The Environmental Benefits of Precision Agriculture in the United States

Executive summary and details

AEM Association of Equipment Manufacturers

ASA American Soybean Association

CropLife America

National Corn Growers Association

OBJECTIVE

The overarching objective for this project is to

quantify the environmental benefits of precision agriculture (P.A.) in the United States.

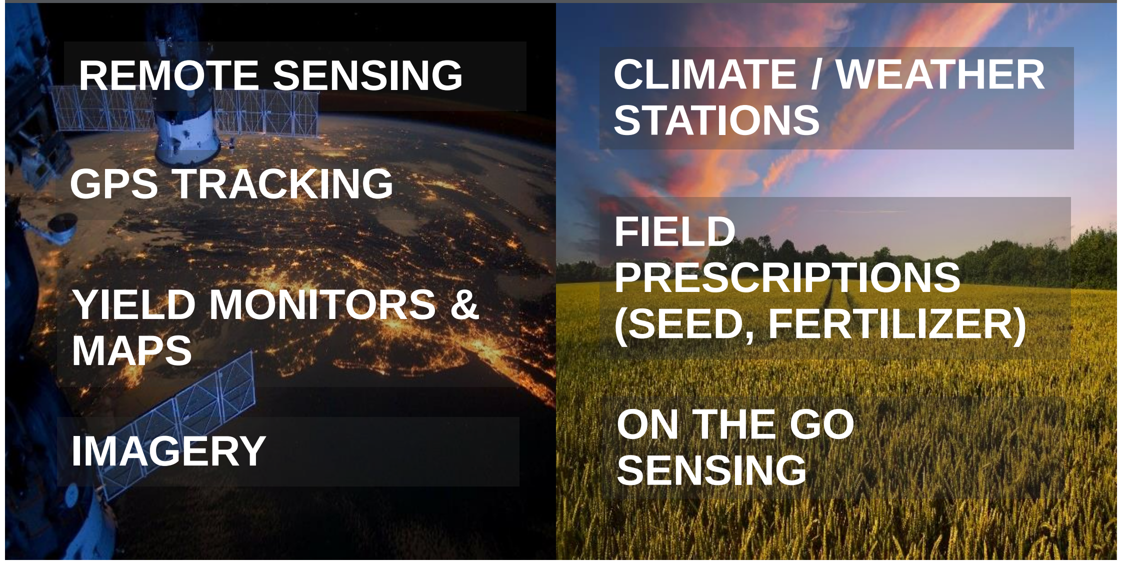
Five key precision agriculture (P.A.) technology areas were identified for this study

P.A.TECHNOLOGY AREA	DEFINITION	TECHNOLOGIES ANALYZED
AUTO GUIDANCE	Auto-steer uses GPS signals to automatically control the tractor in seeding, spraying, fertilizer application and harvesting, reducing overlap of farming operations and leading to substantial fuel savings.	▪ Auto steering
MACHINE SECTION CONTROL	Machine section control technology turns planter, fertilizer or sprayer sections on or off in rows that have been previously seeded/sprayed, or at headland turns, point rows and waterways.	▪ Tillage drag/depth control ▪ Planting row, depth, down pressure control ▪ Fertilizer row control ▪ Spraying row control
VARIABLE RATE	Variable rate technology uses sensors or preprogrammed maps to determine seeding, fertilizer, crop protection application rates. Supporting technologies include variable rate controllers, GPS, yield monitors, crop sensors and soil sensors.	▪ Variable rate planting ▪ Variable rate fertilization ▪ Variable rate spraying, including UAV (drone) applications
MACHINE & FLEET ANALYTICS	Real time monitoring of equipment, providing information like GPS location, equipment idling, traffic control and route suggestions.	▪ Fleet analytics ▪ Telematics
PRECISION IRRIGATION	Ability to switch on/off apply and different amounts of water to different areas of the field. *Focused on center pivots.*	▪ Sensor driven center pivots ▪ Lower energy precision application

How we get to the future: Many technologies enable precision agriculture

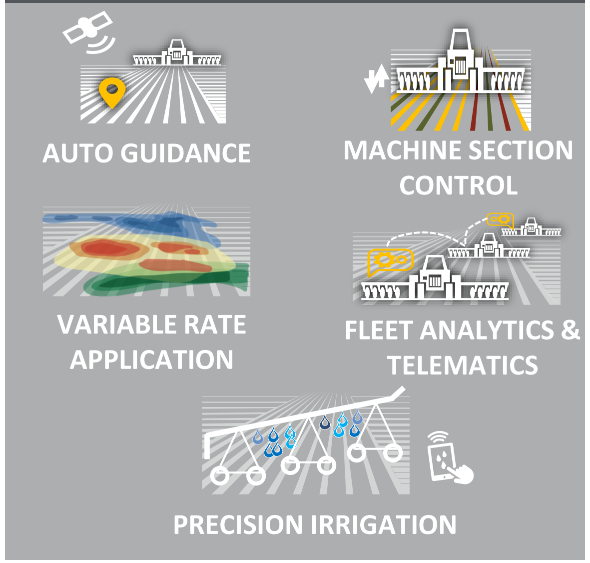
ENABLERS

AG TECHNOLOGY



IMPACTS MEASURED

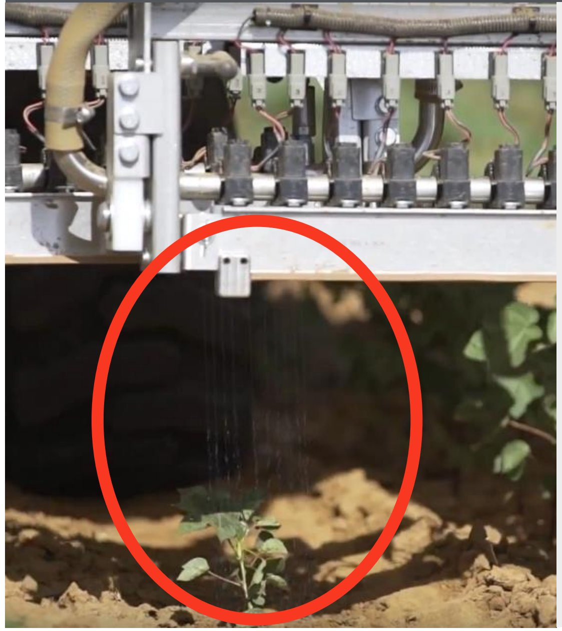
PRECISION AG TECH



Enabling technologies such as **yield mapping** and **soil sampling** were included indirectly within the "execution" of precision ag tech. The environmental benefits of the precision ag technologies are only achievable with accurate and routine use of enabling technologies.

What is NOT in this study: Emerging technologies or other tools of modern ag, i.e. seed traits

SEE AND TREAT WEED CONTROL



Targeted spraying mechanisms from OEMs and startups are beginning to enter the marketplace. Early estimates show that initial savings from herbicide application can be up to 90% **per pass**. Yet, questions remain as to the long-term effectiveness, as residual action on weeds is a major source of control.

SMART COMBINES

Smart combines improve the ability of the operator to automate adjustments usually made by skilled operators. A typical smart combine uses cameras and sensors to detect changes in crop conditions so combine adjustments can be made automatically and maintain optimal performance.

Source: Blue River Technologies

Five key environmental benefits were identified to be quantified as a result of P.A. technology adoption

	Productivity	Fertilizer Use	Herbicide Use	Fossil Fuel Use	Water Use
Direct Outcomes ***(quantified)***	▪ Yield benefit from accurate spacing (pass-to-pass, end/point rows) and population rate	▪ Optimization of fertilizer applications (reduced overlap, avoid skips, best placement and rate of inputs)	▪ Optimization of herbicide applications (reduced overlap, avoided skips, best placement and rate of inputs)	▪ Fuel savings from fewer field passes, variable depth of tillage, and/or more efficient harvest	▪ Application of water avoided due to remote shutoff of center pivots, along with selective application
Indirect Outcomes	▪ Avoid unproductive/ preserved land from being in production ▪ Reduced soil compaction	▪ Improved water quality (reduced nutrient runoff) ▪ Improved soil health ▪ Net GHG reduction (including in production of inputs)	▪ Improved soil health, and reduced erosion through less tillage ▪ Net GHG reduction (including in production of inputs) ▪ Improved water quality ▪ Reduced weed resistance development	▪ Net GHG reduction	▪ Improved water quality through reduced runoff ▪ Less energy use by running pumps fewer hours

The crops studied included a range of row crops, broad acre non-row crops, roots and tubers, and forage

ROW CROPS	BROAD ACRE (NON-ROW) CROPS	ROOTS & TUBERS	FORAGE*
Corn	Wheat	Tubers	Hay
Soybeans			
Cotton	Sorghum	Sugar beets	Alfalfa
Peanuts			

This study focused on crop production, leaving downstream impacts of precision technologies on animal agriculture for future study

*Only hay and alfalfa acres west of the Rockies were considered for P.A. use

A model was built for each of the five environmental benefits, capturing data and contributions from each of the relevant P.A. technology areas

P.A. TECHNOLOGY	How Environmental Benefit is Achieved	ENVIRONMENTAL BENEFITS: Productivity	Fertilizer Use	Herbicide Use	Fossil Fuel Use	Water Use
AUTO GUIDANCE	Reduced overlap + avoided skips for field passes with tillage, planters, sprayers, and harvesters	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Incomplete information to reliably quantify
SECTION CONTROL	Optimized placement of seed / fertilizer / crop protection. Optimized down pressure + depth control to gain machine + fuel efficiencies	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Incomplete information to reliably quantify	Incomplete information to reliably quantify
VARIABLE RATE	Optimized rate of seed / fertilizer / crop protection applications	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Academic literature utilized; Industry experts utilized	Incomplete information to reliably quantify	Incomplete information to reliably quantify
MACHINE & FLEET ANALYTICS	Improved fuel efficiency from machine optimization	Incomplete information to reliably quantify	Incomplete information to reliably quantify	Incomplete information to reliably quantify	Academic literature utilized; Industry experts utilized	Incomplete information to reliably quantify
PRECISION IRRIGATION	Improved water use efficiency	Incomplete information to reliably quantify	Incomplete information to reliably quantify	Incomplete information to reliably quantify	Incomplete information to reliably quantify	Academic literature utilized; Industry experts utilized

Academic literature utilized *Industry experts utilized* *Incomplete information to reliably quantify*

Each of these five environmental benefits directly links to two or more of USDA's three sustainability pillars

USDA PILLARS	ENVIRONMENTAL BENEFITS				
	Productivity	Fertilizer Use	Herbicide Use	Fossil Fuel Savings	Water Use
DIRECT ENVIRONMENTAL BENEFIT		✓	✓	✓	✓
PRODUCTIVITY (YIELD) BENEFIT	✓	✓	✓		
FARMER ECONOMIC BENEFIT	✓	✓	✓	✓	✓

To align on reasonable assumptions for the benefits for each technology, the study utilized the triangulation of numerous data sources and industry experts

TRIANGULATION METHODOLOGY

Industry Experts

Expert 1	Expert 2	Expert 3
▪ Former Director of Precision Ag at John Deere ▪ Skilled in machine design processes, software development, marketing and customer acquisition processes, and more	▪ Former Director of Marketing – Precision Agriculture and Construction at CNH ▪ Skilled at exploring innovative ways to increase agronomic production & sustainability through precision ag	▪ Former President and CEO of crop protection association ▪ Chairman, Board of Advisors, Farm Journal ▪ Leader in agricultural strategy services and entrepreneurial investment

Data Sources & Analysis

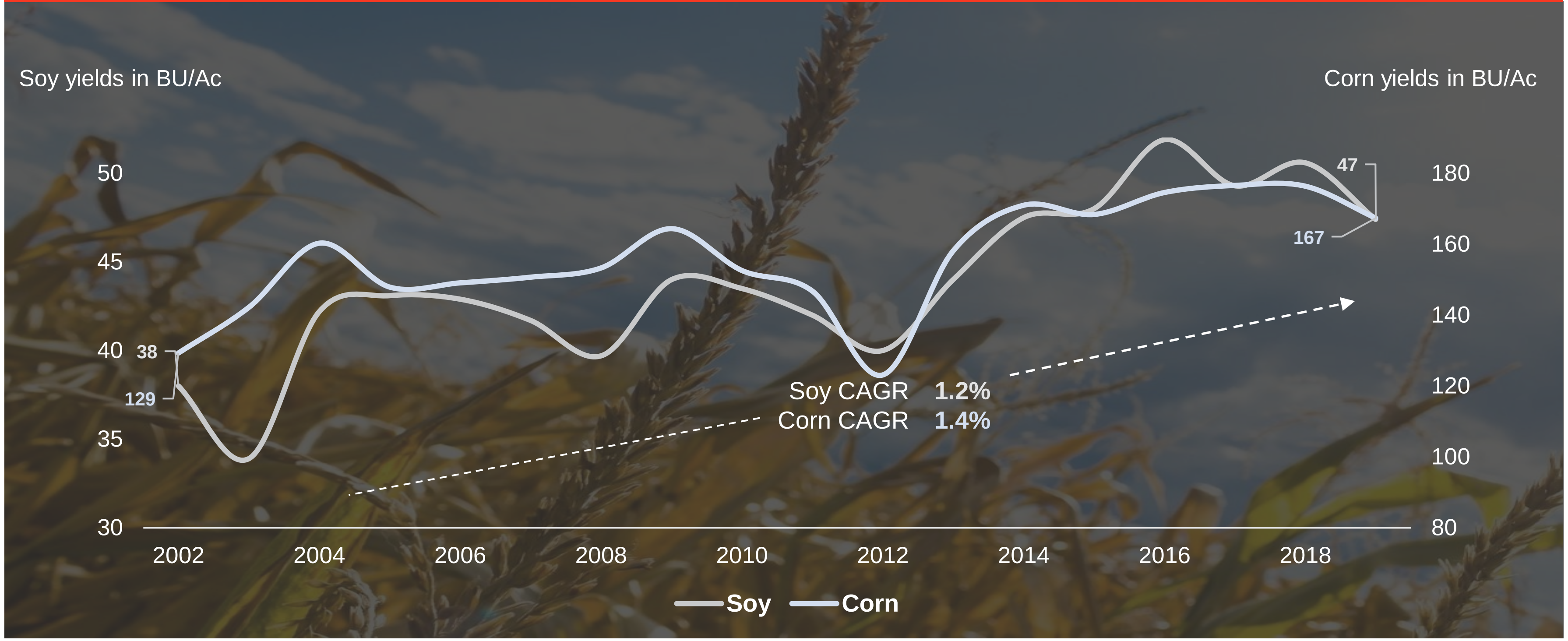
- The Ohio State University
- USDA NRCS
- Purdue University
- Statistics Canada
- University of Kentucky
- North Dakota State University
- Iowa State University
- U of Illinois
- UC Davis
- Agricultural University of Athens, Institute for Agriculture-Belgium, Wageningen Environmental Research, European Commission-Joint Research Centre

Industry Interviews

- Fertilizer Institute representative
- Irrigation Association representative
- USDA representative
- Former Syngenta executive

Over the last 18 years, the growth in corn and soybean yields has coincided with the widespread adoption of precision agriculture technologies

CORN AND SOY YIELDS FROM 2002-2019

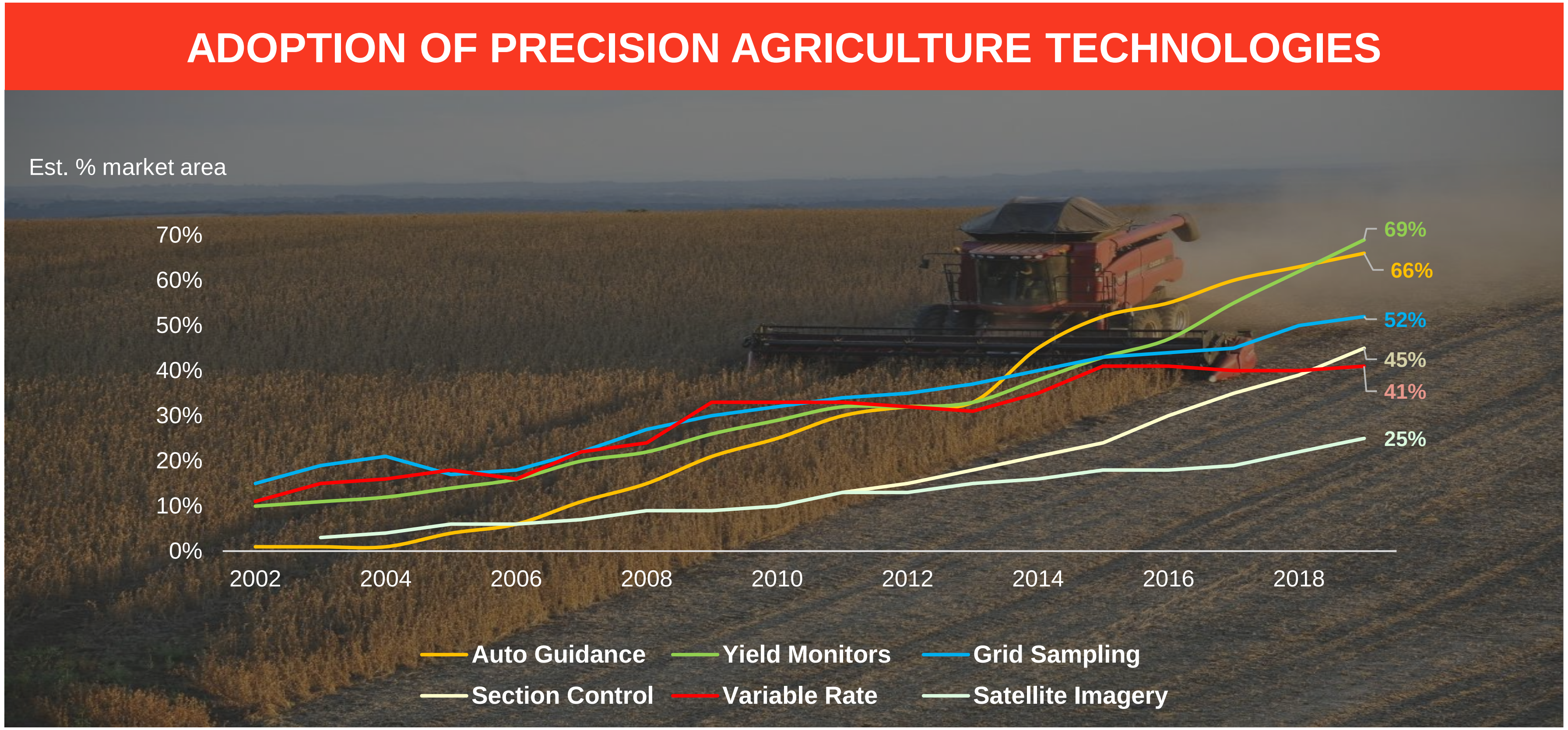


Reasons for rising yields include

1. More effective and resilient hybrids
2. Better inputs & management practices
3. Improved on-farm technology

Source: USDA NASS, Purdue Precision Ag Dealership Survey, Context Analysis and Expert Input

Over the last 18 years, the growth in corn and soybean yields has coincided with the widespread adoption of precision agriculture technologies



Precision agriculture technologies have contributed significantly to the increases in yields for the major crops grown in North America

Source: USDA NASS, Purdue Precision Ag Dealership Survey, Context Analysis and Expert Input

Sustainability has been a part of ag for generations

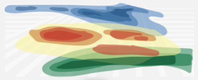
We need to highlight the sustainability gains in terms the public can appreciate.

Productivity has increased an estimated 4% as a result of current P.A. adoption and has the potential to further increase 6% with broader P.A. adoption

Cultivating an estimated 10.2 million acres of cropland was avoided due to more efficient use of existing land. This is an area equivalent to 4.5 Yellowstone National Parks.

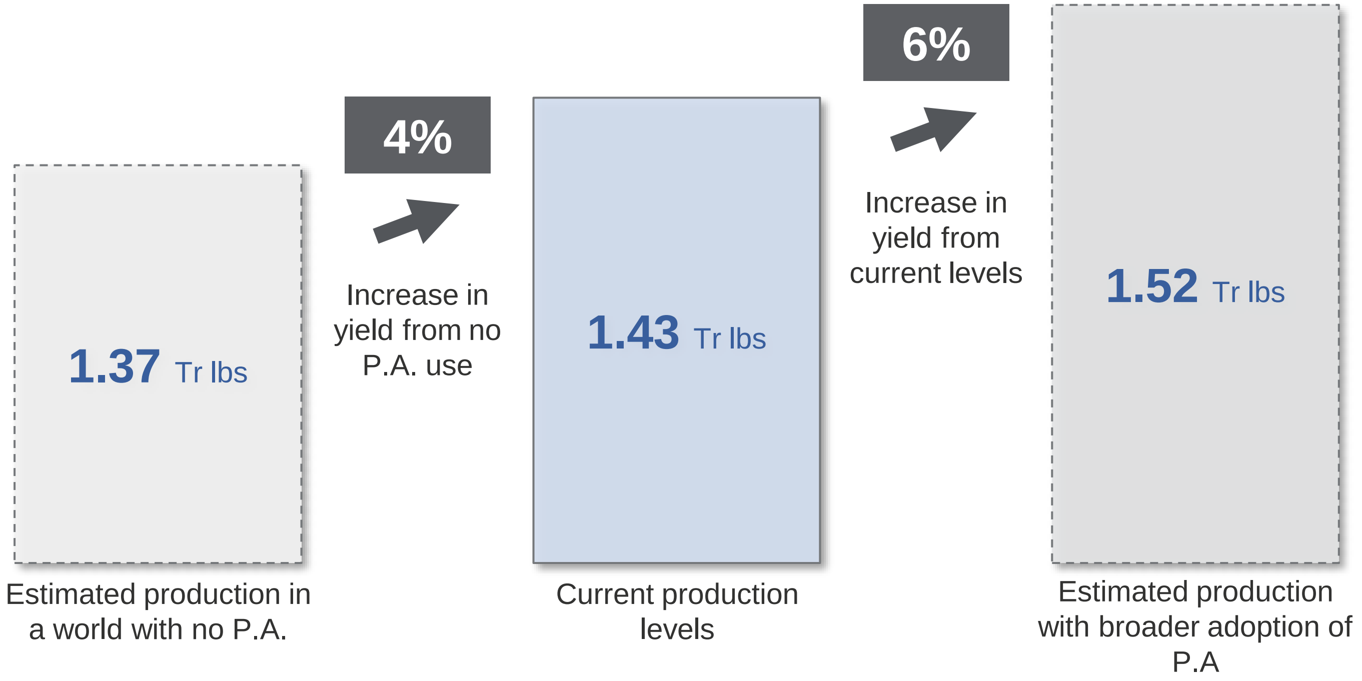
Precision Technologies Analyzed

AUTO GUIDANCE



VARIABLE RATE

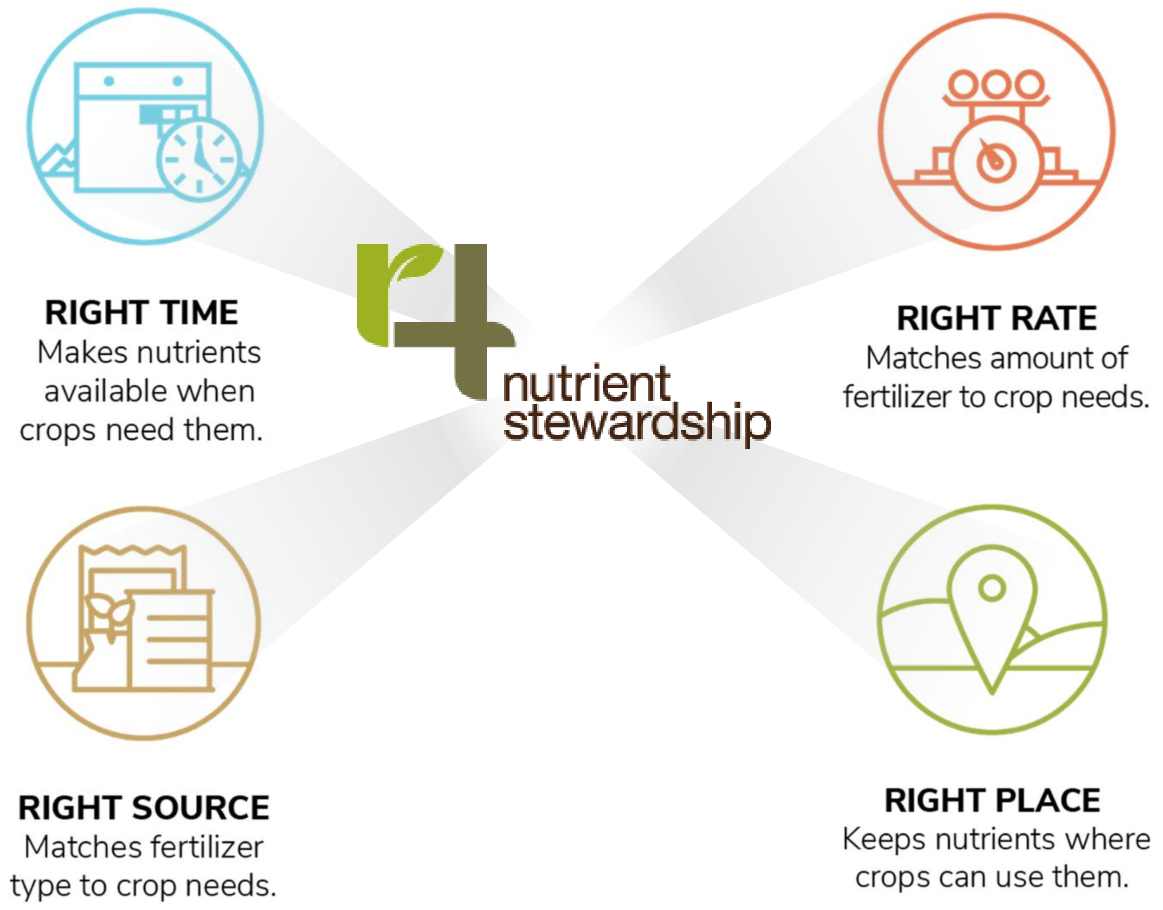
SECTION CONTROL



Production of each of the crops in scope were converted from bushels to pounds in order to normalize for the purposes of aggregation and comparison

Precision agriculture has improved fertilizer placement efficiency by an estimated 7% and has the potential to further improve an additional 14% with broader adoption of P.A. technologies

Precision agriculture affects all pillars of nutrient stewardship, but most specifically, application in the right rate and place through variable rate application, auto guidance and section control



CASE STUDY

By transitioning from basic to advanced 4R practices and including strip till and cover crops, a family farm located in Central Illinois was able to **decrease costs per acre by $67**, while reducing CO2 equivalent **GHG emissions by >15%**.

