Engineering Concerns for Mechanized In-Row Weed Control

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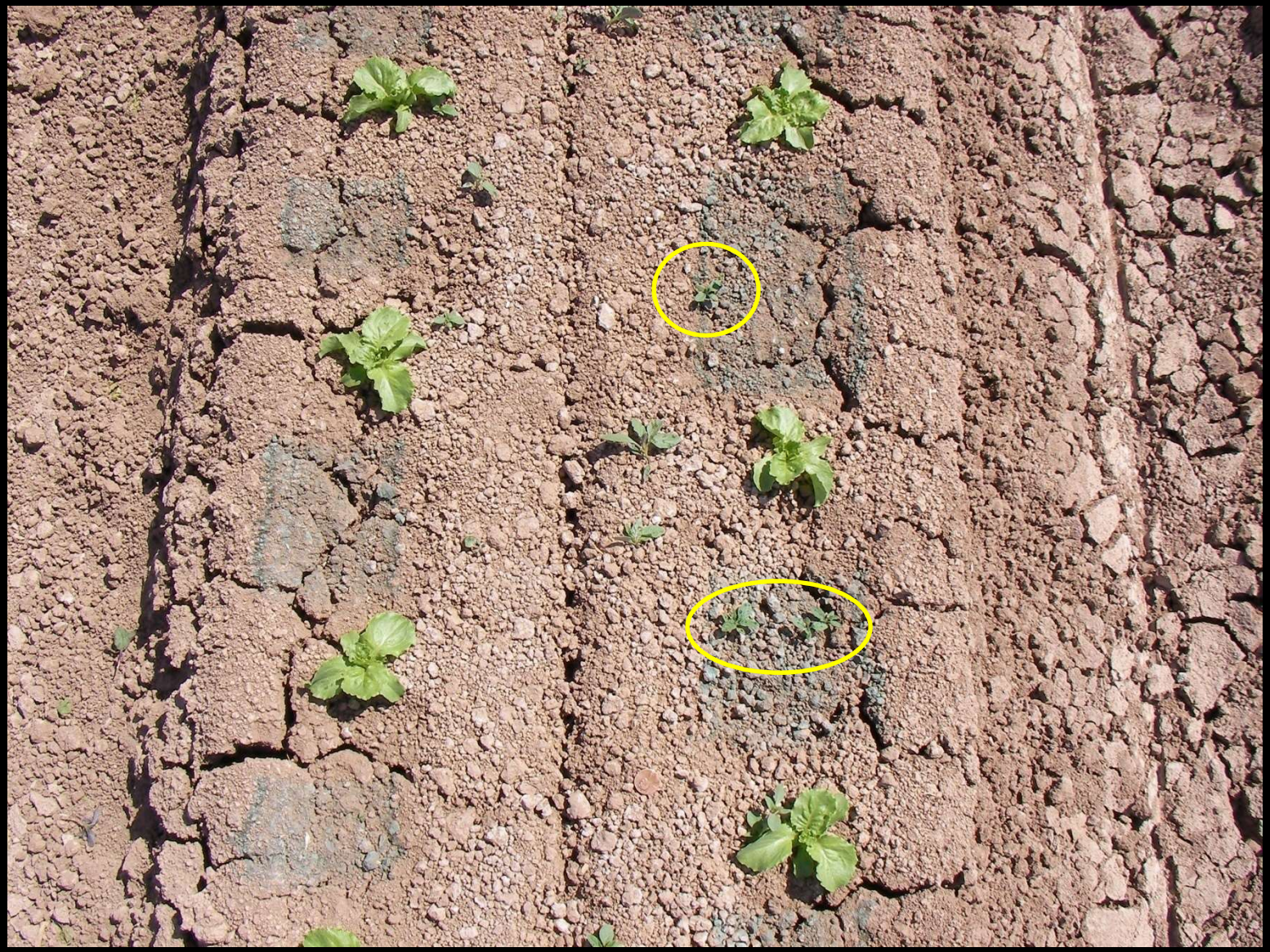
University of Arizona
Department of Ag and Biosystems Engineering

2016 Salinas Valley Weed School, November 2, 2016



In-Row Weeds

In-Row Weeders

- Commercialized – 2008
- Developed in Europe
  - High labor costs
- Latest technologies
  - U.S. market - 2014

Stekettee IC

Distributor – Sutton Ag Enterprises, Inc., Salinas, CA

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Robovator

F. Poulsen Engineering ApS

Distributors – KULT-Kress, New Holland, PA and Pacific Ag Rentals, LLC, Salinas, CA

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Standard Cultivator

Robovator

Weed Control Effectiveness

Cult	Herb[b]	Weed Density[a]									
		Exp. 1		Exp. 2		Exp. 3		Exp. 4		Exp. 5	
		no. ft^{-2}									
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Conv	w/o	45.0 a	15.0 a	12.8 a	3.5 a	1.0 a	0.3 a	31.0 a	15.5 a	12.2 a	3.5 a
Robo	w/o	40.0 a	4.8 b	15.7 a	1.3 b	1.3 a	0.2 ab	37.6 a	5.9 b	10.0 a	1.2 b
Conv	with	5.0 b	0.7 b	5.4 b	0.9 b	0.0 b	0.0 b	9.7 b	3.4 b	0.7 b	0.1 c
Robo	with	6.3 b	0.4 b	6.9 b	0.2 b	0.0 b	0.0 b	6.9 b	0.5 b	0.9 b	0.3 c

[a] Means with the same letter within columns are not significantly different according to Tukey-Kramer Honestly Significant Difference (HSD) test P = 0.05.

[b]Herbicide for experiments 1 and 5 was pronamide at 1.2 lb ai ac^{-1} ($60 ac^{-1}); herbicide for experiments 2, 3 and 4 was DCPA at 7.5 lb ai ac^{-1} ($132 ac^{-1}).

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Pre-Cultivation

Post – In-Row Cultivation

Weed Control Effectiveness

~ 2/3rds In-Row Weeds

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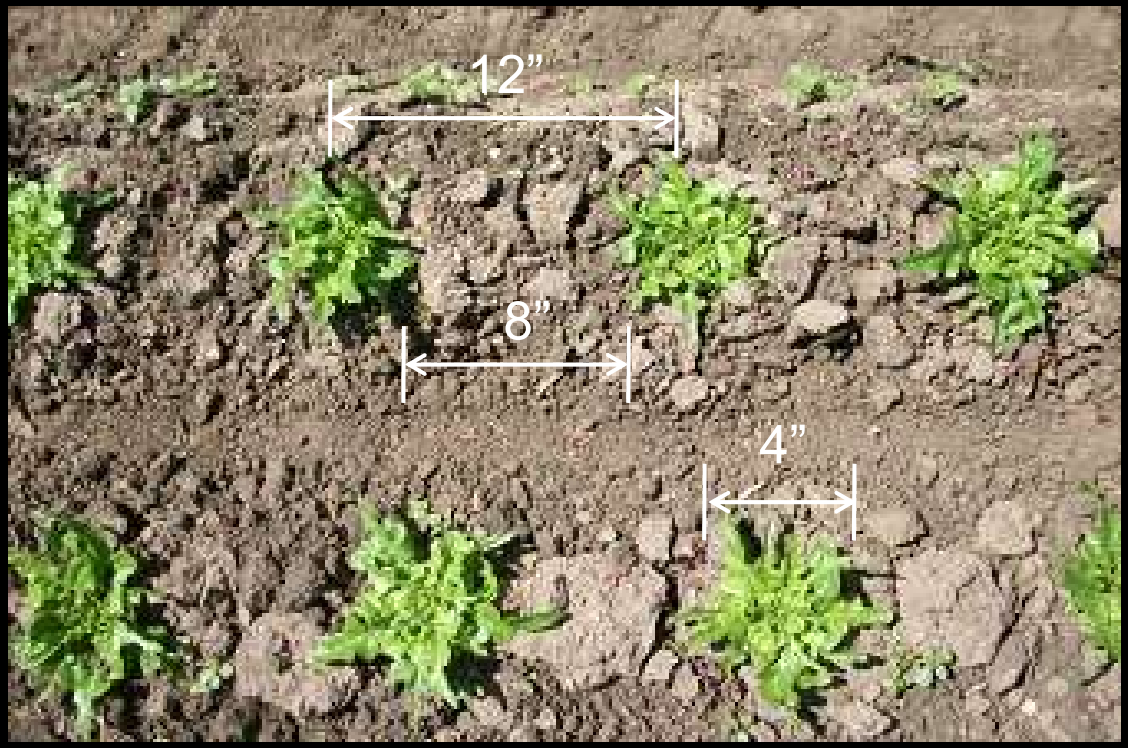
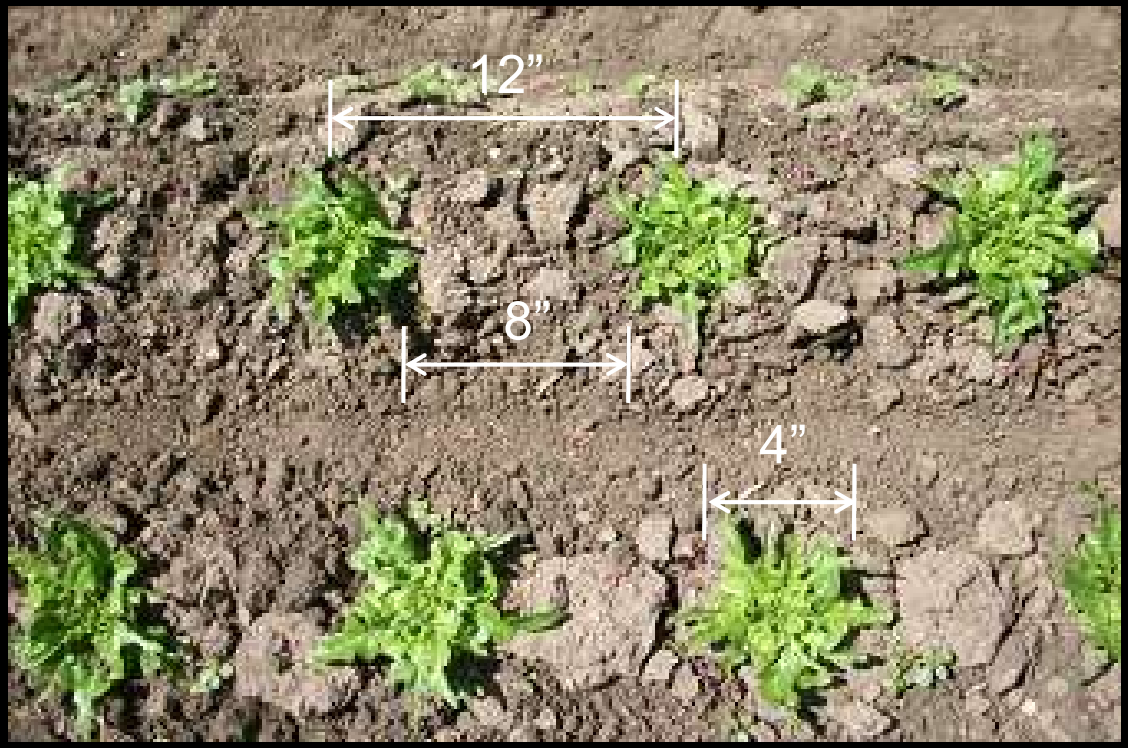
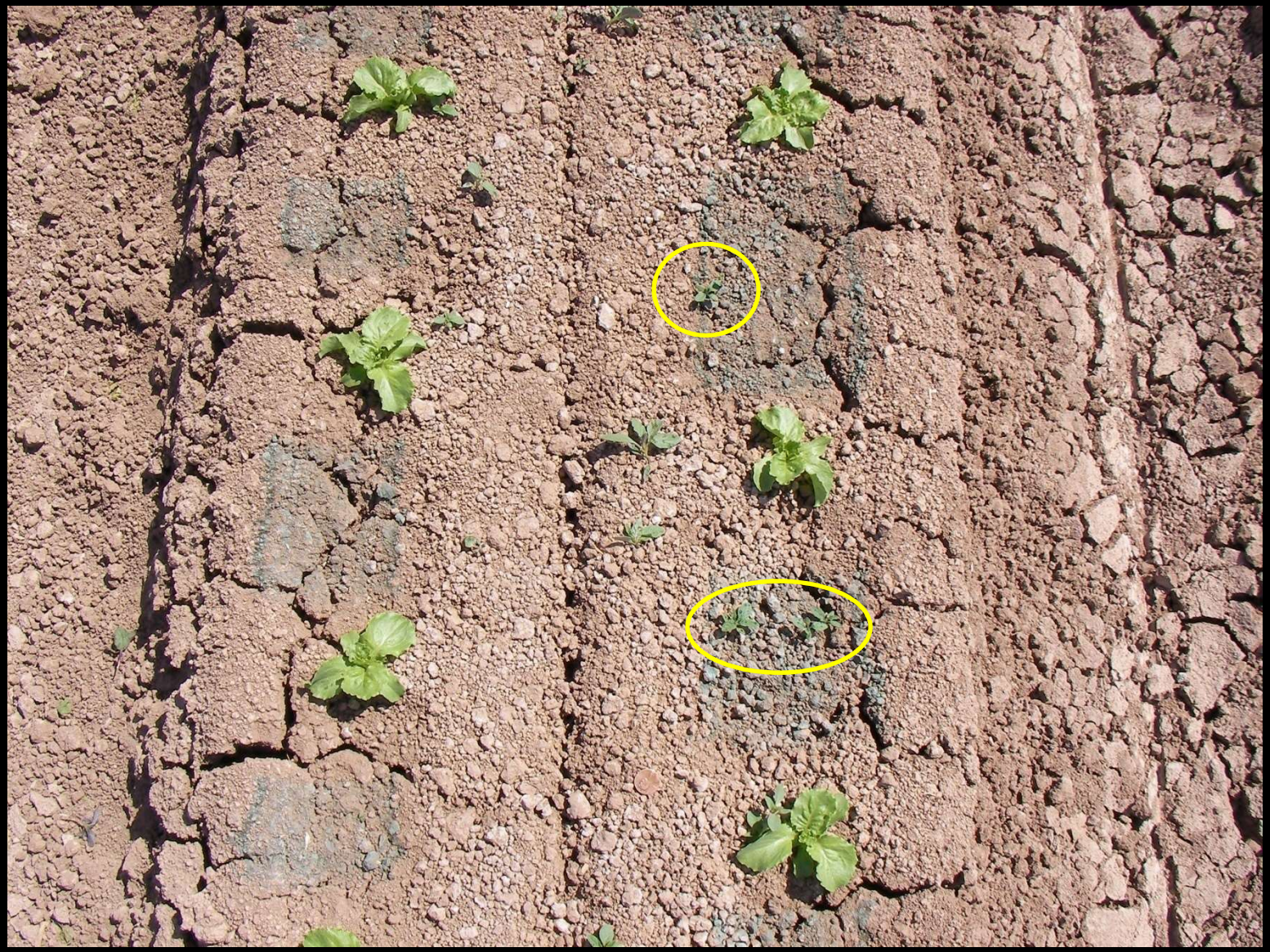
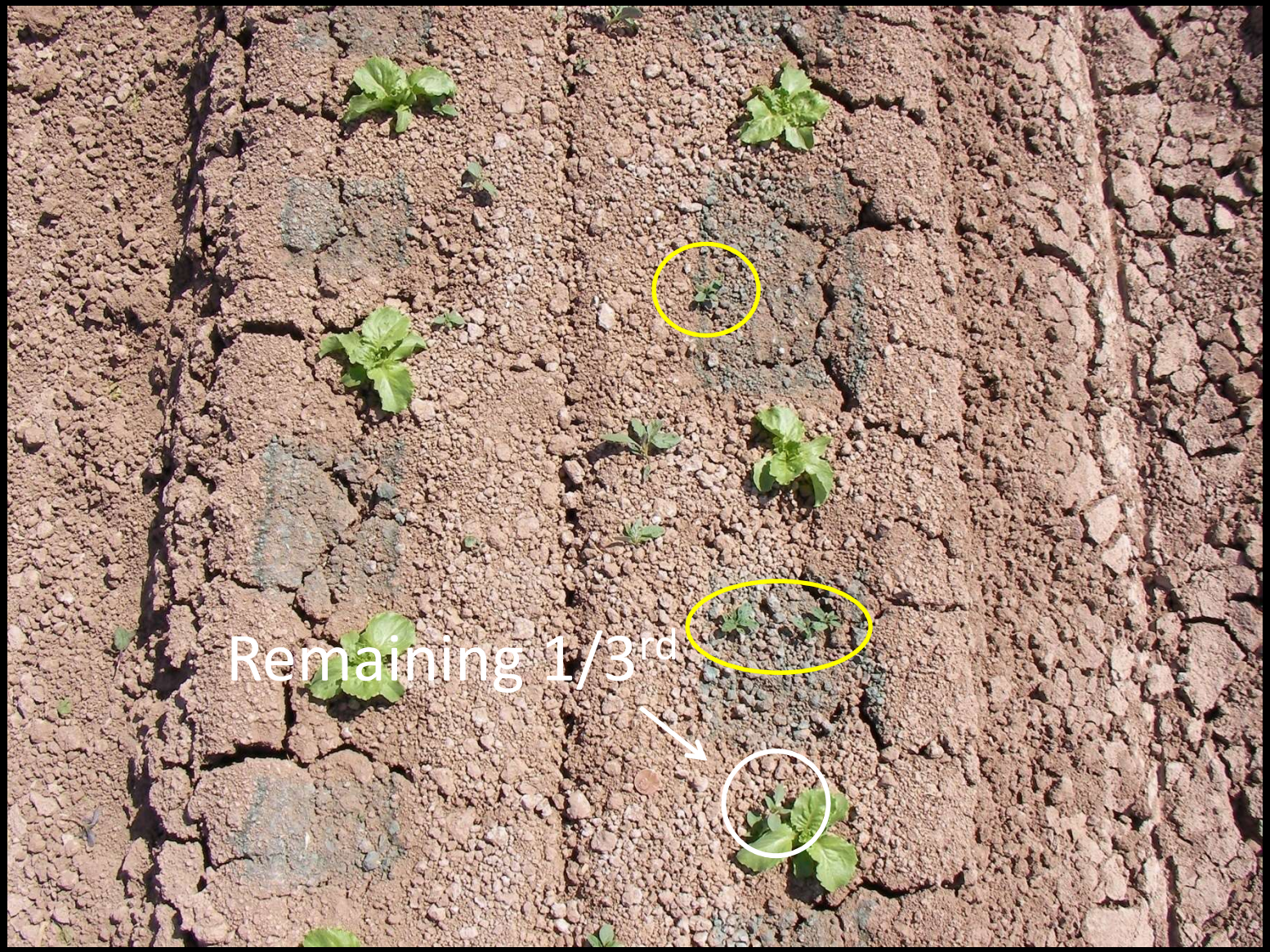

12”
8”
4”



