Implications for Precision Agriculture Applications in Sub-Saharan Africa from 30 years of Research

Presented at the GCRF Networking Workshop,
University of Cape Coast, Ghana
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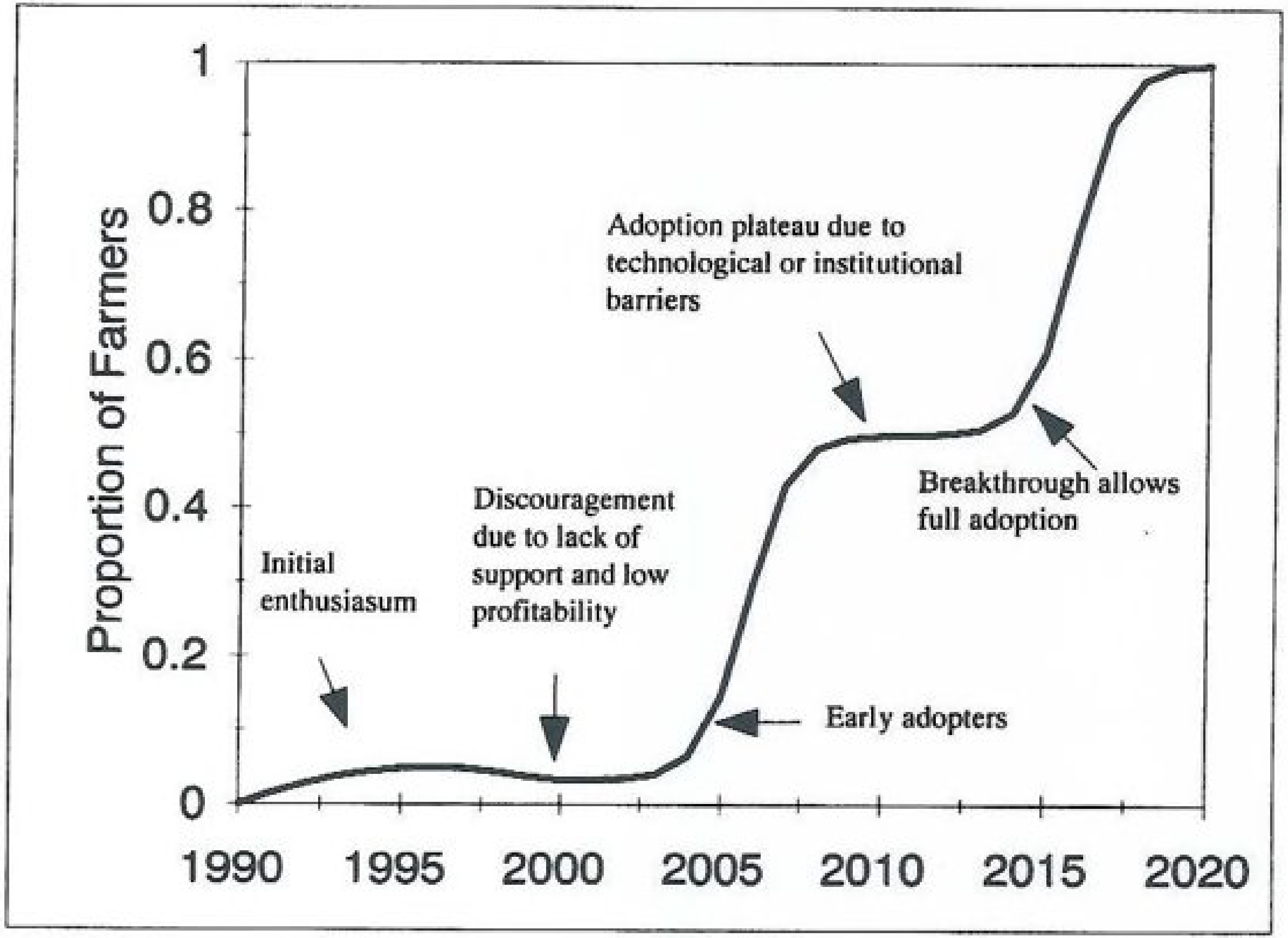

Figure 7. An alternative adoption scenario for integrated precision farming systems using information technology for spatial and temporal management multiple inputs.

Source: Lowenberg-DeBoer, SAE, 1998

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Goals of this presentation:

1) Update on current status of precision ag adoption worldwide.
2) Challenges in estimating and predicting adoption patterns.
3) Anticipating PA and more general agri-tech adoption trends in Sub-Saharan Africa.

Photo source: DJI Facebook page: https://www.facebook.com/100064004012004/videos/503662841718269/?__so__=permalink

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Definition of Precision Agriculture

"Precision Agriculture is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production." (*https://www.ispag.org/about/definition*)

Calf with paired visual and RFID ear tags. Questions about whether the "individual data" in the PA definition includes precision livestock. (Photo from aphis.usda.gov)

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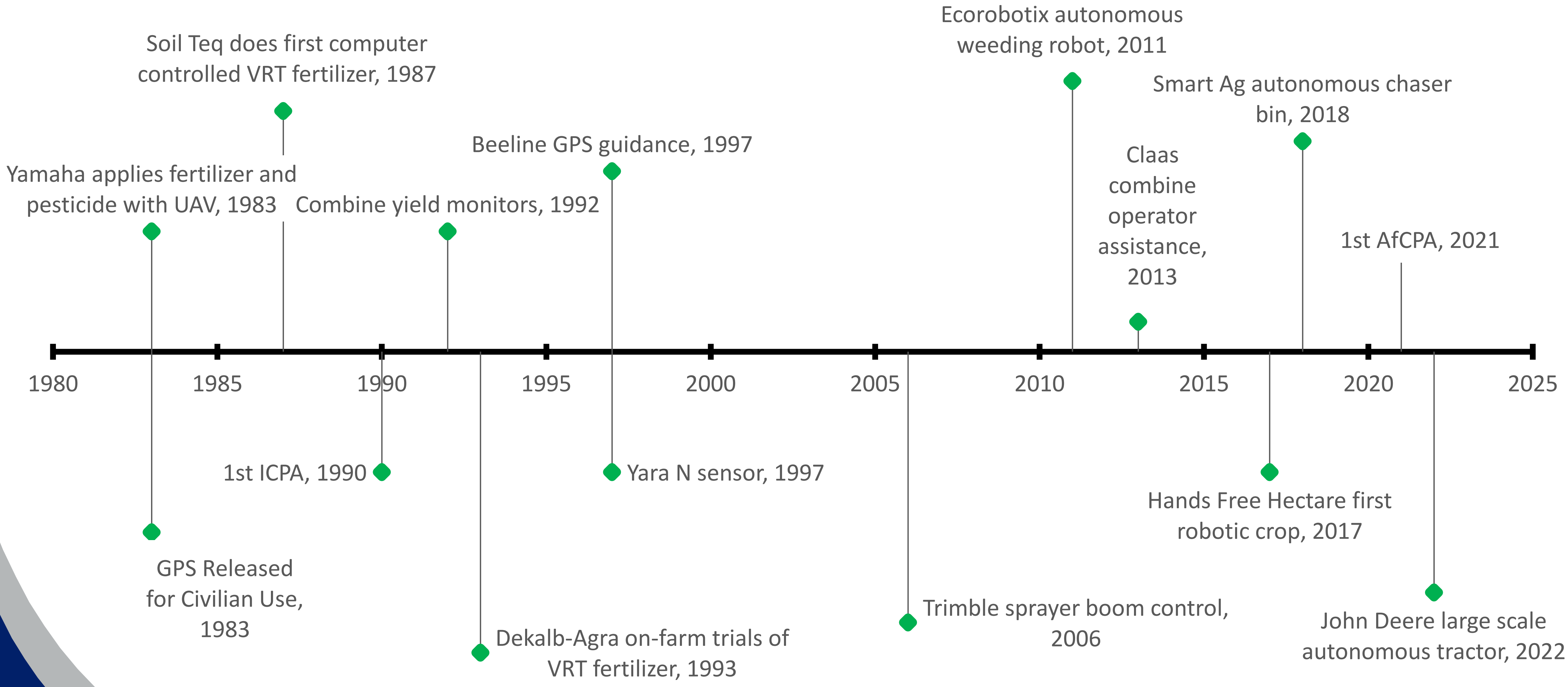
Some Precision Agriculture Milestones



