

Robotic Weeding

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Advanced Crop Advisors Workshop
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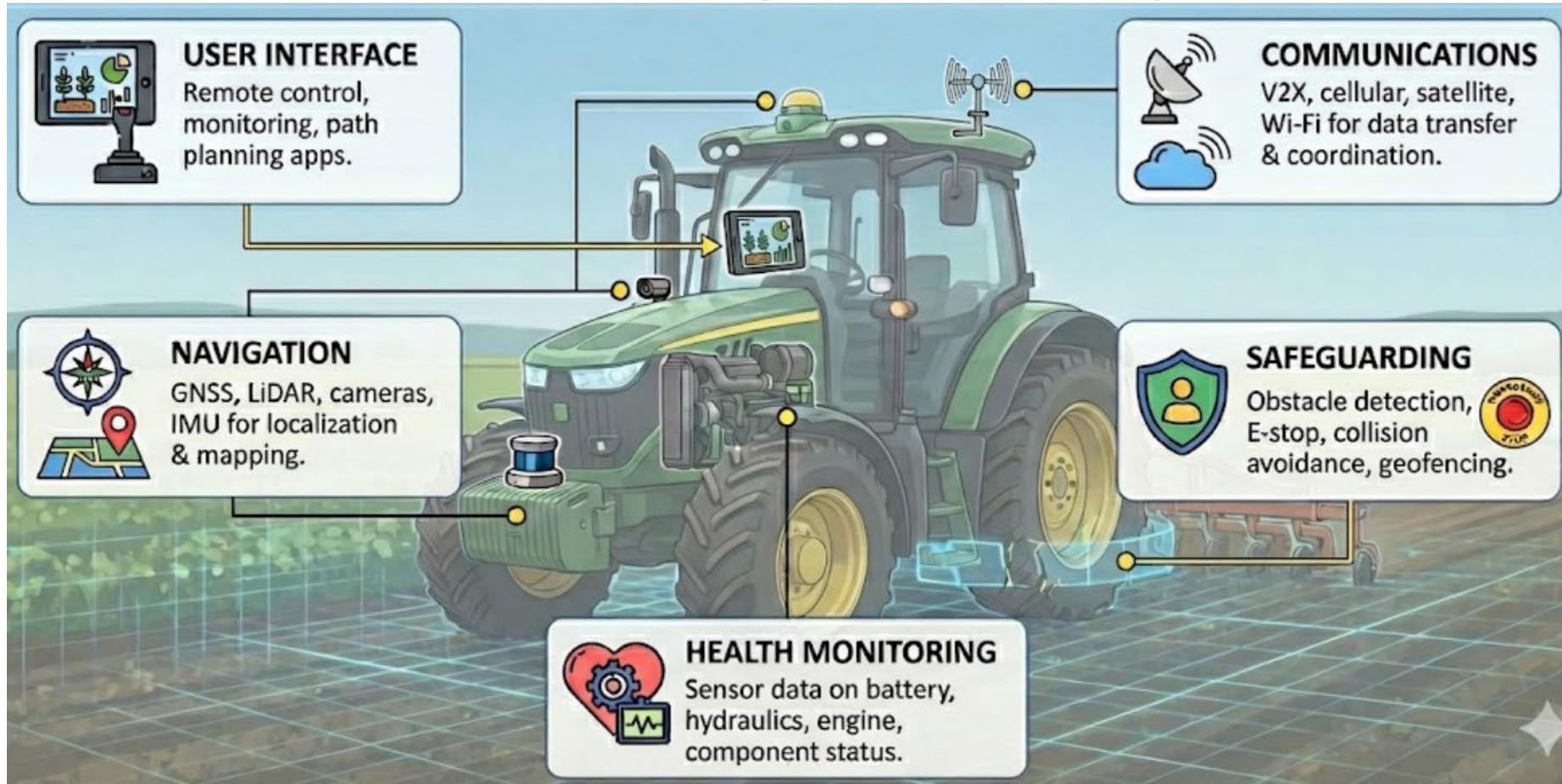
Check	Examples
Fact check	Did Noel misread or misinterpret? Did Noel misspeak? Did I misunderstand?
Context check	Have things changed since the presentation? Is my context different from that in the presentation?
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Covered today:

- Identifying the right role for robotic weeding
- Overview of some weeding mechanisms
- Business model factors
- Some European data on robotic weed control, productivity, and cost



