



# MOISTURE



# AI-driven Food Systems to Sustainably Nourish the World

# Ranveer Chandra

Recommendation  
25 ppm

# We need to increase food production and decrease environmental impact



Over **820 million** people worldwide suffer from hunger



More than **2 billion** people lack vital nutrients



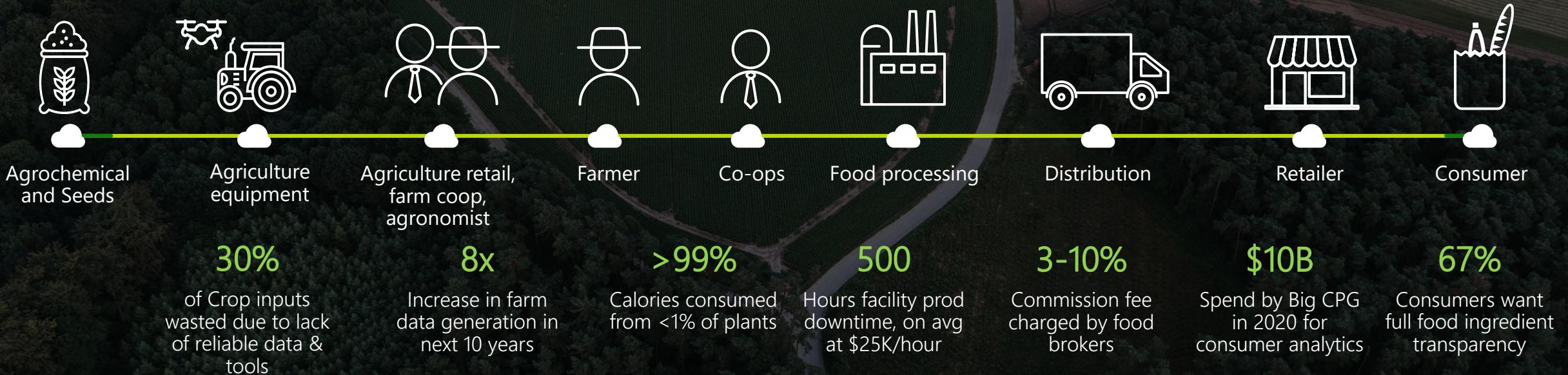
**50%** more food is needed by 2050.  
**40%** food wasted.



**31%** GHG emissions from agri-food systems,  
**70%** fresh water use

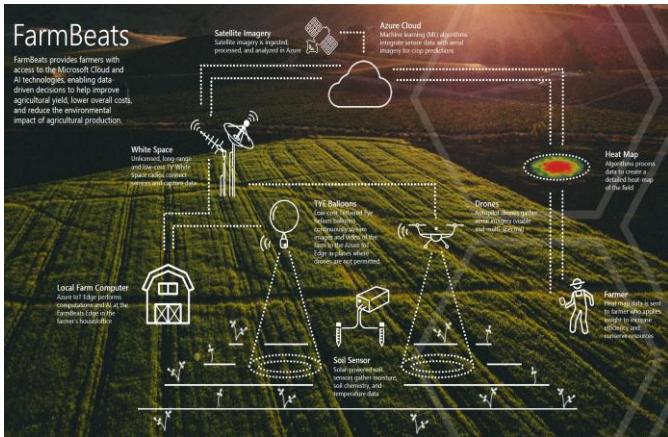
# Data-driven Agri-Food systems

Bringing data to the cloud enables key insights for individuals and organizations.



**When this data is shared, we unlock greater efficiencies and productivity across the supply chain.**

# Food Tech at Microsoft



Data-driven Agriculture  
(ADMA (FarmBeats) + FarmVibes)



Food Supply Chain Transparency (FoodVibes)



Healthy Food Production  
(Modern R&D for Food)

# Agriculture, food production, and climate change



**18.4%** of GHG emissions from Ag, Forestry, & Land Use



Food production accounts for **1/4th** of GHG emissions



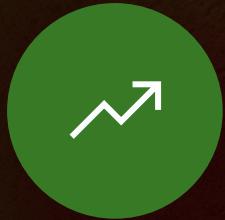
**Longer** growing seasons in different parts of the world



Ag soils can sequester 20 PgC in 25 years, **10%** more than anthropogenic emissions

# Data-driven agriculture

Precision & regenerative agriculture has been shown to:



Improve yield



Reduce cost



Ensure sustainability



# According to USDA, high cost of manual data collection prevents farmers from using data-driven agriculture.

## Exhibit 3

The high cost of agtech is a major barrier to adoption, followed by an unclear ROI.

### High cost of technology

**47%**

of farmers cited as top-three barrier to adoption

### Low willingness to pay

**50%**

of farmers are unwilling to pay anything

### Unclear ROI

**30%**

of farmers cited as top-three barrier to adoption

### High ROI expectation

**3:1**

is the minimum-expected ROI to consider purchasing

Source: Farmers Global Insights Survey, McKinsey, May 2022; McKinsey analysis

# Challenge 1: Connectivity on farms



Cloud



Farmers home/office

Too much distance between  
farm and the house/office



Drone video



Soil moisture  
sensors



Wind speed/  
Direction sensors



pH sensors

# A solution in white space



Cloud



Farmers home/office



Base station

Increasing wireless reach  
with TV White Space



Drone video



Soil moisture  
sensors

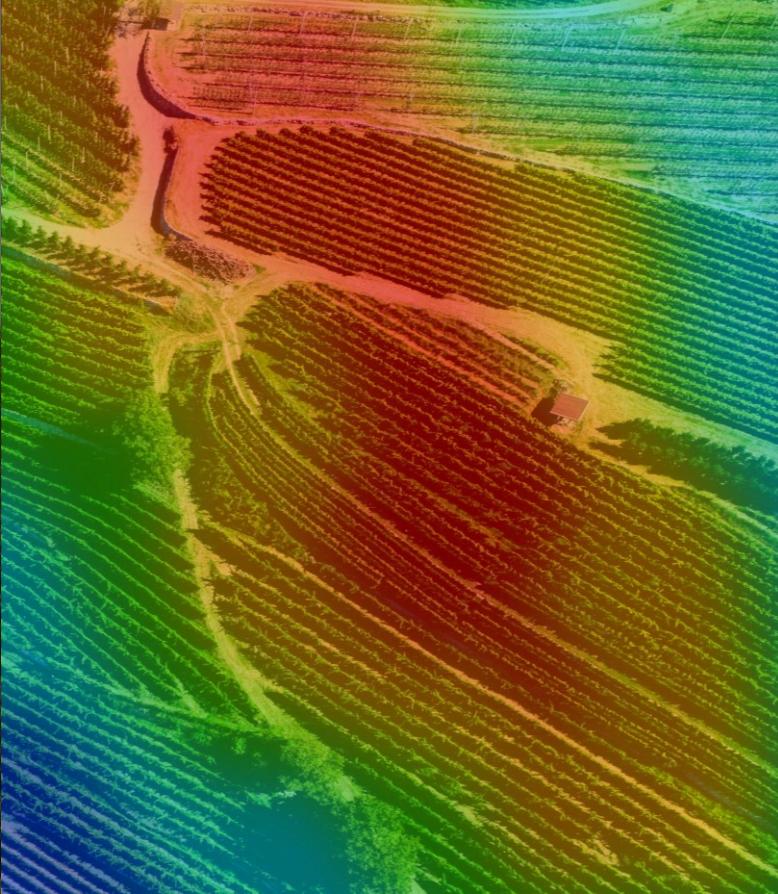


Wind speed/  
Direction sensors



pH sensors

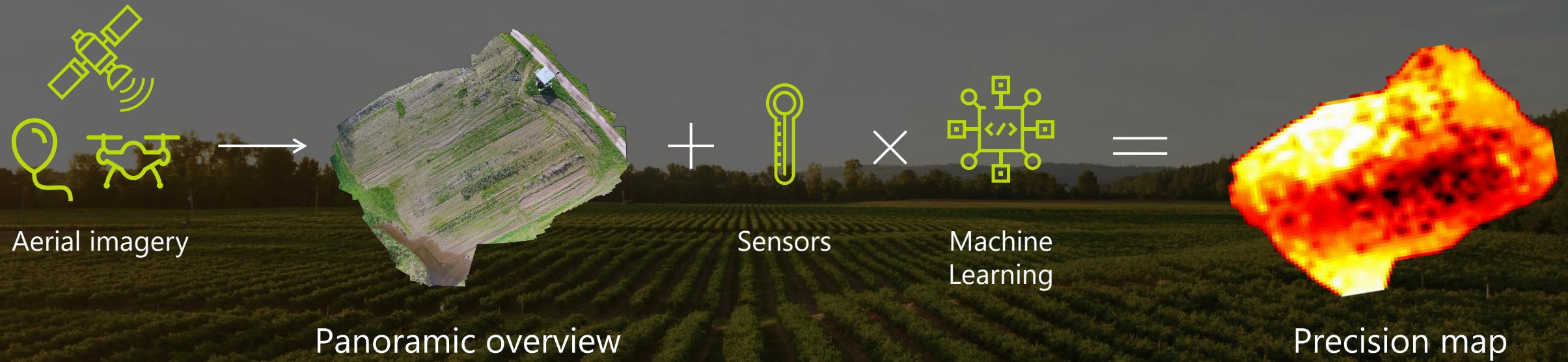
# Challenge 2: Sparse sensor deployments



- Physical constraints due to farming practices
- Too expensive to deploy and maintain