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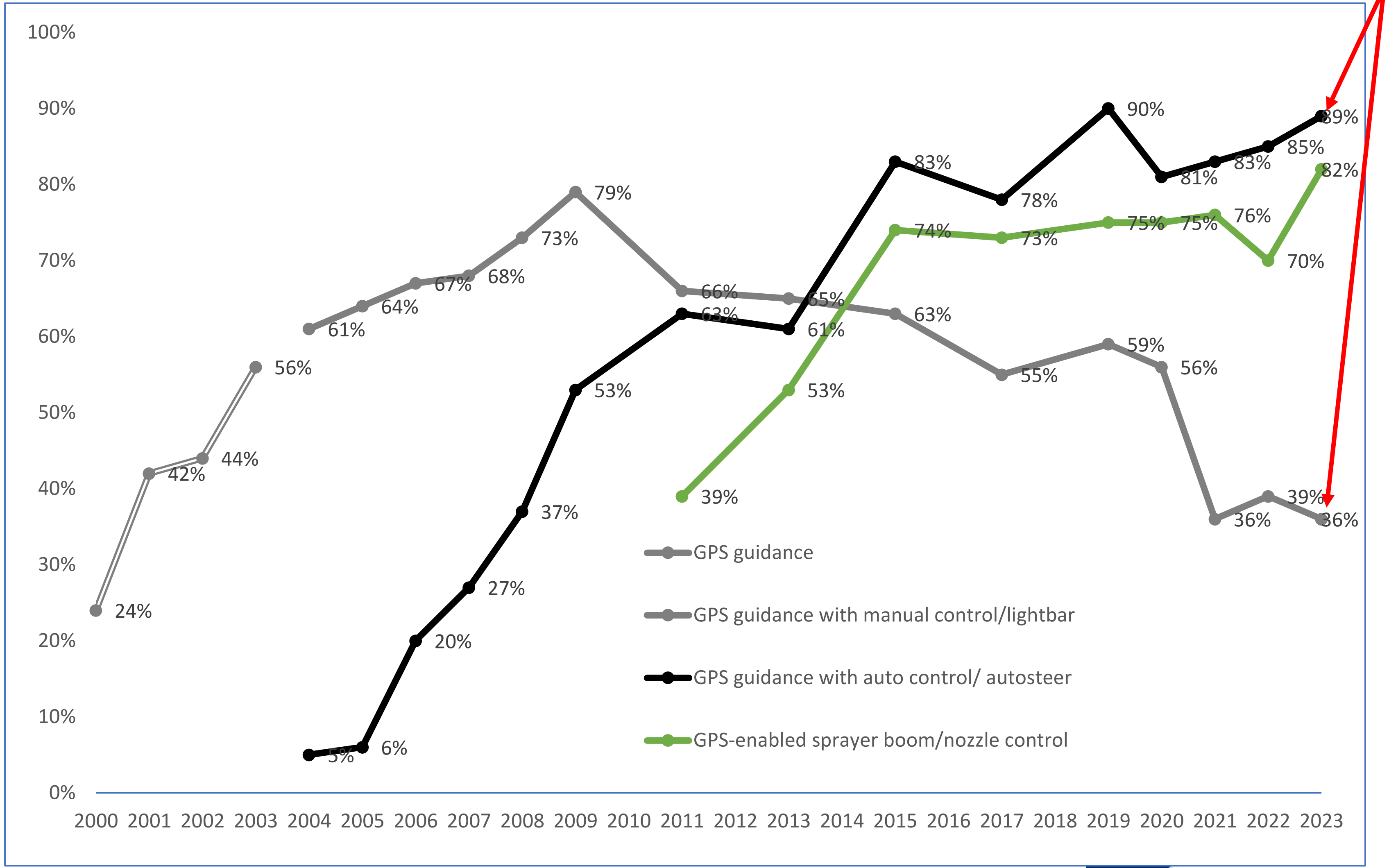
USA Ag Retailer Use of GPS Guidance

In 2023, 93% of ag retailers use either lightbars or autosteer.

- Global Positioning System (GPS) was the first Global Navigation Satellite System (GNSS).
- GPS lightbars rapidly adopted starting in late 1990s and then replaced by autosteer.
- Autosteer rapidly adopted starting in about 2004.
- Both are easy to use and have short run benefits



Source: Erickson and Lowenberg-DeBoer, 2023 – https://www.croplife.com/management/precision-survey-ag-dealers-respond-to-marketplace-shifts/

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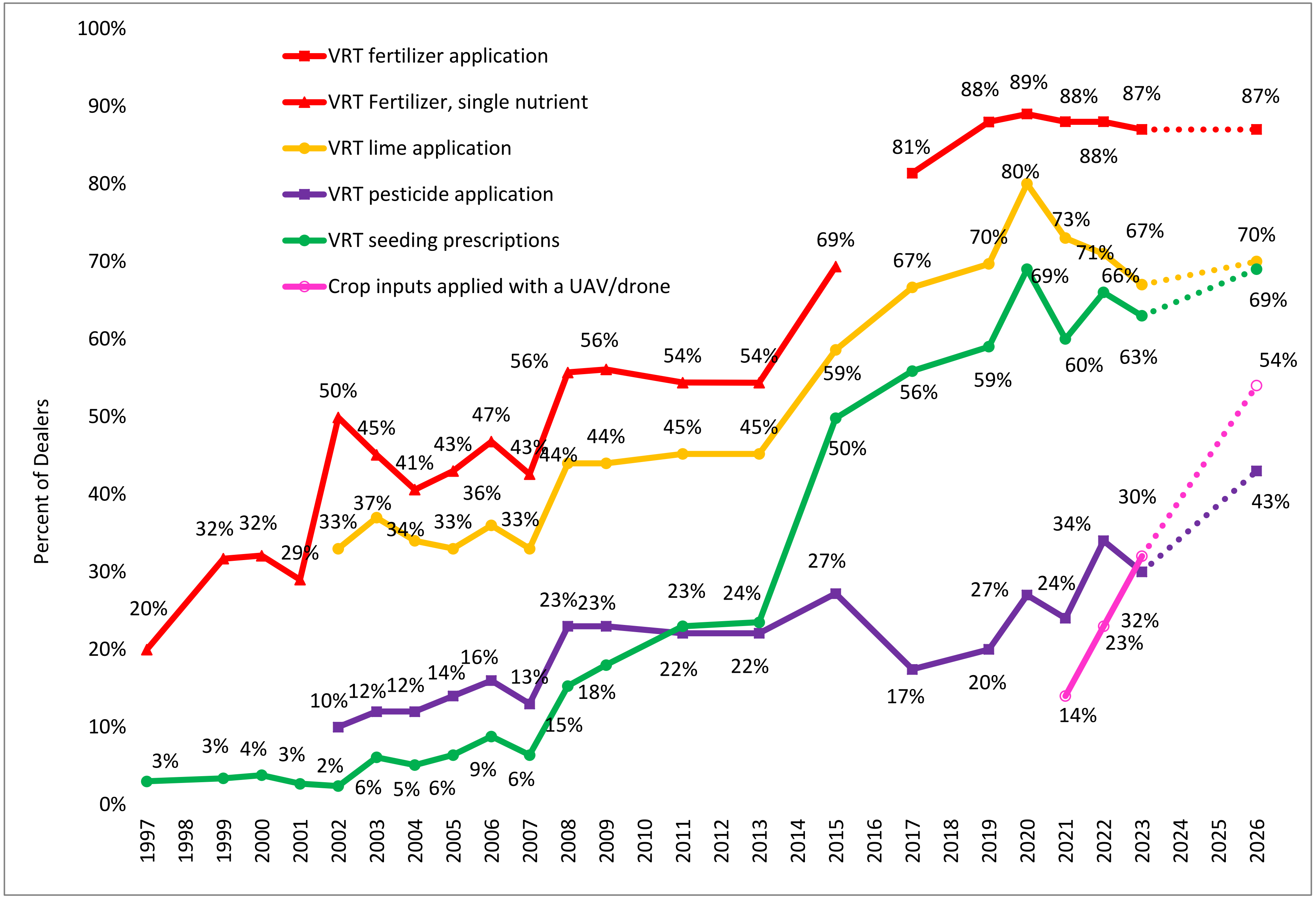
Dealer Adoption of Variable Rate Technology (VRT), % of respondents

- VRT fertilizer was introduced in the USA in the early 1990s.
- Fertilizer dealers moved quickly to provide VRT fertilizer services.
- VRT pesticide services have languished, mostly because annual weeds, insects and plant diseases are difficult and costly to map.
- VRT seeding is done by some farmers, but dealers sometimes help with prescription maps.