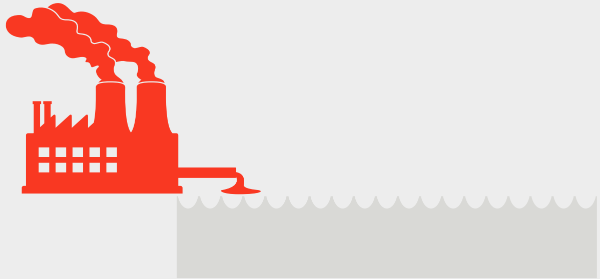
Practices adopted on the farm:

- **Fall strip till of nitrogen with stabilizer**
- **Fall application of P+K – broadcast using Variable Rate**
- **Cover crops – termination in spring**
- **Grid soil sampling**

THE FERTILIZER INSTITUTE

Source: 4RFarming.org

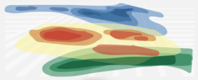
Herbicide Use has been reduced by an estimated 9% as a result of current improved P.A. application practices and has the potential to further decrease 15% at full P.A. adoption



The application of an estimated 30 million pounds of herbicide was avoided due to adoption of P.A. technologies, with an estimated 48 M pounds of additional herbicide that could be avoided with broader adoption.

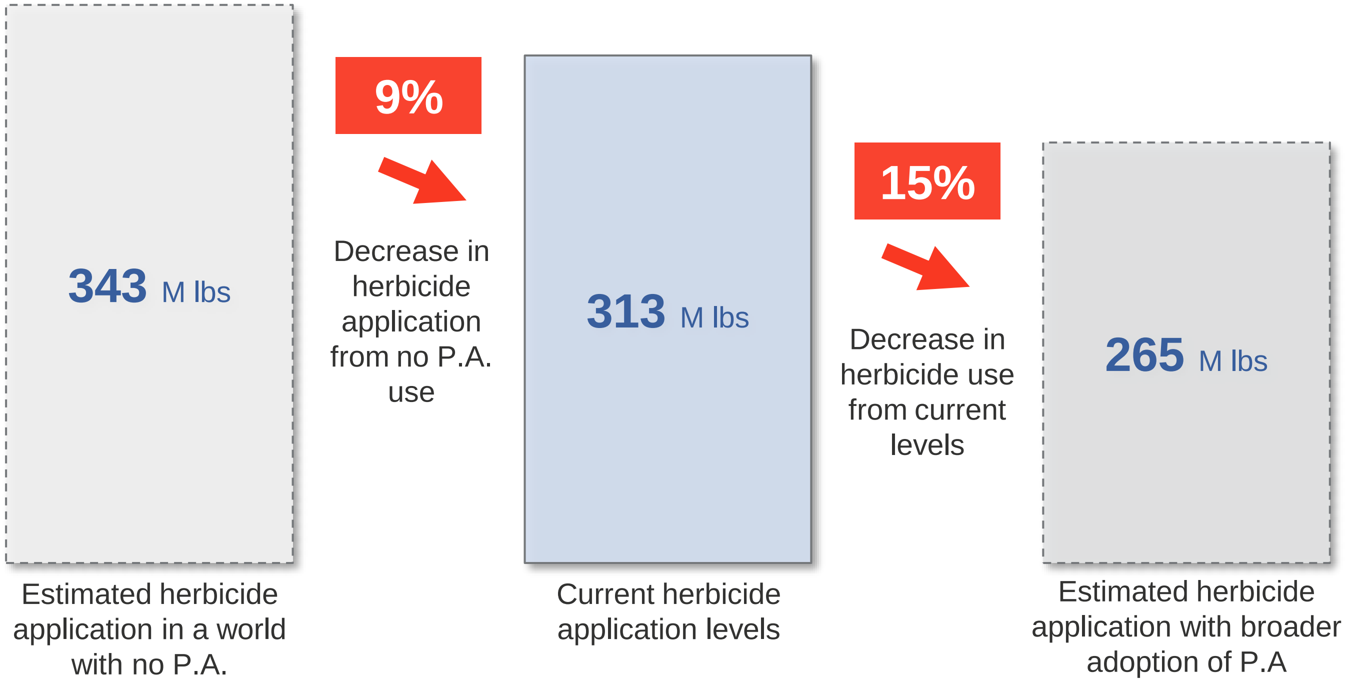
Precision Technologies Analyzed

AUTO GUIDANCE



VARIABLE RATE

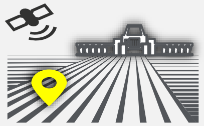
SECTION CONTROL



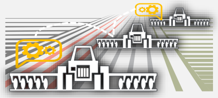
Fossil Fuel Use has decreased an estimated 6% as a result of current P.A. adoption and has the potential to further decrease 16% at full P.A. adoption

The use of an estimated 100 M gallons of fossil fuels was avoided due to adoption of P.A. technologies, equivalent to an estimated 193,000 cars off the road annually or 18,000 average flights.

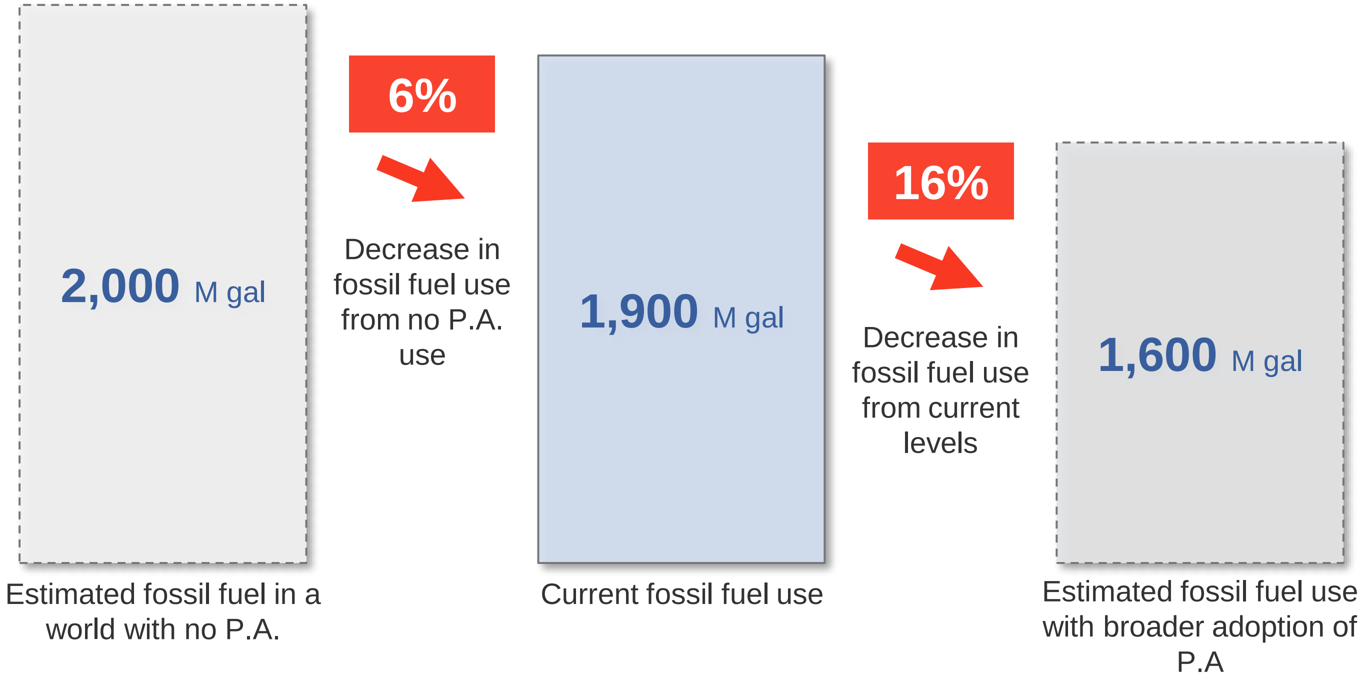
Precision Technologies Analyzed



AUTO GUIDANCE



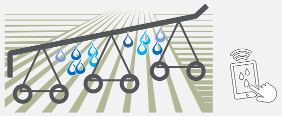
FLEET TELEMATICS



Water use has decreased an estimated 4% as a result of current P.A. adoption and has the potential to further decrease 21% at full P.A. adoption

The application of an estimated 750,000 Olympic swimming pools worth of water was avoided due to adoption of P.A. technologies.

Precision Technologies Analyzed



VARIABLE RATE PRECISION IRRIGATION

SOIL MOISTURE SENSORS

11,800,000 M gal

Estimated water application in a world with no P.A.

4 %

Decrease in water use from no P.A. use

11,300,000 M gal

Current water application levels

21 %

Decrease in water use from current levels

8,900,000 M gal

Estimated water application with broader adoption of P.A

The model only measures the benefits of sensor driven precision pivots that have seen sizable adoption across the crops within scope. Drip and other methods of irrigation do provide water savings but are not widely adopted in the crops within scope of the analysis.

Total CO2 equivalent emissions avoided were approximately 10,100,000 MT with an additional 17,300,000 million MT potentially avoided through broader adoption of precision agriculture

The Precision agriculture study estimated that there were 5 key benefits that were seen as a result of adoption of PA technologies

1. **More productive Land**
   Thereby avoiding farming additional acres to produce the same amount of food
2. **Reduced Herbicide Use**
   From unnecessary over spraying
3. **Fertilizer use efficiency**
   From application of the right amounts at the right place at the right time
4. **Reduced Water Use**
   From more precise application using sensor driven pivots
5. **Reduced fossil fuel use from machines**
   Optimized machine use using analytics and guidance

10,100,00MT
of CO2 were not emitted as a result of Precision Agriculture

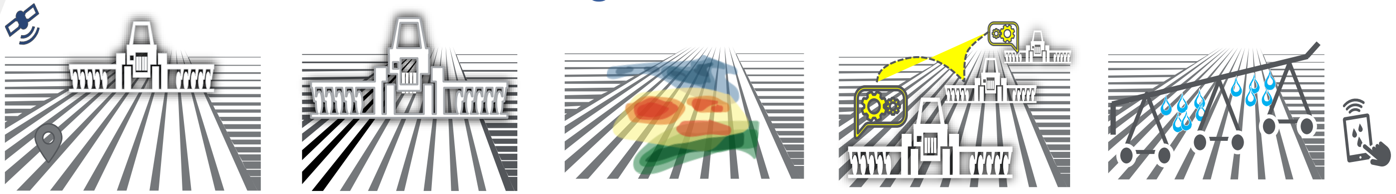
At current adoption levels

→

27,400,000MT
of CO2 would not be emitted as a result of broader adoption of precision agriculture technologies

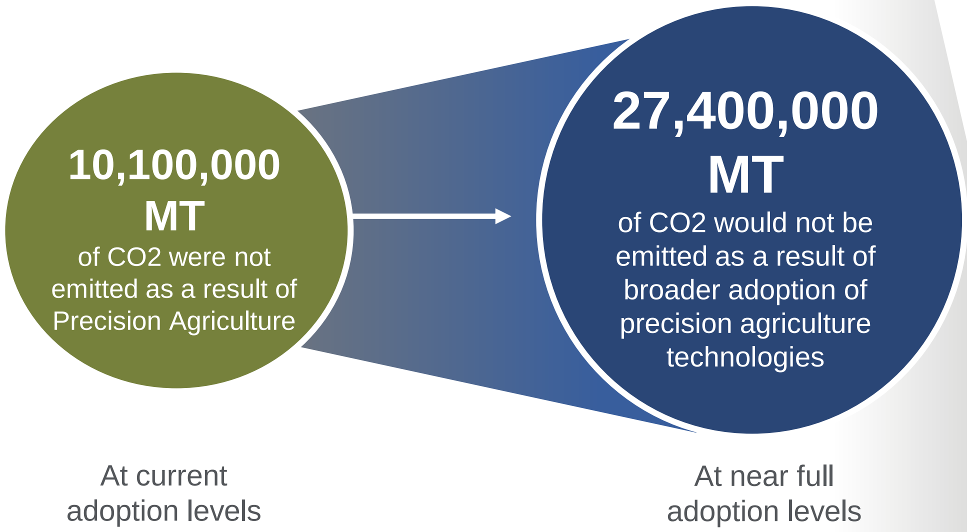
At near full adoption levels

Technologies assessed include:



Auto Guidance | Machine Section Control | Variable Rate | Fleet Telematics | Precision Pivots

At full adoption of precision agriculture, the carbon emissions savings resulting from it would equate to ~6,000,000 passenger vehicles off the road permanently.



The average passenger vehicle in the United states emits roughly **4.6 MT** of CO2 equivalent every year according to the EPA.

The resulting carbon dioxide equivalent reduction at current levels of adoption of precision agriculture would equate to ~**2,200,000** passenger vehicles off the road permanently

At full adoption levels of precision agriculture, this would equate to **6,000,000** passenger vehicles off the roads permanently. This is 2-3% of all vehicles currently on the road in the US.

Significant headway remains for continued increases in yields and further input savings as precision agriculture technologies become widely adopted

Annual crop production could increase a further 6% with broader adoption of Precision Agriculture Technologies

Broader adoption of precision ag technology has the potential to provide significant further improvements

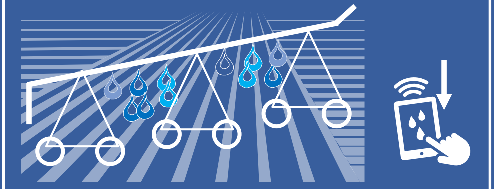
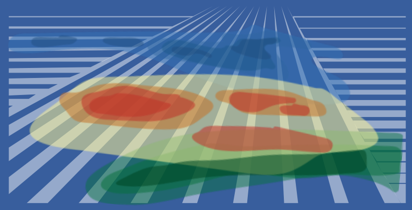
14% Improvement in fertilizer placement efficiency

15% Improvement in herbicide application efficiency

16% fewer fossil fuels

21% less water

Technology Adoption Rates Today

AUTO GUIDANCE/STEER	MACHINE & FLEET ANALYTICS	PRECISION CENTER PIVOT IRRIGATION	MACHINE SECTION CONTROL	VARIABLE RATE
				
25% to 80%	12%	0% to 22%	Fertilizer 10% to 45% Herbicide 5% to 22%	Fertilizer 15% to 54% Herbicide 2% to 13%

How do we get to full adoption?

Policies that reward innovation	**Grow farm income** → Capital to invest in operations
Improve enabling infrastructure → Wireless over croplands	**Improve consumer communication** → Build trust in science

thank you

AEM
Association of Equipment Manufacturers

ASA
American Soybean Association®

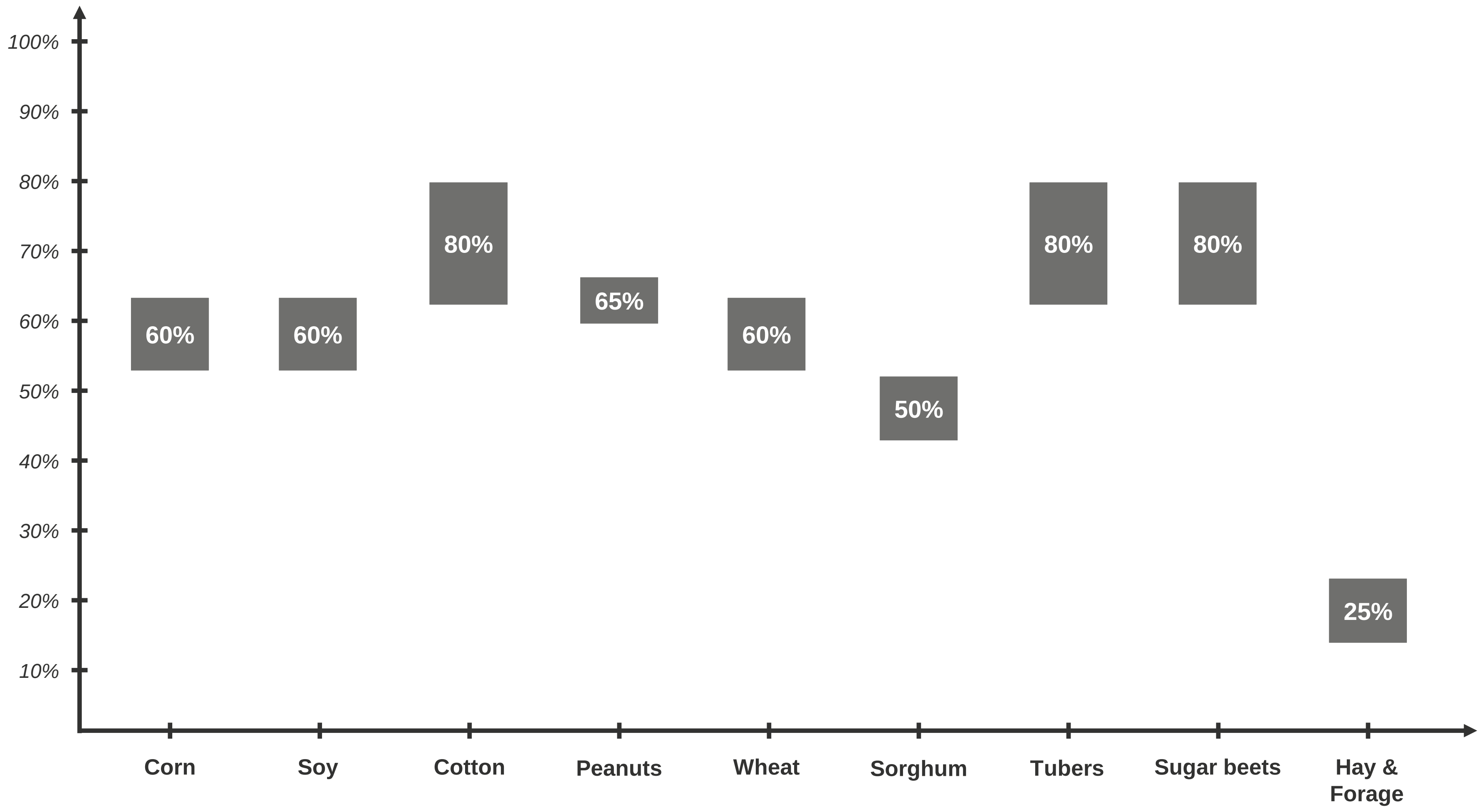
CropLife
AMERICA

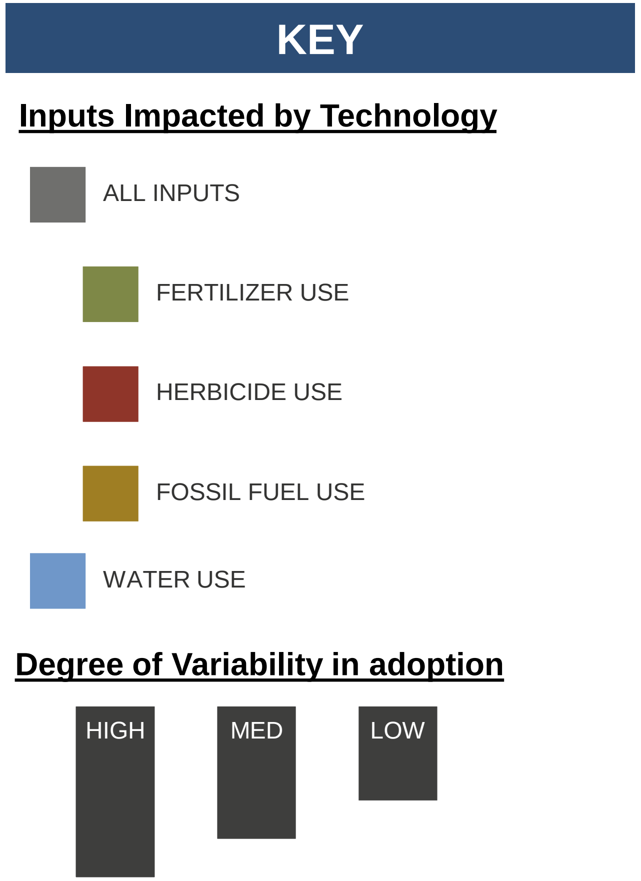
NATIONAL CORN GROWERS ASSOCIATION

APPENDIX MATERIAL

Rate of adoption of Auto Guidance

Auto guidance achieves an environmental benefit from reduced overlap, avoided skips for field passes with tillage, planters, sprayers, and harvesters.