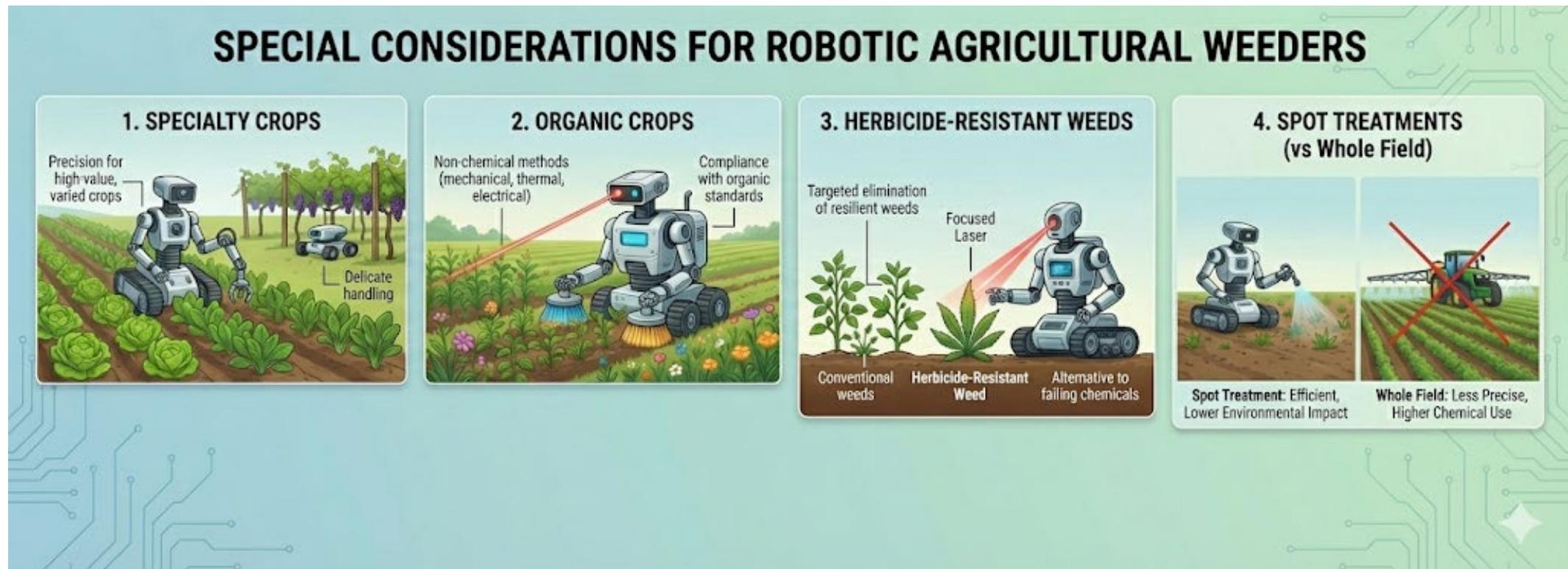
Not covered today: mobility technology



Plus frame and powertrain. See Central Dakota Ag Day Dec 2025 presentation and handout.

What role(s) will the robot be playing?

- Traditional sprayer replacement, **supplement**, or experiment





Specialty vs commodity crop weed control*

Coastal specialty crops	Midwest commodity crops
Higher value / plant or acre	Lower value / plant or acre
Higher cost manual weeding (older data) (\$140/ac lettuce - \$440+/ac organic spinach)	Lower cost chemical weed control (\$40/ac - \$100+/ac soybeans)
Dry, drip-irrigated California central valley	Potentially wet, windy upper Midwest
Crops are shorter	Crops and weeds can outgrow equipment

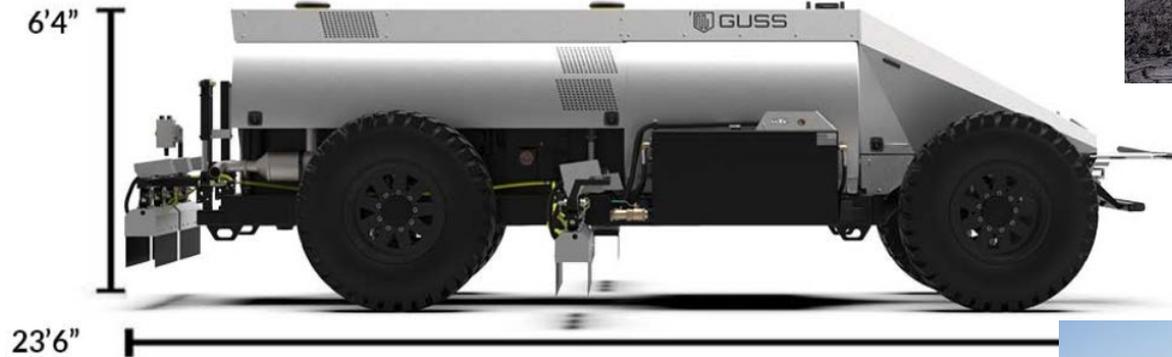
Process*

- Simple area coverage with tillage or chemical
- OR**
- Plant treatment with vision
 - Locate weed(s)
 - Aiming mechanism and adjust for weeder speed (gnd speed $\sim 1/\text{pop}$)
 - Activate mechanism (gnd speed $\sim 1/\text{size}$)
 - Evaluate job quality!