Source: Erickson and Lowenberg-DeBoer, 2023 – https://www.croplife.com/management/precision-survey-ag-dealers-respond-to-marketplace-shifts/

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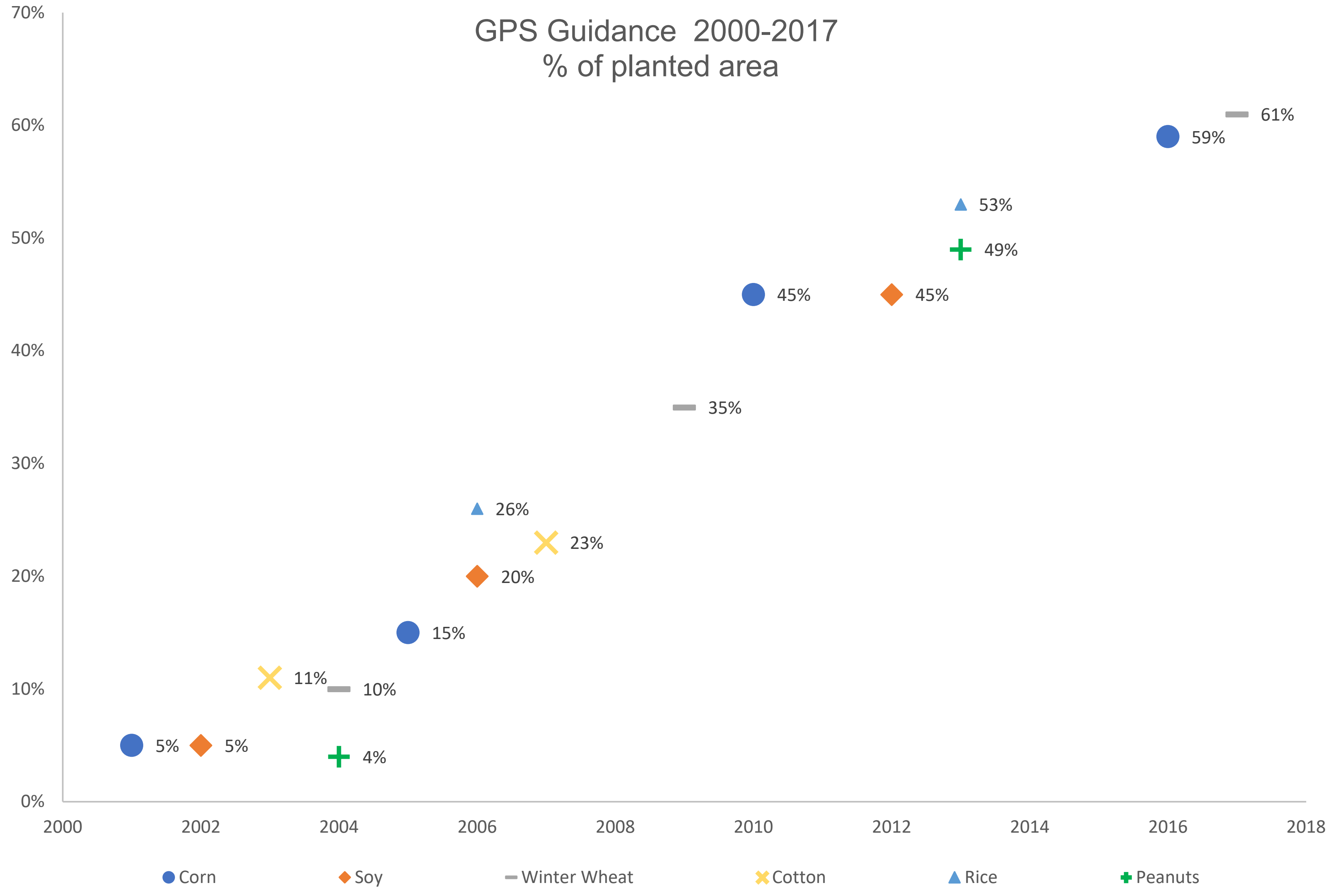
Farmer Adoption of Global Navigation Satellite Systems (GNSS) Guidance in the USA

- USDA ARMS data has an irregular survey cycle with different crops each year.
- Easy to imagine that the cloud of data points forms a classic “S” shaped adoption curve for GNSS guidance
- Other data suggests that sprayer boom control, seeder row shut offs and other GNSS guidance related technology has been adopted rapidly by farmers as well as dealers.



Source: Based on data from USDA ARMS - https://data.ers.usda.gov/reports.aspx?ID=17883

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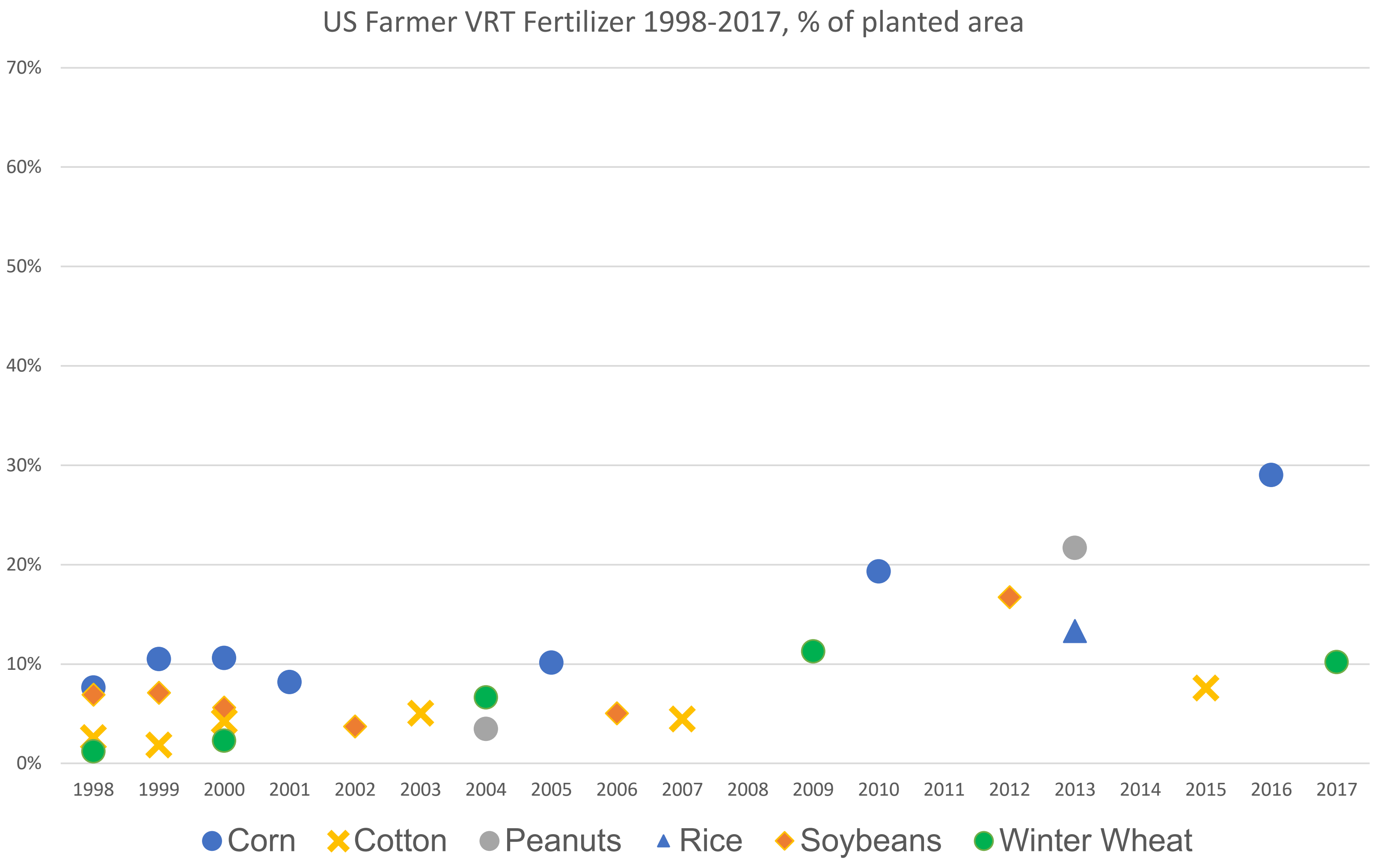
US Farmer Adoption of Variable Rate Technology (VRT)

- Farmer use of VRT fertilizer on cereals and oilseeds rarely exceeds 30%
- In spite of widespread availability of VRT services, intense publicity, and subsidies in some counties and states, VRT use by US farmers shows only a slight upward trend.
- The >20% adoption of VRT in the 2010-12 period was during a period of high grain prices.



Source: Based on data from USDA ARMS - https://data.ers.usda.gov/reports.aspx?ID=17883 and Schimmelpfennig and Lowenberg-DeBoer, 2020.