$$\frac{8"}{12"} = {}^{2}/_{3} \text{ rds}$$



Precision Weeding



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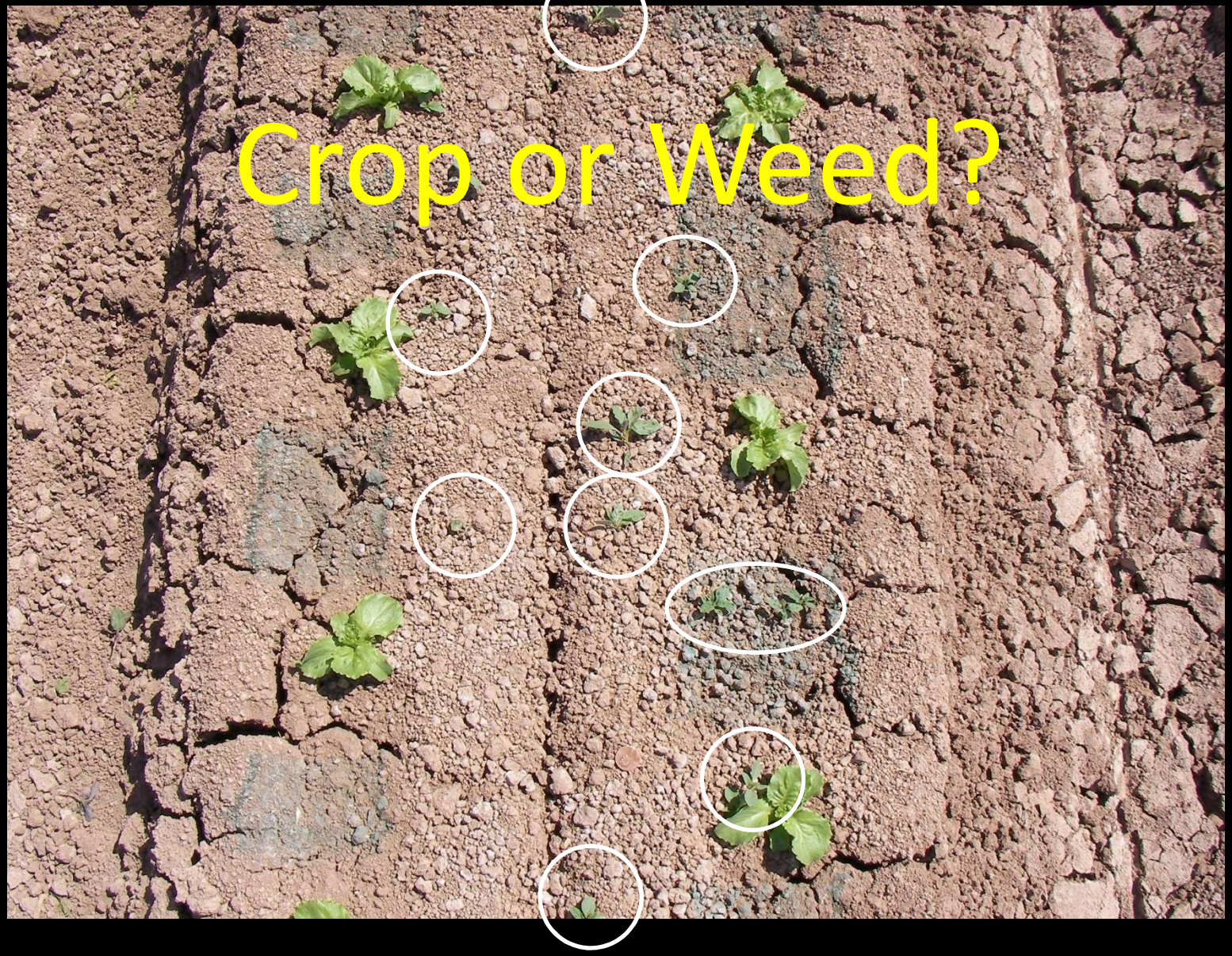
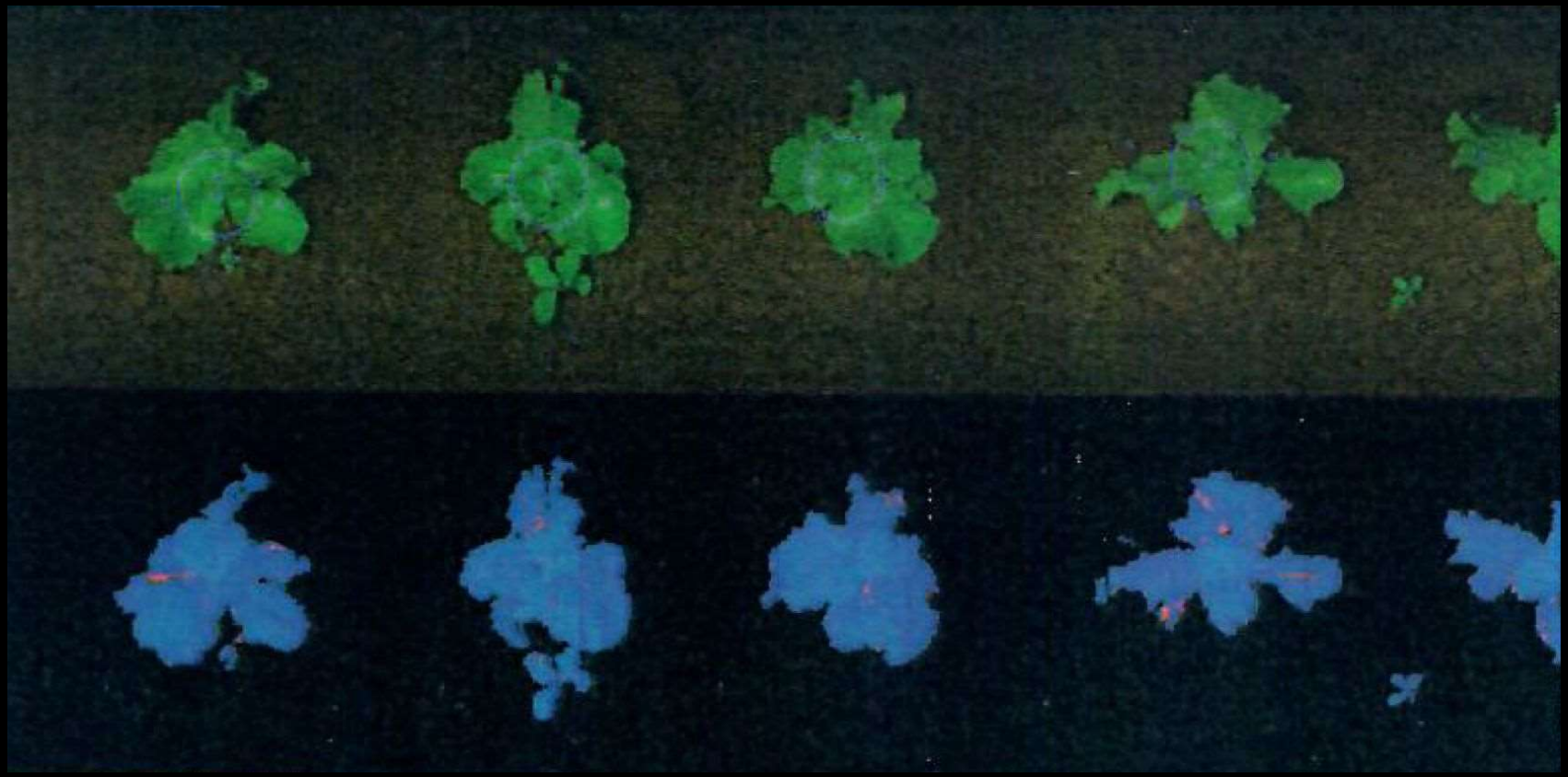


Precision Weeding

Crop/Weed Classification - Size and Location



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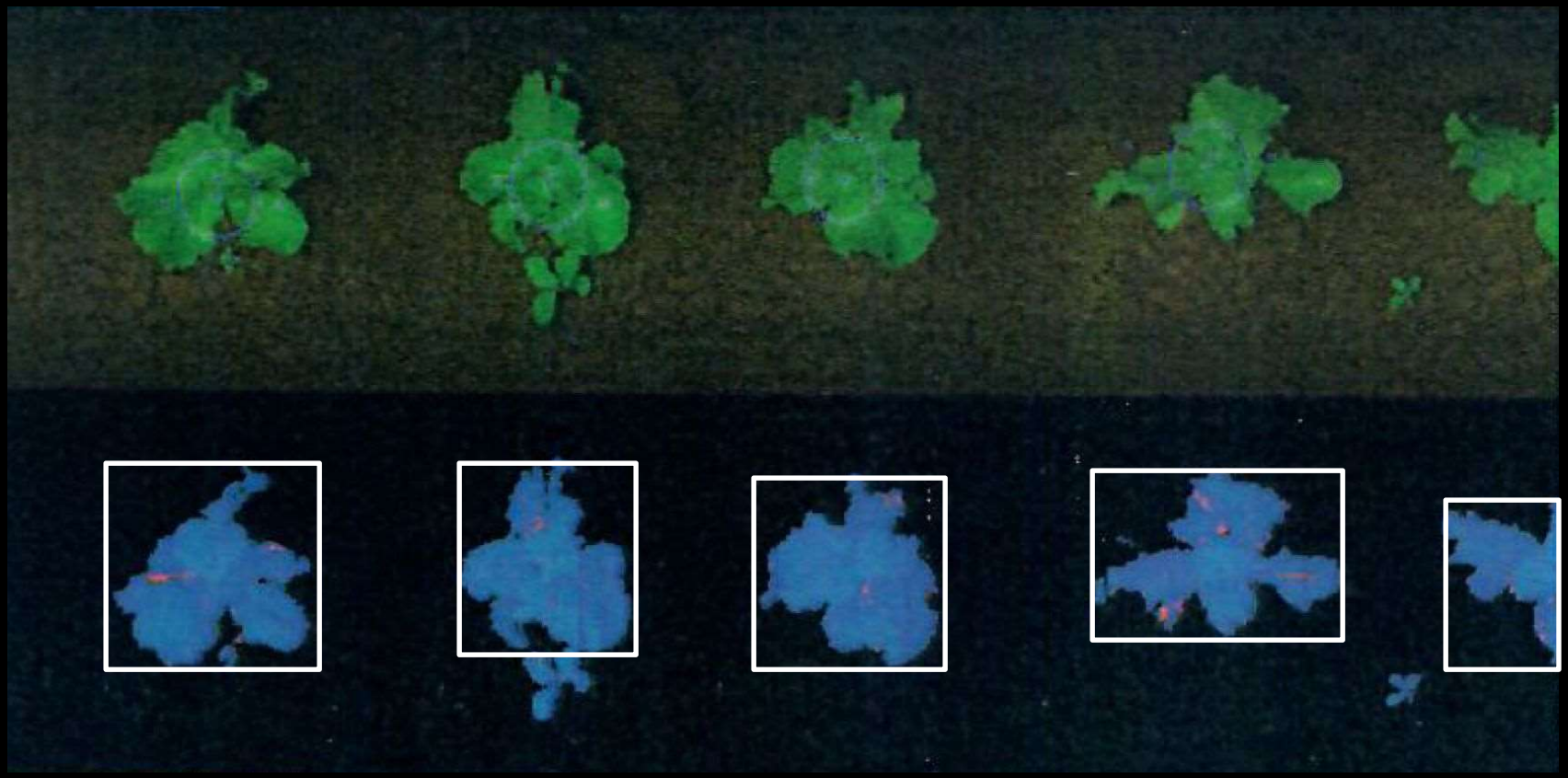

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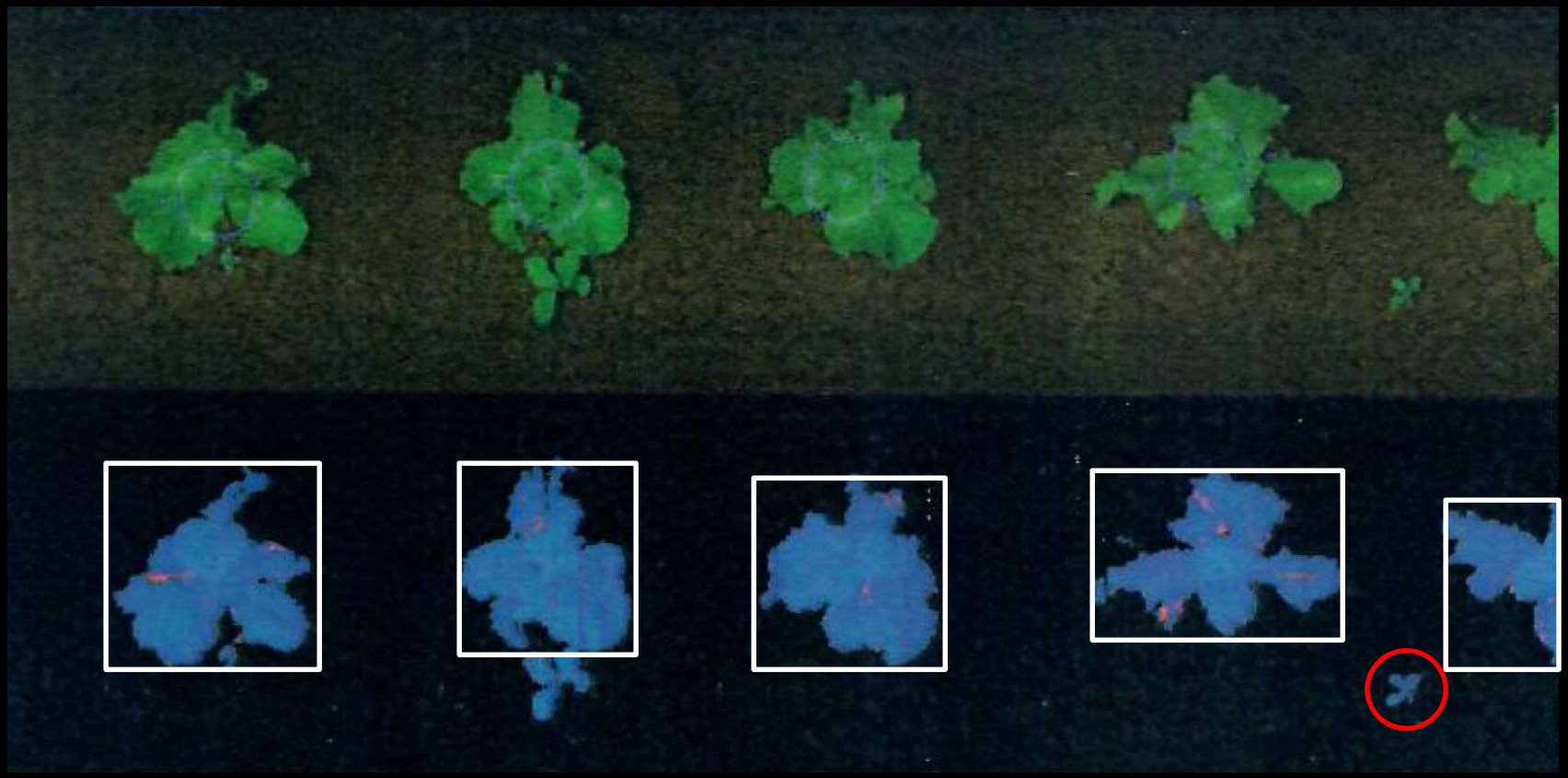

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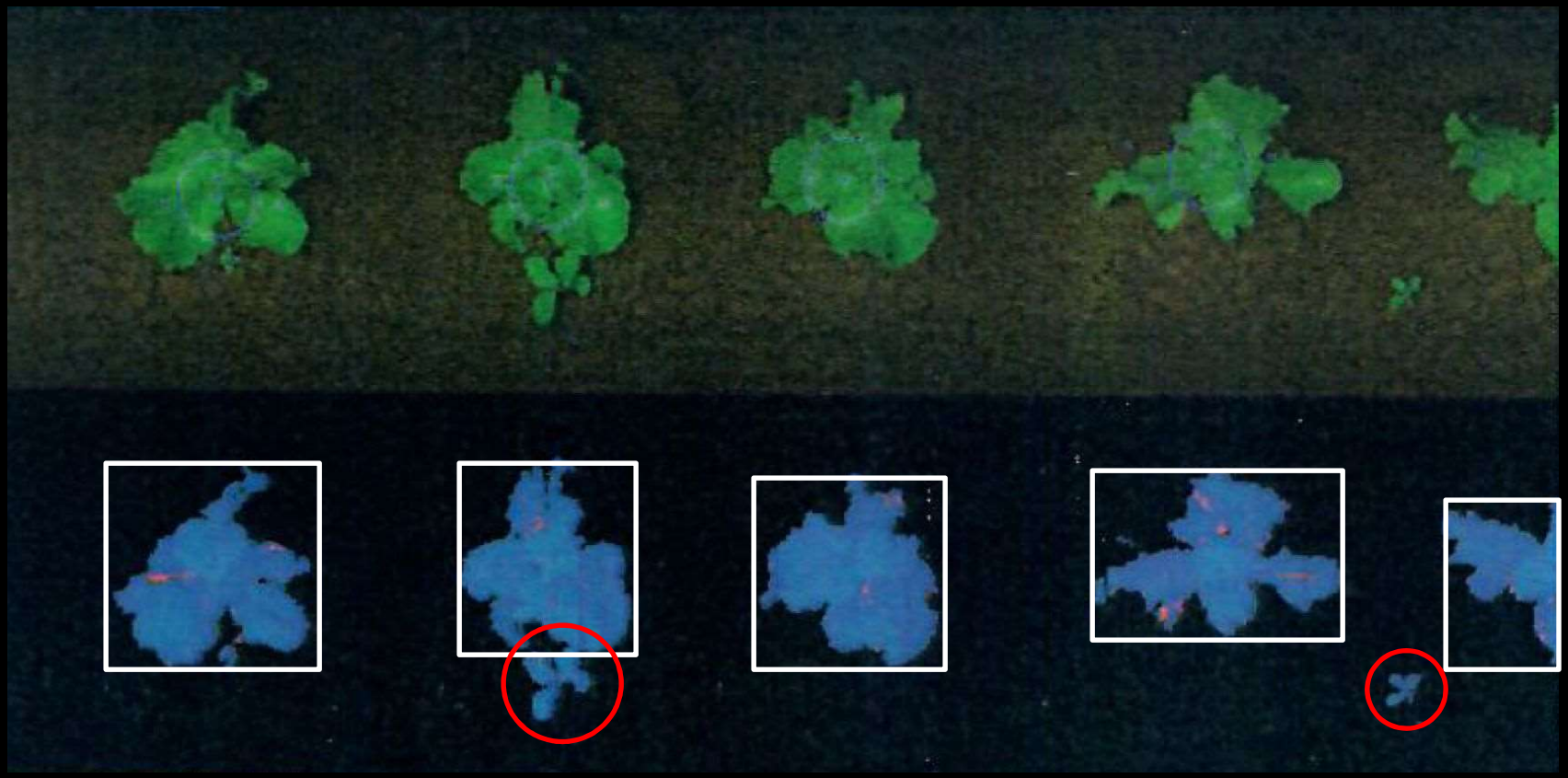


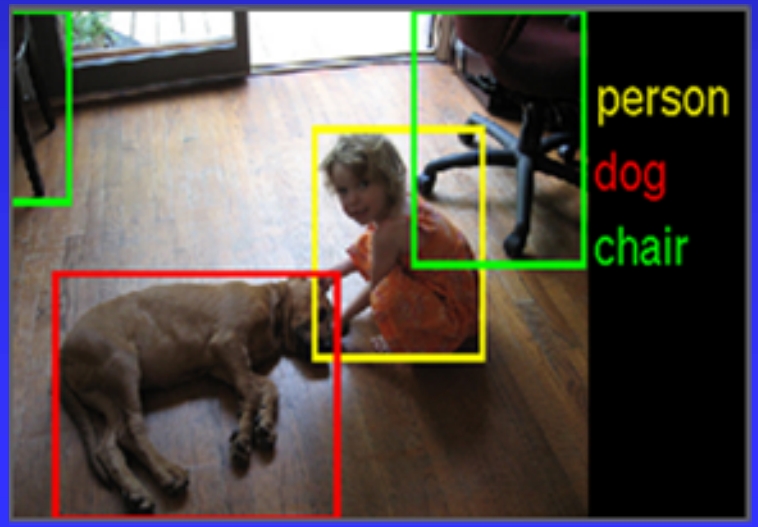
Crop/Weed Classification - Size and Location

Large, Close Weed

Deep Learning

Deep Learning

- Training set – numerous images
- Convolutional neural network
- Develops classification scheme
- ImageNet contest - <1% error



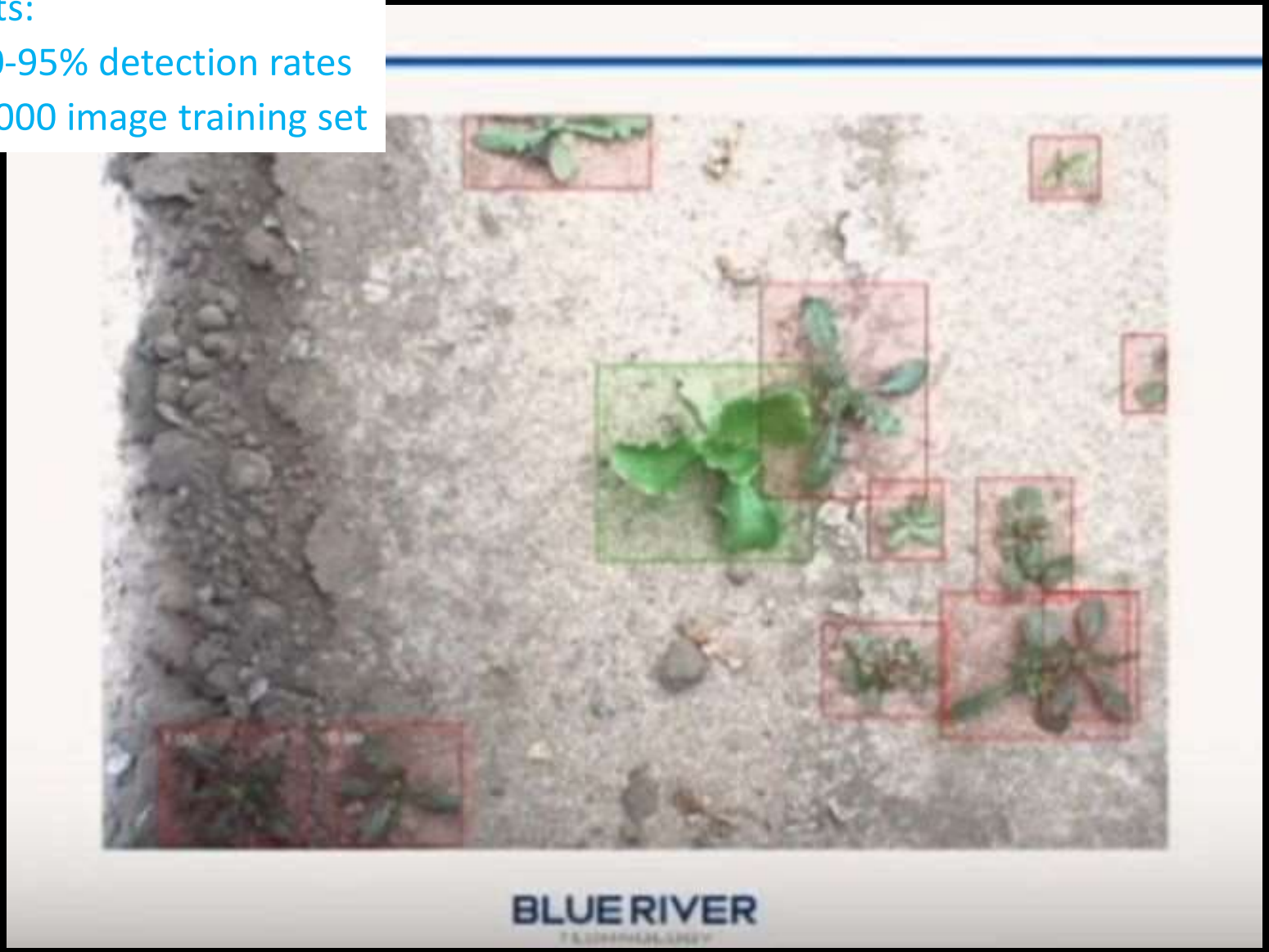
Deep Learning

- Blue River Technologies Inc.
- + $17 million (December, 2015)
- Spray based precision weeder
- Crops – Cotton, lettuce, others

Deep Learning - Crop/Weed Classification

Results:

- 90-95% detection rates
- 1,000 image training set



Deep Learning - Crop/Weed Classification

Spray Transplants with Florescent Dye

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Spray Transplants with Florescent Dye

Specialty Crop Research Initiative Funded Project

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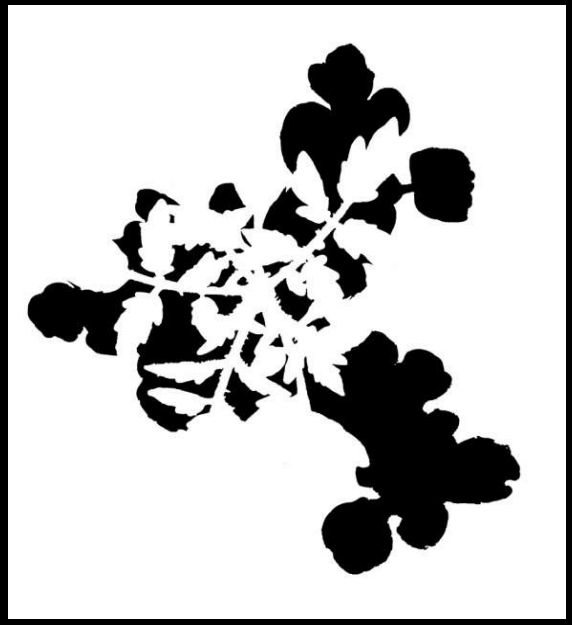