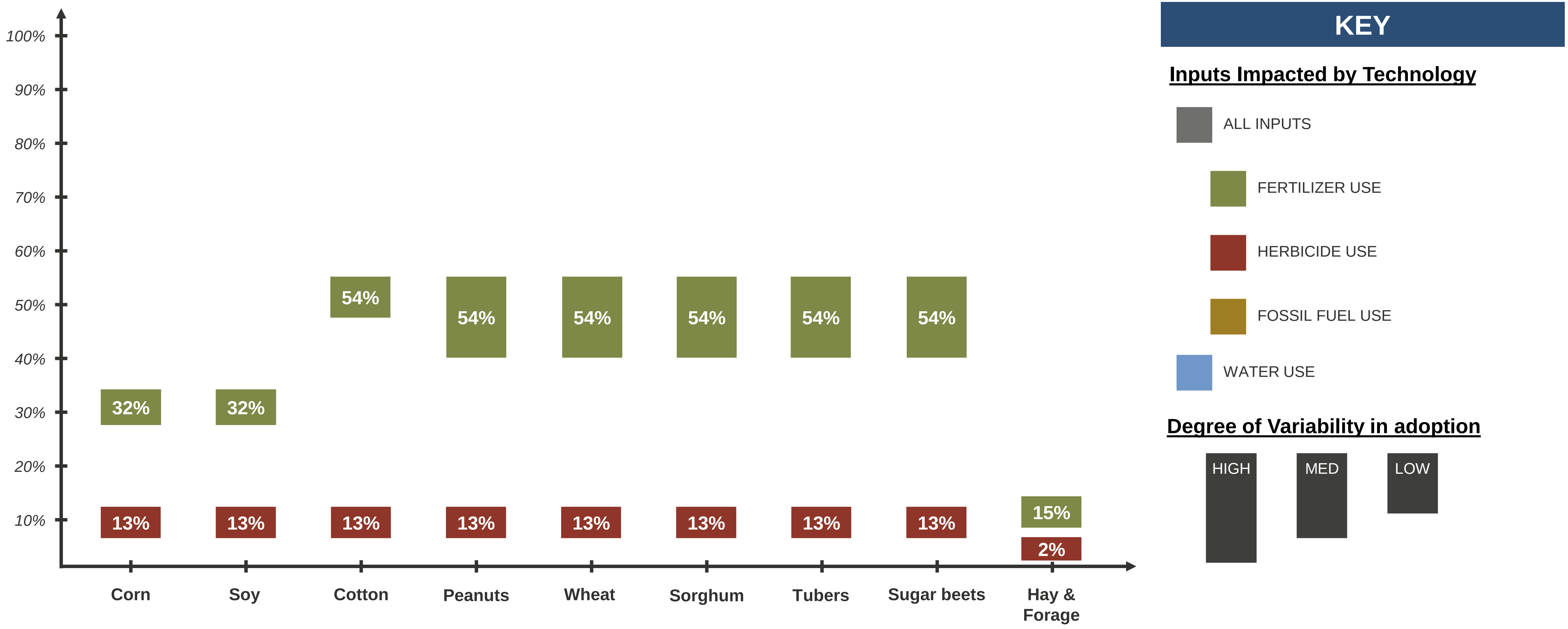




Source: Purdue Precision Agriculture Dealer Survey, Context Expert Estimates

Rate of adoption of Variable Rate Application

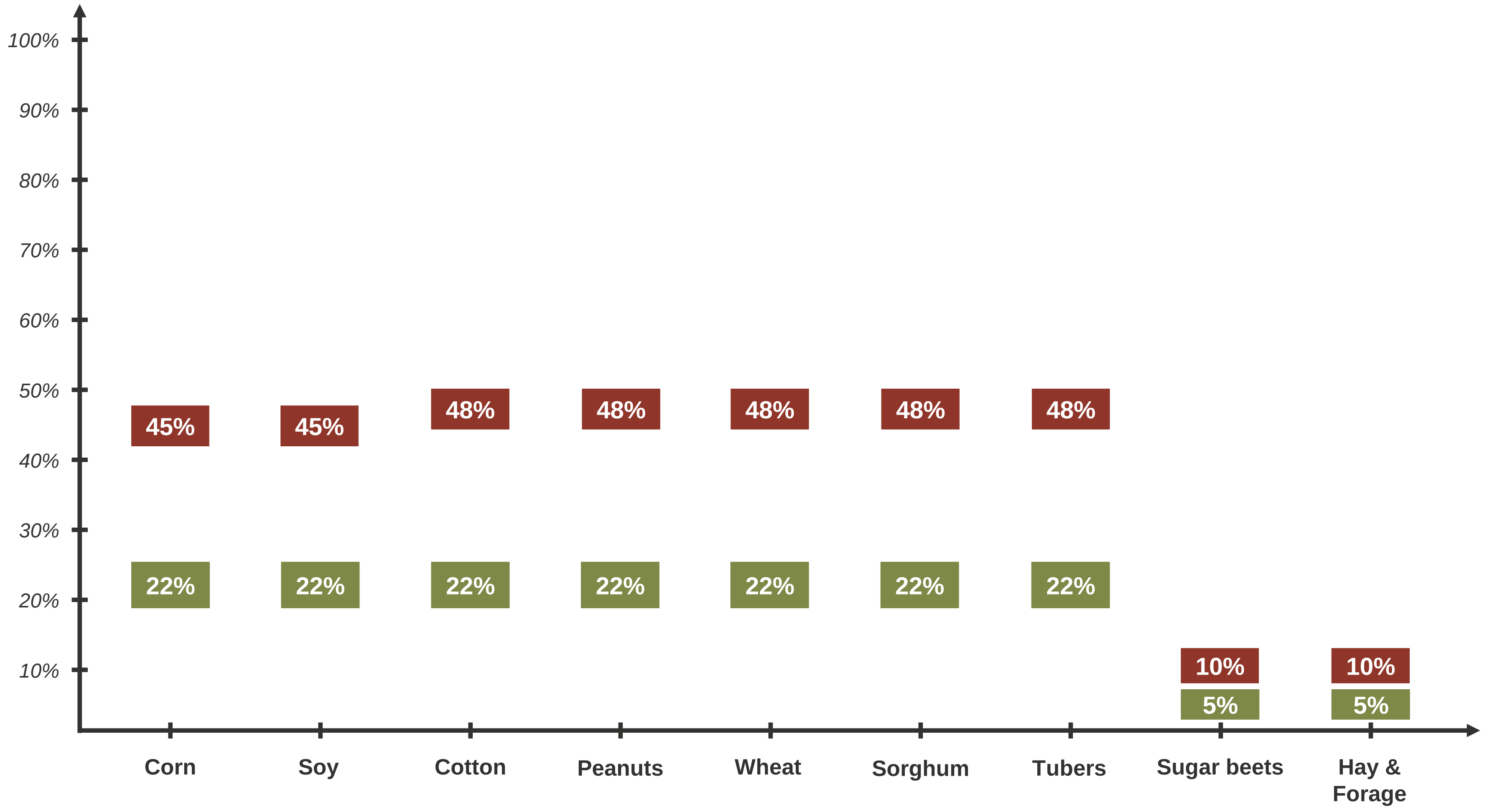
Variable rate technologies achieve and environmental benefit from optimizing the rate of seed / fertilizer / crop protection applications using predetermined prescription maps.

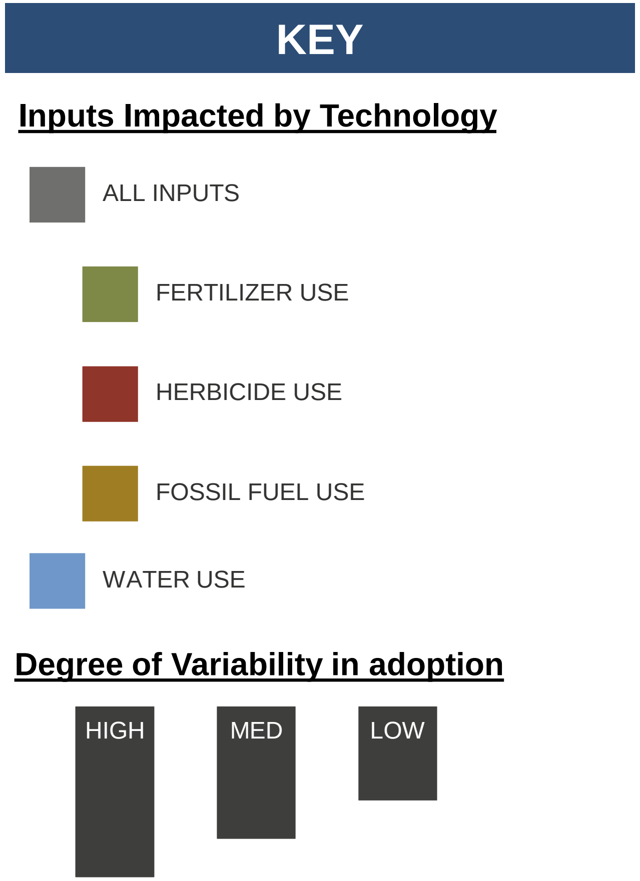


Source: Purdue Precision Agriculture Dealer Survey, Context Expert Estimates

Rate of adoption of Machine Section Control

Machine section control achieves and environmental benefit from the automatic shut off, of the application of inputs on rows that have either been addressed or don't need to at all.

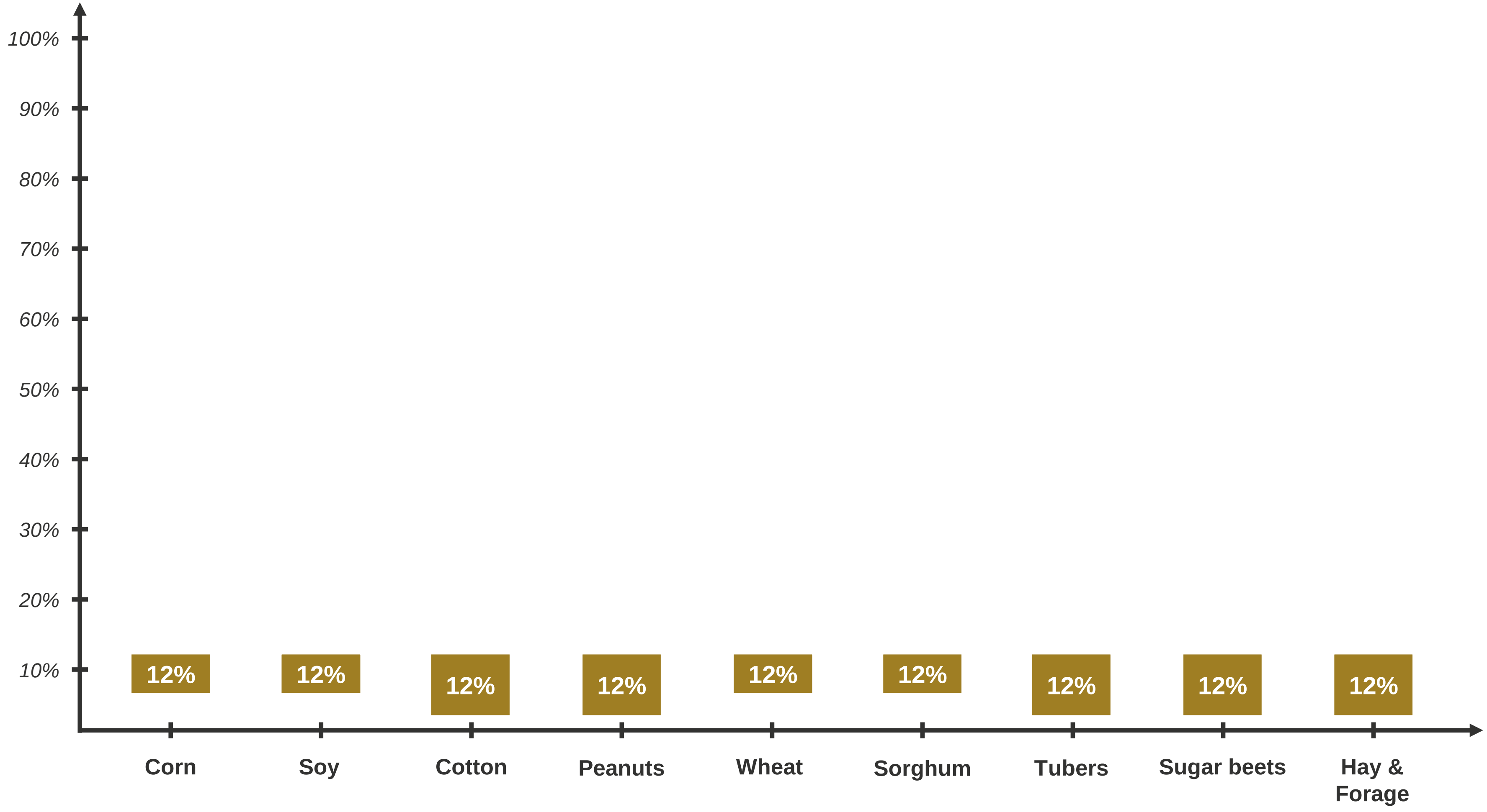


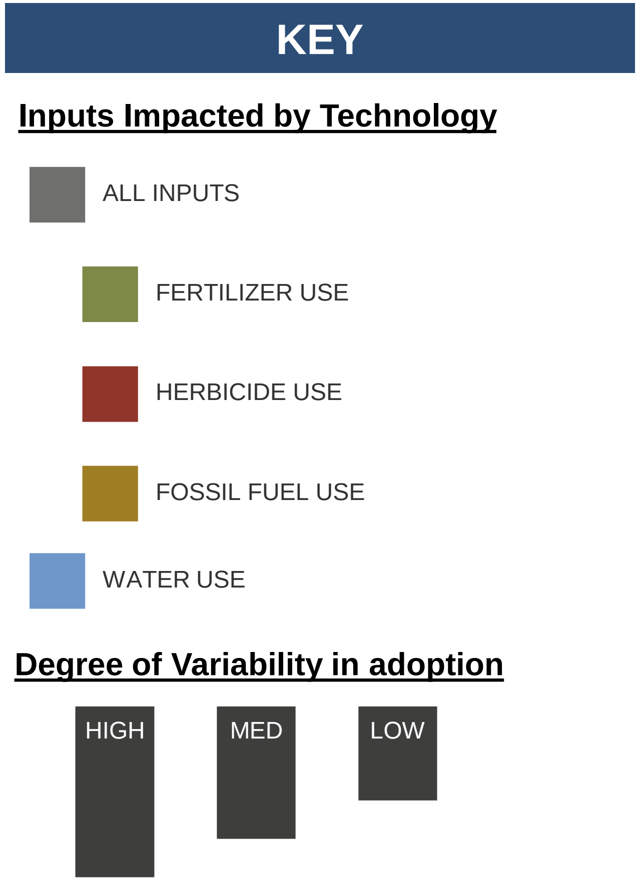


Source: Purdue Precision Agriculture Dealer Survey, Context Expert Estimates

Adoption of Fleet Telematics

Fleet telematics achieves an environmental benefit from allowing the operator of a fleet of machinery to optimize the use of individual machinery and monitor overall fleet utilization thereby generating savings of fossil fuels in the long run.

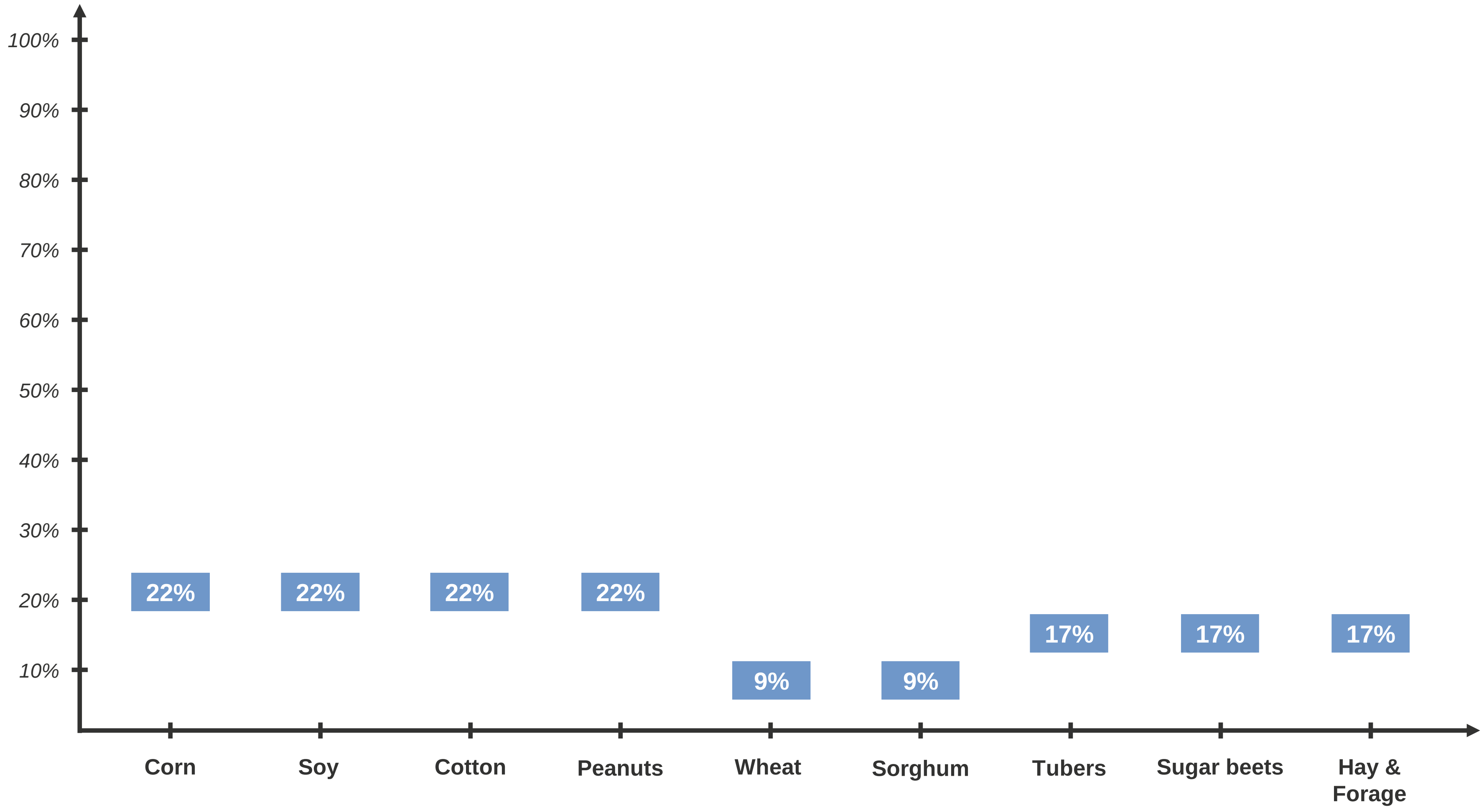


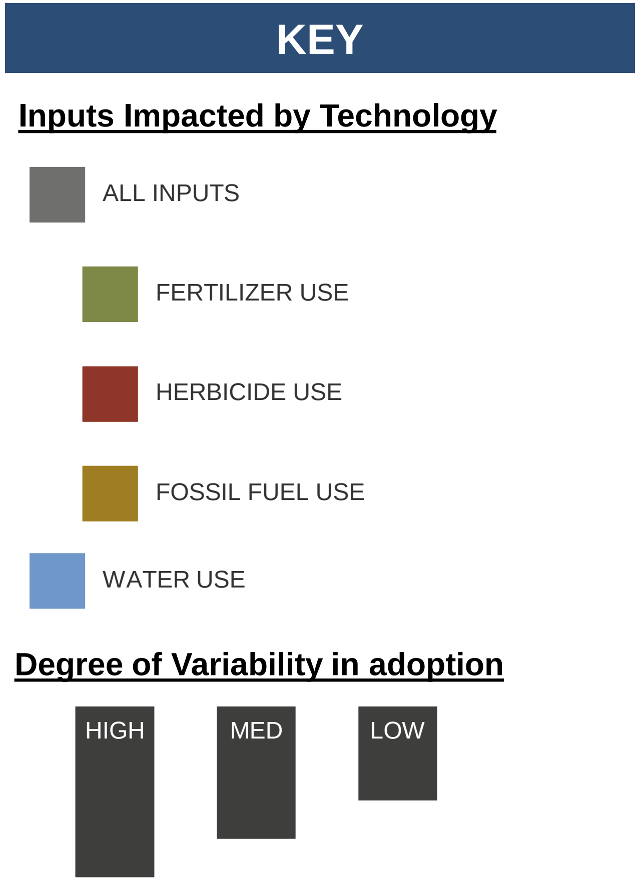


Source: Purdue Precision Agriculture Dealer Survey, Context Expert Estimates

Adoption of Precision Irrigation

Adoption of computer sensor driven precision pivots has reduced the overall usage of water on acres adopting.

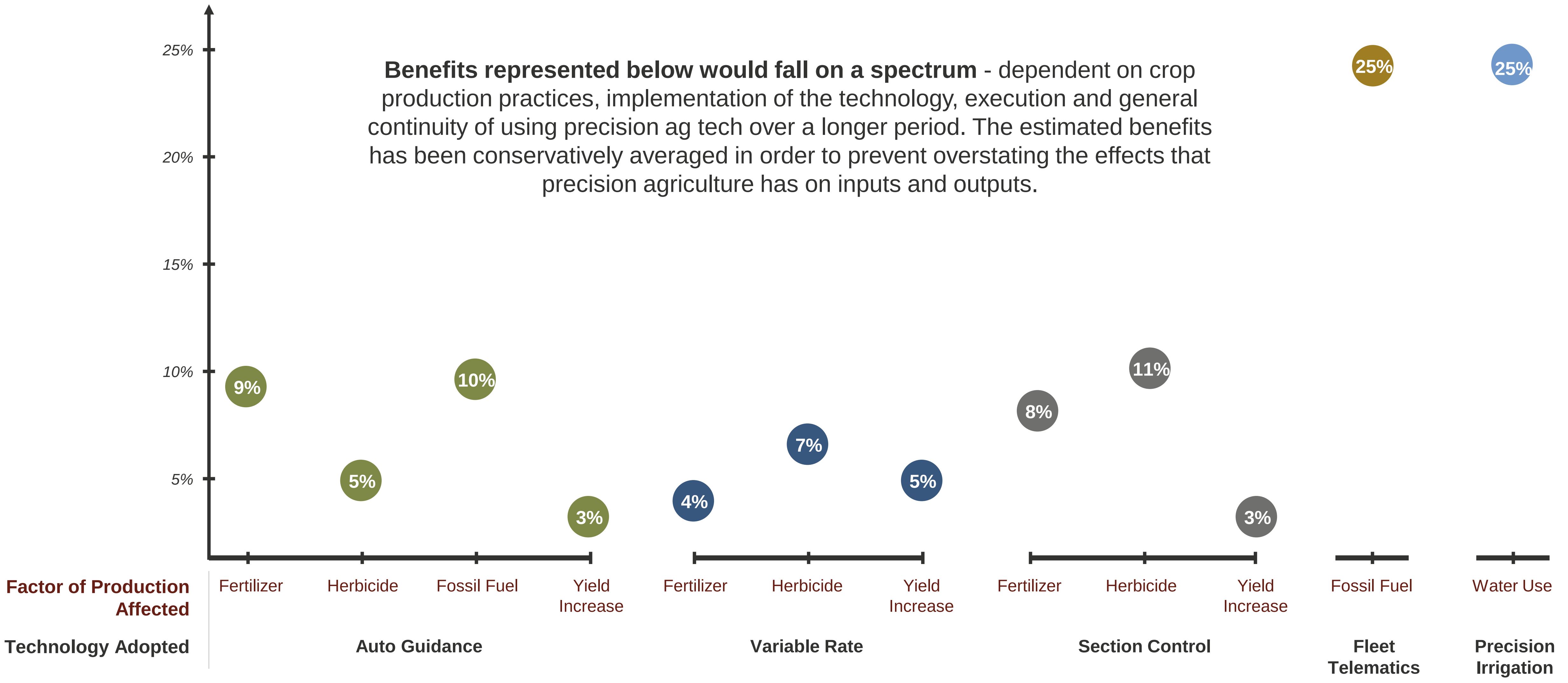




Source: Ohio State University, USDA NRCS, University of Kentucky, NDSU, ISU, University of Illinois, UC Davis, Wageningen University, Context Expert estimates

Estimated benefits of Precision Ag Technologies

Represents the percent decrease in the use of inputs (increase in the case of yields) resulting from the adoption of precision ag technologies applicable to all crops.



