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AGTECH ADVISORY
COLLECTIVE

The Precision Revolution:

Foundations of Precision Spraying in Agriculture

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About Upstream Ag Insights

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Upstream Ag Insights is a weekly publication dedicated to providing timely and insightful news, alongside in-depth analysis, at the crossroads of innovation and business within the agriculture sector.

Our mission is to equip you with strategic frameworks and comprehensive perspectives on emerging trends and transformative developments in agriculture, empowering you to make informed and effective decisions for your business.

The newsletter was founded in January of 2020 and is read by 20,000 individuals from over 120 countries including executives, venture capitalists, leading agtech entrepreneurs and the most ambitious agribusiness professionals that aspire to grow their career and have maximum impact on the industry.

The following report was done as a co-development between Upstream Ag Insights and the AgTech Advisory Collective.

About AgTech Advisory Collective

The AgTech Advisory Collective unites a global network of independent experts in agricultural technology to drive impactful change in modern farming. With extensive industry knowledge and an international presence, we support agtech companies globally from launch to scale, providing local knowledge, strategic insights, technical guidance, and connections in key markets. Our mission is to build lasting partnerships that empower innovation, increase efficiency, and foster a sustainable agrifood system—benefiting farmers, consumers, and the planet.

About the Report

Precision Spraying technology is transforming the agricultural landscape, offering innovative solutions to challenges like herbicide resistance, rising input costs, and the environmental impact of traditional spraying methods. This report serves as a foundational guide to the various types of precision spraying technologies available, from Green-on-Brown (GoB) systems that target weeds on fallow land to advanced Green-on-Green (GoG) solutions capable of differentiating weeds from crops in growing fields. By exploring these technologies, we aim to provide agribusiness professionals and growers with a comprehensive understanding of how precision spraying works, the companies leading innovation in this space, and the potential impact on modern farming practices.

In addition to highlighting the opportunities these technologies present—such as significant cost savings, improved weed management, and enhanced sustainability—this report looks at the challenges that must be overcome for broader adoption. By laying this foundation, the report equips readers with the knowledge needed to assess precision spraying's role in the industry and to prepare for its evolving impact on the future of agriculture.

1. Introduction

Precision Spraying, also known as See & Spray or Targeted Spraying, is a suite of technologies in agriculture with the potential to reshape weed management practices. As agribusiness professionals and growers face rising challenges—such as weed resistance, input costs, and environmental impact—targeted spraying technologies offer a compelling solution to improve outcomes across the board.

At its core, the concept of Precision Spraying seems straightforward: the technology "sees" a weed and directs the sprayer to apply herbicide only to the targeted plant, without spraying the surrounding crops and soil. But this simplicity in concept belies the technology's complexity in practice. The effectiveness of Precision Spraying varies widely depending on crop types, regional growing conditions, weed pressure, and the specific solutions used.
Precision Spraying provides significant opportunities for the agriculture sector by optimizing the application of herbicides, contributing to:

- **Improved Agronomic Practices:** By reducing the volume of chemicals applied, Precision Spraying aligns with best practices in sustainable agriculture, allowing farmers to manage weeds without over-relying on broadcast applications, and even potentially decreasing weed seed banks and total control levels.
- **Healthier Crops and Enhanced Yields:** Limiting herbicide exposure to crops reduces the risk of chemical stress, improving plant health and potentially higher yields.
- **Reduced Weed Resistance:** Targeted spraying helps manage herbicide resistance by allowing tailored applications that limit the development of resistant weed strains.
- **Cost Savings:** Precision Spraying minimizes chemical use, leading to cost reductions in herbicide purchasing and application.

Given the dynamic nature of agriculture, it's crucial to view Precision Spraying technology not just as a new tool but as a holistic shift in weed and agronomy management . While promising, the technology's adoption requires careful consideration of various factors, including weed species, climatic conditions, and equipment capabilities.

This report aims to offer agribusiness professionals a comprehensive view of Precision Spraying's benefits, limitations, and best-use scenarios to facilitate informed decision-making.

History of Precision Spraying

Precision Spraying, though often viewed as a modern technology, traces its origins back to the 1990s.

Early adopters in agricultural technology sought solutions to minimize herbicide use while effectively managing weed growth, especially in regions with extended fallow periods and minimal tillage practices. The initial Precision Spraying applications relied on limited technology like NDVI (Normalized Difference Vegetation Index) and NIR (Near-Infrared) sensors. These sensors could only differentiate green, living vegetation from bare soil, making them suitable for GoB applications, where weeds are targeted on fallow land.

The first major commercialized GoB Precision Spraying systems were pioneered by companies like Rometron, with its WeedIt system, and Ntech, known for WeedSeeker (later acquired by Trimble in 2009). These innovations marked the first generation of Precision Spraying technology and laid the groundwork for the advancements to follow.

Early Commercialization: GoB Adoption in Australia

The initial wave of GoB technology uptake occurred primarily in regions with unique agronomic needs, specifically Australia. With long periods of fallow land and high no-till adoption due to low precipitation, Australian farmers prioritized moisture conservation for their main crops. In these conditions, cover cropping was minimal, and land often remained fallow for up to five to six months, creating a need for efficient weed management to prevent moisture and nutrient loss. This environment fostered early adoption of GoB Precision Spraying, where herbicide applications could reach up to five passes during a single fallow period. The WeedIt and WeedSeeker systems quickly became valuable tools in Australia's agronomic toolkit, where they demonstrated significant herbicide savings and efficiency.

Advances with Computer Vision: Entering the GoG Era

The 2010s brought a new wave of innovation to Precision Spraying, as computer vision and advanced processing capabilities became increasingly accessible. Vision-based technologies could now differentiate crops from weeds within the same field—enabling GoG Precision Spraying, where herbicides are applied selectively within growing crops.

Blue River Technology was one of the pioneers in this field, initially focusing on lettuce thinning before being acquired by John Deere in 2017. John Deere leveraged the Blue River acquisition to further develop its See & Spray system, an advanced solution that identifies and sprays weeds within row crops. This acquisition marked a significant step

forward in precision agriculture, with computer vision providing new potential for herbicide reduction and enhanced weed control.

During this period, several startups entered the market (Carbon Bee, Greeneye, Bilberry), advancing both GoB and GoG solutions with camera-based systems. These new technologies, powered by high-resolution imaging and robust processing algorithms, significantly expanded the scope and accuracy of Precision Spraying, opening up applications beyond fallow fields and into active crop management.

Scaling Commercial Adoption: Strategic Partnerships and Market Momentum

By the 2020s, Precision Spraying technology saw increased momentum as Edge computing and AI became mainstream, driving down costs and enabling more refined applications. Not to mention the build out of models to accurately assess weeds.

Precision Spraying emerged as one of the most promising agtech solutions due to its potential for substantial chemical savings and agronomic outcomes. Recognizing this, major sprayer OEMs began actively positioning themselves in the market through strategic partnerships and acquisitions:

- **Trimble** acquired Bilberry, adding to its portfolio of advanced weed detection technology.
- **BOSCH** and **BASF** formed a cooperative venture, combining Bosch's technology expertise with BASF's agricultural science.
- **AGCO** invested in Greeneye, a company focused on both GoB and GoG solutions.
- **CNH** acquired Augmenta, expanding its precision agriculture offerings.
- Several smaller Sprayer OEMs started forming partnerships, for example Kverneland started working with DAT and Kuhn is cooperating with CarbonBee.

These moves reflect an industry-wide shift toward the integration of Precision Spraying capabilities into mainstream agricultural equipment. As we stand on the threshold of the commercial GoG era, the technology's role in achieving sustainable and efficient weed management is clearer than ever. Precision Spraying is no longer just an emerging tool but a strategic necessity for agriculture, with the potential to redefine weed control practices and chemical usage at a global scale.

2. Trends and Drivers of Precision Spraying Adoption

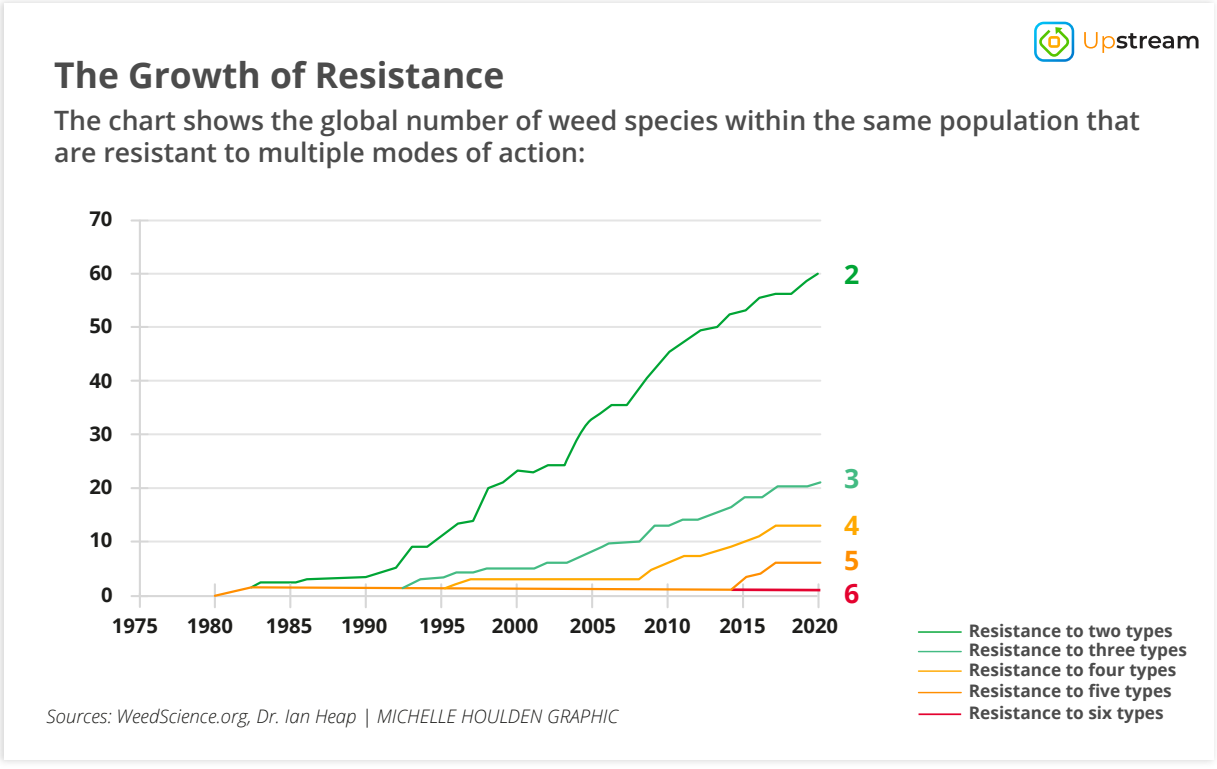
The acceleration of Precision Spraying technology in agriculture can be attributed to a confluence of trends and drivers across five key categories: agronomic, technological, societal, economic, and environmental. Each driver plays a distinct role in shaping the adoption of this technology, reflecting a larger shift in agronomic practices and perspectives toward precision and sustainability in crop management.

Agronomic Drivers

The agronomic landscape is evolving, with weed resistance and changing tillage practices exerting significant influence on weed management strategies.

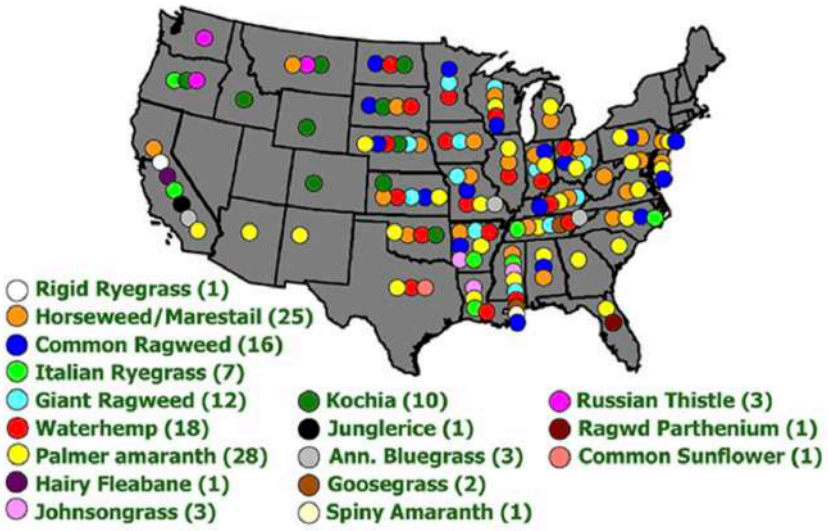
- **Herbicide Resistance:** Herbicide resistance is a major driver of Precision Spraying. As herbicide-resistant weed species proliferate globally, Precision Spraying enables targeted applications that slow resistance development, allowing more selective and judicious herbicide use.

The growth in resistance globally has been immense, particularly over the last 20 years.

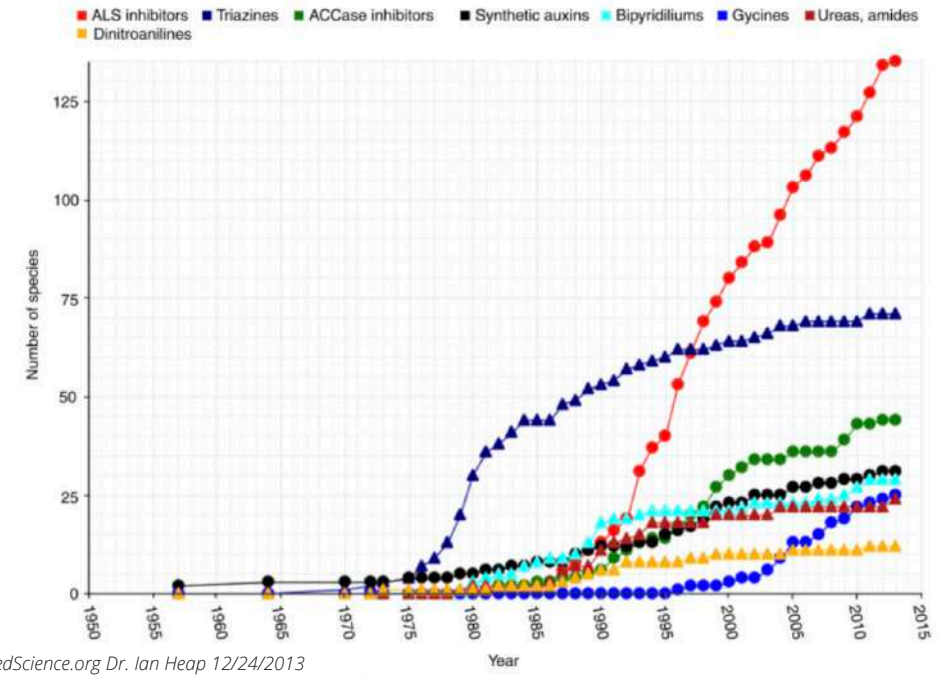


Glyphosate-resistent Weeds in the U.S.

2019: 17 species; 39 states



**Parentheses indicate the number of states in which that resistant weed occurs*
Dr. Kevin Bradley, University of Missouri



© 2013 WeedScience.org Dr. Ian Heap 12/24/2013

- **Impact of Blanket Spraying on Crop Health:** Traditional broadcast herbicide applications affect crop health by exposing all plants to chemicals, often forcing crops to expend energy on recovery. Precision Spraying limits this, targeting only weeds and enabling healthier, more resilient crop growth.

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Crop Injury

Cobra Herbicide Postemergence on Double-Crop Soybean

	Broadcast	See & Spray
Spray Savings	NA	80%
Soybean Injury Index		
7 DAT	36	8
14 DAT	29	7
21 DAT	15	3
28 DAT	7	1
Soybean Yield (bu/acre)	42	46

Trial Notes:
1 Cobra applied at 12.5 fl oz/acre + COC at 1%v/v
2 All soybean injury and yield data were statistically different ($p < 0.05$)
3. Trial ID: BRT-24-ISA-DC (Purdue Univ.)

Source: Purdue University, as shared during John Deere Agronomy Summit in December 2024

- **Innovation Plateau in Herbicides:** Innovation in herbicides has slowed, with fewer new active ingredients entering the market. This lack of novel herbicide options makes precise application essential, as growers can't rely on frequent rotations of new chemicals to tackle resistant weeds as readily. Additionally, the cost to bring molecules to market is increasingly costly.

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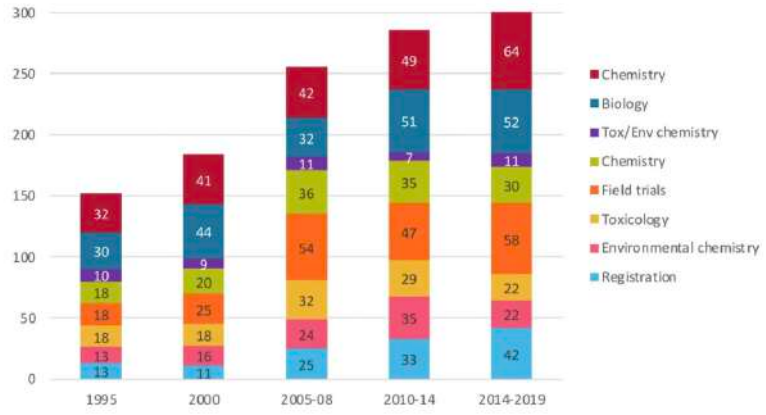
Crop Protection AI Discovery and Development Lead Time

	1995	2000	2005-08	2010-2014	2014-19
Number of years between the first synthesis and the first sale of product containing AI	8.3	9.1	9.8	11.3	12.3

Source: AgBioInvestor

Appendix 2

Discovery and Development Costs of a New Crop Protection Product



Source: AgBioInvestor

Technological Drivers

Technological advancements have paved the way for Precision Spraying, making high-precision weed targeting both affordable and feasible at scale.

- **Affordable Vision Technology:** Over the past decade, vision technology has become more accessible. High-resolution cameras and sensors, which are essential for accurate weed detection, are now both economically viable and reliable, dropping 20x, supporting the development of precision spraying systems.

- **Increased Processing Power and Edge Computing:** Enhanced processing capabilities and the advent of edge computing have been transformative, due to companies like NVIDIA allowing data to be processed in real time on equipment. This real-time data handling is critical for Precision Spraying, where immediate weed identification and response are required.

- **Artificial Intelligence (AI):** AI-powered algorithms enable systems to differentiate weeds from crops with high accuracy. AI also helps optimize spraying decisions, allowing the system to adapt dynamically to different field conditions, weed densities, and crop types.

Societal Drivers

Social concerns and regulatory pressures surrounding pesticide use have increased substantially, impacting the adoption of Precision Spraying as a means to address these issues.

- **Regulatory Pressure on Pesticide Use:** Many governments, including the European Union, are enforcing stricter guidelines on pesticide usage, including the reduction of active ingredients and maximum allowable dose rates. Precision Spraying aligns with these regulations by significantly lowering the total amount of herbicide applied per acre.

- **Increased Public Concern:** Society's growing concern of the risks associated with pesticide use has driven demand for sustainable alternatives. This concern is amplified by high-profile lawsuits over herbicides like Glyphosate, as well as community opposition in some areas to heavy pesticide use on adjacent farmland.

Economic Drivers

Economic factors play a critical role in the adoption of Precision Spraying technology, especially as input costs continue to rise.

- **Increased Spraying Costs:** The prices for herbicide products has increased along with the need for higher dose rates in fields with resistance, or worried about resistance. Precision Spraying offers a cost-effective alternative by targeting only the weeds, reducing the quantity of herbicide required. With more complex and specialized pesticides on the market, input costs have risen significantly. Targeted spraying allows farmers to minimize expenditures by reducing the volume of costly herbicides used.

- **Economic Incentives for Precision:** Precision Spraying's potential to save on herbicide costs creates a compelling economic case for growers. As pesticide costs make up a large portion of input costs, even modest reductions can have a substantial impact on profitability. John Deere announced in Q3 2024 that their See & Spray system decreased herbicide use by an average of 59% over broadcast applications.

Environmental Drivers

Environmental concerns, including climate change and soil health, are influencing weed management strategies, making Precision Spraying a relevant solution for today's challenges.

- **Climate Change and Extreme Weather:** Climate volatility, from droughts to heavy rainfall, has altered farming practices worldwide. In regions prone to drought, reduced tillage and water conservation are critical, but they often lead to increased weed pressure. Precision Spraying helps control weeds without compromising soil moisture or structure.

- **Evidence of Pesticide Harm to Soil Biology:** Emerging research shows that excessive pesticide use can negatively impact soil biology, affecting organisms critical to soil fertility. Precision Spraying helps mitigate these effects by reducing total chemical input and limiting exposure to non-target areas.vvv

Together, these trends underscore the increasing relevance of Precision Spraying in modern agriculture. This technology addresses pressing challenges while aligning with agronomic best practices, regulatory mandates, and the economic realities faced by farmers. As precision agriculture continues to evolve, Precision Spraying represents a powerful tool to balance productivity with sustainability, meeting the needs of today's agriculture in an increasingly complex world.

3. Types and Approaches of Precision Spraying

Types and Approaches of Precision Spraying

The development of Precision Spraying technology has led to a range of innovative approaches, each tailored to specific use cases and operational needs. These methods—Offline Precision Spraying, Online Boom Precision Spraying, Ultra-Precise Precision Spraying, UAV Precision Spraying and Robot Precision Spraying—each bring unique benefits and limitations, influencing their adoption based on factors like weed type, field conditions, and desired precision. Here's a breakdown of each type:

1 Offline Precision Spraying

Offline Precision Spraying leverages drones or satellite imagery to generate weed maps across fields. This method begins with an aerial scan, typically performed by a drone, which identifies weed locations and densities. Using this data, a prescription map is created that specifies exactly where herbicides should be applied. The prescription map is then uploaded to a sprayer equipped with Variable Rate Application (VRA) capability, which applies herbicide precisely according to the mapped weed locations.

Use Case

- Primarily suited for GoB scenarios, such as fallow fields, although it can be adapted for limited GoG applications.
- Useful for larger fields or cases where weeds are spread out, making targeted application more effective than a blanket spray.

Pros

- **Affordability:** Compared to other solutions, Offline Precision Spraying is relatively inexpensive as it doesn't require additional hardware on the sprayer.
- **Waste Prevention:** By mapping weeds beforehand, growers know the exact volume of herbicide required before entering the field, reducing chemical waste.
- **Cloud-Based Processing:** AI models can process imagery in the cloud, eliminating the need for onboard processing power on equipment.

Cons

- **Complexity and Delay:** Requires expertise in drone or satellite operation, which can introduce logistical challenges. There's also a 2-3 day delay between mapping and application, which may reduce accuracy if weed conditions change.

- **Lower Image Resolution:** Aerial images may lack the resolution of ground-based systems, impacting the precision of weed identification.

Example Providers

2 Online Boom Precision Spraying

Online Boom Precision Spraying uses sensors mounted directly on the sprayer boom to detect weeds in real time as the equipment moves across the field. These sensors, often leveraging AI and computer vision, send commands to the nozzles, activating them only when weeds are identified.

Use Case

- Applicable for both GoB and GoG scenarios.
- Ideal for fields with high weed density or mixed weed/crop fields where selective application can minimize crop exposure to herbicides.

Pros

- **Seamless Integration:** Can be retrofitted onto existing equipment, making it easier for farmers to adopt.
- **Increased Efficiency:** Eliminates the need for a separate scouting step and ensures immediate application based on real-time weed detection.
- **Higher Resolution:** Mounted sensors deliver higher-resolution imaging than aerial systems, enhancing the precision of weed identification.

Cons

- **Hardware Investment:** Requires installation of sensors and supporting hardware on the sprayer.
- **Processing Requirements:** High-speed edge computing is essential for real-time processing, which may limit operating speed or impact weed detection quality if underpowered.
- **Logistical Challenges** in forecasting herbicide purchase needs, and challenges in how much product to mix into the spray tank when going to spray the field, leading to over purchasing and the risk of needing to dump product.

Example Providers

3 Ultra-Precise Precision Spraying

Ultra-Precise Precision Spraying builds on the Online Boom concept but with nozzles spaced closely for ultra-precise application. This method targets specific weeds with narrow-spray nozzles, allowing high-accuracy herbicide application tailored for high value crops where chemical savings and minimal crop impact are critical and where machine productivity is less of an issue.

