Harvester Efficiency Research Program

Dr. Qamar Zaman, Professor
Dalhousie University
Objectives

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop improved integrated harvesting system</td>
<td>= coupling of mechanical, biological and environmental processes</td>
</tr>
<tr>
<td>Increase the berry picking efficiency of precision harvester</td>
<td>= LOWER cost of production</td>
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<tr>
<td>Develop machine learning technologies to improve berry quality</td>
<td>= Increase farm profitability</td>
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<tr>
<td>Automate wild blueberry harvester</td>
<td>= DATA ANALYSIS, EFFICIENCY &amp; CONVENIENCE</td>
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</tbody>
</table>
**Precision Harvesting Research Program**

- 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 the bin)
- Evaluate performance efficiency of debris cleaning brush on harvester head to improve berry yield and quality
- Economic analysis of small box and bin loader harvesters

Automation of Mechanical Harvester (2017-2022)

Fields were selected in Nova Scotia, New Brunswick and Maine

Field and plant characteristics, and fruit yield variability was mapped with **Sensor Fusion system**

**Machine parameters:**
- 22” head with 16 bar 67 tooth configuration (traditional)
- 22” head with 12 bar 67 tooth configuration (forward picking)
- 22” head with 12 bar 67 tooth configuration
- 26” head with 16 bar 67 tooth configuration
- 26” head with 16 bar 65 tooth configuration
- 26” head with 16 bar 63 tooth configuration
- Ground speeds ranging from 0.6 mph to 1.25 mph
- Head speeds ranging from 19 rpm to 30 rpm

**Field parameters:**
- Plant density
- Stem diameter
- Plant height
- Leaf wetness
- Soil moisture
- Slope
- Fruit zone height
- Pre-harvest fruit loss
- Collected fruit yield
- Fruit left on the ground
- Fruit left on the stem
- Fruit in debris from blower fan
- Fruit from collection pan (behind head)
- Berry size
- # of plants pulled
- % leaf loss
- GPS Location
Quantification of Losses – High Yield

Area = 9.6 acres
Fruit Yield = 7900 lb acre⁻¹

Fruit yield increased = 474 lb acre⁻¹
12 bar head combed 6 times through each plant

16 bar head combed 9 times through each plant
16 Bars vs. 12 Bars – Total Losses

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

Growers Settings

- Avg. Plant Height = 19 cm
- Avg. Density = 646 plants m⁻²
- Area = 5.1 acres
- Fruit Yield = 6973 lb acre⁻¹
16 Bars and 12 Bars (Back view)

16 bars vs. 12 bars

Aug. 21 (1 mph/28 rpm)
16 Bars and 12 Bars (Side view)

16 bars vs. 12 bars

Aug. 21 (1 mph/28 rpm)
Area = 3.88 ha
Yield = 7601 kg ha$^{-1}$
### Optimum Harvester Settings

#### 22” Diameter Harvester Head:

<table>
<thead>
<tr>
<th>Ground Speed (mph)</th>
<th>Head Speed (rpm)</th>
<th>Yield (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 – 0.8 mph</td>
<td>26 rpm</td>
<td>≥ 3500 lbs/acre</td>
</tr>
<tr>
<td>1 mph</td>
<td>28 rpm</td>
<td>&lt; 3500 lbs/acre</td>
</tr>
</tbody>
</table>

#### 26” Diameter Harvester Head:

<table>
<thead>
<tr>
<th>Ground Speed (mph)</th>
<th>Head Speed (rpm)</th>
<th>Yield (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 – 0.8 mph</td>
<td>19 rpm</td>
<td>≥ 3500 lbs/acre</td>
</tr>
<tr>
<td>1 mph</td>
<td>21 rpm</td>
<td>&lt; 3500 lbs/acre</td>
</tr>
<tr>
<td>Speed ($\text{km h}^{-1}$)</td>
<td>RPM</td>
<td>Fruit Yield ($\text{kg ha}^{-1}$)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>1.2</td>
<td>26</td>
<td>4000</td>
</tr>
<tr>
<td>1.2</td>
<td>28</td>
<td>6000</td>
</tr>
<tr>
<td>1.6</td>
<td>28</td>
<td>6500</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>5500</td>
</tr>
</tbody>
</table>

Optimum Combination of Crop and Machine Parameters To Reduce Berry Loss
Leaves were counted from randomly selected plants in each plot before and after harvest.

