

Responding to the Emerging Global Digital Transformation: Which way for Soil Science?

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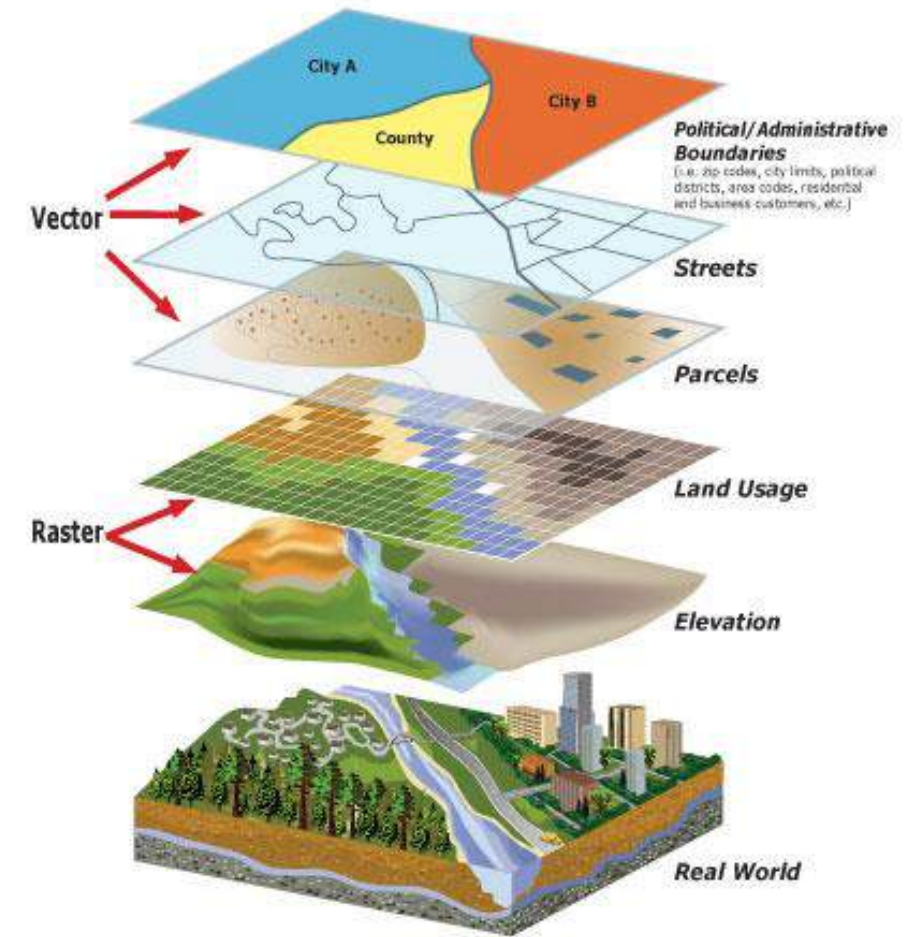


Digital Agriculture-Definition

- Digital agriculture integrates technologies like sensors, AI, and data analytics to optimize farming practices.
- Its applications include precision farming for efficient resource use, automated machinery for tasks like planting and harvesting, and predictive analytics for monitoring crop health and yield.
- This data-driven approach enhances productivity, sustainability, and decision-making across the agricultural value chain.

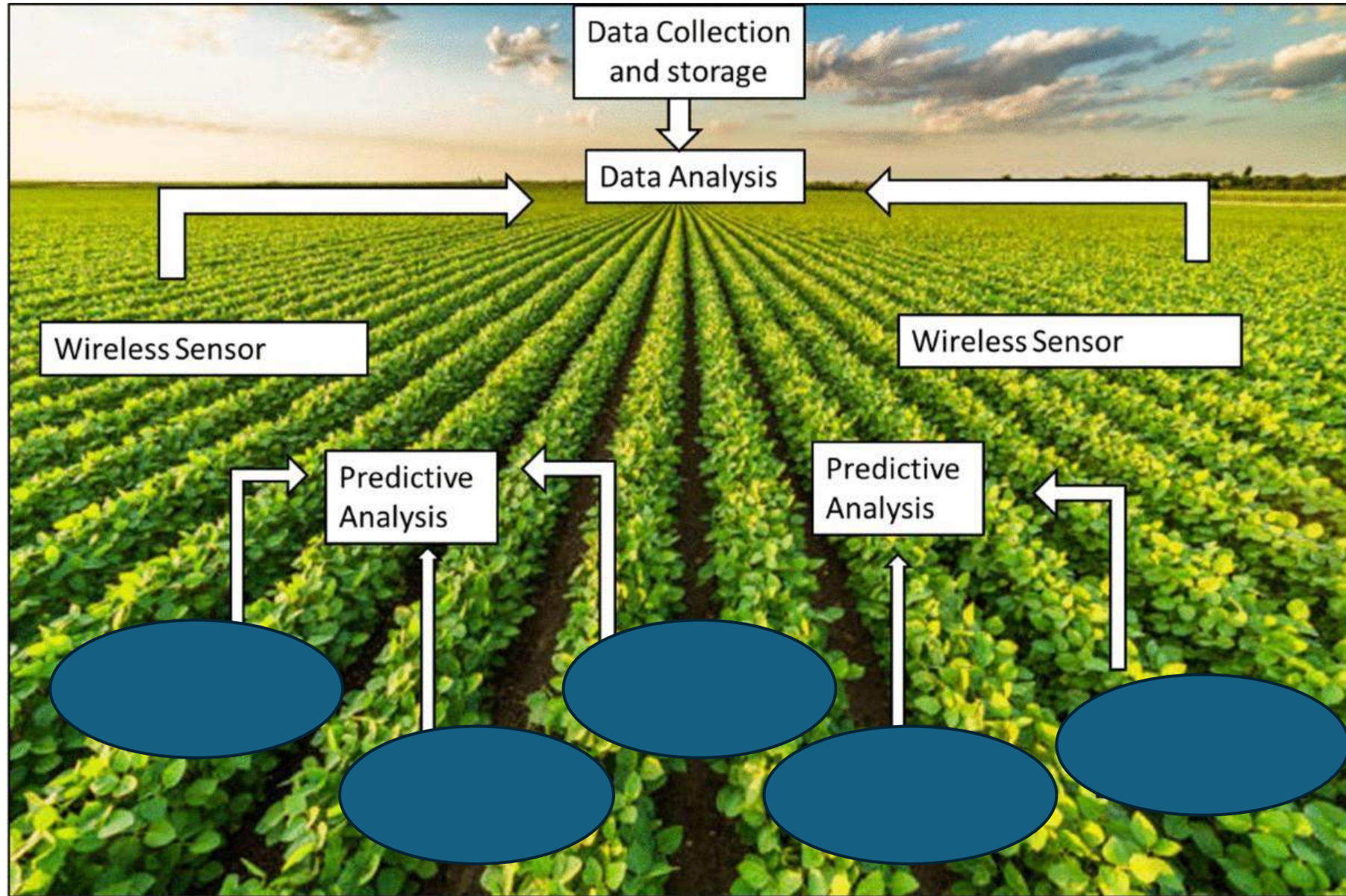
Relevant Technologies

- At the core of digital farming systems is the deployment of advanced tools such as **spatial mapping, remote sensing, mobile applications, and data analytics.**
- These technologies provide farmers with real-time information on soil health, weather, and crop performance while enabling precise resource management.
- Digital platforms also support advisory services and knowledge-sharing across entire farming ecosystems.



