Intra-row weed control automation in California vegetable crops

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Introduction

- Agricultural labor costs are rising
- Weed automation is needed in both agronomic and specialty crops
- Who will pay for the new technology?
- Barriers to adoption
Herbicide markets

- Corn 90.9 million acres
- Soy 89.5 million acres
- Wheat 45.7 million acres
- Cotton 12.1 million acres

- Field corn production labor cost/A $36
- Field corn weed control cost/A $32
  - Iowa State University 2017

USDA NASS 2017
CE DAEERLVEAS

Lettuce 261,100 acres
Spinach 41,190 acres

From the perspective of the Ag Chem industry these are minor crops because they require additional labelling for vegetables –which involves cost, time and risk. These are obstacles!
# Weed Management Practices & Costs 2015*

<table>
<thead>
<tr>
<th>Practice</th>
<th>Romaine Hearts ($/acre)</th>
<th>Organic Spinach ($/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide application</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>Mechanical cultivation</td>
<td>46</td>
<td>39</td>
</tr>
<tr>
<td>Hand weeding</td>
<td>153</td>
<td>440</td>
</tr>
<tr>
<td><strong>Total weed mgt cost</strong></td>
<td><strong>250</strong></td>
<td><strong>479</strong></td>
</tr>
</tbody>
</table>


Costs per acre include materials, equipment, and labor ($16.10/hr. field; $21.70/hr. machine).
Commercial Intelligent cultivators
Development costs: herbicides vs. automation

Total costs million ($)

Herbicide: $286 million
Automation: $12 million

McDougall 2016
Polsen DK, Mol NL 2016
Lower Barriers to Adoption

- Easier to move weeding devices between agronomic and specialty crops
  - Barriers are lower for devices than herbicides
- Standardization is needed if economies of scale are to be realized
  - Automated weeder technology adaptable for agronomic and specialty crops
Inter- & intra-row cultivation

A traditional inter-row cultivator does not reach into the seedline

An intra-row cultivator weeds around and in the row
The objective

- Develop a method for a machine to distinguish between a crop and weed
Crop marking

- The objective is to mark the crop so that a machine can “see” where the crop is and then the machine can remove weeds by spray or cultivation without harming the crop.
Crop Signaling Concept

- Topical Markers

Daylight

Excitation light

Crop Marking at Planting
1. Systemic Seed Marking Technology
2. Machine Vision Technology
3. Targeted Spray Technology

Crop Signal Detection

Precision Weed Control
Crop Signaling Prototype

- Topical Markers
Crop Signaling Results

- Topical Markers

Signaling compound applied to tomato transplants at planting
Plants are tagged with a biodegradable, colored label at planting.
Crop Signaling Results

- Plant Labels
Crop Signaling Results

- Plant Labels
Field trials 2017 - straws

- Romaine lettuce trial Salinas, CA seeded June 5, 15, & 27, 2017, harvested Aug. 18, 25, & Sept. 8, 2017
- Weed density counts before and after cultivation, hand weeding times measured
Field trials 2017

- Trials were arranged in a RCB
- 4 to 8 reps
- No herbicide
- Treatments were automated cultivator, standard inter-row cultivator
- ACOVA, ANOVA using SAS GLM
Weed densities and hand weeding times – lettuce 2017

<table>
<thead>
<tr>
<th>Cultivator</th>
<th>No. ft² (LS Means)</th>
<th>% weed reduction</th>
<th>Time hr./A (LS Means)</th>
<th>% time reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated</td>
<td>4.3</td>
<td>61</td>
<td>45.4</td>
<td>29</td>
</tr>
<tr>
<td>Standard</td>
<td>9.0</td>
<td>0</td>
<td>64.2</td>
<td>0</td>
</tr>
</tbody>
</table>

*P-value* <0.0001

Salinas, CA  June-July 2017
Weed densities and hand weeding times – lettuce 2017

<table>
<thead>
<tr>
<th>Trial 2</th>
<th>Cultivator</th>
<th>No. ft² (LS Means)</th>
<th>% weed reduction</th>
<th>Time hr./A (LS Means)</th>
<th>% time reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Automated</td>
<td>3.3</td>
<td>62</td>
<td>54.3</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>8.5</td>
<td>0</td>
<td>94.3</td>
<td>0</td>
</tr>
<tr>
<td><em>P-value</em></td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

Salinas, CA  June-July 2017
# Weed densities and hand weeding times – lettuce 2017

<table>
<thead>
<tr>
<th>Trial 3</th>
<th>Cultivator</th>
<th>No. ft² (LS Means)</th>
<th>% weed reduction</th>
<th>Time hr./A (LS Means)</th>
<th>% time reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Automated</td>
<td>1.3</td>
<td>63</td>
<td>18.6</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>3.4</td>
<td>0</td>
<td>37.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><em>P</em>-value</td>
<td>&lt;0.0001</td>
<td></td>
<td>0.0008</td>
<td></td>
</tr>
</tbody>
</table>