Source: Ohio State University, USDA NRCS, University of Kentucky, NDSU, ISU, University of Illinois, UC Davis, Wageningen University, Context Expert estimates

Carbon study appendix slides

Total CO_2 equivalent emissions avoided were approximately 10,100,000 MT with an additional 17,300,000 million MT potentially avoided through broader adoption of precision agriculture

The Precision agriculture study estimated that there were 5 key benefits that were seen as a result of adoption of PA technologies

1. **More productive Land**
   Thereby avoiding farming additional acres to produce the same amount of food
2. **Reduced Herbicide Use**
   From unnecessary over spraying
3. **Fertilizer use efficiency**
   From application of the right amounts at the right place at the right time
4. **Reduced Water Use**
   From more precise application using sensor driven pivots
5. **Reduced fossil fuel use from machines**
   Optimized machine use using analytics and guidance

10,100,00MT
of CO_2 were not emitted as a result of Precision Agriculture

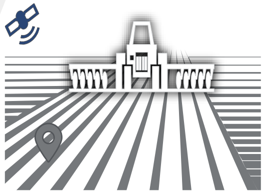
At current adoption levels

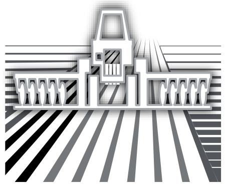
→

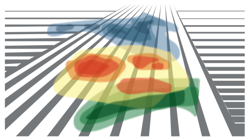
27,400,000MT
of CO_2 would not be emitted as a result of broader adoption of precision agriculture technologies

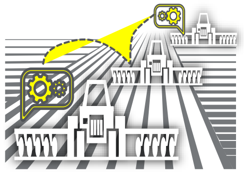
At near full adoption levels

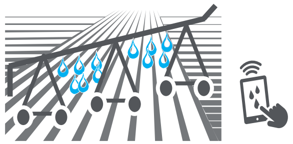
Technologies assessed include:


Auto Guidance

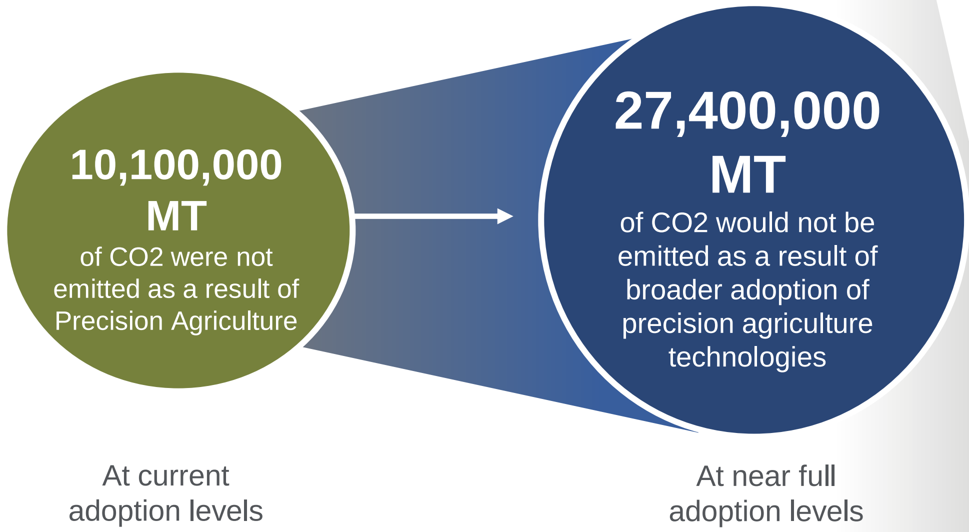

Machine Section Control


Variable Rate


Fleet Telematics


Precision Pivots

At full adoption of precision agriculture, the carbon emissions savings resulting from it would equate to ~6,00,000 passenger vehicles off the road permanently.



The average passenger vehicle in the United states emits roughly **4.6 MT** of CO2 equivalent every year according to the EPA.

The resulting carbon dioxide equivalent reduction at current levels of adoption of precision agriculture would equate to ~**2,200,000** passenger vehicles off the road permanently

At full adoption levels of precision agriculture, this would equate to **6,000,000** passenger vehicles off the roads permanently. This is 2-3% of all vehicles currently on the road in the US.

How does each one of the benefits from precision agriculture impact carbon emissions?

1 More productive Land
Thereby avoiding farming additional acres to produce the same amount of food

More productive land ensures that the same amount of food is produced using less land. This implies that there are CO2e benefits from not having to farm the additional land. These benefits stem from not having to produce and apply inputs that would otherwise go on this land.

2 Reduced Herbicide Use
From unnecessary over spraying

On the land that is farmed, precision agriculture enables the better use of herbicides to ensure that there isn't over spraying or waste, thereby reducing the overall herbicide that is produced. Less herbicide produced implies less emissions through the vertical.

3 Fertilizer use efficiency
From application of the right amounts at the right place at the right time

Better application of fertilizer ensures that the crop receives the required nutrition, improving yields but also to ensure that there isn't over application where it isn't needed. This reduces the overall amount of fertilizer that needs to be produced. Fertilizer production is energy intensive, thereby there is a CO2e benefit from not having to produce it.

4 Reduced Water Use
Reduced fossil fuel consumption from not having to use pumps to pull water from the ground

+

5 Reduced fossil fuel use from machines
Optimized machine use using telematics, machine analytics and guidance systems

Precision irrigation enables water to be used more efficiently. Water not wasted is also water that is not irrigated. Irrigation is a highly energy intensive process with farmers having to pump water from deep below the surface. There are CO2e emissions benefits from not expending fossil fuels and electricity in pumping water and irrigating fields.

A reduction in idling time and better, more optimized use of machinery reduces use of diesel and does away with the need to expend additional fossil fuels. These savings have a direct environmental benefit and carbon saving from not having to extract and burn it.

Carbon emissions from reduced water use and more efficient use of machines ultimately impacts the amount of fossil fuel use, therefore have been combined for purposes of simplicity.

4 Reduced Water Use

A reduction in water used to irrigate fields implies, that a majority of that water will not be required to be pulled from the ground. These irrigation pumps are largely dependent on fossil fuels as a source of energy. This avoidance of water irrigated, would ultimately lead to reduced carbon emissions arising from less emissions from the burning of fossil fuels.

5 Reduced fossil fuel use from machines

More efficient use of machines from the use of technologies like auto guidance and fleet telematics, ultimately reduce the amount of fossil fuels consumed. This arises from lower idle time and reduced number of passes on a field.

Fossil fuel use for irrigation + ***Fossil fuel use for machines***

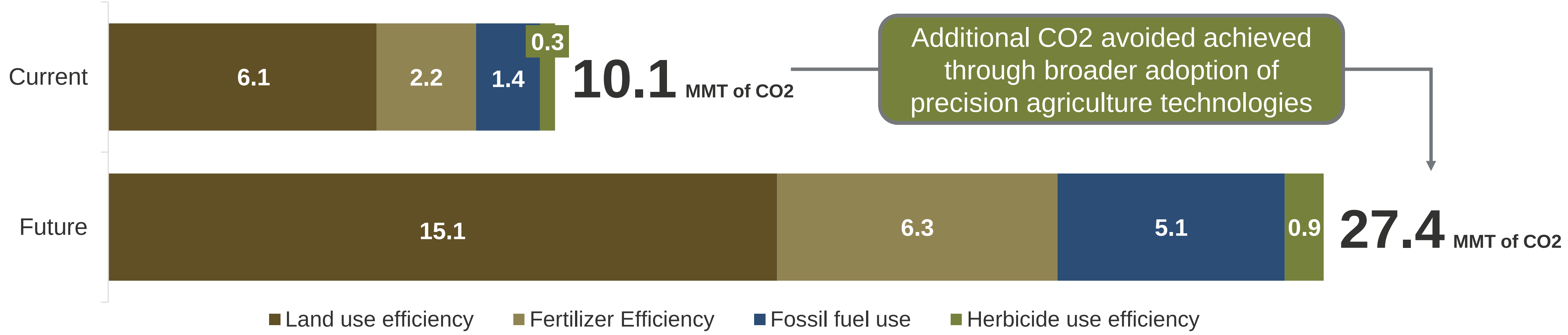
Overall fossil fuel savings

↓

Reduced carbon emissions

Increased land use efficiency is the single largest source of CO2 reduction

BREAKDOWN OF CARBON DIOXIDE EMISSION SAVINGS BY PRECISION AG BENEFIT



Broader adoption of Precision agriculture, driven by better access to internet, tech integration and support will lead to lower CO2 emitted into the atmosphere per unit of crop harvested

Precision Ag Technologies	Current Average Adoption	Adoption Upside
Auto Guidance	60%	>30%
Machine Section Control	40%	>50%
Variable Rate Application	42%	>50%
Fleet Telematics	12%	>80%
Precision Pivots	20%	>70%

Precision agriculture is estimated to have reduced overall agricultural emissions by ~2% with an additional carbon reduction of 4% possible with greater adoption of PA

The CO2 not emitted into the atmosphere as a result of efficiencies from PA amount to ~2% of overall agricultural carbon emissions

Tertiary Benefits

Climate change induced migration, long term farmer prosperity from healthier land, cleaner waterways from reduced runoff

Secondary Benefits

Preservation of forests, Savings along the value chain from not having to transport inputs, Improved soil health

Primary Benefits

10,100,000MT

Of CO2 equivalent

Figure: Total GHG estimated GHG in CO2 eq. not emitted as a result of precision agriculture
Source: Context Analysis

Source: USDA ERS

Model estimation process

Fertilizer, herbicide and fossil fuel use

Input savings as a result of precision agriculture → Total energy required to produce and apply the inputs → Total CO2 emissions savings

Source: Context Precision Ag Study

Source: Iowa State University

Productivity gains
from land that would not have been needed to be farmed to produce the same amount of food.

Total land not farmed as a result of productivity gains from precision ag → Total emissions per acre of crop farmed → Total CO2 emissions savings

Source: Context Precision Ag Study

Source: Field To Market

Reduced fossil fuel savings from less water needed

Total water saved as a result of precision agriculture → Energy required to pull water from different depths → Diesel required to produce that energy → Total CO2 emissions savings

Source: Context Precision Ag Study

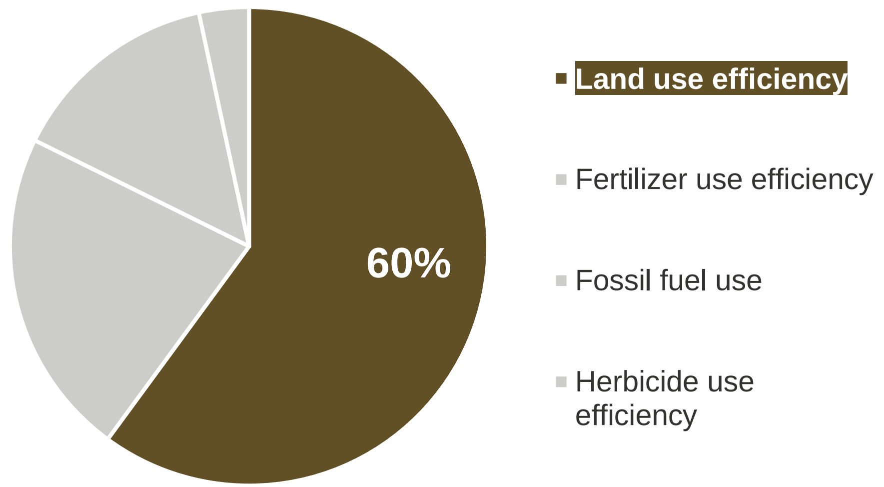
Source: Cotton Info Australia

Source: University of Exeter

Land Use: More productive land accounted for 60% of the carbon not emitted into the atmosphere as a result of current adoption of precision agriculture

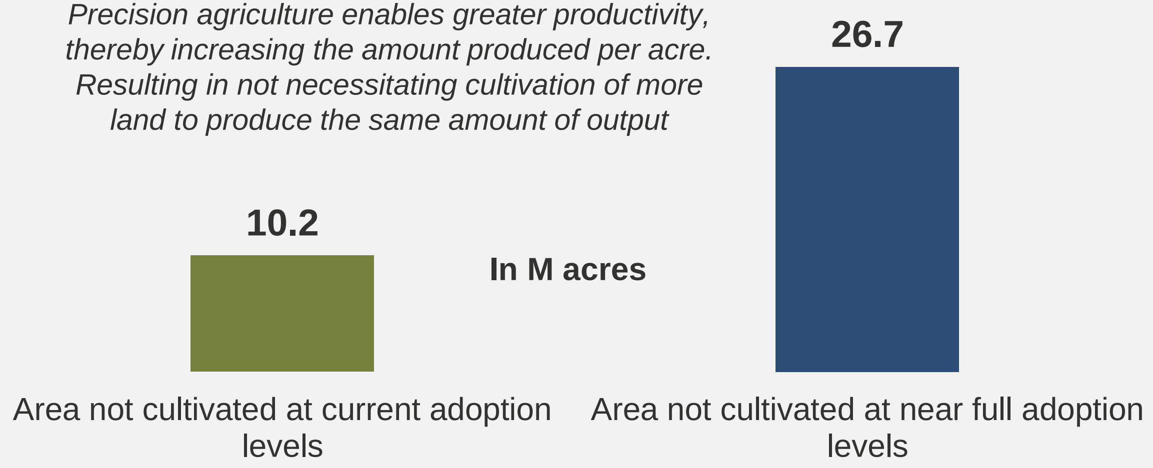
Primary benefits: reduced CO_2 from not having seed the ground, use crop inputs, harvest and process the output.
Secondary benefits: Lifecycle savings from not having to produce the inputs and transport the outputs

CURRENT CO2 BENEFITS FROM PA

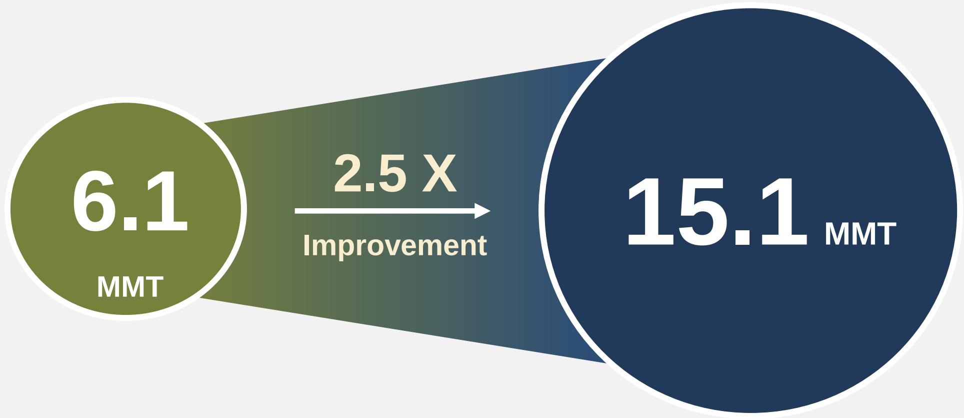


An increase in area that does not need to be cultivated

Precision agriculture enables greater productivity, thereby increasing the amount produced per acre. Resulting in not necessitating cultivation of more land to produce the same amount of output



Greater amount of CO2 that is not emitted



CO2 not emitted at current adoption levels

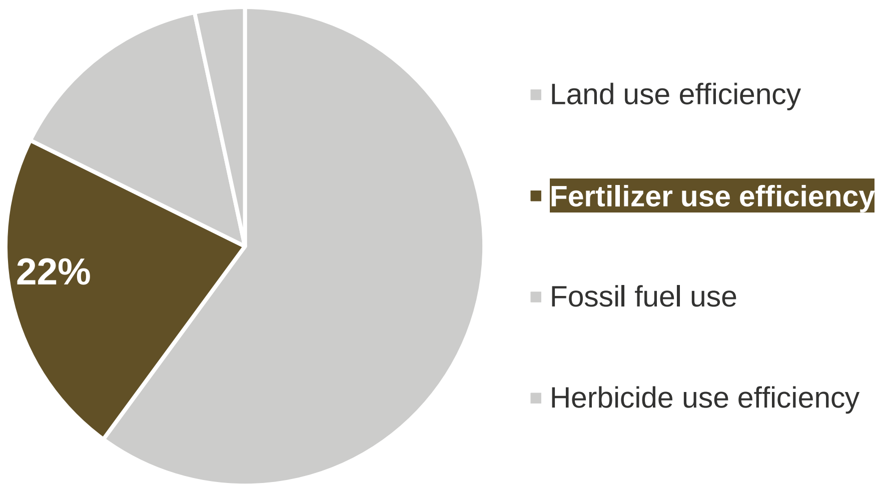
CO2 not emitted at near full adoption levels

Fertilizer use efficiency: The carbon benefit from more efficiently and effectively using fertilizer comes from the need to not manufacture, transport and apply it.

Primary benefits: Not having to manufacture, transport and apply additional fertilizer

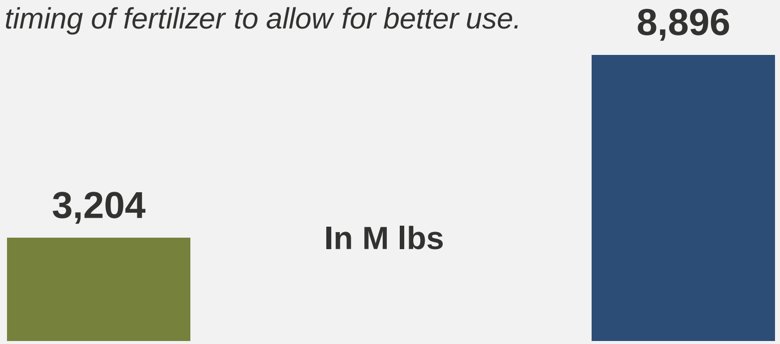
Secondary benefits: Enhanced productivity of land due to accurate application of fertilizer

CURRENT CO2 BENEFITS FROM PA



An increase in fertilizer that is not required to be produced

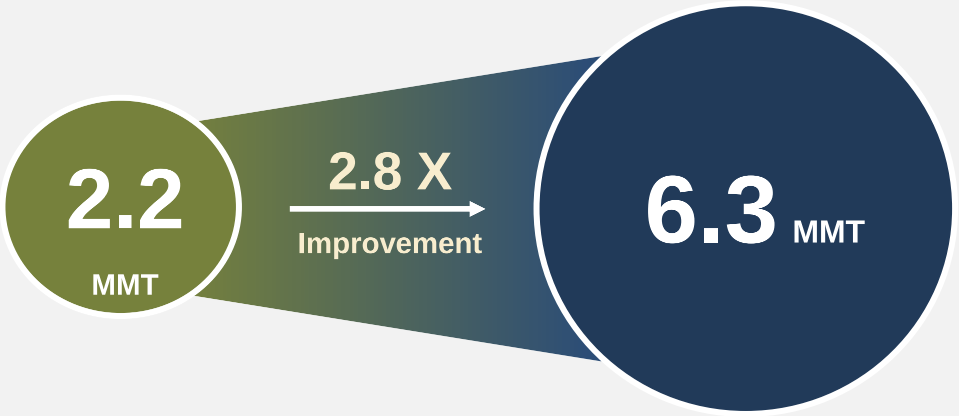
Precision agriculture enables the right placement, rate and timing of fertilizer to allow for better use.



Cumulative fertilizer not applied at current adoption levels

Cumulative fertilizer not applied at near full adoption levels

Greater amount of CO2 that is not emitted



CO2 not emitted at current adoption levels

CO2 not emitted at near full adoption levels

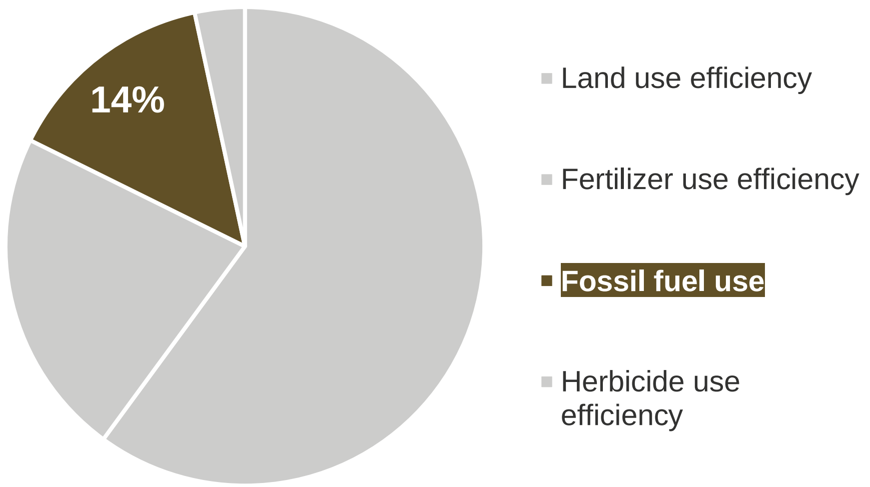
Source: Iowa State University, University of Exeter, Context Analysis

Fossil fuel Use: There is an overall reduced carbon footprint from burning fewer fossil fuels to operate the same machinery and irrigate the same land

Primary benefits: Reduction in direct emissions from producing, transporting and burning of diesel

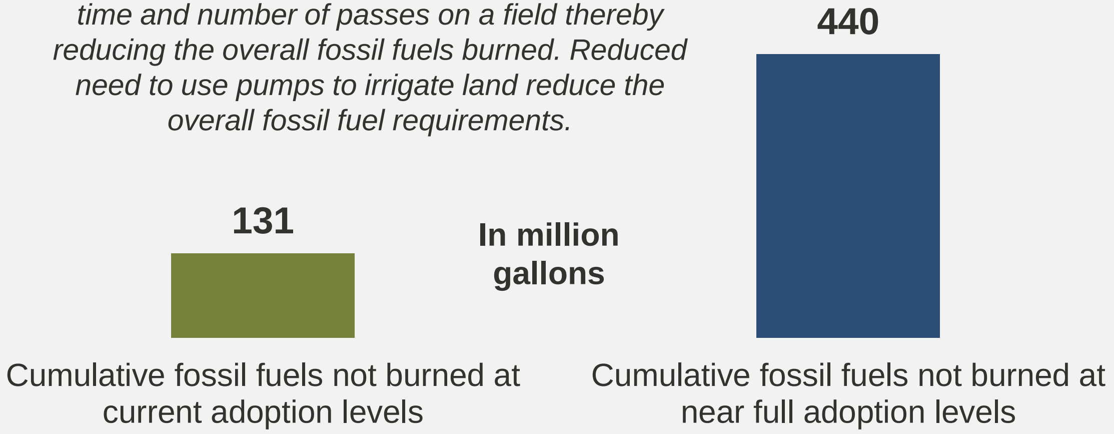
Secondary benefits: Ability for machines to produce the same output with less fossil fuels leading to downstream benefits

CURRENT CO2 BENEFITS FROM PA

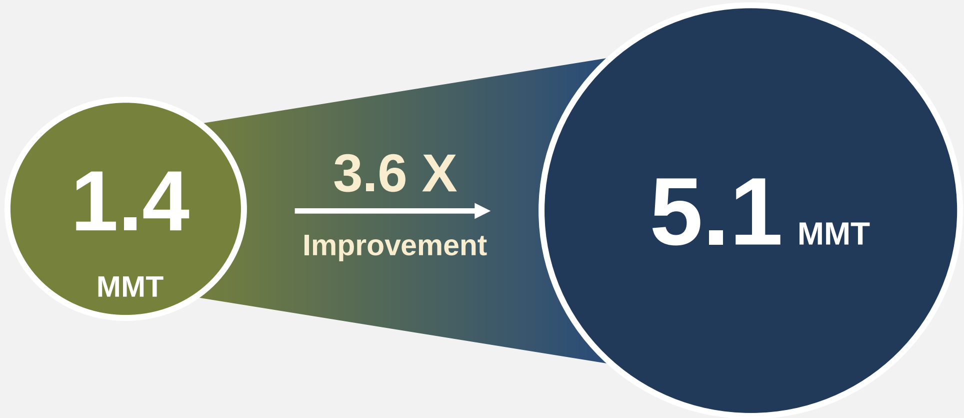


An increase in fossil fuel that is not required to be used

Fleet telematics and auto guidance reduces idle time and number of passes on a field thereby reducing the overall fossil fuels burned. Reduced need to use pumps to irrigate land reduce the overall fossil fuel requirements.