Use Case

- Primarily for GoG applications in high-value crops (e.g., vegetables, specialty crops) where precision is paramount.
- Effective for densely packed crops or cases requiring minimal herbicide drift and crop impact.

Pros

- **Exceptional Precision:** Narrow spacing between nozzles allows for exact targeting, minimizing off-target herbicide exposure.
- **Higher Chemical Savings:** By concentrating herbicide use only on identified weeds, this method achieves maximum reduction in chemical use.
- **Quality Data Collection:** The high-resolution, targeted application provides valuable crop data, supporting better farm management decisions.

Cons

- **Lower Speed Operation:** Achieving such high accuracy typically requires slower equipment operation.
- **Significant Investment:** Requires advanced hardware and calibration, which can increase upfront costs and maintenance needs.

Example Providers

4 Robot Precision Spraying

Robot Precision Spraying leverages autonomous field robots equipped with advanced sensing and spraying systems to detect and treat weeds. These robots move at low speeds through fields, using AI and vision systems to identify and spot-spray individual weeds. Due to their autonomous nature, they can make multiple passes over a field, providing flexible weed control.

Use Case

- Suitable for GoG and GoB.
- Valuable for operations where labor is limited, or where autonomy is desired for multi-pass weed management.
- Robot sprayers are usually equipped with more sensors, which can acquire incremental data for the farmers and advisors, leading to better informed decisions for other agronomic decisions beyond weed and herbicides.

Pros

- **Operational Efficiency:** Robots operate independently, reducing labor costs and enabling continuous operation, even at night.
- **High Accuracy and Adaptability:** Equipped with onboard sensors, robots achieve exceptional accuracy and can adjust application rates based on real-time environmental conditions, such as wind and humidity.

Cons

- **Cost and Complexity:** High capital costs and logistical challenges related to field-to-field transport can hinder widespread adoption.
- **Reliability and Workflow Integration:** New systems require infrastructure changes and consistent maintenance to ensure reliability in field conditions.

Example Providers

SOLINFTEC

SWARM FARM ROBOTIC AGRICULTURE

5 UAV Precision Spraying

UAV Precision Spraying equips a (relatively) small, air-borne machine to fly across the field equipped with sensors, processing capacity and spray capabilities to eradicate weeds in a manor much different than traditional ground spraying systems.

Use Case

UAV systems can meet optimal application due to their flexibility in accessing various spots in a field. Unlike ground sprayers, drones eliminate the risk of soil compaction and crop damage caused by heavy machinery, preserving field health and productivity. Additionally, drones provide unparalleled accessibility, reaching areas that may be inaccessible to tractors or self-propelled sprayers, ensuring thorough and efficient coverage even under difficult field conditions.

Pros

- **Minimal Soil Compaction:** Unlike ground sprayers, drones eliminate soil compaction and crop trampling, preserving field health and productivity.
- **Accessibility in Challenging Conditions:** Drones can operate in wet or inaccessible fields where traditional equipment struggles, providing operational flexibility.
- **Real-Time Data Collection:** Optical sensors provide detailed data on weed density, crop health, and other field conditions, enabling better agronomic decision-making.

Cons

- **Limited Payload Capacity:** Frequent refills are needed, reducing efficiency for large areas compared to traditional sprayers.
- **Regulatory Hurdles:** Evolving regulations and lack of product registrations create operational challenges in some regions.
- **Battery Limitations:** Short flight durations (5–15 minutes) limit coverage per flight and increase downtime.
- **Weather Sensitivity:** Wind and adverse conditions can impact stability, accuracy, and spray patterns, increasing the risk of drift.
- **Infrastructure Needs:** Requires specialized infrastructure for transport, refueling, and maintenance, adding complexity.
- **Data Accuracy Challenges:** Real-time processing may struggle at high speeds or in complex environments, affecting precision.

Example Providers

PRECISION AI

GUARDIAN AGRICULTURE

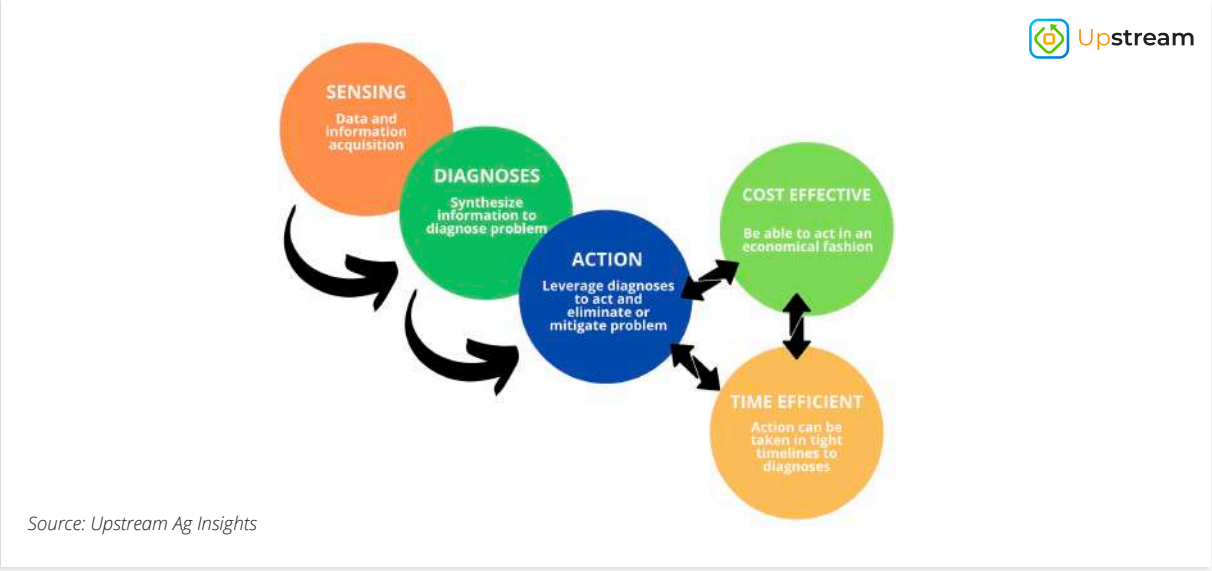
Each of these Precision Spraying approaches addresses specific challenges in weed management, from affordability and ease of implementation to high precision and autonomous operation. As the industry continues to innovate, these methods will likely evolve, integrating more advanced AI capabilities and adapting to a variety of crops and field conditions. The diversity in approach reflects the increasing demand for adaptable, precision-driven weed management solutions in modern agriculture.

Sensing, Diagnosing and Acting

The evolution of digital and precision agriculture has followed a clear progression: **sensing, diagnosing, and acting**. Initially, sensing was the primary focus—collecting weather data, conducting soil sampling, and leveraging NDVI satellite imagery, drones, and tractor-mounted cameras to monitor fields.

With improved **sensing** capabilities came the ability to diagnose issues—identifying disease outbreaks, insect pressure, or abiotic stress like hail damage. However, this is where most agricultural technology has stalled.

The industry has produced a vast array of sensing and diagnostic tools, yet they remain disconnected from real-time action. Farmers receive insights but still rely on separate, labor-intensive equipment to execute treatments, often with a costly time lag.



Source: Upstream Ag Insights

Closing the Loop: From Diagnosis to Immediate Action

The next step in precision agriculture is integrating **real-time action** into sensing and diagnostics. John Deere's **See & Spray** technology is a leading example, enabling sprayers to detect weeds, differentiate them from crops, and apply precise chemical applications instantly. This "Sense and Act" model represents a major leap forward in closing the gap between diagnosis and treatment

Yet, this approach still has **limitations**. Agriculture is an unpredictable and highly variable system. Weeds, diseases, insect pressure, nutrient deficiencies, and planter misses emerge and evolve dynamically. A single herbicide or fungicide pass doesn't address all in-season challenges, and scouting efforts remain constrained by time, labor, and cost.

The Constraints of Traditional Agronomic Systems

Farmers have structured their agronomic management practices around three key constraints:

1. **Labor availability -** Most sprayers and applicators require skilled operators, adding workforce challenges.
2. **Cost structures -** Large, expensive equipment carries high depreciation costs, making frequent applications economically unfeasible.
3. **Available tools -** Traditional agronomic plans optimize around a limited number of applications, usually one herbicide pass, one fungicide pass, and a few scouting visits per season.

While these constraints have shaped modern agronomic decisions, **they do not necessarily optimize agronomic outcomes or farm profitability**. The reality is that truly effective crop protection and nutrient management require continuous monitoring and timely intervention—something current systems struggle to deliver.

The future of precision agriculture isn't just about improving sensing or refining diagnosis—it's about closing the loop **all the way to execution**. Rethinking how equipment functions within the farm system is key to unlocking greater agronomic efficiency, profitability, and sustainability.

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Closing the Digital Ag Loop

Upstream	Sense	Diagnose	Action	Timely Action	Cost Efficient Action
John Deere	✓	✓	✓	✗	✗
Greeneye / CNH / ONE / Silberry	✓	✓	✓	✗	✗
intelinair / sentera / Taranis / ceres	✓	✓	✗	✗	✗
Guardian	✗	✗	✓	✓	✓
Solinftec / Precision AI	✓	✓	✓	✓	✓
Lindsay / valmont	✓	✓	✓	✓	✓

Source: Upstream Ag Insights

4. Use Cases for Precision Spraying Technology

Precision Spraying technologies offer a broad range of applications, each tailored to particular agronomic needs and crop management strategies. These use cases span from basic weed management to complex disease and insect detection, with unique pros, cons, and market opportunities across segments. Here's an in-depth exploration of the key precision spraying approaches and their application scenarios:

GoB

GoB Precision Spraying involves targeting weeds on bare, fallow fields or between crop rows during early crop emergence. This is one of the more established and mature use cases, offering a reliable method for minimizing herbicide use during periods when crops aren't actively growing.

- **GoB on Fallow Fields:** Primarily used after harvest and before planting, GoB on fallow fields detects living plants against a bare soil background. Precision Spraying can significantly reduce chemical use during this non-growing season, as herbicides are applied only to weeds rather than across the entire field.
  - **Pros:** This is a relatively simple and effective method with high accuracy due to clear weed-soil contrast.
  - **Cons:** The limited number of spray passes and the relatively low cost of traditional residual herbicides may impact return on investment (RoI).
  - **Example Applications:** Weed control in cereal production fields between harvest and the following planting season, especially in areas practicing no-tillage.
  - **Maturity:** Mature technology with proven efficacy in multiple regions.

- **GoB Between Rows in Emergent Crops:** For row crops with wider spacing, GoB between rows targets weeds growing between rows early in the season when canopy density is low.
  - **Pros:** Effective in reducing chemical use and preventing weeds from competing with young crops.
  - **Cons:** Limited to low-density, wider row spacing crops where weeds are still easily visible.
  - **Example Applications:** Early-season weed control in crops like corn and soybeans.
  - **Maturity:** Mature technology with high accuracy, particularly for row crops in dry regions.

GoG

GoG applications are more complex, focusing on detecting weeds within growing crops, where weed and crop color are similar. This is a rapidly developing area of Precision Spraying, with substantial potential for chemical savings.

- **Weed Detection in Crop Fields:** GoG Precision Spraying systems must differentiate weeds from crops, which is particularly challenging in cases of grassy weeds within cereal crops.
  - **Pros:** High potential for chemical savings and selective herbicide application, making this a valuable solution for crop health.
  - **Cons:** Differentiating similar plant types, such as grass leaf weeds within cereals, remains a challenge due to variability in crop, weed, and environmental conditions. Challenges to approach current speeds of broadcast sprayers (~18mph).
  - **Example Applications:** In season weed control in cereals.
  - **Maturity:** Relatively mature, numerous commercial products available in the market.
  - **Sensitivity:** Missing weeds is still a challenge.
  - **Speed:** The current speeds for systems ranges from 12-15mph.

Band Spraying

Band spraying targets specific zones, such as crop rows or spaces between rows. This technique can be adapted for both herbicides (between rows) and fungicides or fertilizers (on the crop rows), depending on the desired outcome.

- **Row and Between-Row Spraying:** By focusing herbicide application between crop rows or fungicide application on crop rows, band spraying allows precise treatment of crops or weed zones without blanket coverage.
  - **Pros:** Reduces chemical use by confining applications to target areas, minimizing off-target exposure.
  - **Cons:** Only effective at early growth stages.
  - **Example Applications:** Fungicide application on row crops. Examples include Greeneye Technology Canopy Mode.
  - **Maturity:** Intermediate maturity, with improvements in VRA technology increasing accuracy and efficiency.

Modulation Spraying / Variable Rate Application (VRA)

Variable Rate Application (VRA) beyond herbicides are possible, including adjusting the dosage insecticides, fungicides or nitrogen based on crop conditions. This approach can be executed both online, using real-time canopy sensors, or offline, with data collected by drones or satellites to create a prescription map.

- **Online Canopy-Based VRA:** By measuring canopy density or leaf color, sensors can guide spray intensity to match crop needs.
  - **Pros:** Reduces chemical waste and improves crop health by aligning application rates with plant vigor.
  - **Cons:** Requires high-tech sensors and edge computing, which may be cost-prohibitive and impact operating speed.
  - **Example Applications:** In season, nitrogen and fungicide application in cereals and row crops.
  - **Maturity:** Emerging, with increasing adoption as canopy detection technology advances.

- **Offline VRA with Prescription Maps:** Drones or satellites create detailed maps indicating variable weed pressure or canopy density, guiding applications based on pre-scanned data.
  - **Pros:** Limits in-field hardware needs and supports early decision-making.
  - **Cons:** The delay between data collection and application may reduce efficacy, particularly in rapidly changing field conditions.
  - **Example Applications:** Variable rate nitrogen applications on corn based on physiological demands or crop health in certain areas.
  - **Maturity:** Intermediate on nitrogen; especially used in regions with high variability in field conditions.

Dual Dose and Dual Application

Dual Dose and Dual Application approaches maximize weed control by adjusting herbicide dose rates or combining multiple treatments.

- **Dual Dose:** Applies a low blanket dose across the field, with a higher rate at specific weed sites.
  - **Pros:** Enhances control of persistent weeds without excessive blanket application. Less risk of weed misses.

- **Cons:** More complex to implement, with potential for higher costs due to multiple dose requirements.
- **Example Applications:** Weed control in regions with high weed pressure, for example cereals in Europe.
- **Maturity:** Increasingly used in regions with high weed pressure.

- **Dual Application:** Combines an 'blanket' or 'broadcast' application with a 'spot' application.
  - **Pros:** Broader pest and weed control, optimizing chemical use, operational efficiency due to not needing an extra application such as with a singular tank.
  - **Cons:** Increased complexity and risk of chemical interactions.
  - **Example Applications:** For example a blanket application of growth regulator combined with a spot application for weed control.
  - **Maturity:** Early-stage, but promising in integrated pest management.

Patch Spraying

Patch Spraying applies herbicides across small sections rather than individual nozzles, covering targeted sections, typically 3m-wide patches.

- **Pros:** Useful for fields with patchy weed growth, reducing the need for blanket applications and less expensive because individual nozzle control technology is not required.
- **Cons:** May result in slight overapplication if weeds are unevenly distributed.
- **Example Applications:** In season weed control in cereals with patchy weed distribution - for example DAT Ecopatch.
- **Maturity:** Mature in regions with consistent weed patch patterns.

Disease and Insect Spotting

Disease and insect spotting remain emerging use cases, relying on vision systems to detect symptoms early and apply chemicals only where necessary.

- **Disease Spotting:** Early-stage detection of fungal or, enabling targeted fungicide use before the disease spreads.
  - **Pros:** Prevents disease spread and reduces preventive fungicide use.

- **Cons:** Detection accuracy is highly dependent on environmental conditions and disease symptoms.
- **Maturity:** Early-stage with significant development potential.
- **Example:** A collaboration between Syngenta, John Deere and InnerPlant is being worked on to deliver VRA Fungicide.

5. Precision Spraying Workflow

Precision Spraying Workflow

The Precision Spraying workflow involves several interconnected tasks, each contributing to precise and efficient operation. Here's a breakdown of the process:

1. **Data Acquisition**

   The workflow begins with scanning the crop to collect data with the machine travelling through the field. This step involves imaging or sensing the field to identify weeds.

2. **Intelligent Decision-Making**

   The system's intelligence analyzes the collected data to recognize weeds. Based on this analysis, it decides whether to spray or not. In advanced systems, additional capabilities may include:

   - Adjusting the spray dose (e.g., higher doses for larger weeds).
   - Identifying specific weed species and selecting the appropriate treatment.

3. **Command Execution**

   Once a decision is made, the system sends control commands to the spray rate controller and nozzle control mechanisms. These ensure that the correct amount of spray solution is delivered precisely at the right spot and time.

4. **Delivery by Nozzle Technology**

   The spray is applied using advanced nozzle technology, which must operate with extreme accuracy to align with the system's commands.

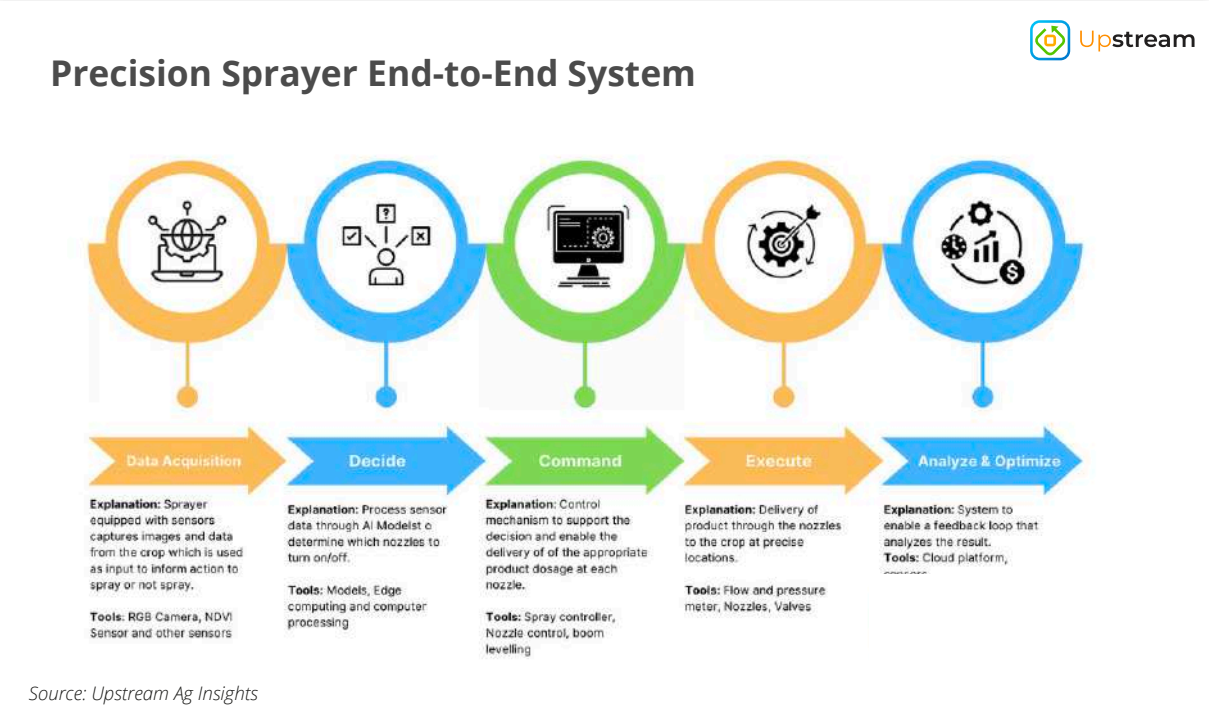
5. **Analysis**

   The solution generates a vast amount of data, which can be leveraged for further analysis and insights. The analysis is done at an offset, so not part of the control loop on the sprayer.

This entire process must occur within milliseconds, as sprayers typically operate at high speeds. The time between image capture and the boom reaching the target spot is incredibly short, requiring the system to process data and execute commands almost instantaneously.

Given these demands, these systems rely on high-performance edge processing, as there is no time to offload the logic to the cloud.

The graphic below illustrates the complete workflow, highlighting the complexity and sophistication of Precision Spraying technology.



Source: Upstream Ag Insights

Key Technical Components

This advanced solution is built upon several essential technical components.

Camera Technology

Cameras play a vital role in precision spraying systems, enabling precise image capture for analysis and decision-making. There are several types of cameras used in these systems. RGB cameras are standard devices that capture red, green, and blue color channels, providing basic visual data. Infrared cameras are useful for detecting heat signatures and specific vegetation indices, while hyperspectral cameras capture a broader spectrum of light, allowing for detailed analysis of crops and soils.

The positioning of cameras is equally important. Downwards-facing cameras are positioned to capture images directly below the equipment, while front-facing cameras, positioned at an angle, capture images ahead of the nozzle. The latter configuration impacts operational efficiency by enabling higher driving speeds, as the increased distance between image capture and nozzle provides additional processing time. However there might a loss of accuracy compared to downward facing cameras - the smallest weeds might not be captured.

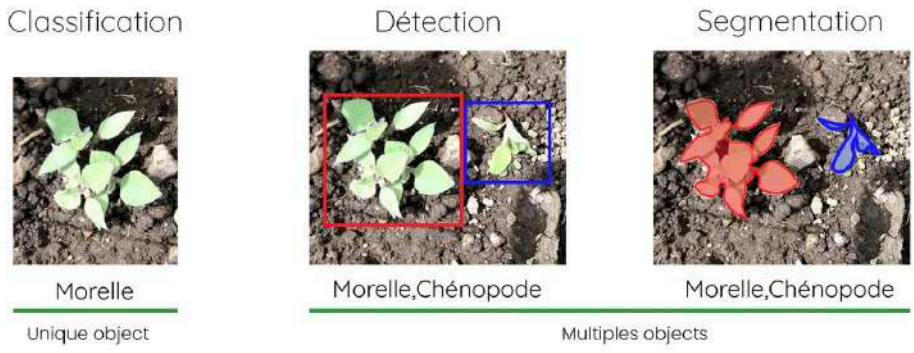
Source: Agrifac website

Artificial Intelligence Models

AI models are fundamental to interpreting the data collected by cameras. These models require a robust data library for training, which must include a diverse dataset featuring various crop varieties, soil types, and light conditions. High-quality annotation of this data is essential, as it directly impacts model accuracy.

Classification and object detection are two primary approaches in AI modeling. Classification models are simpler but less accurate, as they cannot detect multiple objects within a single image. In contrast, object detection models are more accurate and capable of identifying multiple objects, but they require detailed and precise annotation, making them more complex to develop.

The quality of the model significantly influences the system's precision, including the accuracy of weed detection and the overall robustness. A high-quality model ensures reliable performance across varying conditions while consistently delivering excellent results.



Source: Dilepix webiste

Edge Computing

Edge computing enables real-time data processing on the equipment, primarily powered by advanced NVIDIA chips. The processing power of these units significantly influences system performance. Higher processing power improves accuracy, reduces delay times, and allows for increased driving speeds by facilitating faster data processing. More frequent images, means more data load and requires more processing power. Also the level of the detection does impact the required processing power for example, a system that identifies individual weed species requires more processing power, whereas a simpler system that only detects weeds in general demands less processing power.

Tank Configuration

The configuration of tanks in precision spraying systems impacts their functionality and efficiency. A single tank system supports only one use case per field pass, limiting its versatility. This setup cannot accommodate tasks like combining a spot spray of herbicide and a broadcast spray of growth regulator, reducing the value of spot-spray solutions. The one tank limitation will lead to the need to 'split' applications, which reduces the operational efficiency of the spraying operations.

In contrast, dual tank systems allow for multiple use cases in a single field pass. For example, they can manage a broadcast application of one substance while simultaneously performing a spot application of another, greatly enhancing operational flexibility and efficiency. For example, applying a herbicide in a precise fashion while broadcast applying a fungicide.

Upstream

John Deere See & Spray Ultimate Dual-tank configuration
Source: John Deere

Rate Controllers

Rate controllers manage the flow of substances in spraying systems. Classical rate controllers are commonly found on traditional sprayers and are responsible for collecting as-applied data. These controllers are often compatible with ISOBUS, a standard protocol for communication between agricultural machinery.