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Specialty Crop Research Initiative Funded Project

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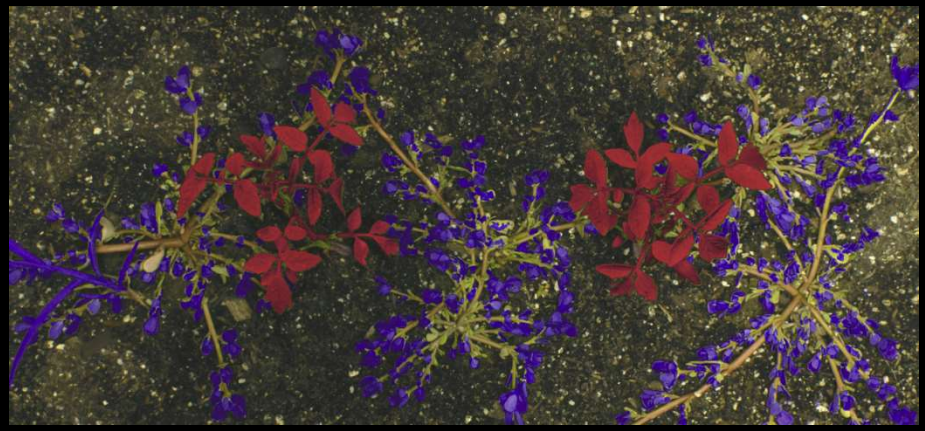

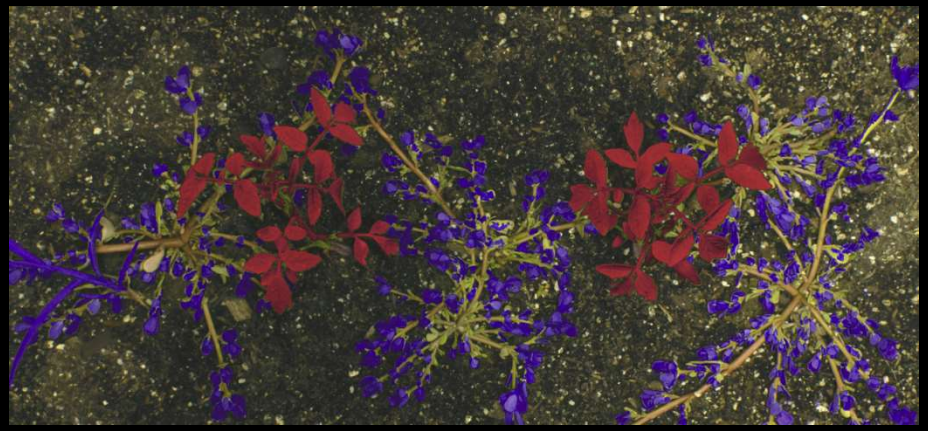

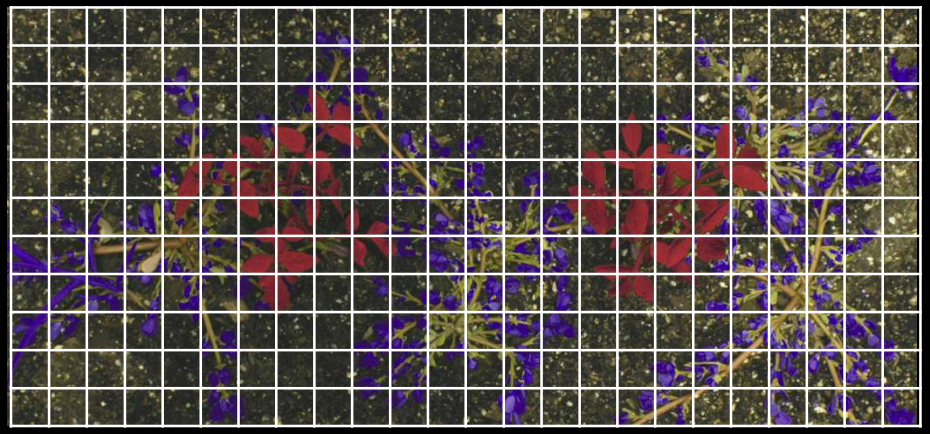

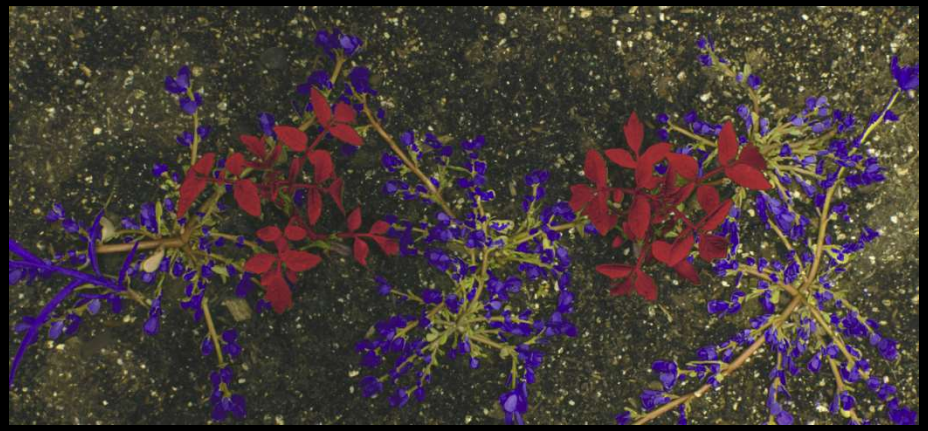

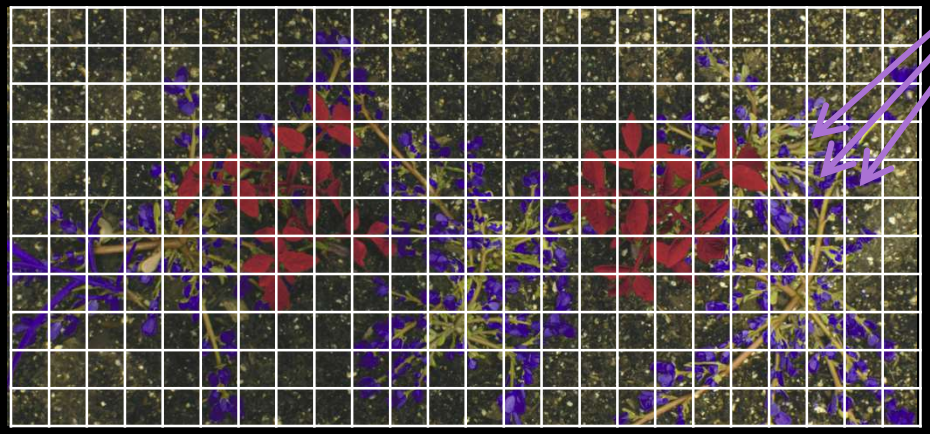

Spray Zone

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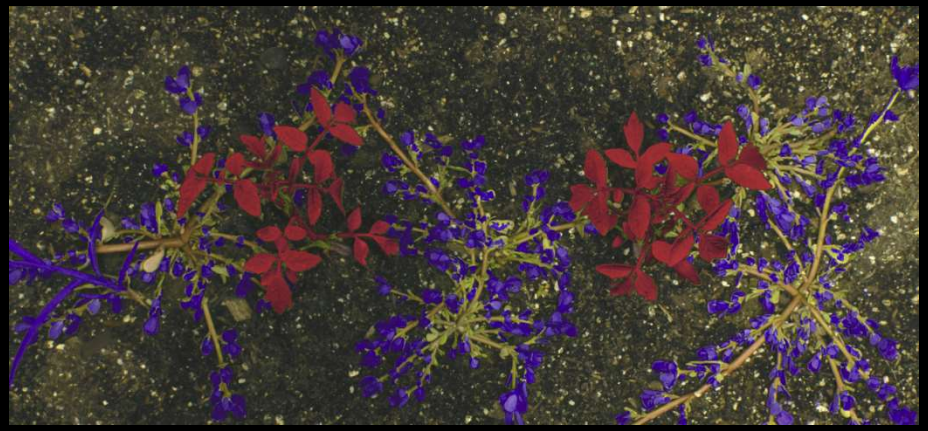

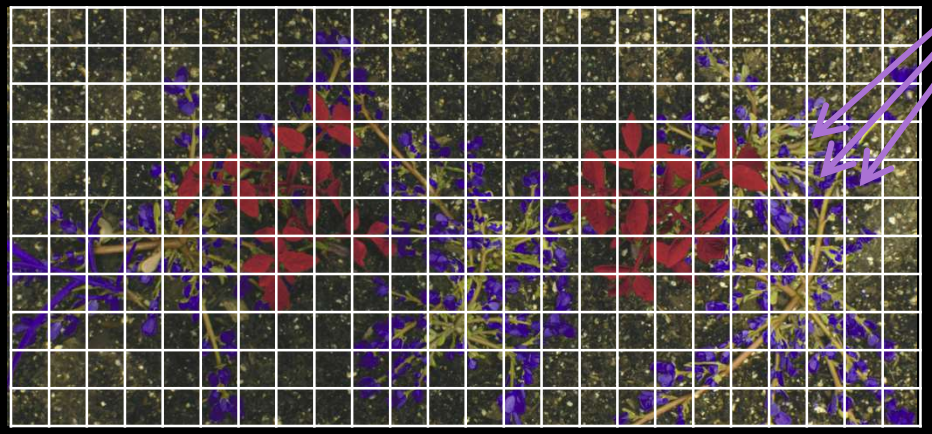

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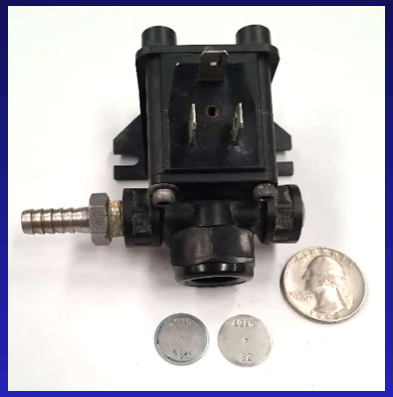
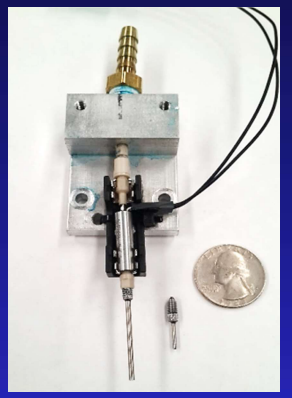
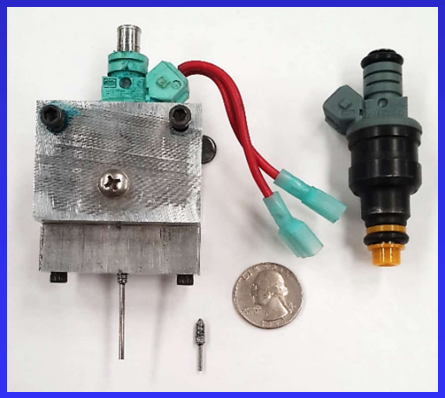
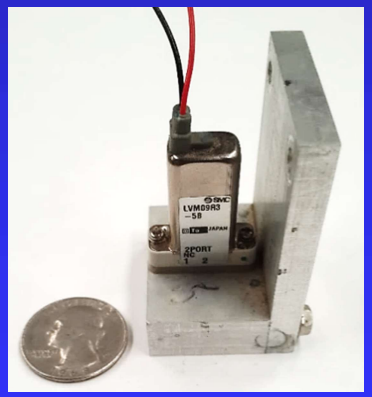
Precision Spray System

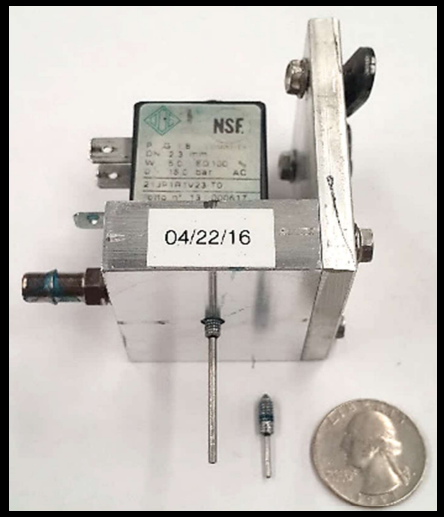
- Design Criteria
  - Deliver herbicides at 1-cm level scale accuracy
  - Travel at commercially viable speeds (2 mph)
  - Economically feasible
  - Suitable for use in agricultural environment

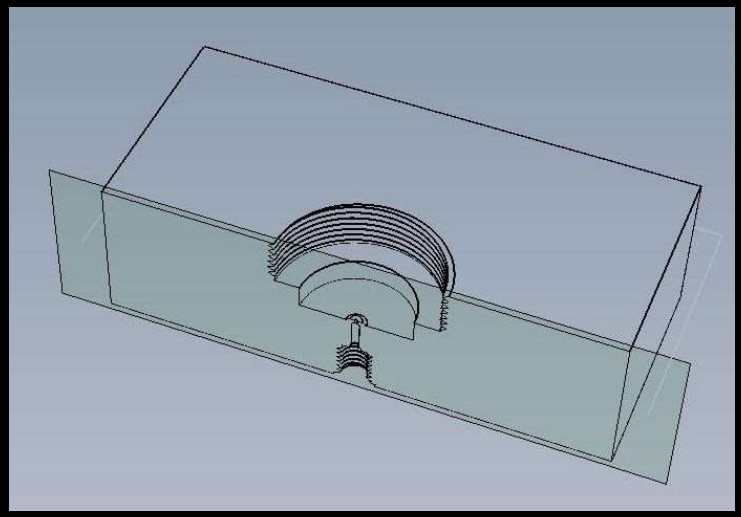
Solenoid Valve/Nozzle Assemblies

	Agriculture	Automotive	Medical
Standard			
Custom			

> 40 Solenoid Valve/Nozzle Body Combinations Tested

Feasible Solenoid Valve/Nozzle Body





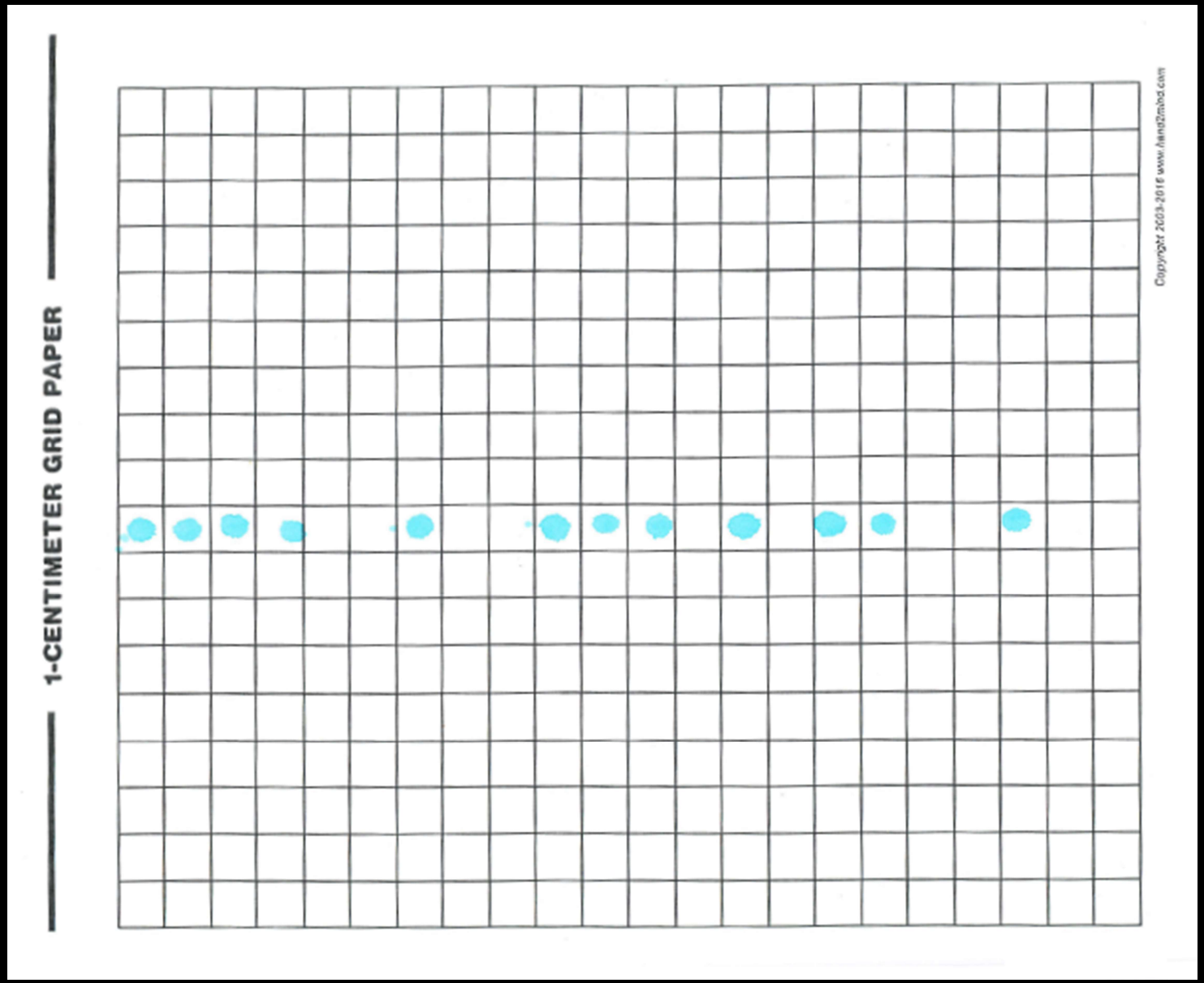
ODE Valve

- $30
- Cycle speed (3-4 ms)
- 24 VDC

Custom Valve Body

- Patterned after micro-dispensing valve designs

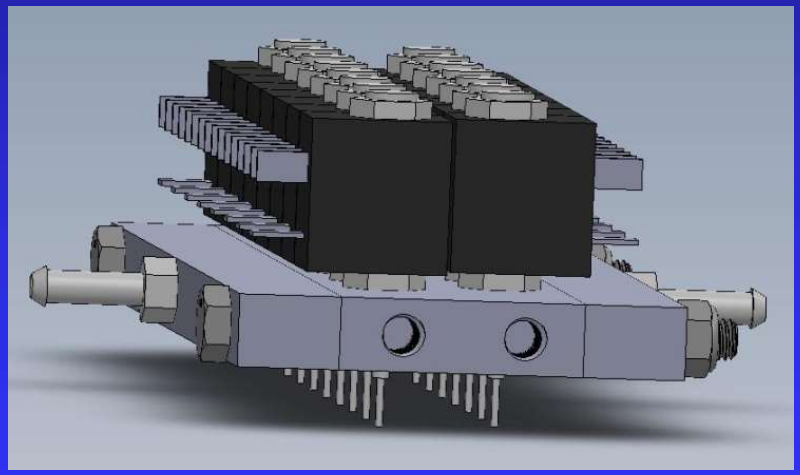
1 cm^2 “Weed Targets” - 2 mph

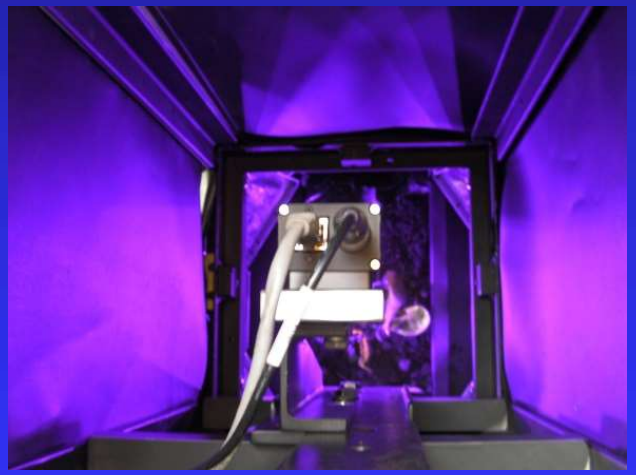


1 cm^2 “Weed Targets” - 2 mphc

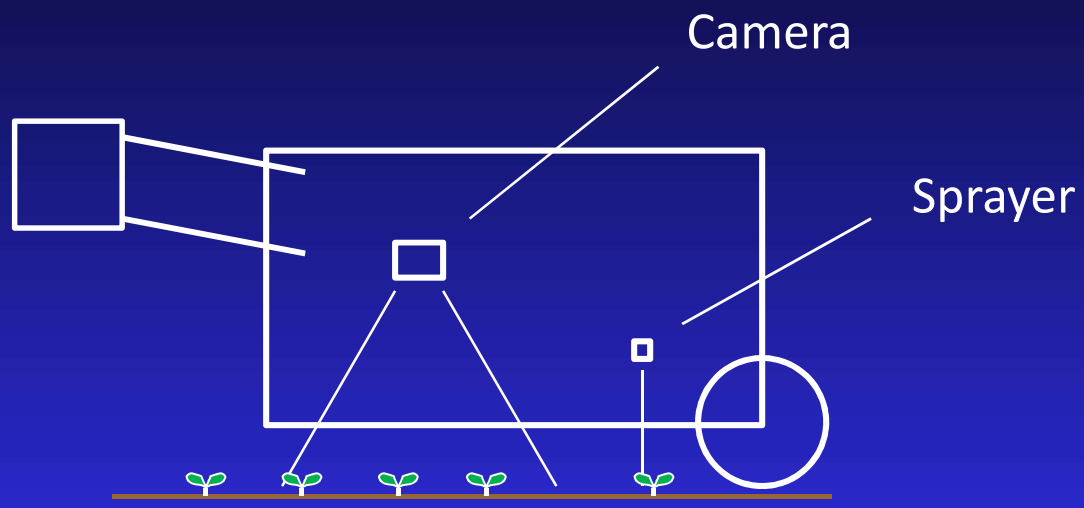
Future Work

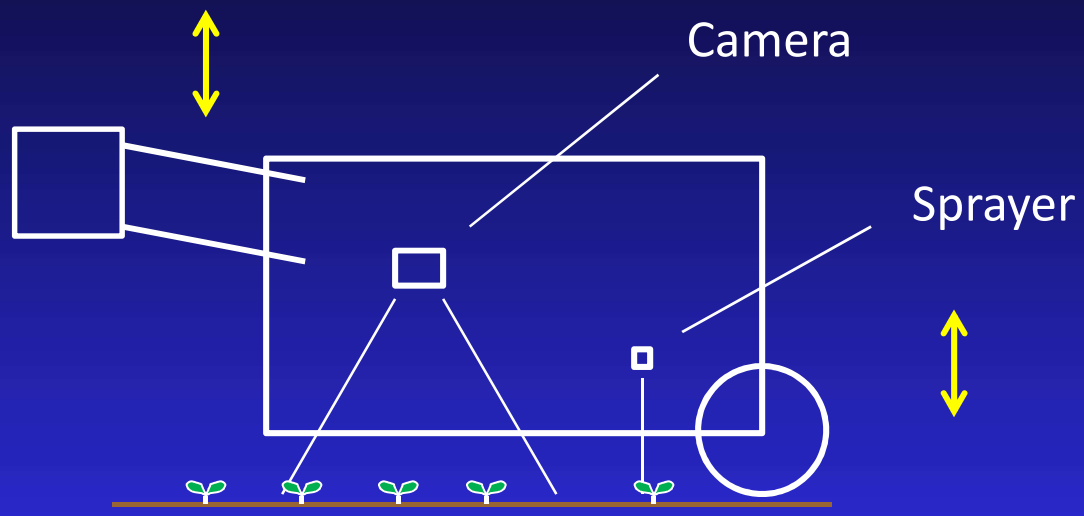
- Integrate Spray and Visions Systems
- Field test





Accuracy - 1/4” ?