**How do we get coverage with a sparse sensor deployment?**

# Use aerial imagery and AI to enhance spatial coverage



# SpaceEye: Seeing through clouds over a farm

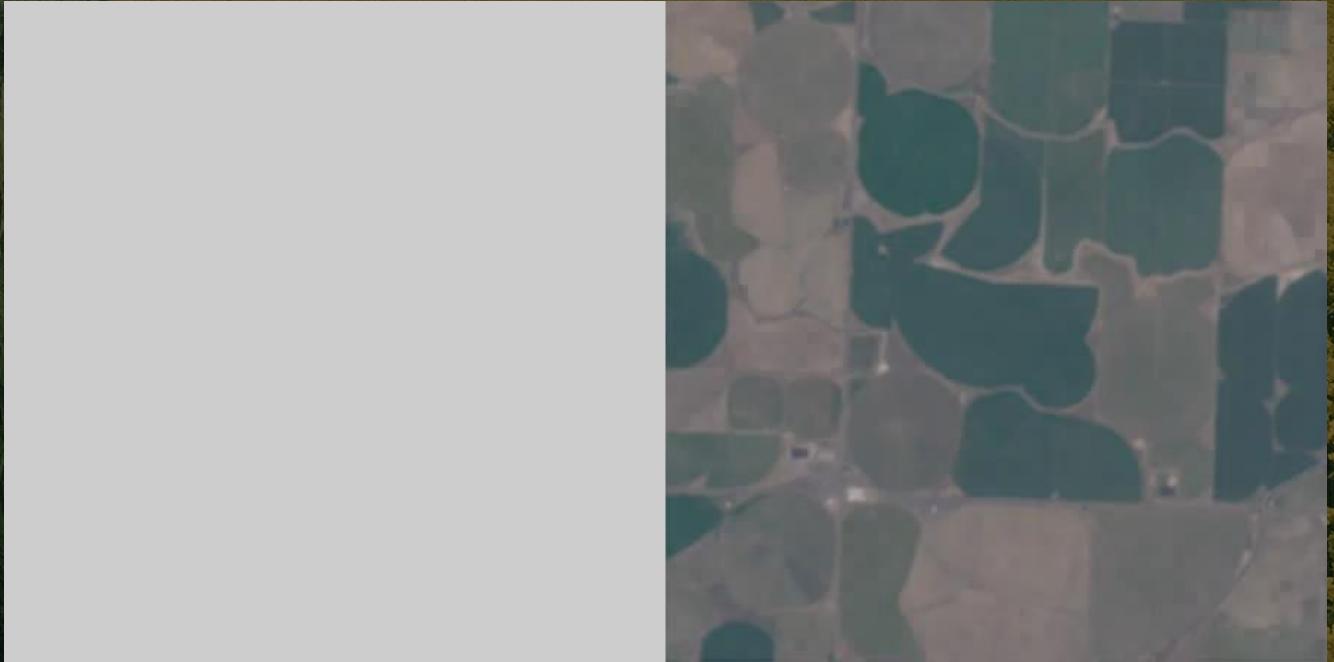
77% of the planet is covered in clouds.

Optical reconstruction machine learning fills the gaps created by cloud-cover

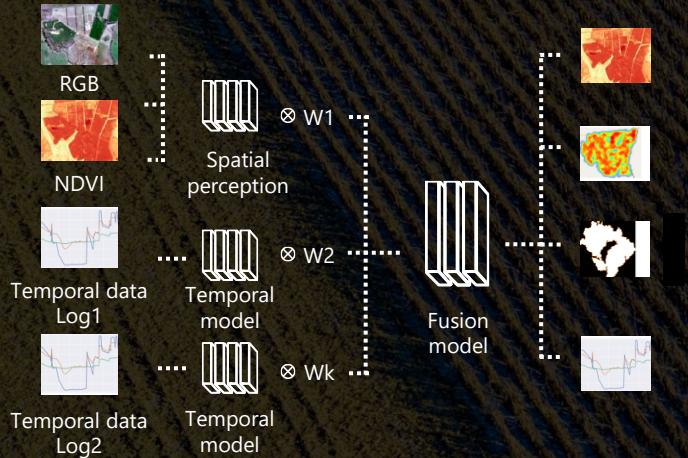
This allows for long term imaging and research without interruption.

Original RGB bands

SpaceEye predicted RGB bands



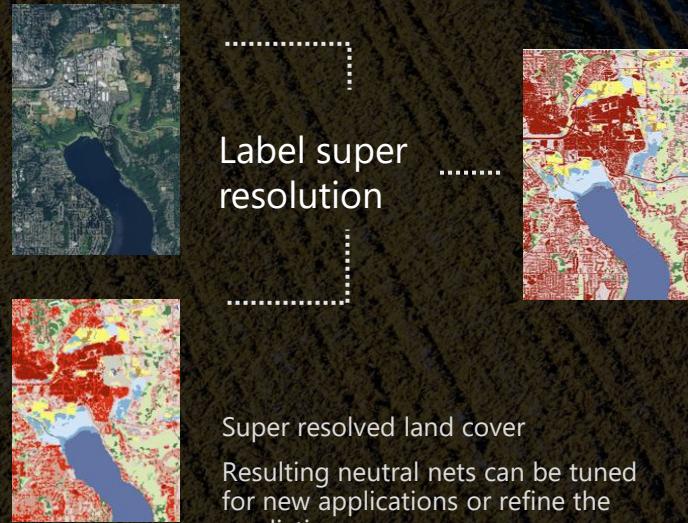
## Spatio-temporal fusion



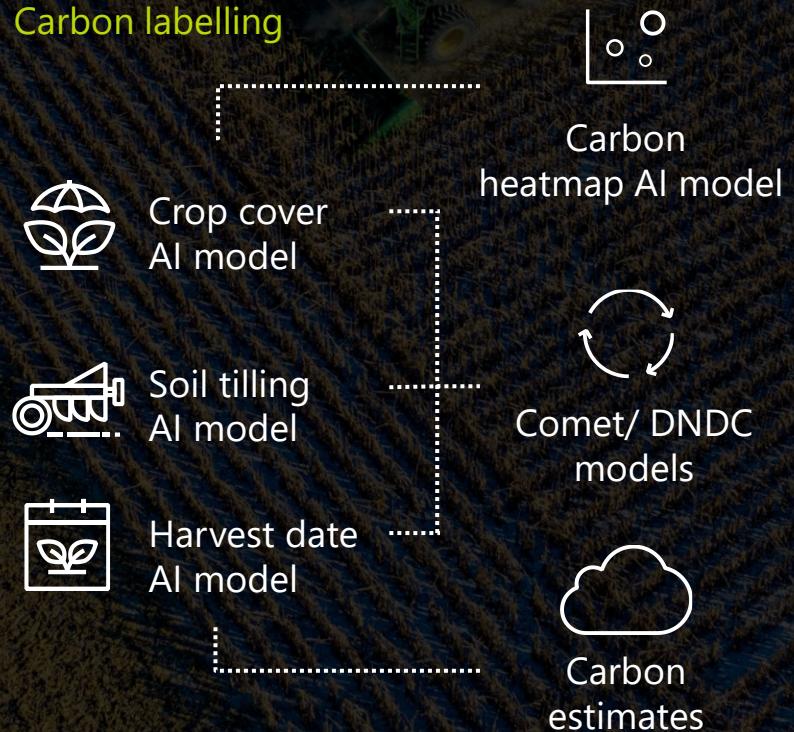
## Project SpaceEye



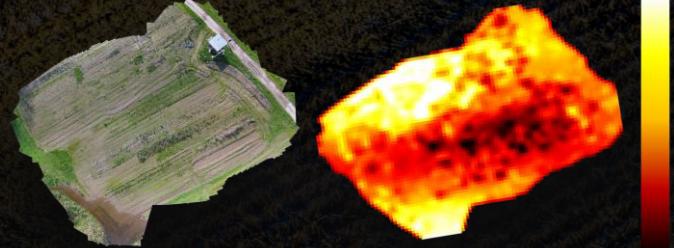
## Landcover labelling



## Carbon labelling



## Moisture heat map



- Yield maximization
- Carbon minimization
- Precision maps
- Emission tracking
- Practice verification



NEWS

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EVENTS

RESOURCES

ABOUT



Search



Trending: SOBA, a Twitch streamer community in Seattle, reboots vision and programming

## Microsoft open-sources farm technologies, planting seeds for data-driven sustainable agriculture

BY TODD BISHOP on October 6, 2022 at 8:00 am

## Microsoft is hoping its algorithms can help farmers—and the planet

You can't eat an algorithm, but data can still be useful when it comes to food production. Here's how.

BY HELEN BRADSHAW | PUBLISHED OCT 7, 2022 10:00 AM

Microsoft

3d



"Project FarmVibes is allowing us to build the farm of the future... it's saving a lot in costs and it's helping us control any issues we have on the farm," says fifth-generation farmer Andrew Nelson.

For Andrew, data is as important as dirt when it comes to agriculture. AI-powered technologies help reduce fertilizer use, forecast wind speeds, and identify soil moisture allowing farmers to reduce costs and boost yields.

Data-driven agriculture is not only important to the future of farming. In fact, it could be a solution to the global food shortage issue, helping increase food production while reducing the amount of natural resources agriculture demands.