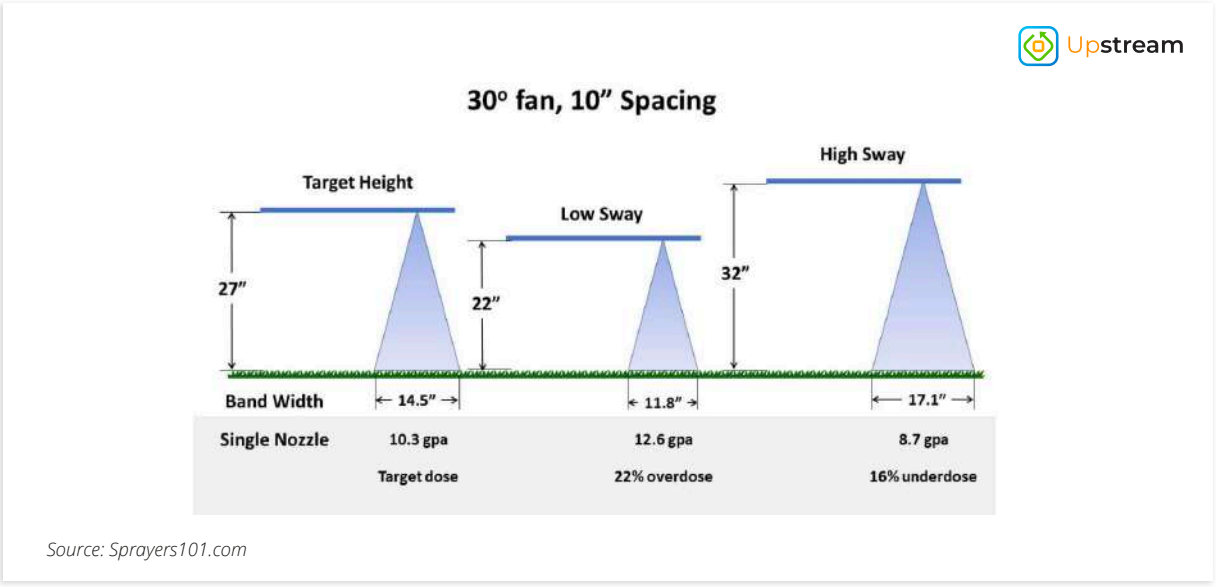
Nozzle Control

Nozzle control is a critical aspect of spraying precision. Section control operates by controlling entire sections of nozzles, but this approach is less accurate and slower to respond. In contrast, Pulse Width Modulation (PWM) technology allows for individual nozzle control, enabling faster response times and precise dose adjustments for each nozzle.

PWM offers superior precision and efficiency in agricultural sprayers compared to section control or standard individual nozzle control. PWM provides precise, real-time control of each nozzle by rapidly pulsing valves. This ensures consistent droplet size, accurate application rates, and reduced overlap or waste, even on irregular fields. With its ability to maintain constant pressure, adapt to varying speeds, and support variable rate applications, PWM is a key enable for precision spraying systems.

Boom Height Control

A stable boom is fundamental for high-quality spraying, as the distance between the boom and the crop directly impacts coverage. In Precision Spraying, boom stability becomes even more critical. Precise weed localization is essential to ensure the correct nozzle activates at the right moment to target the weed. Any movement of the boom increases the risk of missing the target, particularly at high operating speeds or with systems that use narrow nozzle spacing. Stability ensures accuracy and efficiency, even under challenging conditions.



Source: Sprayers101.com

Nozzles

The setup and type of nozzles used in a spraying system significantly impact its performance. Nozzle design affects spray pressure and rates, as well as responsiveness to spot-spray commands. Specialized nozzles are available for spot-spray use cases, but flexibility is key to ensure easy switching between applications such as spot and broadcast spraying.

Additionally, PWM-compatible nozzles are necessary to achieve the pulsing effect required for this technology. These nozzles enable precise application and efficient system operation.

6. Adoption Challenges for Precision Spraying Technology

Adoption Challenges for Precision Spraying Technology

The promise of Precision Spraying technology is substantial, but its adoption in mainstream agriculture faces several key challenges. These barriers, ranging from high costs to logistical complexities, impact the pace of adoption and require practical solutions to encourage broader uptake.

1. Cost

High upfront costs and ongoing subscription fees pose a significant barrier for many farmers considering Precision Spraying technology.

- **Upfront Costs:** For many operations, an initial investment that can reach $250,000 is substantial. High up front costs, and a need for newer high-clearance sprayers can make precision technology inaccessible for some farming operations.
- **Subscription Fees:** Some systems require a yearly subscription that can exceed $10,000, depending on farm size, which includes software updates, data processing, and continued technical support. This recurring cost adds up over time and must be justified by measurable returns. For example, John Deere has upwards of $5/ac when in use, depending on crop.
- **Additional Hardware Requirements:** Precision Spraying systems often require hardware upgrades, such as Pulse Width Modulation (PWM) technology, to manage precise application. This adds to the capital requirements of the entire Precision Spraying solution.
- **Return on Investment (RoI) Variability:** The RoI is influenced by several factors, including the number of acres treated and weed density. For farms with higher weed densities, the financial savings may not offset the technology's cost, reducing its appeal.
- **Cost of Missed Weeds:** Missed weeds can compromise the technology's cost-effectiveness, especially in GoG applications where the complexity of distinguishing between crops and weeds can lead to higher rates of untreated weeds. This missed coverage can add costs later, as untreated weeds may require interventions, such as tillage, or herbicide applications.
- **Limitations:** In terms of adoption, precision spraying technology has traditionally focused on herbicide savings, which, while valuable, limits its appeal to a single crop protection segment. This narrow focus can encourage farmers to take a "wait and see" approach, as the technology's benefits don't fully address their needs for broader spray applications like fungicides or insecticides.

To increase the technology's value across more segments, companies are expanding its capabilities. For instance, Greeneye introduced "canopy mode," which targets only crop rows, allowing the system to be used for fungicides and biostimulants in addition to herbicides. John Deere is also actively collaborating with companies like InnerPlant and Syngenta to enhance precision spraying for fungicides, making the technology more versatile and attractive to farmers by extending its utility beyond herbicides alone.

2. Logistics

Logistical considerations, including chemical handling and inventory management, present adoption challenges.

- **Chemical Volume Estimation:** Calculating the correct volume of herbicide for Precision Spraying is challenging due to the variable rate applicationdue to the variable rate application that is depend on weed density, weed type and weed size.
- **Tank Residuals:** Managing tank leftovers is a logistical hurdle. If herbicides remain after a pass, farmers must decide whether to store or safely dispose of the excess, adding complexity to chemical handling protocols. If too little product is mixed, the sprayer will run out before the job is done; too much, and leftover chemicals present disposal and storage issues.
  - Traditional field spraying is done on a total acre of field basis and then aligning the appropriate volume of product based on registered rates. When it is unknown how much area of the field is required to be sprayed, it opens up a level of uncertainty that farmers, and ag retailers, are uncomfortable with. Being able to empower the farmer to manage volume needs proactively with confidence is an opportunity for precision spraying companies.
- **Inventory Forecasting for Distributors and Retailers:** Input distributors and ag retailers also face challenges, as the variability of Precision Spraying makes it difficult to forecast chemical demand accurately. This impacts inventory management and can create inefficiencies in the supply chain if demand fluctuates unexpectedly.

3. Status of Technology

Precision Spraying is still in its developmental phase, and many farmers remain cautious, adopting a "wait and see" approach.

- **Early Stage Technology:** Precision Spraying is still considered emerging technology, especially in more advanced applications like GoG. Farmers are hesitant to invest in systems that are not yet fully mature or widely proven in diverse agricultural settings.

- **Limited Retrofit Solutions:** Although retrofitting allows farmers to adapt existing sprayers for Precision Spraying, the technology is primarily available for newer sprayer models. This limits accessibility for farmers with older equipment, as their existing machinery may not support the necessary modifications.

- **Accuracy Concerns:** A key challenge is the system's ability to reliably detect and spray weeds. Current GoG systems, for example, may miss up to 40% of weeds due to crop-weed similarities. Farmers question the technology's efficacy in high-weed-density fields where missed weeds can reduce overall benefits.

- **System Complexity:** Precision Spraying systems require extensive calibration and management, particularly for operators.This means additional skills, and the perception of challenges and time to train.

4. Workflow Integration

Integrating Precision Spraying into a farm's existing workflow presents operational challenges that impact its overall feasibility.

- **Herbicide Application Limitations:** Most Precision Spraying systems are currently optimized for herbicide applications, limiting their use in other applications such as fungicides or insecticides. This constrains the technology's versatility and overall appeal to farmers who may seek multi-purpose solutions.

- **Multiple Treatment Splits:** Precision Spraying is not always compatible with treatments requiring different modes of action. For example, residual and non-residual herbicides often need to be applied differently; one may require a blanket application, while the other is suited for Precision Spraying. This split application approach requires dual tank systems, which is a more common offering in U.S. farming but less so in other regions.

- **Additional Field Passes:** In some cases, Precision Spraying requires additional field passes, increasing operational time and fuel costs. For farms operating on tight schedules, these extra passes can complicate workflow and reduce efficiency.

These challenges underscore the complexities that farmers and agribusinesses face when evaluating Precision Spraying technology. While the promise of precise herbicide application is compelling, the high costs, developmental status, integration requirements, and logistical constraints all weigh on adoption rates. Addressing these challenges through cost-sharing programs, expanded retrofit options, simplified workflows, and logistical support will be essential for wider uptake of this transformative technology in agriculture.

7. Adoption Chain Challenges in Precision Spraying Technology

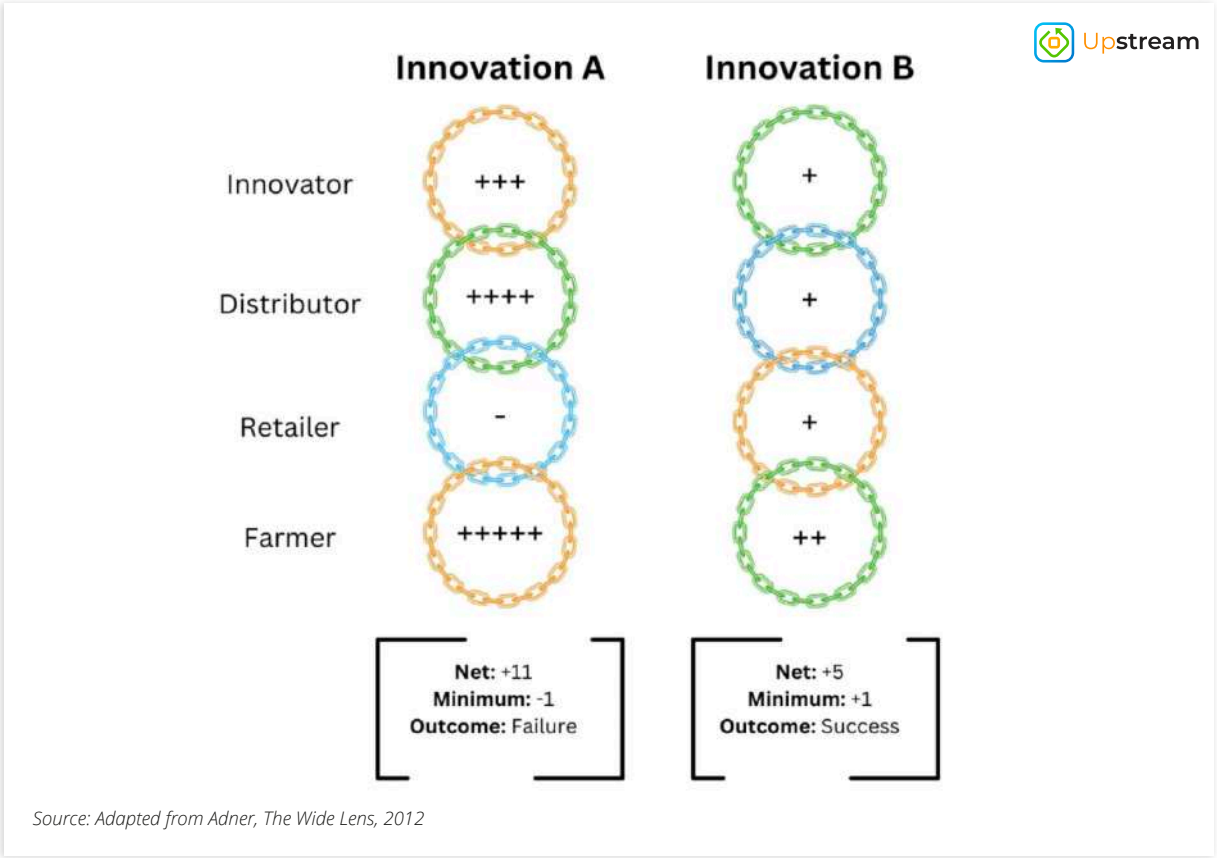
Distribution

The adoption of cutting-edge agricultural technologies often brings with it a unique set of challenges, and precision spraying systems exemplify this complexity. As a revolutionary approach to precision weed management, the technology operates at the intersection of three distinct yet interconnected domains: agricultural equipment, agronomy, and precision agriculture. Each of these areas requires specialized expertise, and the successful implementation of precision spraying hinges on aligning insights from these fields to maximize its potential.

Agricultural equipment specialists must navigate the technical intricacies of deploying advanced optical recognition systems, ensuring seamless integration with existing machinery. Agronomists play a critical role in understanding how targeted herbicide application affects crop health, weed resistance, and broader agronomic systems. Meanwhile, precision agriculture experts are tasked with translating data generated by precision spraying into actionable insights for farmers, tailoring the system to variable field conditions.

This confluence of expertise creates a complex ecosystem where the challenges of education, distribution, and support must be tackled collaboratively. For Precision Spraying to reach its full potential, stakeholders from equipment manufacturers, equipment dealerships, ag input suppliers, agronomists, and local retailers must work in unison, bridging gaps in knowledge and aligning their efforts. The result is not just the introduction of a new technology, but the transformation of how farmers approach crop protection and resource efficiency.

Adopting Precision Spraying technology in agriculture extends beyond direct farmer buy-in; it involves a complex chain of intermediaries, including distributors, retailers, and agronomists. Each link in this "adoption chain" must derive value from the technology for successful adoption, as highlighted in The Wide Lens by Ron Adner. If any participant in this chain perceives a lack of benefit or encounters obstacles, the technology's adoption is significantly hindered.



Source: Adapted from Adner, The Wide Lens, 2012

The Role of Adoption Chain Management

Adoption Chain Management is a strategic framework for recognizing and addressing these intermediary needs, aligning incentives across the distribution network, and ultimately facilitating the technology's journey to farmers. Many agtech companies in the 2010s faced barriers when attempting direct-to-farmer sales, learning that successful technology adoption relies heavily on intermediaries who provide critical endorsements, logistical support, and integration guidance.

Mitigating Adoption Chain Risk: The Path Forward

Successfully navigating the adoption chain for Precision Spraying technology means understanding and addressing the specific needs of each stakeholder. If even one link in the chain lacks a clear benefit, the entire adoption process can falter. Conversely, by ensuring each stakeholder derives tangible value, Precision Spraying technology can achieve positive momentum and more widespread use, ultimately delivering its full potential to transform weed management in agriculture.

Key Considerations

One of the biggest challenges in Precision Spraying is the complexity of needing to understand software, hardware (equipment) and agronomic needs. Today, players in the value chain and farmer support structure, such as equipment dealers, input manufacturers and crop input retailers have different core competencies - all crucial for the effective deployment of the technology, but all with differing incentives and understanding.

One interesting example is ecosystem alignment - integrating the entirety of the support infrastructure around the farmer to effectively deploy the technology for the benefit of the farmer.

Establishing the full range of skills needed to deliver advanced solutions like Precision Spraying can be challenging for a single organization. A promising alternative is forming a consortium of organizations that collaborate to provide comprehensive support to growers.

Example: ecorobotix

A standout example is the distribution of Ecorobotix in the Netherlands. Here, a local precision agriculture service provider partnered with an equipment dealership and an ag retail organization. Together, they distribute and support the Ecorobotix solution, ensuring maximum value for growers.

- **The Equipment Dealer** supplies and services the equipment.
- **The Precision Ag Service Provider** manages software support and customer training.
- **The Ag Retailer** advises growers on innovative crop protection programs, addressing the shift to chemicals that no longer directly impact crops.

This collaborative model has proven highly effective: the consortium has sold 90 units in just two years, contributing significantly to the approximately 500 units Ecorobotix has sold to date. Such partnerships highlight the power of leveraging complementary expertise to drive adoption and deliver meaningful value to growers. Considering the entire value chain in delivering Precision Spraying to farmers will be crucial to success, as adoption hinges on strategic, cross-chain collaboration and support.

8. Benefits of Precision Spraying

Comprehensive Benefits of Precision Spraying in Agriculture

Precision Spraying technology brings considerable advancements across multiple dimensions in agriculture. From cost savings and environmental stewardship to improved agronomic strategies, this technology has the potential to reshape weed and crop management fundamentally. Below is an in-depth exploration of the various benefits, with a focus on financial impacts, sprayer design innovations, agronomic improvements, and data and regulatory implications.

Financial Benefits

1. **Significant Savings in Herbicide Costs:** Precision Spraying can reduce herbicide use by over 50%, representing substantial savings on a farm's total herbicide expenditure. By targeting only the weeds rather than applying herbicides across entire fields, farmers can drastically cut costs without compromising weed control effectiveness.

2. **Environmental Impact Reduction:** Lowering herbicide usage also provides significant environmental benefits, as less chemical runoff enters the surrounding ecosystems. Reduced herbicide application translates to a smaller chemical footprint and aligns with growing regulatory and consumer demand for sustainable farming practices.

Upstream

Crop Injury

Cobra Herbicide Postemergence on Double-Crop Soybean

	Broadcast	See & Spray
Spray Savings	NA	80%
Soybean Injury Index		
7 DAT	36	8
14 DAT	29	7
21 DAT	15	3
28 DAT	7	1
Soybean Yield (bu/acre)	42	46

Trial Notes:
1 Cobra applied at 12.5 fl oz/acre + COC at 1%v/v
2 All soybean injury and yield data were statistically different ($p < 0.05$)
3. Trial ID: BRT-24-ISA-DC (Purdue Univ.)

Source: Purdue University, John Deere Agronomy Summit, December 2024

3. **Spraying Efficiency Gains:** Precision Spraying reduces the frequency and duration of refilling, allowing farmers to cover more ground with less product. This efficiency not only saves on input costs but also conserves fuel and labor.

4. **Positive Impact on Soil Biology:** The precise application of herbicides limits chemical exposure to the soil, preserving beneficial soil microbes and promoting healthier soil biology. This benefit aligns with regenerative agriculture practices and further supports sustainable farming initiatives.

Agronomic Advancements

1. **Extended Herbicide Efficacy and Reduced Resistance Risks:** Precision spraying prolongs herbicide efficacy by applying it only where needed, slowing down the development of resistant weed species. This benefit is crucial as weed resistance continues to pose a significant threat to farm profitability.

2. **Flexibility in Herbicide Choice and Rotation:** By reducing overall herbicide use, farmers can afford to incorporate more effective, higher-cost herbicides selectively. This flexibility allows for more robust herbicide rotations, further mitigating resistance risks and enhancing weed control efficacy over time.

3. **Reinvestment in Crop Health Programs:** The savings generated from reduced herbicide use can be reinvested into other spraying programs, such as fungicides or biostimulants, to support crop health and yield. Investing in additional crop protection measures can enhance crop quality and resilience, creating more profitable and productive fields.

4. **Selective Dose Rates for Weed Hotspots:** Precision Spraying allows for variable dose rates, enabling higher herbicide concentrations on dense weed patches. This targeted approach optimizes herbicide efficacy and prevents under-dosing, which can contribute to resistance.

5. **Incentive to Develop New Chemistry:** The efficiency of Precision Spraying could encourage the development of novel chemistries and crop protection formulations tailored to specific weed species or crop stages. As farmers rely on less herbicide overall, they may be willing to pay a premium for innovative solutions that improve efficacy and environmental safety.

6. **Expanding Applications Beyond Herbicides:** Precision spraying technology has the potential to extend beyond herbicides, allowing for precise applications of fungicides, insecticides, and even plant growth regulators. This versatility enhances the technology's value proposition and aligns it with holistic crop management strategies.

Data and Regulatory Implications

1. **Enhanced Agronomic Insights Through Data Collection:** Precision Spraying systems collect detailed data on weed density, stem count, crop growth, and other field metrics, offering valuable insights for agronomic decision-making. Farmers can use this data to adjust practices based on field-specific conditions, optimizing yields and input use.

2. **Improved Documentation for Compliance and Accountability:** Precision data can serve as documentation of chemical applications, proving that herbicides are applied accurately and within regulatory limits. This accountability can support farmers in audits or in meeting regulatory requirements.

3. **Potential to Preserve Active Ingredients:** With public and regulatory pressure mounting to reduce chemical use, Precision Spraying enables targeted applications that limit overuse and reduce the likelihood of further bans on active ingredients. The technology offers a proactive solution to balance efficacy with regulatory compliance.

4. **Ability to Meet Regional Herbicide Limits:** Precision Spraying allows farmers to stay within region-specific herbicide application limits. Precision Spraying enables farmers to achieve effective weed control without exceeding these thresholds, ensuring compliance and reducing the risk of penalties.

5. **Proactive Crop Management Based on Data:** Data collected from Precision Spraying can help anticipate crop needs and allow input providers to develop customized input solutions. By analyzing data trends, farmers and agronomists can proactively address issues like nutrient deficiencies or pest pressures, further enhancing crop productivity.

By delivering these multi-dimensional benefits, Precision Spraying positions itself as a transformative tool in modern agriculture. Not only does it offer immediate financial savings, but it also promotes environmental stewardship, supports innovative sprayer design, enhances agronomic strategies, and meets increasing regulatory demands. The integration of data and advanced application technology signals a shift toward more informed, efficient, and sustainable crop protection, helping farmers address both current challenges and future pressures.

9. Current Adoption by Region

The following was aggregated through extensive conversations with farmers, agronomists, industry experts, and consultants to assess general status of adoption and adoption potential by region.

North America

Adoption Status

Early Market with Low Adoption:
Precision spraying technology is still in its early stages in North America. Despite being a significant innovation, the adoption rates remain low due to various economic, operational, and behavioral challenges. Farmers and retailers are familiar with traditional methods, and the transition to precision spraying requires overcoming system change and upfront costs.

Market Requires Primarily a GoG Solution:
The demand for advanced GoG solutions, capable of differentiating between weeds and crops during the growing season, highlights the sophisticated needs of this market. However, the technical complexity and cost of GoG systems have limited their broader adoption.

Drivers for Adoption

1. **Large-Scale Farming Simplifies ROI Calculations:**
   The extensive size of North American farms makes the economic benefits of precision spraying easier to calculate and justify. A significant reduction in chemical usage or enhanced weed management across thousands of acres translates into substantial savings and efficiency gains.
2. **Weed Management as a Priority:**
   Farmers place high importance on maintaining clean fields. Precision spraying allows targeted weed control, aligning with their goals of minimal weed competition while optimizing herbicide application.
3. **High-Yielding Crops Demand Precision:**
   With an emphasis on maximizing yields, precision spraying ensures optimal crop protection and weed management, aligning with the region's productivity-driven farming goals.
4. **Major Weed Resistance Problems:**
   Resistance to herbicides, such as glyphosate, drives the need for more effective and precise application methods, further strengthening the case for adoption. It enables to use different modes of action in order to to combat persistent weeds.

5. **Relatively High Weeding Costs:**
   The significant cost of weed management, coupled with the growing need for aggressive strategies to combat weed resistance, highlights the importance of technologies that enhance herbicide efficiency and efficacy. For example, according to Iowa State University's 2025 Cost of Production assessment, in a corn and soybean rotation a farmer can expect herbicide costs to make up between 12% and 15% of total input costs in corn and upwards of 30% in soybean.

6. **Short Equipment Life Cycles:**
   With sprayers typically replaced every few years, there is an opportunity for newer technology to gain traction as farmers and retailers upgrade their equipment more frequently than in other regions.

Adoption Challenges

1. **High Share of Custom Applications:**
   Many farms rely on custom applicators for spraying, meaning decisions are often made by third-party retailers or service providers. Aligning incentives between these stakeholders and farmers is critical but challenging, especially when custom applicators might prioritize productivity over precision.

2. **Complex Crop Protection Strategies:**
   North American farms frequently require combined applications, such as combining herbicides with a growth regulator, adding complexity to precision spraying solutions that need to manage multiple products in a single pass.

