Intra-row weed control automation in California vegetable crops

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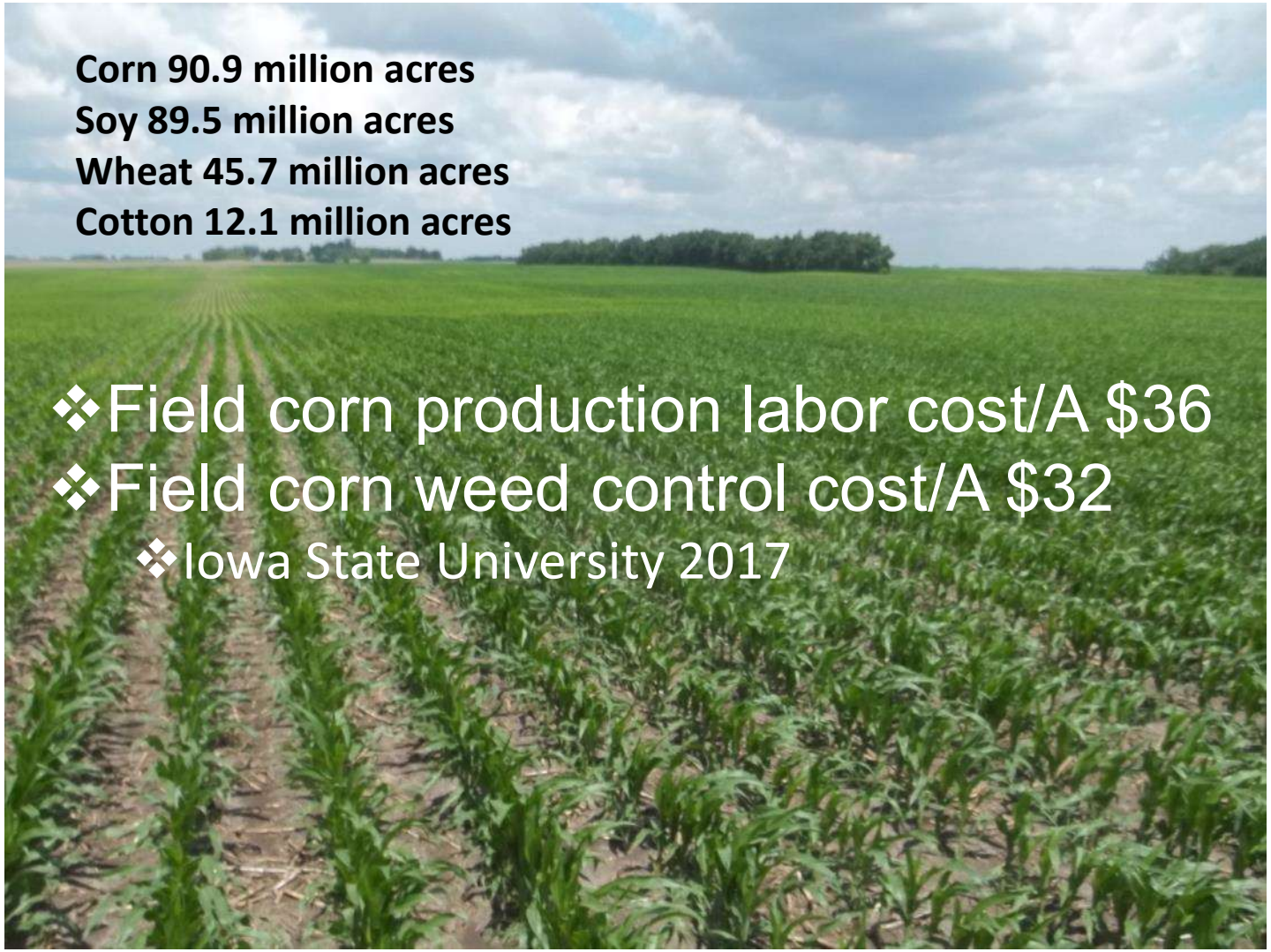
Introduction