Camera
Sprayer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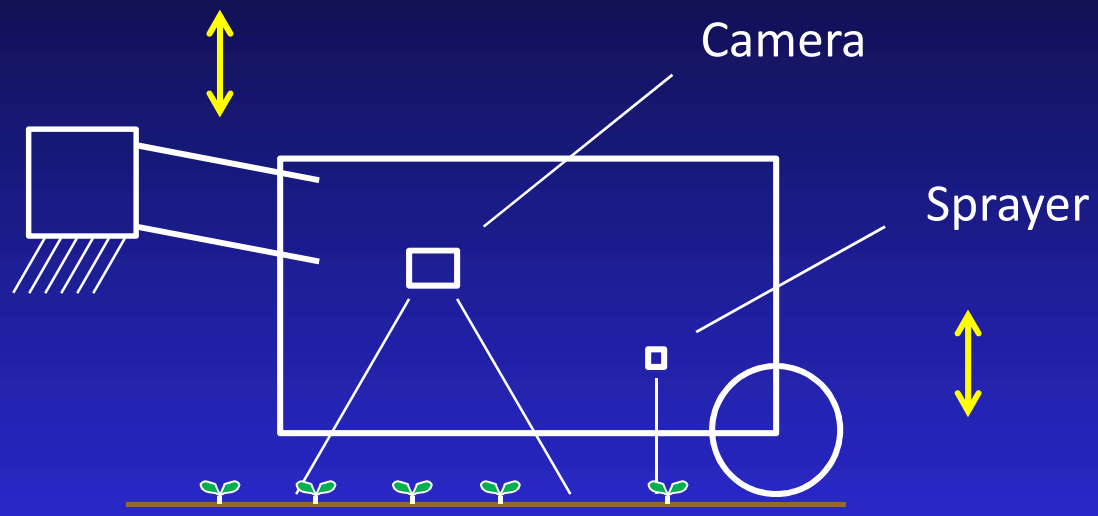
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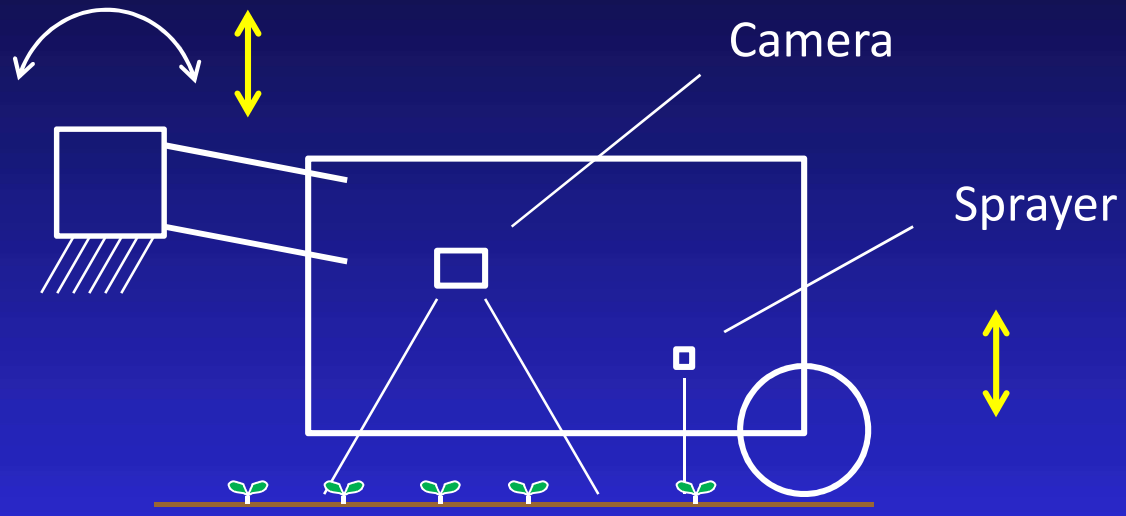
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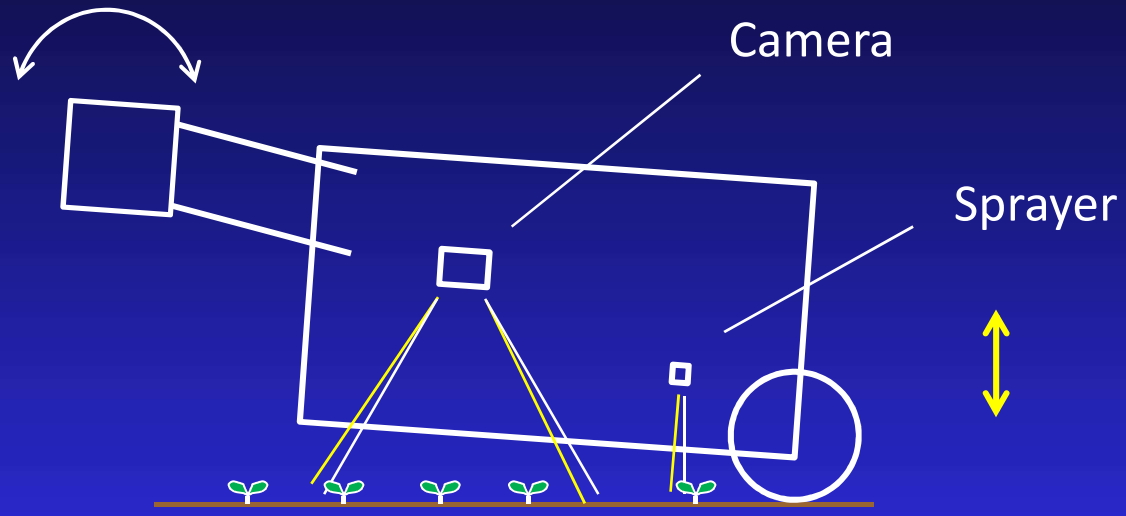
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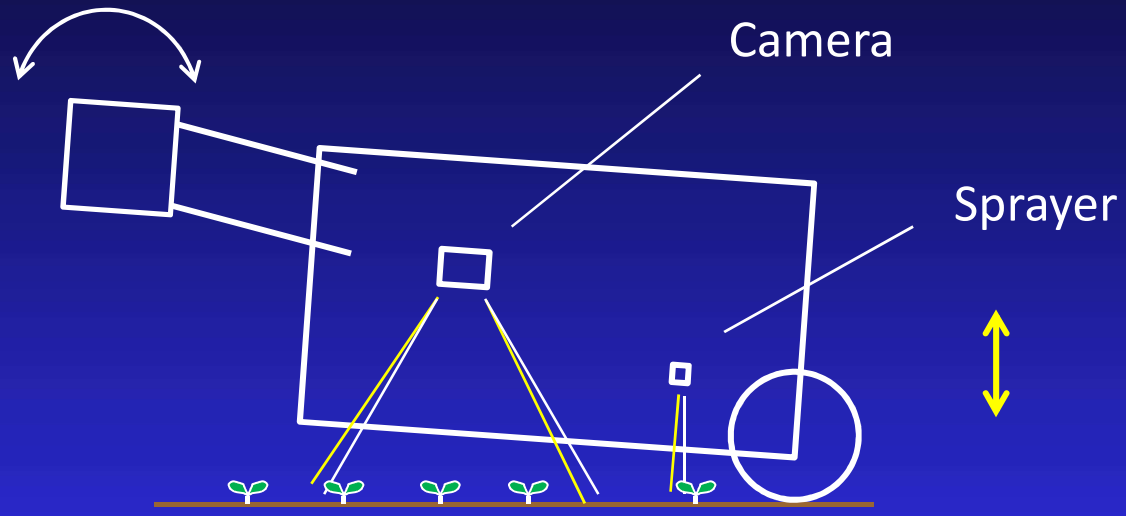
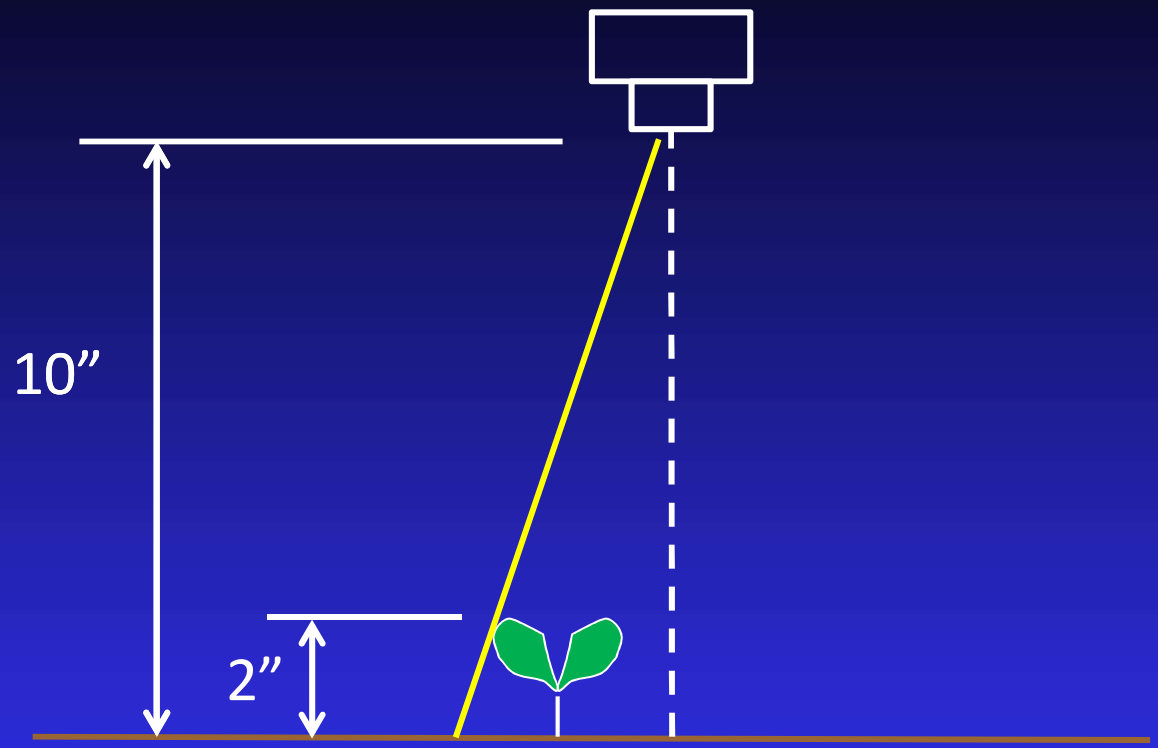


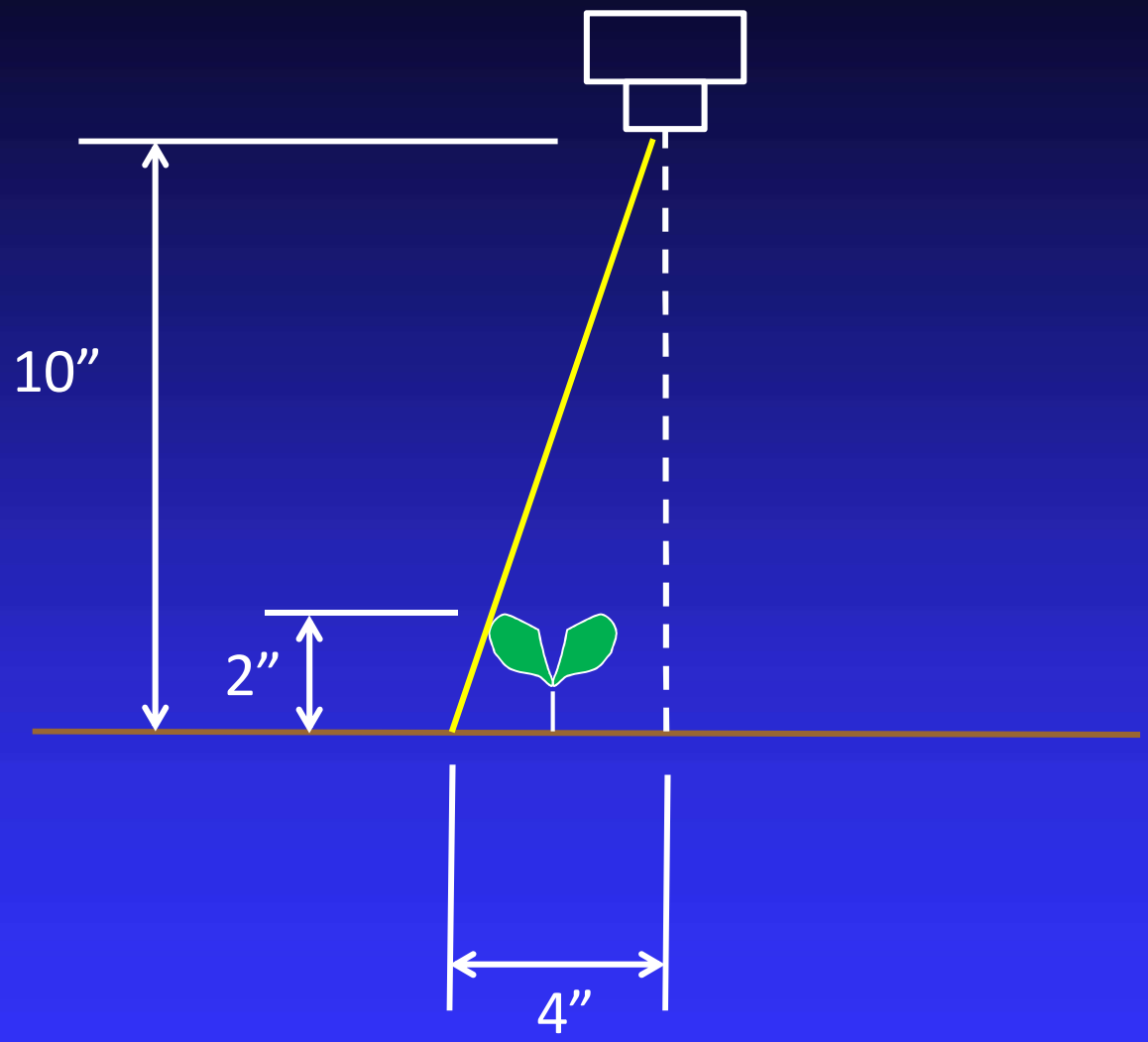
Effect of toolbar rotation:

- Camera height – 10”
- Rotation – 1.4°
- Object displacement – 0.25”