3. **High Focus on Productivity and Tight Operational Windows:**
   Due to the scale of operations and the limited time available for fieldwork, many growers emphasize speed and efficiency. Precision spraying systems need to operate seamlessly without slowing down productivity, which can be a barrier to adoption.

4. **Split Applications Conflict with Large-Scale Farming:**
   Precision spraying with single tank systems might require multiple applications for optimal results. However, large-scale farms in North America prefer fewer passes due to time and cost constraints, making it challenging to accept the need to 'split applications'.

5. **High Share of Tillage Use:**
   While no-till farming is increasing, traditional tillage practices still dominate in many areas. This impacts weed control strategies and the adoption of precision spraying, as tillage is used to manage weeds before planting.

6. **Prevalence of GMO Crops:**
   A large portion of North American crops is genetically engineered for

herbicide tolerance, reducing the need for selective herbicides. Meaning non-selective herbicides like Glyphosate can be used to manage weeds during the growing season. This decreases the immediate value proposition of precision spraying because the non-selective products are still relatively inexpensive.

Precision spraying adoption in North America faces a dual narrative: the potential for significant ROI and weed management improvements is counterbalanced by practical challenges such as the high reliance on custom applications, the complexity of integrated strategies, and a productivity-focused farming culture. To drive broader adoption, solutions must address these unique regional dynamics by ensuring ease of use, aligning with existing farming practices, and delivering clear, tangible benefits for large-scale operations.

Western Europe

Adoption Status

Early Market with Low Adoption:
Precision spraying remains in the early stages of adoption in Western Europe, similar to North America. Despite the potential benefits, penetration is limited due to high initial costs, infrastructure challenges, and the need for greater awareness among farmers.

Market Requires Primarily GoG Solutions:
The high prevalence of winter crops in Western Europe demands advanced GoG technology to differentiate between weeds and crop plants in early growth stages. This specificity further complicates adoption due to the complexity and cost of GoG systems.

Fast Adoption in High-Value Crop Markets:
Precision spraying has seen quicker uptake in specific niches like high-value crops, where ROI is more immediate and regulations are even stricter. For example, solutions like Ecorobotix have demonstrated success in high-value crops like onions.

Drivers for Adoption

1. **High Pressure to Reduce Chemical Usage:**
   Europe's stringent regulations and societal pressures to reduce chemical usage are a significant driver for precision spraying. Bans on many active ingredients and the push toward sustainable farming practices align with the precise application capabilities of precision spraying solutions.

2. **Incentives and Subsidies for Technology Adoption:**
   Governments in several European countries provide financial incentives to

encourage farmers to adopt environmentally friendly technologies. These subsidies help offset the initial investment cost, making adoption more appealing.

3. **High Production and Weed Management Costs:**
   The combination of high rainfall (leading to heavy weed pressure) and high production costs creates a strong financial incentive to optimize inputs like herbicides. Precision spraying can help reduce costs while maintaining crop productivity.

4. **High-Yielding Crops with Long Growing Seasons:**
   The region's focus on high-yielding crops benefits from technologies that provide continuous weed control during longer growing seasons, making precision spraying an attractive solution.

5. **Growing Weed Resistance Problems:**
   The rise of herbicide-resistant weeds increases reliance on selective herbicides, which are expensive and must be used precise. Precision spraying enables precise targeting of these weeds, optimizing herbicide use and lowering costs.

Adoption Challenges

1. **Smaller Farm Sizes Make ROI Calculations Harder:**
   Western Europe's smaller average farm size compared to regions like North America makes it more challenging to justify the upfront investment in precision spraying technology. The ROI calculations become less favorable due to limited economies of scale.

2. **Broad Crop Rotations Demand Versatile Solutions:**
   Farmers in Western Europe often practice broad crop rotations, requiring precision spraying systems that can adapt to diverse crop types, field conditions, and application needs. There are not many system in the marketplace today that can offer this versatility**.**

3. **Longer Sprayer Life Cycles:**
   Unlike North America, Western European farmers tend to own their spraying equipment and retain it for longer periods, often 10–15 years or more. This slower equipment turnover limits the rate at which new technology can penetrate the market and requires retrofit solutions.

4. **High Number of Specialized Sprayer OEMs:**
   The European market has a larger number of specialized sprayer manufacturers, creating a fragmented landscape where no single technology or standard dominates. This fragmentation can slow down widespread adoption and compatibility.

5. **High Share of Intensive Tillage:**
   Tillage is still widely practiced in Western Europe, influencing weed management strategies. While precision spraying aligns better with reduced tillage or no-till systems, the prevalence of tillage reduces its immediate applicability in some farming systems.

6. **Complex Crop Protection (CP) Programs:**
   Western European farmers often apply fungicides, growth regulators, and other crop inputs in addition to herbicides, creating complex spraying requirements. Precision spraying systems need to accommodate these combined applications, adding to their operational complexity.

Precision spraying in Western Europe faces unique challenges tied to the region's smaller farm sizes, longer equipment lifespans, and complex crop protection needs. However, the drivers for adoption are strong, particularly due to stringent regulations, societal pressures to reduce chemical use, and government incentives. Success in high-value crops and increased focus on weed resistance management could pave the way for broader adoption. To accelerate uptake, solutions must be versatile, cost-effective, and compatible with the diverse cropping systems and specialized equipment prevalent in the region.

Australia

Adoption Status

High Adoption - Early Adopter Market:
Australia is a global leader in adopting precision spraying technology. Its farmers have embraced these solutions early, particularly GoB systems, which have proven effective for managing fallow land in the region's no-tillage farming systems.

Homegrown Innovation and Localized Focus:
Several companies, including WeedIt and Bilberry, have concentrated their initial efforts on Australia, tailoring their technologies to the specific needs of its farming landscape. This has fostered a high degree of familiarity and trust in these solutions.

Drivers for Adoption

1. **No-Tillage Dominates Due to Dry Climate:**
   The arid conditions in Australia make no-tillage farming the norm. Fields often remain fallow for extended periods (5+ months), necessitating effective weed management during this time. Precision spraying aligns perfectly with this need, offering cost and input efficiency.

2. **Low Weed Density Maximizes Savings:**
   With low weed density in many regions, Precision Spraying significantly reduces herbicide use. This enhances the cost-effectiveness of precision spraying, making it an attractive choice for broadacre farms.

3. **Large-Scale Broadacre Farms Simplify ROI Calculations:**
   Australia's expansive farms make it easier to demonstrate the economic benefits of precision spraying. The ability to scale savings across thousands of acres helps justify the investment in these systems.

4. **Severe Weed Resistance Problems:**
   Widespread herbicide resistance, particularly to glyphosate, has created an urgent need for more precise weed control. Precision spraying reduces reliance on blanket applications, enabling targeted management of resistant weeds.

5. **Experience with GoB Facilitates GoG Adoption:**
   The long history of using GoB solutions has created a foundation for quickly adopting GoG technologies. Farmers are already familiar with the value of precision spraying, making the transition to more advanced systems smoother.

6. **Open Mindset Toward Innovation:**
   Australian farmers have a reputation for being early adopters of new agricultural technologies. This innovative mindset has driven the rapid uptake of precision spraying, as growers are willing to experiment with and invest in emerging solutions.

Adoption Challenges

1. **Low-Yield Crops and Relatively Low Herbicide Costs:**
   The region's focus on lower-yield crops, combined with relatively low herbicide costs compared to markets like North America or Western Europe, reduces the financial incentive for precision spraying in some cases.

2. **Lack of Regulations and Subsidies for New Technologies:**
   Unlike regions such as Western Europe, Australia lacks strict regulations or subsidies to drive the adoption of precision spraying. This means farmers adopt primarily for economic reasons, with fewer external pressures or incentives.

3. **Lower Budgets and Limited Government Support:**
   The absence of significant government subsidies for agricultural technology reduces the financial resources available for investment in new equipment.

This often leads to longer equipment life cycles, slowing the turnover necessary for rapid adoption.

Australia is a high-adoption market for precision spraying, driven by unique factors like no-tillage farming, low weed density, and the need for efficient fallow land management. The innovative mindset of Australian farmers and the severe weed resistance challenges have further propelled adoption. However, challenges such as low-yield crops, limited governmental support, and longer equipment lifecycles mean that adoption relies heavily on clear and immediate economic benefits. Continued innovation in affordable and adaptable solutions will be key to sustaining Australia's leadership in precision spraying technology.

South America

Adoption Status

Good Adoption of GoB:
Argentina demonstrates a notable uptake of GoB technology due to its suitability in no-till farming systems and reliance on chemical weed management.

Requirement for GoG:
For broader adoption across South America, especially in regions with multiple cropping cycles per year (e.g., Brazil), GoG technology will be essential to address complex weed scenarios that coexist with crops in the field.

Drivers for Adoption

1. **No-Till Farming Practices:**
   A high prevalence of no-till farming leads to dependence on chemical weed control, creating a strong use case for Precision Spraying technologies to optimize herbicide application.

2. **Large-Scale Farms:**
   Larger farming operations make it easier to calculate a return on investment (RoI), particularly as Precision Spraying technology reduces herbicide costs and increases operational efficiency.

3. **Weed Resistance Challenges:**
   Escalating weed resistance to herbicides in regions like Argentina pushes farmers to adopt precision solutions that minimize chemical overuse and target specific weeds.

4. **High Productivity Emphasis:**
   Large farm sizes in combination with intensive cropping systems (growing crops year round in the tropical regions) necessitate high spraying productivity. Precision Sparying technologies reduce refill frequencies, improving capacity and uptime during spraying operations.

5. **Openness to Innovation:**
   South American farmers demonstrate a willingness to explore innovative technologies, especially when they promise clear economic and environmental benefits.

6. **Awareness of Soil Health:**
   Growing awareness of the negative impacts of overusing crop protection chemicals on soil health drives interest in precision solutions that reduce environmental harm.

Adoption Challenges

1. **Year-Round Cropping Systems:**
   In regions with crops in the field throughout the year (e.g., parts of Brazil), the use case for GoB is limited, as fallow periods are shorter, reducing opportunities for targeted herbicide applications.

2. **Regional Priorities – Pest and Disease Management:**
   In areas like Brazil, where pest and disease pressures are more critical than weed management, Precision Spraying adoption may face slower uptake unless the technology adapts to address these challenges.

3. **Custom Application Dominance in Argentina:**
   A high share of custom applicators means adoption depends on aligning incentives between service providers and farmers.Custom applicators may require a clear economic rationale to invest in Precision Spraying-equipped machinery.

4. **Complex Crop Protection Programs:**
   South America has a high share of fungicide and insecticide applications. Integrating Precision Spraying technology into these programs can be challenging without robust compatibility with existing workflows.

5. **Economic Constraints – Subsidies and Regulation:**
   Limited government subsidies or regulatory incentives to promote precision agriculture slow adoption rates.Farmers must perceive clear economic benefits to justify upfront investment costs.

6. **Long Equipment Life Cycles:**
   Farmers in South America often extend the life cycles of their equipment,

making them less likely to replace sprayers with newer, Precision Spraying-compatible models unless the financial benefits are evident.

Precision spraying adoption in South America is growing, with strong uptake of GoB technology in Argentina due to no-till farming and herbicide reliance. GoG technology is key for broader adoption in regions like Brazil with year-round cropping. Drivers include large-scale farms, rising weed resistance, and interest in soil health and efficiency. Challenges include economic constraints, long equipment lifespans, and the need for compatibility with pest, disease, and crop protection programs. Clear financial benefits and tailored solutions will be essential for wider adoption.

10. Precision Spraying Market Overview

The precision spraying landscape is constantly evolving. Below are insights into the key organizations in this space, along with an overview of the main use cases their products support.

Providers of Online Boom Precision Spraying Technology

This overview highlights the key entities in online precision spraying and the solutions they offer, specifically targeting the row crop and broad-acre markets with solutions for boom sprayers.

Precision Spraying Entities

Upstream

COMPANY	PRODUCT
John Deere	See & Spray Ultimate, Premium
CNH Industrial / Augmenta	SenseApply
AGCO / PTx Trimble / WeedSeeker / Precision / bilberry	
Greeneye Technology	Greeneye Sprayer
BASF / Bosch	one
WEED-IT	Quadro
Exxact Robotics	3S Spot Spray Sensor
DAT	Ecopatch
DeepAgro	Sprai
Solinftec	Solix
Carbon Bee	Smart Striker X
Savefarm	SaveFarm
Agtecnic	SenseSpray
ATAR	Smart Sprayer

Overview of Precision Spraying Providers by Solution Type

In Chapter Three, five distinct precision spraying solution types are introduced. The overview below categorizes the key organizations based on their respective solution types:

Online Boom Spraying – These solutions integrate precision spraying technology directly onto boom sprayers, targeting the broadacre and row crop markets. Most modern solutions now offer both GoB and GoG capabilities, except for WeedIt and WeedSeeker, which focus exclusively on GoB.

Ultra-Precise Precision Spraying – Designed for high-value crops, these solutions offer exceptionally precise spraying capabilities. Unlike retrofitted technologies, these systems involve the development of entirely new implements rather than modifying existing sprayers.

Robotic Precision Spraying – These emerging solutions leverage autonomous field robots that perform both scouting and targeted spraying with high precision. Most are developed from the ground up, with the exception of SwarmFarm, which collaborates with existing precision spraying providers like WeedIt.

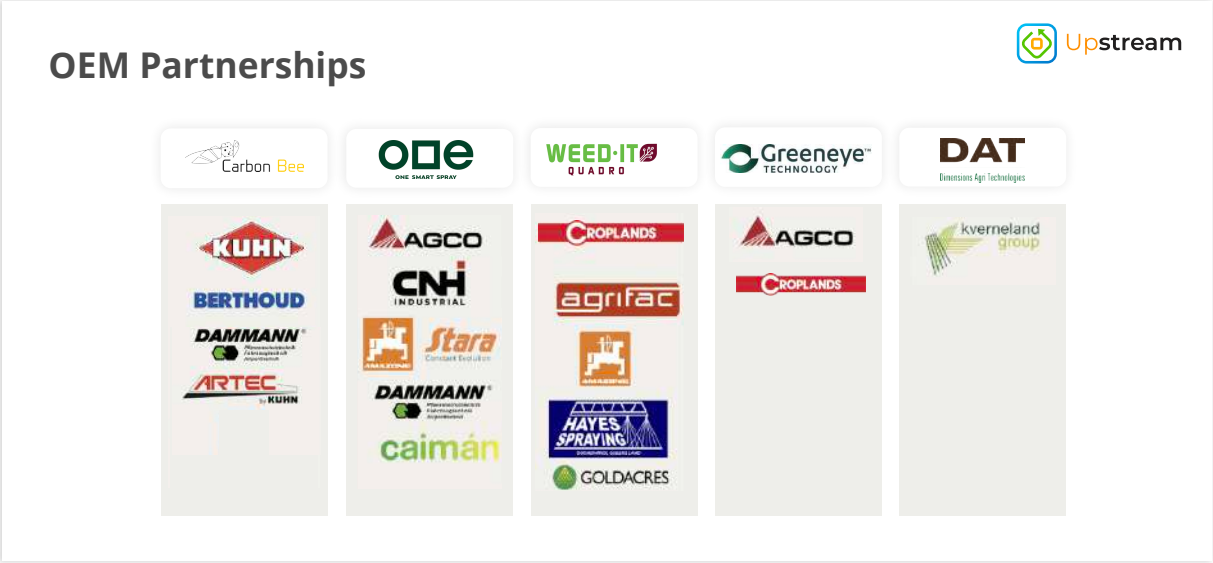
Offline Precision Spraying – This method decouples scouting and spraying into two separate field passes. The first pass involves data collection, often via drones, to map weed locations. The data is then used to create a prescription map for precision spraying during the second pass.

UAV Precision Spraying – Unlike traditional boom sprayers, these solutions utilize drones equipped with spraying technology to fly over fields and target specific weed zones with high accuracy.

This overview highlights the key players in each category, though the landscape is continuously evolving. The Online Boom Spraying segment is the most established, with several long-standing players. However, there is significant momentum in the High-Precision Spraying category, with increasing activity and innovation in this space.

Strategic Collaborations Between Startups and OEMs

Many Precision Spraying Technology providers, often startups, do not solely bring their solutions directly to market. Instead, they establish strategic partnerships with OEMs, allowing their technology to be integrated into OEM equipment. Below is an overview of the key partnerships currently in place.



The next chapter offers a detailed breakdown of each organization listed here. Leading companies are presented with comprehensive profiles, while key information is provided for less established organizations.

11. Precision Spraying Landscape and Company Details

Precision Spraying Landscape and Company Details

Company	AGCO
Description	AGCO released its Symphony Vision Rate and Symphony Vision Spot. Vision Spot is GoB and GoB precision spraying.
Country	United States
Product(s)	Symphony Vision Rate and Symphony Vision Spot
Year Founded	Products Launched in 2025.
Investors	Publicly Traded Company (NYSE: AGCO)
Use Cases	Symphony Spot can be used for GoB and GoB in corn and soybean.
Strategic Partnerships	ONE SMART SPRAY; Greeneye™ TECHNOLOGY
Target Market *(Crops, Countries)*	• **Crops:** Corn and Soybean. • **Countries:** North America, Europe
Business Model	Hardware Fee - Spot priced at $114,000. Rate priced at $72,000
Retrofit *(Y/N)*	Yes
Operating Speed	~15mph
Night Spraying *(Y/N)*	Unknown
Dual Tank *(Y/N)*	No
Type: Section/Patch/Spot	Online Spot spraying.

Carbon Bee

Company	Carbon Bee
Description	Carbon Bee provides spot spray solutions for row crops and broadacre. Their core IP lies in their advanced camera system combined with AI models, enabling high-precision weed detection and Variable Rate Application (VRA).
Country	France (Rhone-Alpes region)
Product(s)	SmartStriker X
Year Founded	2015
Investors	No specific information on investors provided.
Use Cases	• GoB and GoG applications. • Additional use cases include VRA for fungicides and fertilizers.
Distribiution Channels	• Direct sales. • Precision Ag dealers. • OEMs in Europe. • Equipment dealers.
Strategic Partnerships	Collaboration with OEMs to expand product reach. ARTEC BERTHOUD DAMMANN KUHN
Target Market *(Crops, Countries)*	• **Crops:** Broadacre and major row crops. • **Countries:** EU, Australia, North America, Kazakhstan, Argentina, South Africa.
Business Model	• Full system cost around €140,000. • Yearly fee of approximately €10,000 for ongoing product updates and support.
Market Adoption *(if public)*	**Units Sold**: Around 250 units.
Retrofit *(Y/N)*	Yes
Operating Speed	Up to 25 km/h (15.5 mph)
Night Spraying *(Y/N)*	Yes
Dual Tank *(Y/N)*	Not specified.
Type: Section/Patch/Spot	Precision spraying with high precision (spot-level accuracy).

ecorobotix

Company	Ecorobotix
Description	Ecorobotix specializes in ultra-high-precision spraying solutions for high-value crops. Their technology aims to reduce pesticide usage by up to 95% through advanced AI, HD cameras, and autonomous robotic sprayers.
Country	Switzerland (Yverdon-les-Bains, Vaud)
Product(s)	Precision sprayer with a working width of 6 meters, capable of microdroplet application with 6x6 cm resolution.
Year Founded	2014
Investors	• Approximately $80 million raised. • Investors include AQTON Private Equity GmbH, Cibus Capital LLP, Swisscanto Invest, Yara Growth Ventures, BASF Venture Capital, Swisscom Ventures, and others.
Use Cases	• Precision spraying of herbicides, fungicides, and insecticides in high-value crops. • Targeted applications for weed control and crop protection.
Distribiution Channels	• Precision ag dealers, equipment dealers, agronomy partnerships.
Strategic Partnerships	No specific information available.
Target Market *(Crops, Countries)*	• **Crops:** High-value crops such as leafy greens, vegetables, and specialty crops. • **Countries:** Northern Europe and Western USA.
Business Model	• Machine is priced around $150,000 (EU Pricing) • Yearly license fee around $10,000
Market Adoption *(if public)*	• Around 500 units sold globally in early commercial stages. • Growing adoption since 2022.
Retrofit *(Y/N)*	No; the system is a complete implement.
Operating Speed	Average speed of 4–7 km/h (approximately 3 ha/hour, with a maximum of 96 ha in 24 hours).
Night Spraying *(Y/N)*	Yes
Dual Tank *(Y/N)*	Yes; includes a water tank and a spray liquid tank for mobile refilling.
Type: Section/Patch/Spot	Precision spraying with ultra-high precision at 6x6 cm resolution.

Company	Greeneye
Description	Greeneye aims to dramatically reduce chemical usage while improving productivity and profitability for farmers. The company focuses on retrofit precision spraying solutions, particularly targeting the U.S. row crop market.
Country	Israel (Tel Aviv)
Product(s)	Retrofit precision spraying system with dual-tank functionality and advanced AI-powered RGB cameras.
Year Founded	2017
Investors	• Approximately $45 million raised. • Investors include Jerusalem Venture Partners (JVP), Syngenta Group Ventures, Orbia Ventures, and others, along with AGCO.
Use Cases	• GoB and GoG precision spraying. • Band spraying and canopy spraying for fungicides, micronutrients, and insecticides.
Distribiution Channels	• Farmers Business Network (FBN) network. • Recently signed its first dealer outside FBN (Boeck Seeds, a seed dealership in Nebraska).
Strategic Partnerships	• Partnerships with FBN and AGCO. • Custom-developed nozzles with TeeJet.
Target Market *(Crops, Countries)*	• **Crops:** Soybeans, corn, cotton. • **Countries:** United States (Midwest, South, and Great Plains).
Business Model	• **Pricing**: $240,000 for a 120-ft boom system. • No yearly fees.
Market Adoption *(if public)*	• Around 50 systems sold (estimated). • Targeting 200 million acres in the U.S. by 2025, though this is an ambitious goal.
Retrofit *(Y/N)*	Yes (can retrofit most major North American brands). The entire boom is replaced.
Operating Speed	Up to 15 mph (24 km/h).
Night Spraying *(Y/N)*	Yes
Dual Tank *(Y/N)*	Yes
Type: Section/Patch/Spot	Precision spraying with high resolution (weeds as small as 2.5 cm or 1 inch can be detected).

Company	John Deere
Description	John Deere has integrated Blue River Technology into its product offerings, developing advanced precision spraying solutions for both GoB and GoG use cases, emphasizing row crop markets.
Country	United States (Santa Clara, California)
Product(s)	• See & Spray Select (GoB) - Launched in 2021 • See & Spray Premium (Retrofit) - Launched in 2023 • See & Spray Ultimate (GoG) - Launched in 2022
Year Founded	2011 (Blue River Technology acquisition in 2017)
Investors	Blue River Technology raised approximately $30 million before being acquired by John Deere. Key investors included Khosla Ventures.
Use Cases	• GoB and GoG precision spraying. • Band spraying and canopy spraying for fungicides, insecticides, and micronutrients.
Distribiution Channels	• John Deere dealerships with strong field demonstrations through dealers or direct outreach.
Strategic Partnerships	syngenta INNERPLANT partnerships for agronomic and integrated solutions.
Target Market *(Crops, Countries)*	• **Crops:** Corn, soybeans, cotton. • **Countries:** Primarily North America, with expansion to South America and localized products in Europe.
Business Model	• **Pricing**: $143,500 for See & Spray Ultimate; $25,000 for See & Spray Premium retrofit. • **Yearly Fee**: $3/acre for corn, $4/acre for soybeans and cotton, and $1/acre for non-crop areas (pricing to change in 2025 to $5/acre for non-sprayed areas).
Market Adoption *(if public)*	• Approximately 1 million acres covered (per John Deere sustainability report). • Estimated 200 units in the market as of today, with a sales projection of around 1000 units in the near future.
Retrofit *(Y/N)*	Yes (for See & Spray Premium, available for model year 2018 and newer sprayers).
Operating Speed	Up to 15mph for Ultimate, 12mph for Premium.
Night Spraying *(Y/N)*	Limited; only available for See & Spray Select.
Dual Tank *(Y/N)*	Yes (available on See & Spray Ultimate only).
Type: Section/Patch/Spot	Precision spraying with precision at the nozzle level (spot accuracy).

