Vehicle options: carts, tractors, gantry cranes, UAVs and more
Tues, 8:30 AM

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I. Introduction
   A. In considering vehicle options:
      1. Basic challenge is how to transport sensors or imaging systems over crops, while ensuring accurate positioning (x, y, z space + time), providing power and data-logging services, and minimizing damage to the crop and soil.
      2. Other common design issues also apply, including costs (fixed and variable), reliability, safety and possible regulatory constraints.
      3. Some types of vehicles present special challenges
         a) Field access (e.g., cranes)
         b) Portability (e.g., cranes)
   B. In this talk, we discuss the range of options that have been used or proposed for phenotyping, with emphasis on what we see as more promising options.
   C. Table 1 summarizes our thinking to date and is admittedly subjective. We welcome feedback and suggestions of additional vehicle opportunities.

II. Main types of vehicles for field-based HTP (columns in Table 1):
   A. High clearance tractors
   B. Linear-move irrigation systems
   C. Other crane-type vehicles
   D. Aerostats ("blimps" – tethered)
   E. Aircraft
      1. Fixed or rotary
      2. Manned or UAV
   F. Cable robots

III. Criteria for selecting (rows in Table 1):
   A. Proven technology vs. "bleeding edge"
   B. 24 x 7 operation
   C. Easily relocated: within site vs. multiple sites
   D. Payload
   E. Power supply

F. Horizontal positioning (X-Y)

G. Vertical positioning

H. Damage to crop or soils

I. Initial (capital) costs

J. Operating costs

K. Training requirements for operators

1. Example: UAVs may require pilot certification in the US

2. Example: Crane operators may require certification

L. Safety or regulatory

1. "It is estimated that more than 80% of all accidents on a farm involve a tractor, and rollover accidents are the leading cause of tractor-related deaths. A side overturn is the most common type of rollover, and it usually happens when traveling on local roads." (www.LSUAgCenter.com)

IV. Vehicle examples with comments

A. High clearance tractors

1. Existing technology

2. Moderate cost

3. Flexible (?)

4. Portable

5. Issues:

a) Cost

b) Stability and georeferencing of boom

c) Wet soil

d) On-board operator(s)

e) Soil compaction

f) Disease and pest

g) Limited mobility

6. Scope for engineering from the ground up to improve upon tractor/sprayer features

B. Cart

1. Very similar to tractor, but lower cost and capacity

2. Robotic carts as a compromise between tractors and carts

C. Cranes
    1. Gantry (bridge)
        a) "Pros"
            (1) Excellent X-Y control
            (2) Can provide high clearance for imaging and tall crops
        b) "Cons"
            (1) High fixed cost
            (2) Low portability
    2. Jib (boom)
    3. Linear-move
D. Cable robots
E. Fixed and rotary-winged aircraft
    1. Proven technology (+/-)
    2. Random access (in path)
    3. Irregular fields
    4. Issues:
        a) Cost of operation
        b) Reliability
        c) Equipment
        d) Weather (wind)
        e) 500 ft floor for manned craft in the US
        f) FAA certification required for external instrument packages
F. Aerostats
    1. Proven technology (+/-)
    2. Random access (in path)
    3. Weather (wind)
G. UAVs – "The best for last"
    1. "Pros"
        a) Similar performance to manned aircraft but:
            (1) Closer to plots = higher resolution
            (2) Much lower fixed and operating costs
        b) Rapidly improving technology
        c) Relatively low cost

2. "Cons"
    a) Limited flight duration unless tether supplies power
    b) Operation under high winds or at night (?)
    c) Uncertainty over regulation

V. Conclusions

A. No single, universal solution at this time
    1. Choices depend on budget, applications, etc. (Table1)
    2. Field management and damage apt to be overlooked

B. For immediate deployment:
    1. High-clearance tractors
    2. Carts

C. For niche applications & worth pursuing:
    1. Cranes (and linear move irrigation systems)

D. Higher risk, game changing technology:
    1. UAVs
    2. Cable-robots
    3. Fixed towers

References

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Table 1. Possible criteria for selecting different options for field phenomics vehicles.