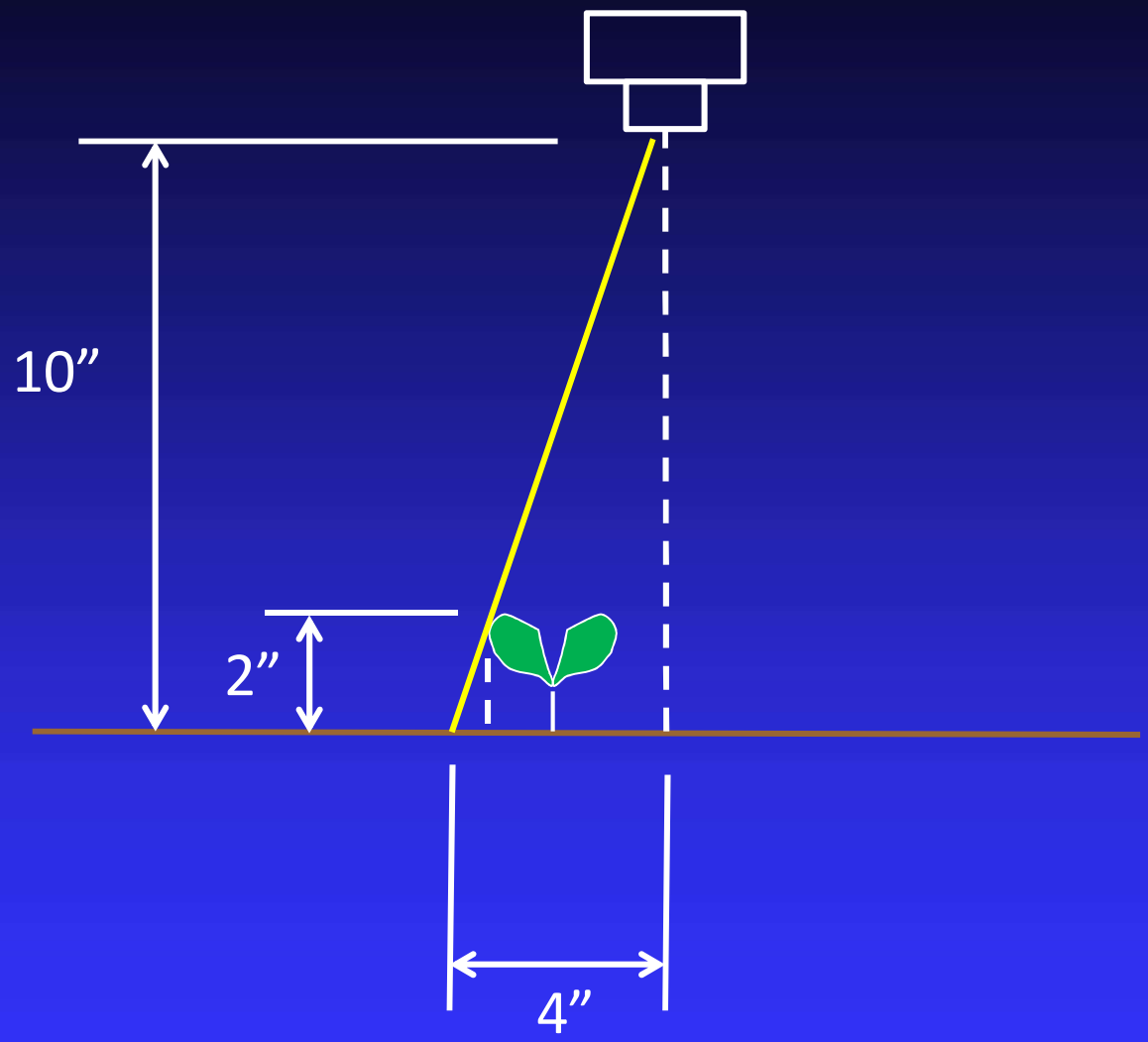
Variable Plant Height



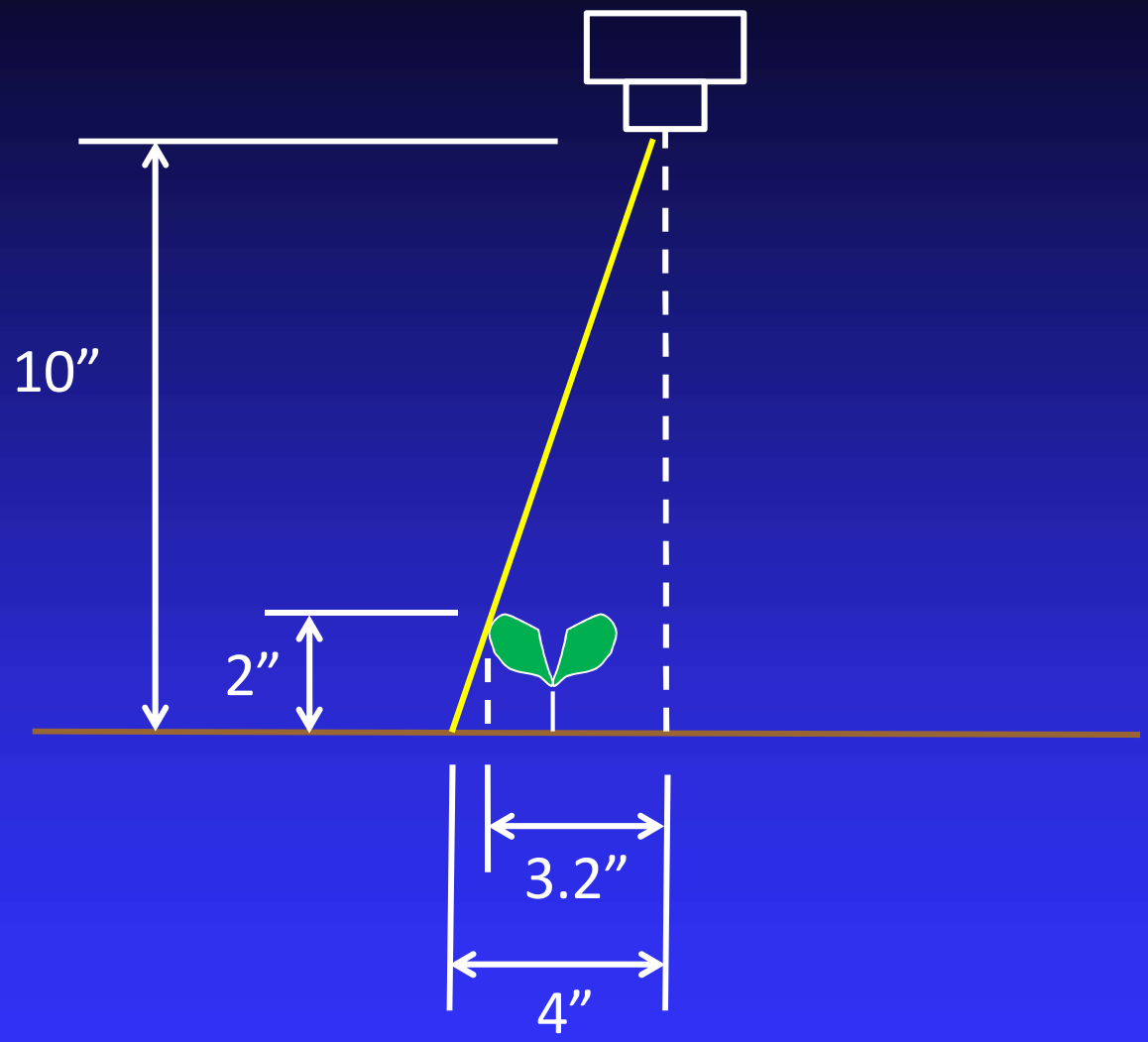
Effect of Plant Height



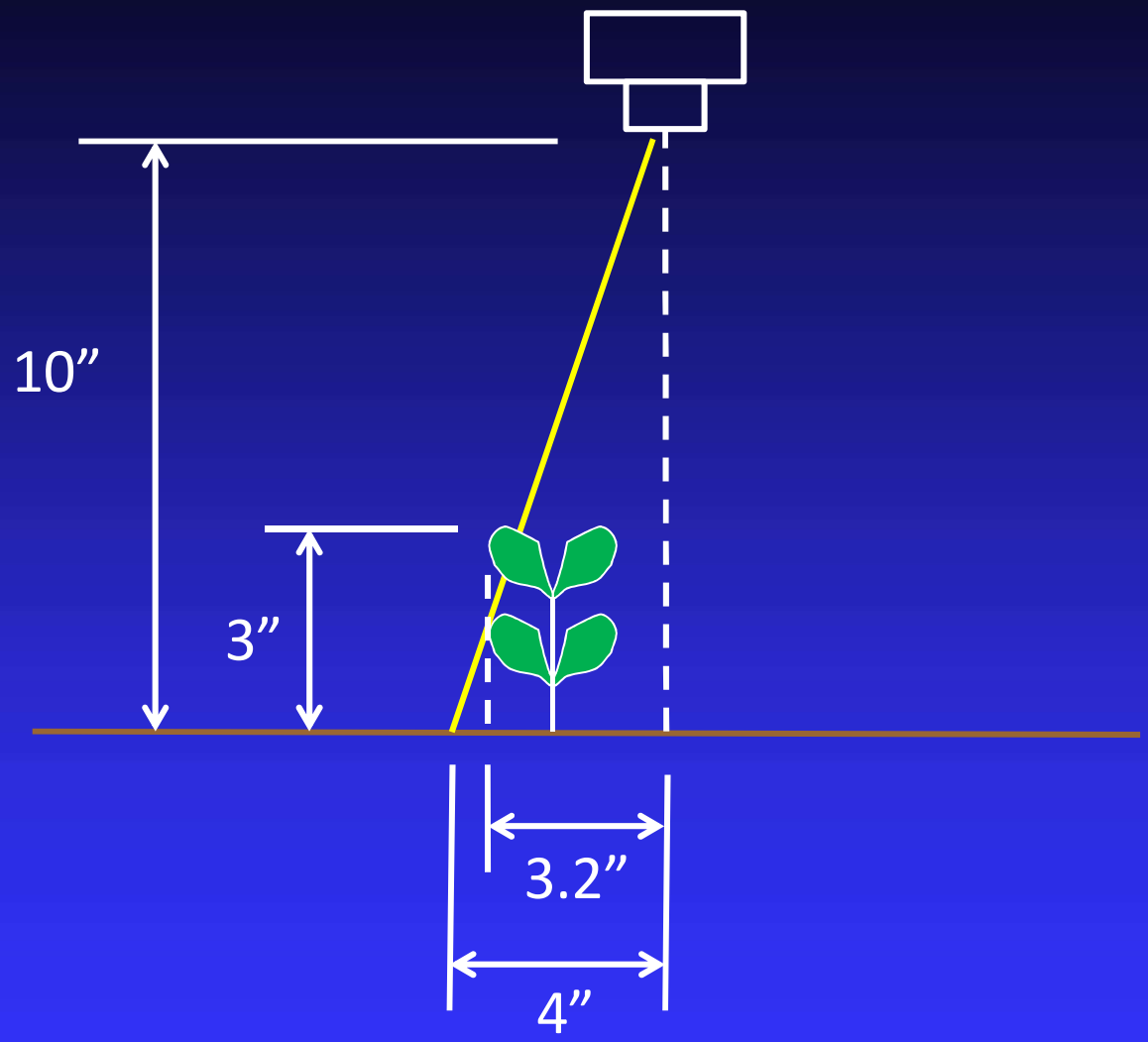
Effect of Plant Height



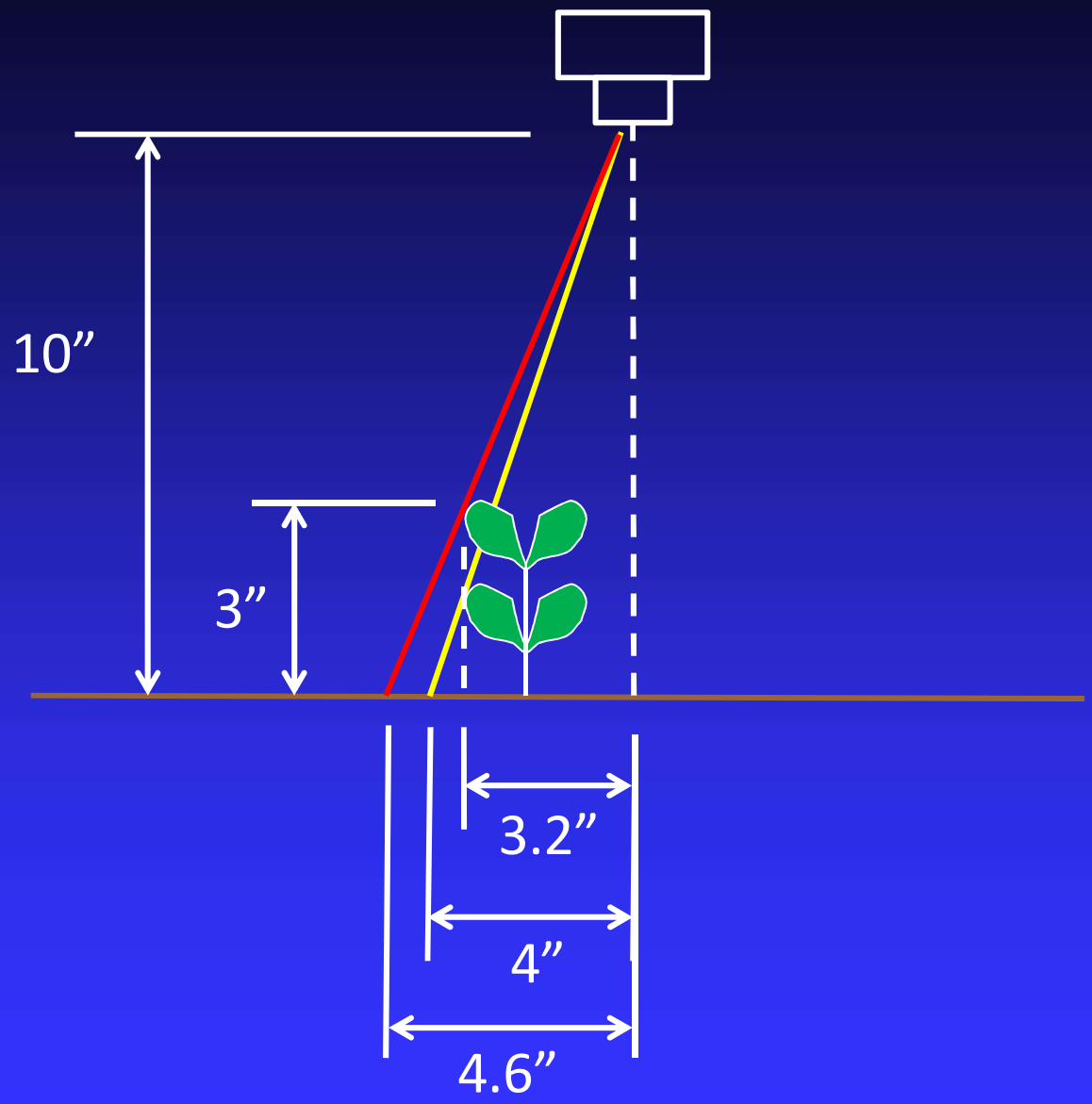
Effect of Plant Height



Effect of Plant Height

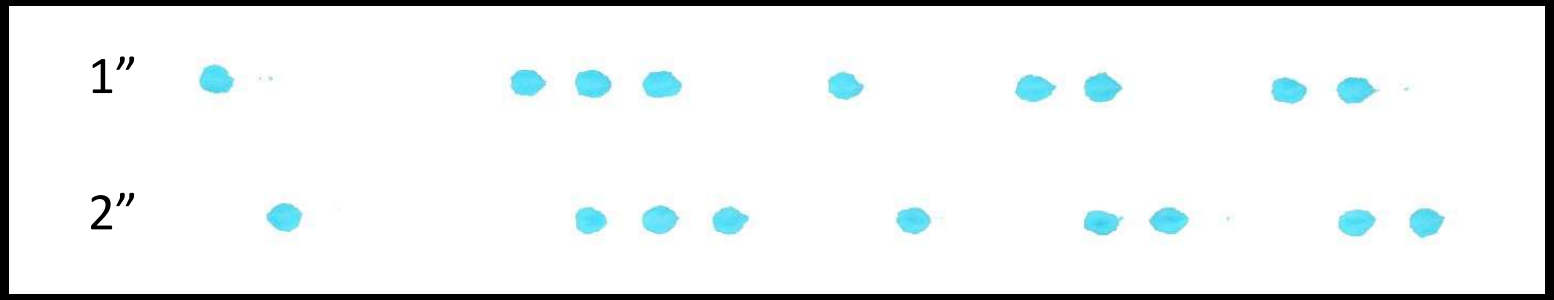


Effect of Plant Height

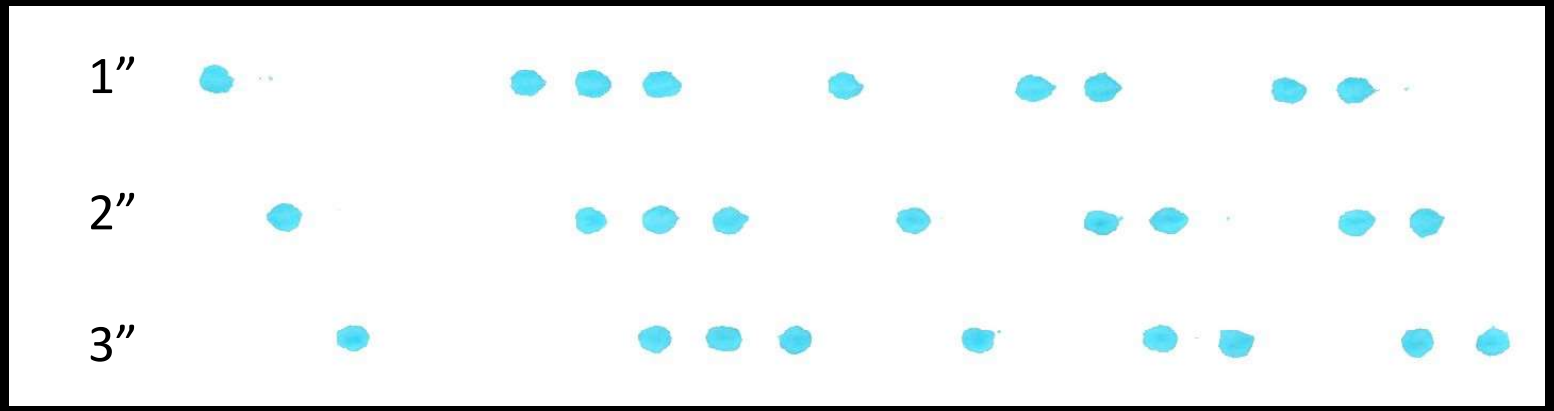


Effect of Plant Height

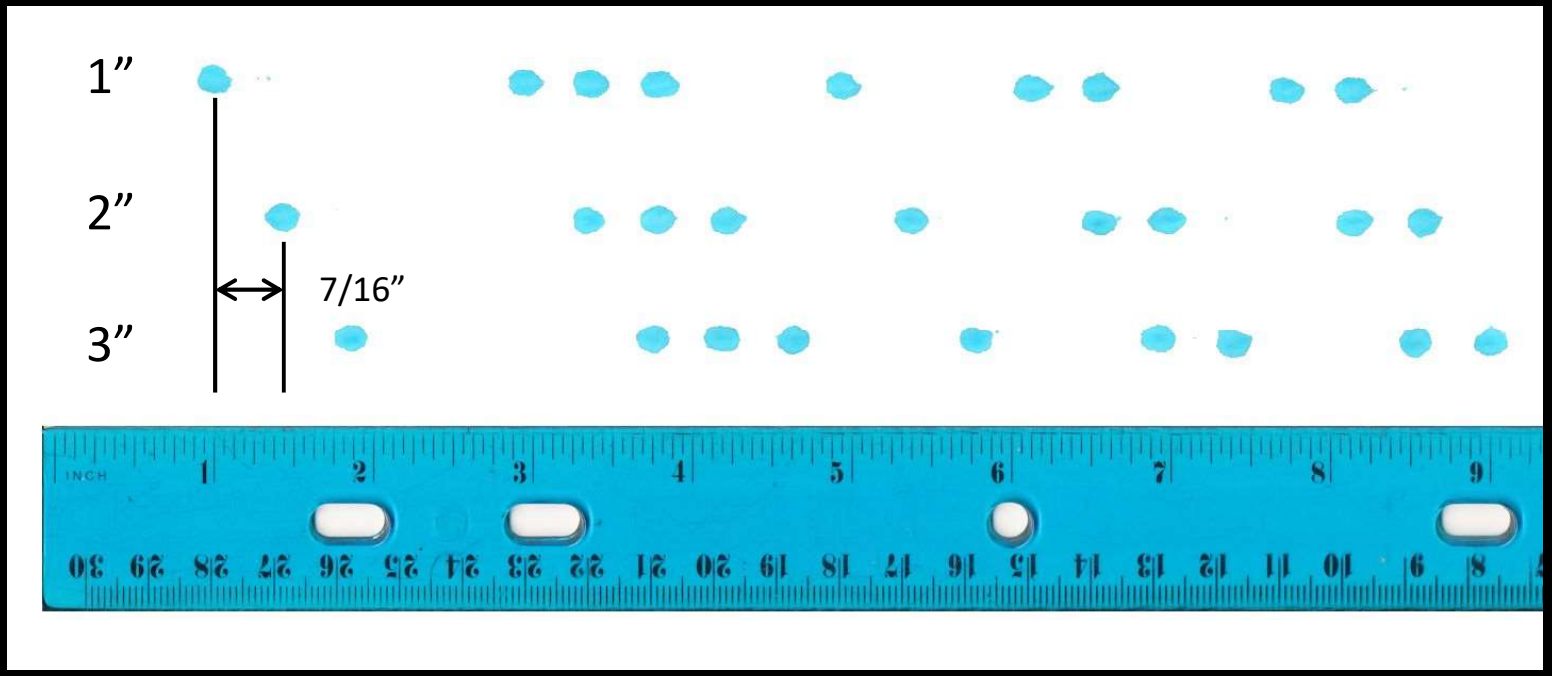
Effect of Target Distance – 2 mph



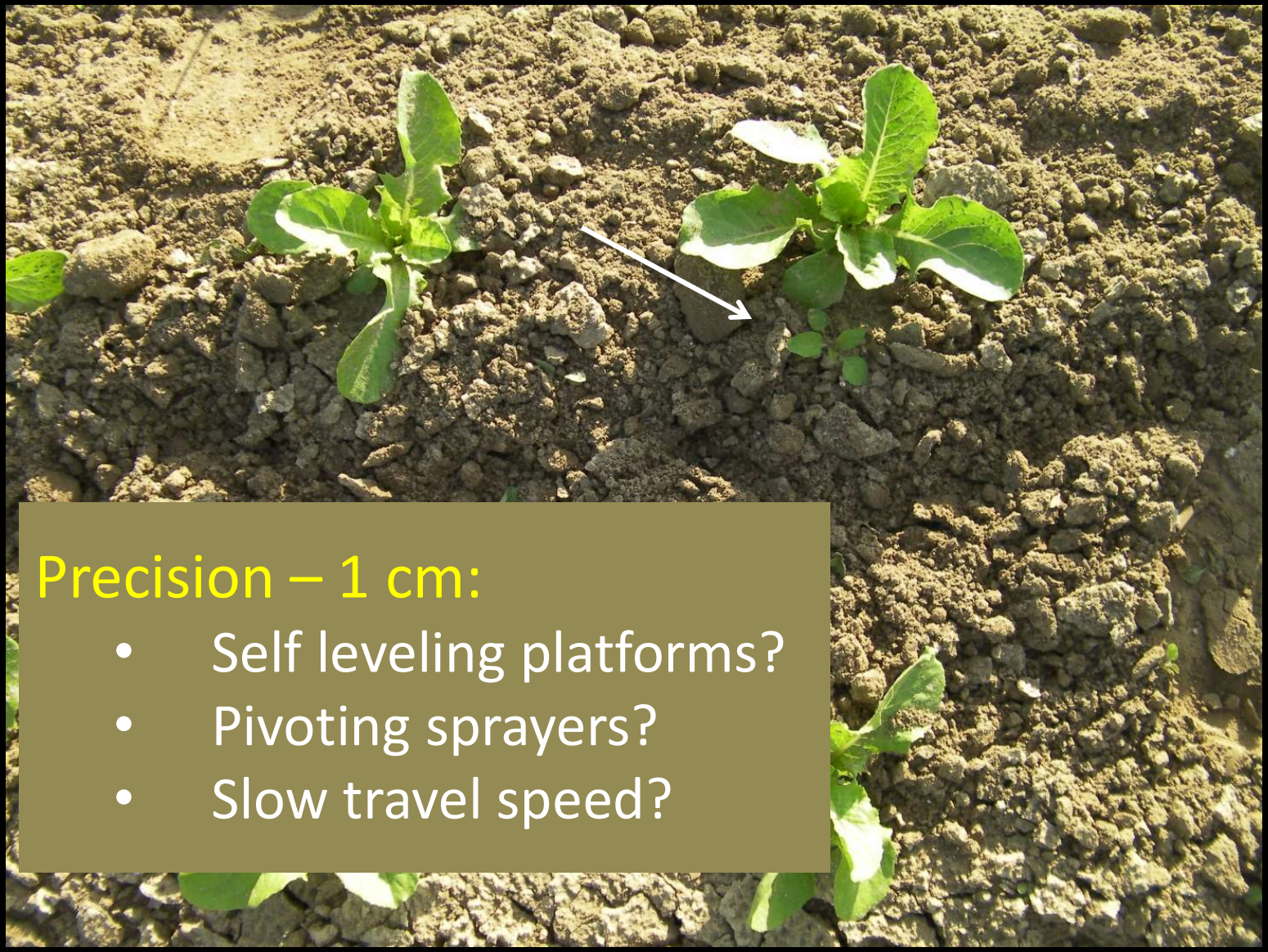
Effect of Target Distance – 2 mph



Effect of Target Distance – 2 mph



Effect of Target Distance – 2 mph

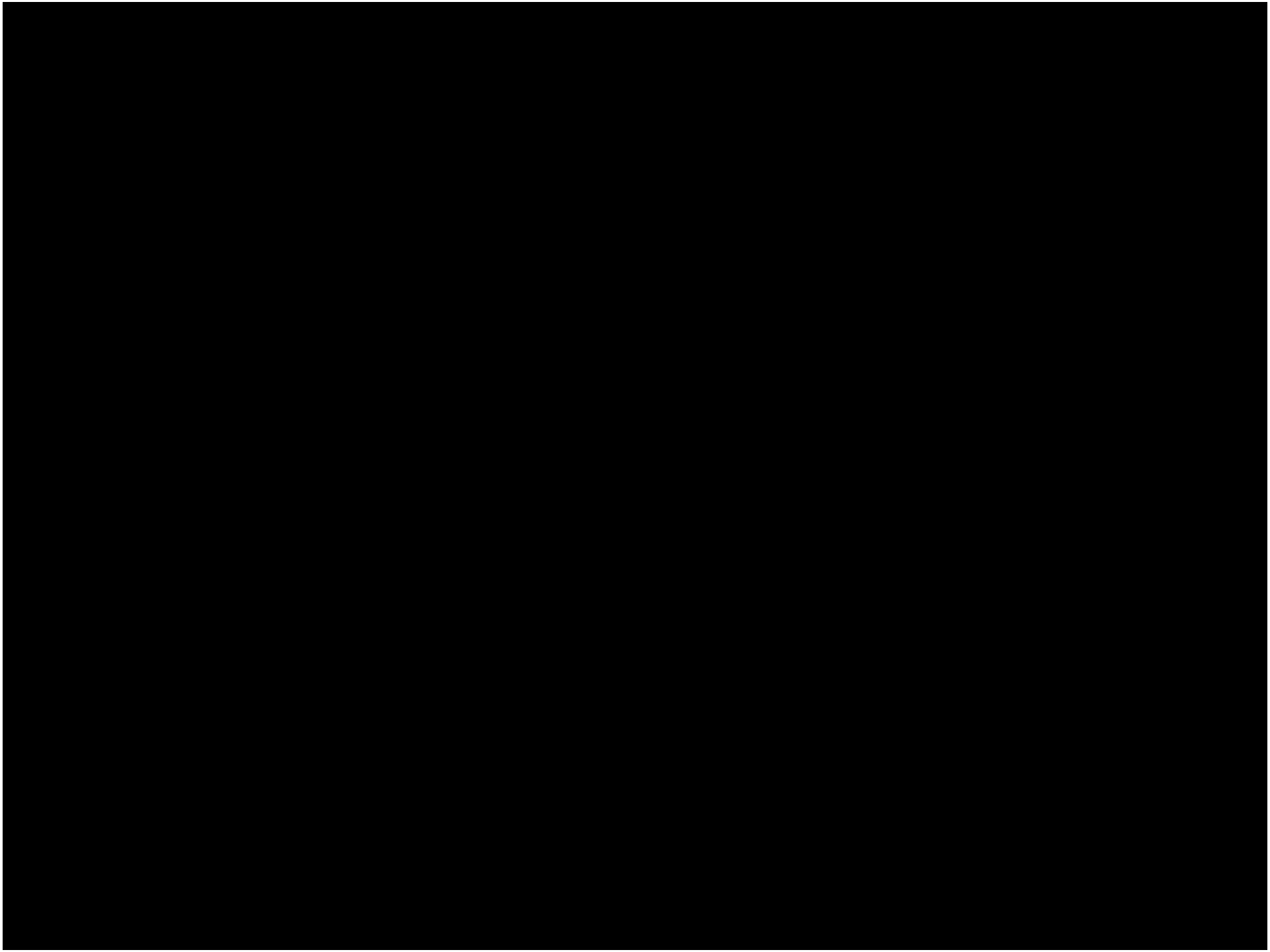

Precision – 1 cm:
• Self leveling platforms?
• Pivoting sprayers?
• Slow travel speed?