Company	Bosch/BASF ONE SMART SPRAY (Joint Venture)
Description	ONE SMART SPRAY integrates Bosch's hardware, software, and connectivity expertise with BASF's digital and agronomic knowledge to deliver precise and smart herbicide spraying solutions.
Country	Germany (Cologne)
Product(s)	ONE SMART SPRAY system for precision herbicide application, integrating infrared cameras and advanced agronomic intelligence.
Year Founded	2021 (Joint Venture formed in 2021; collaboration began in 2016)
Investors	Jointly funded by Bosch and BASF.
Use Cases	• GoB and GoG precision spraying. • Dual application and other integrated precision applications.
Distribiution Channels	Distributed through OEMs (no retrofit offering).
Strategic Partnerships	• Extensive collaboration with OEMs to integrate solutions into sprayers. • Leveraging BASF's Xarvio digital agronomic platform.
Target Market *(Crops, Countries)*	• **Crops:** Soybeans, corn, sunflower, cotton, canola. • **Countries:** North America, South America, Central and Eastern Europe.
Business Model	• **Pricing**: Not disclosed. • No yearly fees or pay-per-use model mentioned.
Market Adoption *(if public)*	Market penetration has been limited, as adoption depends heavily on OEM integration timelines and the high cost of the solution.
Retrofit *(Y/N)*	No (works only through OEM integration).
Operating Speed	Up to 14mph.
Night Spraying *(Y/N)*	Yes (infrared cameras enable night operation).
Dual Tank *(Y/N)*	Yes (depends on the OEM's sprayer design).
Type: Section/Patch/Spot	Precision spraying with high precision (spot accuracy).

Company	Solinftec
Description	Solinftec develops technologies focused on sustainable and productive agriculture. Initially specializing in fleet management and logistics for the sugarcane market, the company now offers robotics and precision agriculture solutions, including precision spraying.
Country	Brazil
Product(s)	**Solix**: A robot capable of performing precision spraying, weed scouting, and insect management with integrated data collection.
Year Founded	2007
Investors	Around $150 million raised. Key investors include The Lightsmith Group, Itaú BBA, Unbox Capital, Gaia Securitizations, and others.
Use Cases	• GoB and GoG precision spraying. • Weed scouting, insect management, and UV light-based solutions for crop protection.
Distribiution Channels	• Direct sales to corporate and large farms. • Partnerships with ag retail companies like Growmark.
Strategic Partnerships	Collaborates with ag retailers to develop new business models, such as selling weed-free fields.
Target Market *(Crops, Countries)*	• **Crops:** Corn, soybeans. • **Countries:** Brazil, United States, Canada.
Business Model	• **Pricing**: $50,000–$70,000 per robot. • No specific yearly fee mentioned.
Market Adoption *(if public)*	• Around 150 units sold as of 2024. • Operates with a focus on continuous field presence and multiple passes for comprehensive data collection.
Retrofit *(Y/N)*	No; offered as a standalone robotic solution.
Operating Speed	1 mph (1.6 km/h).
Night Spraying *(Y/N)*	Yes
Dual Tank *(Y/N)*	No
Type: Section/Patch/Spot	Precision spraying with spot precision.

SOLINFTEC

SOLINFTEC

WEED-IT QUADRO

Company	Rometron (Operating as WEED-IT)
Description	One of the inventors of Precision Spraying technology, focused on Green-on-Brown (GoB) use cases. A market leader with global recognition.
Country	The Netherlands
Product(s)	Precision Spraying systems with proprietary Pulse Width Modulation (PWM) technology.
Year Founded	1999
Investors	Bootstrapped (no external investors).
Use Cases	GoB on fallow land and between rows.
Distribiution Channels	• Independent dealers. • Precision Ag dealers. • Ag retail partnerships. • OEM partnerships.
Strategic Partnerships	Includes collaboration with ag retailers and OEMs GOLDACRES CROPLANDS agrifac HAYES SPRAYING AMAZONE
Target Market *(Crops, Countries)*	• **Crops:** Fallow land, cereals, row crops. • **Countries:** Australia, USA, Canada, South America.
Business Model	• Product cost around $1,500/ft, up to $180,000 for a complete system. • No yearly or pay-per-use fees, making it distinct from competitors.
Market Adoption *(if public)*	Around 1,500 units sold globally, making it a leader in market penetration for precision spraying technology.
Retrofit *(Y/N)*	Yes
Operating Speed	Up to 25 km/h (15.5 mph)
Night Spraying *(Y/N)*	Yes
Dual Tank *(Y/N)*	Yes
Type: Section/Patch/Spot	Precision spraying, with nozzle-level precision every 25 cm (10 inches).

Additional Precision Spaying Solutions focus on boom-sprayers

Below is an overview of other providers offering online precision spraying technologies for broadacre and row crops, utilizing sensor-mounted sprayers.

Upstream

Precision Spraying Solutions Tier 2

Organization	Commercial Status	Use Case	Target Region	Insights
Agtecnic	Commercial	GoB	Australia	Agtecnic is an Australian provider specializing in GoB spot spraying with an operating speed of 12 mph. They have strong ties with CNH in Australia and appear to focus more on OEM partnerships rather than direct sales to growers.
ATAR	Pre-Commercial	GoB & GoG	Central EU *(soybeans, sunflower, corn, sugar beet)*	ATAR, a Central European provider, is developing an affordable spraying system featuring a proprietary nozzle control technology.
DeepAgro	Commercial	GoB & GoG	Argentina	DeepAgro focuses on South America, providing a GoG solution with operating speeds of up to 12 mph. They install an additional spray line on the sprayer, enabling dual application for enhanced efficiency.
EXXACT ROBOTICS	Pre-series 2023	GoB & GoG & VRA	Europe	Exxact Robotics is the technology division of Exel Industries, a group that owns several equipment brands, primarily sprayer manufacturers such as Agrifac, Hardi, and Apache. They have developed an advanced GoB and GoG system, the 3S Spot Spray Sensor, which is being introduced through their sprayer brands, starting with Agrifac.
HORSCH	Pre-Commercial	GoB & band spraying	Europe, mainly row crops	Horsch has tested and validated various third-party precision spraying systems but ultimately chose to develop its own in-house solution focused on weed spotting and band spraying. The system is not yet commercially available.
SAVEFARM PULVERIZAÇÃO SELETIVA	Commercial	GoB & GoG & Dual Dose	South America, Brazil	Savefarm has a strong focus on the Brazilian market, offering a lightweight system with a weight of 1.5 kg per meter of boom. Their primary focus is on a nozzle control system, capable of operating at speeds of up to 15 mph.
SMART SENSING	Commercial	GoB	South America, Brazil	Smart Sensing utilizes WEED-IT technology, making adjustments for the South American market to support GoB and, to some extent, GoG.
WeedSeeker 2	Commercial, 500+ units	GoB	Australia, South America, North America	WeedSeeker is a global pioneer in GoB spot spraying, with a strong presence in Australia, South America, and North America. Their system is widely adopted and is priced at approximately $150,000 for a 120-ft boom.

Another, smaller category of organizations uses a single sensor mounted on the tractor or sprayer cab, rather than multiple sensors on the sprayer boom. These sensors were initially designed for variable rate application (VRA) of fertilizers but also have the potential to support a limited version of precision spraying.

Tractor Mounted Sensors

Organization	Commercial Status	Use Case	Target Region	Insights
AUGMENTA	Commercial	VRA of in-season nitrogen, VRA of growth regulator and fungicides, VRA Burndown	North America and Europe	Augmenta, which was acquired by CNH, developed a crop sensor that mounts on the cab of a tractor or sprayer. The system primarily scans the crop to enable variable rate application of inputs based on canopy density and crop needs. It is expected that CNH will leverage this technology to expand its capabilities, including spot spraying of weeds.
PerPlant	Commercial	VRA of in-season nitrogen, VRA of growth regulator and fungicides, GoB	North and Western EU	PerPlant is a Danish startup developing a versatile crop sensor designed for real-time crop scanning. Mounted on the cab of a tractor, the sensor enables precision application of fertilizers and chemicals based on crop needs. One of its key applications is spot spraying of weeds.

Below is an overview of providers offering ultra-precise precision spraying solutions, primarily targeting the high-value crop market, such as vegetable crops.

Upstream

Ultra-Precise Precision Spraying Providers

Organization	Commercial Status	Use Case	Target Region	Insights
BAYER	Prototype	High Value Crops	Western Europe	At Agritechnica 2023, Bayer introduced the Magic Sprayer as a concept. The system offers high-precision spraying with nozzles spaced every 3 cm. However, Bayer has stated that they do not plan to commercialize the system independently.
FARM-ING	Early Commercial	High Value Crops	Western Europe	Farm-ING initially developed a smart mechanical weeder before expanding into spot spraying technology, leveraging key components from their existing system, such as the vision system. Their solution shares strong synergies with the Ecorobotix machine, but they aim to position it at a more affordable price point.
FLUX	Development	High Value Crops	Australia	FLUX Robotics is an early-stage company developing a spot spraying solution for high-value crops in Australia. While they initially focused on creating an autonomous field robot, they now also plan to offer their solution as an implement. However, the development is still in its early stages.
NIQO ROBOTICS	Commercial	Row Crops and High Value Crops	Asia and North America	Niqo initially developed RoboSpray, an affordable boom-based spot sprayer designed for the Indian market. Their second product, RoboThin, is now a precision sprayer tailored for high-value crops, primarily focused on lettuce thinning.
VERDANT ROBOTICS	Early Commercial	High Value Crops	Western USA	Verdant's SharpShooter is a versatile precision application system designed for targeted spraying of weeds, crop thinning, and fertilizer application. Its unique setup allows it to accurately target weeds even when they are very close to the crop or beneath the canopy, ensuring high-precision input application.

Below is an overview of the emerging and growing category of robotic precision spraying providers.

Upstream

Robot Precision Spraying Providers

Organization	Commercial Status	Use Case	Target Region	Insights
Kilter Systems in balance	Early Commercial	High Value Crops	Northern Europe, Australia, New Zealand	Kilter offers a lightweight robot, weighing 260 kg, designed for ultra-high precision spraying using microdroplets in high-value crops. Their system achieves an impressive 6mm x 6mm accuracy, ensuring precise and efficient application.
	Commercial	Broad Acre Crops GoB	Australia	SwarmFarm collaborates with multiple precision spraying providers, including WeedIt, to enable fully automated targeted weed spraying in cereal crops. Their primary focus is on managing weeds in fallow land.

Below is an overview of offline precision spraying providers, where scouting and execution are separate steps, with scouting primarily conducted using UAVs.

Upstream

Offline Precision Spraying Providers

Organization	Commercial Status	Use Case	Target Region	Insights
sentera	Early Commercial	GoG	USA	Sentera has launched SmartScript, a precision agronomy solution that uses drone-based field scanning to map weed spots and generate a prescription for the sprayer with a turnaround time of under 24 hours. They claim the system can detect weeds as small as 6mm, enabling highly targeted and efficient weed management.
Croptic	Early Commercial	GoG *(insect and disease scanning in development)*	Benelux	Croptic is an early-stage Belgium-based company specializing in weed mapping as a service. They generate prescription maps compatible with most sprayer types, enabling targeted weed control. In addition to weed detection, they are developing algorithms for identifying insects and diseases, including blight in potatoes.
SAM DIMENSION	Commercial	GoG	Germany and Central Europe	Sam Dimension is an early-stage German company offering weed mapping as a service in Germany and the Central European market. They support a variety of crops, including cereals and sugar beets, and provide high-precision mapping at 1mm accuracy. Their prescription maps are designed to be compatible with most sprayers, enabling precise and efficient weed management.
HARDI	Early Commercial	GoB	Australia, cereals	Hardi has launched GeoSelect, an offline spot spraying solution that utilizes UAVs to map weed spots and generate a prescription for targeted application with the sprayer. They claim a scouting capacity of 1,000 hectares per day and are currently focused on the Australian market.

Below is an overview of key providers of UAV technologies that can also be utilized for precision spraying applications.

Upstream

UAV Precision Spraying

Organization	Commercial Status	Use Case	Target Region	Insights
GUARDIAN AGRICULTURE	Commercial	GoB and GoG in Row Crops	North America	Guardian is a U.S.-based drone manufacturer specializing in agricultural spraying solutions. Their drones feature a 91 kg payload capacity and can be equipped with an 18-ft spray boom, enabling both conventional broadcast spraying and targeted weed spraying for precise application.
PRECISION AI	Early Commercial	GoB and GoG in Row Crops	North America	Precision AI has introduced the Stratus AirSprayer, an aerial spraying system capable of carrying up to 100 gallons and precisely targeting weeds at speeds of 38 mph. Its high productivity positions it as a unique hybrid solution, bridging the gap between traditional UAV sprayers and conventional boom sprayers.

12. Other Precision Spraying Solutions and Augmentative Companies

Complementary Technologies Enhancing Precision Spraying

While precision spraying systems are evolving how inputs are applied, a broader ecosystem of innovations is emerging to further enhance their impact. These technologies focus on optimizing droplet behavior, improving spray efficacy, providing precise stress detection, and reducing chemical waste—sometimes working alongside precision sprayers, or in an alternative fashion. From advancements in spray deposition and drift control to improved weed density prediction, these solutions play a critical role in refining application strategies and improving overall agronomic outcomes. This section explores key technologies that complement and augment precision spraying systems, offering additional layers of efficiency and sustainability in modern crop protection.

AgZen

A noteworthy company with a unique approach to precision spraying is AgZen, which introduces a novel "Feedback Optimized" approach that enhances both droplet coverage and adherence for improved crop protection.

AgZen's technology stands out by mounting cameras directly onto the spray boom, a system called RealCoverage. This machine-vision-based system monitors spray droplet behavior in real-time, assessing how well droplets are reaching and sticking to the target (whether crop or weed). By enabling farmers to adjust sprayer settings based on conditions like crop type, water volume, and product mix, AgZen provides immediate, actionable insights to optimize application efficiency.

AgZen's second offering, EnhancedCoverage, further refines droplet application with a specialized nozzle technology. Unlike traditional tank-mixed adjuvants, this system coats droplets with an adjuvant at the nozzle, enhancing adherence to plant leaves. This direct-injection approach helps droplets stay on target, which is critical for effective crop protection.

Why Droplet Management Matters

Effective droplet targeting is foundational to crop protection product performance. Currently, most registered application rates per acre account for inefficiencies like drift, droplet bounce, and coverage inconsistency, which can significantly reduce treatment efficacy and lead to resistance if pests survive undercut doses. When 30% or more of droplets miss or bounce off the target, it effectively results in suboptimal application

rates, undermining pest and weed control.

By optimizing spray settings and droplet adherence, AgZen's technology presents the potential to achieve effective treatment at lower rates, reducing costs without sacrificing efficacy—an attractive proposition for farmers.

AgZen's patented technology has far-reaching utility across various aspects of crop protection and input management, including:

- **Regulatory Use:** Supporting accurate rate registration by ensuring target coverage is sufficient under varied conditions.
- **System Performance Enhancement:** Assessing and improving the efficacy of other precision spraying systems and current sprayer settings.
- **Custom Spray Services:** Benefiting ag retail custom spraying services with real-time adjustments to ensure optimal target adherence.
- **Product Comparisons:** Allowing crop protection companies to evaluate product performance, particularly when comparing branded formulations to generics.

With a primary focus on improving spray accuracy, AgZen's innovations align closely with market needs and offer potential cost savings and effectiveness gains, making it a compelling player within the precision spraying space. Like most ag technologies, AgZen faces adoption chain challenges, requiring buy-in from multiple stakeholders, but its innovative approach offers broad applicability and value across the input supply chain.

Upstream

Source: AgZen website

MagrowTec is another company specializing in spray technology solutions designed to enhance the efficiency and sustainability of crop protection applications.

The company's flagship product leverages patented magnetic technology to optimize spray distribution, reducing drift and improving droplet adhesion to plant surfaces. This approach not only ensures more precise application of crop protection products but also significantly reduces waste, contributing to environmental sustainability and cost savings for farmers.

MagrowTec's solutions are particularly valued for their ability to increase spray efficiency in challenging conditions, such as high wind or uneven canopies. By improving droplet deposition and coverage, the technology supports better crop health and yield outcomes. The company's systems are compatible with a wide range of sprayers, making adoption seamless for growers across different farming systems.

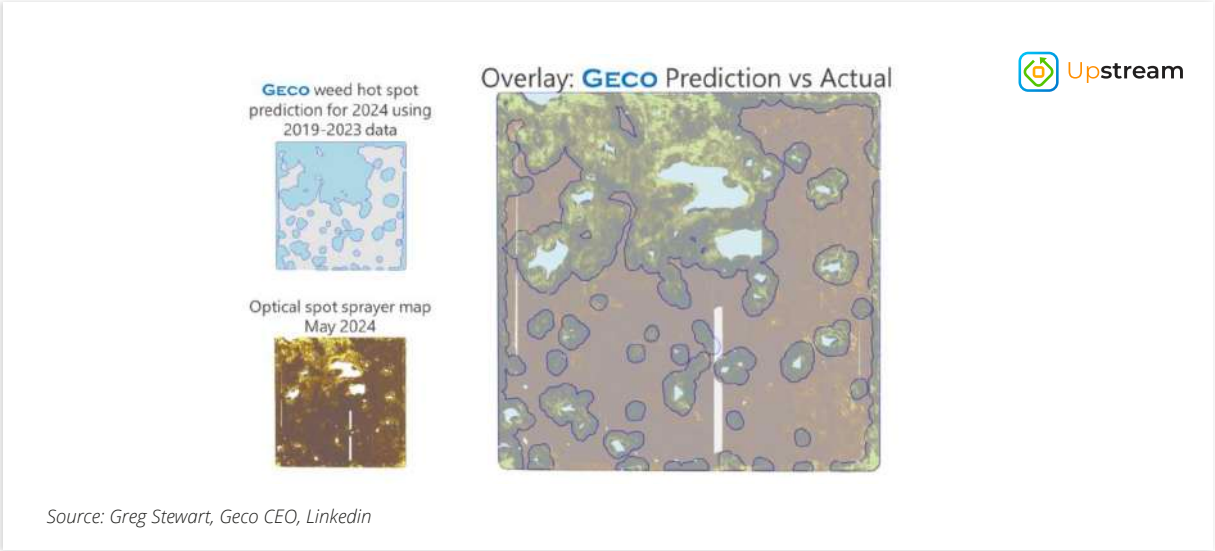
Source: MagrowTec website

Geco Ag's Strategic Weed Management system uses historical farm data, satellite imagery, and agronomic modeling to support more precise herbicide applications. By

analyzing weed emergence patterns and potential herbicide resistance, it helps farmers apply residual herbicides in areas where they are most needed, making the approach compatible with precision spraying solutions moving forward.

The system also has the potential to give a future focused estimate of required herbicide volumes based on past data and expected weed pressure. This allows for more accurate chemical ordering, reducing excess inventory and improving cost efficiency. It also supports better tank-mixing logistics by ensuring the right amount of herbicide is prepared for each application.

Geco Ag is designed to work with existing farm equipment and software systems, making it easier for farmers to refine both residual and post-emergence herbicide applications without additional hardware. This helps optimize chemical use while maintaining effective weed control.



Source: Greg Stewart, Geco CEO, Linkedin

INNERPLANT

September, John Deere announced it was leading the InnerPlant Series A Investment, a company developing genetically engineered soybeans that elicit unique biosignals when they experience specific stressors, such as fungal pressure or insect feeding.

InnerPlant's trait technology platform allows remote sensors, such as satellites, to interpret what a plant is experiencing and when. This ability to take action more proactively and precisely enables better outcomes for farmers.

13. Incumbent Position

Original Equipment Manufacturer

Blue River Technology Acquisition

In 2017, John Deere acquired Blue River Technology for $305 million, marking a milestone in the agricultural technology landscape. Blue River Technology, a pioneer in computer vision and machine learning for agriculture, developed a platform that utilized cameras and AI to differentiate between crops and weeds, starting with high value crops. This innovation was a spray system that could reduce herbicide use, and improve agronomic outcomes on farm.

The Launch of See and Spray Ultimate

In 2021, John Deere unveiled the See & Spray Ultimate, a fully integrated System with dual tanks, a reinforced carbon boom and 36 cameras mounted on a sprayer boom to deliver high-resolution imagery of fields in real time.

Key Features:

- **Dual Mode Spraying:** The ability to perform both broadcast and targeted spraying in a single pass because of the dual tank.
- **Herbicide Savings:** Up to 77% reduction in herbicide use, translating to significant cost savings and environmental benefits. As of 2024, Deere stated that they saw an average of 59% reduction in herbicide use across 1 million acres in 2024.
- **High-Speed Performance:** as of 2024 can be used at upwards of 15mph.

See & Spray Premium

In 2022, John Deere introduced the See & Spray Premium, a retrofit system that could be added onto 2018 and newer John Deere sprayers. This iteration was designed to offer access to a wider array of farms. While maintaining core functionalities such as weed detection and selective spraying, the Premium model offered a more accessible price point and slightly reduced capabilities compared to the Ultimate, such as a singular tank system and difference reinforcement on the spray boom.

Current Updates

In 2024, John Deere hosted a Virtual Agronomy Summit spotlighting its See & Spray system.

The event offered a glimpse into the lessons learned from real-world usage and the insights driving this product's evolution.

From technical adjustments to practical applications in the field, to the potential of See & Spray in enhancing efficiency, and outcomes for growers, the Summit was focused on enhancing understanding of the See & Spray system.

1 The Need for Speed

John Deere shared a nice comparison chart, illustrating the differences between See & Spray Ultimate and See & Spray Premium:

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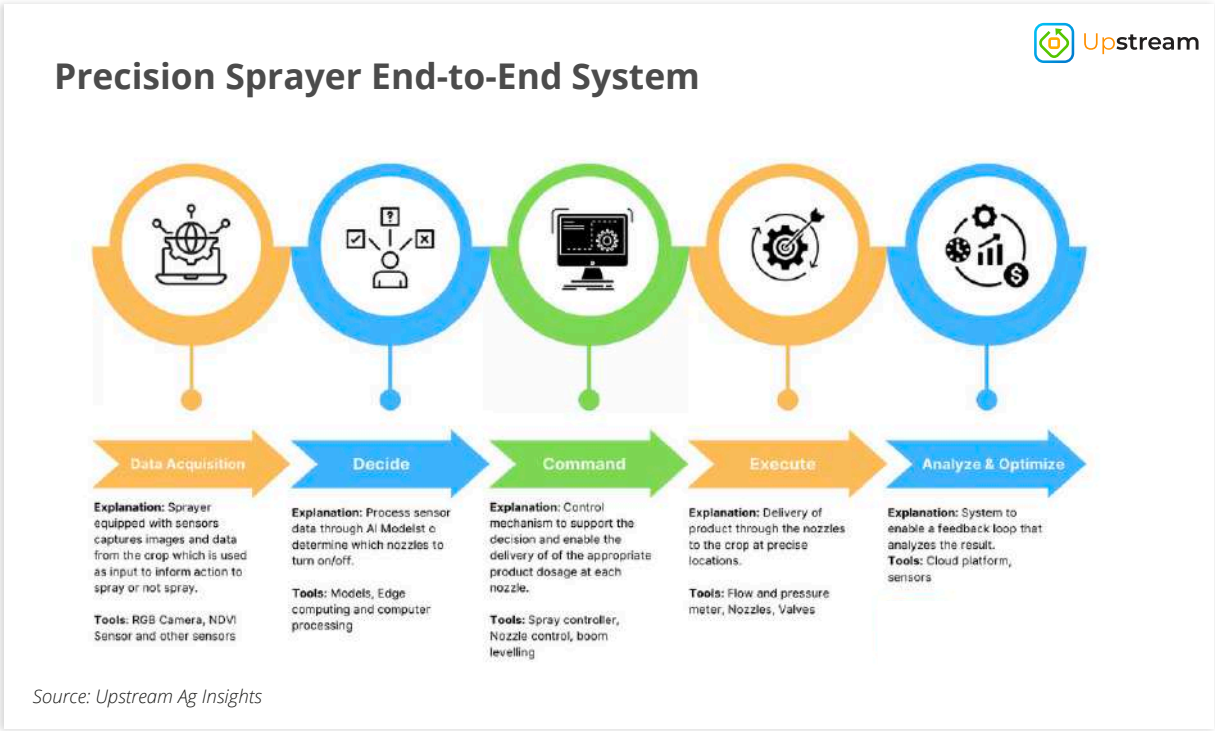
How to See & Spray Premium and Ultimate Options **Compare?**

	PREMIUM	ULTIMATE
Traditional Broadcast Spray Application	●	●
Targeted Spary Apllication (Fallow)	●	●
Targeted Spary Apllication (GoG)	●	●
Max Speed while Target Spraying	*12 MPH*	*15 MPH*
Tank Configuration	*Single Tank*	*Dual-Product Solution System/Split Tank*
Vision Processing Units	*6 VPUs*	*10 VPUs*
Boom Type & Control	*100' or 120' Steel Boom w/ BoomTrac Pro 2*	*120' Carbon-fiber truss-style w/ BoomTrac Ultimate*

Source: John Deere 2024 Agronomy Summit



Source: Upstream Ag Insights

The constraint on speed stems from the needs of the system to reduce the time it takes for the end-to-end process: capture the image, process it through the model, make a decision, tell the right nozzle(s) to turn on then off. Some of the time comes from machine learning processing, and some comes from the communication (getting an image from the camera to the controller and sending the message to the nozzle).

