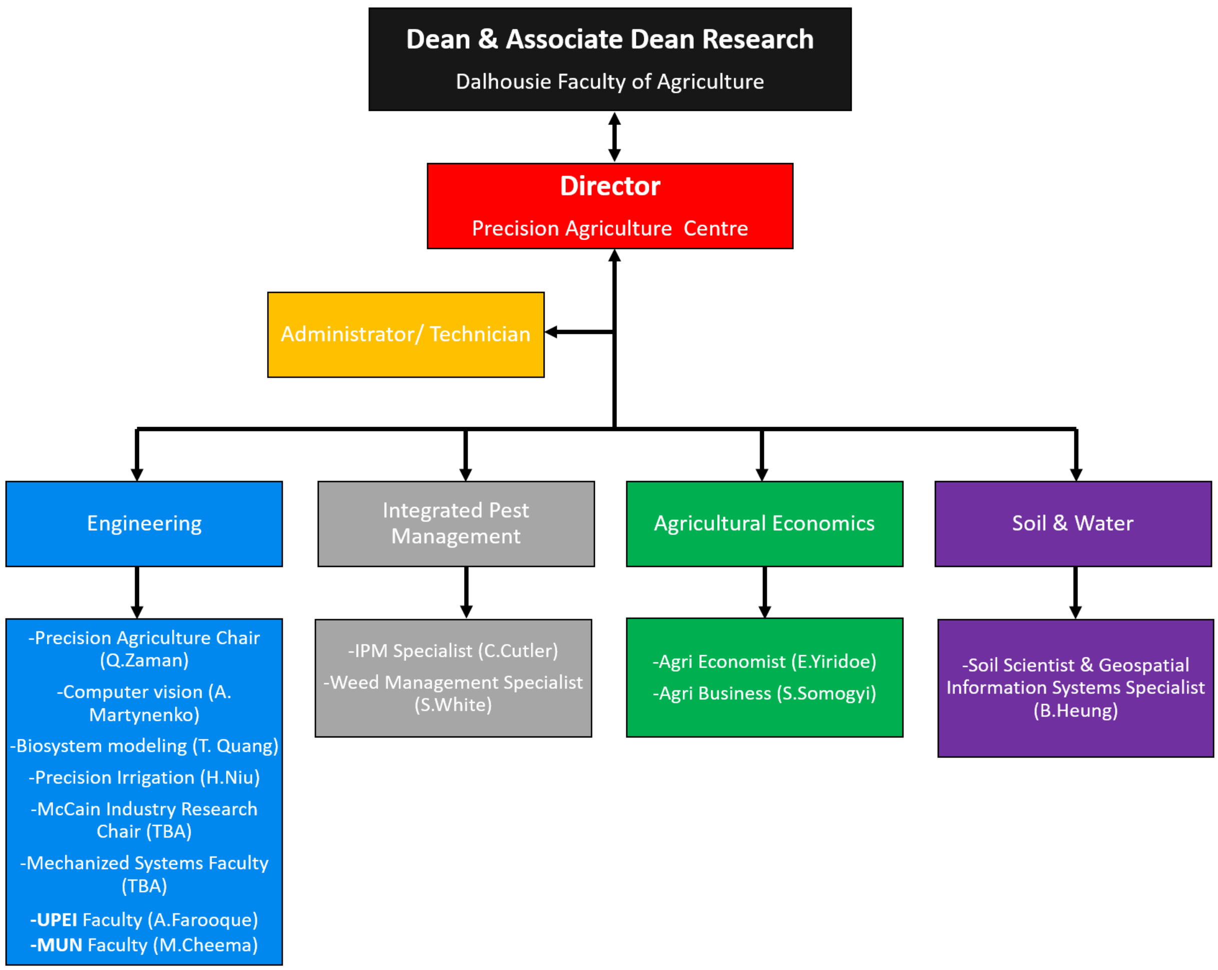
World population is expected to grow to 9.8 billion by 2050. If we are going to feed all those people, it means that we must double livestock operations and increase food production by 70%. It is imperative, therefore, that we find new and innovative ways to enhance productivity of the food chain whilst protecting the environment and preserving global resources.

PAC is the largest connected agricultural ecosystem in the world. It exists to advance commercialization of PRECISION AGRICULTURE technologies. **Specifically, <u>information communication technologies that harness the power of interconnected sensors, networks and data analytics to propel "smart agriculture" decision support systems</u>.** It's a $3.5 billion market growing at over 25%/year!

PAC is the FIRST common platform in the world that integrates talent and infrastructure across the crop and animal science, computer and engineering disciplines. Our close partnership with industry ensures that the research, innovation and technology commercialization conducted here fights world hunger and leads to greater prosperity in our economy.