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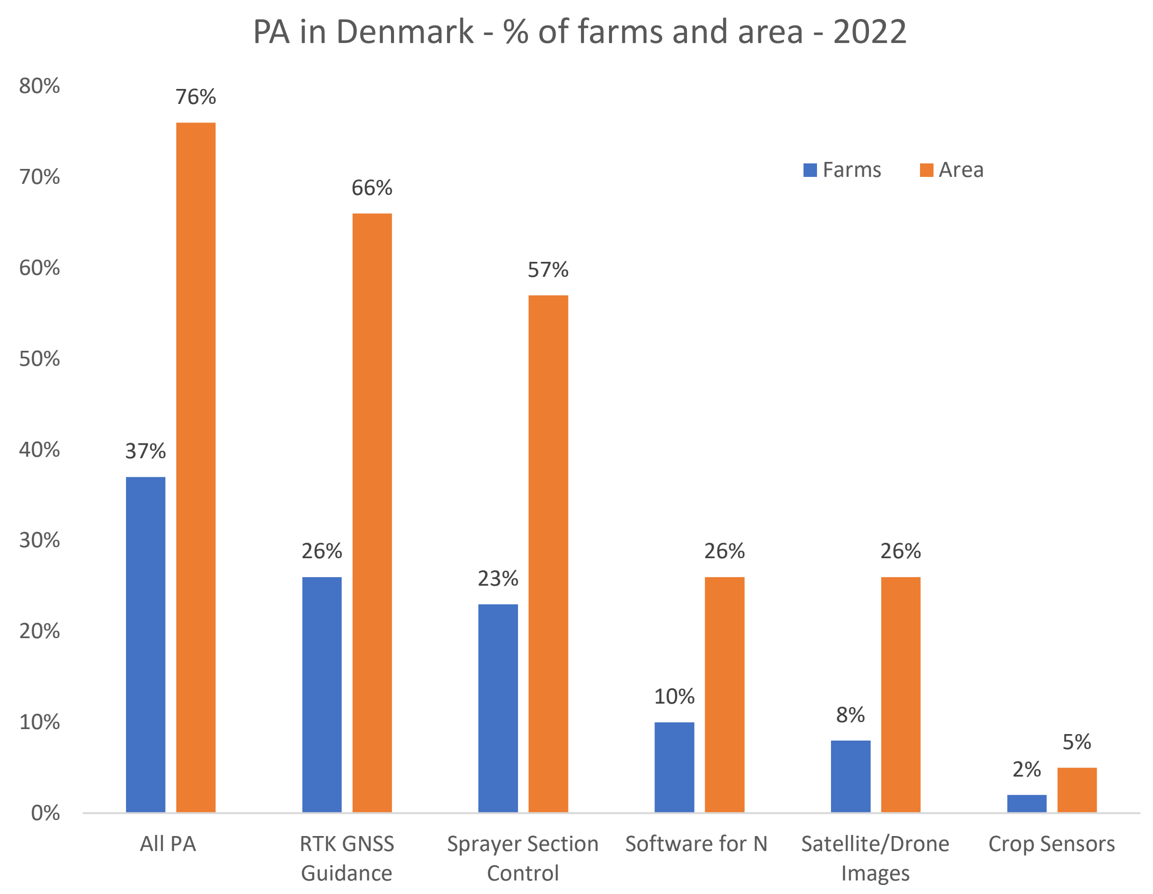
Precision Agriculture in Denmark

- Denmark Statistics did a PA survey of all Danish farms with crop area in 2017, 2018, 2019, 2020, 2021 & 2022.
- Familiar adoption patterns:
  - Guidance most common PA technology.
  - More PA on larger farms
  - VRT fertilizer adoption modest - In 2017, VRT used by 7% of farms. VRT not reported in recent surveys.



Source: Denmark Statistics, 2022

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Robots are starting to appear in crop fields, but data scarce

- Weeding robots are being trialled all over Europe led by France, where roughly 150 robots are being used for mechanical weeding of vegetable and sugar beet crops in 2020.
- The worldwide agricultural robots market was estimated at US$13.5 billion in 2023.
- An estimated 250 companies worldwide are developing crop robots.
- The 2022 FutureFarming crop robot catalogue (https://www.futurefarming.com/dossier/field-robots/) has 52 robots being marketed by 46 medium and small manufacturers, plus two companies with tractors that can be operated autonomously and 6 companies with retrofit kits to convert conventional tractors for autonomous use.
- In North America John Deere and CNH Raven are commercializing autonomous crop equipment.

Robotti, weeding robot, weeding French beans on Sandfield Farm, Stratford on Avon, UK, 25 June 2021

Source: James Lowenberg-DeBoer

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Precision Agriculture Adoption in Africa

- In Africa no statistically representative data comparable to the CropLife, USDA or Denmark Statistics surveys.
- Classic PA (i.e. yield monitors, VRT) were used in African mechanized farming in the 1990s.
- Plantation tree crop PA was part of early PA efforts with some adoption on large plantations.
- In the last decade, there have been many projects and startups aimed at providing better data for smallholder farmers.
- Drone projects and startups may help African farmers implement decisions made with better data.

For example, Zenvus, a Nigerian startup, has several clever videos on YouTube describing use of their soil sensors to improve crop management (e.g. https://www.youtube.com/watch?v=fNWlv0C1-Fg)

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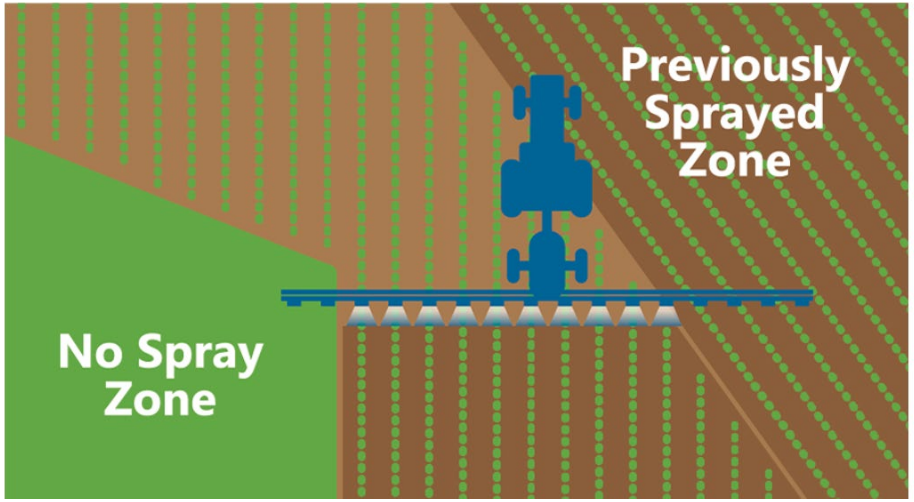
GNSS Guidance Success Story

- GNSS guidance being widely adopted on mechanized farms almost everywhere.
- Sprayer boom control, seed row shut offs and other technology linked to GPS guidance being widely adopted.
- Investment in GPS guidance and related technologies cashflowed by reduction in overlap and more efficient field operations. Other benefits (e.g. reduced fatigue, flexibility in hiring) are unquantified side effects.



GPS sprayer boom control reduces pesticide skip and overlap.

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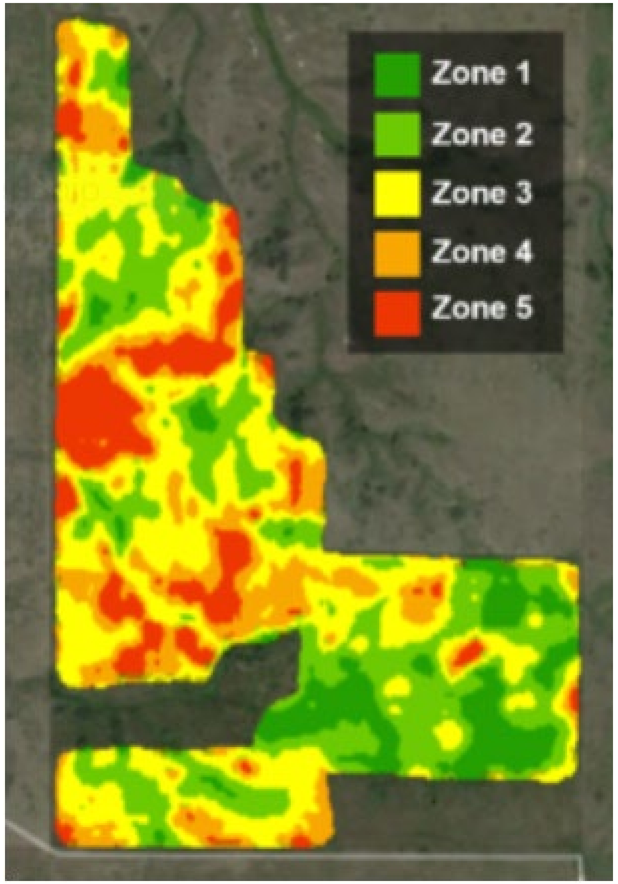
Variable Rate Technology Adoption has Lagged

- Variable Rate Technology (VRT) being adopted in niches where it is highly profitable, but VRT adoption for all broad acre crops only rarely exceeds 20% of area or farms.
- Constraints to VRT adoption include:
  - High cost of site specific information (e.g. grid or zone soil sampling)
  - Cost of developing individualized prescription maps
  - Lack of demonstrated value – impact on yields and profits often hard to see
  - Cost of being wrong (and over applying) is often small because environmental impacts not measured



https://www.agvise.com/zone-soil-sampling-and-variable-rate-fertilization-optimizing-profits/

“Why the low adoption of robotics in the farms?”