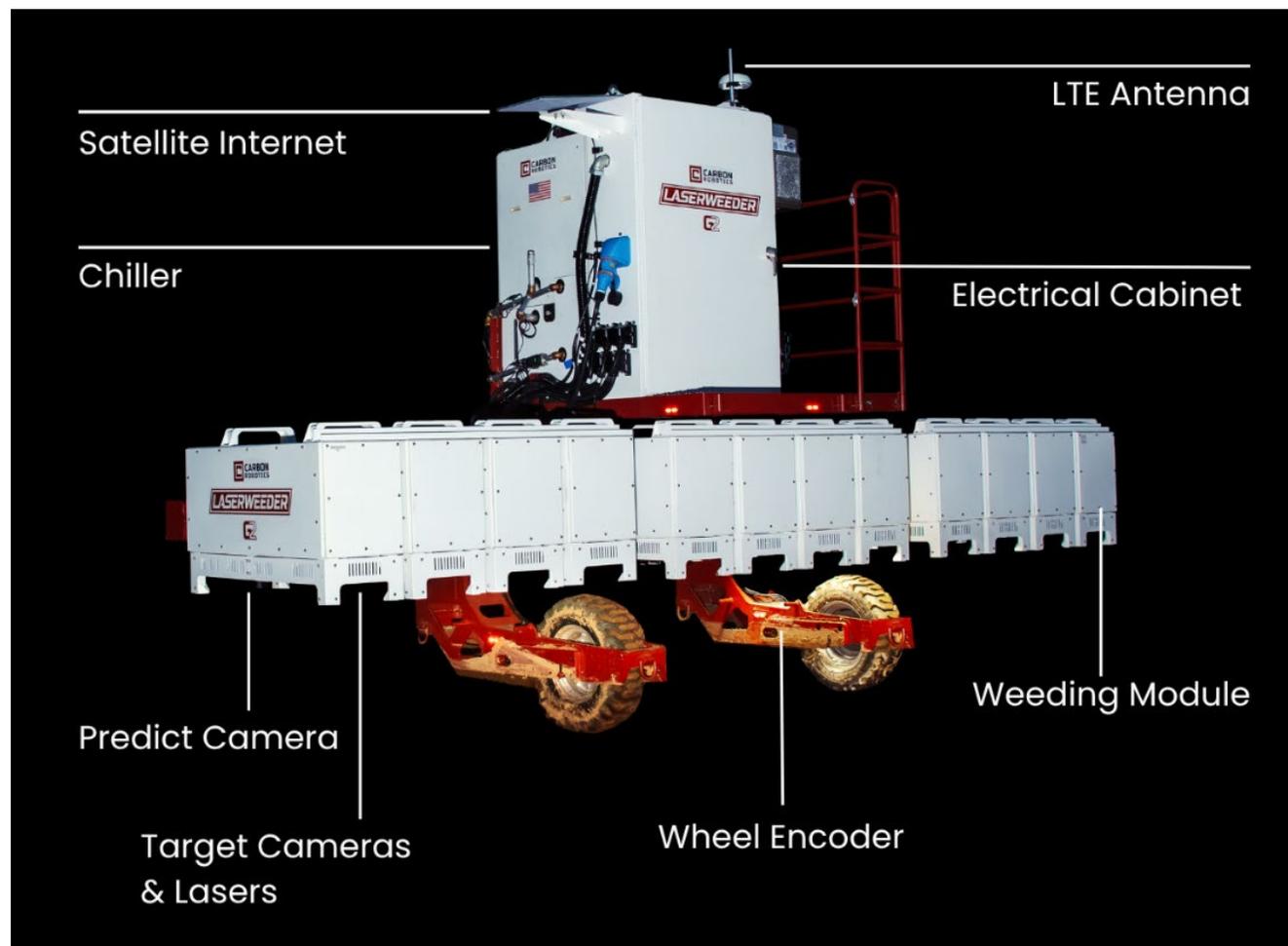
Weeding mechanism(s)

- Chemical spray (savings ~ non-weed areas)
- Mechanical
 - Inter-row
 - Intra-row
- Light: Spectrum
- Heat
 - Fire
 - Liquid/steam
 - Electrical
 - Plasma



Carbon Robotics G2*

- 20-60 foot widths
- Up to 600,000 weeds/hr (5-10 ac/hr)
- \$1-1.7 million plus annual fees (20-60 ft)
- \$267/ac vs \$900/ac manual per one study





Mis-treatment	Cost
<p>Crop damage Mobility Treatment</p> <p>Weed escapes Not treated Insufficient treatment Missed window (weather) Surviving seeds etc</p>	<p>Yield Quality Cleanliness Re-treatment</p>



AI generated image.

Actions	Costs	Multipliers
Pre-season maintenance and set-up	Labor	Rows Machines
To-field transport	Cost of capital Depreciation	Road miles
In-field set-up	Wear items Consumables	Fields Acres
In-field attention	Note: If the robot is used for more than weeding, costs may be split over more operations.	Hours
Off-field attention		Years
In-field tear-down		



Economics data are lacking*

- Small set of farmers using the technology, especially Midwest
- Technology is evolving, last year's pain point may be gone...
- Small amount of data collection and studies:
 - Experts in 2018 found 4 robotic weeding economics papers out of a first-pass set of 4817.
- For discussion: How can Grand Farm, NDSU, or ARS help you?

UIUC model study (2024)

- Yu, Chengzheng et al, “Herbicide-resistant weed management with robots: A weed ecological-economic model”, *IAAE Agricultural Economics*, Oct 2, 2024.
<https://onlinelibrary.wiley.com/share/R3R4DYUCZADREGYBAU97?target=10.1111/agec.12856>
- “This paper examines a farmer's incentive to adopt robotic mechanical weed control by developing an I-WEED model that combines a cohort-based weed growth model with a resistance spread model and an economic analysis. The model relates yield damage with effective weed density, which considers observed weed density, timing of weed emergence, and duration that weeds are alive in the field. ”

European SB and rapeseed study (2024)

- Gerhards, R., Risser, P., Spaeth, M., Saile, M. & Peteinatos, G. (2024) A comparison of seven innovative robotic weeding systems and reference herbicide strategies in sugar beet (*Beta vulgaris subsp. Vulgaris* L.) and rapeseed (*Brassica napus* L.). *Weed Research*, 64(1), 42–53. Available from: <https://doi.org/10.1111/wre.12603>
- Table 5: Weed control
- Table 6: Productivity and cost

FD20 from FarmDroid.com*

- Solar powered robot that seeds and weeds
 - Uses only RTK GPS, no camera
 - Inter and intra-row mechanical weeding
 - Micro-sprays plant protection products
 - 1250kg, 5 ha/day, 2-12 rows from 22.5 cm
 - Price: \$80-100,000 (2024)
-
- Compare to Aigen.io, having camera
 - Used for sugar beets in the RRV (2025)
 - Weeding as a service business model
 - \$50,000 ea + \$20,000 ea/yr fee (2025)



W4 from Farming-Revolution.com*

- Used for sugar beet weeding
- Electric with diesel generator
- RTK GPS guidance, IR+R cameras
- Inter and intra-row mechanical weeding
- Up to 10 ha/day (GT model)
- Price: 100-200,000
(USD or EURO for GT model?)