This can be tough to execute at higher speed, while maintaining adequate weed control.

The bottle neck to the above then is inference latency (eg: how long the neural network takes to determine if a weed is in the image). John Deere, or any other company, can reduce this latency without increasing detection error, a farmer can drive faster.

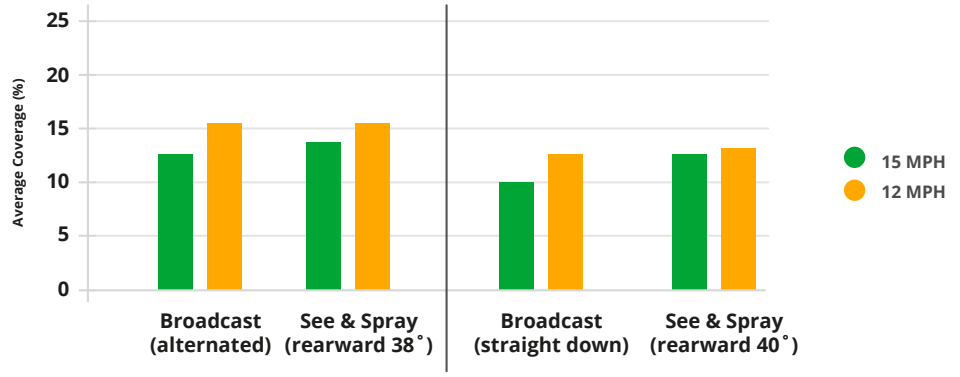
Reducing latency of any networked process comes from two things:

1. faster software (algorithm improvements/optimizations)
2. faster hardware (eg: microchips)

The biggest contributor is likely the hardware, which means John Deere relies on chip improvements from companies like NVIDIA, potentially camera positioning to generate incremental lead time or nozzle positioning:

See & Spray - Application Technology

See & Spary provides equivalent or better spray coverage* on 6-inch targets compared to broadcast at 12 and 15 mph application speeds

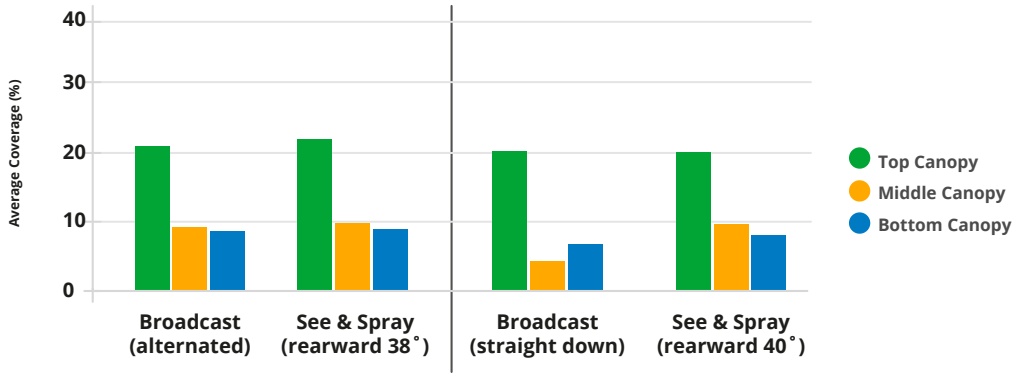


**Spray coverage averaged across three target heights.*
Rated speed for See & Spray Premium: 12 mph
Rated speed for See & Spray Ultiamte: 15 mph

Source: John Deere | Agronomy Summit | In the Weeds with See & Spray™

See & Spray - Application Technology

See & Spary provides more complete coverage through the canopy on 6-inch targets



Source: John Deere | Agronomy Summit | In the Weeds with See & Spray™

**Results running at 15 mph*

15mph is still slower than many broadcast applications will go (17+mph), but that gets incrementally closer to the same sort of in-field efficiency as a broadcast application. John Deere has also shared insights into See & Spray parameters by crop:

See & Spray Premium & Ultimate System

Capability by Crop

	Minimum Crop Height	Maximum Crop Height	Weed Size	Row Spacing w/Row Travel	Cross Row Travel
CORN	≥ V2	≤ 16 in.	Sees weeds ~1/4" x 1/4"	30 in. minimum	
SOYBEANS	≥ V1			15 in. minimum	• 12 mph max • Max crop height: 9 in. • 30° spray angle • Wide fan nozzle tips only
COTTON	≥ Cotyledon			30 in. minimum	

Source: John Deere 2024 Agronomy Summit

Along with the different tank modes they have:

See & Spray Ultimate Tank Modes

Capability by Crop

Single Independent

Carring a different product in Tank 1 and Tank 2
AND
Only spraying from one tank at a time

Dual Independent

Spray two different products simultaneously

Tank 1: Broadcast OR S&S
Tank 2: Broadcast Only

Combined
(See & Spray Premium)

Combining the volume of both tanks when running a single mix to get maximum capacity

Source: John Deere 2024 Agronomy Summit

The dual independent tank is where See & Spray gets compelling as more than a herbicide tool and becomes a multi-use agronomic solution— enabling broadcast sprays of fungicides, nutrients or biostimulants while also being able to manage weeds.

This doesn't even include the data insights acquired from the cameras on the system being captured every pass.

2 Sensitivity Settings

John Deere has also shared the ability to set the sensitivity of the system to focus on control or savings:

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All Crops _____ Ultimate & Premium

Lowest Setting:	Medium Setting:	Highest Setting:
Product savings is prioritized. Some targets will be ignored.	Balance of product coverage and product savings. Some targets will be ignored.	Product coverage is prioritized. Closest equivalent to broadcast.

Source: John Deere 2024 Agronomy Summit

John Deere shared examples to illustrate the variance between low, medium and high settings. Low and High shared below:

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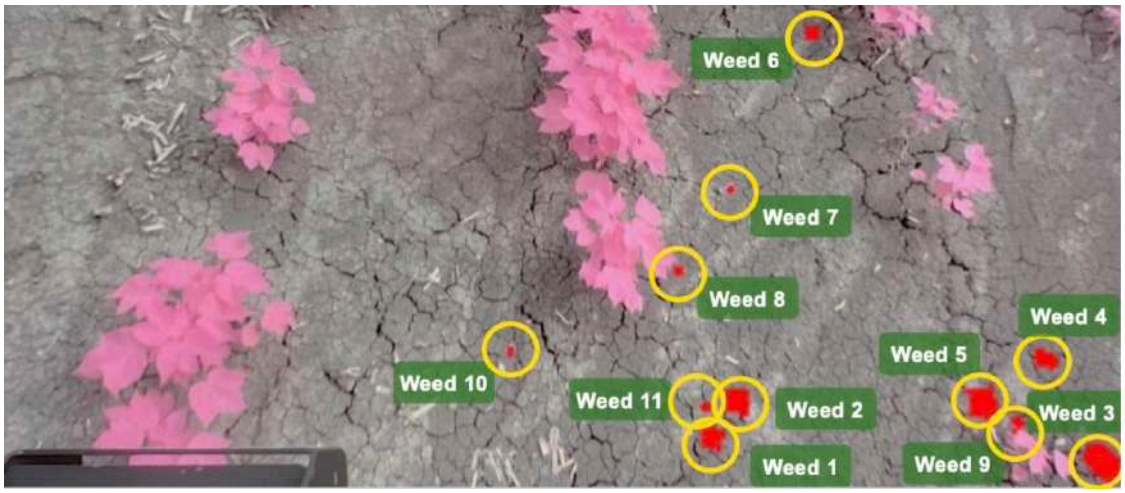
Lowest Sensitivity Setting

Source: John Deere | Agronomy Summit | In the Weeds with See & Spray™

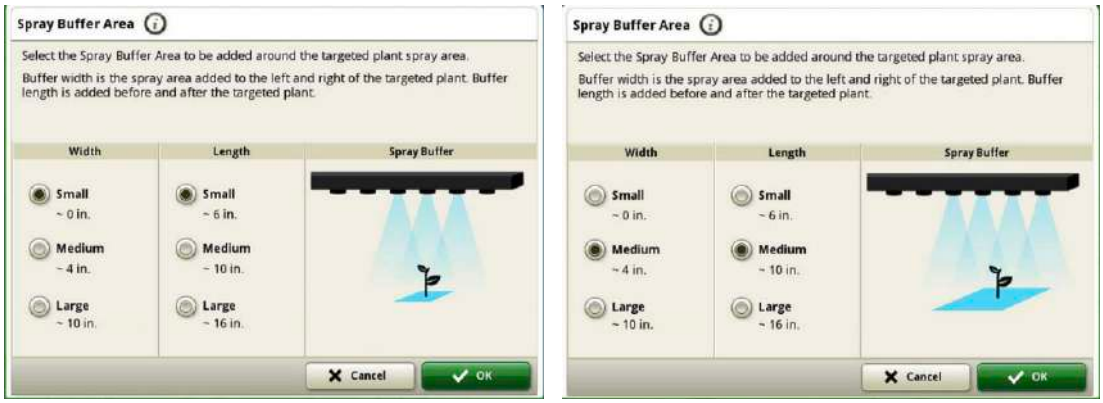
Highest Sensitivity Setting



Source: John Deere | Agronomy Summit | In the Weeds with See & Spray™

John Deere also shared the buffer settings around the precision of the nozzle, which plays into farmer control along with potential to manage the amount of herbicide that touches the crop itself:

See & Spray Buffer Settings



Source: John Deere 2024 Agronomy Summit

3 Display and Field Analyzer

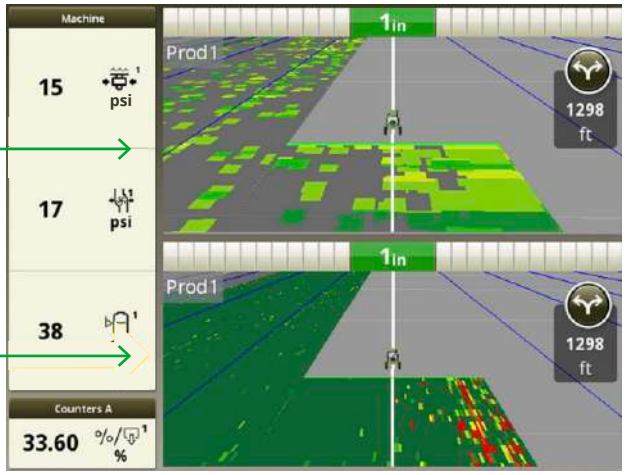
One crucial consideration for See & Spray is ensuring farmer confidence in where and what was sprayed. John Deere has shared images from their software that illustrates weed maps and as-applied data, delivering enhanced confidence to the farmer in See & Spray performance:

In the Display

Upstream

Applied Rate

Weed Pressure



Source: John Deere 2024 Agronomy Summit

Field Analyzer Applied Rate Map

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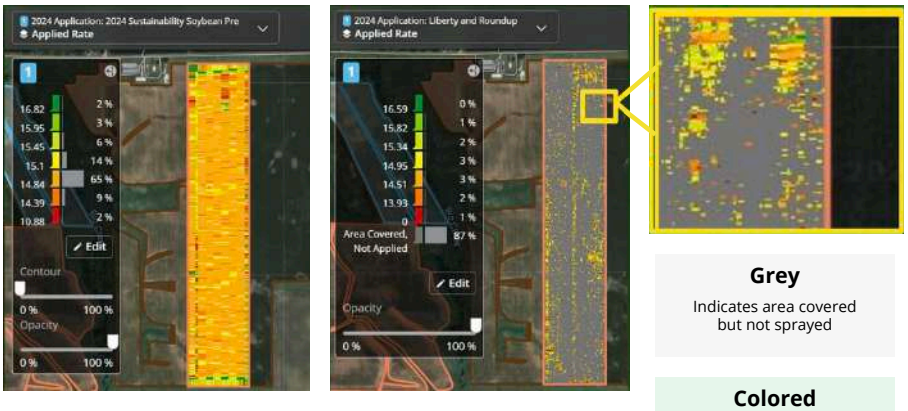
Without See & Spray

With See & Spray



Grey

Indicates area covered but not sprayed

Colored

sections indicate where product was applied at the designated rate

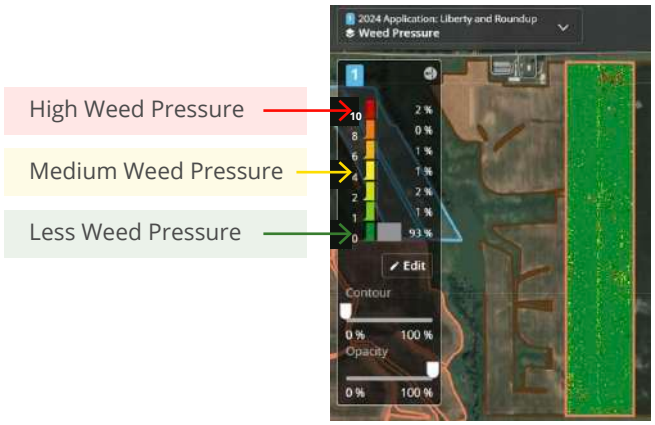
Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

Incumbent Position

The Weed Pressure Map is built based on the sensitivity selection the farmer makes.

Upstream

Field Analyzer Weed Pressure Map



Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

Than Hartsock, Vice-President of Precision Upgrades at John Deere shared the following with Upstream Ag Insights:

> *"The rationale for the current implementation is that the sensitivity adjustment actually does result in the machine interpreting presence or absence of a weed. Higher sensitivity will catch more weeds, but also potentially more false positives. Lower sensitivity will let a few very small weeds pass by, but it will also have false negatives or misses. So in a way, the farmer or operator tunes the system to represent what they would consider true weed pressure in their field. And that is what the map then represents."*

Deere also shared Field Analyzer Summary examples:

Field Analyzer Summaries

Upstream

Combining See & Spray data with standard information like application speed, target rate, and totals in Operations Center gives you a complete picture of your application work.

Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

Work Analyzer See & Spray Performance Report

Upstream

Report Includes:

- Weekly Area and Savings Summary
- See & Spray Technology Utilization
- Optimization opportunities
- Highlights fields with highest and lowest savings

Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

4 Weed Pressure Insight

71.5% of weed pressure is in the headlands and/or along waterways.

If you ask any farmer, spray operator or agronomist they would tell you “most weeds” are in those areas, however, there would not be such a precise quantification.

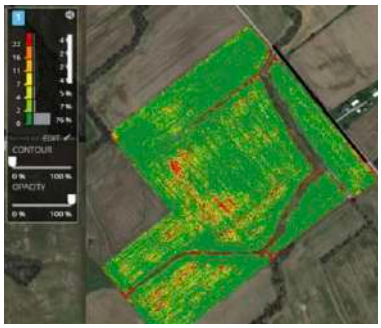
The interesting part about this stat is that is highlights the capability of John Deere in assessing and understanding precise aspects of infield agronomics, giving them (and the farmer) an information advantage:

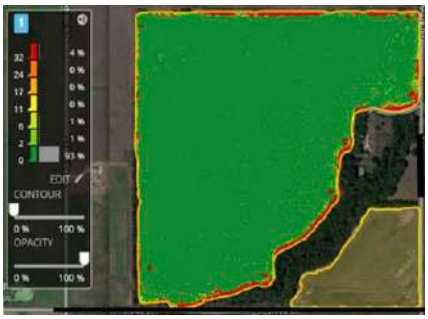
Weed Distribution

Upstream

71.5% of field weed pressure is in the headlands pass and/or along waterways*

Evenly distributed weeds	Condensed weed presence in the end rows





** Based on anonymized data shared with consent by John Deere sprayer customers from 2024 spray season.*
Results vary based on weed pressure, crop types, machine settings, and environmental conditions.

Crop protection companies will have less access to the data about what weeds are in a field (and then rolled up to a geography), empower the farmer to have better information to make crop protection decisions.

When layering this capability into See & Spray assets, it delivers a precise ability to inform future herbicide product decisions, rate decisions, mixing decisions and more. All of which the input manufacturer could be less engaged in, leading to commoditization risk.

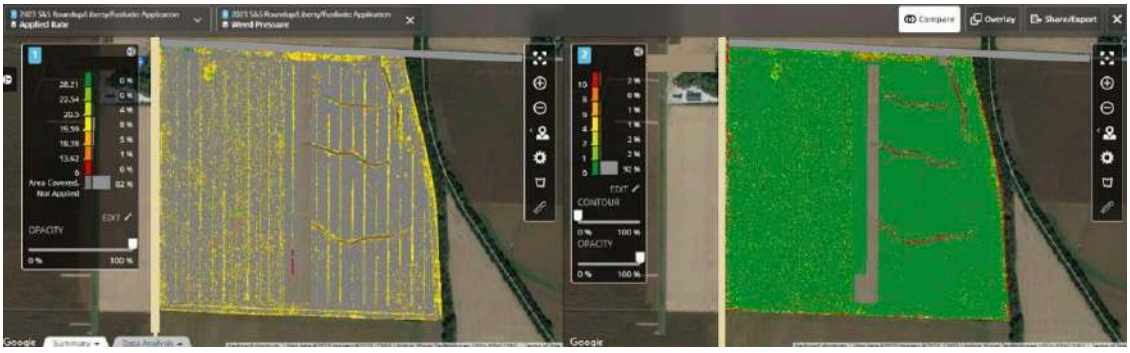
On top, Deere shared how the system can help inform other decisions, like tillage:

Tillage Decisions

Upstream

Reduced Tillage Decreased Early Season Weed Pressure

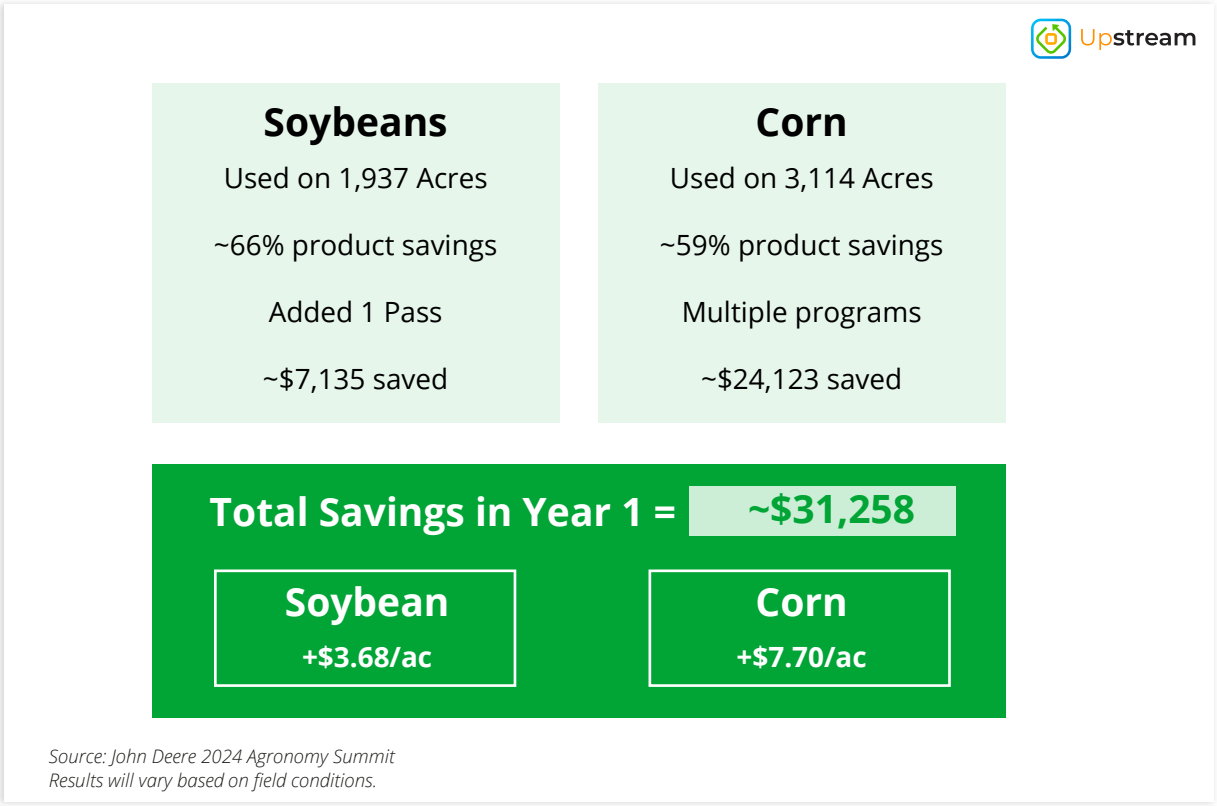
Applied Rate Map	Weed Pressure Map



Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

5 Savings

Deere gave some updated numbers on savings, which does a great job illustrating how varying approaches can lead to savings, including their new initiatives to ensure that only acres where there are savings are charged to the farmer on a per acre basis.



Source: John Deere 2024 Agronomy Summit
Results will vary based on field conditions.

AGCO's Precision Spraying Strategy

Overview

AGCO's precision spraying strategy reflects its commitment to advancing precision farming practices through cutting-edge technology. By investing in strategic partnerships, leveraging innovative technologies, and aligning with industry leaders, AGCO is positioning itself as a key player in the precision spraying market, specifically for retrofits. This section explores AGCO's approach, including its investments, collaborations, and acquisitions that contribute to its broader precision agriculture goals.

AGCO Symphony AGCO has introduced Symphony Vision Rate and Symphony Vision Spot, its latest precision spraying technologies designed to enhance crop protection efficiency in corn and soybean farming. Launched in 2025, these systems leverage

vision-based technology to enable green-on-brown (GoB) and green-on-green (GoG) precision spraying, optimizing herbicide application while reducing input costs.

Symphony Spot and Symphony Rate are part of AGCO's Precision Strategy, reflecting the company's push into high-speed, retrofit precision spraying solutions. With an operating speed of ~15 mph, Symphony provides efficient coverage while maintaining accuracy. Unlike some competitors, it does not feature a dual tank system, and its night spraying capabilities remain unknown.

Designed for retrofit compatibility, Symphony allows farmers to upgrade existing equipment rather than purchasing new sprayers outright. The business model is upfront and hardware-based, with Symphony Spot priced at $114,000 and Symphony Rate at $72,000 and no continued pricing. AGCO is positioning Symphony for North American and European markets, aiming to support large-scale growers seeking more precise, cost-effective herbicide application.

Greeneye Technology Investment

In 2021, AGCO announced an investment in Greeneye Technology (Resulting in a 3% ownership stake in the company), an Israeli startup renowned for its advanced AI and machine learning capabilities in precision spraying. Greeneye's technology enables ultra-targeted herbicide application by identifying weeds and crops at the plant level with exceptional accuracy.

Greeneye's high-resolution camera system operates at field speeds of up to 20 km/h while maintaining 95% accuracy, offering significant herbicide savings of up to 90%. Additionally, its retrofit solution allows farmers to integrate the technology into existing sprayers, lowering barriers to adoption.

ONE Smart Spray Partnership

AGCO's collaboration with Bosch BASF Smart Farming led to the development of ONE Smart Spray, an advanced precision spraying solution designed to integrate seamlessly with AGCO's sprayers. This partnership combines AGCO's agricultural equipment expertise with Bosch BASF's digital and agronomic capabilities to create a comprehensive solution for targeted weed control.

ONE Smart Spray employs real-time camera and sensor technology to identify weeds and selectively apply herbicides, minimizing chemical use and maximizing efficiency. Fully integrated with AGCO's Ag Command system, the platform provides farmers with detailed application performance data. This solution underscores AGCO's commitment to innovation and its ability to offer scalable precision agriculture tools.

Precision Planting's Spraying Solutions

AGCO's Precision Planting division, known for its innovative planting technologies, is actively developing precision spraying solutions. These initiatives focus on enhancing chemical application accuracy by leveraging Precision Planting's existing control systems and agronomic expertise.