Greater amount of CO2 that is not emitted



CO2 not emitted at current adoption levels

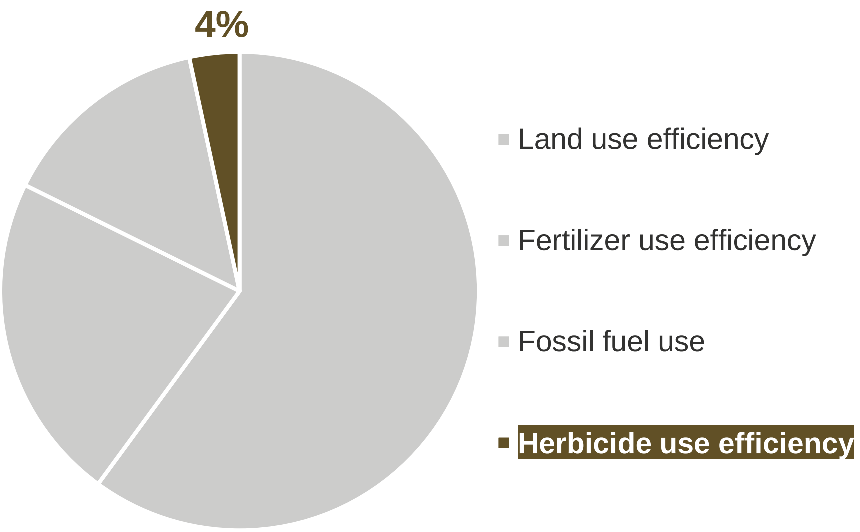
CO2 not emitted at near full adoption levels

Source: The University of Exeter, Context Analysis

Herbicide use: Applying less herbicides reduces the overall carbon footprint lowering the need to manufacture, transport and apply it

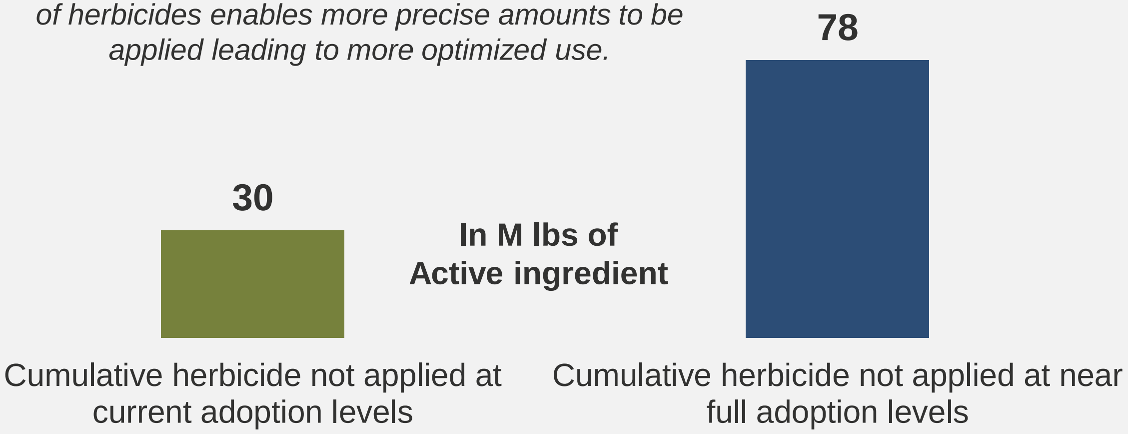
Primary benefits: Reduction in emissions from not having to manufacture, transport and apply herbicide. Reduction in emissions from not having to pump water out of the ground
Secondary benefits: Reduced runoff from additional herbicide that would have been applied

CURRENT CO2 BENEFITS FROM PA

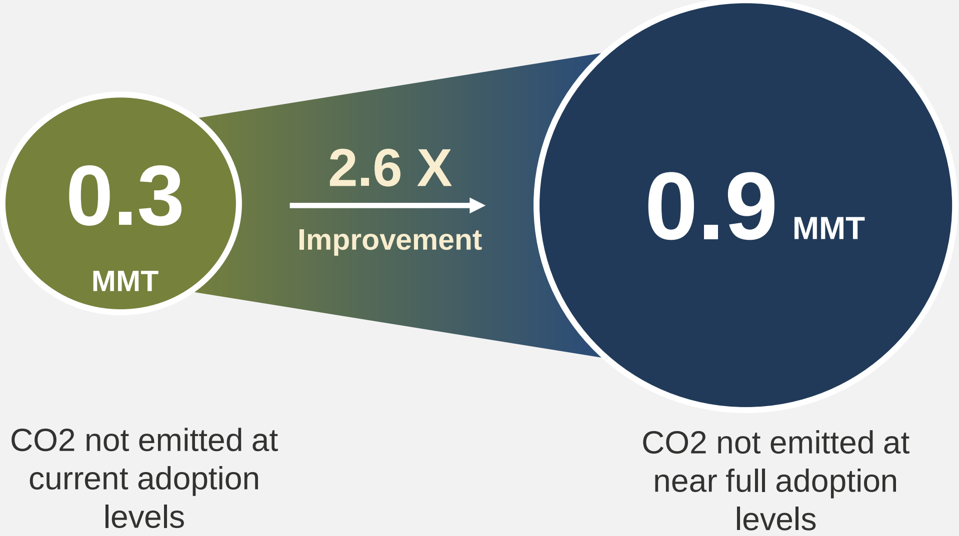


An increase in herbicide that is not required to be used

Auto guidance, section control and VR application of herbicides enables more precise amounts to be applied leading to more optimized use.



Greater amount of CO2 that is not emitted



Source: Iowa State University, The University of Exeter, Context Analysis

References

Source details: In addition to the context precision agriculture study, the following sources were used to triangulate information regarding carbon benefits arising from precision agriculture

Herbicide reduction:

https://farm-energy.extension.org/energy-use-and-efficiency-in-pest-control-including-pesticide-production-use-and-management-options/
https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm
https://store.extension.iastate.edu/product/13385 [need to download the paper]

Land use:

http://fieldtomarket.org/media/2016/12/Field-to-Market_2016-National-Indicators-Report.pdf

Water Use:

https://www.cottoninfo.com.au/sites/default/files/documents/Fundamentals%20EnergyFS_A_3a.pdf
https://pubs.acs.org/doi/10.1021/acs.est.0c02897
https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris13_1_008_008.pdf

Fertilizer Use:

https://store.extension.iastate.edu/product/13385 [need to download the paper]
https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm

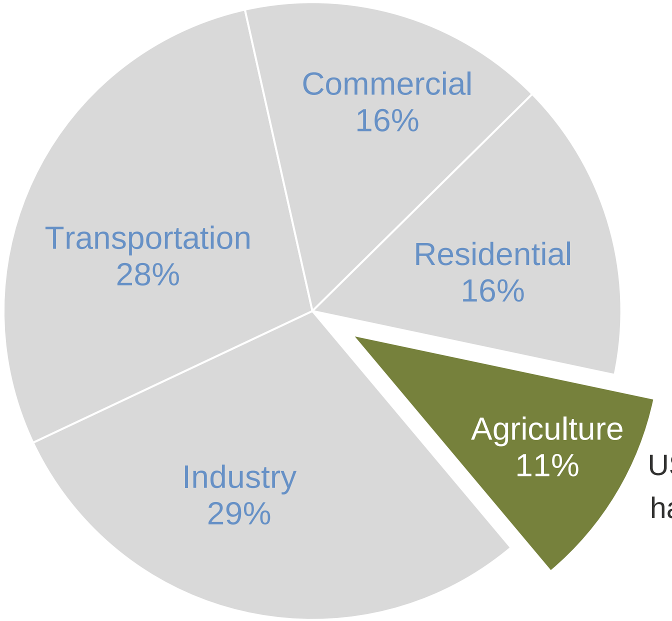
Diesel use:

https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm

Precision agriculture is estimated to have reduced overall agricultural emissions by ~2% with an additional carbon reduction of 4% possible with greater adoption of PA

Total 2018 GHG emissions in the U.S was **6,677 MMT** of CO2 Equivalent

The CO2 not emitted into the atmosphere as a result of efficiencies from PA amount to ~2% of overall agricultural carbon emissions



US Agriculture is estimated to have produced **~700 MMT** of CO2 equivalent

Figure: total GHG emissions in the U.S in 2018 (CO2 equivalent)
Source: USDA ERS

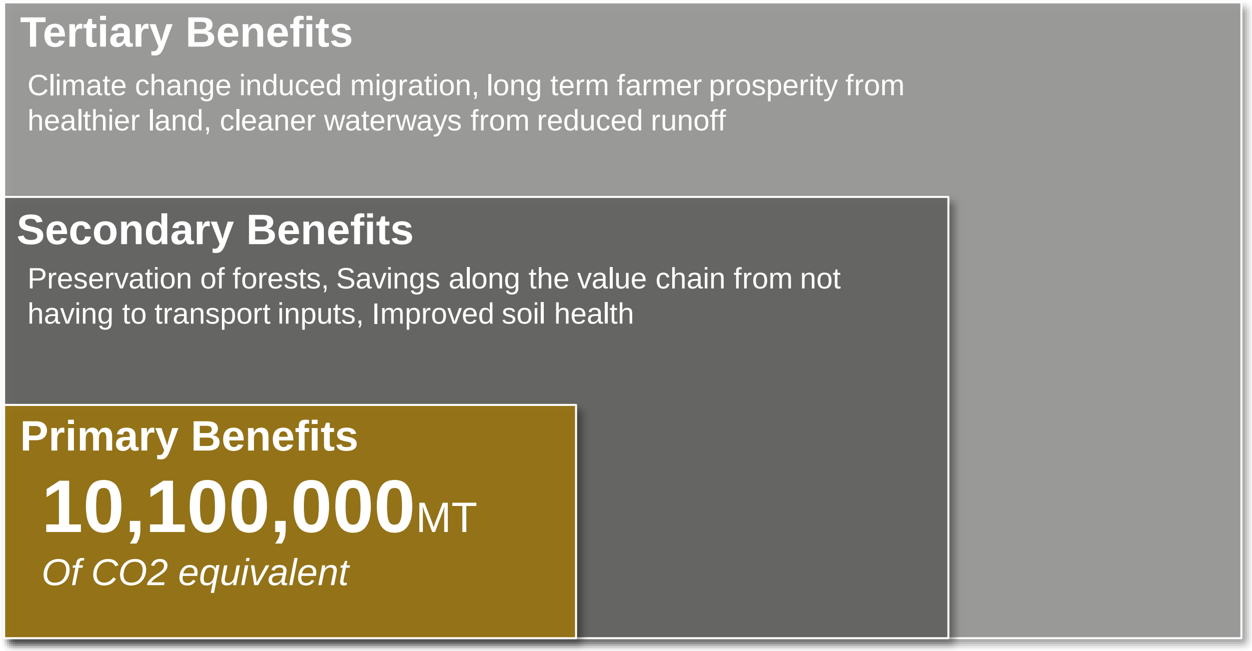


Figure: Total GHG estimated GHG in CO2 eq. not emitted as a result of precision agriculture
Source: Context Analysis

Source: USDA ERS

Project Objectives & Methodology

Project Objective is to quantify the environmental benefits to precision agriculture (P.A.) in the U.S.

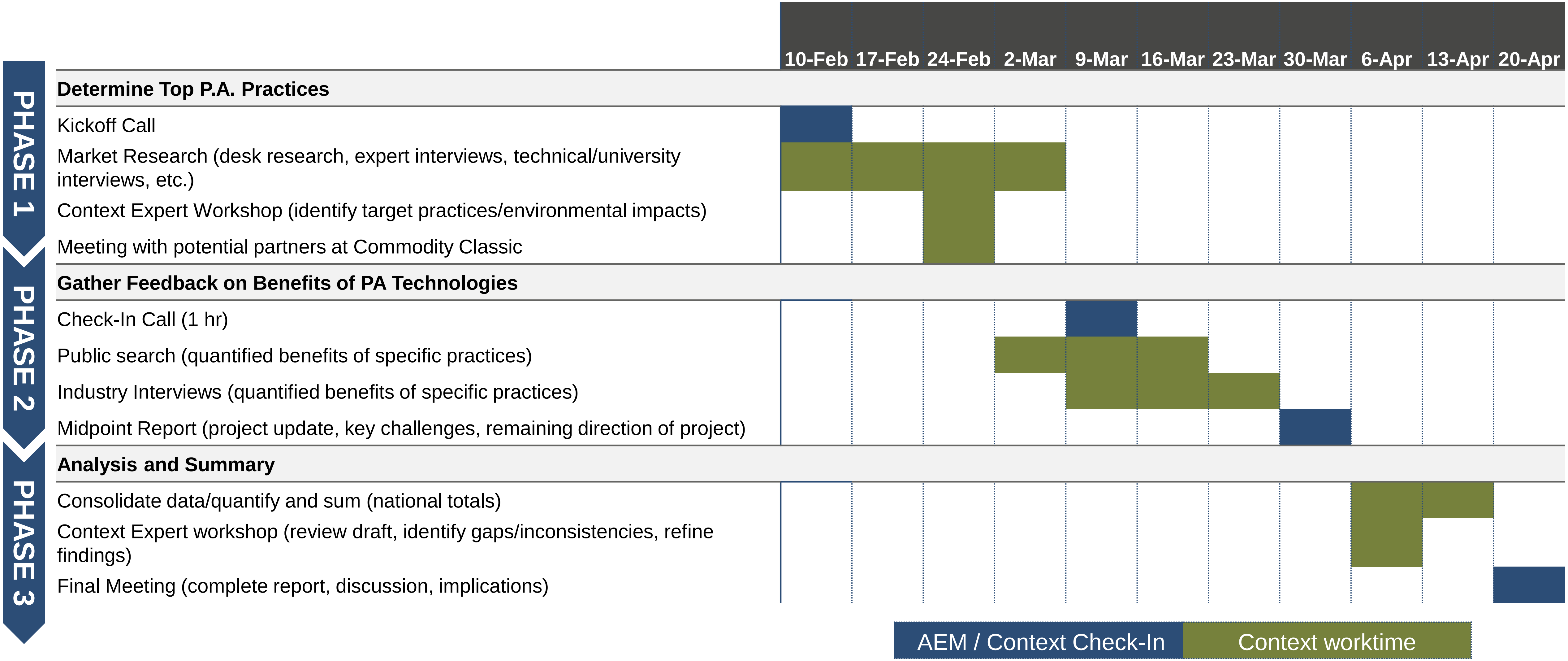
The overarching objective for this project is to **quantify the environmental benefits of precision agriculture (P.A.) in the U.S.** for equipment manufacturers

CONTEXT'S SPECIFIC OBJECTIVES INCLUDE:

- Define the primary precision agriculture practices of U.S. production agriculture and estimate the penetration of each of those practices
- Determine tangible and quantifiable environmental benefits associated with the various practices
- Summarize the benefits to determine an overall view of the quantified benefits of precision agriculture in the U.S.

The outcome of this project is expected to provide a baseline for potential deeper-dive analyses in future bodies of work

Project Timeline (Feb-April 2020)



Modeling Framework & Detailed Outcomes

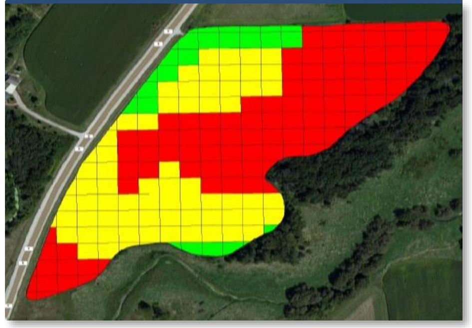
A high-level framework of DATA CREATION → ANALYTICS → DECISION → EXECUTION was utilized to prioritized technologies; EXECUTION was of greatest focus

Data Creation / Collection

Data Analytics

Decision Point

Variable Rate Prescriptions



Section Control Maps

Execution

Variable Rate Seeding & Fertilizer

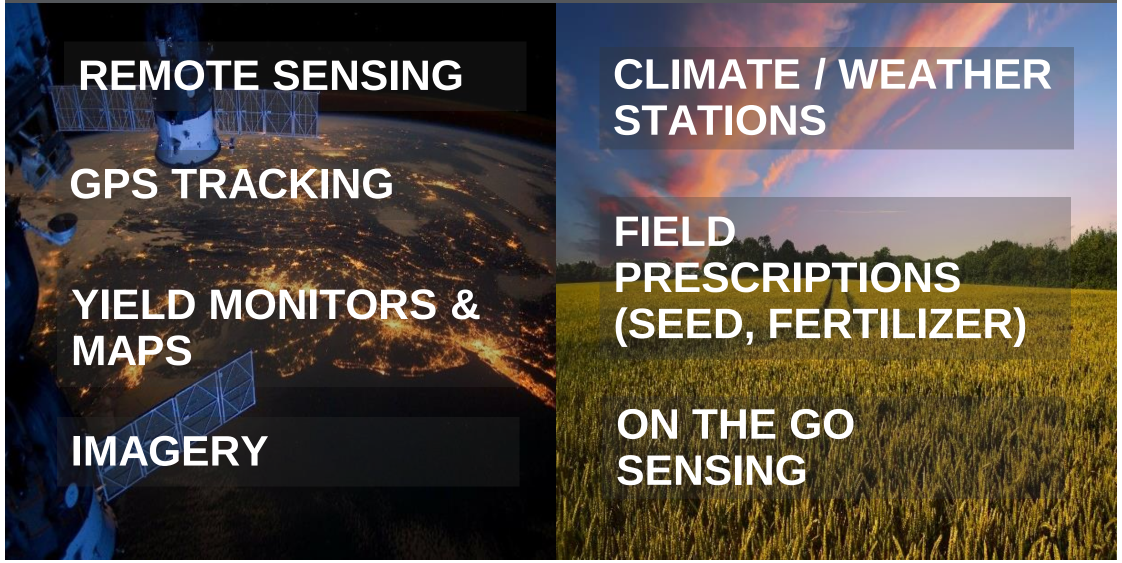
Planted, Nutrient, CP Section Control

Many technologies do not offer environmental benefits in isolation, but rather aid in enabling other technologies to deliver environmental / economic benefits

How we get to the future: Many technologies enable precision agriculture

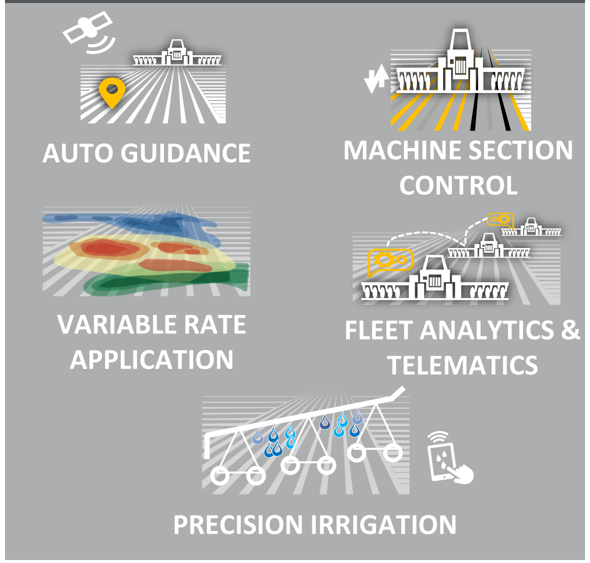
ENABLERS

AG TECHNOLOGY



IMPACTS MEASURED

PRECISION AG TECH



Enabling technologies such as **yield mapping** and **soil sampling** were included indirectly within the “execution” of precision ag tech. The environmental benefits of the precision ag technologies are only achievable with accurate and routine use of enabling technologies.

Most relevant technologies were captured and quantified for the purposes of estimating the environmental benefits of precision agriculture

Precision Ag Technologies *(preliminary list)*
GPS // Auto Guidance
Climate // Remote Sensing
Drone Imagery
Satellite Imagery
Fixed Wing // Manned Imagery
Variable Rate Seeding
Planter Section Control
Depth Control
Down Pressure Control
On-the-go Planter sensing
Variable Rate Fertilizer
Fertilizer Section Control
Soil Mapping/Sampling
Constituent Manure Sensing
Crop Protection Section Control
Drone Application
Robotic CP Application

Removed "data collection / cleanup / decision point" tools as ***standalone*** technologies (still considered as enablers)

Grouped according to season timing / activity:

1. Planting / Seeding
Fertilization
Crop Protection
Field Prep (Tillage)
Plant Seed
2. Growing
Fertilization
Crop Protection
Irrigate
3. Harvesting
Optimization
Logistics
Storage
4. Planning

Much overlap in the underlying technology (ex: auto guidance is beneficial for planting, fertilizer, and harvest)

Grouped according to underlying technologies ***(that most impact ag equipment companies)***

Auto Guidance
Field Prep (Tillage)
Planting Seed
Fertilization
Crop Protection
Harvesting
Section Control
Field Prep (Tillage)
Planting Seed
Fertilization
Crop Protection
Harvesting
Variable Rate
Planting Seed
Fertilization
Crop Protection
Machine & Fleet Analytics
Entire season

Most complete and robust framework with minimal overlap

Isolates the technology from the machinery
(ex: VR could be utilized via traditional machinery or via drone)

More definition of the groupings of technologies (that most impact ag equipment companies)

TECHNOLOGY	DEFINITION & EXAMPLES
AUTO GUIDANCE	
Field Prep (Tillage)	Auto guidance (reduced overlap + avoided skips) during tillage passes
Planting Seed	Auto guidance (reduced overlap + avoided skips) during planting passes
Fertilization	Auto guidance (reduced overlap + avoided skips) during fertilization passes
Crop Protection	Auto guidance (reduced overlap + avoided skips) during spraying passes
Harvesting	Auto guidance (reduced overlap + avoided skips) during harvest passes
SECTION CONTROL	
Field Prep (Tillage)	Section control (optimized placement) during tillage, including drag/depth control
Planting Seed	Section control (optimized placement) during planting, including row, depth, and down pressure control
Fertilization	Section control (optimized placement) during fertilization, including row control
Crop Protection	Section control (optimized placement) during spraying, including row control
Harvesting	Smart combines (efficient speed, height, internal settings) during harvest
VARIABLE RATE	
Planting Seed	Variable rate (optimized rate) during planting
Fertilization	Variable rate (optimized rate) during fertilization
Crop Protection	Variable rate (optimized rate) during spraying, including UAV application
MACHINE & FLEET ANALYTICS	
Entire Season	Vehicle-to-vehicle connectivity; vehicle-to-office connectivity; remote operations & decision-making

The study process has iterated through several different frameworks for capturing the ENVIRONMENTAL BENEFITS most relevant for it in a way that is thorough and not redundant

BENEFITS
Use of Inputs
Energy Consumption
Nutrient Loss
Water Quality
Soil health
Net GHG impact
Other

Considered potential conflict with double-counting

Ex:
- GHG impacted by energy consumption
- GHG impacted by use of inputs
- Water quality impacted by Nutrient Loss

Grouped the outcomes that are most quantifiable and distinct (avoided overlap)

		OUTCOMES DIRECTLY RELVENT FOR AEM		
		Crop Input Use	**Productivity / Land Use Efficiency**	**Fossil Fuel Savings**
	Direct Outcomes *(to be quantified)*	– Optimization of inputs (reduced overlap, avoid skips, best placement and rate of inputs)	– Yield benefit from accurate spacing (pass-to-pass, end/point rows) and population rate	– Fuel savings from fewer field passes, variable depth of tillage, and/or more efficient harvest
USDA PILLARS	DIRECT ENVIRONMENTAL BENEFIT	●		●
USDA PILLARS	PRODUCTIVITY (YIELD) BENEFIT	●	●	
USDA PILLARS	FARMER ECONOMIC BENEFIT	●	●	●
	Secondary / Indirect Outcomes	– Improved water quality (reduced nutrient runoff) – Improved soil health – Net GHG reduction (including in production of inputs)	– Avoid unproductive / preserved land from being in production – Soil compaction	– Net GHG reduction

Resulting Matrix

KEY:

N/A
Benefit, but difficult to quantify OR benefit may be economical only
Strong benefit that is feasible to quantify