Criteria	Manual cart	Powered cart	High-clearance tractor	Tractor with side-reaching boom	Light gantry crane	Heavy gantry crane	Jib (boom) crane	Linear move	Cable robot (NFL)	Fixed posts	Unmanned aerial system (UAS)	Teathered UAV	Aerostat (baloon)
Instrumentation													
Maximum payload	25 kg	25 kg	200 kg	100 kg	10 kg	Over 500 kg	100 kg	?	100 kg	5 kg	1 kg	1 kg	10 kg
Accuracry of height control	5 cm (?)	5 cm (?)	10 cm (?)	10 cm (?)	< 5 cm	< 5 cm	< 5 cm			< 5 cm			
Georeferencing	GPS	GPS	GPS	GPS	GPS or encoder	GPS or encoder	GPS or encoder	GPS or encoder	Encoder	Fixed positions	GPS + postprocessing	GPS + postprocessing	GPS + postprocessing
Can support sensors spaced for multiple rows			Yes	Yes		Yes	Yes		Weight limited	Yes	No	No	Weight limited
Can sense/image multiple 1 m wide plots	2 to 4	2 to 4	4 to 6	4	> 10	> 20	> 10?	~40	?	> 10	> 50	> 50?	> 50
Potential for high-frequency vibration	Moderate	Moderate	High	High	Low	Low	Low	Low	No	Low	High	High	No
Minimum sensor distance to canopy	10 cm	10 cm	10 cm	10 cm	10 cm	10 cm	10 cm	10 cm	10 cm	7 m (?)	50 m (?)	50 m (?)	1 m
Maximum vertical clearance	1.2 m	1.2 m	2 m	4 m		5 m	5 m		5 m	NA	> 100 m	> 100 m	> 10 m
Power supply	Batteries	Batteries	Alternator	Alternator	Mains/generator	Mains/generator	Mains/generator	Mains/generator	Mains/generator	Mains/generator	Battery	Battery/generator	Battery
Installation													
Portability with a research site	High	High	High	High	Limited	Limited	Limited	Limited	Low	Low	High	High	Low
Portability to multiple sites	High	High	High	High	None or ?	None	None	None	Low	Low	High	High	Low
Suitable for irregular terrain	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Obstacles for other field operation	None	None	None	None	Yes	Yes	Yes	Moderate	Low	Yes	None	None	None
Based on well-established engineering	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	?	Yes	Yes	Yes
Impact of installation on site	Low	Low	Low	Low	High	High	High	Medium	High	High	Low	Low	Low
Power supply	Battery	Battery	On-board	On-board	Battery	On-board or cable	On-board or cable	On-board or cable	Battery or cable	Battery or cable	Battery	Battery	Battery or cable
Operation													
Ease of operation when soil is wet	Low	Low	Low	Low	High	High	High	High	High	High	High	High	High
Ease of night operation	Moderate	Moderate	Moderate	Moderate	High	High	High	High	High	High	No (?)	No (?)	No (?)

Potential for damaging plants	Moderate	Moderate	Moderate	Moderate	Low	Low	Low	Low	No	No	No	No	No
Potential for trasmitting pathogens	Moderate	Moderate	Moderate	Moderate	Low	Low	Low	Low	No	No	No	No	No
Potential for compacting soil	Low	Low	Moderate	Moderate	Low	Low	Low	Low	No	No	No	No	No
Random access to specific field positions, with start/stop	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes[c]	Yes[c]	Yes
Ease of static control of instrument height	High	High	High	High	High	High	High	High	High				
Ease of dynamic control of height for individual plots	Moderate	Moderate	High	High	High	High	High	High	High	None	None	None	None
Type of operator required	Technician	Technician	Driver	Driver	Technician	Technician	Technician	Technician	Technician	Technician	Pilot plus assistant	Pilot plus assistant	Technician plus assistant
Costs													
Base cost (exclusive of sensors, dataloggers, fuel, operators, maintenance, etc.)	$500	$500	$100,000			?	?		?	?			$3,000
Cost of operation (fuel, parts, etc.)	Low	Low	Moderate	Moderate						Low			
Other issues													
Regulatory issues	No	Safety	Safety	Safety	Safety	Safety	Safety	Safety	Safety	No	Aviation, safety, privacy	Aviation, safety, privacy	Aviation, safety, privacy
Examples	PSC at ALARC		P Andrade's tractor; ALARC's Avenger	IRRI (?)	IRRI gantry; Lemnatec			AgIIS (no longer in service)					
References/Contacts	White & Conley, 2013		Andrade et al., 2013		S Klassen, IRRI			Colaiizi et al., 2003; Haberland et al., 2010					