Putting datasets together in a digital platform

Digital Agriculture





Personal Devices



Data Center



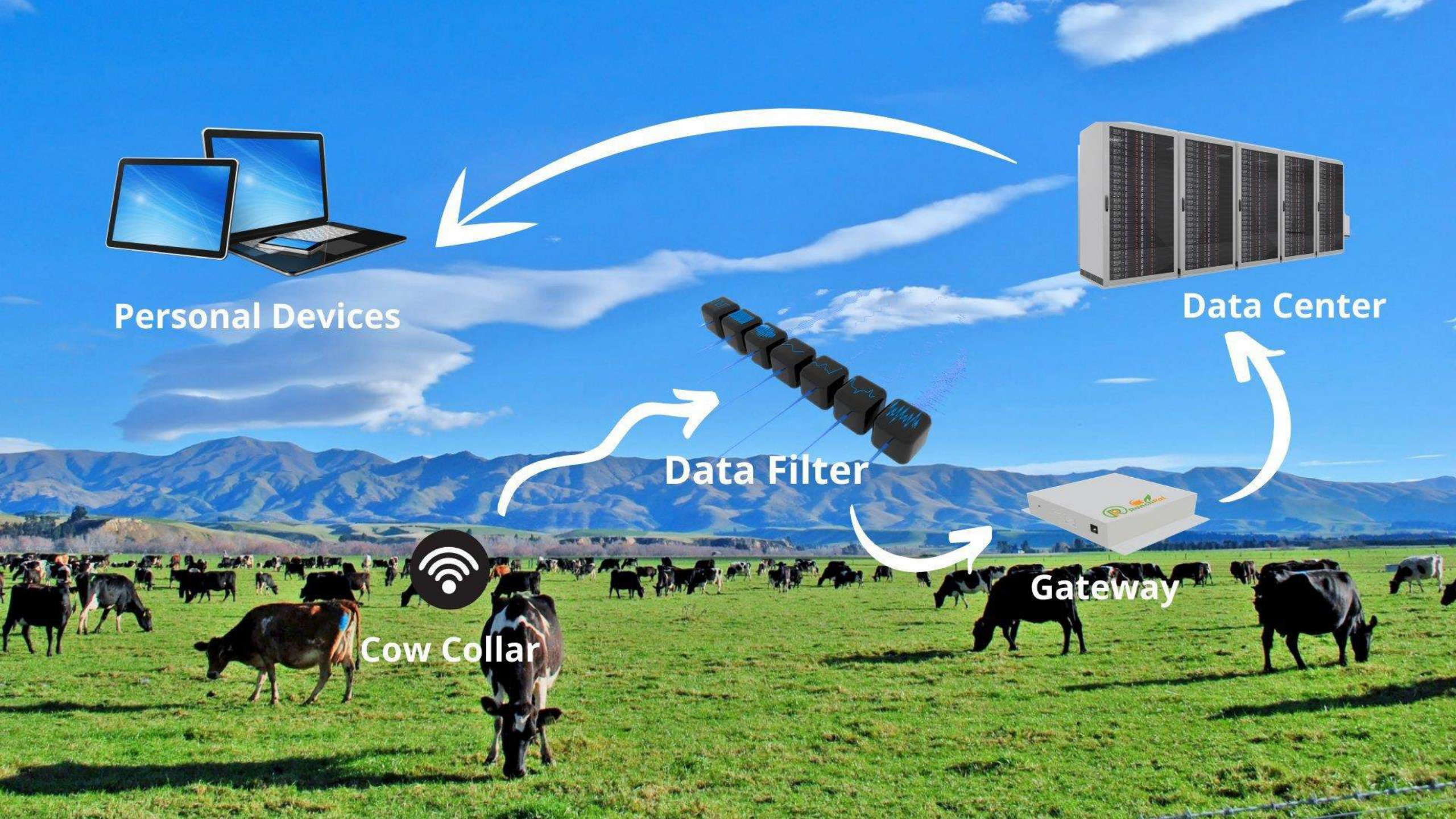
Data Filter



Gateway



Cow Collar



Types of land use mapping satellites

Satellites used for land use mapping are generally categorized by their sensor type, such as **Optical satellites** (like Landsat, Sentinel, SPOT), **microwave/SAR satellites** (like TerraSAR, RADARSAT), and those with **multi-mode sensors** (like MODIS). The choice of satellite depends on factors like required resolution, weather conditions, revisit time, and the specific land cover features to be mapped.

The mostly depend on the electromagnetic spectrum. The electromagnetic spectrum is the complete range of electromagnetic waves, arranged according to their wavelengths or frequencies, from radio waves to gamma rays.



The Earth Resources Technology Satellite (ERTS, later renamed Landsat 1) launched aboard a Delta 900 from Vandenberg Air Force Base on July 23, 1972.

(NASA photography courtesy Landsat science team.)

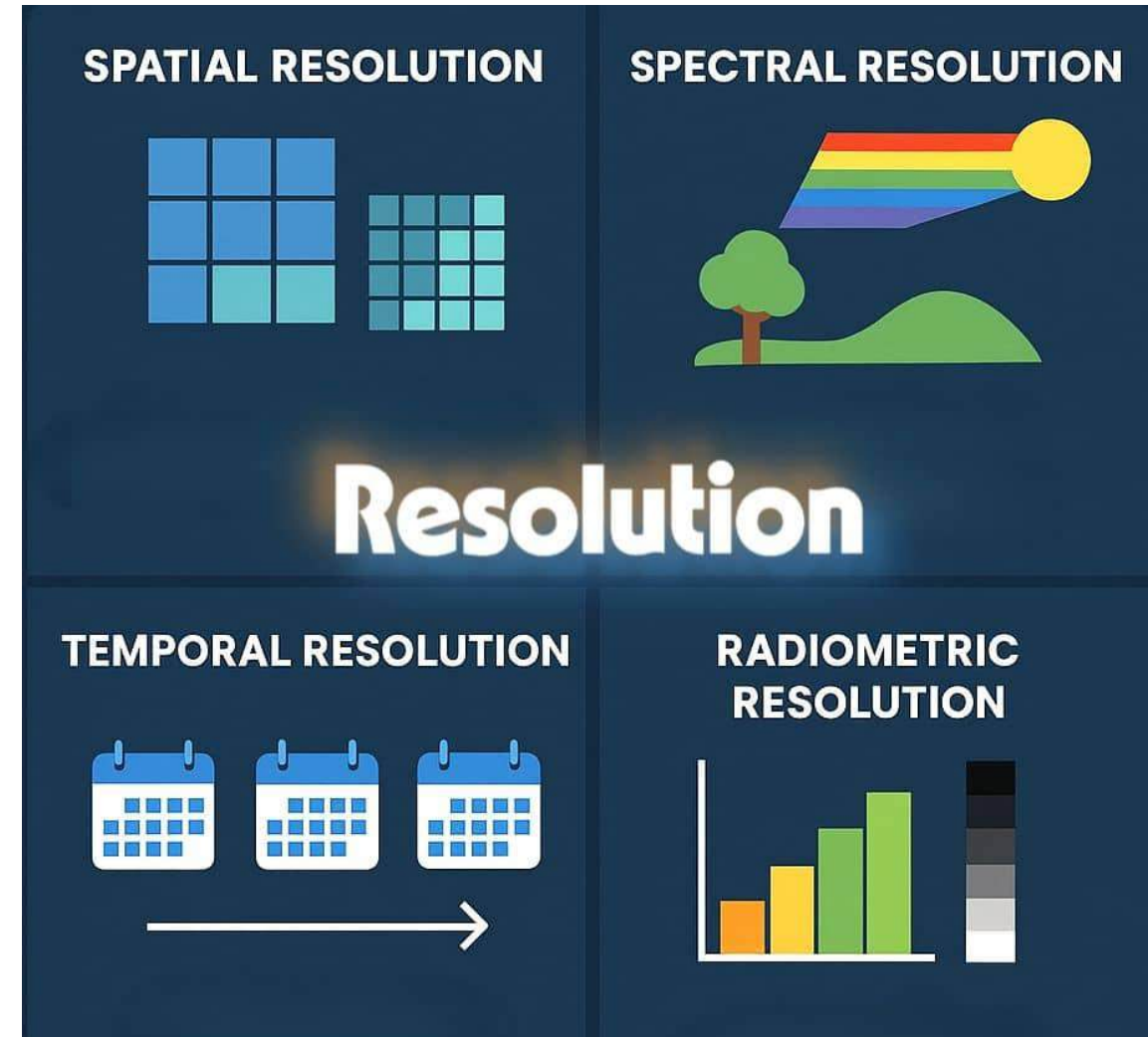
Types of RS mapping resolutions

Spatial resolution in remote sensing is the size of the smallest ground feature that a sensor can distinguish, typically expressed as the dimensions of one pixel on the Earth's surface.

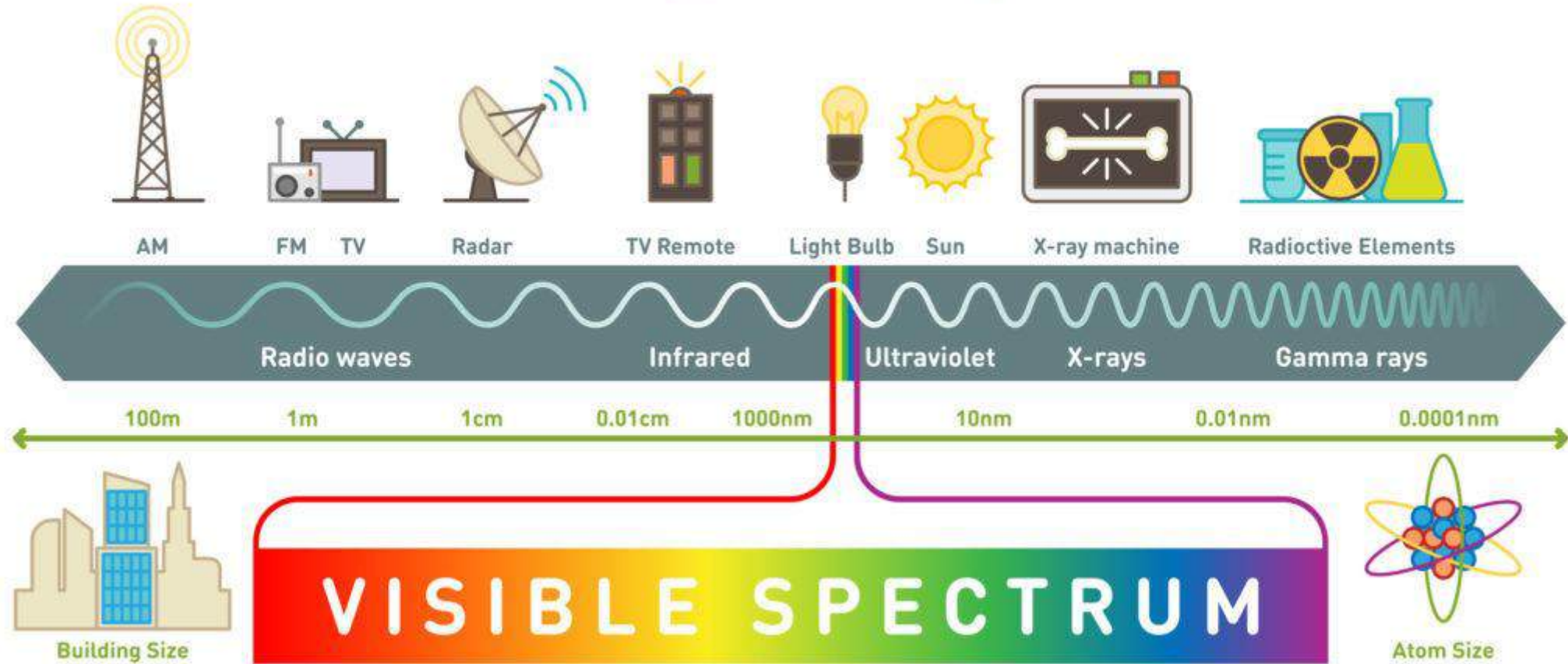
Spectral resolution in remote sensing is the ability of a sensor to distinguish and record specific, narrow wavelength ranges within the electromagnetic spectrum.

Temporal resolution in remote sensing refers to how frequently a satellite sensor revisits and captures imagery of the same location over time.