6.3 STRUCTURE OF THE CENTRE

From a governance perspective, the Centre will be directed by the Dalhousie University Precision Agriculture Research Chair under the supervision of the Dalhousie Faculty of Agriculture Dean and Associate Dean Research. An administrator (25% time) / technician (75% time) will be responsible for overseeing and communicating the link between the director and industry, academia and government personnel. The administrator/ technician will also focus on supporting the research with data collection, testing and report writing. Four key research pillars for the centre will include engineering, integrated pest management, agricultural economics, soil and water. The precision agriculture centre director will work closely with faculty and research specialists within each pillar and different agriculture industries in Atlantic region. Each subject specialist will be linked together via the director to ensure seamless research goals and to promote teamwork across the wide range of cutting-edge expertise available. The group will meet routinely and be comprised of local, national and international researchers who, together, have expertise in each of the select research areas. Governance structure is illustrated in figure below.

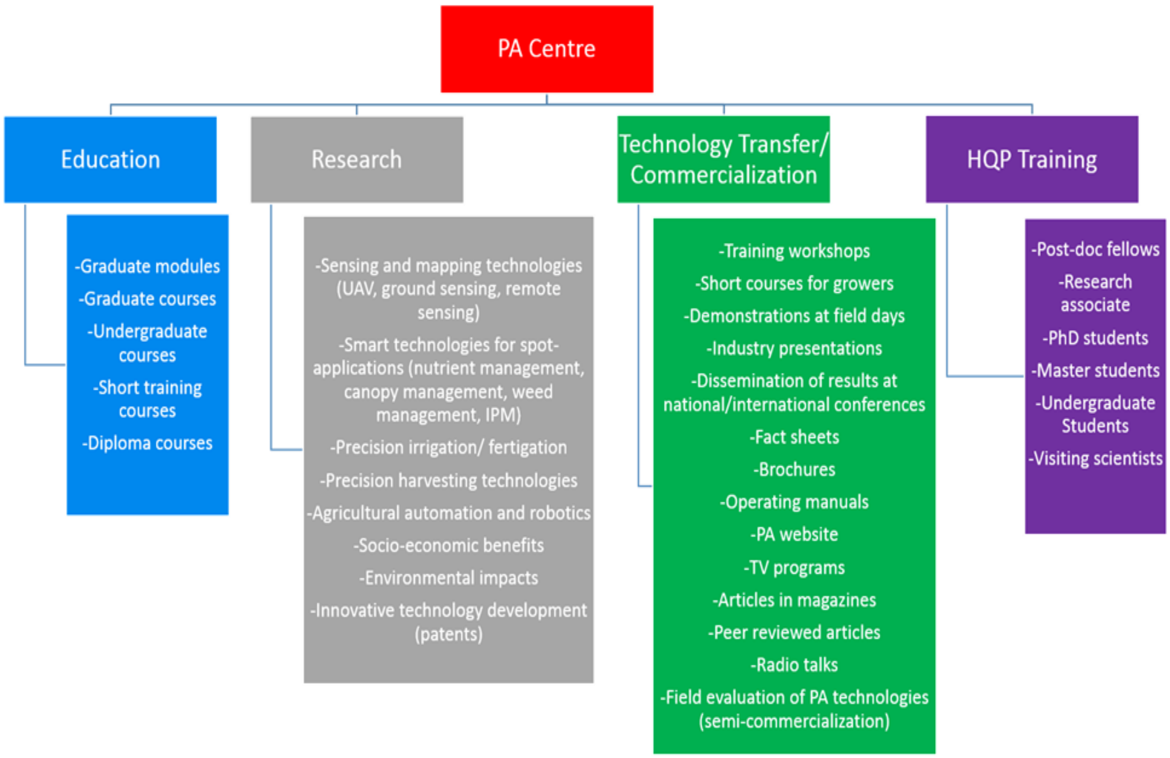


Proposed Research Centre Governance Structure

6.4 COMPONENTS OF PAC

The Precision Agriculture Centre will be focus of four critical sections including; education, research, technology transfer/ commercialization and HQP training. Education training stemming from the Precision Agriculture Centre will include undergraduate and graduate courses/modules as well as short training courses. Research will be focused on leading edge areas for precision agriculture advancement including sensing and mapping technologies, smart technologies, irrigation, harvesting, automation and mechanization. Technology transfer and commercialization will play a vital role in transferring the research outcomes to the farmers and industry personnel.

Dissemination of results will include training workshops, demonstrations, presentations, fact sheets, brochures, manuals, websites, peer-reviewed articles etc. Training of HQP (post-doctoral fellows, research associates, PhD/MSc students, visiting scientists) will play a pivotal role to ensure the future success of the Precision Agriculture Centre. An organizational chart is illustrated in figure below.



Proposed Research Centre Areas of Focus

ACKNOWLEDGEMENTS

PRECISION AGRICULTURE
TEAM DAL-AC

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