KULT iVision*

- Add-on along with hydraulic side-shift sweeps
- One treatment included intra-row movement and weed identification
- Row detection with RGBcamera for row following



Components of the PV

- hydraulic parallel displacement
- 3-point mounting
- Cat II attachment
- Camera system with touch screen
- hand control box
- Speed sensor
- lift-out sensor
- optional with night driving lights

Treatment	Herb. Savings (%) (mean/min/max)	Weed Control Eff. (%) (mean/min/max)	Crop Loss (%) (mean/min/max)
Herbicide broadcast	0	82.7 (61.5–98.9)	2.2 (0–8.8)
Conventional hoeing + harrowing	100	74.0	21.4
Band spraying + inter-row hoeing (offline)	75	95.3 (93–97.6)	4.7 (2.0–7.4)
FD20®-band spraying + inter- row hoeing (online)	83.1	66.5	1.8
FR-W4® inter-row + in-row hoeing	100	93.0	39.5
FD20® inter-row + in-row hoeing	100	92.0 (89.7–94.2)	20.7 (0.9–40.4)
FD20® inter-row+ in-row hoeing + Amazone spot spraying®	92.2	94.2	2.3
KULT-Vision Control® inter-row hoe	100	80.2 (69.9–90.5)	2.5 (0–7.4)
KULT-Vision Control® inter-row hoe + finger weeding	100	92.9	0
KULT-iSelect® with Hohenheim camera	100	93.5	0



Treatment	Working width (m)	Speed (km h ⁻¹)	Working rate (ha h ⁻¹) ^a	Treatment costs (min/max) (€ ha ⁻¹) ^b
Herbicide broadcast application	18	8	6.2	308.6 (oil-seed rape), 307.4 (sugar beet Ihinger Hof), 383.4 (sugar beet Kirschgartshausen)
Conventional hoeing + harrowing	5.4 (12)	4 (8)	1.0	230.6
Band spraying + inter-row hoeing (offline)	12 (5.4)	8 (4)	1.0	298.7
FD20®-band spraying + inter-row hoeing (online)	2.7	(2.5) ^c 5	0.95	804.2
FR-W4® inter-row + in-row hoeing	2.7	1	0.42	804.2 ^d
FD20® inter-row + in-row hoeing	2.7	1	0.42	733.4
FD20® inter-row and in-row hoeing + Amazone spot spraying®	2.7	1	0.42	804.2
KULT-Vision Control® inter-row hoe	3	(3) ^c 8	1.3	102.5 (sugar beet) 205 (oil-seed rape)
KULT-Vision Control® inter-row hoe + finger weeding	3	(2.5) ^c 5	1.0	220.8
KULT-iSelect® with Hohenheim camera	3	1	0.4	554.7

Robotic weeding news for 2026

- Two key ND Dept of Commerce Grants
 - Greenfield robotics full season autonomous farming pilot including weed management. Some work at Carrington.
 - Grand Farm including expanding applied robotics research



- Opportunities to see ag robots in action at the Grand Farm Innovation Campus near Casselton, ND during field days, Autonomous Nation conference, and more. **Autonomous Nation @ Grand Farm: Sep 17, 2026.**
- Watch for NDSU events, especially Extension, Ag Engineering, and the Peltier Institute.



DISCUSSION & FUTURE DIRECTIONS



Thank you!

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Supplemental slides

Harper-Adams Univ. (UK) study (2019)

- Lowenberg-DeBoer, J., Huang, I.Y., Grigoriadis, V., and Blackmore, Simon. Economics of robots and automation in field crop production. *Precision Agric* **21**, 278–299 (2020).
<https://doi.org/10.1007/s11119-019-09667-5>
- Review of literature **between 1990 and 2018**
“on the economics of agricultural mechatronic automation and robotics, and identified research gaps.”
- **4817 initial docs** -> 119 full text docs -> 18 for fuller analysis
-> 8 docs autonomous ag equipment -> **4 docs weeding**

Harper-Adams Univ. (UK) study (2019)

- “All of the studies found some scenarios in which automation and robotic technologies were profitable.”
- **Sorenson (2006) reported savings 36.20 euro/ha/yr for horticultural crops**
- “Most of the studies reviewed estimated economic implications assuming that technology design parameters were achieved and/or based on data from prototypes. **Data are needed on the benefits and problems with using automation and robotics on farm.**”
- “The results of this study will be of interest to agricultural researchers, agribusinesses, farmers and agricultural policy makers.”