Get to know the farms of the future: <https://msft.it/6044dJRJE>

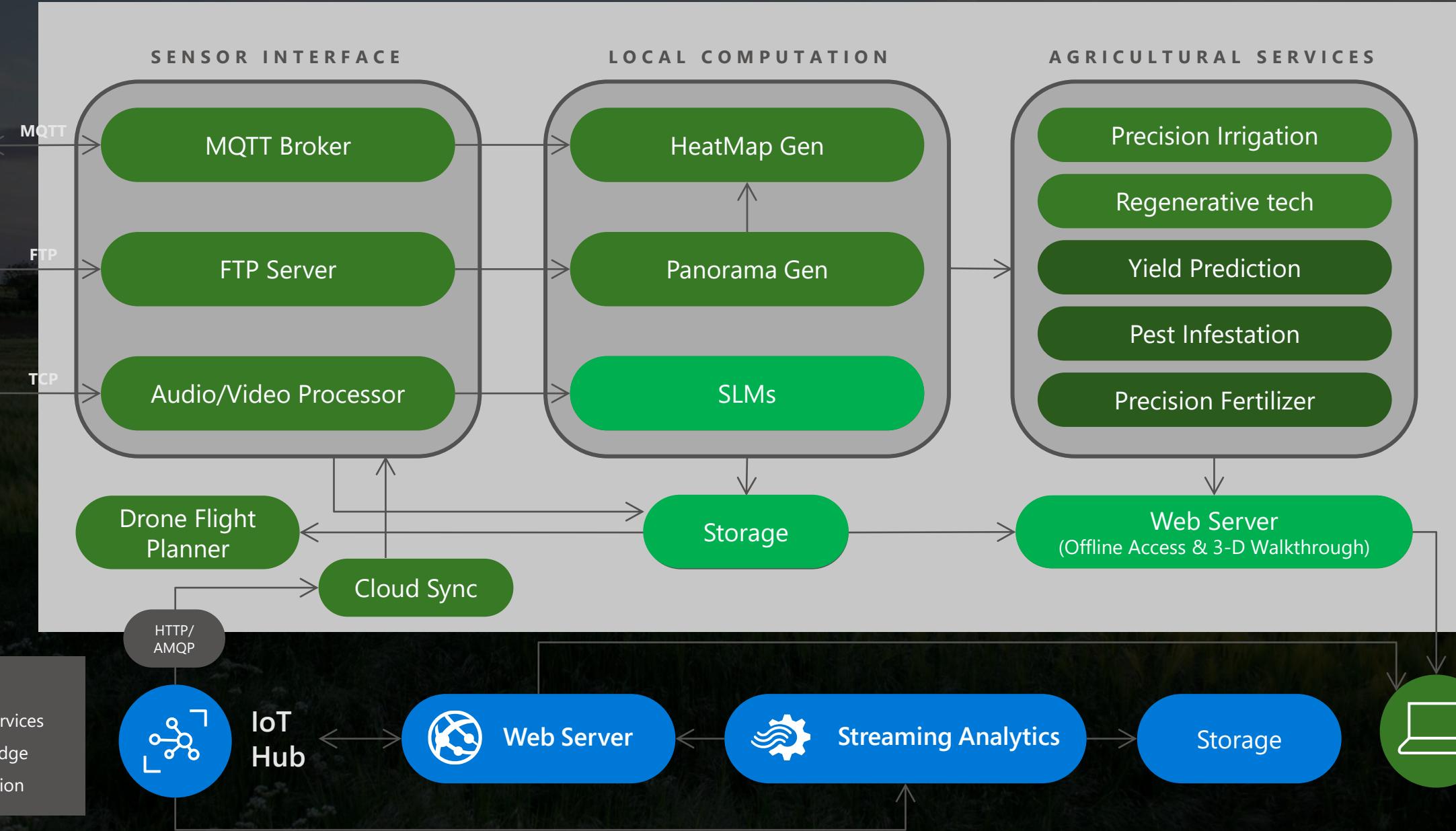


# Challenge 3: Connectivity to the Cloud



# Azure Edge

SENSORS



- Can run offline
- Unique Gateway services
- Deep Learning at Edge
- Component Migration

# Deployment

Deployments in several locations including WA, CA, NY

Farm sizes range from 0.5 – 9000 acres

## Sensors:

- DJI Drones
- FarmBeats sensor boxes with soil moisture, temperature, wind speed/direction sensors
- IP Cameras to capture IR imagery as well as monitoring

Cloud Components: Azure IoT Suite



# Micro-Climate Forecasting

## Goal:

Microclimate weather forecasting model based on FarmBeats sensors in the field.

## Impact:

Knowing microclimate enables better modeling of plant diseases, application timing, and risk management.

## Challenges:

Forecast important variables for accurate plant disease prediction, not included in current weather forecasts (results shown).

## Results:

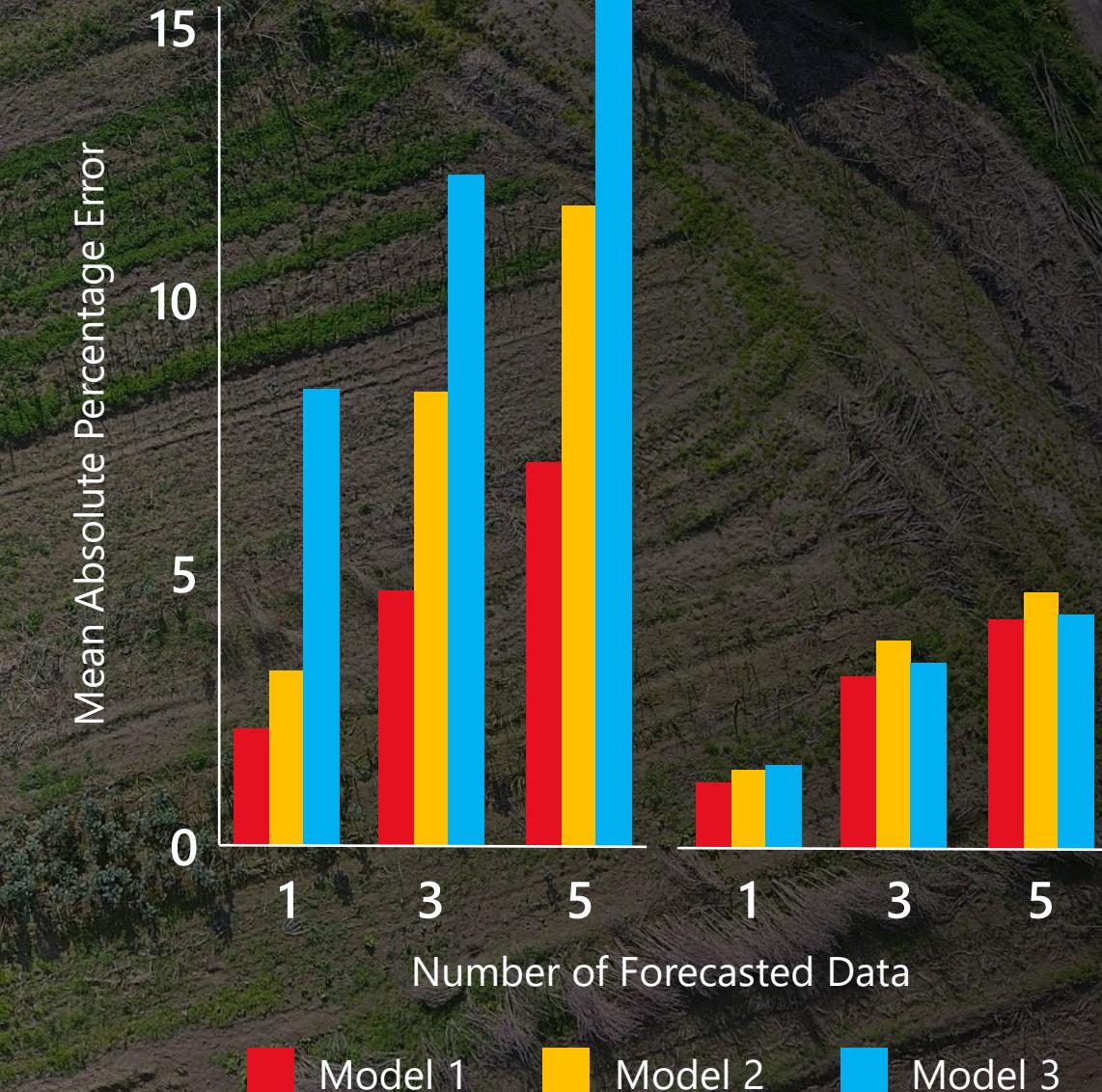
Soil moisture & temperature forecasting error less than 10%.

*Forecast for low temp was 42 degrees. Micro-Climate forecast was 31 degrees in lower areas of the field. Actual was 30 degrees. Instead of spraying grass herbicide, the farmer waited and avoided large crop damage in some of the most productive areas.*

\*The **lower the error**, the better the prediction.