The anticipated solutions include individual nozzle control to deliver plant-level precision and seamless integration with Precision Planting's platforms like 20|20. This development is expected to cater to mid-sized farms, offering retrofittable solutions that align with AGCO's goal of democratizing access to advanced technologies.

Trimble Acquisition and Its Implications

In a strategic move to expand its precision agriculture capabilities, AGCO acquired Trimble's Ag Business in 2023. This acquisition brought several valuable assets under AGCO's umbrella, including advanced GPS guidance systems and precision spraying technologies developed by Trimble. Among these are Bilberry's AI-driven weed detection system and the WeedSeeker technology.

- **Bilberry Technology:** Bilberry's solutions use advanced machine learning to distinguish between crops and weeds in real time, enabling ultra-precise herbicide application. This technology is particularly effective in complex field environments, offering significant savings in chemical use and labor. It appears that Bilberry is in the process of being phased out given the launch of Symphony products. Bilberry will be discontinued apart from in Australia.

- **WeedSeeker Technology:** One of the Pioneers in precision spraying, originally developed by NTech and later acquired by Trimble, WeedSeeker employs optical sensors to detect and spray only on weeds, making it an ideal solution for GoG use cases, such as fallow fields and row crop applications. The

technology reduces herbicide use by up to 80%, providing both cost savings and environmental benefits. Its compatibility with various sprayer systems makes it a versatile addition to AGCO's portfolio.

The Trimble acquisition enhances AGCO's ability to offer integrated precision spraying solutions, solidifying its position as a leader in sustainable farming technologies.

CNH Industrial's Precision Spraying Strategy Overview

CNH Industrial is advancing its precision spraying capabilities through a combination of strategic partnerships and acquisitions aimed at delivering cutting-edge solutions for modern agriculture.

1. **Partnership with ONE Smart Spray:**
   CNH announced early 2023 a partnership with **ONE Smart Spray**, a joint venture between Bosch and BASF Digital Farming, to integrate their advanced precision spraying technology into CNH's equipment portfolio. This collaboration focuses on developing intelligent spraying systems that utilize cameras, sensors, and AI to detect and spray weeds selectively. By combining precision targeting with advanced analytics, this technology aims to optimize chemical use, reduce environmental impact, and increase farmer profitability.

2. **Acquisition of Augmenta:**
   CNH Industrial further strengthened its precision spraying strategy by acquiring **Augmenta for $110 million USD**, a leader in sensor-based variable rate application technology. Augmenta's systems use AI and machine vision to analyze crops in real-time and adjust inputs dynamically, ensuring optimal application of fertilizers, pesticides, and other crop inputs. The system was not originally designed for targeted weed spraying, but CNH may leverage the technology to develop this application.

Case IH has recently introduced SenseApply™, an automated Live Variable Rate Application (VRA) solution designed to optimize input efficiency as the next iteration of Augmenta technology. The system features a single cab-mounted camera that enables multi-season use. It operates at speeds of up to 25 mph, with the camera

self-calibrating within 150 feet during Live VRA applications. Positioned on top of the cab for an optimal field of view, the camera detects plant biomass and adjusts application rates in real time based on the selected mode.

SenseApply supports multiple application methods, including Selective Spray and Live Variable Rate Application. The Selective Spray feature includes Green-on-Brown Spot Spray for targeted weed control and a Base + Boost mode that applies a consistent base rate while increasing application in high-weed-pressure areas. Live VRA applications include BoB burndown, nitrogen, harvest aid, plant growth regulators, and fungicides.

The system is designed as a cost-effective solution with no annual subscriptions or per-acre fees. A one-time activation fee applies to Selective Spray, while Live VRA use is included for the lifetime of the device. By offering flexibility, efficiency, and multi-season adaptability, SenseApply provides growers with a practical approach to precision application while optimizing input usage.

CNH Industrial does not currently have a flagship precision spraying product that competes with John Deere's See & Spray or Greeneye Technologies in the GoG Online Spot Spraying market segment. CNH could look externally to acquire a company, such as Greeneye Technologies, or develop internally, extending capabilities such as Augmenta.

Crop Protection Manufacturers

BASF
We create chemistry

BASF is unique in their effort as the only crop protection entity to outright build a precision spraying business.

BASF's **ONE Smart Spray**, developed in collaboration with Bosch, is a precision spraying system designed to enhance efficiency and sustainability in crop protection. The system uses advanced camera sensors and AI-powered weed detection to identify and target weeds in real time, applying herbicides only where needed. This targeted approach can reduce herbicide use by up to 70%, lowering input costs and environmental impact while improving crop health by minimizing overspray. With features like cloud integration and data analytics, farmers can optimize field operations, monitor weed pressure, and make data-driven decisions.

By focusing on precision and sustainability, ONE Smart Spray delivers economic and environmental benefits that align with modern agricultural challenges. ONE Smart Spray

focuses on OEM partnerships, offering its solution exclusively through OEM integrations rather than as a retrofit option. BASF positions the system as a competitor to technologies like John Deere's See & Spray, leveraging Bosch's expertise and BASF's crop protection portfolio to offer a comprehensive solution for farmers.

The Bayer MagicSprayer 6000 is a prototype spot sprayer developed by Bayer Crop Science to enhance precision in weed control and reduce herbicide usage in European agriculture. Unveiled at the Agritechnica trade fair in November 2023, the MagicSprayer 6000 features a 6-meter working width divided into three elements. Its spray nozzles are positioned 3 centimeters apart, creating 'pixels' of 4 by 4 centimeters on the ground, allowing for highly targeted weed control.

Equipped with advanced LED lighting and camera systems, the sprayer ensures optimal conditions for weed detection. The LED lights provide superior illumination, while integrated cameras and sensors accurately identify and locate weeds for precise application.

During testing, the MagicSprayer 6000 operated at speeds up to 6 km/h, with expectations to reach 8 to 12 km/h in future developments. Bayer does not plan to market the MagicSprayer 6000 directly but views it as part of broader efforts to reduce herbicide use in agriculture.

Upstream

Source:
https://www.materielagricole.info/pulverisation/article/860945/bayer-un-prototype-de-pulverisateur-cible-magicsprayer

Syngenta Ventures is invested in Greeneye Technology, but they do not have any other public initiatives that directly tie their commercial efforts to a precision spraying solution.

The one exception is their collaboration with InnerPlant and John Deere.
Syngenta is collaborating with John Deere and InnerPlant to revolutionize fungicide application using precision spraying technology. This partnership focuses on integrating InnerPlant's biosignal technology with John Deere's See and Spray capabilities, starting with two key soybean diseases: **septoria glycines** and **frog eye leaf spot**.

How Syngenta Fits In

The collaboration enables Syngenta to adapt to the growing demand for precision spraying. InnerPlant's genetically engineered crops emit early signals of stress, detectable weeks before visible symptoms appear. These signals would guide John Deere sprayers to apply fungicides proactively and precisely, ensuring better efficacy while reducing broadcast usage.

Syngenta's involvement goes beyond participation. By leveraging plant-level insights and precision application data, Syngenta can develop tailored fungicide formulations, adjust application rates, and refine product labels to better utilize the data insights and precision spraying capabilities. This adaptability positions Syngenta to differentiate its products.

Corteva is not currently associated with any precision spraying company and has not came forth with any specific initiative surrounding the segment.

Corteva CEO Chuck Magro has commented on the concept on analyst calls though. Chuck Magro has consistently framed precision spraying technologies like John Deere's See & Spray as complementary but not a central concern or a priority to navigate within their strategy.

Magro emphasizes Corteva's focus on low-use-rate chemistries that deliver efficacy with standard equipment, suggesting their products accomplish similar outcomes without the high upfront costs of precision systems.

He has highlighted opportunities with drone applications several times, which could align with these new chemistries and may suggest an area they are more closely looking at for the evolution of spraying crop protection products.

While their may be merit to Magro's comments, it seems to overlook the primary value proposition of precision spraying: reducing input costs and addressing herbicide resistance management.

Precision spraying systems are fundamentally about farm economics and outcomes, offering measurable cost savings and agronomic benefits such as reduced crop stress and improved weed control. In contrast, Corteva's premium-priced low-use-rate herbicide products focus on sustainability and efficacy but are unlikely to directly lower farmers' overall costs.

While Corteva acknowledges precision spraying's potential, their messaging suggests a dismissive attitude about its long-term impact. The company's cautious framing of See & Spray reflects a broader hesitance to fully address how this technology could disrupt traditional crop protection business models. Precision spraying may not dominate acres in the near term, but its ability to deliver cost savings and better outcomes positions it as a meaningful challenge for Corteva to closely consider.

14. Impact on the Broader Industry Ecosystem

Business Model Evolution

Theoretical Case Study: How Could Precision Spraying Impact Nutrien Ag Solution's Retail Business?

The adoption of precision spraying technology presents both challenges and opportunities for agricultural retailers such as Nutrien Ag Solutions.
As the largest agricultural retailer in North America, Nutrien's business model is built around product sales and services, with crop protection products representing a significant portion of its revenue. Understanding the financial implications of precision spraying is critical for considering the future strategic direction of the broader retail sector.

Quantifying the Risk to Herbicide Revenue

In 2023, Nutrien Ag Solutions generated approximately $4.4 billion in retail gross margin across all business segments.

Crop protection products accounted for 35% of this margin, or $1.55 billion, though Nutrien does not publicly disclose the breakdown between herbicides, insecticides, and fungicides. Given industry dynamics, it is reasonable to estimate that 50% of crop protection revenue is derived from herbicides, placing $775 million in herbicide gross margin dollars potentially at risk due to precision spraying technology.

Precision spraying does not eliminate herbicide use entirely; rather, it optimizes application rates based on weed presence. Reductions in herbicide volume can vary widely, from 15% to 90% per application, depending on field conditions. A conservative assumption of 50% average herbicide reduction suggests that almost 10% of Nutrien's total gross margin dollars, or approximately $387 million, is at risk due to precision spraying technology.

It is important to note that this estimate is imperfect. A portion of herbicides is applied pre-plant, which precision spraying does not directly impact. Additionally, herbicide resistance and weed management complexities will ensure continued demand for certain products, mitigating total losses.

Opportunities in Precision Spraying Services

While a shift away from broad-acre herbicide applications presents a revenue challenge, it also creates an opportunity for Nutrien's service business. The company's "Services" segment generated $927 million in revenue in 2023, with 77% gross margins. Given Nutrien's scale, particularly in the United States, its retail network is well-positioned to monetize precision spraying technology as a service.

If Nutrien increases service revenue by 10% augmenting its spray fleet with precision application offerings, it could push total service revenue to over $1 billion. Additionally, assuming a 5% increase in service gross margin, Nutrien's service segment could reach $880 million in gross margin—an increase of $170 million. While the Nutrien financials include dollars beyond just product application, they illustrate that incremental service revenue could counteract some losses from herbicide sales.

Strategic Implications for Nutrien

Beyond financial impact, precision spraying alters Nutrien's go-to-market strategy and presents new opportunities to capture value:

1. **Reallocating Sales Focus:** With reduced time spent on herbicide sales, agronomists can shift focus toward plant and soil testing, specialty nutrition, and biological products—categories with lower treatment intensity and the ability to grow, along with higher potential margin capture. In 2025, Nutrien Ag Solutions President Jeff Tarsi stated that they are intending to grow this segment of their business by 15%.

2. **Integration with Sustainability Initiatives:** Nutrien's Sustainable Agriproducts Program could benefit from a fleet of precision -enabled sprayers, improving alignment with sustainability objectives and potentially unlocking additional revenue streams through sustainability-linked incentives.

3. **Novel Services:** Nutrien has the potential create unique service offerings that might include optimized fields and new data support services given the increase level of understanding going on within the customer fields.

Key Challenges and Industry Questions

Despite these opportunities, several industry-wide considerations remain:

- **Manufacturer Program Adaptations:** Many crop protection manufacturers structure pricing and incentives around volume-based rebates. If precision spraying reduces overall product sales, manufacturers may shift incentive structures toward **treatment intensity per acre** rather than total volume. This shift could impact retailer and manufacturer profitability alike.

- **Fleet Evolution Costs:** Transitioning to a **multi-tank See & Spray fleet** requires significant capital investment. The pace at which Nutrien and other large retailers adopt this technology will depend on cost-benefit analyses, access to financing, and potential **partnerships with manufacturers** such as John Deere. Alternative technology providers, such as **Solinftec**, may also play a role in adoption.

Conclusion

Precision spraying technology represents a fundamental shift in crop management, altering herbicide consumption patterns while creating new service-based revenue streams. Nutrien Ag Solutions, given its scale and service infrastructure, is positioned to capitalize on this shift through premium service offerings and integration with broader agronomic strategies. However, success will depend on strategic adaptation, manufacturer collaboration, and investment in fleet modernization. For agricultural retailers, embracing precision spraying is not merely an option—it is a necessity for remaining competitive in the evolving agribusiness landscape.

Jevons Paradox, Complement Disruption, and the Future of Crop Protection

As precision spraying technology advances, the natural expectation is that it will lead to a reduction in overall crop protection product usage—less waste, greater efficiency, and lower input costs for farmers.

However, historical economic and technological trends suggest a more complex reality. Jevons Paradox, an economic principle that challenges the conventional wisdom of efficiency gains, suggests that rather than reducing overall consumption, increased efficiency often drives expanded use. In agriculture, this could mean that precision spraying technologies such as Precision Spraying will not necessarily lead to a reduction in crop protection volumes but could instead shift how, where, and when these products are applied—potentially increasing total usage.

Beyond Jevons Paradox, another shift is occurring: disruption through complements. Traditionally, herbicides and other crop protection products have been the primary drivers of weed control, with sprayers serving as the enabling tool. However, as sprayers equipped with precision solutions become the point of decision making for crop protection products, the power dynamic is shifting. The ability to precision apply diminishes the relative importance of herbicide product differentiation—commoditizing the product and shifting value capture from the input itself to the application technology. This change, known as complement disruption, could erode crop protection manufacturers' influence and margins, forcing them to rethink their market positioning and business models.

Together, Jevons Paradox and complement disruption are concepts for the upstream agriculture industry to be cognizant of. Precision spraying is not just about reducing waste—it is about reshaping product demand, altering competitive dynamics, and redefining who holds the power in the value chain. The implications for manufacturers, retailers, and farmers alike require a reevaluation of strategies, alliances, and business models in the changing landscape.

Other Agribusiness Considerations

Jevons Paradox is named after the English economist William Stanley Jevons. It's a counterintuitive economic theory that suggests improvements in efficiency for using a resource can lead to an overall increase in the consumption of that resource, rather than a decrease. This paradox has primarily been applied to sustainability efforts, specifically in the context of energy consumption and environmental conservation.

The implications reach beyond energy consumption, though. More specifically, the concept can be directly applied to crop input usage and precision agriculture.

Introduction Jevons Paradox

At the heart of Jevons Paradox is the concept of the **rebound effect**, where the gains in efficiency lead not to a reduction in resources use, but to an increase.

This occurs because as a resource becomes more efficient to use, its cost of use decreases, making it more accessible and attractive for consumption. This increased affordability can lead to higher consumption rates that may offset, or often exceed, the efficiency gains.

Real World Examples

Energy and Iron

One of the most cited examples of Jevon's Paradox is in the energy sector. As technologies become more energy-efficient, the logic would suggest that less energy should be consumed. However, evidence shows that improvements in energy efficiency often lead to an increase in energy demand. For instance, as LED lighting technology has become more efficient and cheaper, its use has proliferated, leading to an overall increase in energy consumption for lighting.

In the 1800's when Jevon's wrote his original paper, he shared that if some technological advance made it possible for a blast furnace to produce iron with less coal, then profits would rise, new investment in iron production would come, and the price of iron would then fall, stimulating additional demand. Eventually, he concluded, *"the greater number of furnaces will more than make up for the diminished consumption of each."* This turned out to be true.

Transportation

In the transportation sector, fuel-efficient vehicles exemplify the paradox. As cars become more fuel-efficient, the cost per mile of driving decreases, which often leads to people driving more. This increased vehicle usage can offset the benefits of the fuel efficiency gains. Despite significant improvements in fuel economy over the decades,

total fuel consumption and vehicle miles traveled have continued to rise.

This has also been experienced with highway infrastructure and congestion— as investment in more highways or more lanes built out, the usage of vehicles increases, leading to more congestion.

Extrapolating to Farming

Yield and Quality as a Primary Revenue Method

In farming today, the primary way a farmer increases revenue on an acre is increasing the yield and/or the yield quality. That means unless there are changes to the underlying system (eg: paid for a reduction in pesticide usage, carbon intensity score, or changing to novel more practices like intercropping etc), there is going to be continued desire to increase yield and quality.

There are cultural practices and an improvement from improving traditional practices (eg: better placed seed) to increase yield, but once those efforts have been implemented, **the next way to increase yield and quality typically comes from an increase inputs— a fungicide to manage disease, more fertilizer to fuel the crop, a biostimulant to enhance plant health, or an additional herbicide to clean up a field for next year.**

When costs are reduced, there is often a re-allocation of funds, not an elimination of the spend and realization of savings. Just like the iron example above, there is likely a reinvestment into producing more— this can be extrapolated beyond herbicide and to fungicide.

Today, there is a generally a black and white "go/no-go" decision for a field. As we see the ability to precisely apply fungicide where it is needed most, such as through the InnerPlant, John Deere, Syngenta, Collaboration, or other precision approaches, we may see less acres per field applied to, but total number of fields treated (treatment intensity) increase through only spraying certain areas that are at risk.

There is also the ability to break apart the field into different targets or timings— meaning multiple passes for fungicide and herbicide for example where volume applied each application could decline, but the total number of passes increases.

This reinforces that Precision Spraying is not limited to influencing herbicide use, but many other areas of crop protection— from herbicides to fungicides, to biostimulants for example. The implication of precision spraying technology is not on just herbicides, but all crop protection products.

Early Examples and Practice Evolution

New tools bring new strategies. One new strategy might include an increase in pass number and change in timing. I am cognizant that each pass still has a cost (eg: fuel, depreciation, compaction etc) and time is still a limited resource— but one thing worth considering is that one of the biggest time drag of spraying is tank-filling, which can be drastically reduced with Precision Spraying.

For the mid-west United States, we can take an early indication from this Wisconsin Weeds post from Weed Scientist Rodrigo Werle, where he states on to state the following about adding an additional pass when a farmer has the "Premium" model:

> *If a PRE-emergence soil residual herbicide is to be applied early in the season (at planting time or shortly after), which is highly recommended for weed management in corn and soybean particularly for growers dealing with waterhemp, the targeted application modality of the See & SprayTM Premium system becomes of no use,* ***unless a grower is willing to make two trips on the same field****, one targeting established weeds with a burndown program (See & Spray modality on; GoB application) and a second immediate trip delivering the residual herbicide program through a regular broadcast application (See & Spray modality off).*

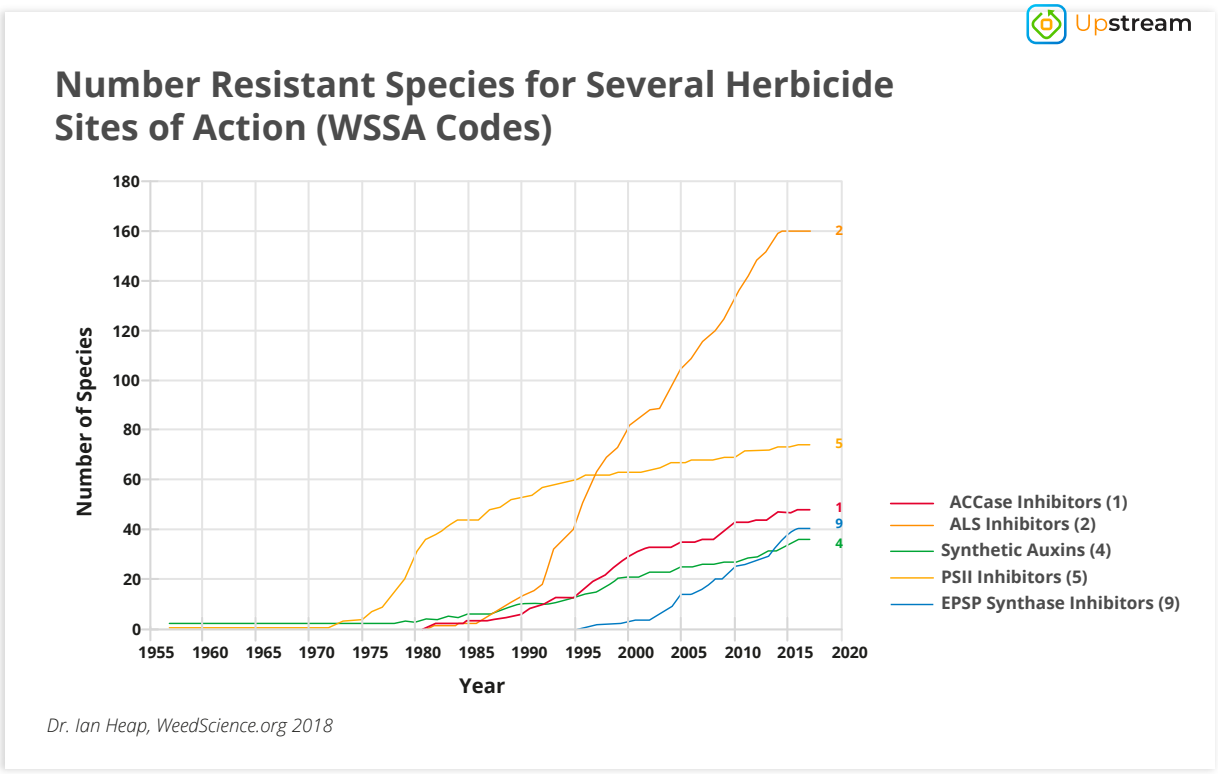
Dr. Werle's commentary was specific to a "Premium" See and Spray model with only one tank. The "Ultimate" product however has two tanks, which gives the ability to manage weeds in a novel way, that could lead to an increase in product utilization (more below in Herbicide Resistance). Greeneye's system includes two tanks, as well.

A two tank system allows for delivering a broadcast application + a spot spray application, which means when a broadcast fungicide is being applied, a farmer could consider adding a herbicide to the other tank, or when applying a herbicide, a farmer might reinvest the savings into a biostimulant in the broadcast tank.

Herbicide Resistance

One of the biggest risks to farmers profitability is herbicide resistance (along with fungicide and other pest resistance). **Biology tends to be more clever than all of us**.

No matter what you throw at a weed, there will inevitably be some novel mutation that has the potential for that weed to overcome a tool. Today, there are hundreds of resistant weeds, and growing every year:



One of the things that seems inevitable is the **need to reinvest precision application herbicide savings into more tank mixed products, more sprayer passes, more adjuvants, higher rates or some combination**. Without a consideration for herbicide resistance, weed issues will continue to arise. This reality is likely to drive an increase in product usage.