- 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



USDA NASS 2017

VEGETABLES

Lettuce 261,100 acres
Spinach 41,190 acres

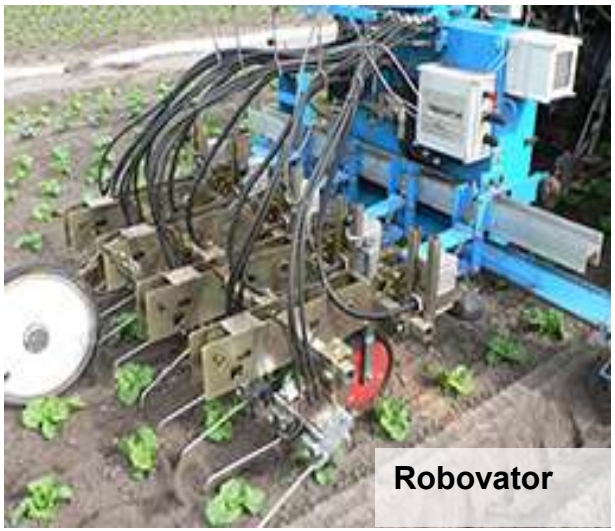
From the perspective of the Ag Chem industry these are *minor* crops because they require additional labelling for vegetables –which involves cost, time and risk. These are obstacles!

*Weed Management Practices & Costs 2015**

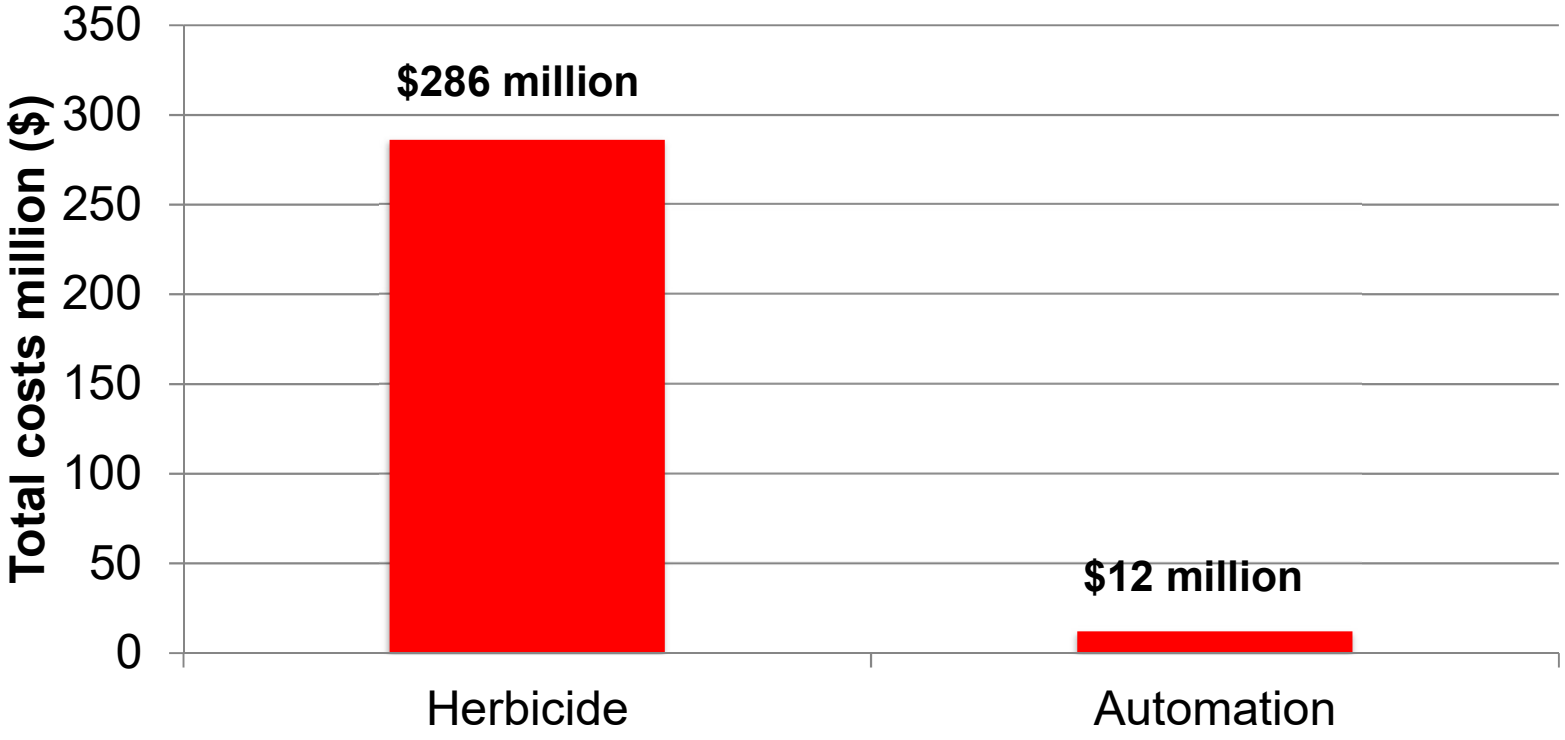
Practice	Romaine Hearts ($/acre)	Organic Spinach ($/acre)
Herbicide application	51	0
Mechanical cultivation	46	39
Hand weeding	153	440
Total weed mgt cost	***250***	***479***