Soil Moisture

Soil Temperature



# Example: Panorama



Water puddle



Cow excreta



Cow herd

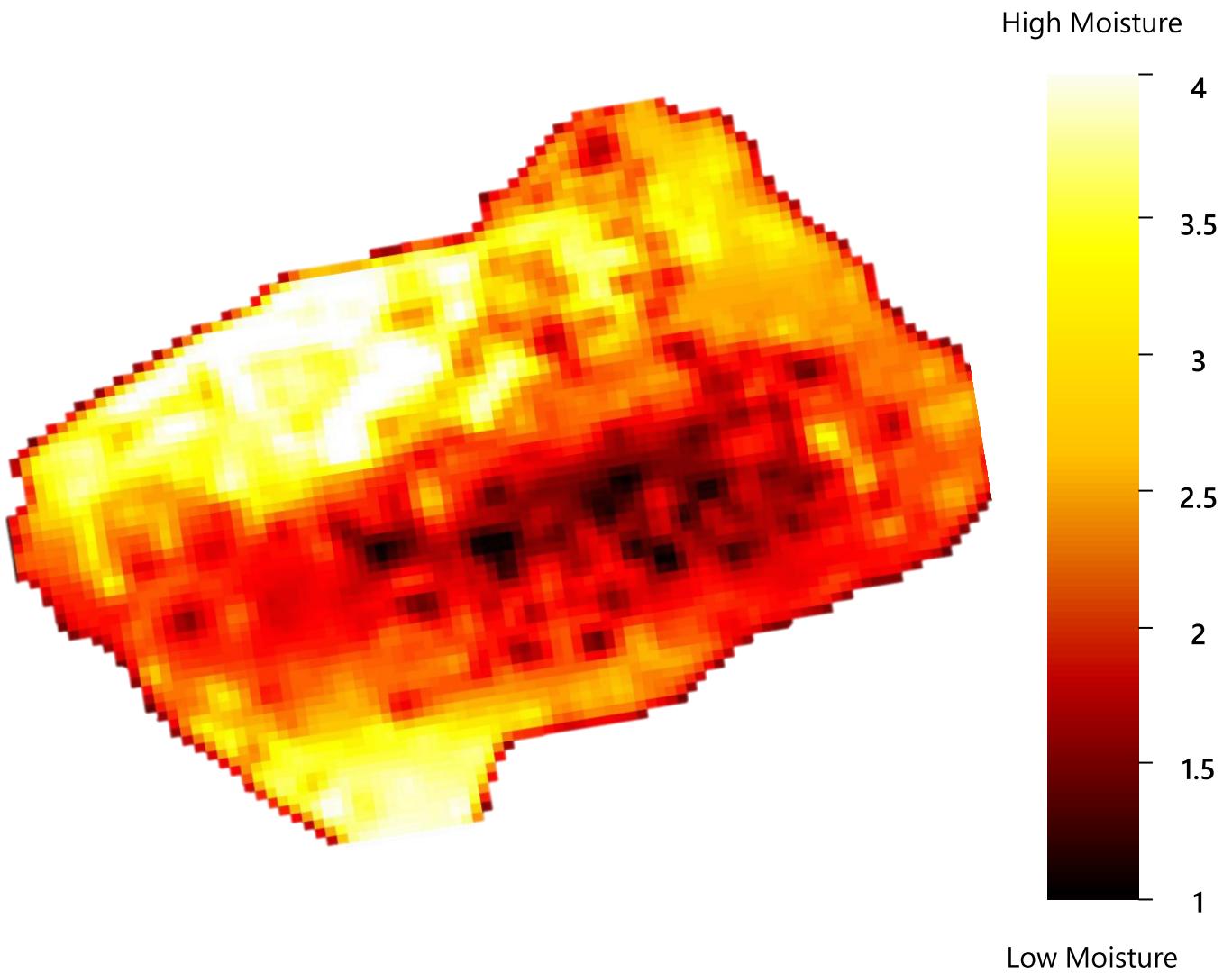


Stray cow

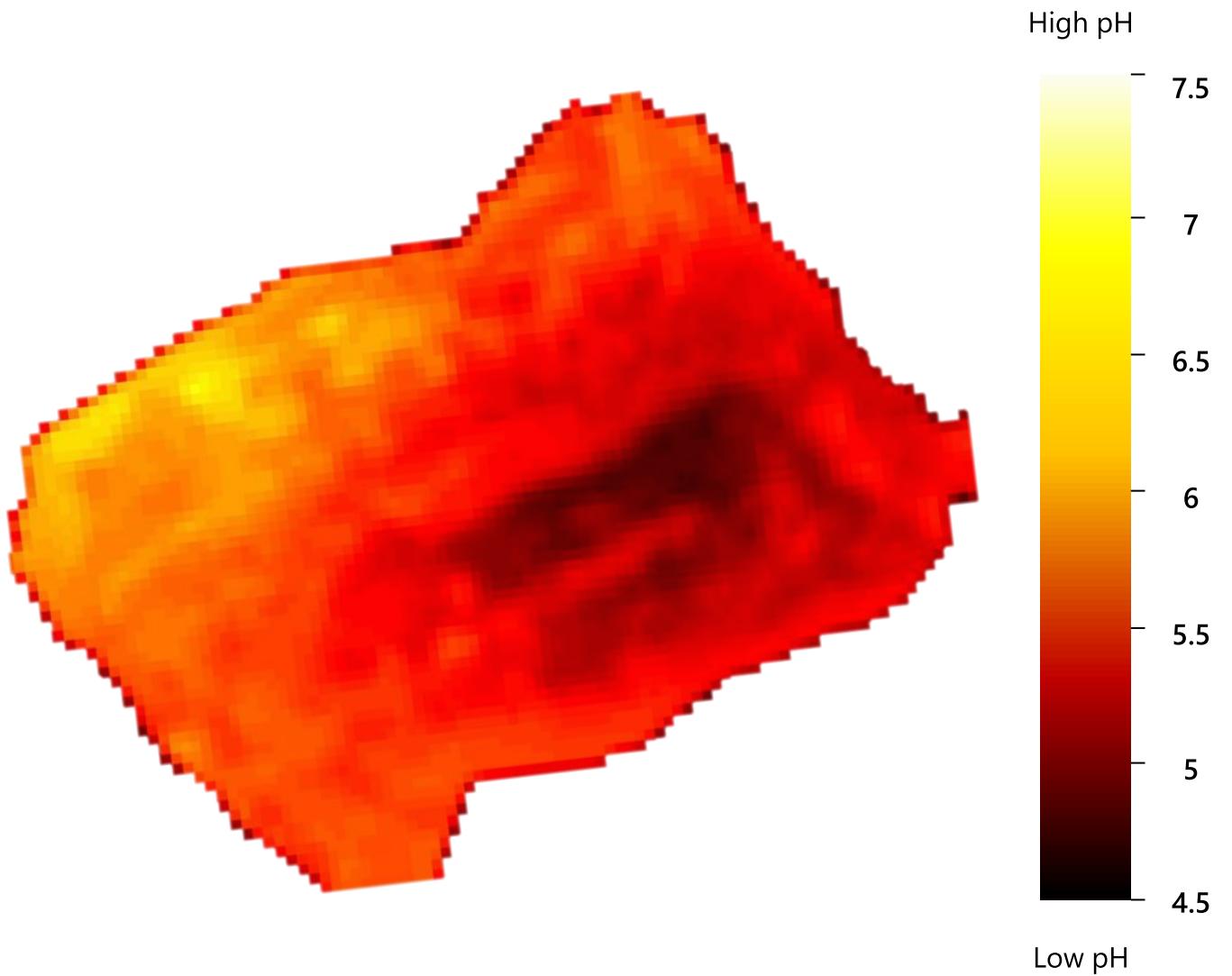
# Precision Map: Panorama Generation



# Precision Map: Moisture



# Precision Map: pH

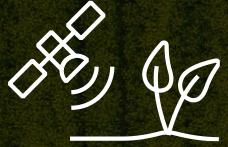


# Application: Cow-shed monitor



# Crop lifecycle

## Pre-plant field preparation



### Operations

- Eliminate weed and cover crop
- Plan and prepare for optimized carbon sequestration

### Tech Used

- Carbon sequestration what-if analysis
  - FarmVibes.AI - CarbonWhatIf
- Li-Cor CO<sub>2</sub> monitoring
- Multispectral drone flights
- Nutrient mapping
- Cloud free satellite imagery
  - FarmVibes.AI - SpaceEye
- Multispectral drone image processing
  - FarmVibes.Edge
- Variable rate glyphosate spraying

## Planting



### Operations

- Variable rate seeding, fertilizations, and depth seed planting

### Tech Used

- Cloud free satellite imagery
  - FarmVibes.AI - SpaceEye
  - NDVI maps
- Soil testing locations
  - Innov8 sensor and/or crysalabs sensor
- Traditional lab tests
- Soil moisture sensor data collected
  - FarmVibes.Connect
- TVWS broadband/private LTE tractor connectivity
- Micro climate prediction
  - FarmVibes.AI - DeepMC
- Previous drone images
  - FarmVibes.Edge
- Drone application of cover crop seed

## Post-planting/pre-emergence



### Operations

- Apply variable rate for herbicides and target different weed herbicides

### Tech Used

- Cloud free satellite imagery
  - FarmVibes.AI -SpaceEye
- Multispectral drone image processing
  - FarmVibes.Edge
- Weed detection AI from previous year's drone imagery
- Variable rate map for large sprayer
  - FarmVibes.AI
- Micro climate wind seed predictions
  - FarmVibes.AI - DeepMC

# Crop lifecycle

## Emerged crop



### Operations

- Spray under recommended temperature and wind speed
- Apply variable rate herbicides and fertilization
- Monitor wildlife on fields
- Track in-season plant growth, health, and nutrients

### Tech Used

- Cloud free satellite imagery
  - FarmVibes.AI - SpaceEye
- Nutrient mapping
  - Innov8, manual soil samples, chrysaLabs
- Temperature/wind speed prediction
  - FarmVibes.AI - DeepMC
- Multispectral drone image processing
  - FarmVibes.Edge
- Drone Image based AI maps
- AI camera-based Wildlife detection

## Crop harvest



### Operations

- Grain storage utilization
- Harvest tracking at truck level
- Measure truck weight at grain silos
- In field operational communication
- Harvest traceability at management zones level

### Tech Used

- Tracking Pucks
- TVWS Broadband/Private LTE
- PowerBI
  - Grain bin utilization monitoring
- Custom application built in Azure(TicketTracker)
- Azure IoT Central

## Post harvest



### Operations

- Monitoring humidity, temperature, and CO2 for crop in grain silos
- Field Management Zone level tracking

### Tech Used

- Tracking Pucks
- PowerBI
  - Grain bin environment monitoring
- Azure IoT Central

# Impact to NelsonFarms

- Reduced precision pesticide and fertilizer application time
- Saved more than 38% of previously used on a chemical

## Grain Storage Utilization

- Utilized 18% more grain storage
- Timing market for better price

## Precision Seeding

- Optimized seeding for reduced waste



# Future Farmers of America + FarmBeats + FarmVibes

The Microsoft TechSpark initiative is bringing precision agriculture and AI to the classroom with **FarmBeats** student kits.