Radiometric resolution in remote sensing is the sensor's ability to detect and represent subtle differences in energy intensity, expressed as the number of possible digital levels (bits) per pixel.



Electromagnetic Spectrum



Landsat 9

Landsat 9, launched in September 2021 as part of the U.S. Landsat program, carries two instruments: the **Operational Land Imager-2 (OLI-2)** and the **Thermal Infrared Sensor-2 (TIRS-2)**. Together, they collect imagery in **11 spectral bands** ranging from visible to thermal infrared.

What Landsat 9 does beyond Landsat 8

- **Improved Radiometric Resolution:** Landsat 9 can detect **up to 16,000 shades of a given wavelength (14-bit data)** compared to Landsat 8's 4,096 shades (12-bit). This means Landsat 9 captures subtler differences in surface features such as vegetation health, water quality, and soil conditions.
- **Updated Instruments:** Landsat 9 carries **OLI-2** and **TIRS-2**, essentially upgraded versions of Landsat 8's sensors, providing continuity but with improved calibration and reliability for long-term monitoring.
- **Data Continuity for Climate Monitoring:** It ensures seamless overlap with Landsat 8, effectively doubling imaging capacity (two satellites now revisit the same spot every **8 days** instead of 16).

Each scene is about **185 km wide × 180 km long** (~33,300 km²). Landsat 9 data, like Landsat 8, is **free of charge** through the **U.S. Geological Survey (USGS) EarthExplorer** platform and other access points.

Band	Name	Wavelength (µm)	Resolution	Main Applications
1	Coastal/Aerosol	0.43 – 0.45	30 m	Coastal and aerosol studies, water quality, atmospheric correction
2	Blue	0.45 – 0.51	30 m	Bathymetric mapping, soil/vegetation differentiation, water quality
3	Green	0.53 – 0.59	30 m	Vegetation vigor, water quality, urban features
4	Red	0.64 – 0.67	30 m	Vegetation discrimination, soil, and crop analysis
5	Near Infrared (NIR)	0.85 – 0.88	30 m	Biomass, crop health, water body delineation
6	SWIR-	11.57 – 1.65	30 m	Soil and vegetation moisture, snow/ice discrimination
7	SWIR-	22.11 – 2.29	30 m	Geological mapping, moisture content, burned areas
8	Panchromatic	0.50 – 0.68	15 m	High-resolution mapping, sharpening multispectral imagery
9	Cirrus	1.36 – 1.38	30 m	Detecting high, thin clouds (cirrus cloud masking)
10	Thermal Infrared 1	110.6 – 11.19	100 m (resampled to 30 m)	Surface temperature, soil moisture, evapotranspiration
11	Thermal Infrared 2	211.5 – 12.51	100 m (resampled to 30 m)	Surface temperature mapping, volcanic activity, water stress

Optical Satellites- Landsat

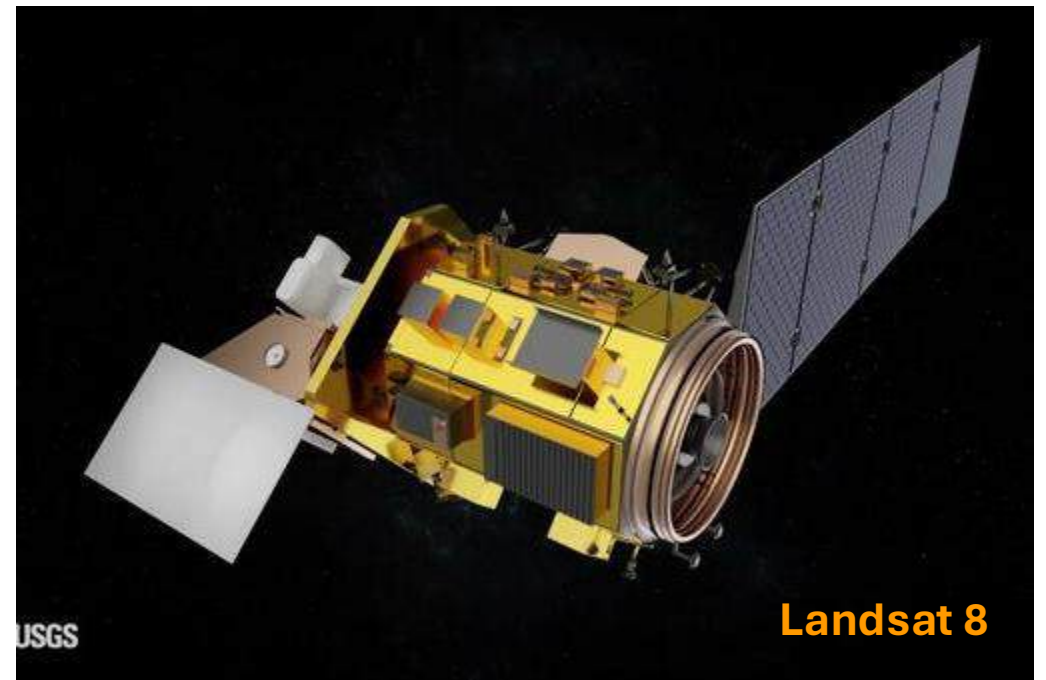
The Landsat satellite program, jointly managed by NASA and the U.S. Geological Survey, is the longest-running Earth observation mission, providing continuous imagery since 1972. It delivers medium-resolution data used worldwide for monitoring land use, agriculture, forestry, water resources, and environmental change.

Landsat satellites provide data at multiple resolutions, including 15 m (panchromatic), 30 m (multispectral), and 100–120 m (thermal), enabling detailed observation of Earth's surface features.

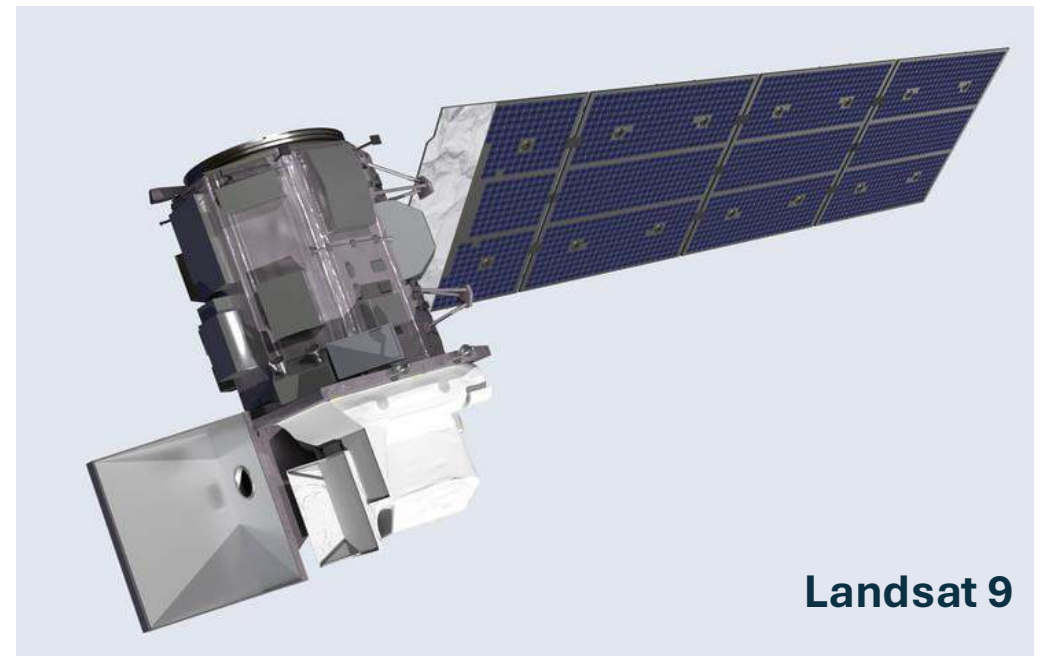
Current Landsat capabilities are defined by **Landsat 8** and **Landsat 9**. The two satellites provide multi-spectral images of Earth's land surface from two main instruments: the Operational Land Imager (OLI) for visible, near-infrared, and shortwave-infrared bands, and the Thermal Infrared Sensor (TIRS) for heat measurements.

Key functions include the long-term, consistent monitoring of land and resource changes, detailed observation of phenomena like urban growth, glacier retreat, and disasters, and the provision of free, open-access data for applications in agriculture, water management, and environmental change. Landsat 9 offers enhanced radiometric resolution over Landsat 8 for greater data precision and a consistent multi-decadal view of Earth.