* Source: UC Cooperative Extension Cost and Return Studies. http://coststudies.ucdavis.edu. Costs per acre include materials, equipment, and labor ($16.10/hr. field; $21.70/hr. machine).

Commercial Intelligent cultivators



Development costs: herbicides vs. automation



McDougall 2016

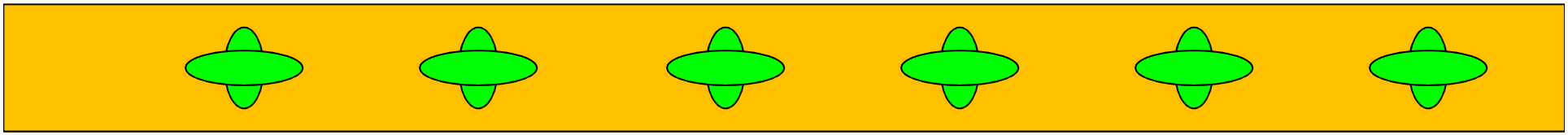
Polsen DK, Mol NL 2016

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

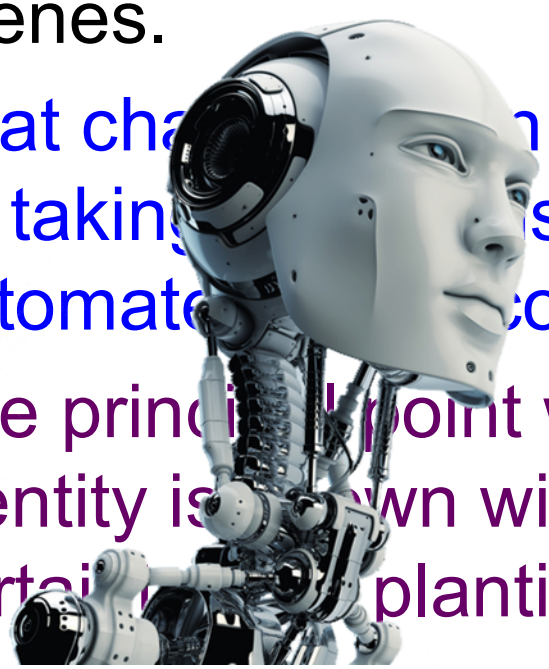
- Develop a method for a machine to distinguish between a crop and weed