	Crop Input Use	Productivity / Land Use Efficiency	Fossil Fuel Savings
DEFINITION	*- Optimization of inputs*	*- Yield benefit - Avoid unproductive / preserved land from being in production -Soil Compaction*	*-Fuel savings from fewer field passes -Fuel savings from efficient harvest -Fuel savings from variable depth of tillage*
AUTO GUIDANCE			
Tillage			Fuel savings from fewer field passes
Planting	reduced overlap and avoid skips (limited / unclear environmental benefit)	positive yield b/c of accurate spacing (pass-to-pass)	Fuel savings from fewer field passes
Fertilization	reduced overlap and avoid skips	positive yield b/c of accurate placement (pass-to-pass)	Fuel savings from fewer field passes
Crop Protection	reduced overlap and avoid skips	positive yield b/c of accurate placement (pass-to-pass)	Fuel savings from fewer field passes
Harvesting			Fuel savings from fewer field passes
SECTION / ROW / DEPTH / DOWN PRESSURE CONTROL			
			optimized drag due to depth control
Planting	optimization of placement	positive yield b/c of accurate spacing (end/point rows)	
Fertilization	optimization of placement	positive yield b/c of accurate placement (end/point rows)	
Crop Protection	optimization of placement	positive yield b/c of accurate placement (end/point rows)	
Harvesting			
VARIABLE RATE (Including drone applications & mechanical)			
Tillage			
Planting	optimization of rate	positive yield b/c of accurate population rate	
Fertilization	optimization of rate	positive yield b/c of accurate application rate	
Crop Protection	optimization of rate	positive yield b/c of accurate application rate	drone CP application vs. traditional sprayers - theoretical fossil fuel savings
Harvesting		smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)	smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)
MACHINE & FLEET ANALYTICS			
Tillage Planting Fertilization Crop Protection Harvesting		soil compaction - vehicle-to-vehicle connectivity; vehicle-to-office connectivity and remote operations/decision-making	fuel savings - vehicle-to-vehicle connectivity; vehicle-to-office connectivity and remote operations/decision-making

8 distinct calculations will be done according to the green areas with the highest level of information available and relevance to AEM

	Crop Input Use	Productivity / Land Use Efficiency	Fossil Fuel Savings
DEFINITION	*- Optimization of inputs*	*- Yield benefit* *- Avoid unproductive / preserved land from being in production* *-Soil Compaction*	*-Fuel savings from fewer field passes* *-Fuel savings from efficient harvest* *-Fuel savings from variable depth of tillage*
AUTO GUIDANCE			
Tillage			Fuel savings from fewer field passes
Planting	reduced overlap and avoid skips (limited / unclear environmental benefit)	positive yield b/c of accurate spacing (pass-to-pass)	Fuel savings from fewer field passes
Fertilization	reduced overlap and avoid skips	positive yield b/c of accurate placement (pass-to-pass) **2**	Fuel savings from fewer field passes **3**
Crop Protection	reduced overlap and avoid skips **1**	positive yield b/c of accurate placement (pass-to-pass)	Fuel savings from fewer field passes
Harvesting			Fuel savings from fewer field passes
SECTION / ROW / DEPTH / DOWN PRESSURE CONTROL			
			optimized drag due to depth control
Planting	optimization of placement	positive yield b/c of accurate spacing (end/point rows)	
Fertilization	optimization of placement	positive yield b/c of accurate placement (end/point rows) **5**	
Crop Protection	optimization of placement **4**	positive yield b/c of accurate placement (end/point rows)	
Harvesting			
VARIABLE RATE (Including drone applications & mechanical)			
Tillage			
Planting	optimization of rate	positive yield b/c of accurate population rate	
Fertilization	optimization of rate	positive yield b/c of accurate application rate **7**	
Crop Protection	optimization of rate **6**	positive yield b/c of accurate application rate	rone CP application vs. traditional sprayers - heoretical fossil fuel savings
Harvesting		smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)	smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)
MACHINE & FLEET ANALYTICS			
Tillage			
Planting			
Fertilization		soil compaction - vehicle-to-vehicle connectivity; vehicle-to-office connectivity and remote operations/decision-making **8**	fuel savings - vehicle-to-vehicle connectivity; ehicle-to-office connectivity and remote operations/decision-making
Crop Protection			
Harvesting			

SAMPLE: Section 1 – Impact of Auto Guidance on Crop Input Use

		Crop Input Use
Auto Guidance	Fertilization	reduced overlap and avoid skips 1
	Crop Protection	reduced overlap and avoid skips

		Crop Input Use
Auto Guidance	Fertilization	reduced overlap and avoid skips 1
	Crop Protection	reduced overlap and avoid skips

QUANTIFIED BENEFITS

FERTILIZER

- Current Application (volume) by ADOPTION vs. NON-ADOPTION Acres
- Application (volume) AVOIDED due to EXISTING ADOPTION
- Potential Application Reduction at 100% ADOPTION

CROP PROTECTION

- Current Application (volume) by ADOPTION vs. NON-ADOPTION Acres
- Application (volume) AVOIDED due to EXISTING ADOPTION
- Potential Application Reduction at 100% ADOPTION

ADDITIONAL BENEFITS

Fertilizer:

– Reduced nutrient runoff to waterways, resulting in increased water quality
– Improved soil health
– Net GHG reduction (including in production of fertilizer)

Crop protection:

– Improved soil health
– Net GHG reduction (including in production of crop protection)

At the last project update, 8 distinct calculations were identified

	Crop Input Use	Productivity / Land Use Efficiency	Fossil Fuel Savings
DEFINITION	*- Optimization of inputs*	*- Yield benefit - Avoid unproductive / preserved land from being in production -Soil Compaction*	*-Fuel savings from fewer field passes -Fuel savings from efficient harvest -Fuel savings from variable depth of tillage*
AUTO GUIDANCE			
Tillage			Fuel savings from fewer field passes
Planting	reduced overlap and avoid skips (limited / unclear environmental benefit)	positive yield b/c of accurate spacing (pass-to-pass)	Fuel savings from fewer field passes
Fertilization	reduced overlap and avoid skips	positive yield b/c of accurate placement (pass-to-pass) 2	Fuel savings from fewer field passes 3
Crop Protection	reduced overlap and avoid skips 1	positive yield b/c of accurate placement (pass-to-pass)	Fuel savings from fewer field passes
Harvesting			Fuel savings from fewer field passes
SECTION / ROW / DEPTH / DOWN PRESSURE CONTROL			
			optimized drag due to depth control
Planting	optimization of placement	positive yield b/c of accurate spacing (end/point rows)	
Fertilization	optimization of placement	positive yield b/c of accurate placement (end/point rows) 5	
Crop Protection	optimization of placement 4	positive yield b/c of accurate placement (end/point rows)	
Harvesting			
VARIABLE RATE (Including drone applications & mechanical)			
Tillage			
Planting	optimization of rate	positive yield b/c of accurate population rate	
Fertilization	optimization of rate	positive yield b/c of accurate application rate 7	
Crop Protection	optimization of rate 6	positive yield b/c of accurate application rate	rone CP application vs. traditional sprayers - heoretical fossil fuel savings
Harvesting		smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)	smart combines - adjusting settings real time for efficient harvest (speed, height of header, internal settings)
MACHINE & FLEET ANALYTICS			
Tillage			
Planting			
Fertilization		soil compaction - vehicle-to-vehicle connectivity; vehicle-to-office connectivity and remote operations/decision-making	8 fuel savings - vehicle-to-vehicle connectivity; ehicle-to-office connectivity and remote operations/decision-making
Crop Protection			
Harvesting			

CONTEXT WILL ESTIMATE:

PAST / CURRENT VIEW

Application (volume) AVOIDED due to EXISTING ADOPTION

FUTURE VIEW

Potential Application Reduction at 100% ADOPTION

Since then, the framework has been adjusted slightly to form logical groupings of models around five environmental benefits

Previously "Crop Input Use" (Fertilizer Use, Herbicide Use)

Added to measure benefits of Precision Irrigation (Water Use)

Technology	Fertilizer Use	Herbicide Use	Productivity	Fossil Fuel Use	Water Use
Auto Guidance					N/A
Section Control				N/A	N/A
Variable Rate				N/A	N/A
Machine & Fleet Analytics	N/A	N/A	N/A		N/A
Precision Irrigation	N/A	N/A	N/A	N/A	
MODEL:	**A**	**B**	**C**	**D**	**E**

Model Inputs & Definitions
ENVIRONMENTAL BENEFITS

	Fertilizer Use	Herbicide Use	Productivity	Fossil Fuel Use	Water Use
Direct Outcomes *(to be quantified)*	– Optimization of fertilizer applications (reduced overlap, avoid skips, best placement and rate of inputs)	– Optimization of herbicide applications (reduced overlap, avoid skips, best placement and rate of inputs)	– Yield benefit from accurate spacing (pass-to-pass, end/point rows) and population rate	– Fuel savings from fewer field passes, variable depth of tillage, and/or more efficient harvest	– Water saved from evaporation and excess runoff through more precise application
Secondary / Indirect Outcomes	– Improved water quality (reduced nutrient runoff) – Improved soil health – Net GHG reduction (including in production of inputs)	– Improved soil health, and reduced erosion through less tillage – Net GHG reduction (including in production of inputs) – Improved water quality – Reduced weed resistance development	– Avoid unproductive / preserved land from being in production – Soil compaction	– Net GHG reduction	– Improved water quality through reduced runoff

Model Inputs & Definitions
TECHNOLOGIES

TECHNOLOGY	DEFINITION
AUTO GUIDANCE	Auto-steer uses GPS signals to automatically control the tractor in seeding, spraying, fertilizer application and harvesting, reducing overlap of farming operations and leading to substantial fuel savings.
MACHINE SECTION CONTROL	Machine section control technology turns planter, fertilizer or sprayer sections on or off in rows that have been previously seeded/sprayed, or at headland turns, point rows and waterways.
VARIABLE RATE	Variable rate technology uses sensors or preprogrammed maps to determine fertilizer, Seed and CP application rates. Supporting technologies include variable rate controllers, GPS, yield monitors, crop sensors and soil sensors.
MACHINE & FLEET ANALYTICS	Real time monitoring of equipment, providing information like GPS location, equipment idling, traffic control and route suggestions.
PRECISION IRRIGATION	Ability to apply different amounts of water to different areas of the field. *Focused around Center pivots in Western states*.

Due to the unique value proposition of each of these technologies, the overall benefits were considered additive with no "discount" or "coefficient" for any acres where multiple technologies are in use.

REMINDER:
Enabling technologies such as **yield mapping** and **soil sampling** were not directly measured for their environmental impact as they are considered "data collection" or "decision point" as opposed to "execution." Important to note, however, that the environmental benefit of the technologies listed here are only achievable with accurate and routine use of enabling technologies. Also not considered were "**intangibles**" such as farmer fatigue, ability to use inexperienced labor, etc. as well as largely "**mechanical**" technologies such as **singulation**.

- Source: NDSU

Each individual adoption rate and benefit was triangulated with the Industry expert team’s detailed feedback

BENEFITS ESTIMATES
[CORN & SOY]

Source	Fertilizer Use (% decrease)			Herbicide Use (% decrease)			Productivity (% increase)			Fossil Fuel Use (% decrease)		Water Use (% decrease)
	Auto Guidance	Variable Rate	Section Control	Auto Guidance	Variable Rate	Section Control	Auto Guidance	Variable Rate	Section Control	Auto Guidance	Fleet Analytics	Precision Irrigation
Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics	3-5%	4-37%		3-5%				1-10%				
The Ohio State University					5-8%					6-25%		
USDA NRCS								3.30%				
University of Kentucky			2.3-14.5%			2.3-14.5%						
North Dakota State University			4.30%			4.30%						
Iowa State University		7.20%										
Economic Feasibility Study	8-10%						7%					
UC Davis												18%
Industry Expert Estimate											25%	10-30%
Estimate Used for % Benefit	**9%**	**4%**	**8%**	**5%**	**7%**	**11%**	**3%**	**5%**	**3%**	**10%**	**25%**	**15%**

Where data was more limited (such as with certain crops), the industry expert team would align on directional relationship compared to a sourced data point (such as corn/soy data). Context used conservative estimates to account for the variability and ambiguity of data specific to environmental benefits.

MODEL A / Increase in Productivity: Assumptions

Legend
Sourced Numbers
Calculated Numbers
Expert Input Utilized

Data Input Needs	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
Million Acres of crop	86.7	75	12	1.4	46.5	5.7	0.97	1.1	11.1	6.9
Average yield by crop*	168 bu/a	47 bu/a	775 lbs/a	3,949 lbs/a	54 bu/a	73 bu/a	50,228 lbs/a	58,400 lbs/a	3 ton/a	5 bu/a

AUTOGUIDANCE

	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
Adoption by crop in % of acres	60%		80%	65%	60%	50%	80%		20%	
Estimated Yield Increase by crop	3%			2.5%	3%	2.5%				

VARIABLE RATE

	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
Adoption by crop	32%		54%						15%	
Estimated Yield Increase by crop	5%		5%							

SECTION CONTROL

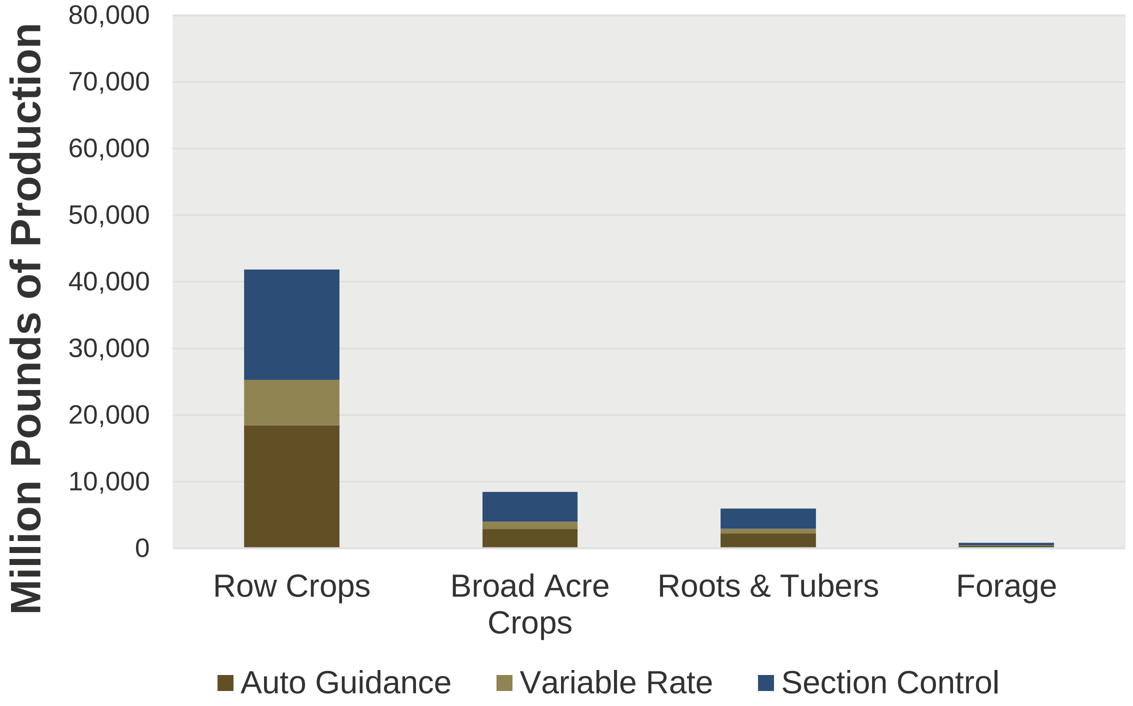
	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
Adoption by crop	22%		22%						5%	
Estimated Yield Increase by crop	3%		3%							

Source: USDA, University Extension, Context Analysis

MODEL A / Increase in Productivity: Past/Future Breakdown by crop & by technology

ANNUAL* Increase in Production due to EXISTING ADOPTION

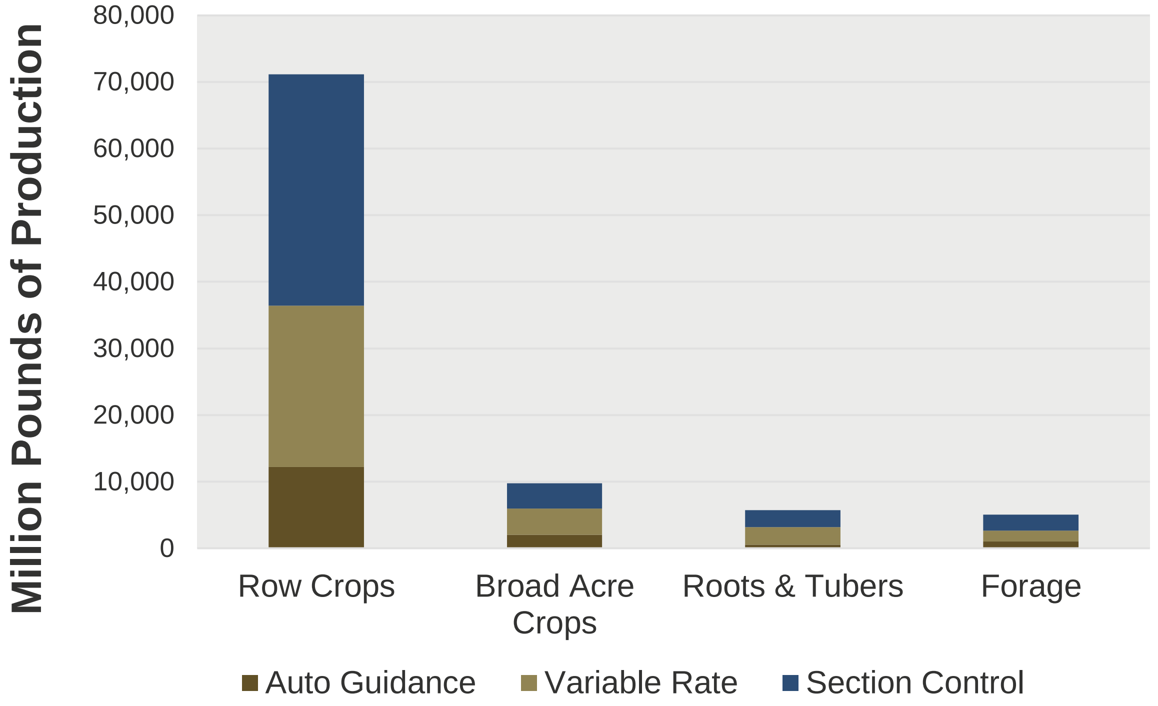
As a result of current adoption of PA across these key crops, there has been a yield increase which has resulted in production increasing by **57,000 million lbs of produce**



2019

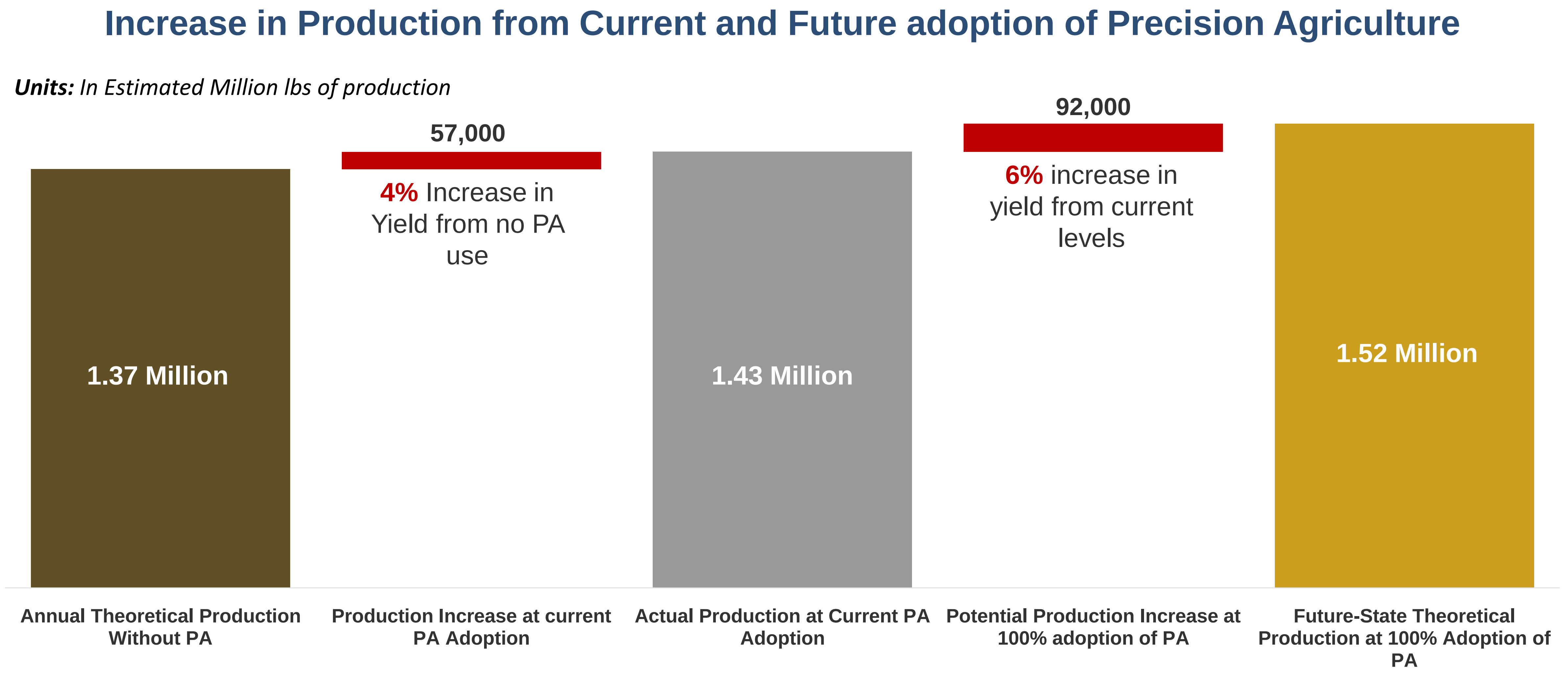
ANNUAL* Potential INCREMENTAL INCREASE in Production at 100% ADOPTION

The potential to FURTHER production from unadopted acres amounts to **92,000 million lbs of produce**



- *Assuming 2019 numbers of adoption, use and benefit

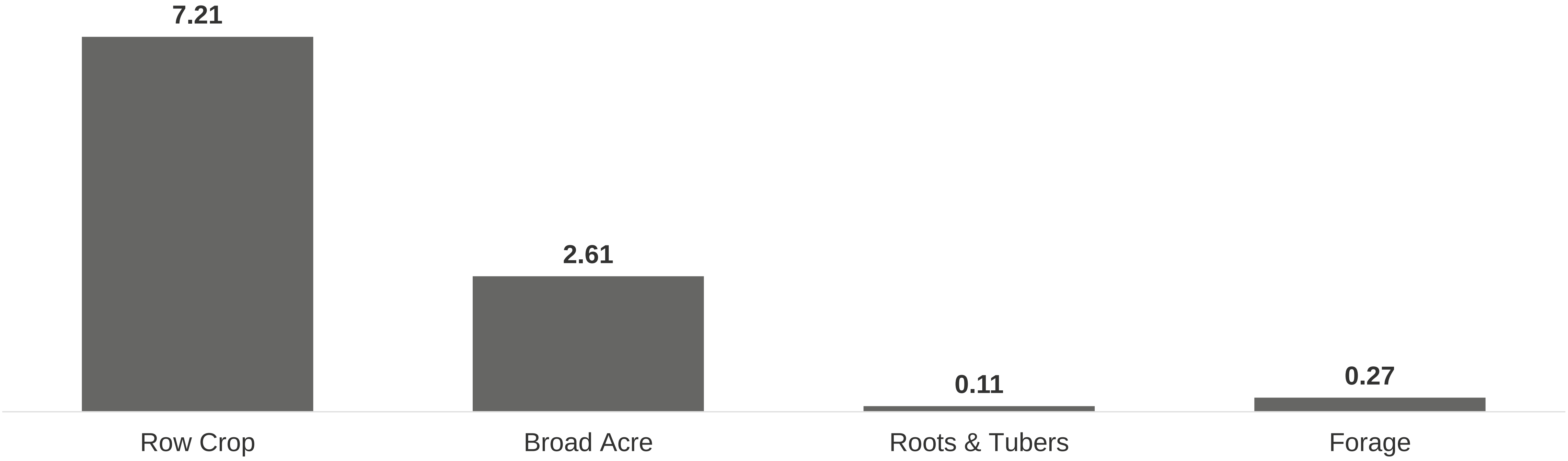
MODEL A / Increase in Productivity: Past/Future Breakdown compared to total