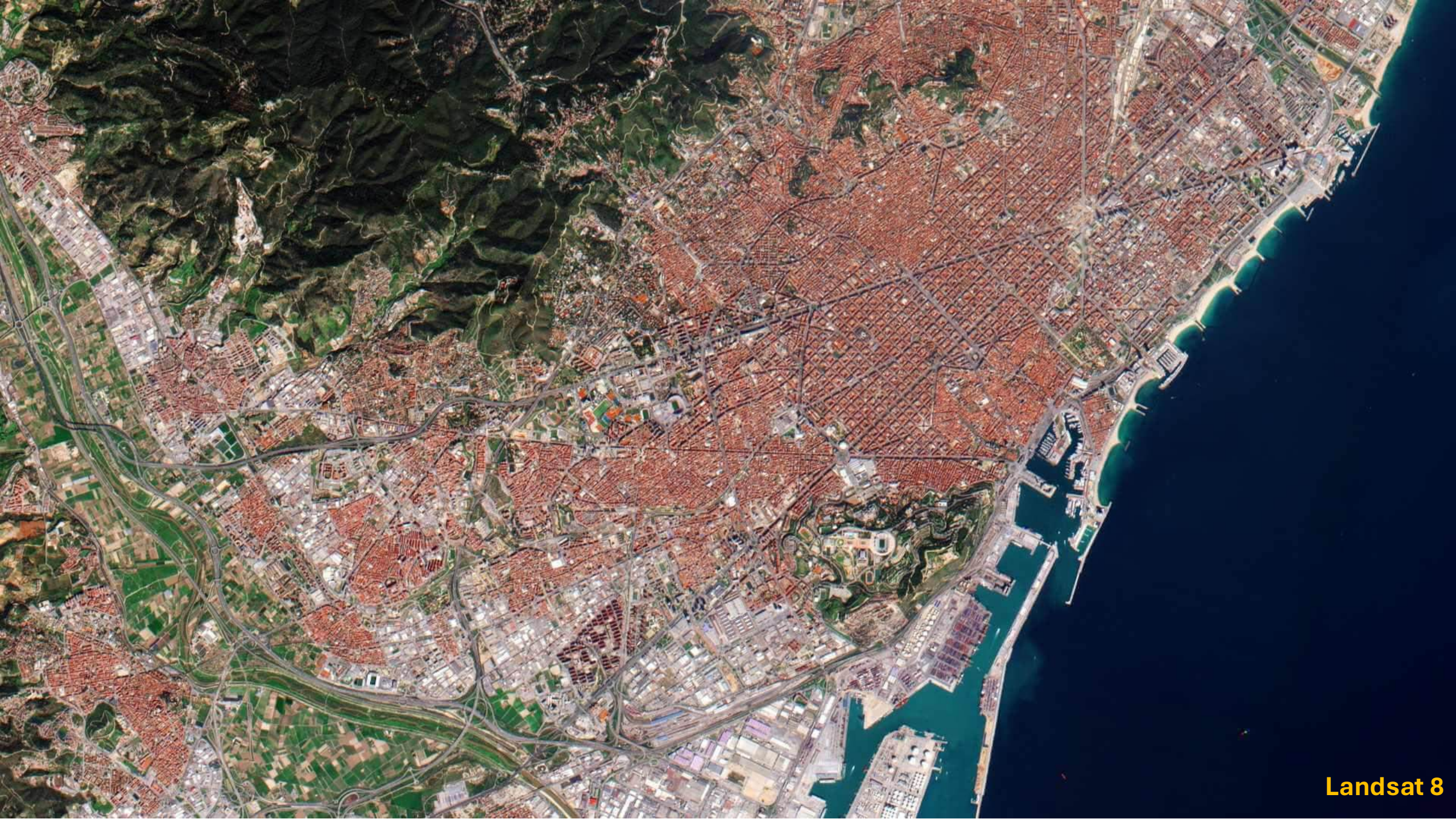
Functions: Detects changes in land cover, monitors vegetation health and agricultural conditions, identifies coastal zone changes, and maps pollution and dust in the atmosphere.



Landsat 8



Landsat 9



Sentinel Satellite Data

Sentinel 2 Data
Po Valley Italy
10 m resolution

False colour
composite in the
Infra-Red spectrum
band



Landsat 8 & 9 Data Processing

Item Measured	How Landsat Does It (Bands/Indices)	Watershed/Basin Level Application
Land Cover	Multi-spectral classification	Model Input: Determines runoff, infiltration, and pollution sources. Special formulae
Vegetation Health	NDVI (Red, NIR) normalized difference vegetation index	Estimates water use (ET), identifies erosion risk areas, monitors riparian zones. $(\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$
Water Presence	NDWI (Green, NIR) ND water index	Maps stream networks, monitors reservoir and wetland extent. $(\text{Band 3} - \text{Band 5}) / (\text{Band 3} + \text{Band 5})$
Water Quality	Blue, Green, Red bands	Estimates turbidity (sediment load) and chlorophyll-a (algal blooms). Special formulae

Note: The calculated indices range from -1 to +1

The Benefits

- The integration of **digital systems in farming** is transforming agricultural value chains into more connected, efficient, and sustainable ecosystems.
- By leveraging **spatial mapping and mobile applications**, farmers gain real-time insights for decision-making, climate adaptation, and productivity improvement.
- These systems enable seamless **commerce and trade**, linking cooperatives, agro-dealers, and markets while fostering inclusivity for **youth and women** in agribusiness.
- Partnerships with **agricultural research organizations** strengthen innovation and knowledge transfer, ensuring that smallholder farmers access cutting-edge technologies and practices. Ultimately, digital farming systems create resilient, market-driven, and sustainable agricultural environments that empower communities and drive rural economic growth.



Artificial Intelligence

- Artificial Intelligence (AI) is the simulation of human intelligence in machines that are programmed to think, learn, and make decisions like humans.
- It enables computers to perform tasks such as reasoning, problem-solving, speech recognition, and visual perception.
- AI applications include virtual assistants, autonomous vehicles, medical diagnosis, fraud detection, and precision agriculture.

Business Environment

Place of Soil
Science

Agribusiness Value Chain

Provision of
inputs

Production

Bulking
Cleaning
Grading

Transport &
Storage

Processing,
Packaging &
Trade

Retail &
Distribution

Services (financial, certification, advice, etc.)

Components of AI

- **Artificial Intelligence (AI)** is not a single technology but a collection of interrelated components. When combined, they create powerful systems for the food sector.
- It is important to mention that AI components work together to create a **smarter, more efficient, and resilient food system**-from the farm where robots plant and harvest, to the supply chain that minimizes waste, to the consumer whose preferences directly influence production.
- Following are the key components of AI and their applications in food systems:

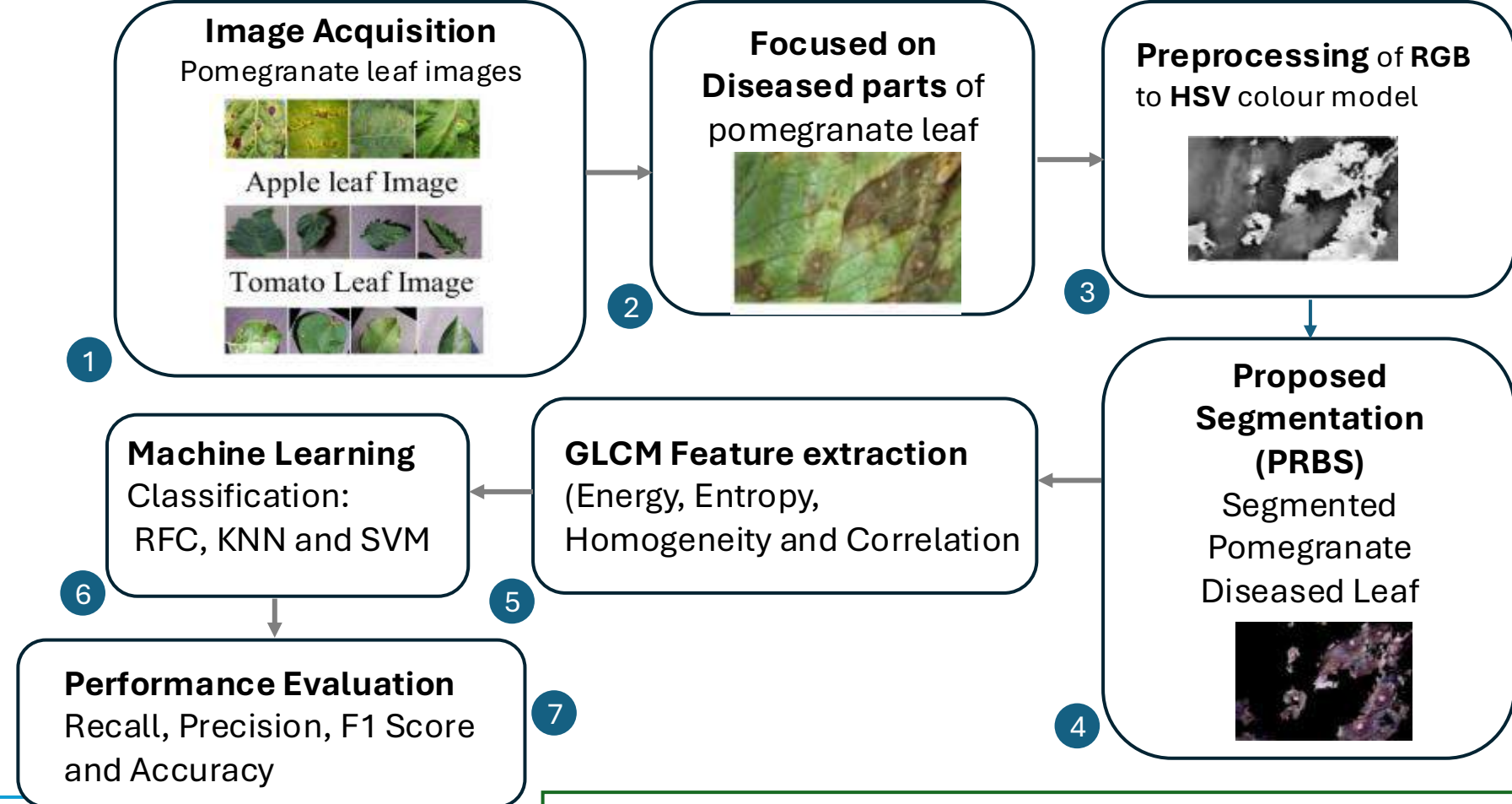
1. Machine Learning (ML) & Deep Learning

This is the core of most modern AI. **ML algorithms** find patterns in data to make predictions or decisions without being explicitly programmed for every scenario. **Deep Learning**, a subset of ML using neural networks, is excellent for complex tasks like image recognition.

Applications in Food Systems:

- **Precision Agriculture:** ML models analyze soil data, weather patterns, and drone imagery to predict optimal planting times, fertilizer needs, and irrigation schedules for specific areas of a field.
- **Yield Prediction:** By analyzing historical data and satellite imagery, **ML** can forecast crop yields with high accuracy, helping with supply chain planning and financial forecasting.
- **Food Sorting and Quality Control:** Deep Learning systems powered by cameras can instantly sort fruits, vegetables, and grains by size, color, ripeness, and defects with far greater speed and accuracy than human workers.