# Affordable sensing low-cost soil moisture and EC sensing using wi-fi

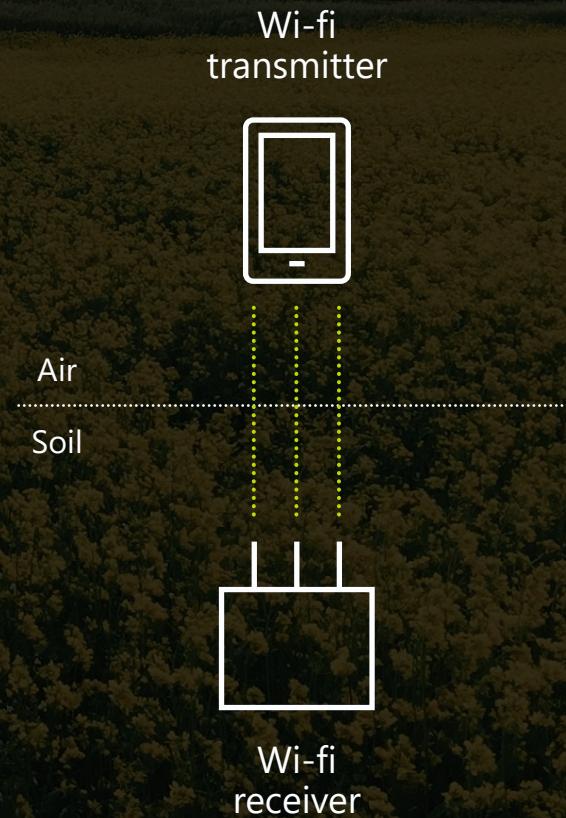
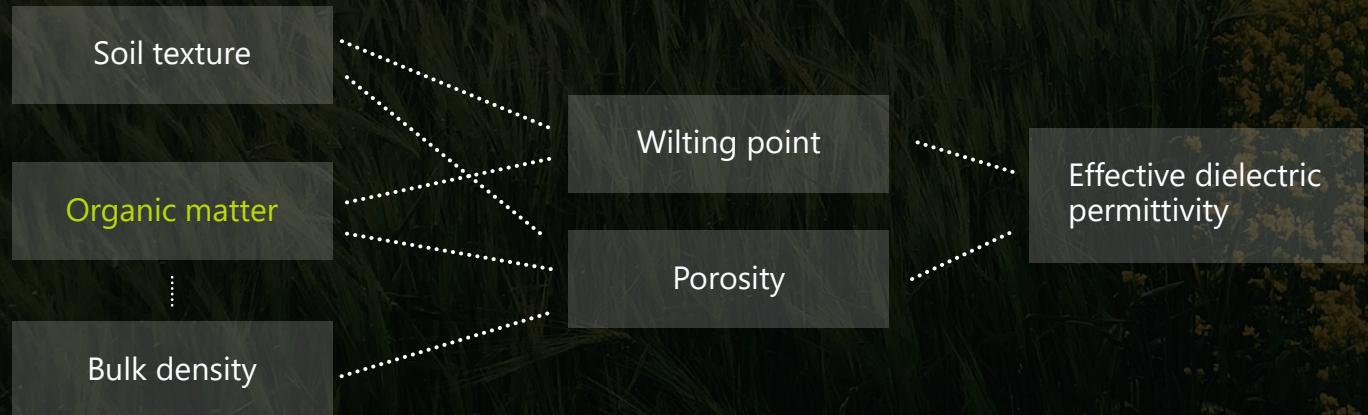
**Motivation:** existing sensors are expensive

- ~100s of dollars

**Strobe design:** Wi-Fi cards with 2+ antennas

- Relative time-of-flight and amplitude

**Results:** Strobe can accurately detect moisture and EC change in soil



# Food Tech at Microsoft



Sustainable Agriculture  
(FarmBeats + FarmVibes)



Food Supply Chain Transparency (FoodVibes)



Healthy Food Production  
(Modern R&D for Food)

# The Food Supply Chain Challenge



**50%** more food  
needed by 2050.  
**40%** food wasted.



**2B+** lack vital nutrients.  
**500M+** suffer from  
foodborne illnesses.



**31% GHG emissions**  
from agri-food systems.  
**8%** from food waste.



**\$1.2T** of food  
lost/wasted annually

COVID stretched the food supply chain:

- Food shelves were empty
- Food prices are up more than 20% over the last year
- Malnutrition increase by 15% in 2020
- .... Yet, even more food was wasted

# Transparent Food Chains: Creating new opportunities for food

## Traceability

Gain visibility across the food chain to improve safety



Track and trace



Food Safety & Recall

## Nutrition

More accurate nutrition using info about ingredient sources, and supply chain conditions



Food Manufacturing



Alt Proteins

## Sustainability

Provide farm & supply chain visibility to consumers, e.g. using regenerative ag

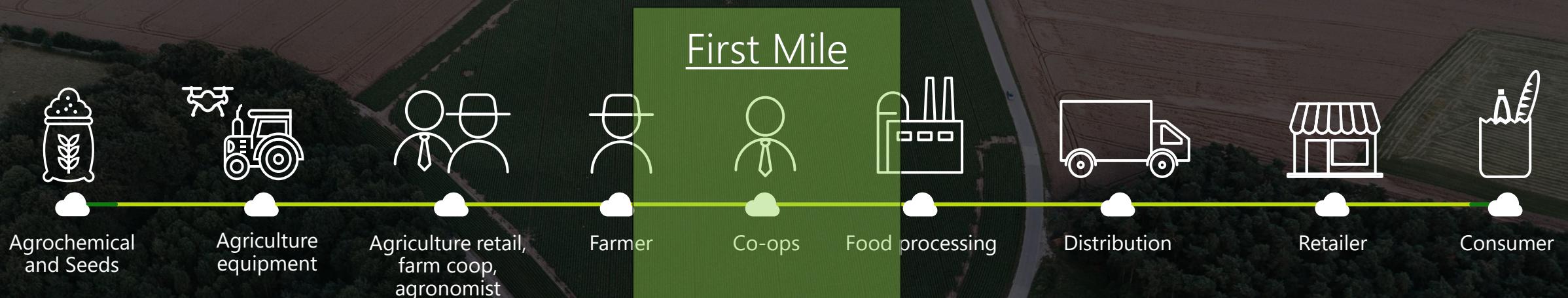


Food Waste



Sustainability labels

# Key Challenge: The Opaque “First” Mile



From the farm gate to the first handoff: shipper/processor



50% food waste happens in 1<sup>st</sup> mile



6% GHG emissions by food waste in 1<sup>st</sup> mile



Salmonella, E. coli often start in 1<sup>st</sup> mile

# 4 challenges hindering digitization of the 1<sup>st</sup> mile...



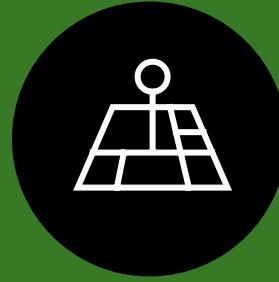
No connectivity  
in 1<sup>st</sup> mile



Low digital  
skills



No visibility  
in transport



Sensing is  
expensive

# FoodVibes: **Hands-off, Low-Cost** Digitization of Food Supply Chain's 1st Mile



# Several companies have made commitments



## Unilever's Knorr to launch 50 regenerative agriculture projects over five years

The CPG giant says it prioritizes "big, audacious goals" on sustainability over what it describes as incremental efforts by rivals.

Food Dive · 12d

## Pepsi Launches Sustainable Agriculture Campaign for Climate Crisis

The recent climate summit has focused attention on global agriculture, which accounts for about 10 percent of the greenhouse gas emissions in the United States alone, and nearly 24 percent globally.

R Research and Markets · 2d

Food Navigator

## Danone talks regenerative agriculture: Linking dairy and plant

...

Danone talks regenerative agriculture: Linking dairy and plant-based at a farm level can yield sustainability gains ... Danone was an early...