Salinas, CA  June-July 2017
# Fresh weight yields – lettuce 2017

<table>
<thead>
<tr>
<th>LS Means</th>
<th>Cultivator</th>
<th>Market heads no./100ft</th>
<th>Market heads lbs./100ft</th>
<th>Cull heads no./100ft</th>
<th>Culls lbs./100ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Automated</td>
<td>66</td>
<td>167</td>
<td>26 b</td>
<td>50 b</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>64</td>
<td>136</td>
<td>50 a</td>
<td>95 a</td>
</tr>
<tr>
<td></td>
<td><em>P</em>-value</td>
<td>0.86</td>
<td>0.16</td>
<td>0.0017</td>
<td>0.013</td>
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</table>

Salinas, CA  August-September 2017
### Fresh weight yields – lettuce 2017

<table>
<thead>
<tr>
<th>LS Means</th>
<th>Cultivator</th>
<th>Market heads no./100ft</th>
<th>Market heads lbs./100ft</th>
<th>Cull heads no./100ft</th>
<th>Culls lbs./100ft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trial 2</strong></td>
<td>Automated</td>
<td>65</td>
<td>202</td>
<td>42</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>54</td>
<td>160</td>
<td>54</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td><em>P-value</em></td>
<td>0.42</td>
<td>0.37</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>LS Means</td>
<td>Cultivator</td>
<td>Market heads no./100ft</td>
<td>Market heads lbs./100ft</td>
<td>Cull heads no./100ft</td>
<td>Culls lbs./100ft</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Automated</td>
<td>66</td>
<td>152</td>
<td>36</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>71</td>
<td>154</td>
<td>38</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>P-value</td>
<td>0.60</td>
<td>0.88</td>
<td>0.72</td>
<td>0.78</td>
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</tbody>
</table>

Salinas, CA  August-September 2017
Weed densities and hand weeding times – tomato 2017

<table>
<thead>
<tr>
<th>Cultivator</th>
<th>No. m²</th>
<th>% weed reduction</th>
<th>Time hr./A</th>
<th>% time reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated</td>
<td>14.2 B</td>
<td>82</td>
<td>46.3 B</td>
<td>39</td>
</tr>
<tr>
<td>Standard</td>
<td>78.1 A</td>
<td>0</td>
<td>76.0 A</td>
<td>0</td>
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<tr>
<td>P-value</td>
<td>&lt;0.0001</td>
<td></td>
<td>0.0021</td>
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</tbody>
</table>

Davis, CA  May 2017
Fresh weight yields per 100 m row – tomato 2017

<table>
<thead>
<tr>
<th>Cultivator</th>
<th>Kg 100/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated</td>
<td>186.6</td>
</tr>
<tr>
<td>Standard</td>
<td>212.9</td>
</tr>
<tr>
<td>P-value</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Davis CA  Sept. 2017
Summary

- The intra-row cultivator removed more weeds than the standard cultivator.
- Hand weeding times were reduced by the intra-row cultivator compared to standard cultivator.
- Crop yields were similar between both cultivator treatments.
Band steam

- Heating soil to 150-160°F for a few minutes kills soil pathogens and weed seed
- Band Steaming has been evaluated in Denmark, Italy & Sweden with good weed control results
Field steam application setup
Heat bars aligned with seed lines

Steam is injected into intra-row soil
Disinfested seed lines

Disinfested bands scored by marker
Seed lettuce into the disinfested band

Weed emergence and lettuce drop inoculum is reduced in intra-row

Weeds outside seedline can be cultivated out.
Methods

- Innoculate soil with special blend
- Innoculate crops
- Grow to maturity
Methods continued

- Applied steam August 28 and 30, 2017
- Then transplanted lettuce August 31, 2017
Steam evaluations in lettuce

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Temp min&gt; 140°F</th>
<th>Weeds #ft²</th>
<th>% lettuce drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>13.5</td>
<td>2.6 b</td>
<td>1.5</td>
</tr>
<tr>
<td>Steam + Quick Lime</td>
<td>9.5</td>
<td>1.6 b</td>
<td>2.9</td>
</tr>
<tr>
<td>Control</td>
<td>0.0</td>
<td>37.2 a</td>
<td>8.1</td>
</tr>
</tbody>
</table>
Steam – summary

- Is slow but we have new funding from USDA NIFA & will work to improve
- Weed control is >90%
- Lettuce drop evaluations will continue
Funding Acknowledgements

- Thanks to USDA NIFA Specialty Crop Research Initiative
- California Leafy Greens Research Program
- California Tomato Research Initiative