Machine Learning Process for Plant Disease Detection

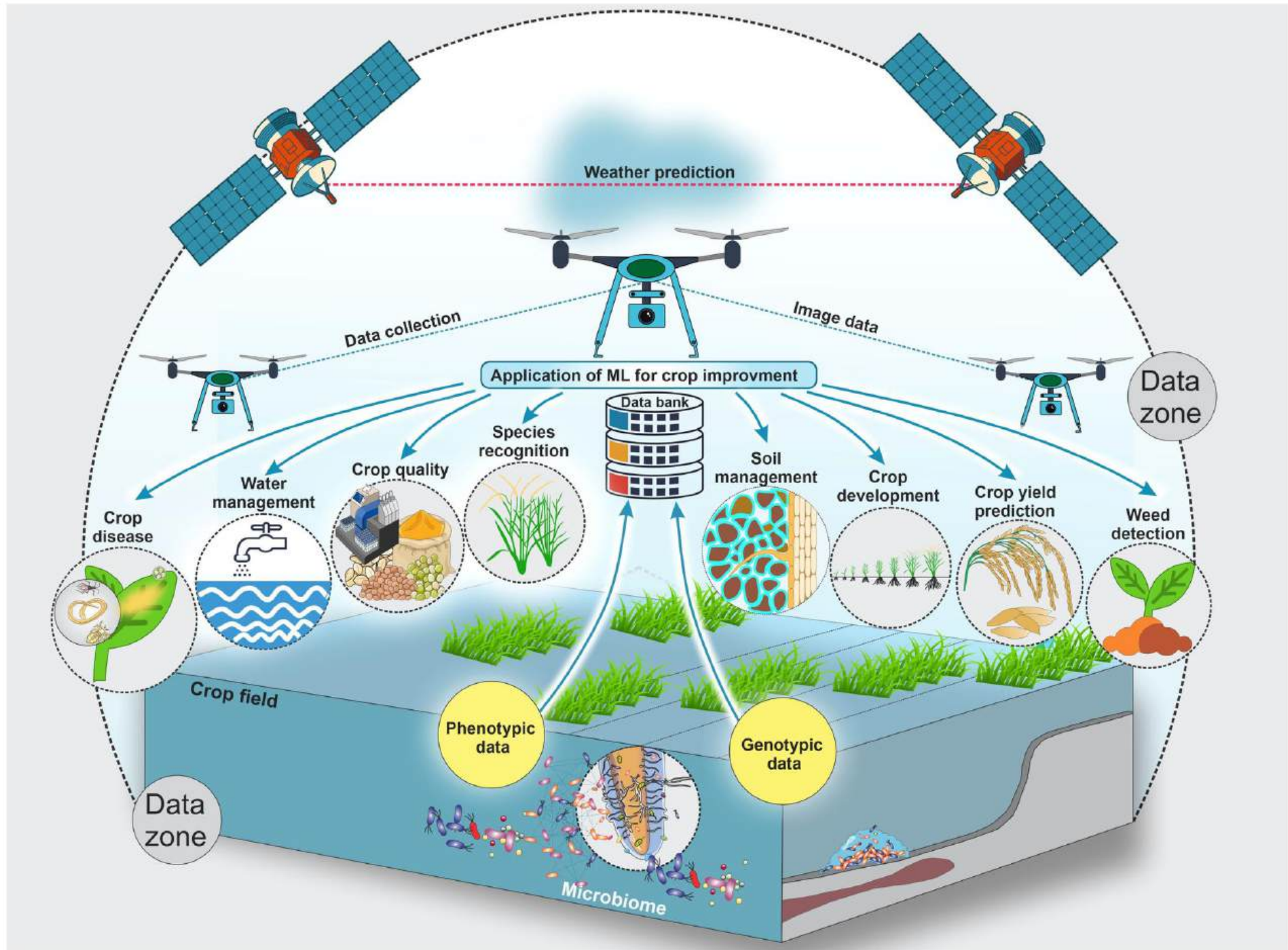


A **GLCM feature extraction module** is a component within an image processing or machine learning system that uses the **Gray-Level Co-occurrence Matrix (GLCM)** method to extract quantitative data about an image's texture. These extracted features, known as texture features, are numerical representations that can be used for tasks like image classification or pattern recognition. 3

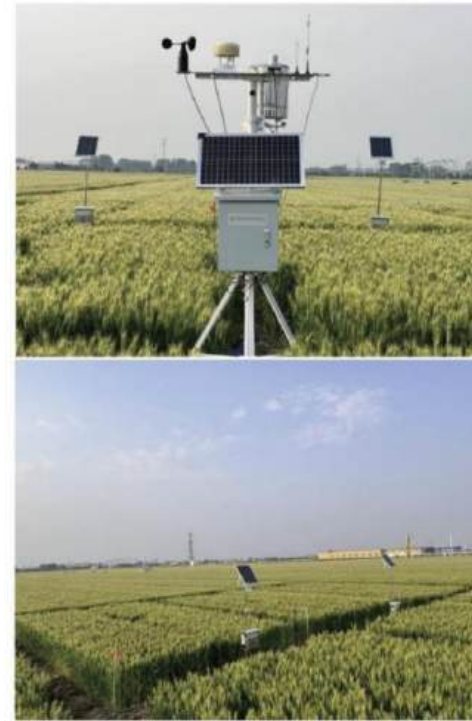
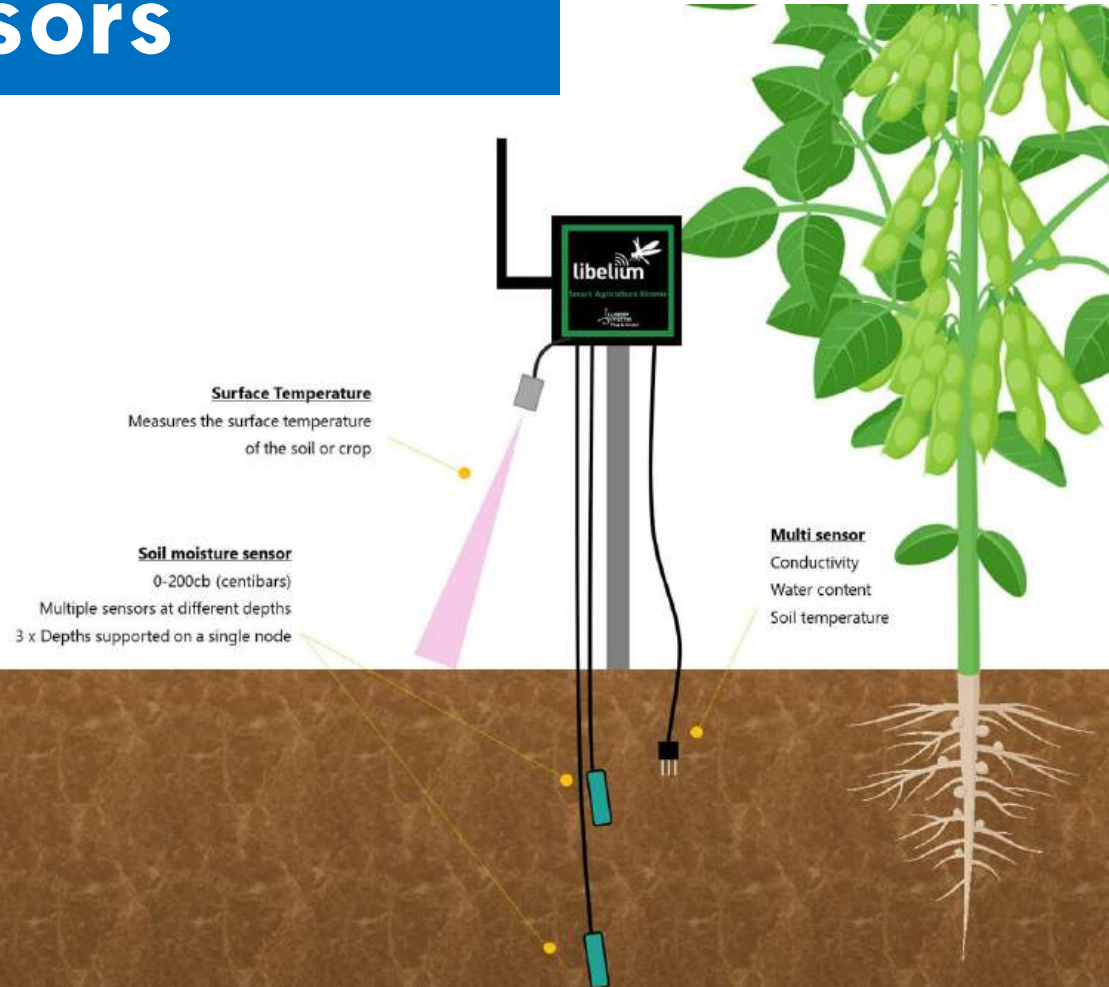
Random Forest (RFC), **K-Nearest Neighbors (KNN)**, and **Support Vector Machines (SVM)** are all supervised machine learning classification algorithms, but they work differently. RFC uses an ensemble of decision trees, KNN classifies based on the majority class of the 'k' nearest neighbors, and SVM finds an optimal hyperplane to separate classes. 4

The **HSV** color model represents colors using **hue**, **saturation**, and **value** (also called brightness), making it more intuitive for humans than the RGB model. 1

A **PRBS** is a specific type of binary sequence (a series of 1s and 0s) that, despite being generated by a deterministic algorithm (typically a linear-feedback shift register, or LFSR), exhibits statistical properties similar to a truly random sequence. 2



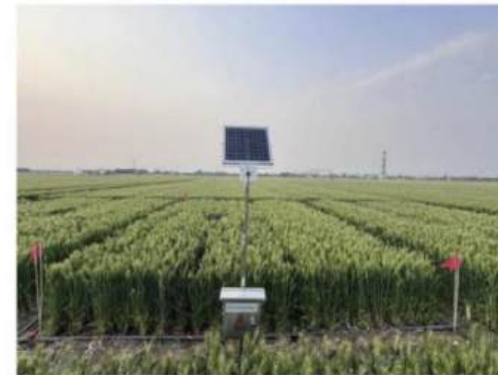
Examples of Sensors



(a)



(b)



(c)

2. Computer Vision

This technology enables machines to "see" and interpret visual information from the world, such as images and videos.