Robotic Weeding: Concepts and Options

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Grand Farm

Central Dakota Ag Day and
Crop Advisers Workshop
Carrington, ND

December 19, 2025



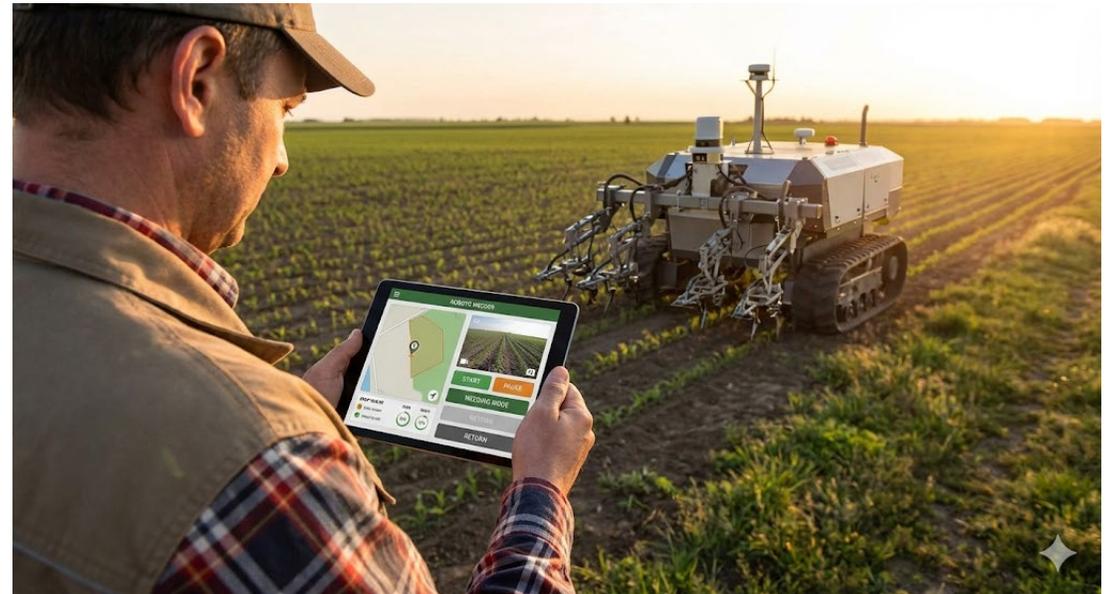
Frame, power, and powertrain

- Automated traditional machine vs dedicated autonomous platform
- Solo or coordinated fleet
- Size: Large, small, single row
- Diesel, gas, electric
- Wheels, tracks, legs
- Towed or attached implements
- Driven, convoyed, or trucked between fields