Pulled plants by each harvester head were counted from each plot.
26” (67 tooth bar) Head vs 26” Modified (65 tooth bar) Head

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Speed (mph)</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.75</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>0.75</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>1.00</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>1.00</td>
<td>19</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>1.25</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>1.25</td>
<td>19</td>
</tr>
<tr>
<td>11</td>
<td>1.25</td>
<td>21</td>
</tr>
<tr>
<td>12</td>
<td>1.25</td>
<td>23</td>
</tr>
</tbody>
</table>
## Suitable Harvester Head to Reduce Plant Damage and Increase Fruit Quality

<table>
<thead>
<tr>
<th>Head Diameter and No. of bars</th>
<th>No. of teeth</th>
<th>Plants Pulled/acre</th>
<th>Leaf Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22”, 12 bar</td>
<td>67</td>
<td>29000</td>
<td>40%</td>
</tr>
<tr>
<td>26”, 16 bar</td>
<td>67</td>
<td>17000</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>10000</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>6200</td>
<td>13%</td>
</tr>
</tbody>
</table>
Side view of three Heads

12 Bar Head

26" Head

26" Modified Head
Berry Quality Variable Speed Blower Fan

Effective Use of Air from Variable Speed Blower to Separate Berries, Debris (leaves, shoots, dirt) – 22” head and 26” head
Critical Velocity Lab Testing

- Anemometer (air speed measurements)
- Variable speed controlled air tunnel
- Debris (leaves, stems, weeds, dirt)
Field Testing

✓ Added variable speed blower fan & controller to separate debris (leaves, stems, dirt) from collected fruit.

![Field Testing Image]

**Blower Fan Speeds**

- **Off**: 0 m/s
- **Low**: 14 m/s
- **Standard**: 18 m/s
- **High**: 23 m/s
Debris Cleaned with Variable Speed Blower
What is a worn out brush???

1) 12cm (4.72”) → 0h
2) 11.5cm (4.53”) → 200h
3) 10.6cm (4.17”) → 300h
4) 8.7cm (3.43”) → 400h

Optimizing Cleaning Brush Performance
Data Collection

Debris thrown from brush:

Debris removed using blower fan:

Debris remaining in teeth:

Yield collection:
Data Collection

Record of time stopped for debris cleaning  Yield collection

Fine hair fescue

Bin weights
Cleaning Brush Performance

Debris in teeth

- Weedy
- Non-weedy

<table>
<thead>
<tr>
<th>Brush wear level</th>
<th>Debris (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New 12 cm</td>
<td></td>
</tr>
<tr>
<td>200 hrs 11.5 cm</td>
<td></td>
</tr>
<tr>
<td>300 hrs 10.6 cm</td>
<td></td>
</tr>
<tr>
<td>400 hrs 8.7 cm</td>
<td></td>
</tr>
</tbody>
</table>
Cleaning Brush Performance

![Bar chart showing brush wear level over time.](chart.png)

- Time stopped (%)
- Brush wear level
- New
- 200 hr
- 300 hr
- 400 hr
Cleaning Brush Performance Comparison
Cleaning Brush Performance Comparison
WILD BLUEBERRY HARVESTER FACT SHEET
Brush Adjustment Guide to Improve Picking Performance & Extend Lifespan

Table 1: Harvester brush adjustment chart.