Applications in Food Systems:

- **Livestock Monitoring:** Cameras in barns can monitor animal behavior, weight, and health (e.g., detecting lameness or signs of illness), allowing for early intervention.
- **Weed and Pest Detection:** Drones or tractors with computer vision can identify specific weeds or pest damage in a field, enabling targeted pesticide application instead of blanket spraying.
- **Automated Processing:** In slaughterhouses and food processing plants, computer vision guides robotic arms to make precise cuts, improving efficiency and safety.

3. Natural Language Processing (NLP)

NLP allows machines to understand, interpret, and generate human language.

Applications in Food Systems:

- **Supply Chain Management:** NLP can analyze [weather reports](#), [news articles](#), and [social media](#) to predict disruptions (e.g., storms, political unrest) that could impact the transportation of food.
- **Consumer Sentiment Analysis:** Food companies use **NLP** to [scan online reviews and social media posts](#) to understand consumer preferences, track reactions to new products, and identify emerging food trends.
- **Smart Assistants for Farmers:** Voice-activated AI systems can provide farmers with hands-free access to information about [weather](#), [market prices](#), or [best practices](#).

4. Robotics and Automation

This involves physically intelligent machines that can perform tasks in the real world, often guided by ML and Computer Vision.

Applications in Food Systems:

- **Autonomous Farming:** **Self-driving tractors** and **harvesters** can operate 24/7, performing tasks like planting, weeding, and harvesting with extreme precision.
- **Picking and Packing:** **Robotic arms equipped with sensors** can gently pick delicate fruits like strawberries or tomatoes and efficiently pack them into boxes, addressing labor shortages.
- **Warehouse Logistics:** **Autonomous mobile robots** in food distribution centers can transport goods, manage inventory, and fulfill orders much faster than manual systems.



5. Predictive Analytics

This component uses historical data, statistical algorithms, and ML techniques to identify the likelihood of future outcomes.

Applications in Food Systems:

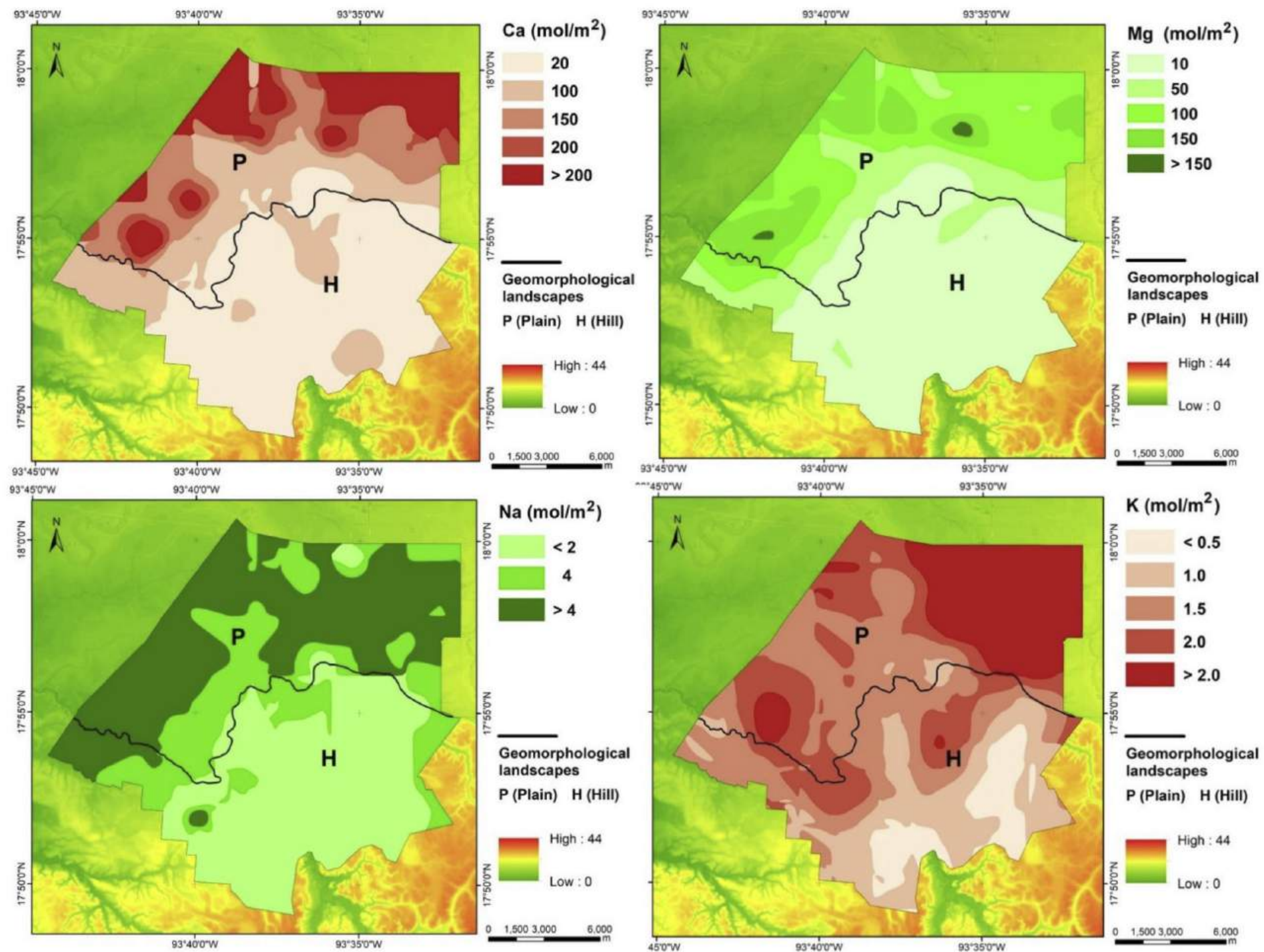
- **Supply and Demand Forecasting:** Retailers and producers use **predictive analytics to optimize inventory levels, reducing food waste** by ensuring supply more closely matches consumer demand.
- **Spoilage Prediction:** By analyzing data from IoT sensors that monitor **temperature and humidity** during transportation and storage, **AI can predict** the remaining **shelf-life of perishable goods**.
- **Disease Outbreak Prediction:** Analyzing data from various sources can help predict the **outbreak and spread** of crop diseases or livestock illnesses, enabling preventative measures.

Practical Application In Soil Science

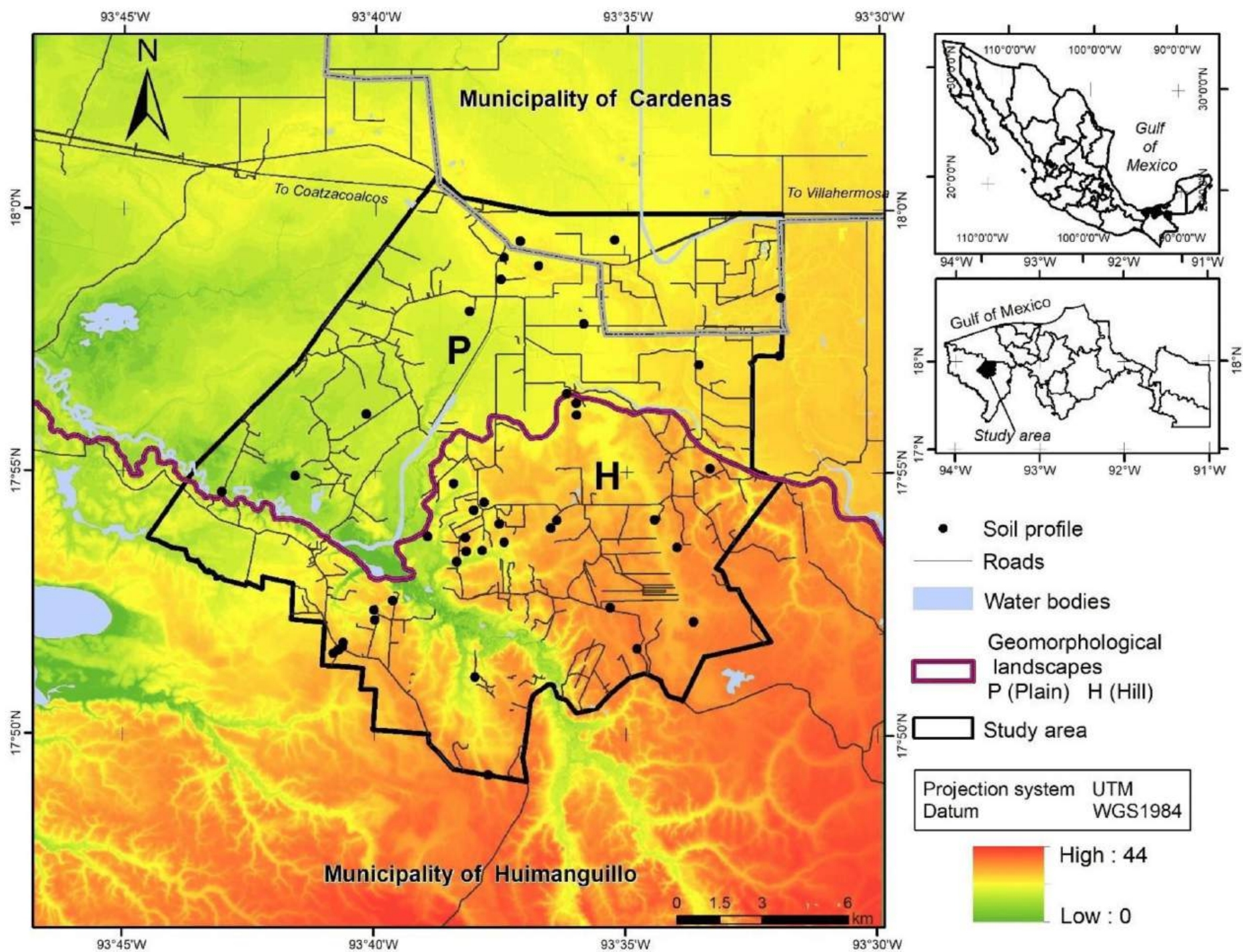
Level of analysis	Digital Tools	Key Purpose	Implementing Actors	End-Users
(100s - 100,000s km ²)	<p>Cloud GIS & Modeling Platforms:</p> <ul style="list-style-type: none"> ○ Google Earth Engine, ○ SWAT Model, ○ InVEST Model, <p>Satellite Imagery:</p> <ul style="list-style-type: none"> ○ MODIS, ○ Landsat, ○ Sentinel Hub 	<ul style="list-style-type: none"> ● Large-scale hydrology, sediment & nutrient loading analysis, ● Climate change impact assessment, ● Ecosystem service valuation, policy simulation. 	<p>Government Agencies</p> <ul style="list-style-type: none"> ○ EPA, ○ USDA, ○ Water Boards. <ul style="list-style-type: none"> ● NGOs & Research Institutions ● Large Consulting Firms 	<ul style="list-style-type: none"> ● Policymakers & Regulators <p>The Public (via public dashboards)</p> <ul style="list-style-type: none"> ● Downstream Water Users (municipalities, industries)