- That premature question is from the title of Gil et al. (*Smart Agricultural Technology*, 2023).
- A better question would be why companies have been slow to commercialize ag robots?
- Some hypotheses include:
  - Engineering challenges – still exist for horticulture and for swarm robot coordination.
  - Regulatory issues – e.g. in field human supervision rules
  - Business model – swarm robotics do not fit the large scale agribusiness model

Smart Ag started selling autonomous chasers bins in 2019. Several companies now offer this co-robotic technology.

https://www.oemoffhighway.com/trends/gps-automation/news/21020794/smart-ag-unveils-autocart-driverless-tractor-technology-at-2018-farm-progress-show

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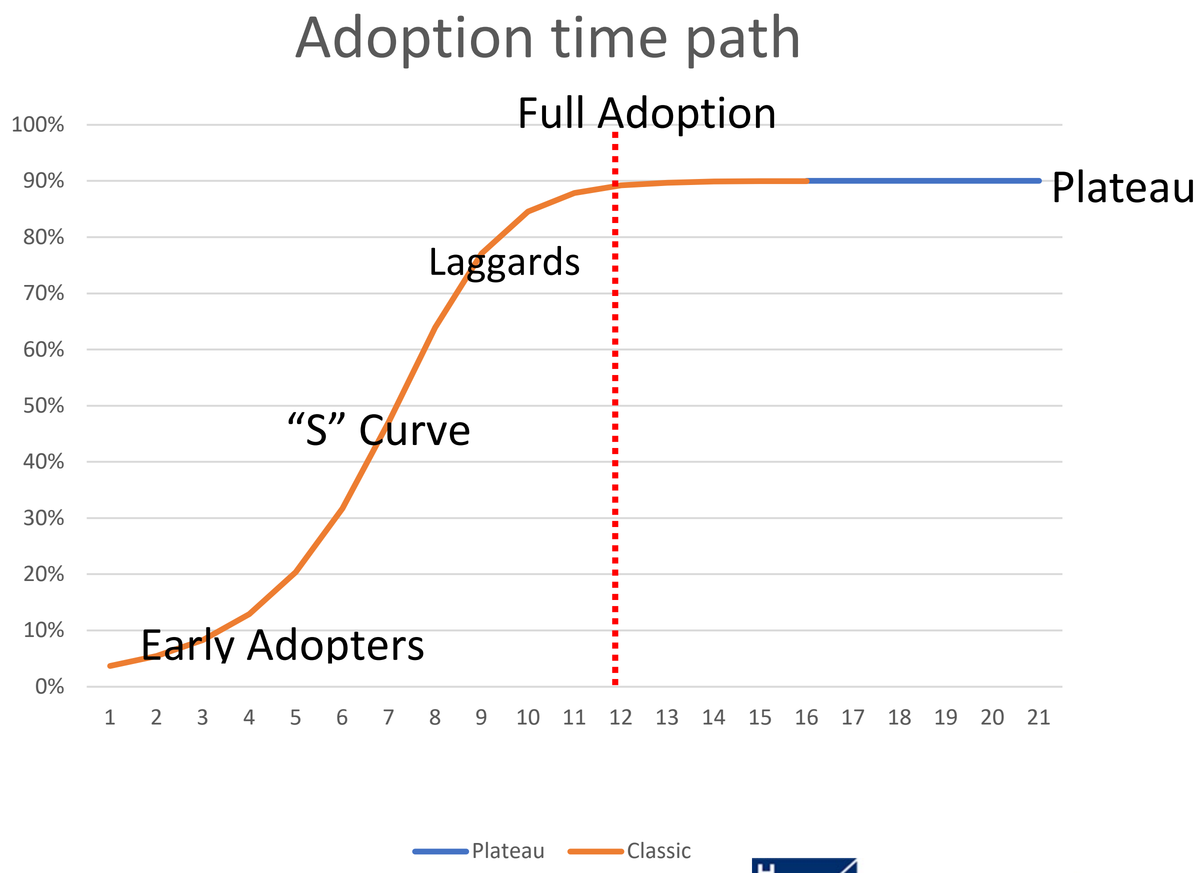
Adoption Time Path Theory

- The classis adoption time path is usually shown as an “S” curve.
- The “Plateau” is the long run adoption
- “Full adoption” is the leftmost point at which the plateau is reached.
- “Early adopters” are those who adopt before the technology is proven.
- “Laggards” wait until almost everyone else has adopted



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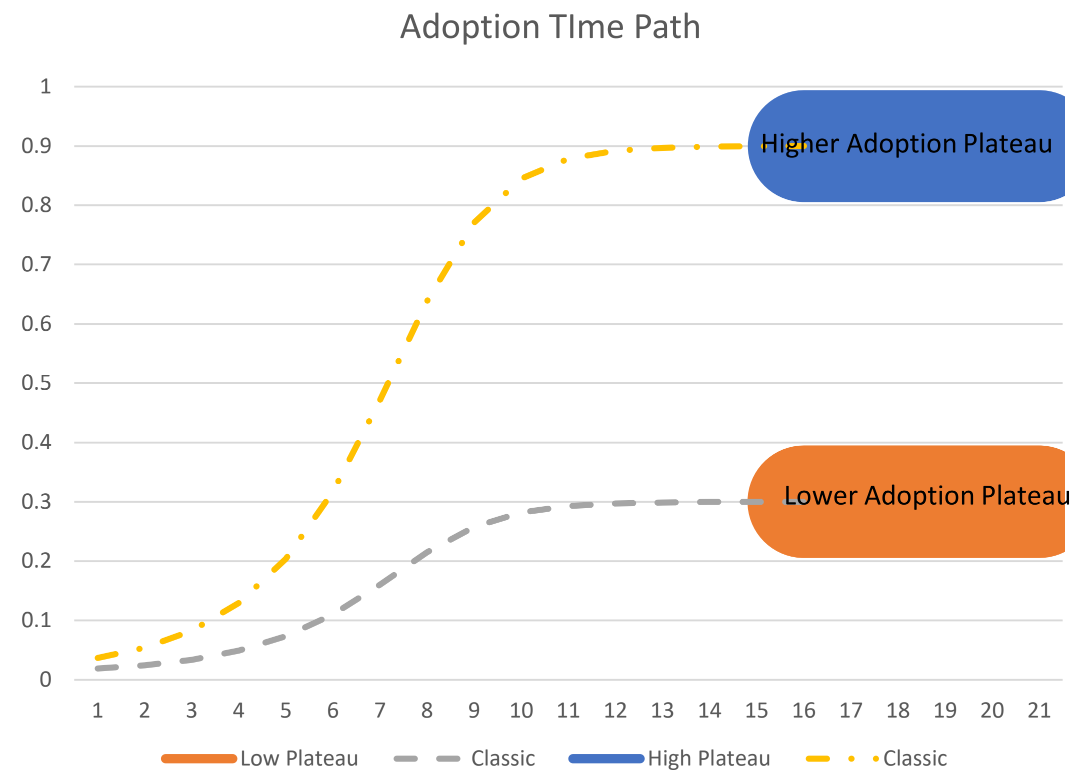
Challenges in Estimating Adoption Time Paths

- It is often possible to estimate the long run adoption plateau range based on:
  - Farm level benefits of the innovation, often profits, but may be in labour saved or other factors.
  - Physical constraints – soil type, access to infrastructure, etc.
  - Social constraints – religious and cultural rules