Aug 27, 2021



The Food Beverage News

## Nestlé's Plan to Shift to a Regenerative Food System – The

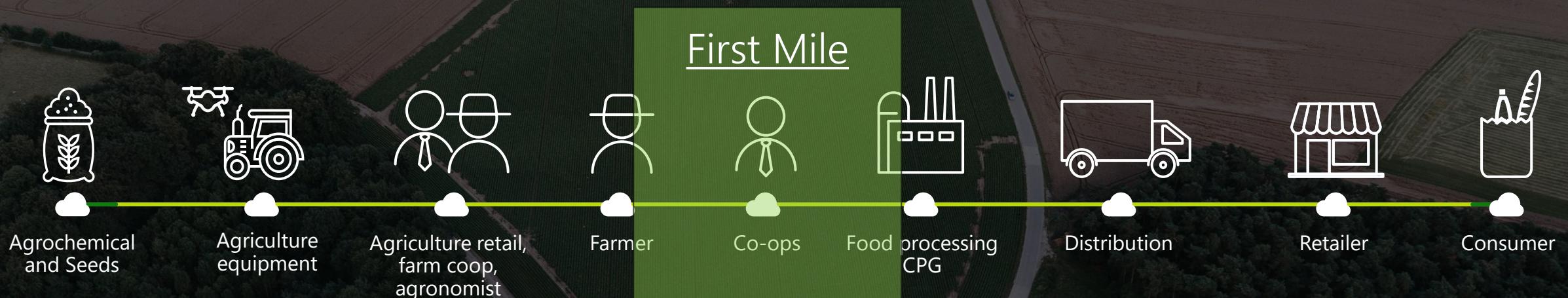
...

Nestle is investing around 1.7 billion over the period of 5 years to encourage regenerative agriculture across the supply chain of the...

1 day ago



# Go-To-Market: The Partnership Ecosystem



- Partner with 1<sup>st</sup> mile providers
- CPG margins channeled upstream

**GS1 Extended Data:  
FOODVIBES 1<sup>st</sup> Mile**  
Sustainability Practices  
Harvest Date  
Storage Temp, Humidity

*FoodVibes Partner Ecosystem*



**Sustainability service**  
GHG emissions, water use, chemicals used

**Nutrition service**  
Time since harvest, nutrient content

**Traceability service**  
Food safety, Protocols followed, Diseases

# Copilots in Agriculture



## Farmer

*Decision making for seeds, purchases, management*



## Agronomist

*Communicate with farmer & advisories*



## Policy Maker

*Make policy documents accessible to farmers*



## Banker

*Communicate with farmers about loans, insurance*



## Supply Chain

*Coordinate w/ farmers on prices, food standards*



## Ag Retailer

*Help farmers with purchasing decisions*



## Ag/Data Scientist

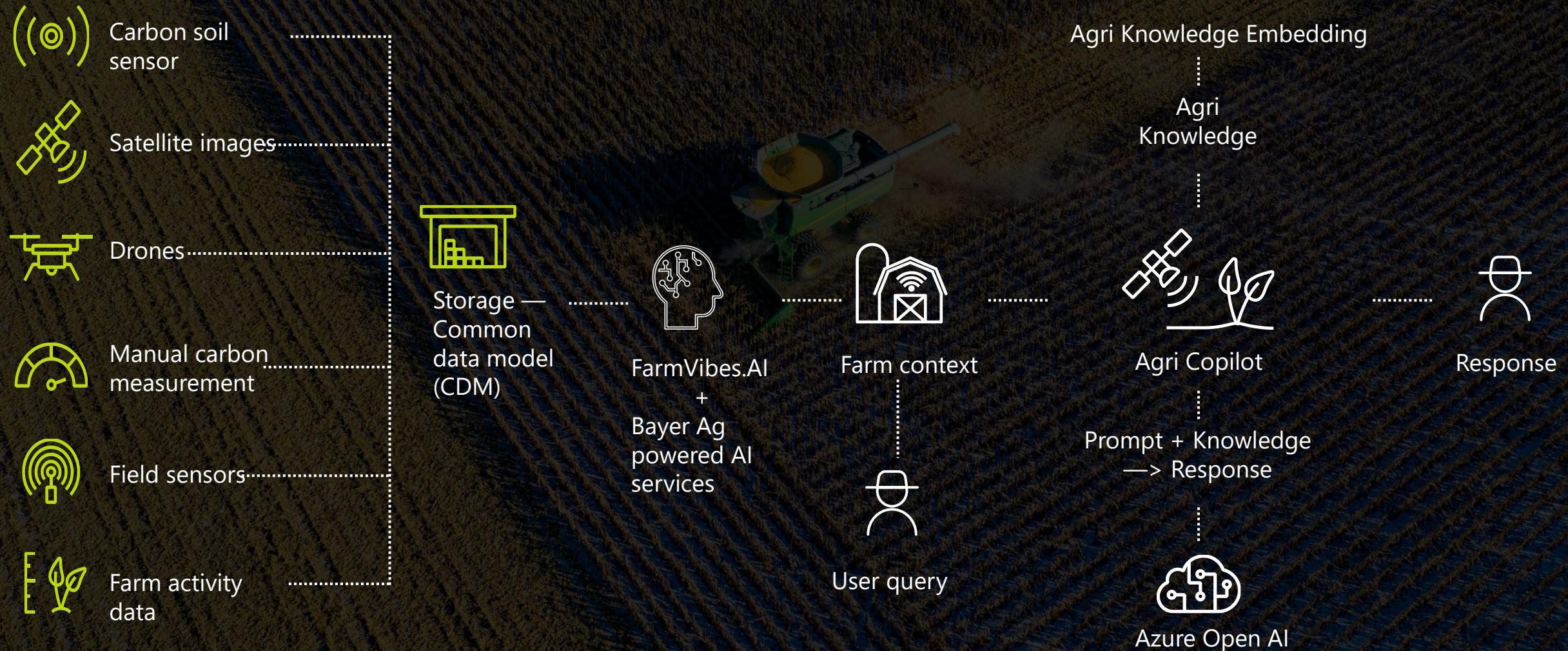
*AI workflow automation*



## Food Manufacturing

*Help farmers meet C standards*

# Agri CoPilot

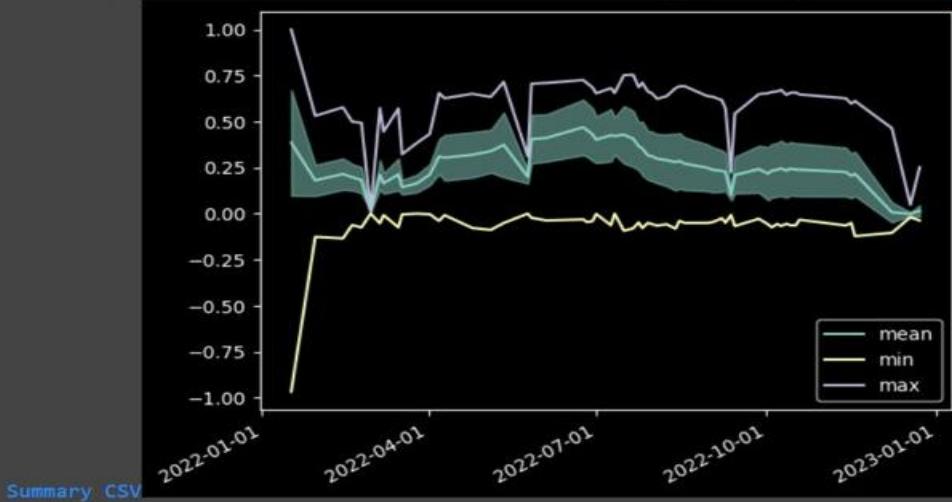




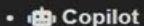
You  
Please analyze the summary of the health and vigor of my crops over the wheat growing season of 2022 in Farmington, WA.



Copilot  
I have analyzed the health and vigor of your crops over the wheat growing season of 2022 in Farmington, WA. The NDVI summary provides information on the mean, standard deviation, maximum, and minimum NDVI values for the specified area and time range. You can access the results in CSV format by following this link: [NDVI](#)



You  
Yeah, but what the NDVI values you found for my crops mean? Anything I should pay attention to?



Copilot  
Based on the NDVI values extracted from the CSV file, here's a summary of the crop health during the wheat growing season of 2022 in Farmington, WA:

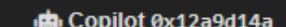
- Mean NDVI values ranged from 0.00698 to 0.46860, indicating varying levels of vegetation health throughout the season.
- Minimum NDVI values ranged from -0.96667 to 0.0, with some negative values suggesting the presence of non-vegetated surfaces or stressed vegetation.
- Maximum NDVI values ranged from 0.22456 to 0.99955, with higher values indicating healthier and denser vegetation.

It's important to monitor the NDVI values throughout the growing season to identify any potential issues with crop health. If you notice a significant drop in NDVI values or consistently low values, it may be worth investigating further to determine the cause and take appropriate action to address any issues.

# Agri CoPilot



You  
What products were applied to my Lowery field in the year 2023?



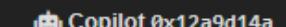
Copilot 0x12a9d14a  
In 2023, the following products were applied to your Lowery field:

1. 32-0-0 UAN: 85.2 acres at an average rate of 1.0 gal/ac
2. Ally Extra: 85.2 acres at an average rate of 0.4 oz/ac
3. Liberate: 85.2 acres at an average rate of 2.4 oz/ac
4. MiCrop: 85.2 acres at an average rate of 10.0 oz/ac
5. Osprey Xtra: 18.8 acres at an average rate of 4.8 oz/ac
6. Power-Up: 85.2 acres at an average rate of 1.0 gal/ac
7. Truslate: 85.2 acres at an average rate of 24.0 oz/ac

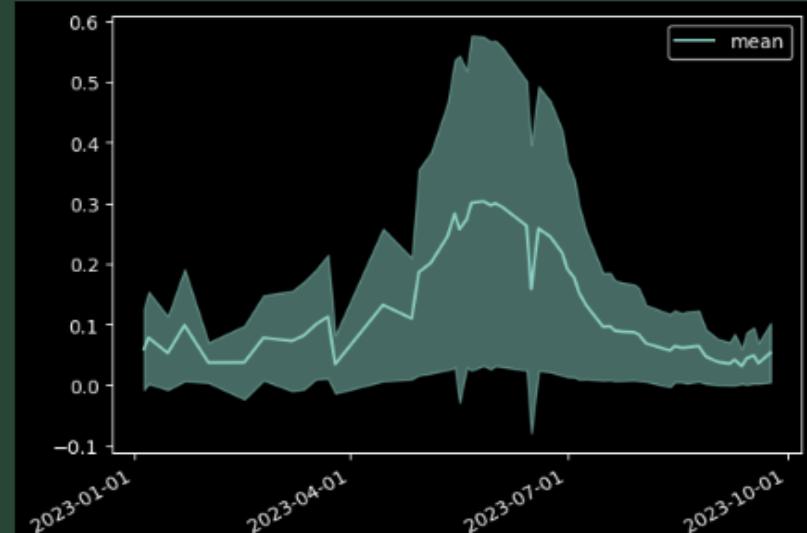
Please note that this information is based on the data available for your field.