Level of analysis	Digital Tools	Key Purpose	Implementing Actors	End-Users
(1,000 - 10,000's km ²)	<ul style="list-style-type: none"> • Desktop GIS: QGIS, ArcGIS Pro • Conservation Planning Tools: <ul style="list-style-type: none"> ○ Marxan, ○ Zonation • Land Use Planning Platforms 	<ul style="list-style-type: none"> • Regional conservation planning, • Habitat connectivity, • Land use zoning, • Permitting, monitoring land cover change, siting of infrastructure. 	<ul style="list-style-type: none"> • Regional Planners & Government (County/City) • Conservation NGOs (The Nature Conservancy, etc.) • Forestry & Mining Companies 	<ul style="list-style-type: none"> • Land Developers • Farmers Cooperatives • Conservation Groups • General Public

Soil Properties Mapping

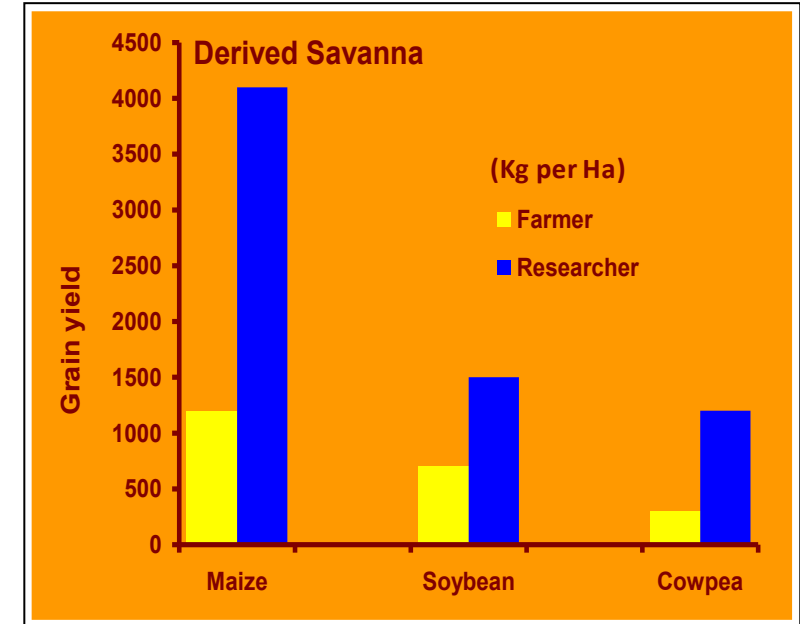
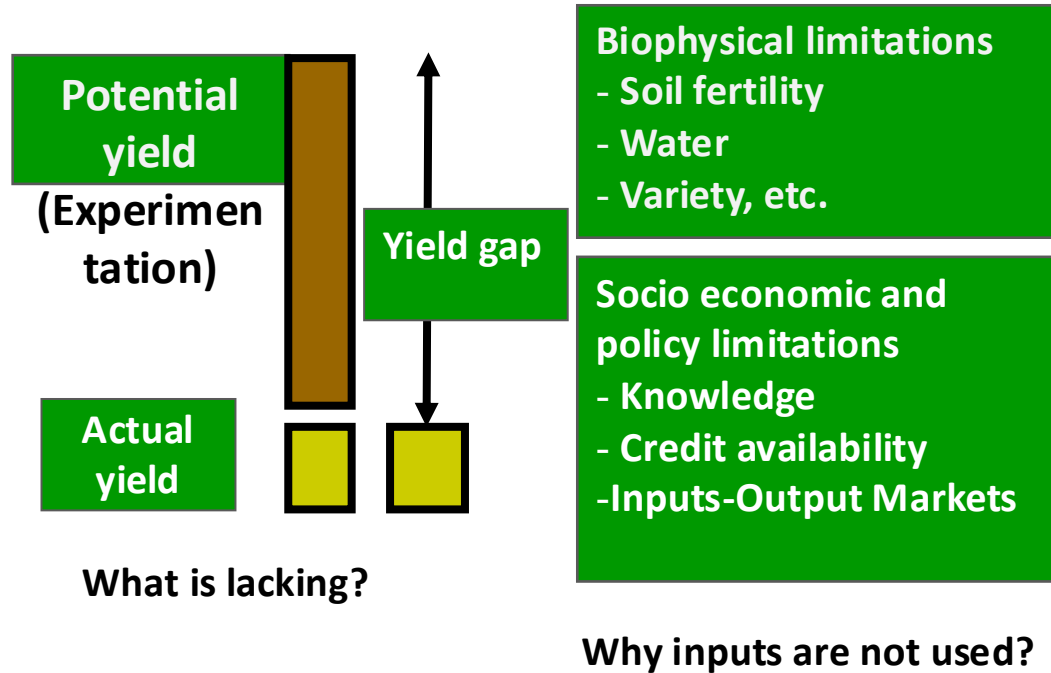


Soil mapping at farm level

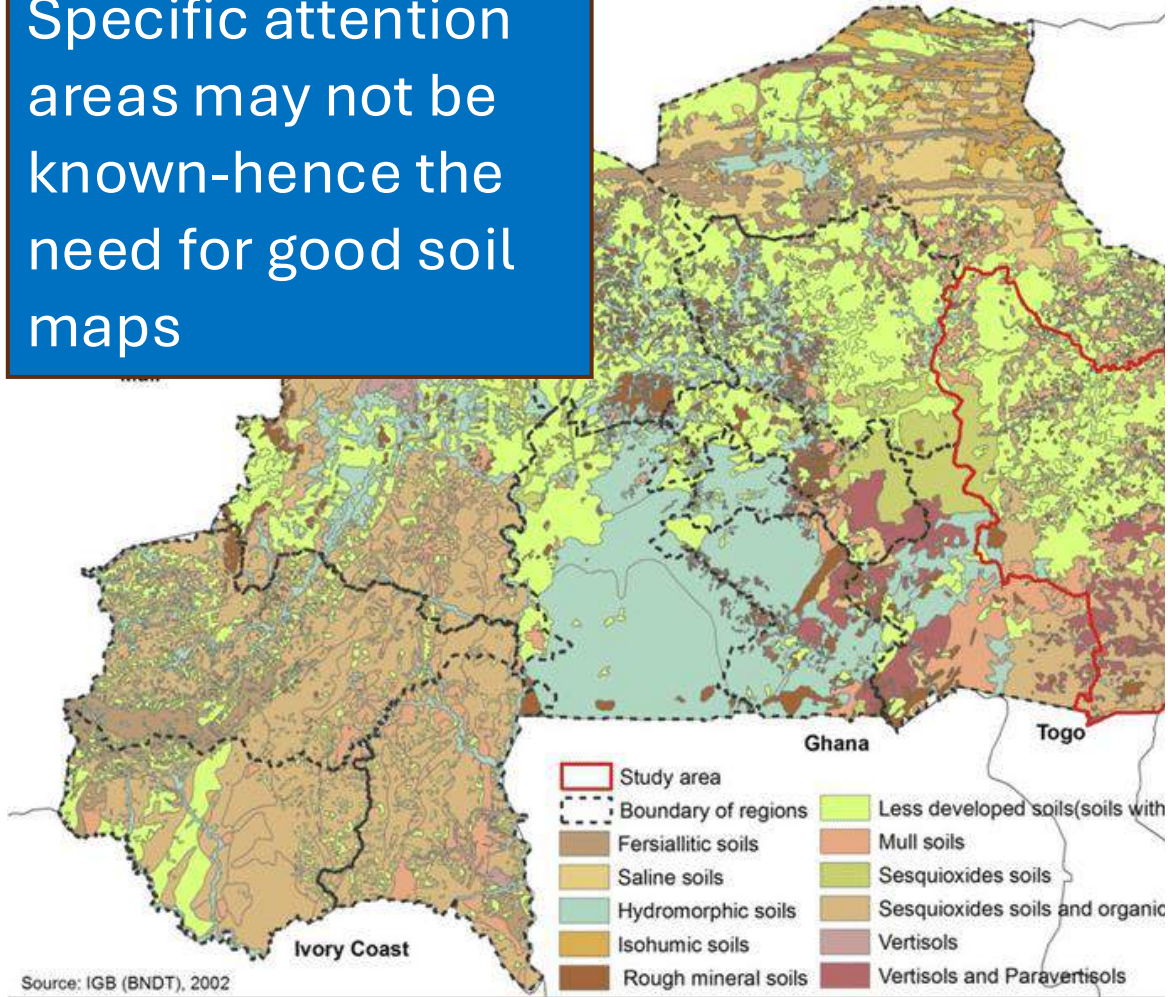


Level of analysis	Digital Tools	Key Purpose	Implementing Actors	End-Users
(0.1 – 100's ha)	<p>Precision Ag Platforms: (Often within FMIS)</p> <p>IoT & Sensor Networks:</p> <ul style="list-style-type: none"> ○ Soil moisture probes, ○ Weather stations ○ Temperature sensors ○ Radiation sensors ○ Evaporation sensors <p>Drones (UAVs) & Scouting Apps:</p> <ul style="list-style-type: none"> ○ DroneDeploy, ○ Sentera ○ VRT (Variable Rate Technology) 	<ul style="list-style-type: none"> ● Hyper-localized management, ● Soil health monitoring, ● Variable rate application of inputs, ● Yield mapping, ● Pest/disease scouting, ● Irrigation scheduling. 	<ul style="list-style-type: none"> ● Farmers & Agronomists ● Custom Applicators ● "AgTech" Service Providers ● Trained Youth with relevant degrees 	<ul style="list-style-type: none"> ● The Farmer (direct economic benefit from input savings & yield increase) ● Sustainability Verifiers