<table>
<thead>
<tr>
<th>Bristle Length cm</th>
<th>Adj. Distance cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.00</td>
<td>4.72</td>
</tr>
<tr>
<td>11.99</td>
<td>4.69</td>
</tr>
<tr>
<td>11.98</td>
<td>4.68</td>
</tr>
<tr>
<td>11.97</td>
<td>4.66</td>
</tr>
<tr>
<td>11.96</td>
<td>4.65</td>
</tr>
<tr>
<td>11.95</td>
<td>4.64</td>
</tr>
<tr>
<td>11.94</td>
<td>4.63</td>
</tr>
<tr>
<td>11.93</td>
<td>4.62</td>
</tr>
<tr>
<td>11.92</td>
<td>4.61</td>
</tr>
<tr>
<td>11.91</td>
<td>4.60</td>
</tr>
<tr>
<td>11.90</td>
<td>4.59</td>
</tr>
<tr>
<td>11.89</td>
<td>4.58</td>
</tr>
<tr>
<td>11.88</td>
<td>4.57</td>
</tr>
<tr>
<td>11.87</td>
<td>4.56</td>
</tr>
<tr>
<td>11.86</td>
<td>4.55</td>
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<tr>
<td>11.85</td>
<td>4.54</td>
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<tr>
<td>11.84</td>
<td>4.53</td>
</tr>
<tr>
<td>11.83</td>
<td>4.52</td>
</tr>
<tr>
<td>11.82</td>
<td>4.51</td>
</tr>
<tr>
<td>11.81</td>
<td>4.50</td>
</tr>
<tr>
<td>11.80</td>
<td>4.49</td>
</tr>
</tbody>
</table>

Optimum range

Increasing brush cleaning performance

Figure 1: Harvester brush side view.

Step 1: Measure the bristle length on each side of the harvester cleaning brush (Fig. 1).

Figure 2: Harvester brush adj. prong side view

Step 2: Using the harvester brush adjustment chart (Table 1) find the corresponding adj. distance for each side of the brush based on the bristle lengths found in Step 1. Using a ruler fine-tune the brush position (Fig. 2) following the suggested adjustment guide.

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Stephen Bragg, Doug Bragg Enterprises (stephen@dbca.ca)


March 2018
Optimum Harvesting Time

Effect of Harvesting Time on Berry Quality (firmness)

Inside Head Conveyor

Inside to Side Conveyor

Side to Back Conveyor

Back Conveyor to Bin
Berry Quality - Firmness

Texture analyzer for firmness
Berry Loss–Time of Harvest

Harvesting Season
- Early
- Middle
- Late

Growers Settings
- 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

Losses (%)
Comparison of 36” vs 42” wide picking head

Methods

- Commercial fields
- Six replications per field
- 200 m long test strips
- Parameters measured:
  - Plant density
  - Slope
  - Stem diameter
  - Plant height
  - Berry density
  - Plants pulled
  - Berry loss
  - Yield collected
  - Head height
Comparison of 36” vs 42” wide picking head

Preliminary results

Harvested Yield (lbs/acre)

- 36" head: 4,246
- 42" head: 3,969

42" head has 17.6% wider picking width

-6.5% difference
Field Efficiency of Automated Handling System for Wild Blueberry Harvesting

30% increased picking time with bin loader system
Field Efficiency - Bin Handling System vs Small Box System

<table>
<thead>
<tr>
<th>Year</th>
<th>Small box system</th>
<th>Bin handling system</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>87</td>
<td>106</td>
</tr>
<tr>
<td>2018</td>
<td>91</td>
<td>117</td>
</tr>
</tbody>
</table>

- Bin Handling System vs Small Box System

- 2017: 22% increase in harvest time
- 2018: 29% increase in harvest time
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, fact sheets, 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 harvesters 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 ft²
  - Fruit zone = 7.5
  - Fruit Loss < 1.0%

- **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 conveyor has improved berry handling capacity:**
  - Larger circumference with the 26” head allowed for debris to be more thoroughly cleared from the picker bar, (stretched bar spacing on the 26” diameter head).
  - Improved cum 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”, so 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 plugged with debris when wet).
  - The wider conveyor also allows for better berry handling when traveling 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:**
  - More brushing increases 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.

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What's next?

→ Automate the wild blueberry harvester to be less reliant on the operator for maintaining optimum picking performance.

Automation of Wild Blueberry Harvester – Plan 2017-2021
Sensing and Control System for Wild Blueberry Harvester

Why radar sensor?

Technology of microwave RADAR Sensor
ACKNOWLEDGEMENTS
Thank You!

E-mail: qzaman@dal.ca