You  
How is the health of the crops since seeding?



Copilot 0x12a9d14a  
Based on the NDVI data from 2023, the crop health in your Lowery field has shown fluctuations throughout the year. The NDVI values started relatively low in January, increased in May, and then gradually decreased until September. It's important to note that NDVI values can be influenced by various factors such as weather conditions, crop growth stages, and management practices. Overall, the crop health has experienced ups and downs, but without more context, it's difficult to determine the exact cause of these fluctuations. Source of data





You

what is the best method of planting lettuce seeds?

Copilot 0x12a9d14a

The best method for planting lettuce seeds depends on the scale of your operation and the resources available. For small-scale gardens or home use, you can sow seeds directly into the soil or start them indoors in seed trays or pots. Space seeds about 1 inch apart and cover them with a thin layer of soil, about 1/8 to 1/4 inch deep. Keep the soil consistently moist and provide adequate light. For larger-scale operations, using a seed drill or precision seeder can help ensure even spacing and proper planting depth. Regardless of the method, it's important to thin seedlings to the appropriate spacing for the specific variety once they have developed their first true leaves.



what depth do we plant the lettuce seed for optimal germination?

Copilot 0x12a9d14a

For optimal germination, lettuce seeds should be planted at a shallow depth of about 1/8 to 1/4 inch. This allows the seeds to receive adequate light, which is essential for germination. Keep the soil consistently moist and provide a temperature range of 60-70°F (15-21°C) for the best germination results.



what soil temperature will my seeds germinate?

Copilot 0x12a9d14a

Lettuce seeds typically germinate best in soil temperatures between 60-70°F (15-21°C). However, they can still germinate at temperatures as low as 40°F (4°C) and as high as 80°F (27°C), although the germination rate may be slower outside the optimal range.



what is the ideal soil humidity for lettuce seed germination?

Copilot 0x12a9d14a

The ideal soil humidity for lettuce seed germination is consistently moist but not waterlogged. Aim for a soil moisture level of around 70-80% of field capacity. This ensures that the seeds have enough water to germinate without being overly saturated, which can lead to issues like damping-off or seed rot.

# Agri CoPilot



You

If you're currently on a 3-year rotation with fall wheat, spring wheat, and a legume on a 200-acre farm, how would you estimate your current budget based on this?

Copilot 0x12a9d14a

Here's a summary of the estimated budget for a 200-acre farm with a 3-year rotation of fall wheat, spring wheat, and a legume:

## Initial Investments:

- Land Acquisition: \$3,000,000
- Soil Testing and Preparation: \$20,000
- Initial Crop Planting: \$40,000
- Initial Equipment Purchase: \$510,100
- Licenses and Permits: \$5,000

## Recurring Expenses:

- Input Costs: \$45,000
- Labor Costs: \$140,000
- Maintenance: \$40,000
- Utilities: \$45,000
- Financing Costs: \$75,000
- Miscellaneous Costs: \$25,000

## Revenue Streams:

- Crop Sales: \$450,000
- Government Subsidies and Grants: \$20,000
- Agritourism: \$10,000
- Crop Insurance Payouts: \$5,000

## Profit Loss Metrics:

- Gross Revenue: \$480,000 per year
- Net Revenue: \$175,000 per year
- Operating Margins: 36.46%
- Breakeven Point: 17.14 years
- ROI: 4.89%

## Funding and Capital:

- Personal Savings: \$500,000
- Bank Loans: \$1,000,000
- Government Grants: \$50,000
- Crowdfunding: \$25,000

Please note that these estimates are based on available data and assumptions.

Actual costs and revenues may vary depending on various factors such as location,

# Can GPT-4 pass Agriculture Exams?



**US  
Multiple Choice Questions**

Model	Accuracy	+ RAG	+ Context	+ RAG + Context
GPT 3.5	82%	82%	82%	88%
GPT 4	90%	90%	93%	93%



**Brazil  
long form answers**

Model	Accuracy	+ Context
GPT 3.5	59%	78%
GPT 4	72%	84%



**India  
Multiple Choice Questions**

Model	Accuracy	+ RAG	+ Context	+ RAG + Context
GPT 3.5	65%	69%	67%	68%
GPT 4	70%	78%	76%	<b>79%</b>
Human (#1 in the exam)			78%	

*GPT also makes mistakes....*

Who is the advocate of the "Marthandam" Rural Development Programme?

- a) Spencer Hatch
- b) Daniel Hamilton
- c) A.T. Mosher
- d) M.K. Gandhi

Ref Answer: a) Spencer Hatch

GPT Answer: b) M.K. Gandhi

# Fine Tuning vs RAG vs FT+RAG



**Agri Dataset  
(USA, Brazil, India)**



**Q&A Generation**



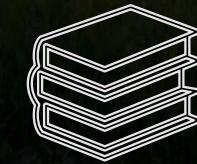
**Fine Tuning**



**FT GPT-4  
FT GPT3.5  
FT Llama 13B**



**GPT-4 based  
Eval**



**RAG**



**GPT-4  
GPT3.5  
Llama 13B**

# Insights on RAG vs FT vs FT + RAG

RAG improves accuracy for large models

- \* RAG on fine-tuned model gives best results
- \* integration with satellite + farm context lights up new scenarios

Fine-tuning might help learn new knowledge

- \* early results show promise

	<b>RAG</b>	<b>Fine Tuning</b>
Cost – Input token size	Increased Prompt Size	Minimal
Cost – output token size	More verbose, harder to steer	Precise, tuned for brevity
Initial cost	Low – creating embeddings	High – fine tuning
Accuracy	Effective	Effective
New Knowledge	If data is in context	New skill in domain

# I am a cotton farmer in India, and found a worm on the flower. What is it?

Without a clearer image, it is difficult to accurately identify the worm. However, based on its location on the flower and its appearance, it could be a caterpillar of the cotton bollworm (*Helicoverpa armigera*). This pest is known to feed on cotton flowers and can cause damage to the crop.



# I am a chili farmer in India, and I am seeing this disease in the image below. What is it?

This appears to be root-knot nematode damage. Root-knot nematodes are microscopic roundworms that infect the roots of plants, causing them to form galls or knots. This reduces the plant's ability to take up water and nutrients, leading to stunted growth and reduced yield. The presence of the galls on the roots is a characteristic symptom of root-knot nematode infection. Other symptoms may include yellowing and wilting of the leaves, and reduced fruit size and quality. Control measures for root-knot nematodes include crop rotation, soil solarization, and the use of nematicides. It is also important to practice good sanitation and hygiene in the field to prevent the spread of the nematodes.

**Are you sure it is not root rot? (this was originally the agronomist's recommendation)**

I have seen similar symptoms in chilli plants affected by root rot. It is possible that root rot could also be present, as root-knot nematode damage can make plants more susceptible to other soil-borne diseases. However, the presence of the galls on the roots is a characteristic symptom of root-knot nematode infection, which is why I believe that is the primary issue here.



## Testimonial:

This was very cool. The agronomist first said, root rot. GPT-4 said root nematode. I called other experts to confirm that it was indeed root nematode!

I am a farmer  
has been infected  
causing it

This is another picture:



what should i do to control bacterial leaf spot on my chili plants in karnataka

- ✓ Searching for: bacterial leaf spot chili plants karnataka
- ✓ Generating answers for you...



Your personal and company data are protected in this chat

According to an article from The Hindu<sup>1</sup>, bacterial leaf spot in chili plants can be controlled by spraying Agrimycin 100 alone or with 3gm/l copper oxychloride/ copper sulphate or 2gm/l mancozeb. Infection takes place under a wide range of temperatures with peak infection during July-September. The bacterium spreads within the field by wind driven rain droplets, clipping of transplants and aerosols. I hope this helps!

Learn more: [1. thehindu.com](http://thehindu.com) [2. bing.com](http://bing.com) [3. kssdb.karnataka.gov.in](http://kssdb.karnataka.gov.in) [+5 more](#)

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# LLMs + Reasoning

An agricultural retailer has 3 warehouses and serves 5 farming regions.

Each warehouse has a limited stock of three types of fertilizers:

Nitrogen (N), Phosphorus (P), and Potassium (K). The demand for each fertilizer type in each region is known, and the transportation cost per ton of fertilizer from each warehouse to each region is also provided.