MODEL A / Increase in Productivity: Additional Perspectives and/or Indirect Benefits

An estimated 10.2 million acres of cropland was avoided as a result of more efficient use of existing land

Estimated avoided need for additional crop land in million acres



MODEL B / Improvement in fertilizer placement efficiency: Assumptions per crop cycle

Legend
Sourced Numbers
Calculated Numbers
Expert Input Utilized

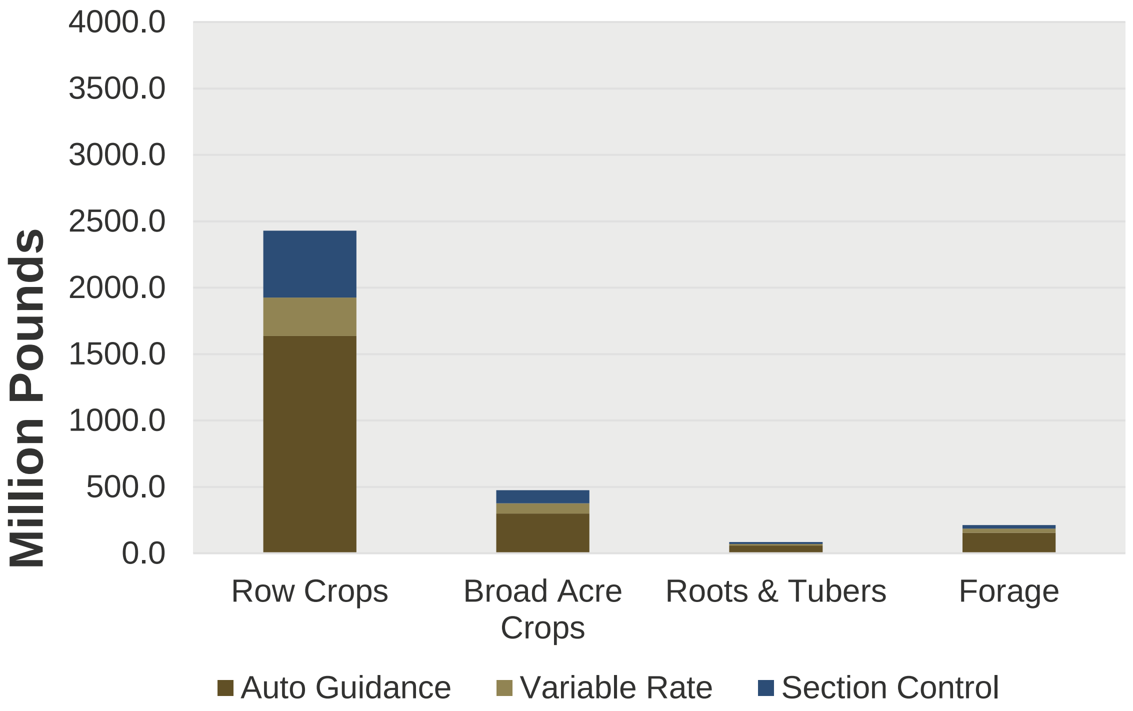
	Data Input	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
	Application of **Nitrogen** by crop in M lbs	12,008	416	822	14	2,872	912	182	145	4,716	5,324
	Application of **Potassium** by crop in M lbs	4,526	3,222	326	16	254	285	118	78	2,620	5,022
	Application of **Phosphorous** by crop in M lbs	4,510	1,974	298	30	938	228	129	100	2,096	1,206
AUTOGUIDANCE	**Adoption by crop in % acres***	60%		80%	65%	60%	50%	80%		25%	
AUTOGUIDANCE	Estimated benefit by crop	9%		9%							
VARIABLE RATE	Potassium and Phosphorous Adoption by crop	32%		54%						15%	
VARIABLE RATE	Nitrogen adoption by crop	16%		27%						7.5%	
VARIABLE RATE	Estimated benefit by crop	4%		4%							
SECTION CONTROL	Adoption by crop	22%		22%						5%	
SECTION CONTROL	Estimated benefit by crop	8%		8%							

Source: USDA, Context Analysis

MODEL B / Improvement in fertilizer placement efficiency : Past/Future Breakdown by crop & by technology

ANNUAL* Volume AVOIDED due to EXISTING ADOPTION

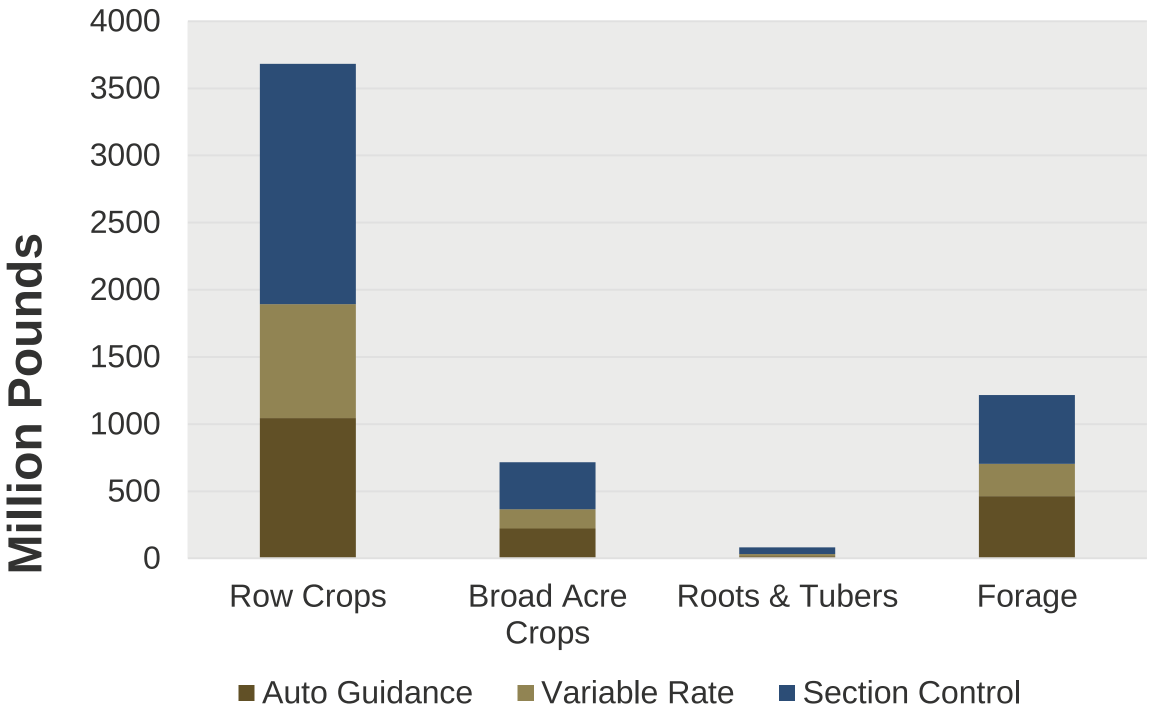
As a result of current adoption of PA across these key crops, nutrient (NPK) application has been reduced by an estimated **3,200 million lbs applied**



2019

ANNUAL* Potential Application INCREMENTAL REDUCTION at 100% ADOPTION

The potential to FURTHER reduce fertilizer application from unadopted acres amounts to **5,700 million lbs**

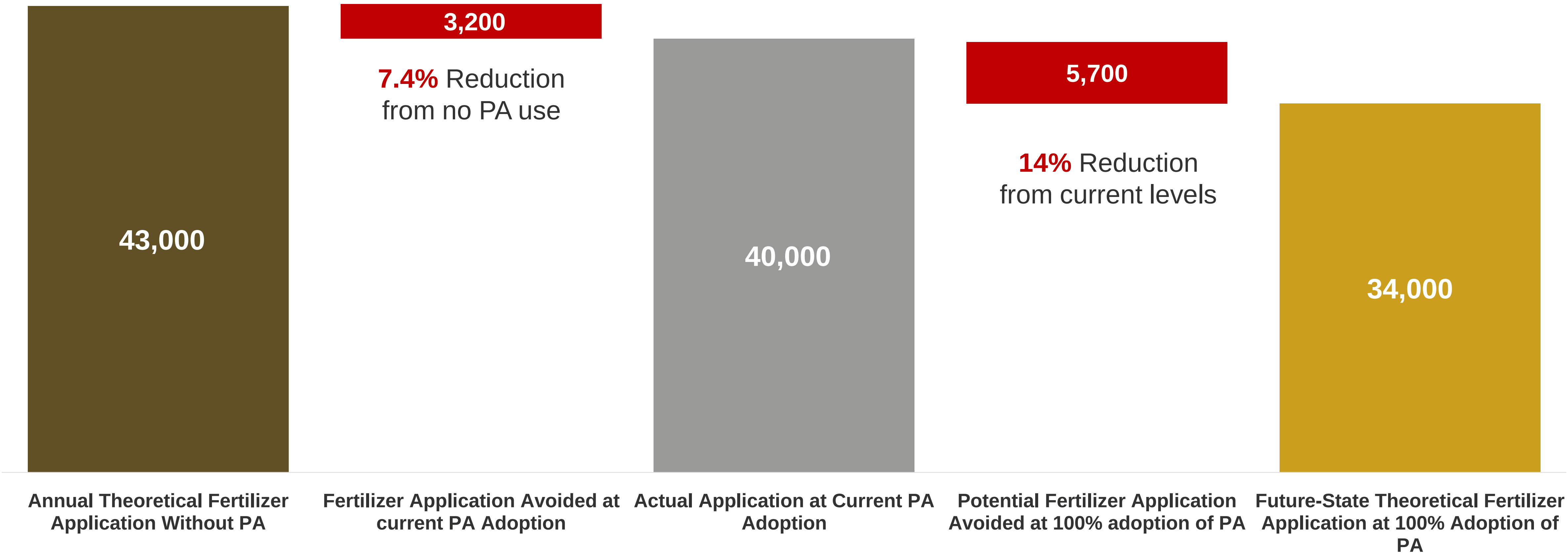


*Assuming 2019 numbers of adoption, use and benefit

MODEL B / Improvement in fertilizer placement efficiency : Past/Future Breakdown compared to total

Reduction in Fertilizer use from Current and Future adoption of Precision Agriculture

Units: *In Estimated Million lbs of Fertilizer Applied*



MODEL B / Improvement in fertilizer placement efficiency: Additional Perspectives and/or Indirect Benefits

Benefits to biodiversity in freshwater

1. Above certain levels, Nitrogen and Phosphorous cause algae to grow faster than ecosystems can handle. When algae die, the decomposition process has the potential to consume all the oxygen creating dead zones and potentially killing all aquatic organisms.

2. According to the EPA's latest National Rivers and Streams Assessment, ~ 40% of the nation's river and stream length has elevated levels of phosphorus, and 28% has elevated levels of nitrogen, putting these waters at risk for poor quality as measured by their ability to support aquatic life.

GHG savings in production of Nitrogen

1. ~80% of synthetic Nitrogen is produced from natural gas.
2. Significant leakages of natural gas from production and transport of the material. Estimated 20% wastage in the US.
3. Nitrogen fertilizer application rates are directly related to the amount of nitrous oxide released into the atmosphere by soil microbial activity. Reduced application of Fertilizer would only stand to benefit this emission.

10.1 Billion Pounds of CO_2 Saved per Year

18.9 Billion Pounds of CO_2 of potential savings

Source: Blonk Consultants, Field to Market

MODEL C / Optimized Herbicide Application: Assumptions

Sourced Numbers
Calculated Numbers
Expert Input Utilized

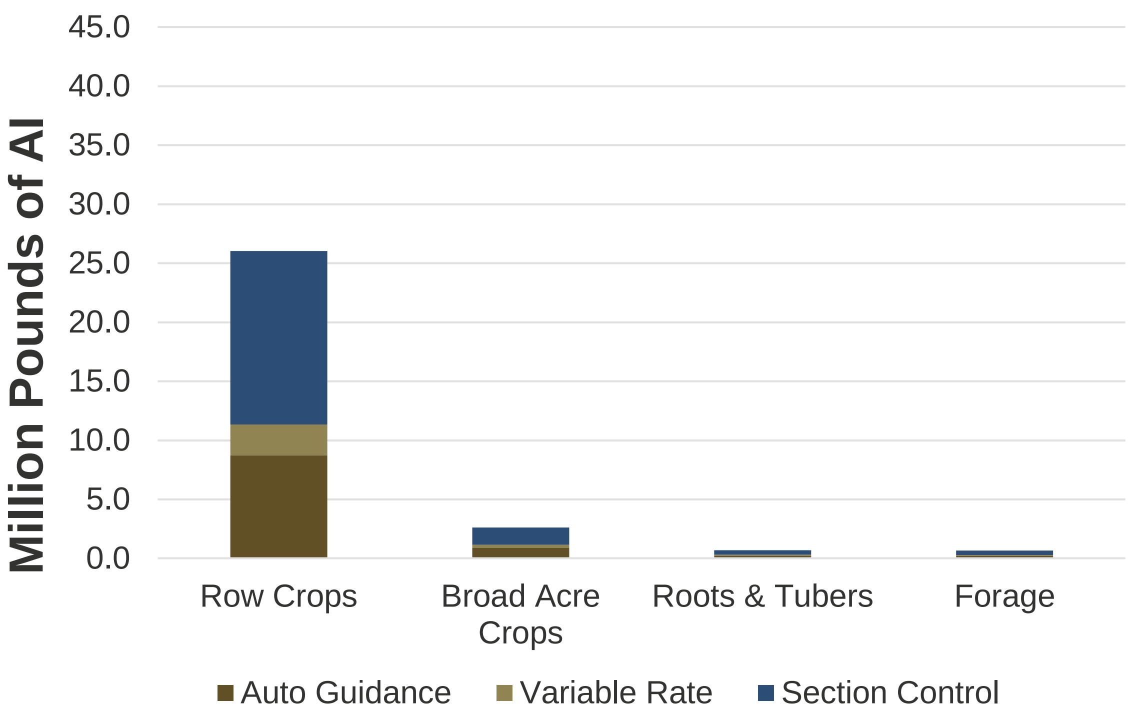
<table>
<tr><th></th><th>Data Input Needs</th><th>Corn</th><th>Soybeans</th><th>Cotton</th><th>Peanuts</th><th>Wheat</th><th>Sorghum</th><th>Tubers</th><th>Sugar-beets</th><th>Hay</th><th>Alfalfa</th></tr>
<tr><td></td><td>Million Pounds of Herbicide AI Applied</td><td>159.9</td><td>103.5</td><td>18.2</td><td>0.9</td><td>17.7</td><td>10.7</td><td>5.3</td><td>2.1</td><td>1.5</td><td>5.7</td></tr>
<tr><td rowspan="2">AUTOGUIDANCE</td><td>Adoption by crop in % of acres</td><td colspan="2">60%</td><td>80%</td><td>65%</td><td>60%</td><td>50%</td><td colspan="2">80%</td><td colspan="2">25%</td></tr>
<tr><td>Estimated benefit by crop</td><td colspan="2">5%</td><td colspan="8">5%</td></tr>
<tr><td rowspan="2">VARIABLE RATE</td><td>Adoption by crop</td><td colspan="2">13%</td><td colspan="6">13%</td><td colspan="2">2%</td></tr>
<tr><td>Estimated benefit by crop</td><td colspan="2">7%</td><td colspan="8">7%</td></tr>
<tr><td rowspan="2">SECTION CONTROL</td><td>Adoption by crop</td><td colspan="2">45%</td><td colspan="6">48%</td><td colspan="2">10%</td></tr>
<tr><td>Estimated benefit by crop</td><td colspan="2">11%</td><td colspan="8">11%</td></tr>
</table>

Source: USDA, Context Analysis

MODEL C / Optimized Herbicide Application : Past/Future Breakdown by crop & by technology

ANNUAL* Volume AVOIDED due to EXISTING ADOPTION

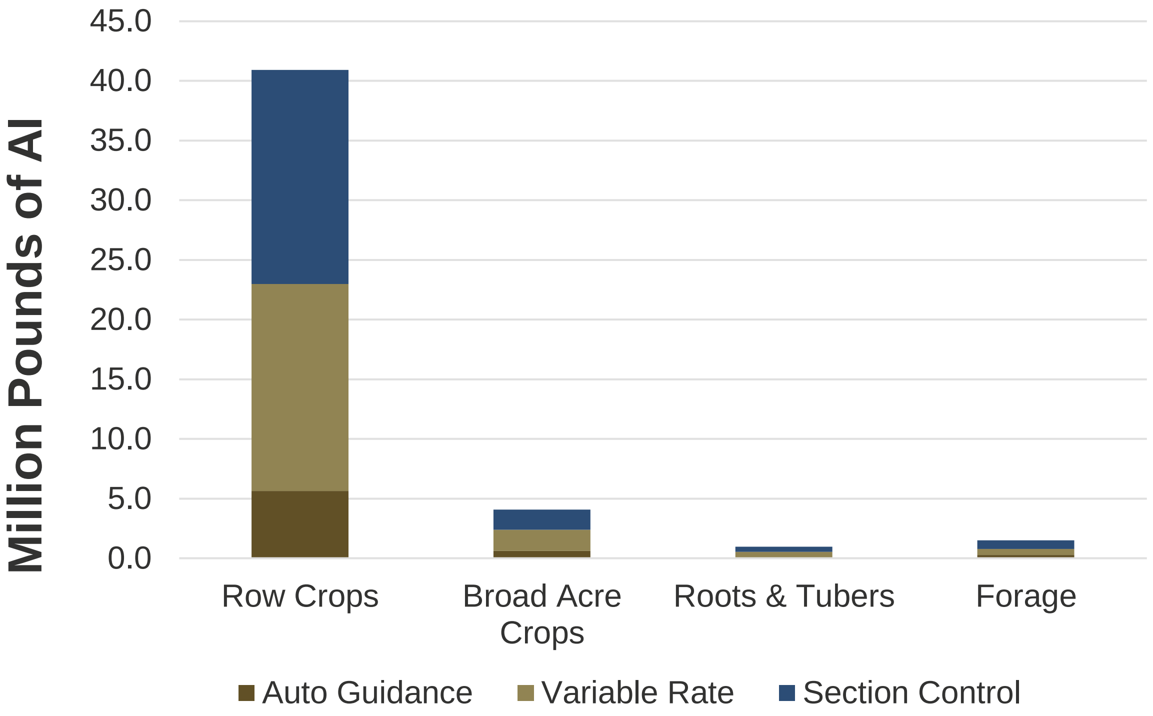
As a result of current adoption of PA across these key crops, Herbicide application has been reduced by an estimated
30 million lbs applied



2019

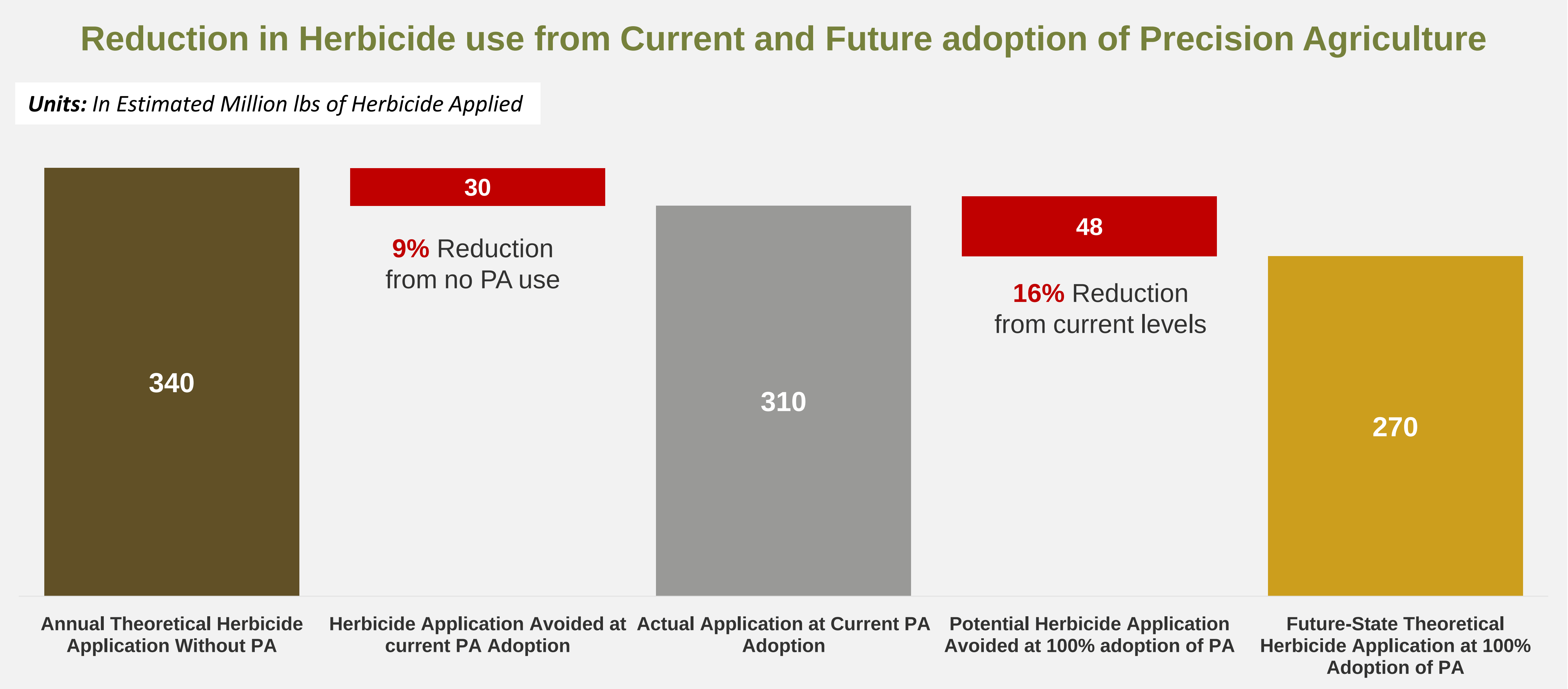
ANNUAL* Potential Application Incremental Reduction at 100% ADOPTION

The potential to FURTHER reduce Herbicide application from unadopted acres amounts to
48 million lbs



*Assuming 2019 numbers of adoption, use and benefit

MODEL C / Optimized Herbicide Application: Past/Future Breakdown compared to total



MODEL C / Reduction in Herbicide Application: Additional Perspectives and/or Indirect Benefits

Benefits to biodiversity in freshwater

1. Leaching is the main source of groundwater contamination by herbicides

2. Leaching is essential for the incorporation of herbicides in the soil profile in order to reach the soil seed bank, contributing to the efficiency of the products in weed control .However, negatively, herbicides can be transported to deeper layers of the soil profile until they reach sites less exploited by the roots, contaminating the groundwater table

GHG savings in production of Nitrogen

1. Pesticide manufacturing represents about 3% of the 100-year Global Warming Potential (GWP) from crops. This lower value is because about 50% of the GWP from arable crops is due to the field emissions of nitrous oxide from the soil which has a very large GWP.

Life cycle emissions of Carbon are 25.5 pounds of emissions per pound of AI produced.

Equating to **765** million pounds of Carbon of current savings

Life cycle emissions of Carbon are 25.5 pounds of emissions per pound of AI produced.