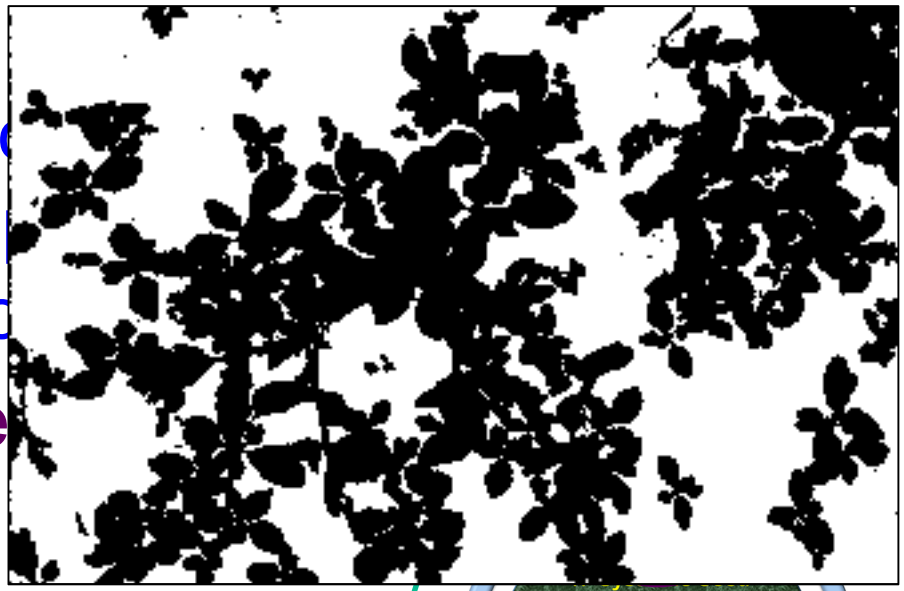
Crop marking

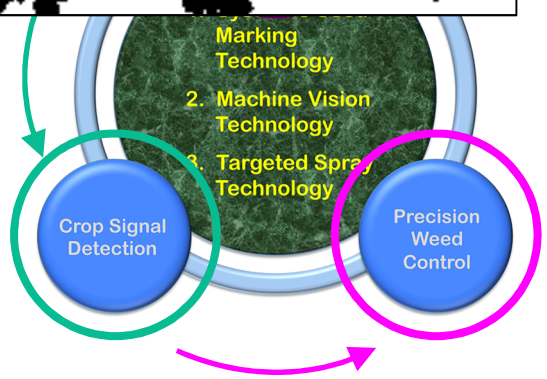
- The objective is to mark the crop so that a machine can “see” where the crop is and then the machine can remove weeds by spray or cultivation without harming the crop

Crop Signaling Concept

1. Machine Learning remains challenged by complex natural scenes.
2. That cha[illegible]n be [illegible] by takin[illegible]s ap[illegible] automate[illegible]contro[illegible]
3. The princi[illegible]point whe[illegible] identity is [illegible]wn with 1[illegible] certai[illegible] planting.
4. The systems approach transfers the knowledge of crop identity forward in time
5. For later use in automated weed management.