Details:

Warehouse Capacities (in tons):

Warehouse A: 300 tons of N, 200 tons of P, 100 tons of K

Warehouse B: 400 tons of N, 300 tons of P, 200 tons of K

Warehouse C: 500 tons of N, 400 tons of P, 300 tons of K

Region Demand (in tons):

Region 1: 150 tons of N, 100 tons of P, 80 tons of K

Region 2: 200 tons of N, 150 tons of P, 100 tons of K

Region 3: 100 tons of N, 120 tons of P, 60 tons of K

Region 4: 250 tons of N, 180 tons of P, 150 tons of K

Region 5: 200 tons of N, 150 tons of P, 120 tons of K

Transportation Cost (in \$ per ton):

Warehouse A to Regions 1-5: \$50, \$70, \$60, \$80, \$90

Warehouse B to Regions 1-5: \$60, \$50, \$70, \$90, \$80

Warehouse C to Regions 1-5: \$70, \$60, \$80, \$90, \$50

Problem:

Determine the optimal allocation of fertilizers from the warehouses to the regions to minimize the total transportation cost while meeting the demands of all regions and not exceeding the stock capacities of the warehouses.

Constraints:

Each warehouse's fertilizer stock cannot be exceeded.

Each region's fertilizer demand must be fully met.

Transportation is limited to available routes and their respective costs.

Thought for 1m 30s ^

### Formulating variables and objective function

I'm setting up variables for the allocation of fertilizer P from warehouses to regions, balancing transportation costs, balancing supplies and demands at regions.

### Aligning resources

Ensuring supply at warehouses aligns with demand paths, while keeping non-negative values.

### Analyzing costs

Mapping out transportation cost per ton, considering distance and unit type. This helps determine the most cost-effective routes.

### Mapping linear programming

I'm working out a linear programming model for fertilizer distribution between warehouses, demand constraints, and total cost.

### Breaking down the problem

I'm thinking of simplifying this large problem by breaking it down into smaller parts. The consistent unit trick is helping here.

### Isolating the issue

I'm simplifying things by tackling one region at a time. This approach trims down the complexity of the problem.

### Allocating supplies

Ensuring the total supply of 900 tons is distributed to meet regional demands, revealing a partial surplus at W\_C.

### Balancing supplies

I'm allocating supplies to different regions to balance remaining unfound surplus for better efficiency.

### Assessing transportation options

I'm exploring cost-saving measures by shifting allocations from W\_B and W\_C to R4, revealing reduced costs.

### Re-evaluating paths

I'm looking at reallocating W\_B and W\_C to R4. The new path is consistent, meaning no clear cost savings.

### Mapping out supply routes

I'm analyzing the allocation of W\_C to R4. The new path is consistent, making any cost-savings potential minimal.

### Evaluating cost shifts

I'm noting that reallocating W\_B to R4 increases total cost compared to the original \$28,000, totaling \$31,000.

### Finding the best route

I'm assessing the initial allocations. The new path makes me think about optimizing the overall distribution.

### Adjusting allocations

I'm finalizing the reallocation of W\_B to R3. This adjustment is more efficient than the previous shift.

### Wrapping up allocations

I'm finalizing the distributions to meet demand and minimize waste. However, R2's demand of 200 units remains unmet, highlighting a need for further adjustment.

### Optimizing allocations

I'm tweaking the allocation of W\_C to R2, but the new distribution is costing \$64,000, which is more than the previous \$55,500. This suggests more adjustments are needed.

### Evaluating alternatives

Taking a closer look, it seems the initial solution is likely the most cost-effective. This conclusion comes from comparing the total costs incurred, confirming there's no need for further tweaks.

### Allocating supplies

OK, let me see. I'm thinking about distributing fertilizer P from warehouses to regions, matching the initial solution's cost. Total supply surpasses demand, ensuring all needs are efficiently met.

### Assessing options

I'm looking at reallocating W\_B to R5 at \$80 per ton or W\_C to R4 at \$90 per ton, but both paths are equally costly.

### Piecing together costs

I've identified the supply and demand, ensuring all needs are met. The total cost for distributing fertilizer P is \$43,600, with no potential for further savings at this time.

### Reallocating supplies

I'm thinking through shifting W\_C's surplus to R4, adjusting all supplies and demands. This fine-tunes the distribution, revealing potential ways to enhance efficiency and cost-effectiveness.

### Reallocating for efficiency

I'm shifting W\_B's 110 units to R3 at \$70 per ton. With all demands now met, the leftover W\_B units can be reallocated to other regions to further optimize the distribution.

## Conclusion

By allocating fertilizers according to the above plan, we minimize the total transportation cost to \$131,600 while meeting all regional demands and not exceeding warehouse capacities.

**Answer:**

An optimal allocation that minimizes total transportation cost while meeting all demands is:

**Nitrogen (N):**

- Warehouse A sends 150t to Region 1 at \$50/t and 100t to Region 3 at \$60/t.
- Warehouse B sends 200t to Region 2 at \$50/t and 200t to Region 4 at \$90/t.
- Warehouse C sends 200t to Region 5 at \$50/t.

**Phosphorus (P):**

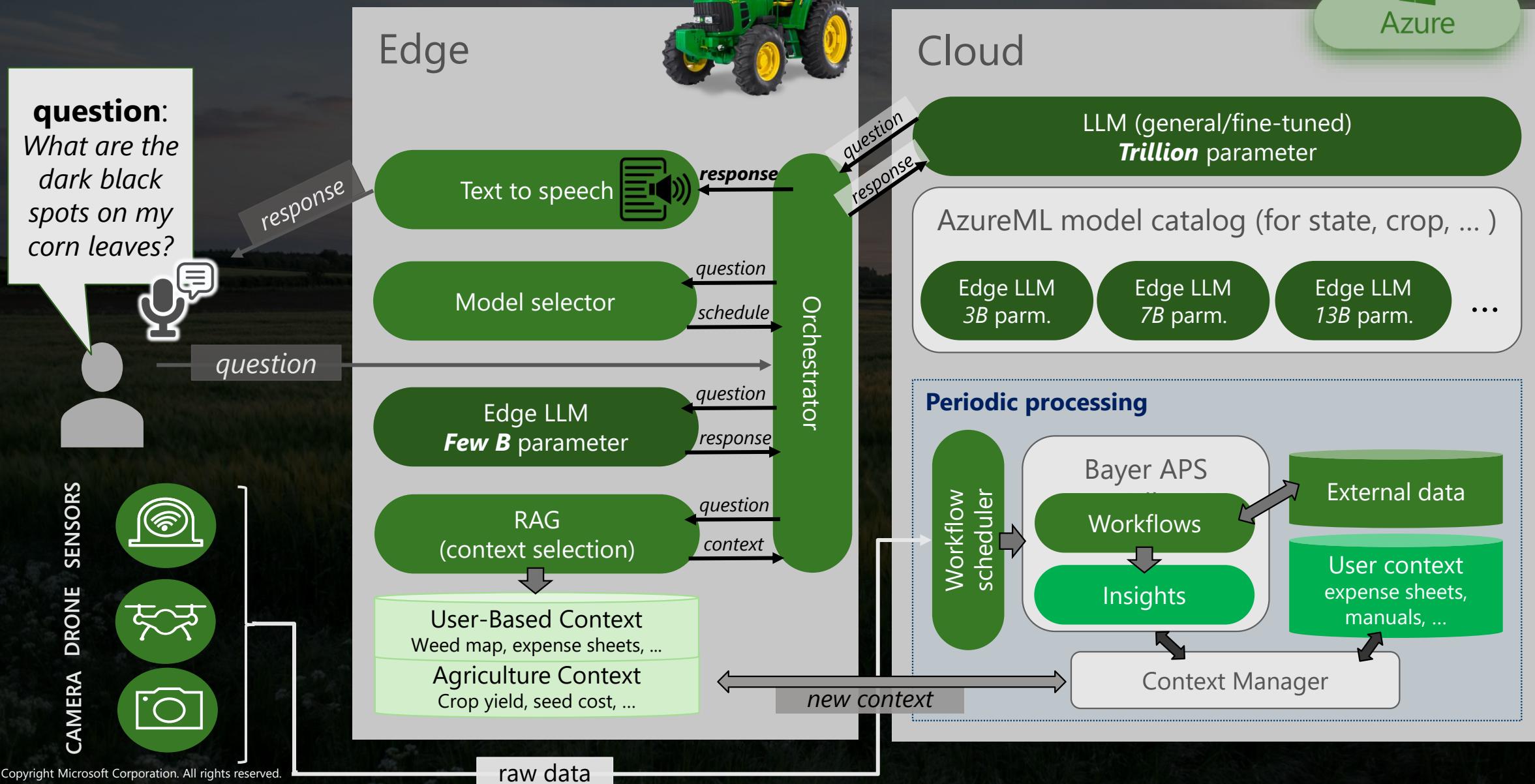
- Warehouse A sends 100t to Region 1 at \$50/t and 100t to Region 3 at \$60/t.
- Warehouse B sends 150t to Region 2 at \$50/t, 20t to Region 3 at \$70/t, and 130t to Region 4 at \$90/t.
- Warehouse C sends 150t to Region 5 at \$50/t and 50t to Region 4 at \$90/t.

**Potassium (K):**

- Warehouse A sends 80t to Region 1 at \$50/t and 20t to Region 3 at \$60/t.
- Warehouse B sends 100t to Region 2 at \$50/t, 40t to Region 3 at \$70/t, and 60t to Region 4 at \$90/t.
- Warehouse C sends 120t to Region 5 at \$50/t and 90t to Region 4 at \$90/t.

This plan minimizes total transportation cost  $\downarrow$  \$131,600 while satisfying all constraints.

# Tractor Co-Pilot







Microsoft

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