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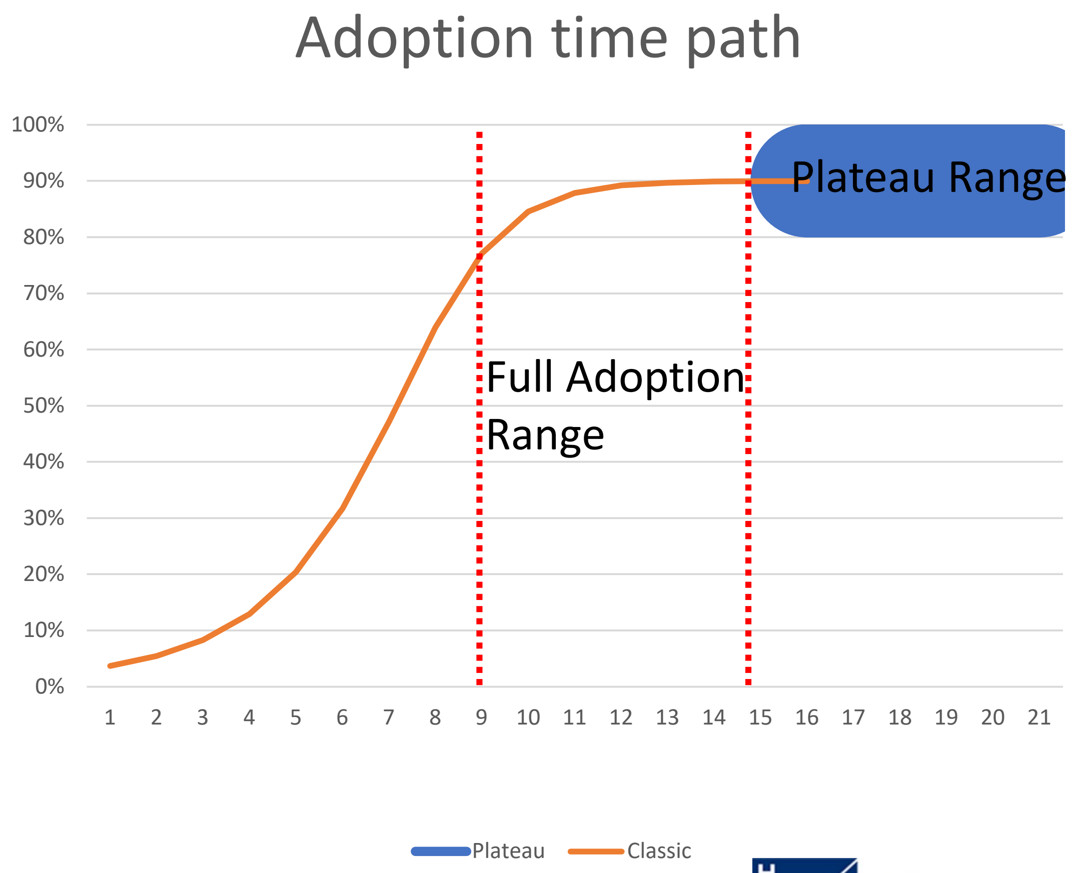
Sometimes there are clues to full adoption time

- Ease of use
- Easily measurable benefits
- Similarity to previous innovations
- High profitability
- Lack of alternatives



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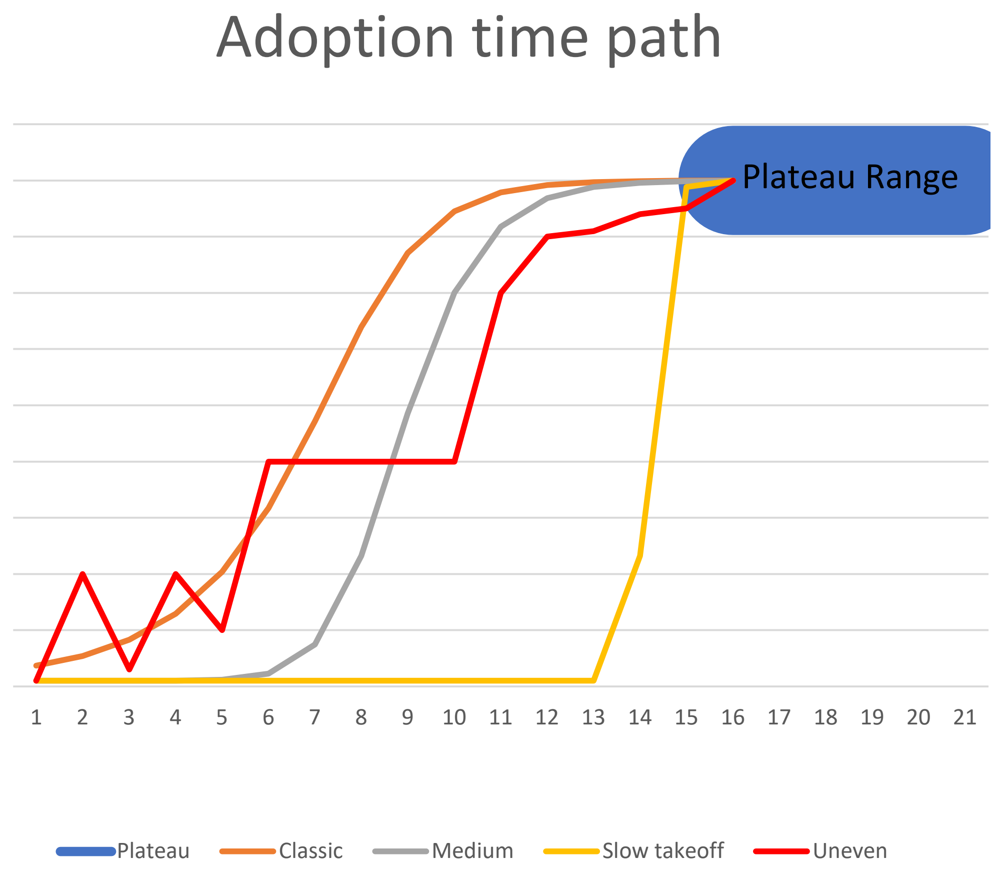
Many different time paths can be consistent with the same long run adoption level

- Pattern of adoption is influenced by many factors, including:
  - Ease of use
  - Education of farmers
  - Gender
  - Access to capital
  - Social acceptance
  - Farm size
- The ADOPT software can help you estimate the long run adoption plateau and time to full adoption (https://www.csiro.au/en/research/technology-space/it/adopt).



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Sometimes a partial budget is all it takes – GNSS guidance example:

- In 1998 with encouragement from Trimble and other companies, we did the first economic analysis of GNSS guidance.
- This analysis showed substantial gains from reducing skip and overlap in input application.
- Given ease of use, relatively low cost of trialling, and easily visible results we predicted quick and widespread adoption for GNSS guidance.

Table 1. Cost and Benefit Examples for GPS Guidance and Foam Markers for Use by Producers.

Item	Foam Marker	GPS Guidance	Lightbar Only
Costs:			
Purchase Price, $	$1000	$7000	$3000
Useful Life, years	5	3	3
Annualized Cost, $.yr	$264	$2815	$1206
Recurring Cost:			
Foam, $/yr	$336	0	0
Differential			
Correction, $/yr	0	$800	0
Annual Cost, $/yr	$600	$3615	$1206
Annual Cost, $/a/yr	$0.20	$1.20	$0.40
Benefits in Reducing Overlap:			
Percent of Area Overlapped	10%	5%	5%
Overlap Acres	300	150	150
Opportunity Cost Sprayer Operation			
$/a	$4.40	$4.40	$4.40
$/yr	$1320	$660	$660
Extra Chemical and Fertilizer, $.yr	$3000	$1500	$1500
Overlap Cost, $/yr	$4320	$2160	$2160
Overlap Cost, $/a/yr	$1.44	$0.72	$0.72
GPS Net Benefit		-$0.29	$0.52

Source: Lowenberg-DeBoer (Purdue Agricultural Economics Report, 1999)

The earliest VRT fertilizer trials generated adoption concerns

- From the beginning on-farm VRT fertilizer trials showed mixed results profitable some years and not others.
- The early trials also showed implementation challenges in soil testing, creating recommendation maps, and spreading accuracy.
- Based on mixed profitability and implementation issues adoption challenges were predicted in the mid1990s.

Table 2. Crop and net return by farm and year for on-farm trials of variable rate P and K

Year and farm no.	Crop	Net returns by treatment: Whole field	Grid	Soil type
		$/acre		
1993				
2	Corn	311.61	281.36	244.13
4	Corn	141.21	128.65	157.20
5	Corn	153.78	93.14	187.72
1994				
1	Wheat	110.19	136.20	120.39
2	Soybeans	164.73	140.78	139.96
3	Soybeans	216.52	202.57	149.83
3	Wheat	100.76	95.37	87.66
4	Soybeans	211.98	114.68	205.89
6	Corn	141.45	186.98	196.76
1995				
1	Corn	193.70	206.98	177.72
2	Corn	64.91	122.24	130.04
6	Soybeans	96.91	116.60	142.48

Some of the first variable rate fertilizer trials using GPS and yield monitors were done in Dekalb County, Indiana (Source: Lowenberg-DeBoer and Aghib, 1999)

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Table 3. Profitability conclusions from nine university field research SSF studies that compared whole-field average with VR fertilizer application rate determined on or prior to date of application (minimum grid cell areas of 0.5 acres).