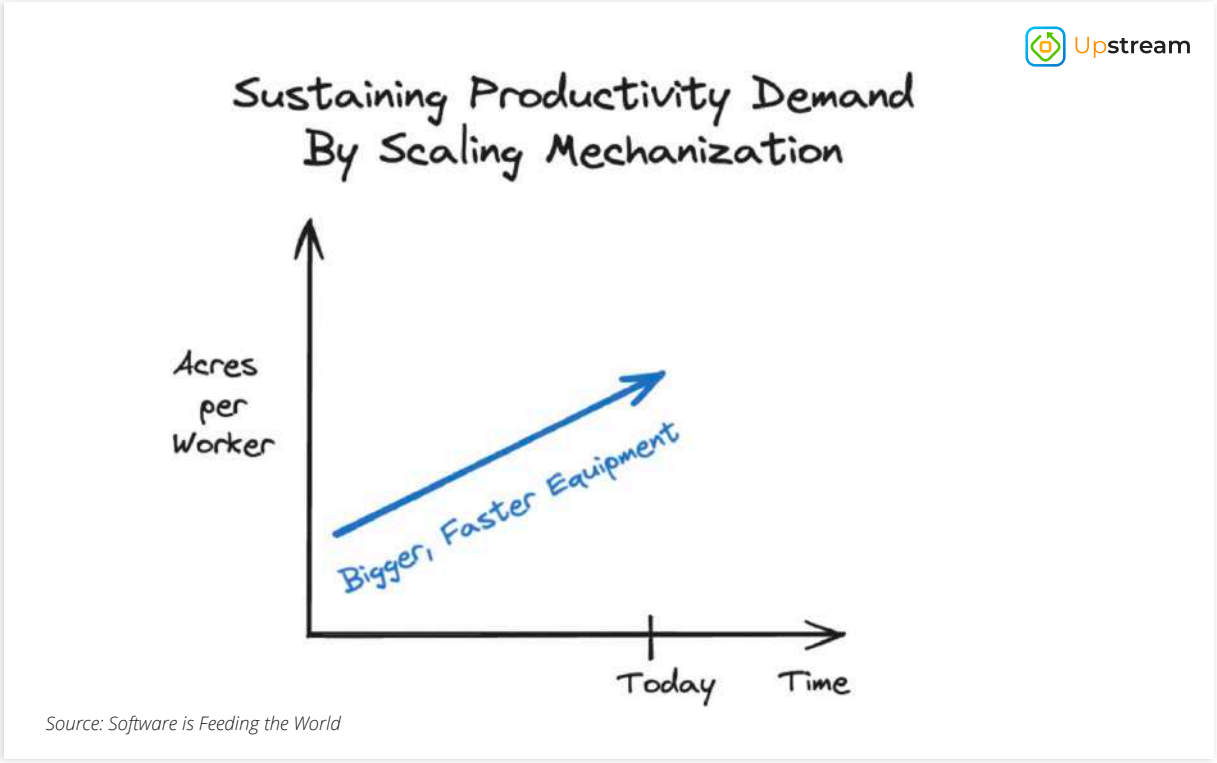
Not An Isolated Technology

We can never look at a new technology in isolation. It needs to be looked at with consideration to other converging or emerging trends.

That brings up the question of how autonomous tractors influence precision applications.

Today, there is a cost of labor with every pass. By 2030, John Deere, and other OEM organizations like AGCO, have stated they want to deliver an autonomous production system to the market. Once there is a reduction in labor cost (I purposely do not state elimination, there is still a need for obtaining product, mixing products for spray tank, yard work etc) there is a more streamlined ability to deploy a sprayer to a field for a lower cost. Even consider the Solinftec and the Solix Platform.

Equipment companies have traditionally tried to solve this through scale.



Source: Software is Feeding the World

Bigger equipment still has constraints, though.

In agronomy and farming, there is the often cited statement that **logistics trumps agronomics**, suggesting efficiency gets prioritized over proper agronomics. But with autonomy and automation, **it decouples the labor constraints from operational needs**, allowing for optimization of agronomic outcomes— and as stated above, optimizing agronomic outcomes often means more crop input products used.

Note: Business models and true costs will be dependent on how frequently various assets will run through a field. Just because labor is eliminated doesn't mean an additional pass has no cost— depreciation, fuel, trample, compaction and more all contribute to the marginal expense of a field pass.

Given the realities of crop production, the nuance of biology and other emerging trends (autonomy) there is potential for crop protection volumes to increase, not decrease thanks to precision application, while delivering enhanced outcomes to farmers— better herbicide control, enhanced ability to manage pesticide resistance, and ultimately higher yields. That is a great thing for farmers, and the entire input value chain.

But what are the second order implications of precision application and Jevons Paradox?

Commoditization of Crop Protection Products

The Jobs-to-be-Done Lens Behind Crop Input Decision Making

Business strategy legend Clay Christensen came up with Jobs to Be Done theory. The theory of Jobs to Be Done is a framework for better understanding customer behaviour.

Basically the framing is that people don't buy products, they "hire" them to perform some job in their life or within their business that moves them forward to an outcome or goal.

It's based on the classic quote that "people don't want a quarter-inch drill bit, they want a quarter-inch hole". The premise of the idea is to figure out what kinds of situations people might find themselves in, what kind of pains they experience, and why they might go looking for solutions to solve that problem.

In the instance of crop protection products, **there is a need to protect the crop from a specific pest**. If we think about weeds in a field, then we would naturally say the "job to be done" is to kill the weed. But the "job to be done" at a level higher is to have a weed free field (which could be supportive of other future efforts from John Deere in the combine with a seed destructor or laser technology, for example) which is generally supported by using a herbicide, which is assessed on a continuum of parameters before a farmer "hires" the right herbicide for the job, including:

- efficacy on target weeds
- crop type *(and trait)*
- crop safety and safe stage
- price *(and programming)*
- tank mixability
- soil residual
- other including bulkiness of product *(eg: rate used per acre)*, formulation *(eg: solutions vs. granule)*, applicator safety, volatility etc.

In the broadcast herbicide application across the entire field scenario we currently operate in, each herbicide will be differentiated in some way (either worse or better) vs. competitors across each of those continuums to which a farmer or agronomist will determine the best fit based on their specific needs.

Along those parameters are how the majority of herbicides are marketed and positioned today, being differentiated across one or some combination of those parameters allows organizations like Corteva or Syngenta to make incremental margins on their IP protected products and compete against generic products or one another.

In our current application system that we operate in, the sprayer has to spray the entire field.

Today, performance of a herbicide, which is the ultimate arbiter of the job to be done (weed free field), will deliver essentially the same outcome whether using a John Deere 612R or a Case IH Patriot 4450. There is some nuance in efficiencies due to water tank size, service thanks to dealership choice or even a tweak in nozzles but generally the efficacy and all other performance parameters of a herbicide on Palmer Amaranth in corn or kochia in wheat comes down to the herbicides unique performance capabilities and the herbicide trait in the crop variety, not what sprayer is being used.

Today, **the sprayer is a complement to the herbicide**.

What happens when the system changes and the biggest point of differentiation is the sprayers ability to identify and spray weeds with precision while having multiple tanks?
All of a sudden the value of tank mixability, crop safety, price and even to a degree, relative efficacy decrease in importance and the ability to "see and spray" becomes the "choke point" where value accrues to, commoditizing the value of differentiated herbicides leading to potentially lower margins for crop input companies. And it is unlikely to stop at herbicides and herbicide traits.

This is known as disruption through complements.

Disruption Through Complements

Disruption through complements arises from a combination of forces according to strategy experts Ron Adner and Marvin Lieberman:

1. technological change alters the calculations of cost and benefit
2. organizational learning alters the understanding of opportunity
3. capability building alters the complementor's effectiveness in pursuing new goals.

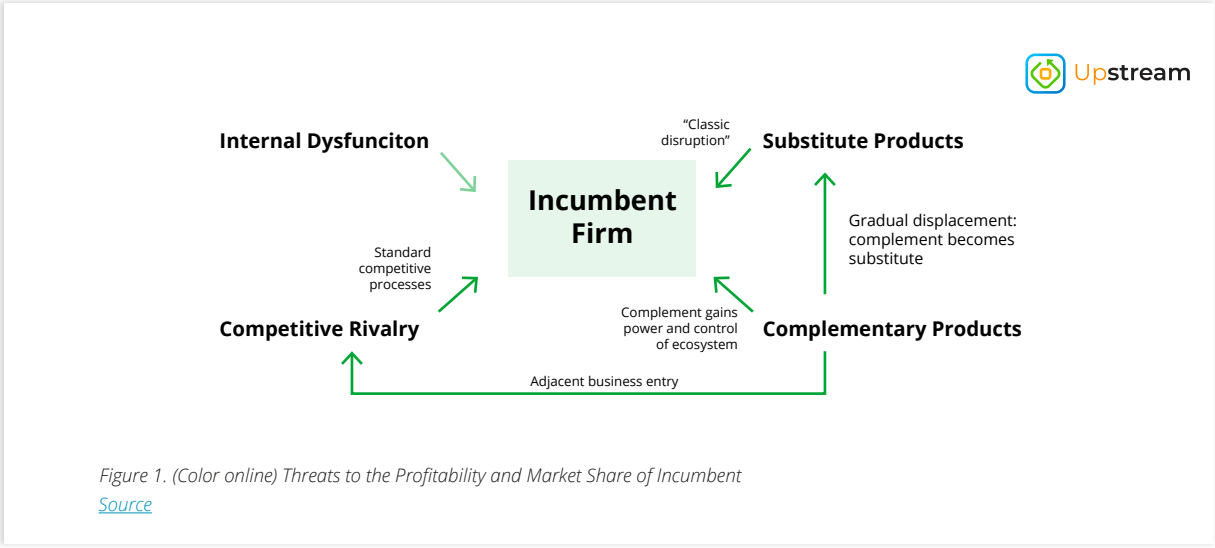


Figure 1. (Color online) Threats to the Profitability and Market Share of Incumbent
Source

Precision spraying more specifically commoditizes herbicides in a combination of two different types of disruption through complements.

The first and less commonly talked about with this technology is through reduced influence and margin, which is alluded to above.

From Adner and Lieberman's study :

> *The first mode of disruption through complements involves commoditization of the core offer. Unlike traditional substitution, the impact here is not reduced demand for the core but, rather, reduced influence and margin.* ***Commoditization shifts the "locus of differentiation" from one position in the system to another.***

If we read the below explanation of disruption through complements, we get almost a perfect illustration, which is alluded to above about with herbicides and sprayers:

> *Firm A, which produces the core offer, is initially dominant in the ecosystem, but a strategic change empowers firm B, which produces the complement. As the power of the complement rises, the added value of firm A falls, contributing to a commoditization of firm A's role. Commoditization occurs when (1) the complement reduces the entry barriers to participation in the core, for example, by reducing the fixed costs of operation required for entry, or (2)* ***the complement becomes a key driver of differentiation, determining the pace and direction of innovation, or (3) the complement becomes the guarantor of quality, increasing the substitutability among core producers in the eyes of consumers.***

The second way disruption through complements occurs is by what we have typically focused on with precision spraying; a potential reduction in usage of the core product:

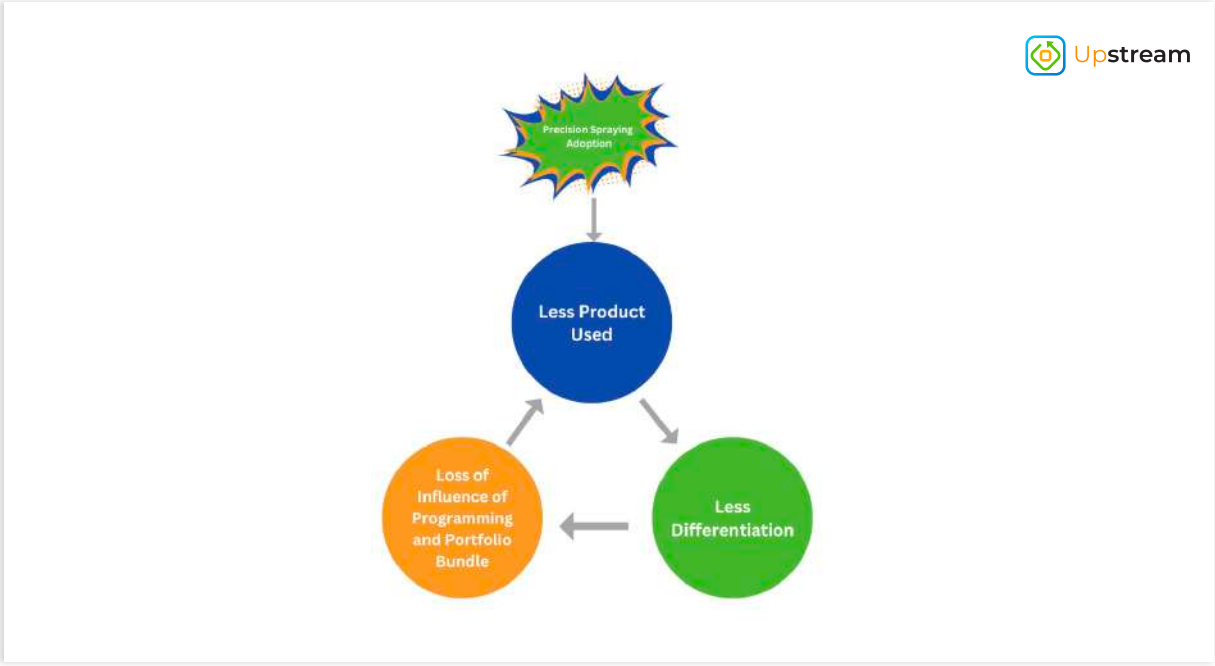
> *Most critical for understanding ecosystem disruption is the third trajectory, value inversion, whereby the complement's continued improvement beyond a certain point begins to undermine the focal offer's value.*

In the paper, they even highlight our specific example for this second means of complement disruption:

Smart tractors reduce waste in planting and, hence, volumes of seeds and fertilizer used.

If we think through the lens of "stacking the deck" in ones favour, a company eroding the influence of its complementor across two different mechanisms theoretically increases the chance of brand commoditization over time and the value accruing to the equipment company, or precision spraying manufacturer.

Both of these happening in unison turns itself into a *negative fly* wheel for input companies surrounding their core business:



This gives generic products an in-road and forces crop protection manufacturers to try and differentiate across other areas in search for generating higher margins and more revenue.

There are implications for ag retailers too, specifically those with sprayer fleets, to change their supplier relationship strategy, or build novel services through their fleet becomes interesting, however, it is ultimately the farmer and the precision spraying manufacturer winning in this scenario.

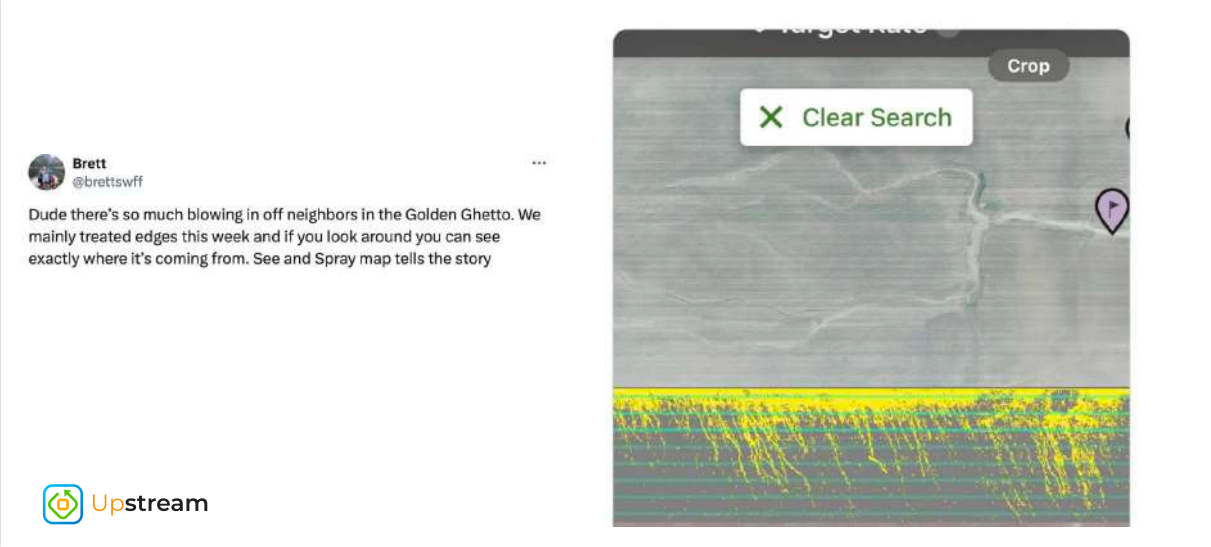
Access to Information

The other factor to consider is access to information. **Crop protection companies will have less access to the data about what weeds are in a field (and then rolled up to a geography)**, empowering the farmer (and potentially retailer), and becoming a form of information asymmetry. Consider this patent granted to Blue River Technology (John Deere):

Plant group identification: *A farming machine moves through a field and includes an image sensor that captures an image of a plant in the field. A control system accesses the captured image and applies the image to a machine learned plant identification model. The plant identification model identifies pixels representing the plant and categorizes the plant into a plant group (e.g., plant species). The identified pixels are labeled as the plant group and a location of the pixels is determined. The control system actuates a treatment mechanism based on the identified plant group and location. Additionally, the images from the image sensor and the plant identification model may be used to generate a plant identification map. The plant identification map is a map of the field that indicates the locations of the plant groups identified by the plant identification model.*

When layering this capability into See and Spray assets, it delivers a more precise ability to inform future herbicide product decisions, rate decisions, mixing decisions and more. All of which the input manufacturer could be less engaged in, leading to further commoditization risk.

We are already seeing this type of functionality in the sprayer systems in terms of mapping where weeds are:



Volumes of crop protection going up is a very real potential, as Jevons Paradox illustrates to us. However, what is under discussed is how precision spraying commoditizes the major crop protection manufacturers IP and market influence.

It's difficult to extrapolate exactly what future margin numbers might be, however, we could see the crop protection spend looking much different than today, which means the potential for margins to accrue at different points and among different players throughout the industry:

The natural reaction from input manufacturers will be to emphasize the sustainability of their products vs. generic competitors, or products that are best applied in broadcast fashion (eg: pre-emergent herbicides), bundle more broadly (eg: insurance, financing, and sustainability programs) and move crop protection into and onto the seed (traits and seed treatment). We see much of this occurring today. However, these have their limitations and because there are limited new modes of action in the pipeline from manufacturers, traditional IP defence is a lesser option.

The next level approach is to consider other business models and alliances.

Take Syngenta and fungicides and their coalition with John Deere and InnerPlant, in an effort to differentiate with data.

FMC has not shared their business model, however, what they are bringing to market in a stacked way with Arc Intelligence (digital system) and Pheromone based insecticides is an example of a new approach.

Organizations that are successful will be open to re-thinking **how they capture value**, the **units they sell in**, **and their strategic partnerships** (eg: Does it make sense to go-to-market in a unique way such as through a unique equipment company, like Solinftec or SwarmFarm?).

There is an evolving tension between input manufacturers and equipment manufacturers— companies like John Deere have went all-in on making precision spraying a default for farmers in the future and for that to become a reality, they need the precision spraying assets to add value to farmers beyond herbicides. This progression will be interesting to watch in the coming decade.

Adoption of these technologies will not happen overnight. There is not a fire alarm going off in any crop input manufacturer board room. But, there is a need to think critically through what it means to manage the gradual shift in how crop protection products are used, the impacts on margins and where the influence of what to use comes from.

15. Future of Precision Spraying

We are still in the early stages of commercializing precision spraying solutions, and wide-scale adoption remains a distant goal. However, it's already clear that this technology creates significant value and is poised to become a crucial tool in the farmer's and agronomist's toolbox. Below, we explore how this technology could evolve and the impact it may have on spraying systems.

Expanding Use Cases

As highlighted in this report, the applications of precision spraying are vast. Most current solutions focus narrowly on spotting weeds, but there is significant potential to broaden these use cases. Expanding functionalities will make precision spraying more versatile and improve its ROI. Here are a few high-interest examples:

- **Selective Weed Spraying:** Targeting individual weed species with customized treatments.
- **Band Spraying:** Spraying specific areas, such as crop rows or between rows, for fungicide and insecticide applications.
- **Online Variable Rate Spraying:** Dynamically adjusting spray rates based on the crop canopy during application.
- **Insect and Disease Detection:** Although further in the future, this functionality could allow targeted spraying for pests and diseases.

Adding these use cases will increase the versatility of precision spraying, making it more valuable for diverse agricultural needs.

Achieving Higher Precision

The risk of missing weeds remains a significant concern for precision spraying solutions today. However, as more systems are deployed, the vast amounts of data collected will continuously refine and improve detection models. Over time, this process will enhance accuracy, increase hit rates, and enable the detection of even smaller weeds.

Another aspect of achieving higher precision is the ability to identify individual weed species and provide tailored treatments for each. This ties directly to selective spraying use cases and highlights the need for sprayers to be equipped with multiple tanks. These tanks can hold various herbicide mixes, ensuring that the right mode of action is available for different weed species.

Rethinking Sprayer Design

Innovation in sprayer design will be a key area of development as precision spraying technology evolves. Since precision spraying uses significantly less product, it allows for more acres to be covered per sprayer fill. While this might suggest the possibility of smaller tank sizes and lighter machines, the increasing emphasis on productivity—driven by tighter operating windows, larger farm sizes, and efficiency demands—makes it more likely that tank sizes will remain similar, with the focus shifting toward optimizing overall productivity.

Here are a few key areas where improvements can enhance the future of precision spraying:

1. **Adding More Tanks:** Future sprayers could feature three or more tanks, each capable of holding a different tank mix. These tanks could operate independently or in combination, depending on the application requirements.
2. **Improving Fluid Delivery Systems:** Current dual-tank systems utilize two lines on the sprayer boom, but this approach may not scale with an increasing number of tanks. Enhanced direct injection systems could offer a more scalable and efficient solution.
3. **Developing Versatile Nozzles:** As precision spraying use cases become more diverse, the demand for adaptable nozzles will grow. There are also ongoing initiatives to create specialized nozzles designed specifically for spot applications.
4. **Boom Height Control:** Accurate boom height control is essential for effectively targeting weeds. Spraying closer to the crop allows systems to treat smaller, more precise sections. This creates opportunities for innovation in boom height control, enabling precision spraying at high speeds while maintaining a minimal distance between the boom and the crop canopy.

By addressing these areas, sprayer designs can better meet the needs of modern precision spraying, enhancing efficiency, versatility, and performance across a wide range of applications.

Unlocking More Insights

The extensive data collected by advanced precision spraying systems offers immense potential for generating valuable agronomic insights. By analyzing this data, farmers and agronomists can gain a deeper understanding of specific weed problems, such as where weeds tend to grow and which species cause the most challenges. Combining this information with other datasets can lead to more informed and effective agronomic decision-making.

Additionally, each field pass provides not only weed data but also insights into crop health and status. These crop-specific insights further enhance the value of the collected data, offering a more comprehensive view of field conditions.

It's clear that we are only beginning to explore the possibilities of this data. As systems evolve, the potential to derive actionable insights will grow, unlocking new opportunities to optimize farm management and improve outcomes.

Business Model Innovation

New business models will play a pivotal role in driving adoption and aligning incentives across the agricultural value chain. To make precision spraying solutions more accessible, we anticipate the development of flexible business options, including:

- **Purchase vs. Subscription Models:** Farmers could choose between outright purchasing the technology or opting for a license or subscription-based model.
- **Outcome-Based Pricing:** Business models tied to measurable results, such as pricing based on the successful elimination of weeds, are expected to emerge.

Beyond the technology itself, we foresee innovation at the distribution level. For example, rather than charging growers for specific products and custom application services, distributors might adopt models like charging a fixed fee per acre for delivering a weed-free field. In this scenario, the distributor would manage decisions about what to spray and when, streamlining the process for the grower.

These new models have the potential to shift the industry dynamic, aligning incentives between growers, distributors, and solution providers. While precision spraying is still in the early stages of commercialization, it's clear that these innovations in business strategy will be crucial to achieving widespread adoption. The evolving landscape will be fascinating to watch as these ideas take shape.

16. Conclusion

Conclusion: The Potential and Early Stage of Precision Spraying Technology

Precision Spraying technology, epitomized by advancements from the likes of John Deere's, represents a significant shift in not just precision agriculture and for the equipment manufacturers, but also in influencing the traditional incumbent entities in the world of crop protection and ag retail, sparking an opportunity for business model evolution and a need to rethink how products and services are delivered to farmers. By combining AI, vision systems, and precision application, this technology offers significant value across weed management, input efficiency, and delivering overall better outcomes on farm.

Key Data Points and Takeaways

1. **Herbicide Savings:** Systems like See & Spray have demonstrated herbicide use reductions of up to 59%, highlighting the potential for substantial input cost savings.

2. **Weed Resistance Management:** Precision Spraying can help farmers manage resistance development by minimizing unnecessary herbicide exposure and allowing for tailored chemical applications.

3. **Regional Variance in Adoption:** The future is already here, it's just not evenly distributed is a commonly referenced quote, and it applied to Precision Spraying.

4. Crop Input companies need to consider how complement disruption and Jevons Paradox will influence their business and establish strategic and tactical efforts in consideration, for example, looking at unique partnerships, business models or emphasizing new product segments like biostimulants.

5. **OEMs and start-ups continue to jockey for unique approaches:** Solinftec "lives in the field," John Deere has an emphasis on its high value "Ultimate" product segment, AGCO is emphasizing retrofit systems, while CNH Industrial has opted not to lean launch a GoB product yet. As technology is adopted by farms and service providers, the feature expansion will be crucial to keep an eye on.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