Equating to **1,224** million pounds of Carbon of current savings

MODEL D / Reduction in Fossil Fuel Use: Assumptions

Sourced Numbers
Calculated Numbers
Expert Input Utilized

AUTOGUIDANCE

Data Input Needs	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay	Alfalfa
Million Acres of crop	86.7	75	12	1.4	46.5	5.7	0.97	1.1	11.1	6.9
Average Fuel Consumption of crop in a season in Gallons/Acre (Excluding drying)	8.9	8.9	8.2	9.3	3.9	5.0	6.2	17.8	3.9	3.9
Adoption by crop in % acres	60%		80%	65%	60%	50%	80%		25%	
Estimated Fossil Fuel Reduction by crop	10%		10%							

FLEET ANALYTICS*

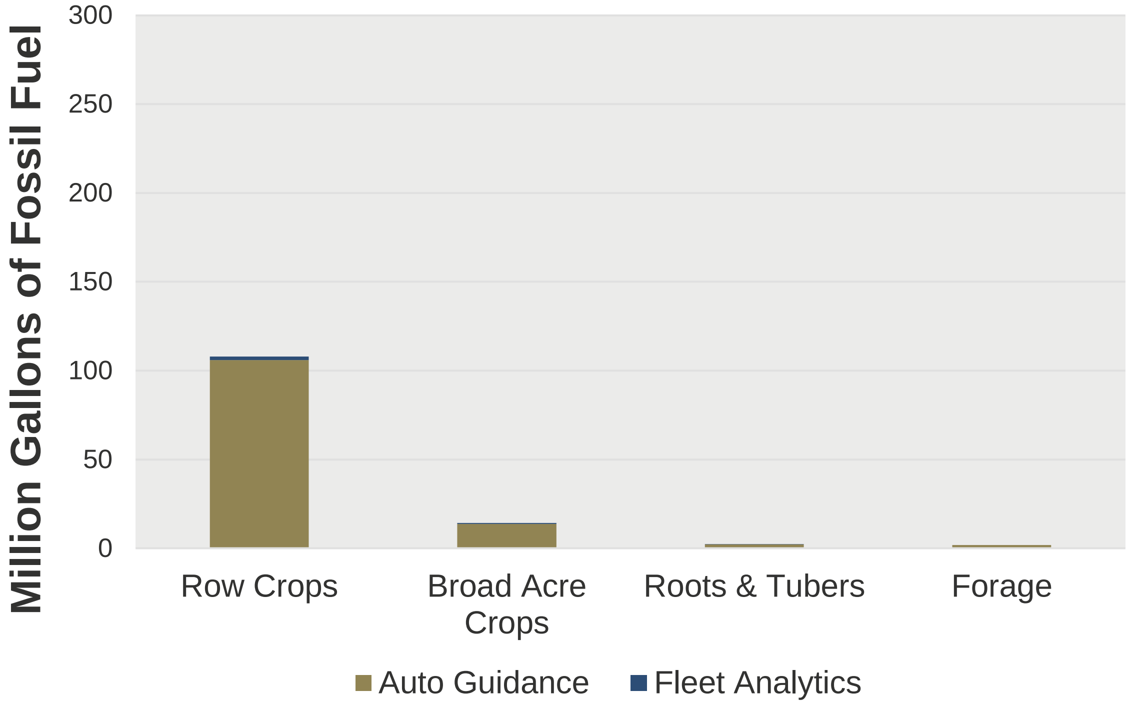
Data Input Needs	2WD 40-100 HP	2WD 140+ HP	4WD	Combine, Forage Harvester	Sprayer
Estimated Number of Machines on the Market	617,686	90,621	49,602	81,633	54,843
Adoption Of Fleet Analytics	-	12%	12%	12%	12%
Est. hours used in a year	400	400	400	300	200
Fuel use during full load	4.8	7.3	14	15	15
Fuel use while Idling	1.0	1.5	2.8	3.0	3.0
Est. Idle Time	25%				30%
Est. Benefit (Reduction in Idle Time)	25%				

*Model only considered relative fossil fuel savings from idle time vs. active machine use; does not consider potential longevity of the machinery or number of equipment in the field

MODEL D / Reduction in Fossil Fuel Use: Past/Future Breakdown by crop & by technology

ANNUAL* Decrease in Fossil Fuel use due to EXISTING ADOPTION

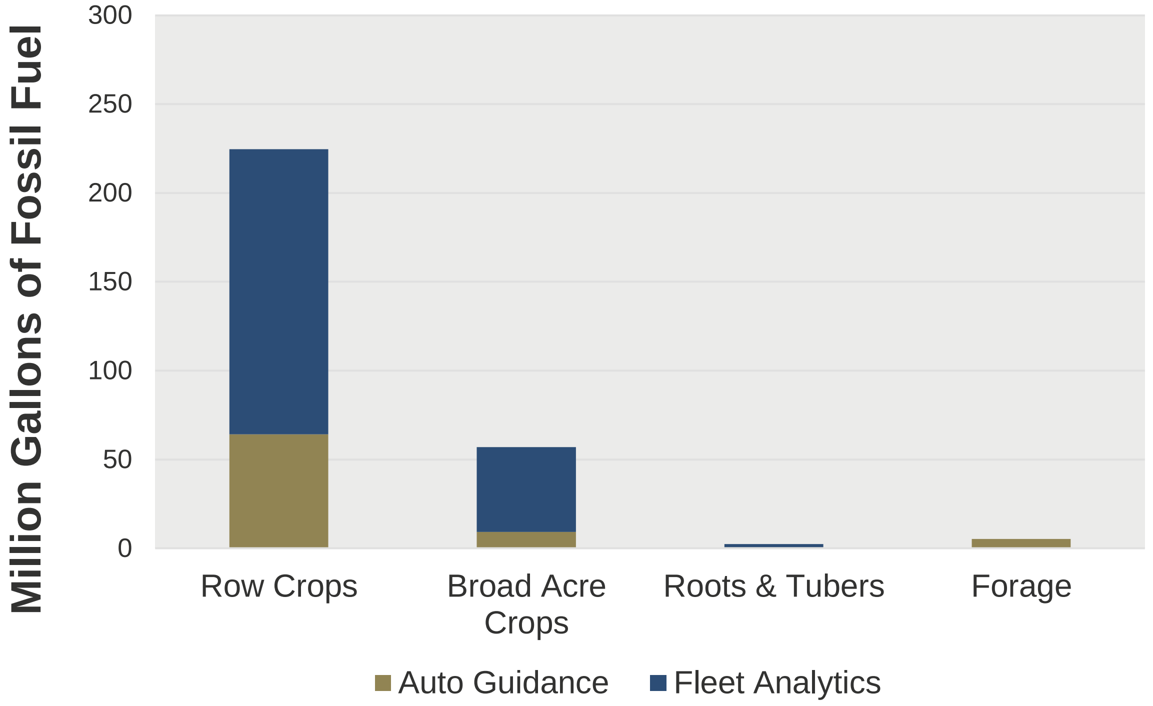
As a result of current adoption of PA across these key crops, there has been a reduction in fossil fuel use by **130 million gallons**



2019

ANNUAL* Potential INCREMENTAL DECREASE in Fossil Fuel use at 100% ADOPTION

The potential to FURTHER reduction in fossil fuel use from unadopted acres amounts to **290 million gallons**

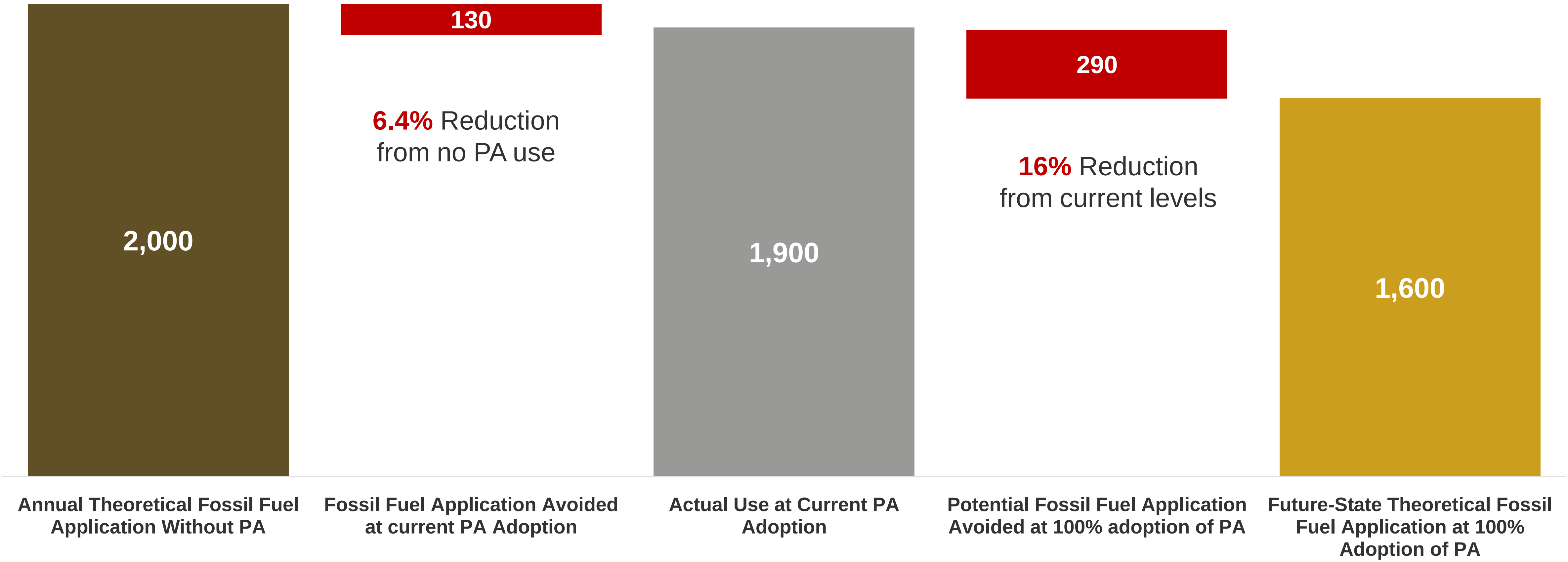


*Assuming 2019 numbers of adoption, use and benefit

MODEL D / Reduction in Fossil Fuel Use: Past/Future Breakdown compared to total

Reduction in Fossil Fuel use from Current and Future adoption of Precision Agriculture

Units: *In Estimated Million Gallons of Fossil Fuel*



MODEL D / Reduction in Fossil Fuel Use: Additional Perspectives and/or Indirect Benefits

In addition to the reduced usage of fossil fuels there are other life cycle benefits from reduced use like Green House Gas emissions from drilling and transportation of the fuels.

Current savings of 130 million gallons	Potential savings of 290 million gallons
193,000 cars off the roads	**441,000** cars off the roads
18,000 Domestic flights	**42,000** Domestic flights

MODEL E / Reduction in Water use: Assumptions

Sourced Numbers
Calculated Numbers
Expert Input Utilized

Data Input Needs	Corn	Soybeans	Cotton	Peanuts	Wheat	Sorghum	Tubers	Sugar-beets	Hay*	Alfalfa*
Pivot/Sprinkler Irrigated Acres	11.04	4.50	2.33	0.45	1.83	0.23	0.85	0.00	1.21	3.79
Acre Feet of Water Used Per Acre	1.2	0.6	1.4	0.7	1.4	1.3	1.8	1.37	1.7	2.2

PRECISION IRRIGATOIN

Adoption of Precision Pivots in % acres	22%				9%		17%		13%	
Estimated Water Reduction by crop	5%									

% of acres adopted represent the % of farmers reporting that they use soil sensors on their irrigated acres

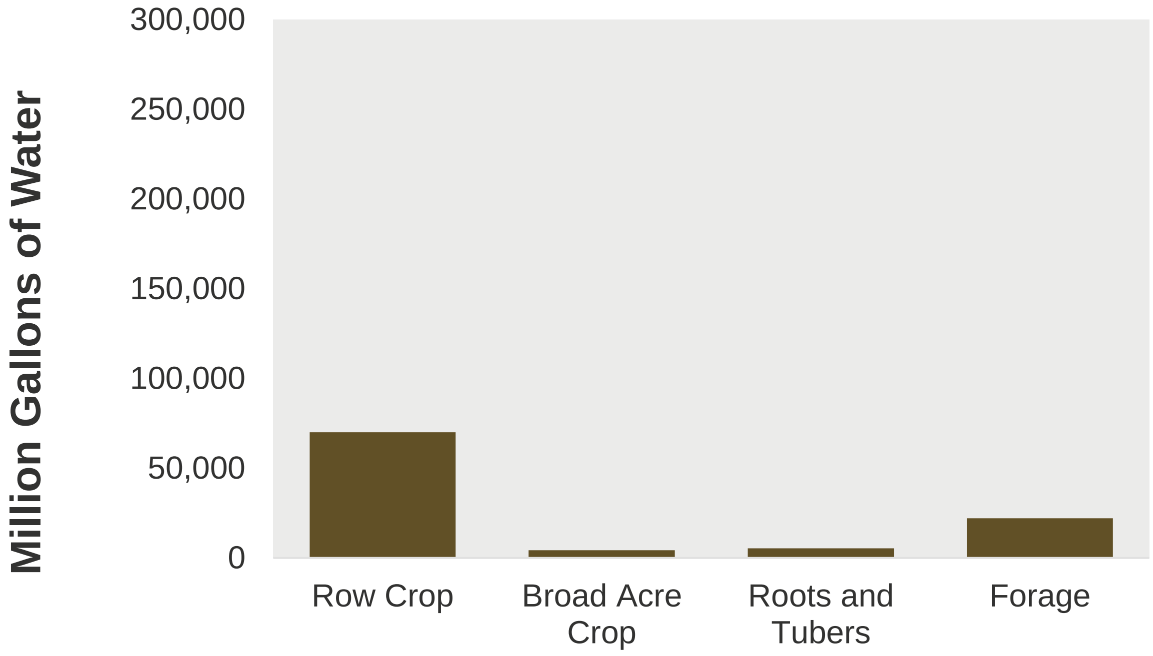
Data does not include potential benefits from fertigation and chemigation

*Hay and alfalfa acres west of the Rockies

MODEL E / Reduction in Water use: Past/Future Breakdown by crop

ANNUAL* Decrease in Water use due to EXISTING ADOPTION

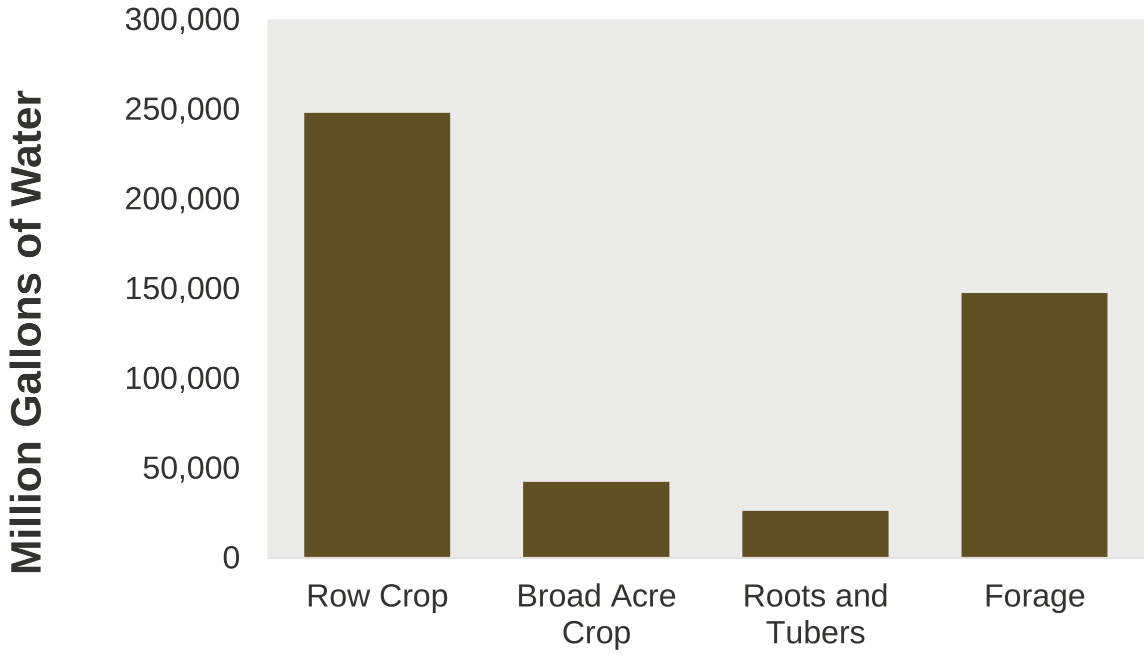
As a result of current adoption of PA across these key crops, there has been a reduction in water use by **100,000 million gallons**



2019

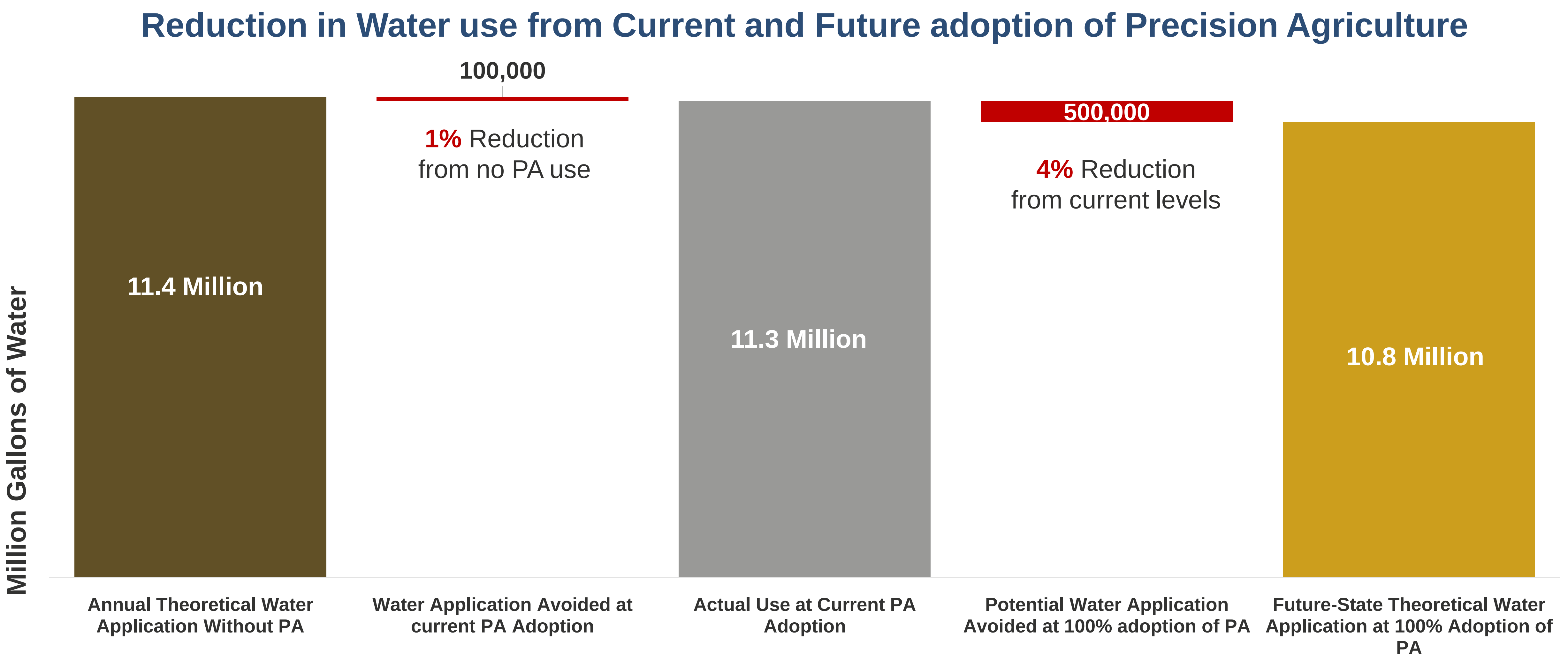
ANNUAL* Potential INCREMENTAL DECREASE in Water use at 100% ADOPTION

The potential to FURTHER reduction in water use from unadopted acres amounts to **500,000 million gallons**



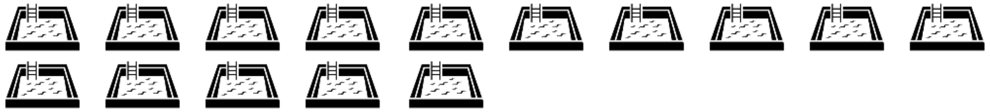
*Assuming 2019 numbers of adoption, use and benefit

MODEL E / Reduction in Water use: Past/Future Breakdown compared to total



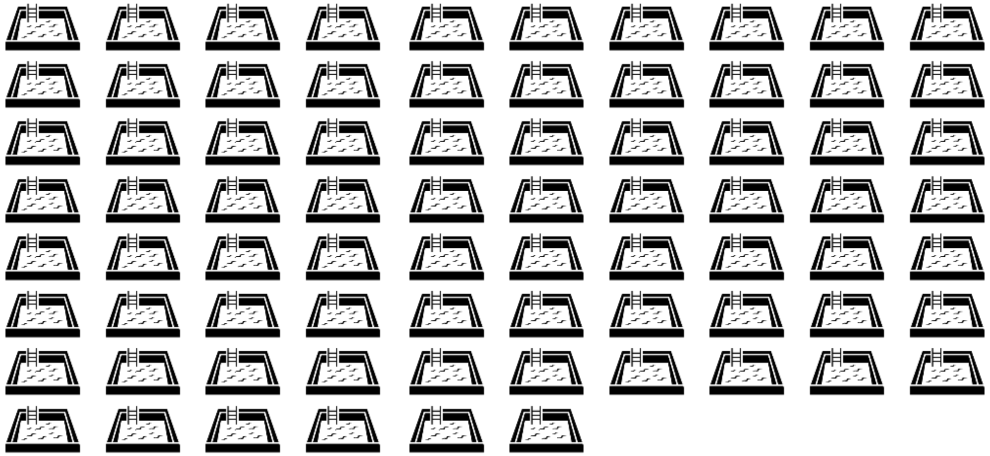
MODEL E / Reduction in Water use: Additional Perspectives and/or Indirect Benefits

At current adoption levels, 100 billion gallons of water is being saved using precision agriculture on crop pivot irrigated acres



151,000 Olympic Sized Swimming Pools

At full adoption levels, 500 billion gallons of water could be saved using precision agriculture on crop pivot irrigated acres



760,000 Olympic Sized Swimming Pools

Key Conclusions

	Productivity / Land Use Efficiency	Fertilizer Use	Herbicide Use	Fossil Fuel Savings	Water Use
TECHNOLOGIES CONSIDERED	1. Auto Guidance 2. Variable Rate 3. Section Control	1. Auto Guidance 2. Variable Rate 3. Section Control	1. Auto Guidance 2. Variable Rate 3. Section Control	1. Auto Guidance 2. Fleet Management	1. Precision Irrigation
LOOKING BACK	Overall production of crop has increased **4%** from 1.37 trillion lbs to 1.43 trillion lbs	Fertilizer (NPK) use has decreased **7%** from 43 Billion lbs to 40 Billion lbs	Herbicide use has decreased **9%** from 340 Million lbs of AI to 310 Million lbs of AI	Fossil fuel use has reduced **6%** from 2 Billion gallons to 1.9 Billion gallons	Water use has been reduced by **2%** from 11.5 trillion gallons to 11.3 trillion gallons
LOOKING FORWARD	Production could increase a further **6%** from 1.43 trillion lbs to 1.52 trillion lbs	Fertilizer use could reduce an additional **14%** from 40 Billion lbs to 34 Billion lbs	Herbicide use could potentially reduce another **16%** from 310 million lbs of AI to 270 million lbs of AI	Fossil fuels could be reduced by a further **16%** from 1.9 Billion gallons to 1.6 Billion gallons	Water use has been reduced by **14%** from 11.3 trillion gallons to 9.8 trillion gallons

thank you

AEM
Association of Equipment Manufacturers

ASA
American Soybean Association®

CropLife
AMERICA

NATIONAL
CORN GROWERS
ASSOCIATION®