Study	Crop	Inputs managed	Grid cell area (acres)	Proportion of site-years where SSM more profitable than whole-field management	Treatment of annual sampling & VR costs (plus adjustments made to original data)
Anonymous, 1996	Sugarbeet	N	2.75	100% (2 of 2)	S & V† cost of $22/acre included
Carr et al., 1991	Wheat, barley	N, P, K	Soil map unit (3.0 ac. assumed)	20% (1 of 5)	S & V cost of $4/acre added
Fiez et al., 1994	Wheat	N	Plot trials (3.0 ac. assumed)	0% (0 of 4)	S & V cost of $4/acre added‡
Lowenberg-deBoer and Aghib, 1997, unpublished data	Corn	P, K	3.0	42% (5 of 12) for grids 50% (6 of 12) for soil type	S & V & data mgt. cost of $9.85/acre included
Schnitkey et al., 1996	Corn, soybean	P, K	2.5	83% (15 of 18)	S & V cost of $4/acre included
Snyder et al., 1996	Corn (irrig.)	N	0.75	50% (2 of 4)	S & V & data mgt. cost of $17.31/aere included
Wibawa et al., 1993	Wheat, barley	N, P	Soil map unit (assumed 3.0 ac)	0% (0 of 2)	VR cost of $3/acre substitutes for $1/acre§
Wollenhaupt and Buchholz, 1993	Corn (Missouri data only)	P, K	2.5	50% (1 of 2)	S & V cost of $3.30/acre included
Wollenhaupt and Wolkowski, 1994, unpublished data	Corn	P, K	2.1	100% (5 of 5): Grid pt.0% (0 of 2): Cell avg.¶	VR cost of $3/aere subs. for $1.44/acre

† Sampling and VR application costs

‡ Comparing cases 1 and 2. We assume that nitrate N is known, but not site-specific unit N requirements.

§ Only 1989 and 1990 years included a whole-field average treatment. Soil map unit treatment in 1990 assumed equivalent to 3-acre sampling unit.

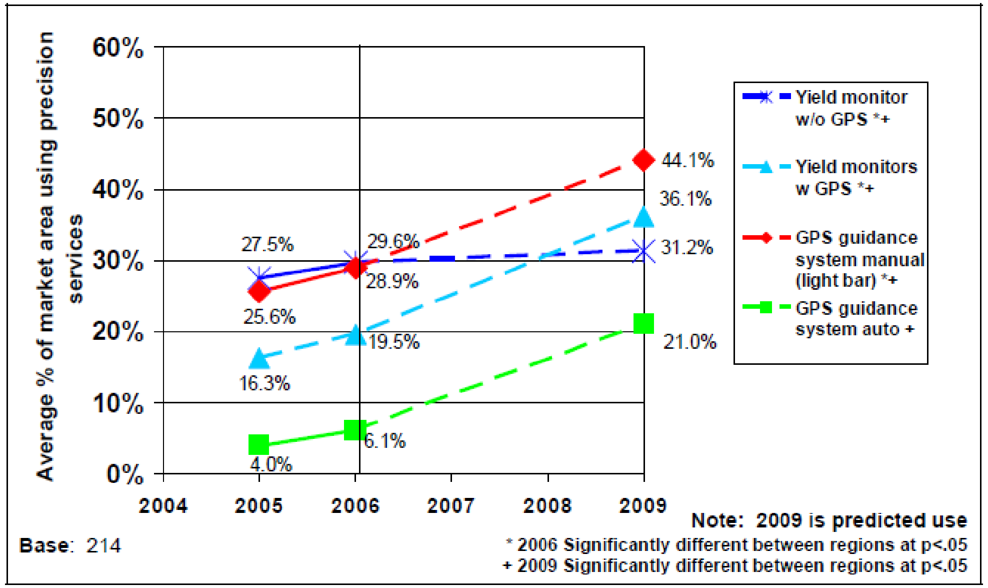
¶ Grid point bases nutrient map on interpolations between points; cell average bases map on average of boundary points.

Source: Swinton and Lowenberg-DeBoer, Jr. of Prod. Ag. 1998

Predicting Short Term Adoption is Difficult

- Good understanding of factors influencing long term technology adoption.
- Adoption time pattern is harder to anticipate because there are too many variables
- Short term adoption matters most to ag manufacturers and retailers, and they struggle.
- Short term adoption can be an urgent issue for food security and climate change policy.

Figure 62. Estimated Market Area Using Yield Monitors and Guidance Systems in the Midwest



Source: Whipker and Akridge, Dept. of Ag Economics Staff Paper #06-10, Purdue University, 2006.

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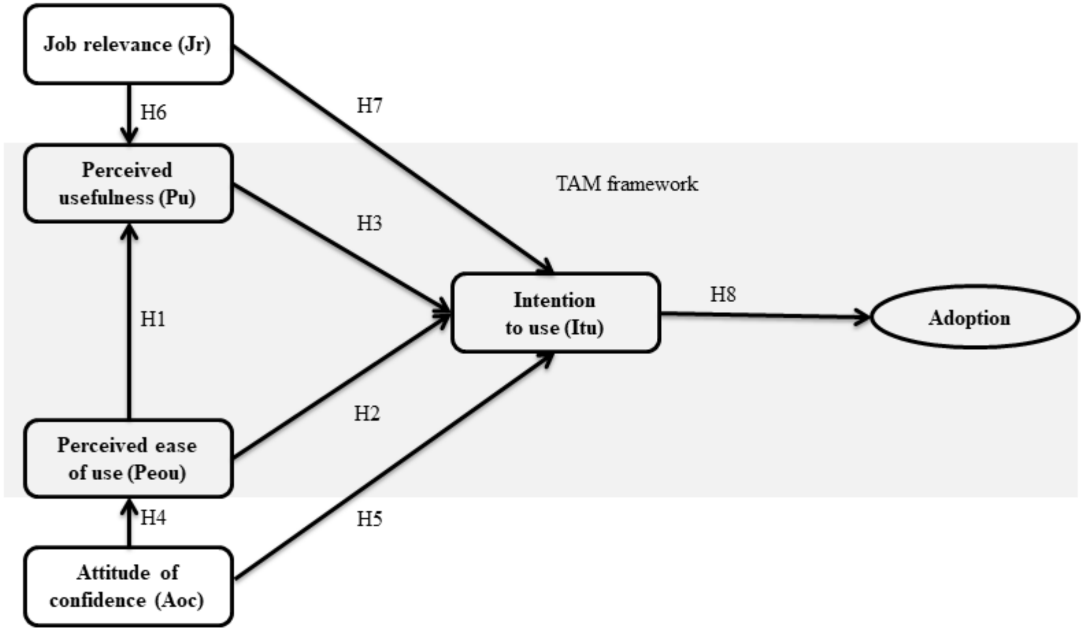
“Intention to Adopt” Studies Looking For Advance Notice

- Intention to adopt is several steps removed from long term adoption.
- No good studies that show intention to adopt is highly correlated with actual adoption.
- Usually find the same important factors as adoption studies.



Michels et al. (Precision Agriculture, 2021)

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Common Flaws in PA Intention to Adopt Studies

- Many PA intention to adoption studies use non-representative data from volunteer internet surveys, interviews at farm shows, and other non-random sources. Consequently, they do not produce generalizable results.
- Use complex econometric models with latent variables and several estimation steps that make it difficult to follow the analysis.

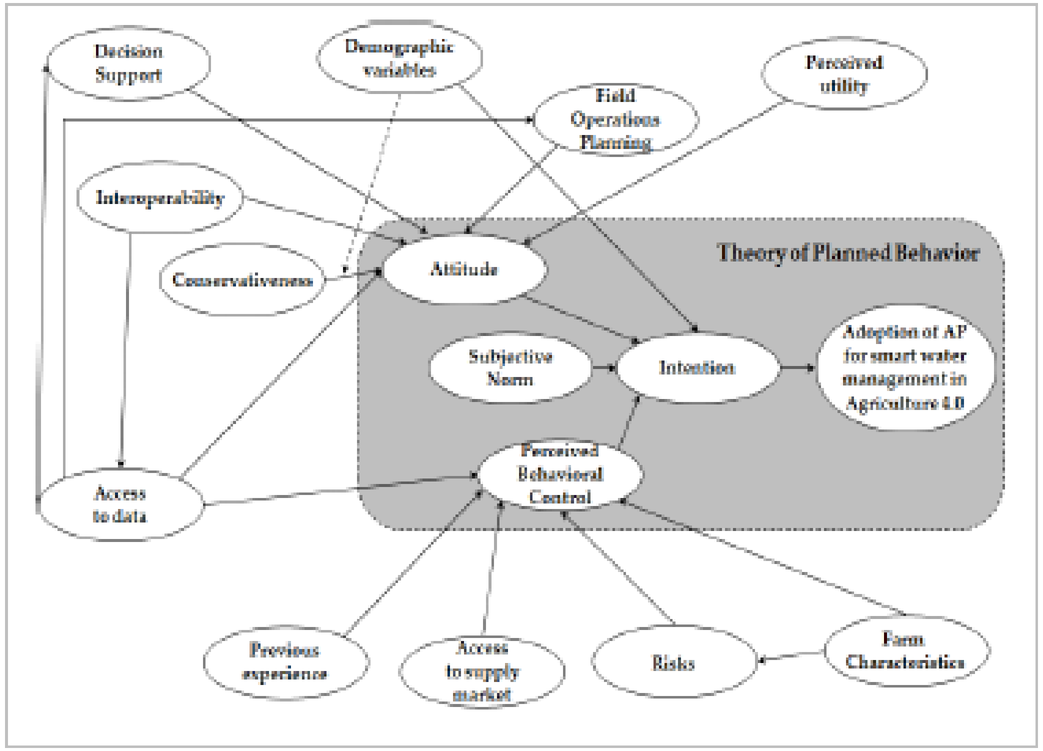

Fig. 2. The conceptual model.