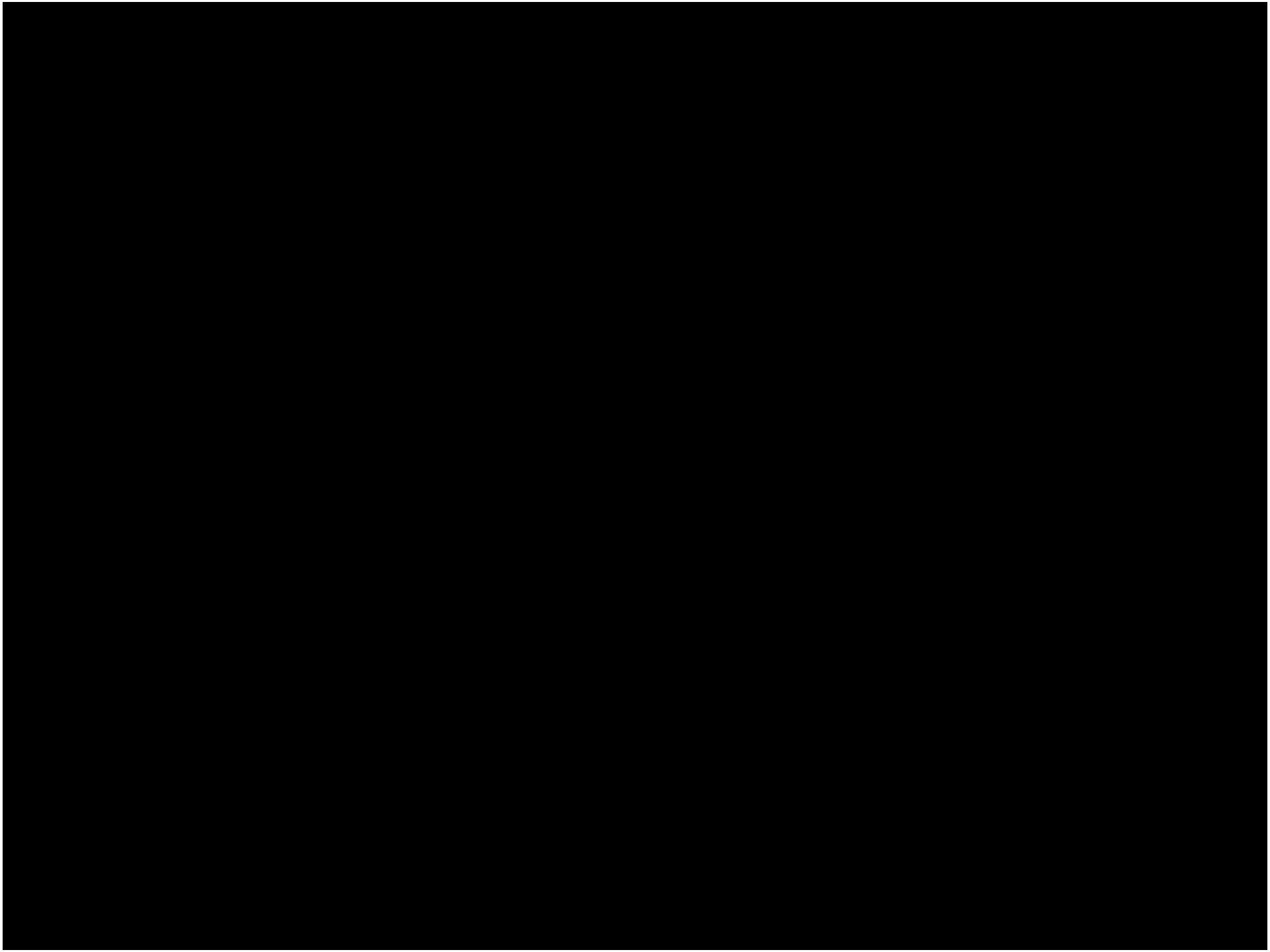

Height Sensing:
• Sonar sensors?
• Range finders?
• 3-D cameras?

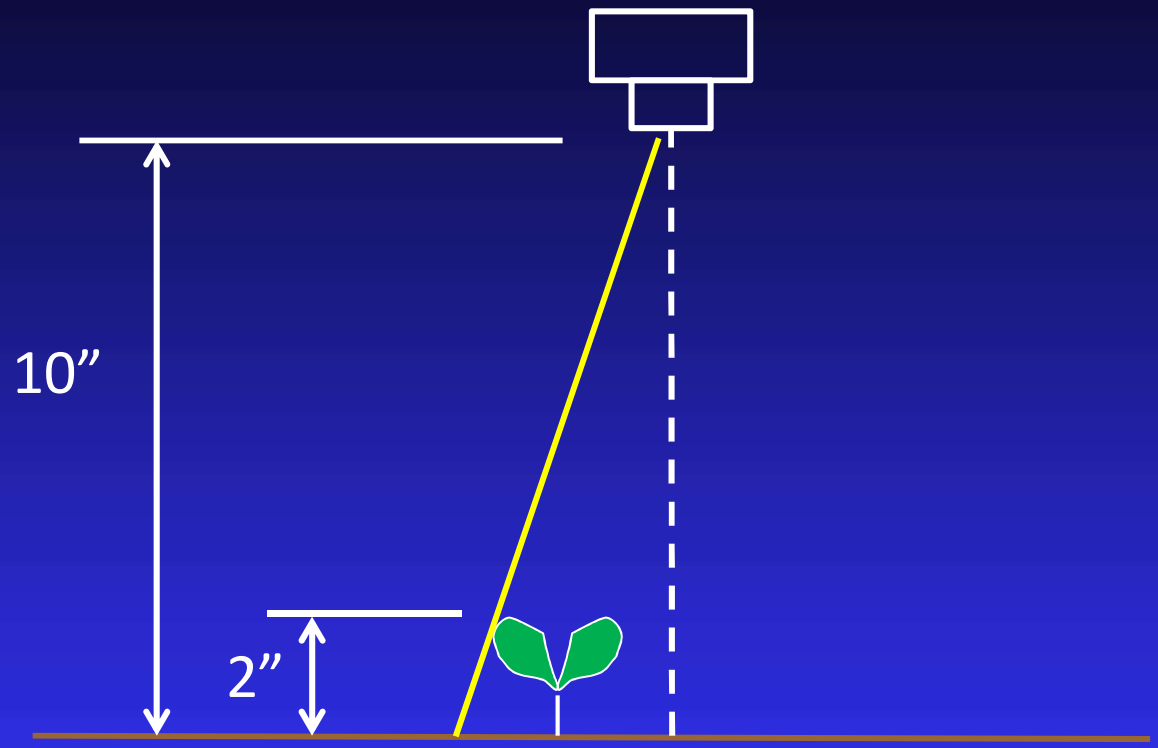
Deepfield Robotics - Bosch Startup Co. (2015)
Mechanical Precision Weeding Machine