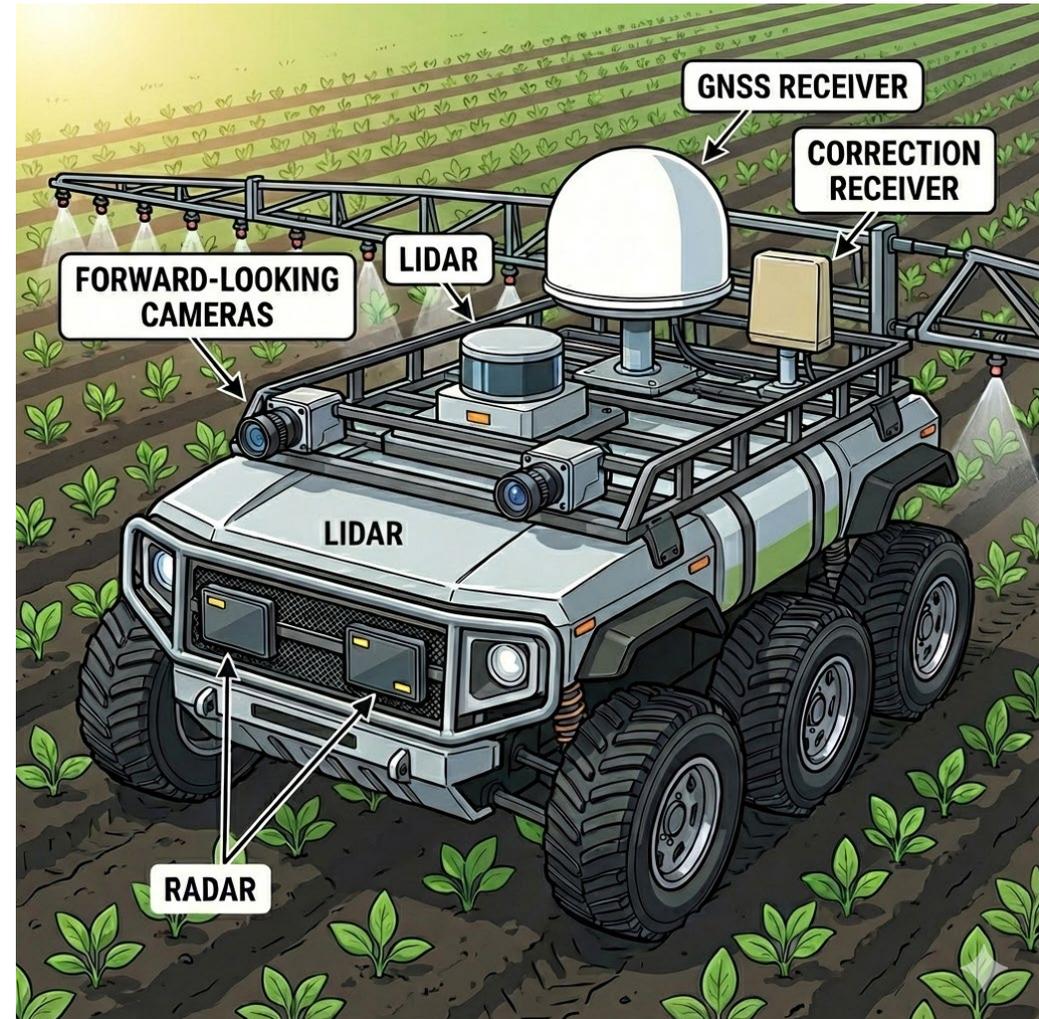
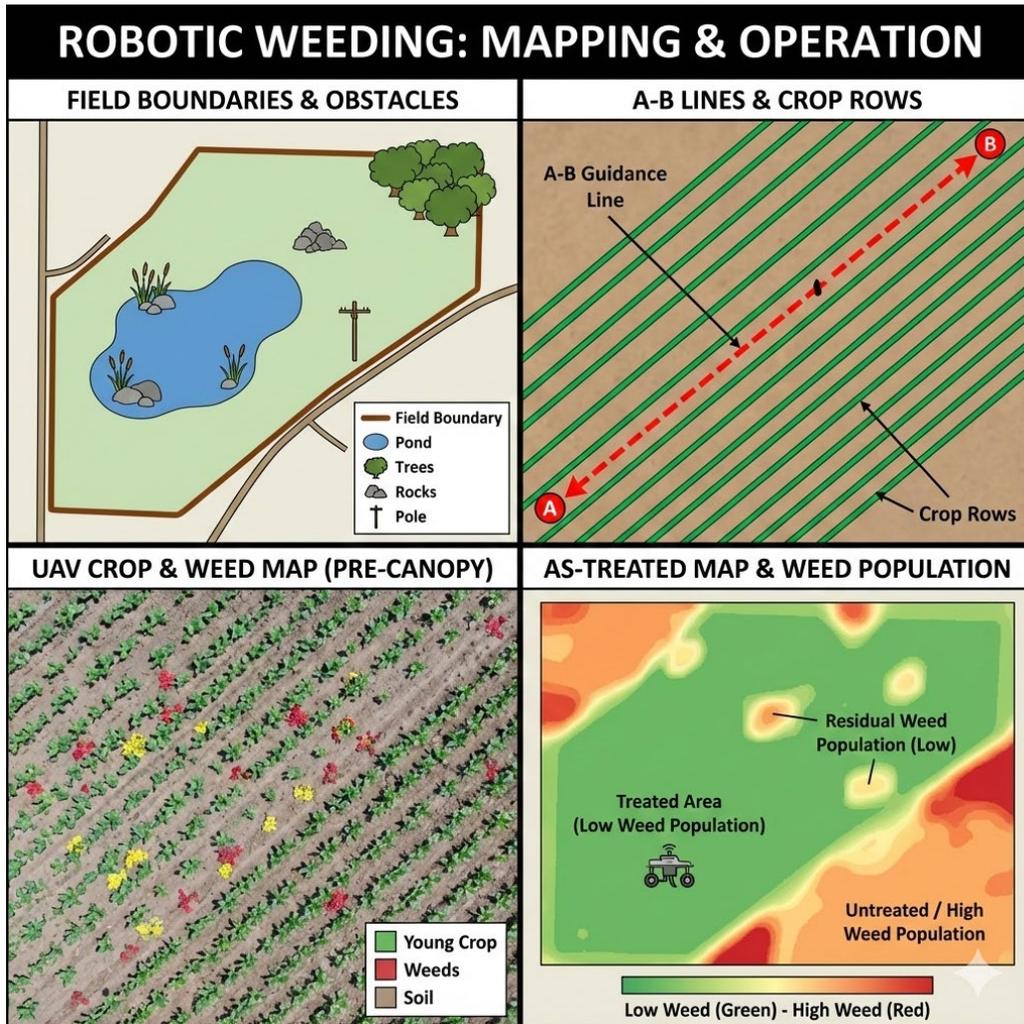


User interface / communication

- Try before you buy! Ease and “fullness” of use including diagnostics
- Dedicated console or general platforms (phone, tablet, laptop, etc)
- Single user or multiple users with roles
- Long range communications
 - Tech: cellular, satellite, or other
 - Coverage
 - Added fees
- Short range communications: Wifi, Bluetooth, USB, etc