Monteleone et al. (IEEE, 2019)

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Adoption potential of PA technology in the pipeline?

UAV input application:

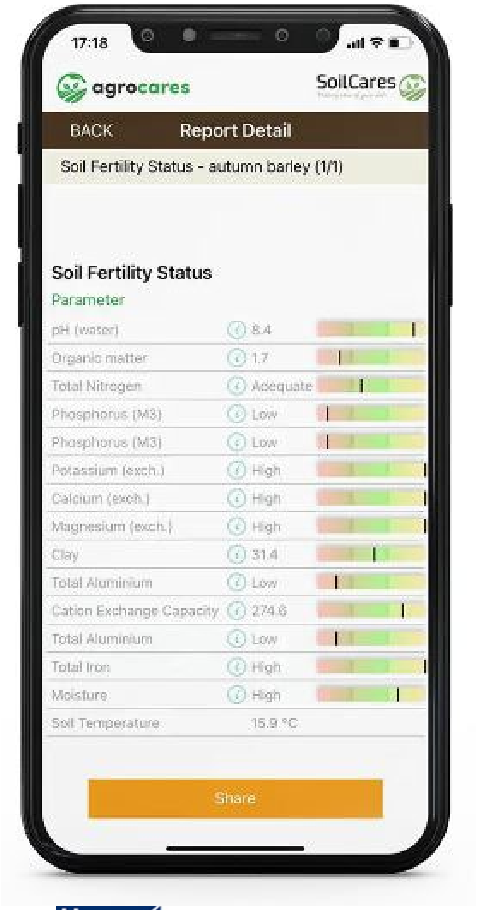
- Many UAV agricultural input start ups in Africa. Often donor or venture capital funded.
- UAVs have potential for cost-effective site-specific spray, seeding and input applications on small, irregularly shaped fields.
- Challenges include:
    - Initial investment cost
    - Logistics and scheduling
    - Regulation
    - Spray drift

Photo source: https://dronenews.africa/new-solution-for-crop-spraying-drones/

Soil management apps?

- Technology has been on the market for several years (e.g. Soilcares, Zenvus), but not taking off.
- Not just an app, but requires some physical soil testing. For example:
  - Zenvus sensors
  - Soilcares scanner
- Challenges:
  - Initial investment
  - Business model
  - Trained technicians

https://www.agrocares.com/soilcares/



Pest management apps?

- Some donor funded apps available for free download.
- Challenges:
  - Business model for making the app sustainable
  - Coverage – Apps seem to cover only some species and in specific areas.
  - Education – Not all farmers literate.

+254-Kenya

+256-Uganda

+255-Tanzania

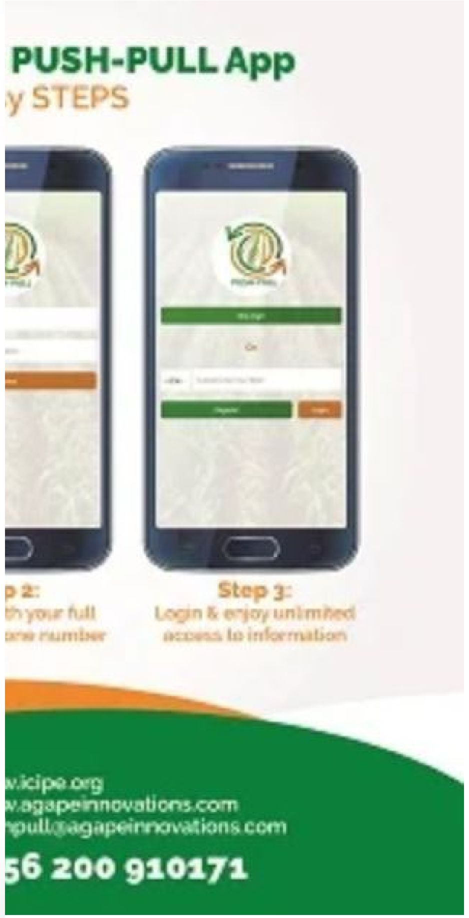
+250-Rwanda

+250-Burundi

+211-South Sudan

+7-840-Abkhazia

+93-Afghanistan



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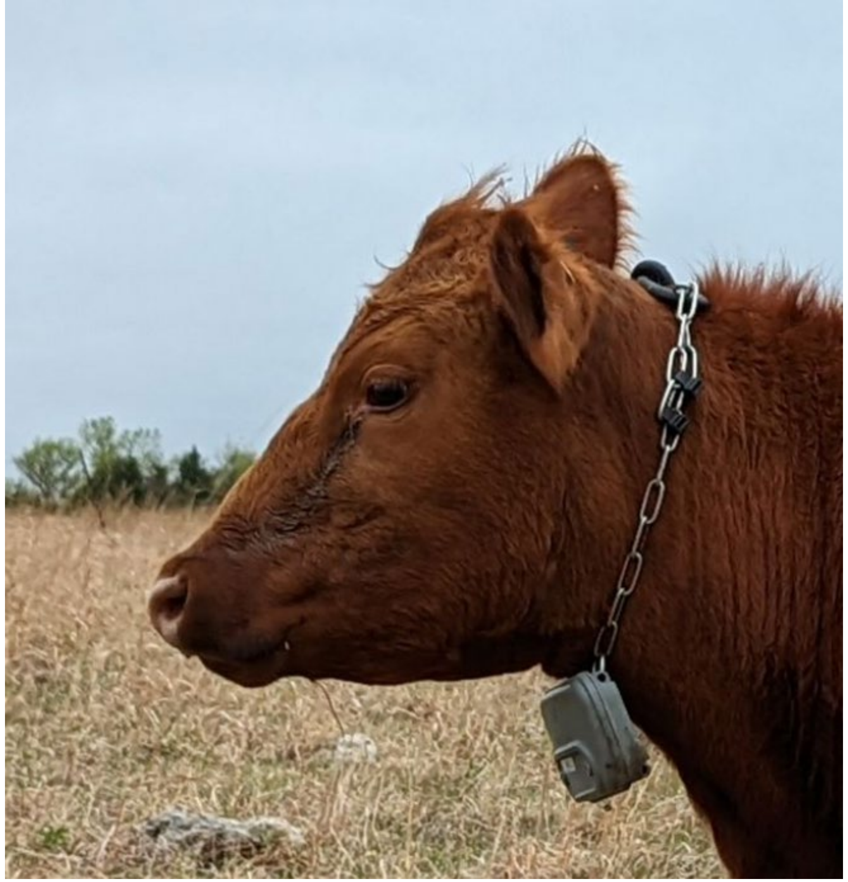
Is virtual fencing a solution for extensive grazing?

- GPS collars for livestock marketed in Europe, USA, Canada, NZ, Australia.
- Some farmers use virtual fencing for rotational, especially in conservancy areas where building physical fences is discouraged.
- Research application in Africa
- Challenges for application in Africa:
  - Cost of the collars
  - Internet signal in remote areas
  - Education for herders



https://www.nature.org/en-us/what-we-do/our-priorities/provide-food-and-water-sustainably/food-and-water-stories/virtual-fencing-research-conservation-tool/

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Could basic crop robots be built for cost of a motorbike?

- If basic crop robots with the capacity to plant, weed and harvest crops could be sold for the cost of a motorbike, they could be used by smallholder farmers.
- When human drivers are removed the economic drive to use large machines almost vanishes.
- Farming with many small autonomous machines radically changes the economies of size in agriculture.
- Challenges:
  - Initial investment
  - Internet signal in fields
  - Business model for sustainable use
  - Learning how to optimize robot use by smallholders

Many researchers envision swarms of small robots, instead of large machines – Pedersen, Fountas and Blackmore, 2008

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Take home messages:

- Achieving widespread adoption of agri-tech innovations in Africa requires adapting technology to the economic, social and environmental conditions including:
  - ❑ Effective business models for manufacturing, distribution and use of that technology.
  - ❑ Conducive regulatory framework
  - ❑ Time
- Approximating long run adoption levels can be based
  - Farm level benefits (e.g. profits, labour flexibility)
  - Physical and social constraint
- Predicting short run adoption patterns is very difficult and not needed for most strategic planning and public policy.

By Fiona Graham, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=77829776

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Africa led the world in adoption of mobile money transfer.

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