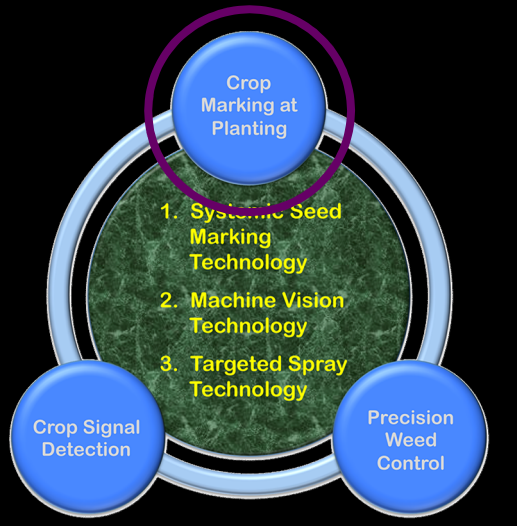






Crop Signaling Concept

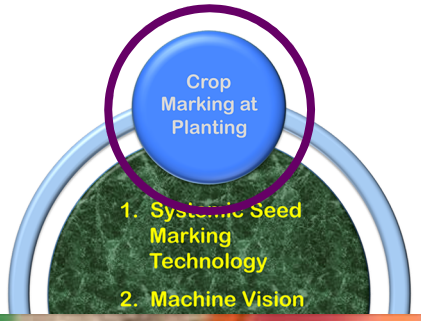
- Topical Markers



Daylight

Excitation light

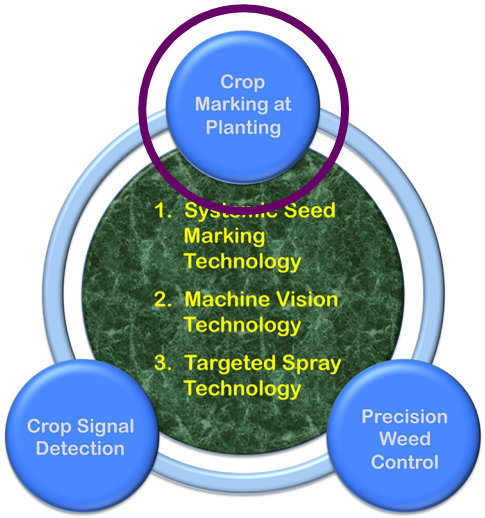
Crop Signaling Prototype



- Topical Markers

Crop Signaling Results

- Topical Markers



Signaling compound applied to tomato transplants at planting

Crop Signaling Prototype

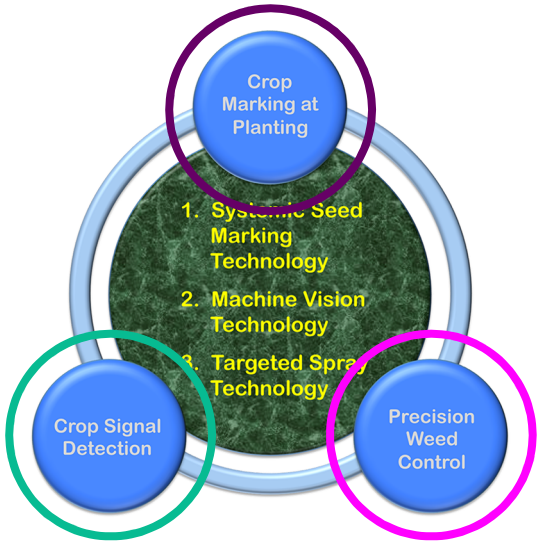
- Plant Labels

- Plants are tagged with a **biodegradable**, colored label at planting

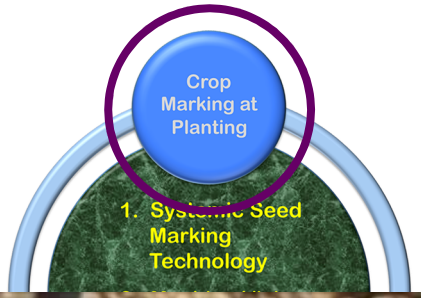
UC tomato plant labeling system

Crop Signaling Results

- Plant Labels



Crop Signaling Results



- Plant Labels

Field trials 2017 - straws

- Processing tomato trial Davis, CA transplanted May 19, harvested Sept. 6, 2017, second trial transplanted July 2017.
- 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

	Cultivator	No. ft² (LS Means)	% weed reduction	Time hr./A (LS Means)	% time reduction
Trial 1	Automated	4.3	61	45.4	29
	Standard	9.0	0	64.2	0
	P-value	<0.0001		0.0204	

Salinas, CA June-July 2017

Weed densities and hand weeding times – lettuce 2017

	Cultivator	No. ft² (LS Means)	% weed reduction	Time hr./A (LS Means)	% time reduction
Trial 2	Automated	3.3	62	54.3	42
	Standard	8.5	0	94.3	0
	P-value	<0.0001		<0.0001	

Salinas, CA June-July 2017

Weed densities and hand weeding times – lettuce 2017

	Cultivator	No. ft² (LS Means)	% weed reduction	Time hr./A (LS Means)	% time reduction
Trial 3	Automated	1.3	63	18.6	50
	Standard	3.4	0	37.5	0
	P-value	<0.0001		0.0008	

Salinas, CA June-July 2017

Fresh weight yields – lettuce 2017

LS Means	Cultivator	Market heads no./100ft	Market heads lbs./100ft	Cull heads no./100ft	Culls lbs./100ft
Trial 1	Automated	66	167	26 b	50 b
	Standard	64	136	50 a	95 a
	P-value	*0.86*	*0.16*	*0.0017*	*0.013*