Deepfield Robotics Mechanical Weeder

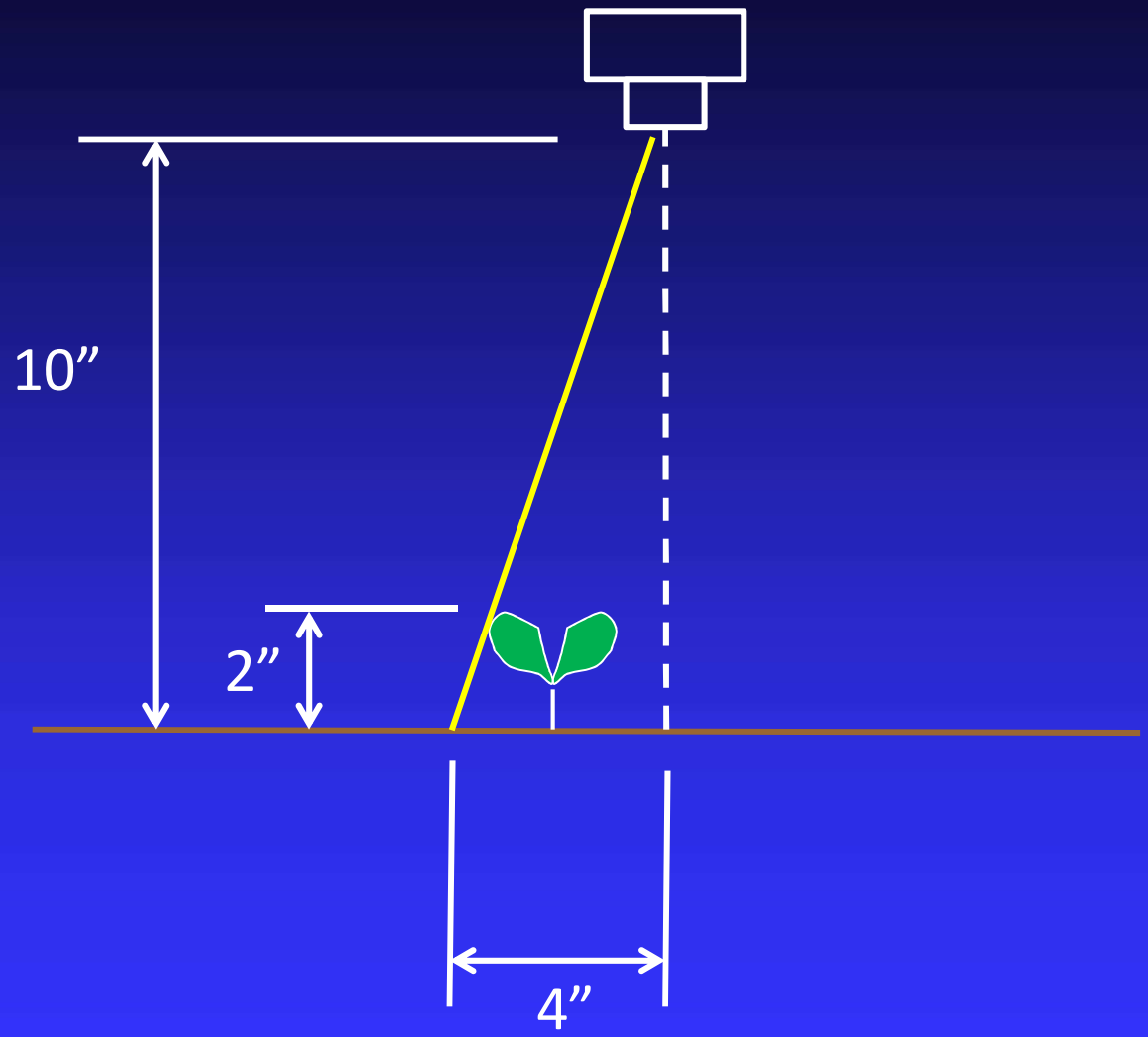

Thank You



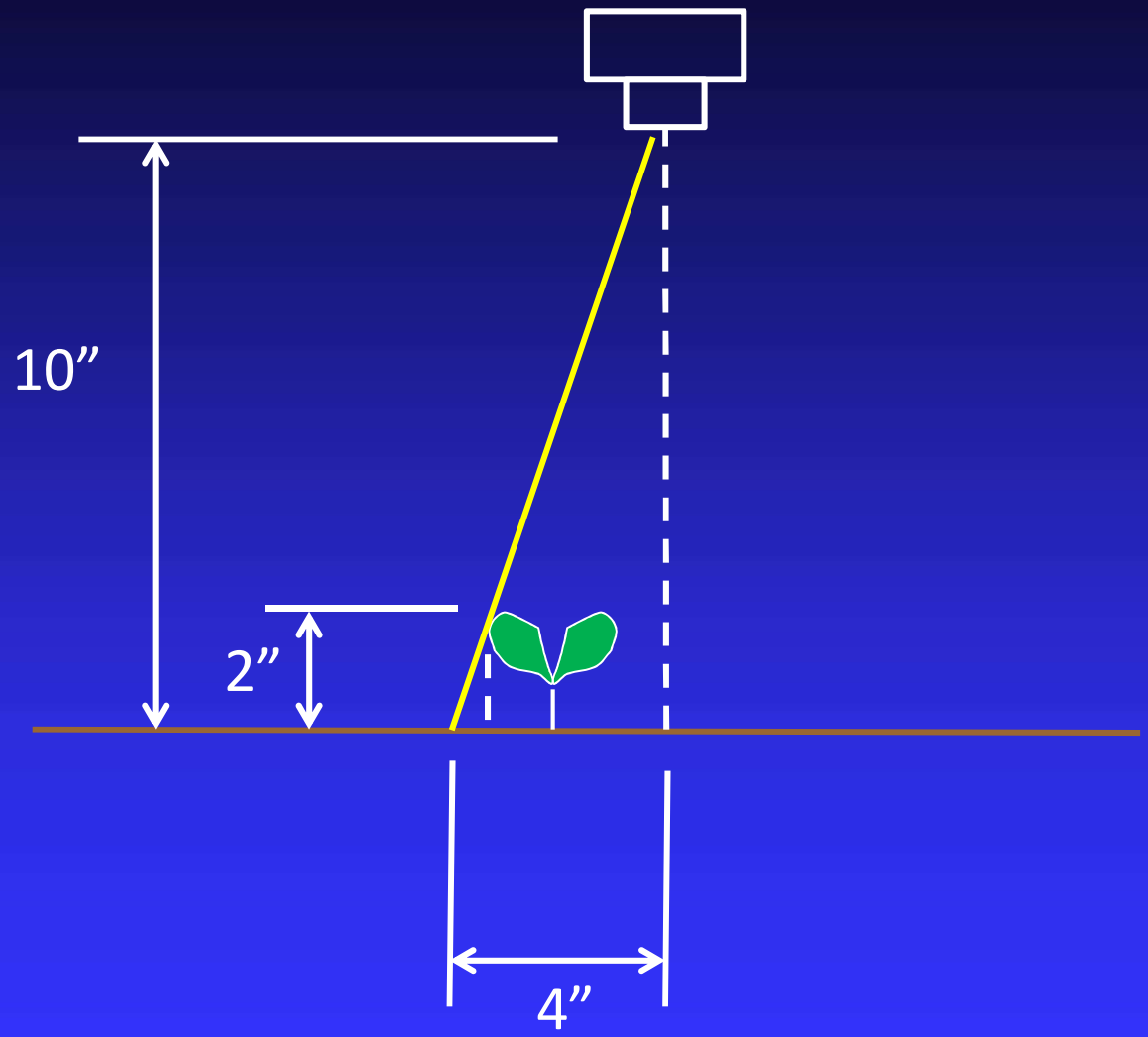




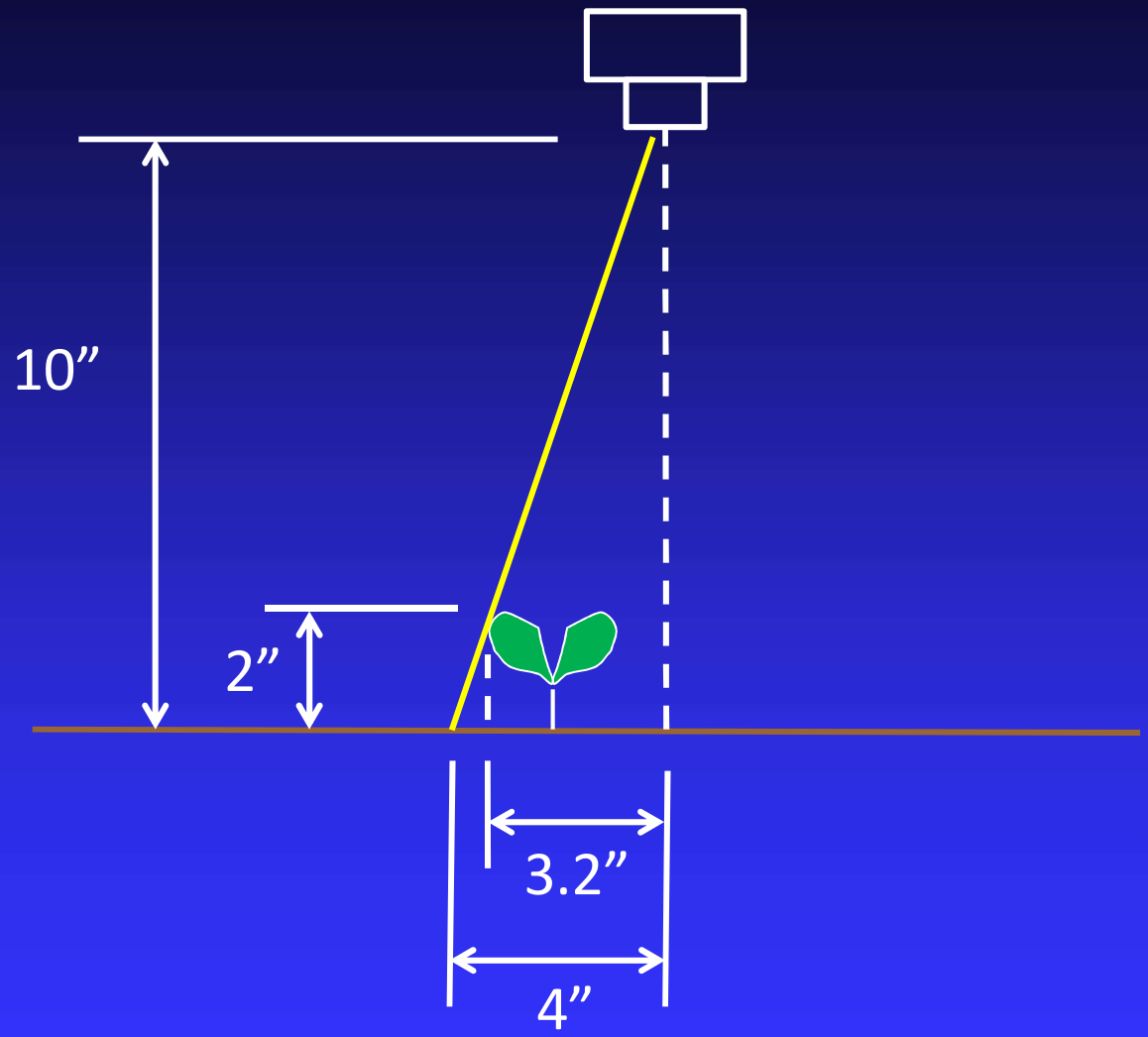
Effect of Plant Height



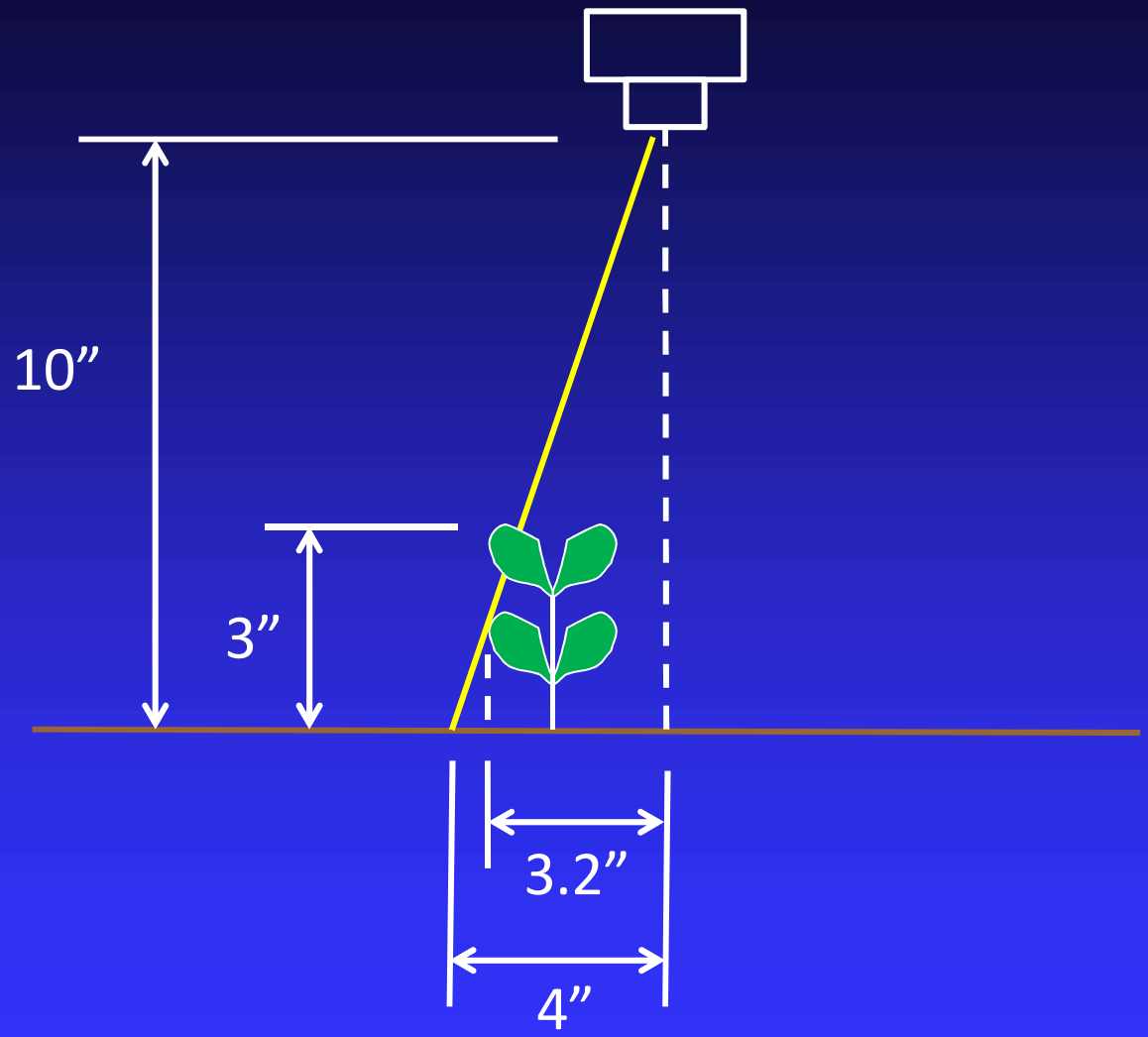
Effect of Plant Height



Effect of Plant Height



Effect of Plant Height



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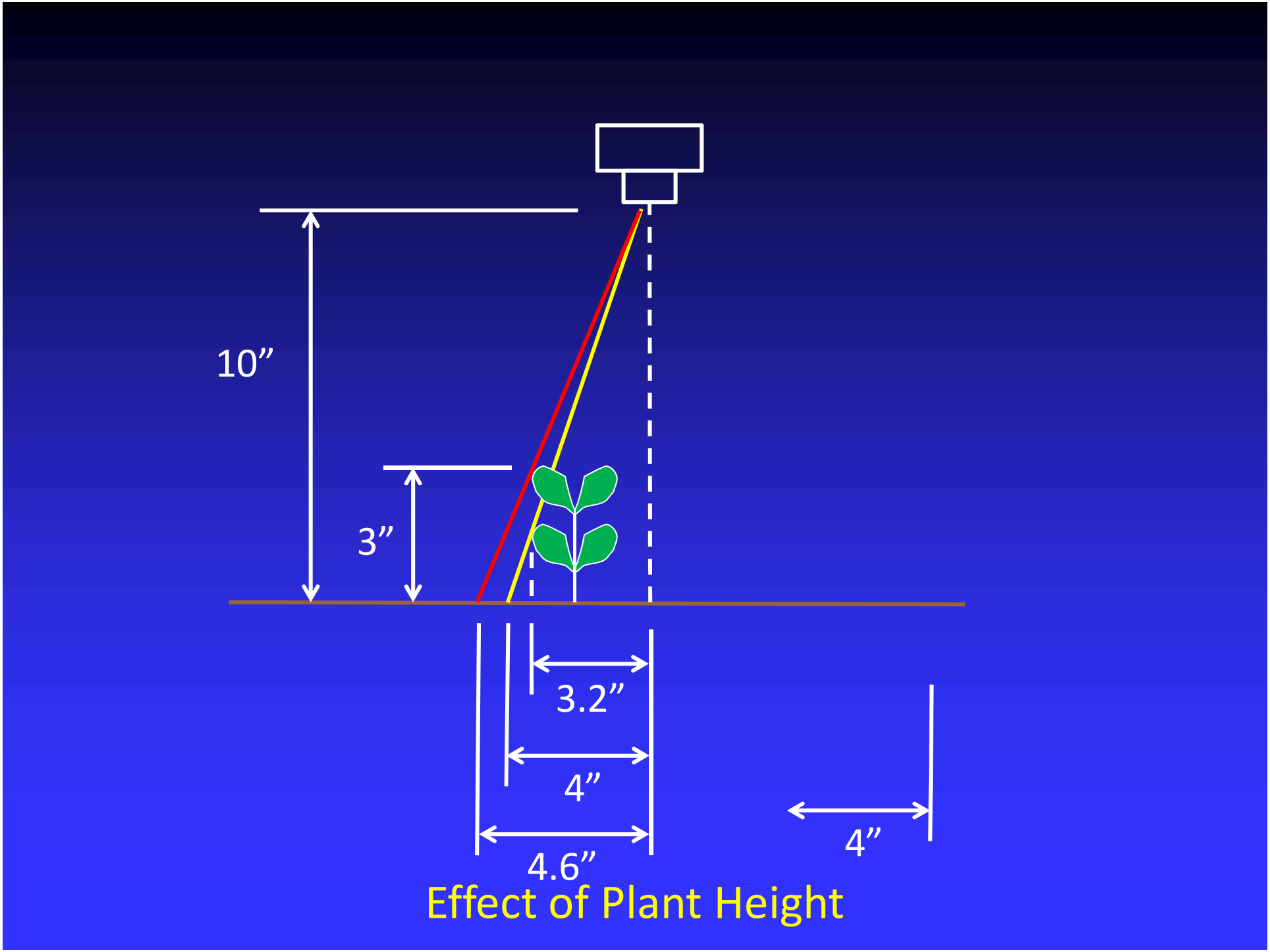

Effect of Plant Height

Spray Transplants with Florescent Dye

Specialty Crop Research Initiative Funded Project

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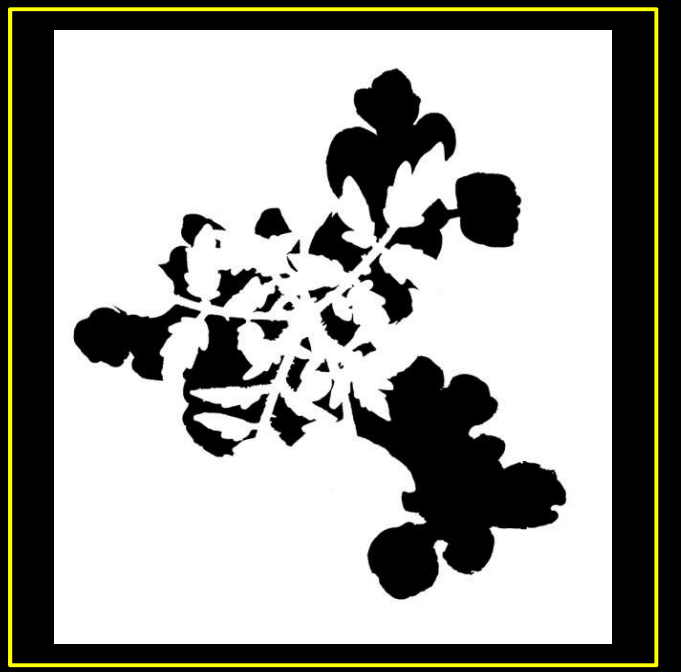

Spray Transplants with Florescent Dye

Specialty Crop Research Initiative Funded Project

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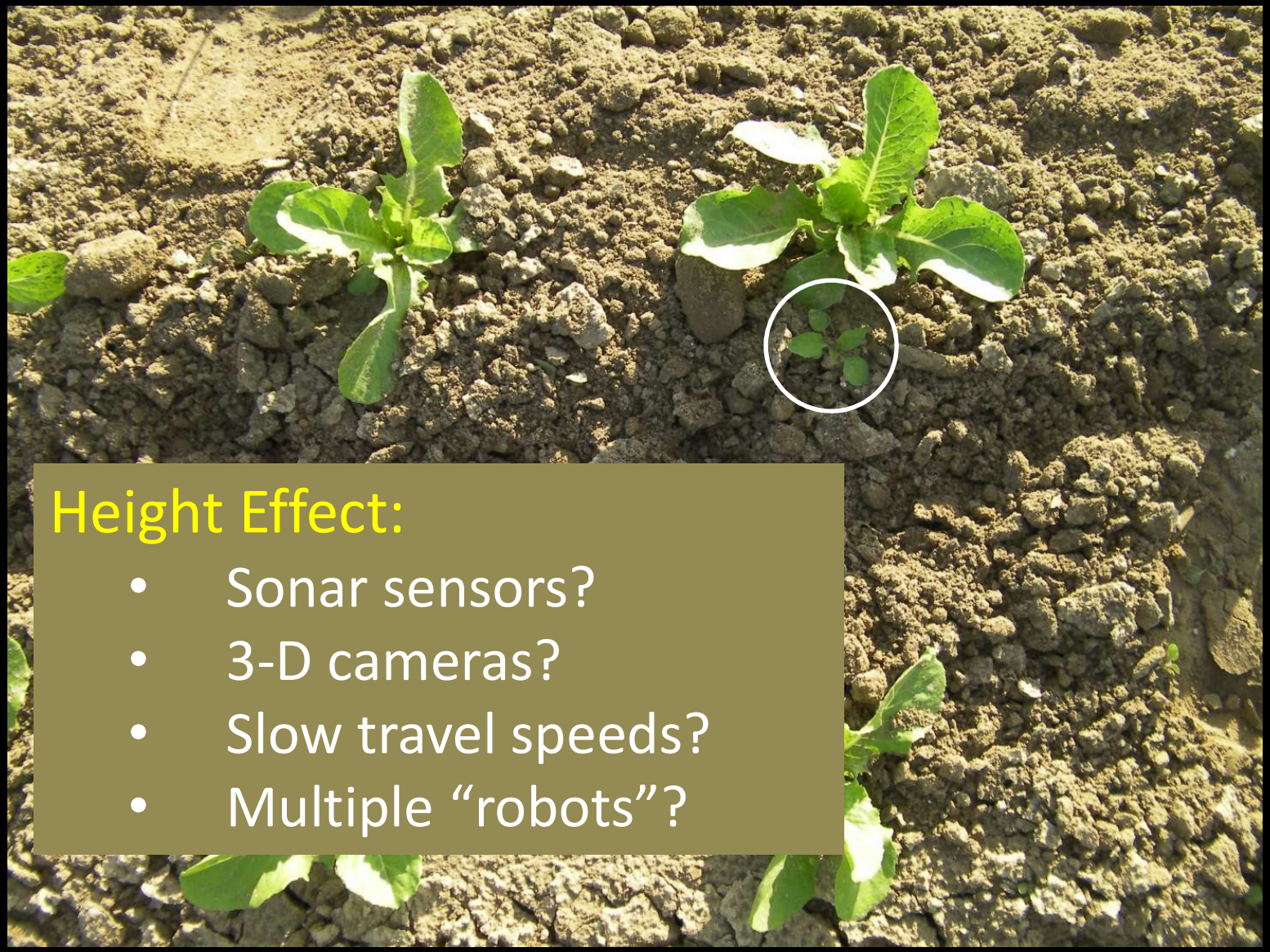
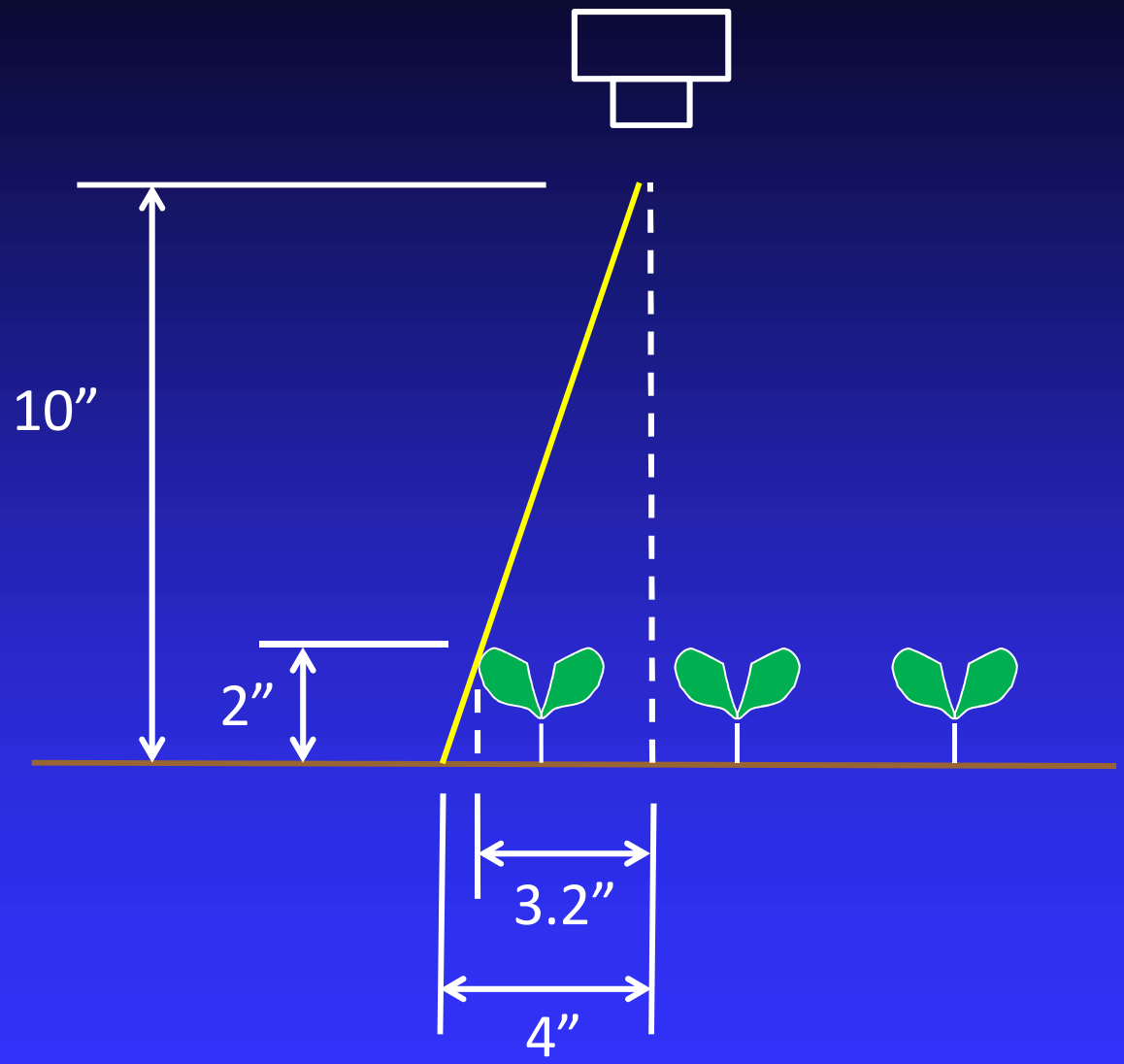
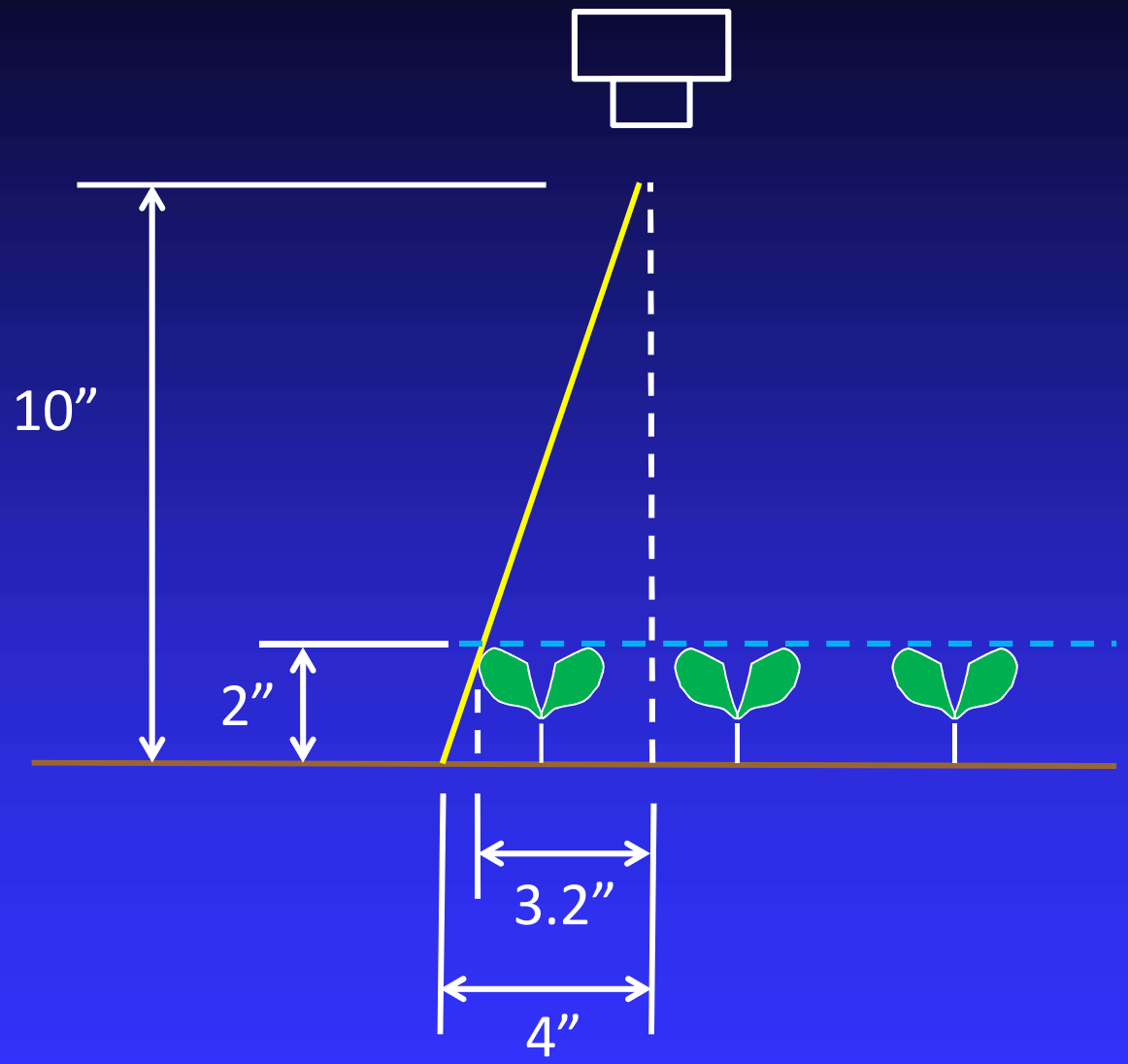
Precision – 1 cm:
• Self leveling platforms?
• Pivoting sprayers?
• Small FOV?
• Multiple “robots”?

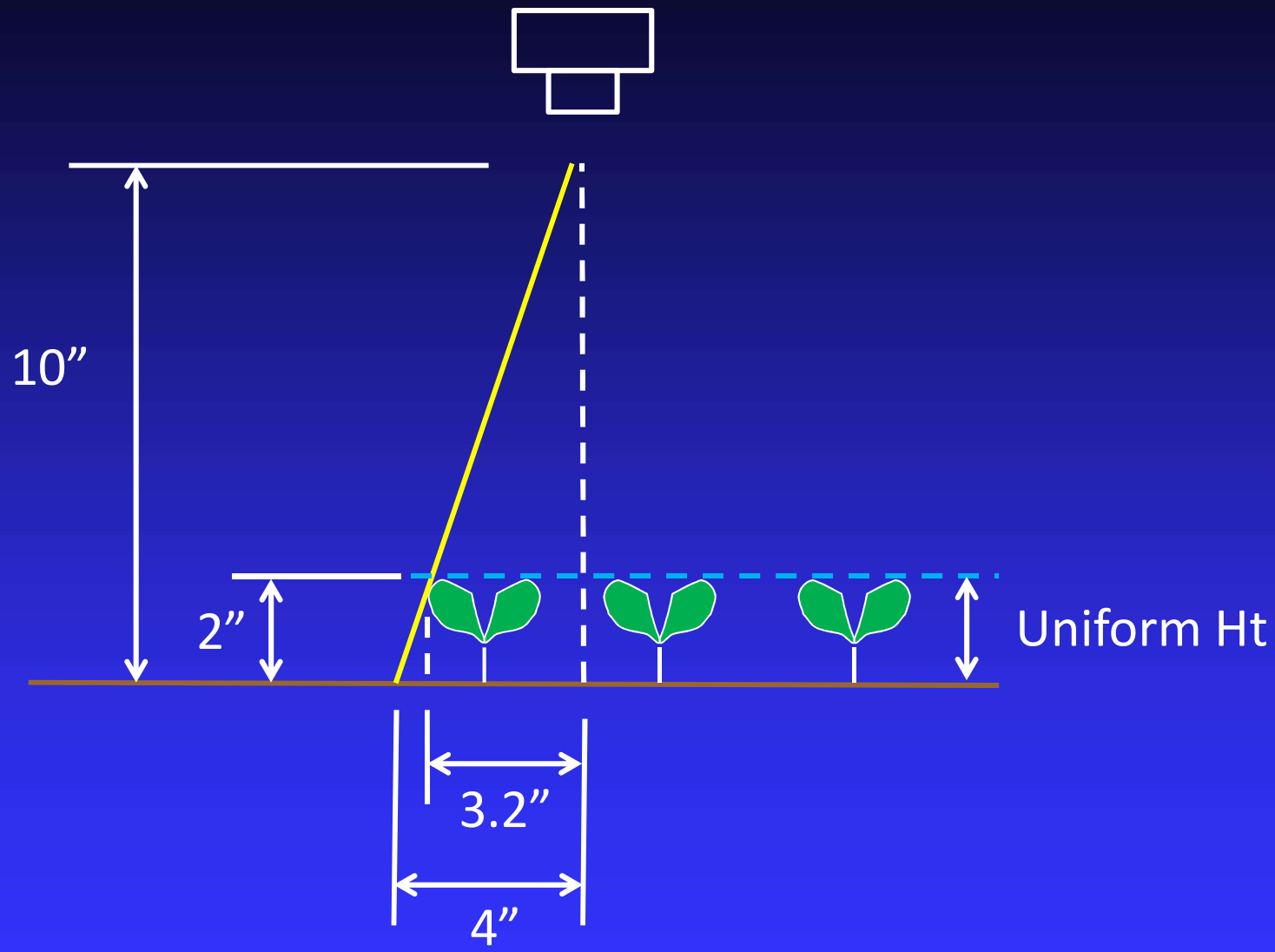

Height Effect:
• Sonar sensors?
• 3-D cameras?
• Slow travel speeds?
• Multiple “robots”?



Effect of Plant Height



Effect of Plant Height



Effect of Plant Height

Large Tall Weed

Precision Weeding

Small Clumped Weeds

Summary

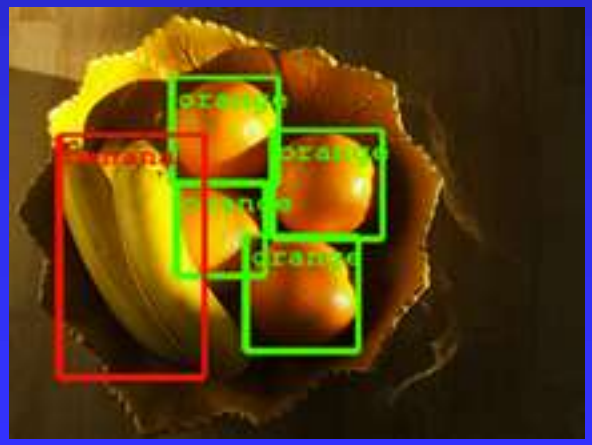
- In-row weeders today
  - Remove ~ 2/3rds in-row weeds
- Crop/weed differentiation
  - Deep learning
  - Fluorescent marking
- Precision weeding
  - > 1/2” challenging

Blue River Technologies Inc.