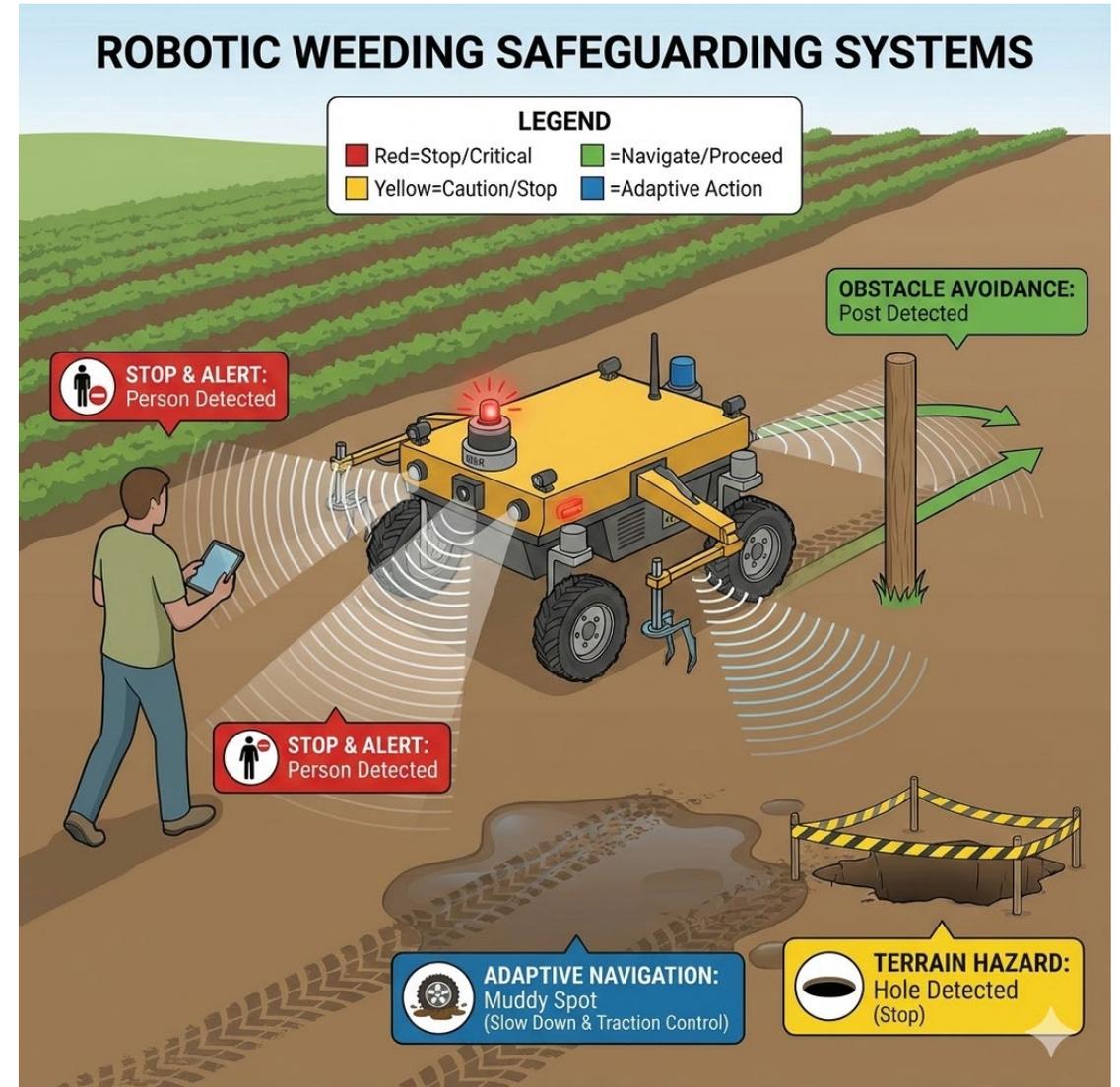


Navigation



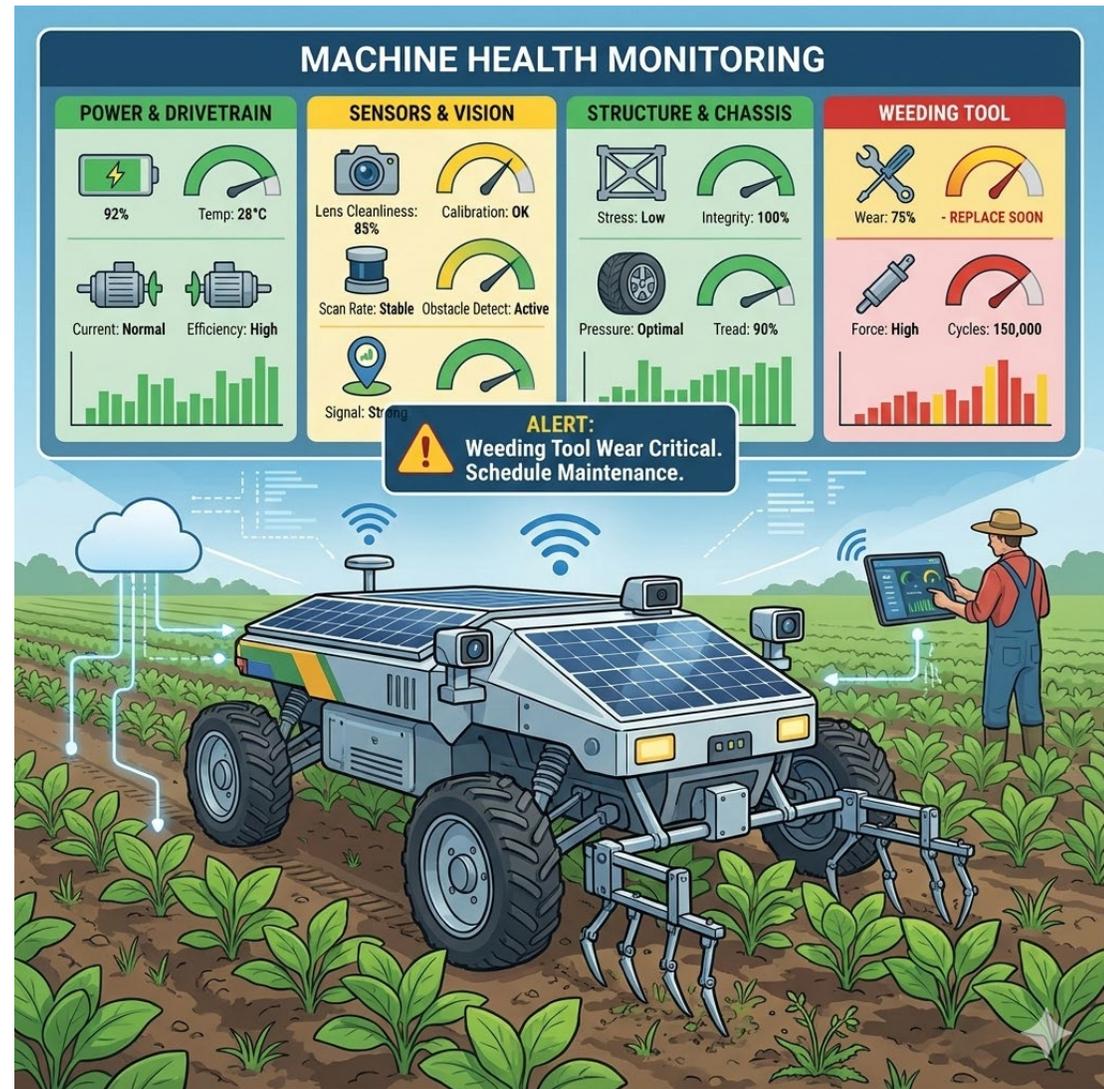
Safeguarding

- No harm to humans!
 - Start-up
 - Person “sleeping” in field
 - Taunting teens
- No damage to external objects
- No harm to self (the robot)
 - Collisions
 - Holes, ruts, rocks
 - Mud (including rescue)

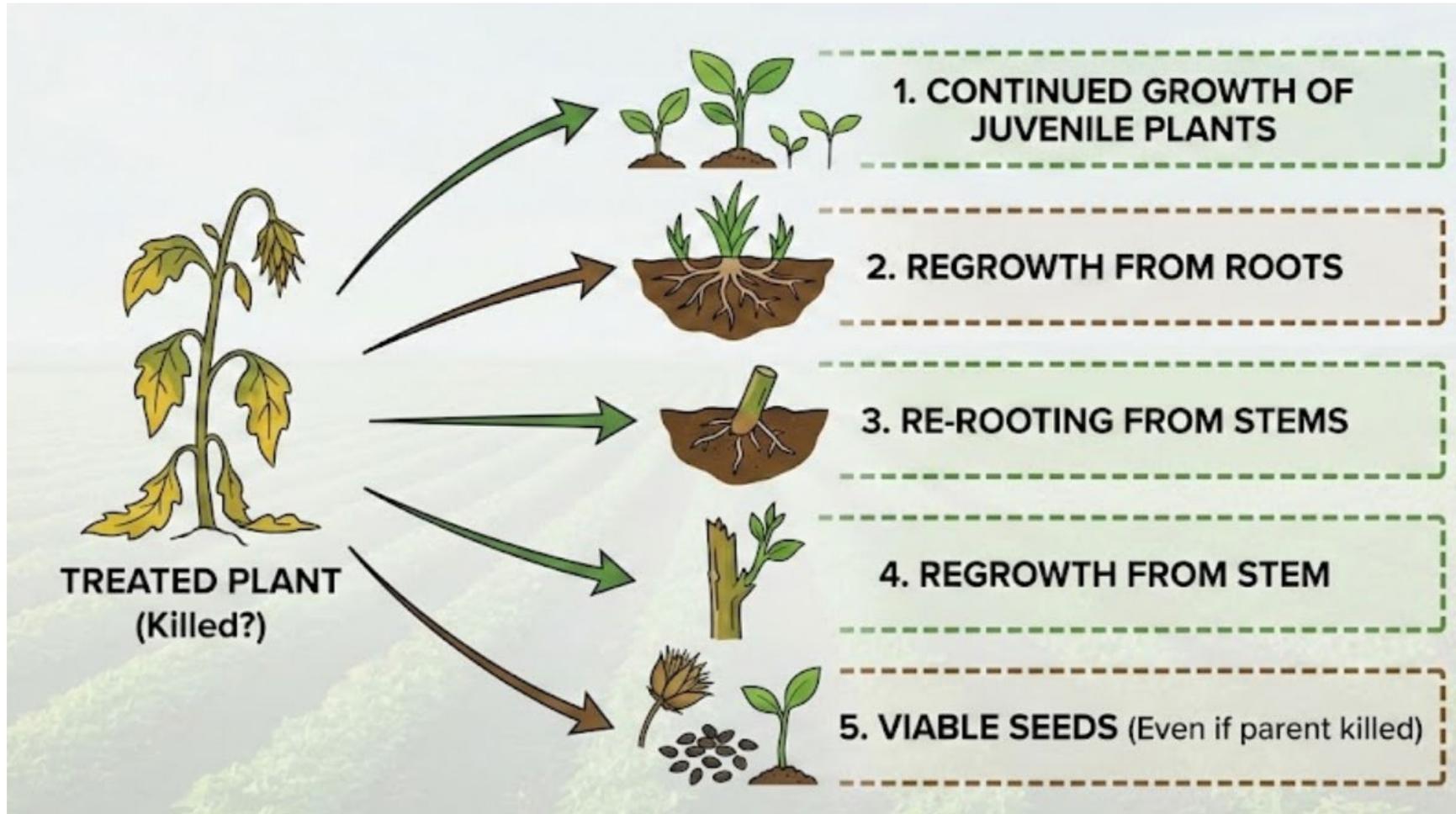


Health monitoring: diagnostics, prognostics

- Key point: Is all operator monitoring automated?
- Mobility subsystems
- Task subsystem / job quality
 - Targeting (eg cameras)
 - Liquid distribution subsystem
 - Nozzle -> droplets
 - Mechanical
 - Laser etc



Know your weeds by propagation



Also be alert to the speed of natural selection and attributes of surviving plants.

Thank you!

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