Salinas, CA August-September 2017

Fresh weight yields – lettuce 2017

LS Means	Cultivator	Market heads no./100ft	Market heads lbs./100ft	Cull heads no./100ft	Culls lbs./100ft
Trial 2	Automated	65	202	42	80
	Standard	54	160	54	99
	P-value	*0.42*	*0.37*	*0.33*	*0.36*

Salinas, CA August-September 2017

Fresh weight yields – lettuce 2017

LS Means	Cultivator	Market heads no./100ft	Market heads lbs./100ft	Cull heads no./100ft	Culls lbs./100ft
Trial 3	Automated	66	152	36	66
	Standard	71	154	38	64
	P-value	*0.60*	*0.88*	*0.72*	*0.78*

Salinas, CA August-September 2017

Weed densities and hand weeding times – tomato 2017

Cultivator	No. m2	% weed reduction	Time hr./A	% time reduction
Automated	14.2 B	82	46.3 B	39
Standard	78.1 A	0	76.0 A	0
P-value	<0.0001		0.0021	

Davis, CA May 2017

Fresh weight yields per 100 m row – tomato 2017

Cultivator	Kg 100/m
Automated	186.6
Standard	212.9
P-value	0.30

Davis CA Sept. 2017

Weed densities and hand weeding times – tomato 2017

Cultivator	No. m2	% weed reduction	Time hr./A	% time reduction
Automated	4.8 B	67	7.1 B	30
Standard	14.6 A	0	10.2 A	0
P-value	<0.0001		0.0007	