- + $17 million (December, 2015)
- Spray based precision weeder
- Crops – Cotton, lettuce, others later
- Deep Learning

Deep Learning

- Training set – millions of images
- Convolutional neural network
- Develops classification algorithm
- ImageNet Contest - <1% error



Precise weeding:

- Self leveling platforms ?
- Pivoting sprayers?
- Slow travel speeds?
- Multiple “robots”?


Thank You

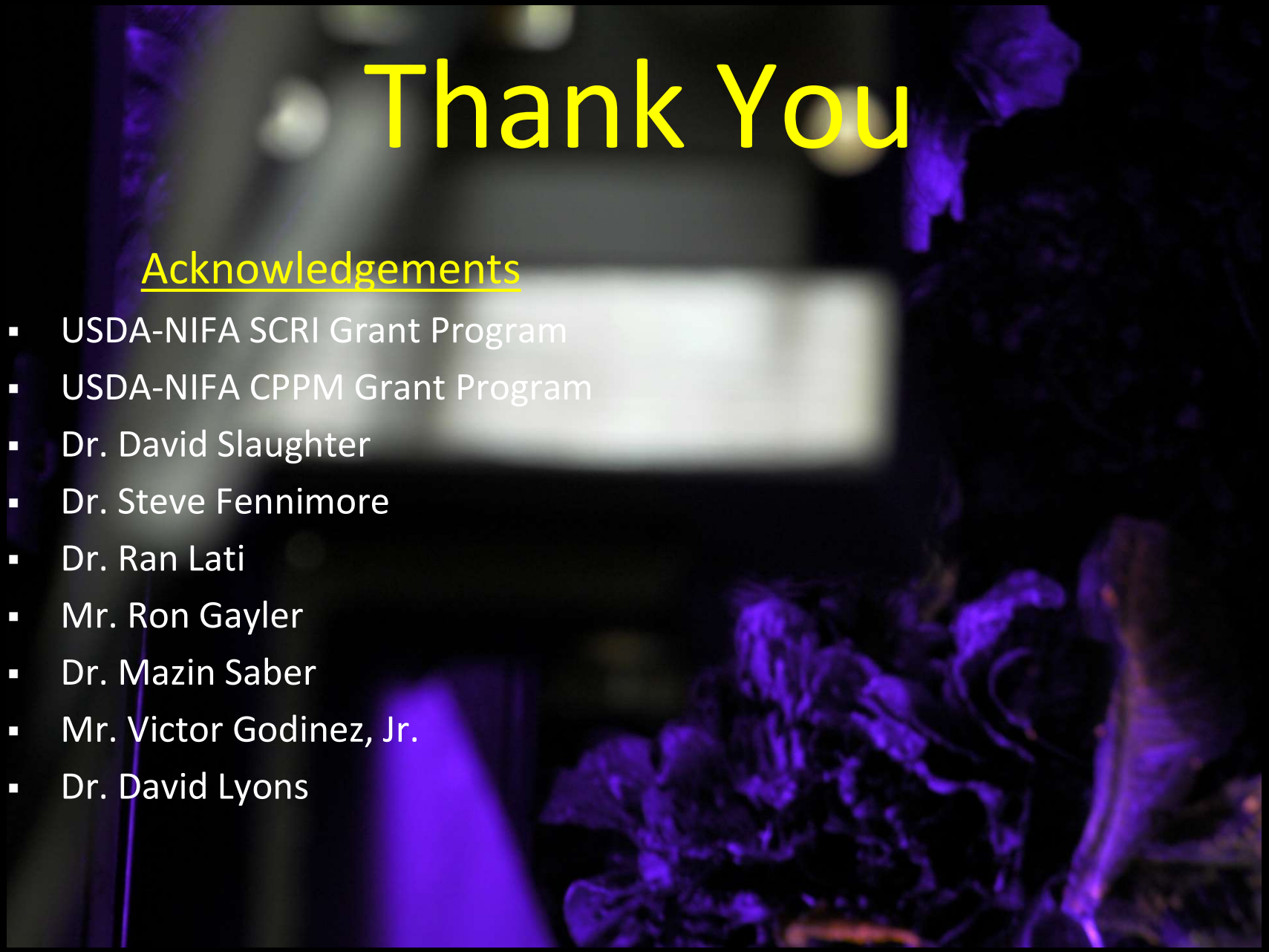

Thank You


Thank You

Thank You

Acknowledgements

- USDA-NIFA SCRI Grant Program
- USDA-NIFA CPPM Grant Program
- Dr. David Slaughter
- Dr. Steve Fennimore
- Dr. Ran Lati
- Mr. Ron Gayler
- Dr. Mazin Saber
- Mr. Victor Godinez, Jr.
- Dr. David Lyons



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Solution?

Deep Learning

Blue River Technologies Inc.

- + $17 million (December, 2015)
- Spray based precision thinner/weeder
- Demo- Winter 2016
- Sell Units – Spring 2017

Features

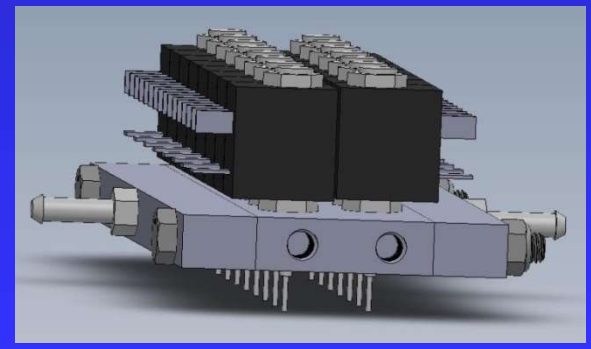
- Self leveling
- Constant height
- Side shift – 4” left or right
- Soil throw on plants
- Limited/no visibility
- ~ 2.5 mph
- $110,000 for 5 row

Stekettee IC

Distributor – Sutton Ag Enterprises, Inc., Salinas, CA

Automated Technologies for In-Row Weed Control

Mark C. Siemens
University of Arizona
Department of Ag and Biosystems Engineering



Pre-Season Vegetable Workshop, August 24, 2016

Post Cultivation
Hand Weeding Rate

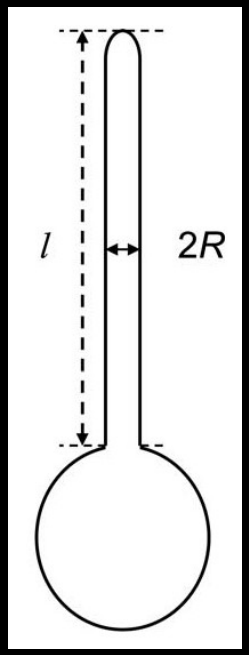
Cult.	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
	----------hr ac^{-1}----------				
Conv	35.8 a	12.6 a	10.5 a	23.2 a	10.5 a
Robo	25.3 b	8.4 b	8.4 a	12.6 b	8.4 a
Diff.	10.5	4.2	NS	10.5	NS

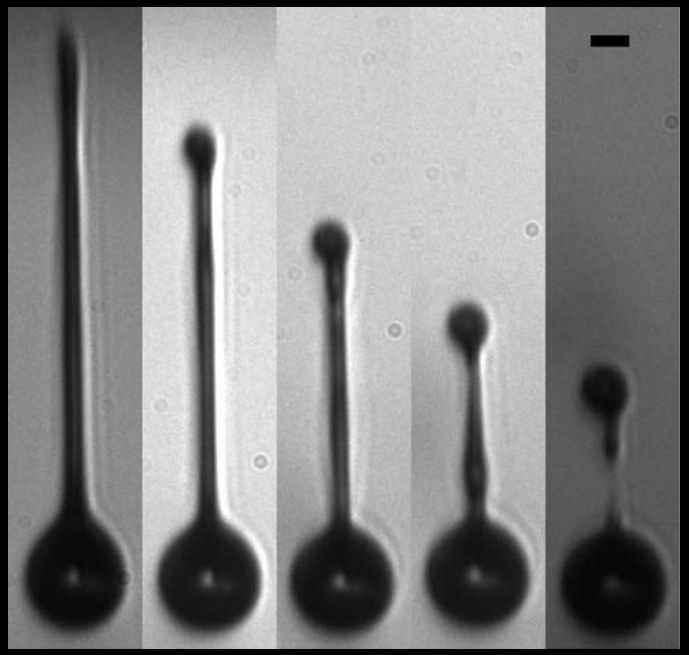
Post Cultivation
Hand Weeding Rate

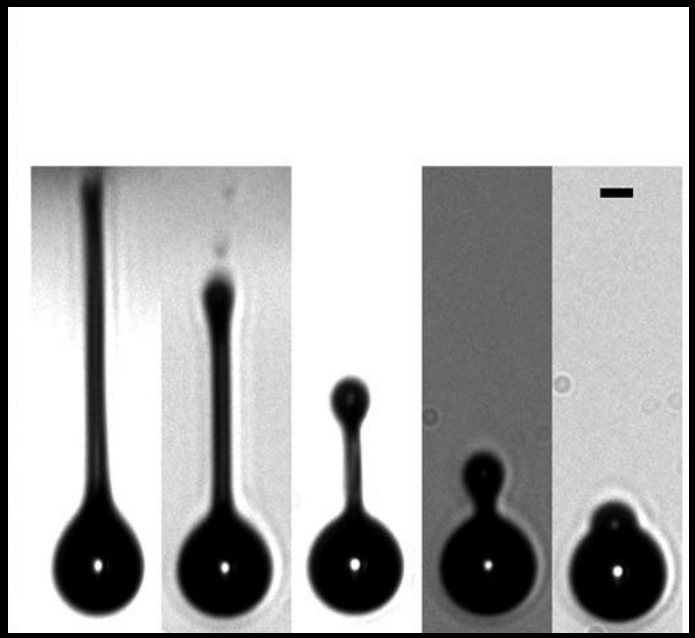
Cult.	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
	----------hr ac^{-1}----------				
Conv	35.8 a*	12.6 a	10.5 a	23.2 a	10.5 a
Robo	25.3 b	8.4 b	8.4 a	12.6 b	8.4 a
Diff.	10.5	4.2	2.1	10.5	2.1

* Difference in means significantly different according to Tukey-Kramer HSD test (P=0.05)

Technically Challenging

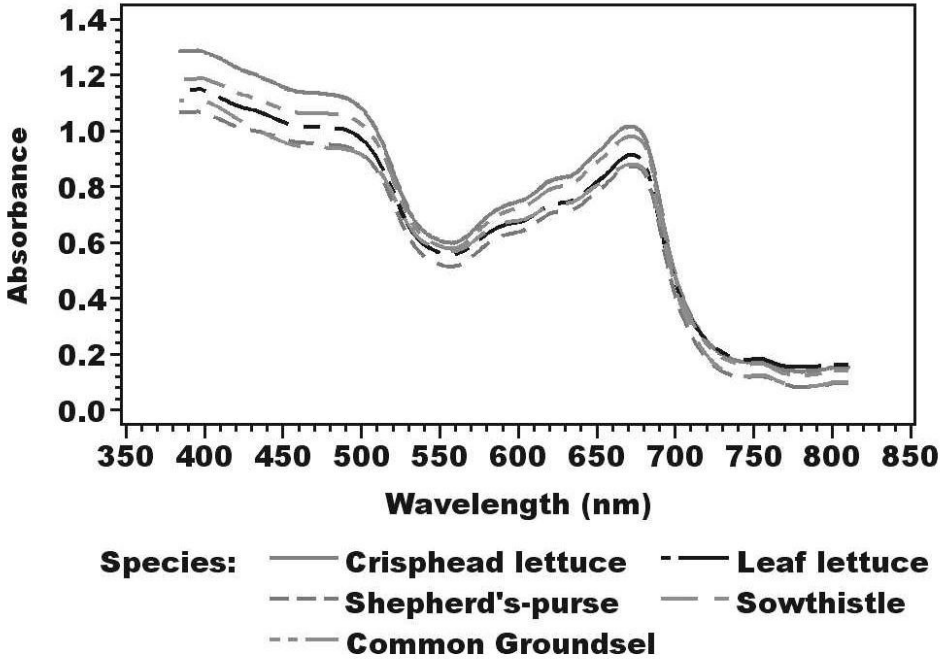




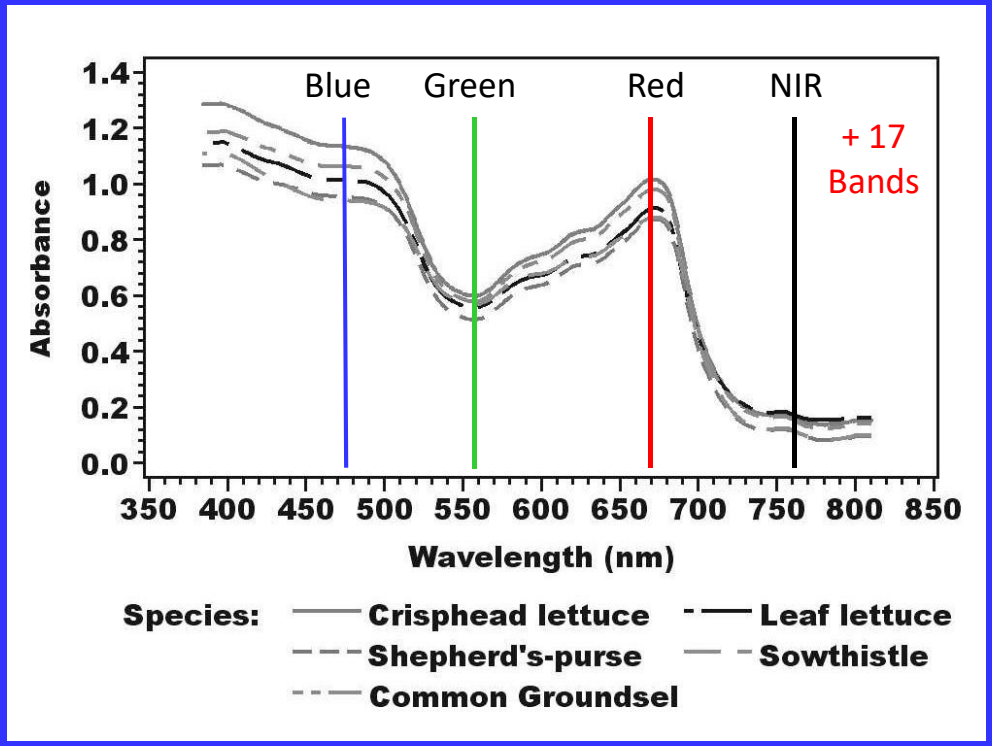


Droplet Stability

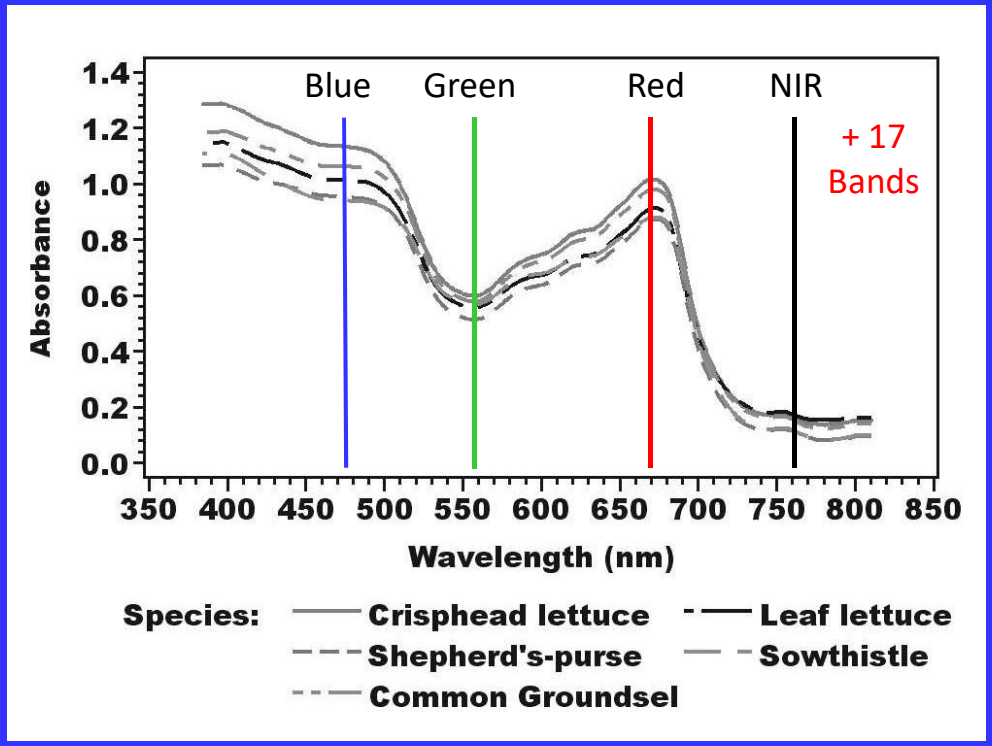
- Filament length (l)
- Filament radius (R)
- Droplet diameter
- Velocity
- Density
- Viscosity
- Surface tension



Slaughter et al., 2008



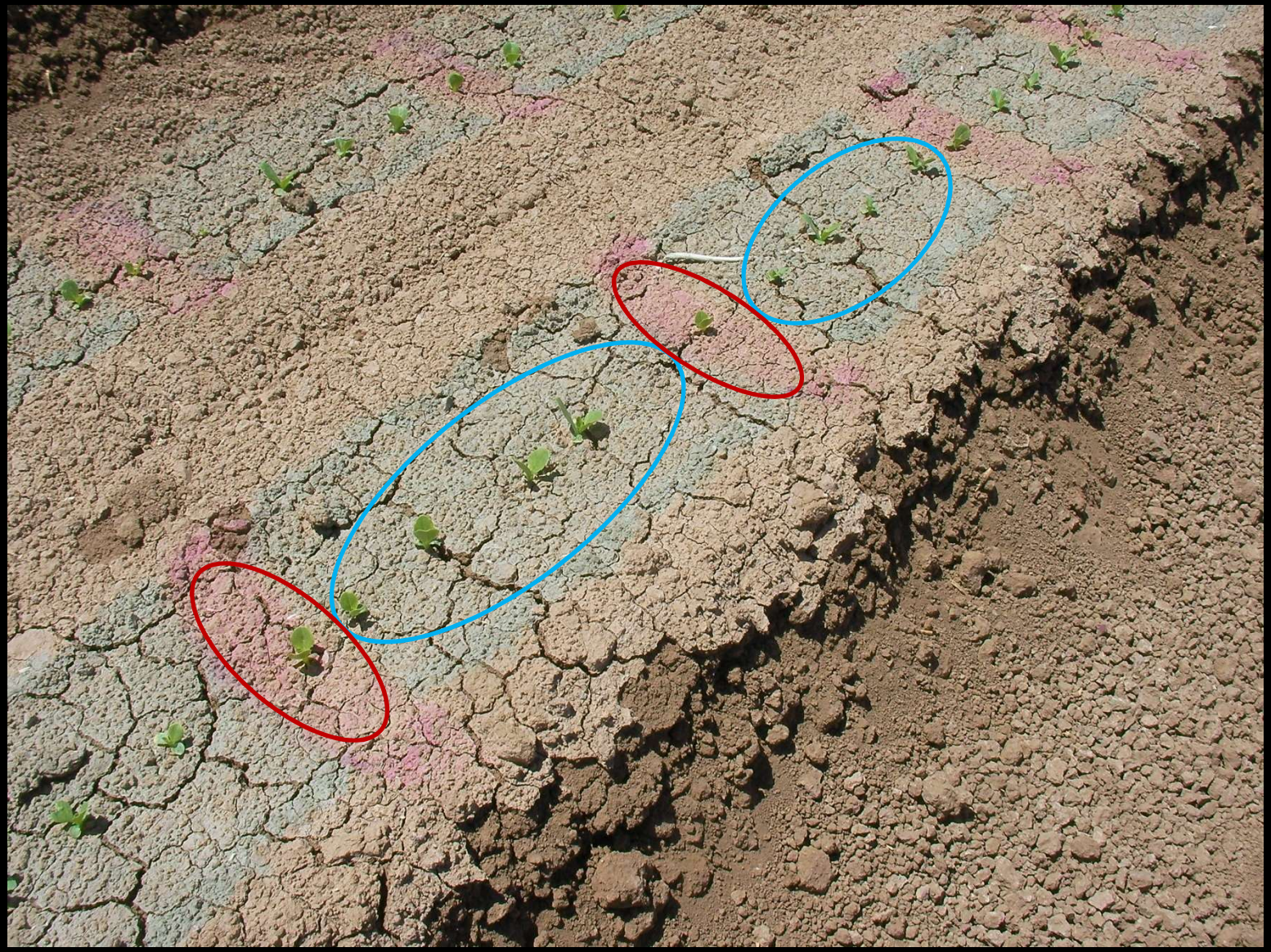
Slaughter et al., 2008



Slaughter et al., 2008

Performance of Multispectral Machine Vision System

Plant Species	Classification Accuracy
Head lettuce	89.4%
Groundsel	83.6%
Leaf lettuce	94.0%
Shepherd's-purse	89.4%
Sowthistle	92.5%
All lettuce	91.3%
All weeds	87.8%
Overall average	90.3%



Thin and Spot Spray Marker Dye

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Tillet-Hague Weeder

"Robocrop" - Garford Corp., Peterborough, EN

Limited Adoption in U.S.

- Transplanted crops - adequate
  - Yield, net returns similar
- Direct seeded crops – not recommended
  - Stand decreased
  - Yield and net returns lower

Fennimore et al. (2014)

Robotic In-Row Weeders

- Commercialized – 2008
- Developed in Europe
  - High labor costs
  - Transplanted crops
- Mechanical
  - Oscillating and rotating blades

Blue River Technologies Inc.

- + $17 million (December, 2015)
- Spray based precision weeder

Thank You