Davis, CA August 2017

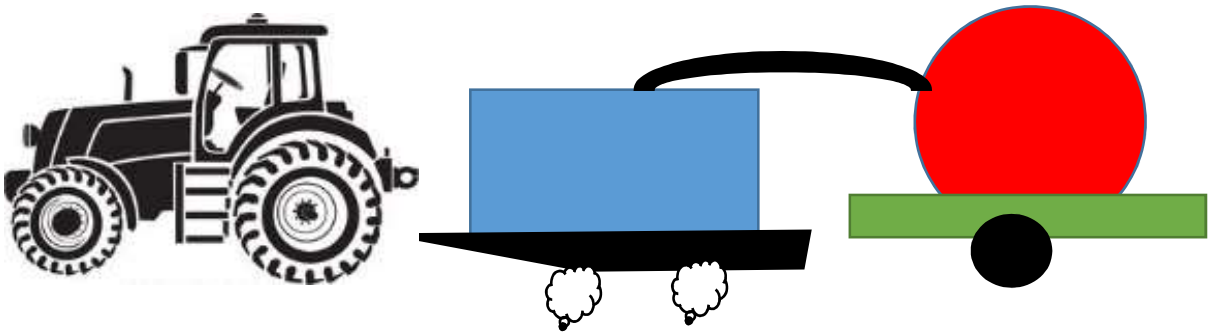
Summary

- 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

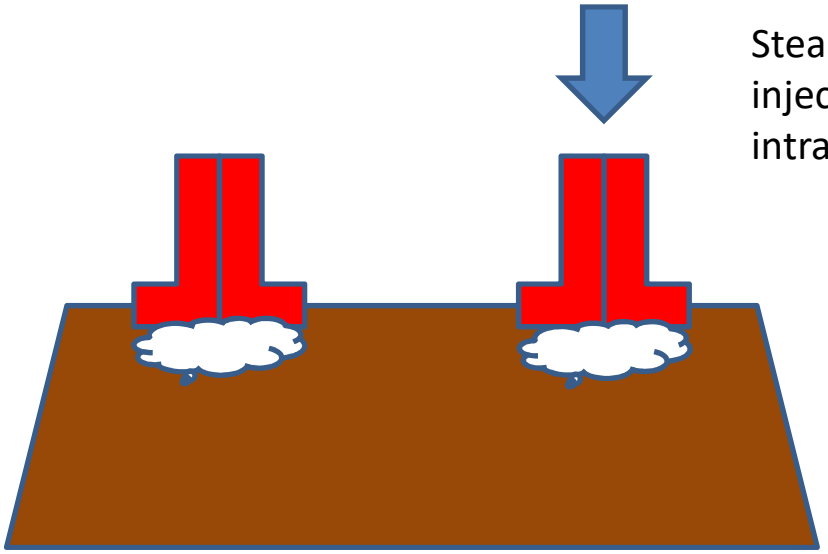
Band steam

- 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

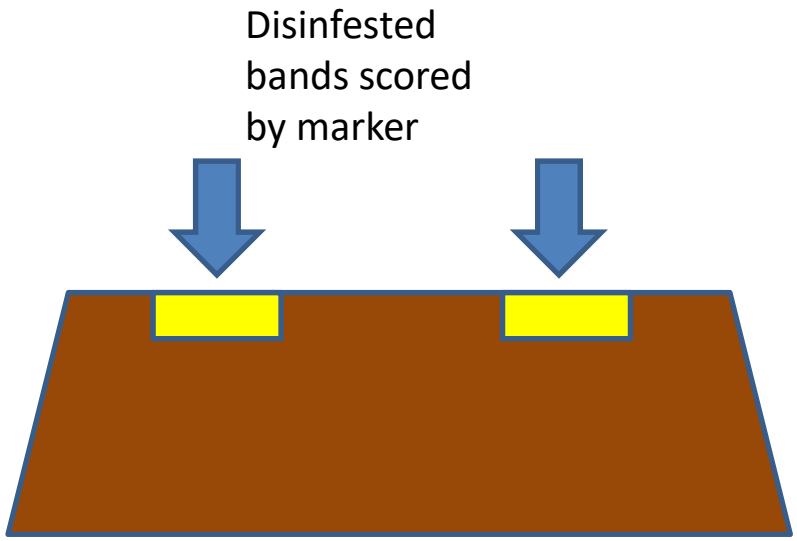


Heat bars aligned with seed lines

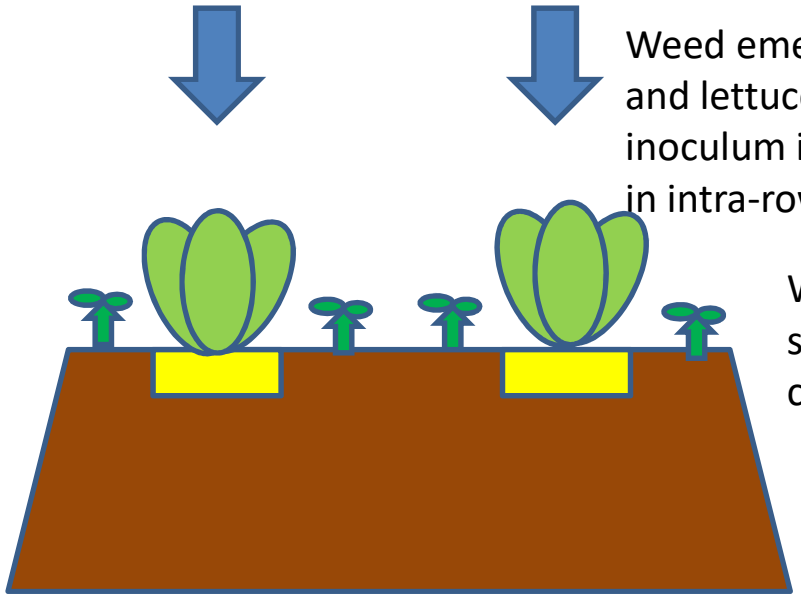


Steam is injected into intra row soil

Disinfested seed lines



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

- ❖ Innocul[illegible]special blend”
- ❖ Innocul[illegible]
- ❖ Grow to[illegible]

Methods continued

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

Steam evaluations in lettuce

Treatment	Temp min> 140°F	Weeds #ft^2	% lettuce drop
Steam	13.5	2.6 b	1.5
Steam + Quick Lime	9.5	1.6 b	2.9
Control	0.0	37.2 a	8.1

Steam photos

No steam

Steam

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