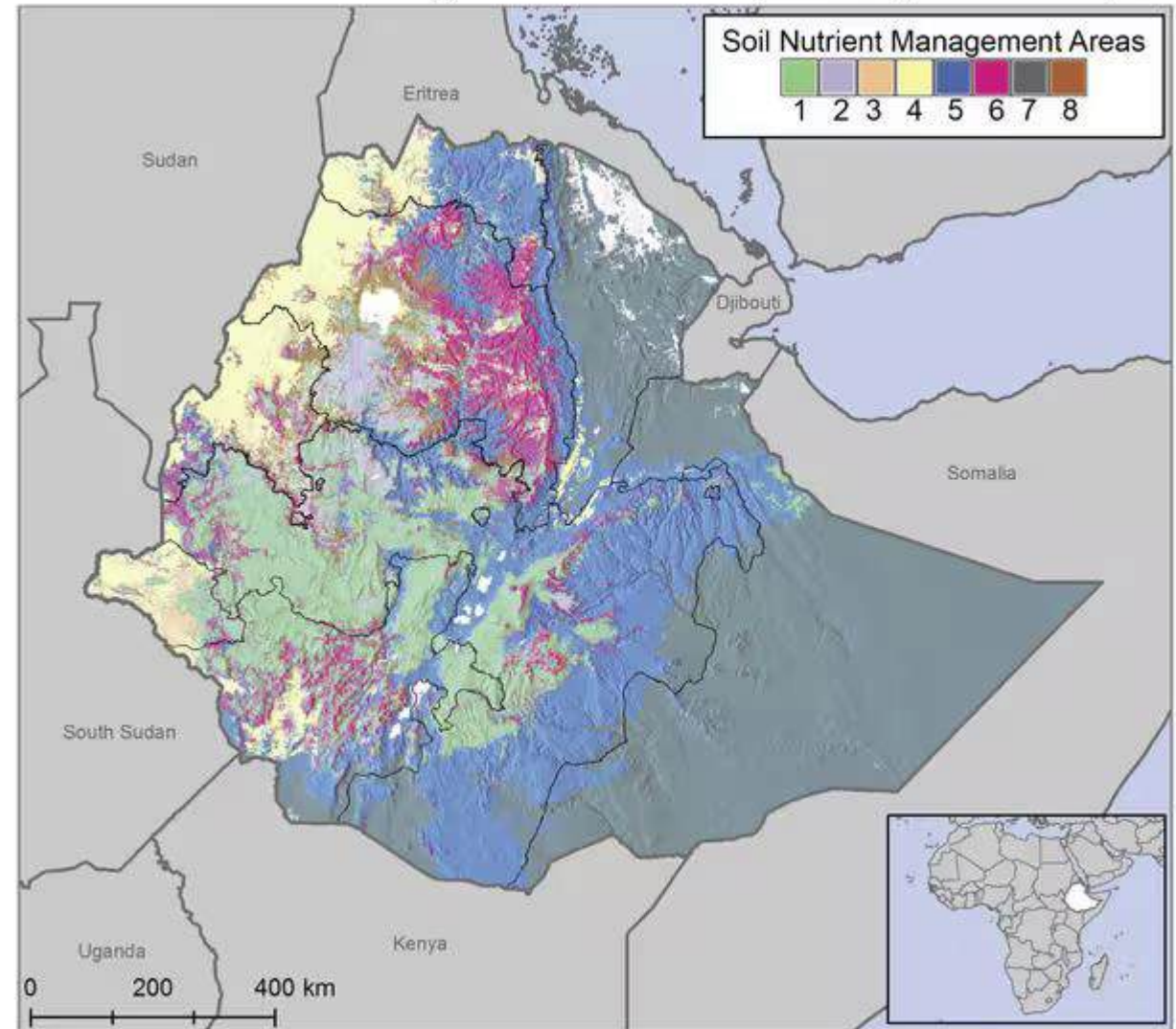
The yield gap analysis and the limitations that could cause it



Specific attention areas may not be known-hence the need for good soil maps



Soil Nutrient Management Areas (SNMA) of Ethiopia

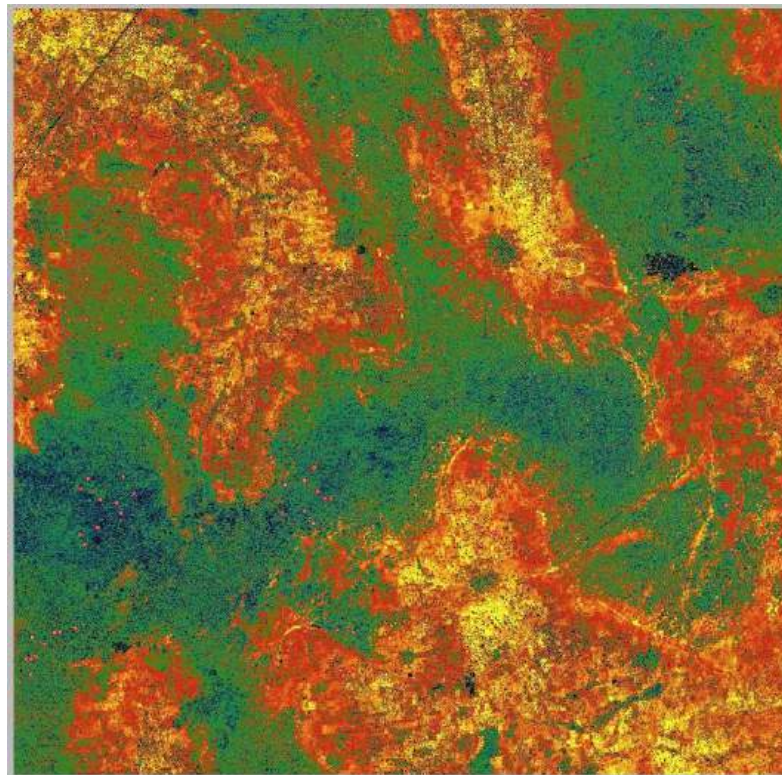


Map Credit: CIESIN and Agriculture and Food Security Center Columbia University, Sept. 2013

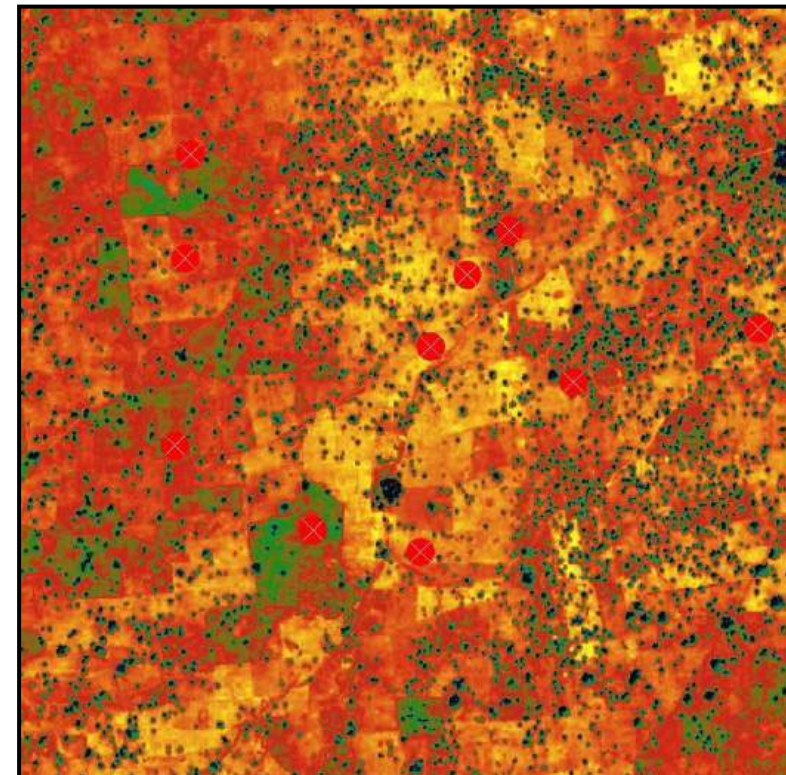
Example of a digital soil carbon condition map of Segou in Mali

Spectroscopy Soil
Properties Diagnosis

(AfSIS Project Data)



Low resolution-wider coverage



High resolution-less coverage

Africa Soil Information Service - Map Tool

map about how to methods data

Bounding Box:

Click-drag Mode:

- Pan Map
- Select Region

E-mail:

AfSIS Soil Profile Data (click points for info)

- Legacy Data Collection
- New Data Collection (Sentinel Sites)

Overlays

- National Boundaries
- Rivers
- Project Area

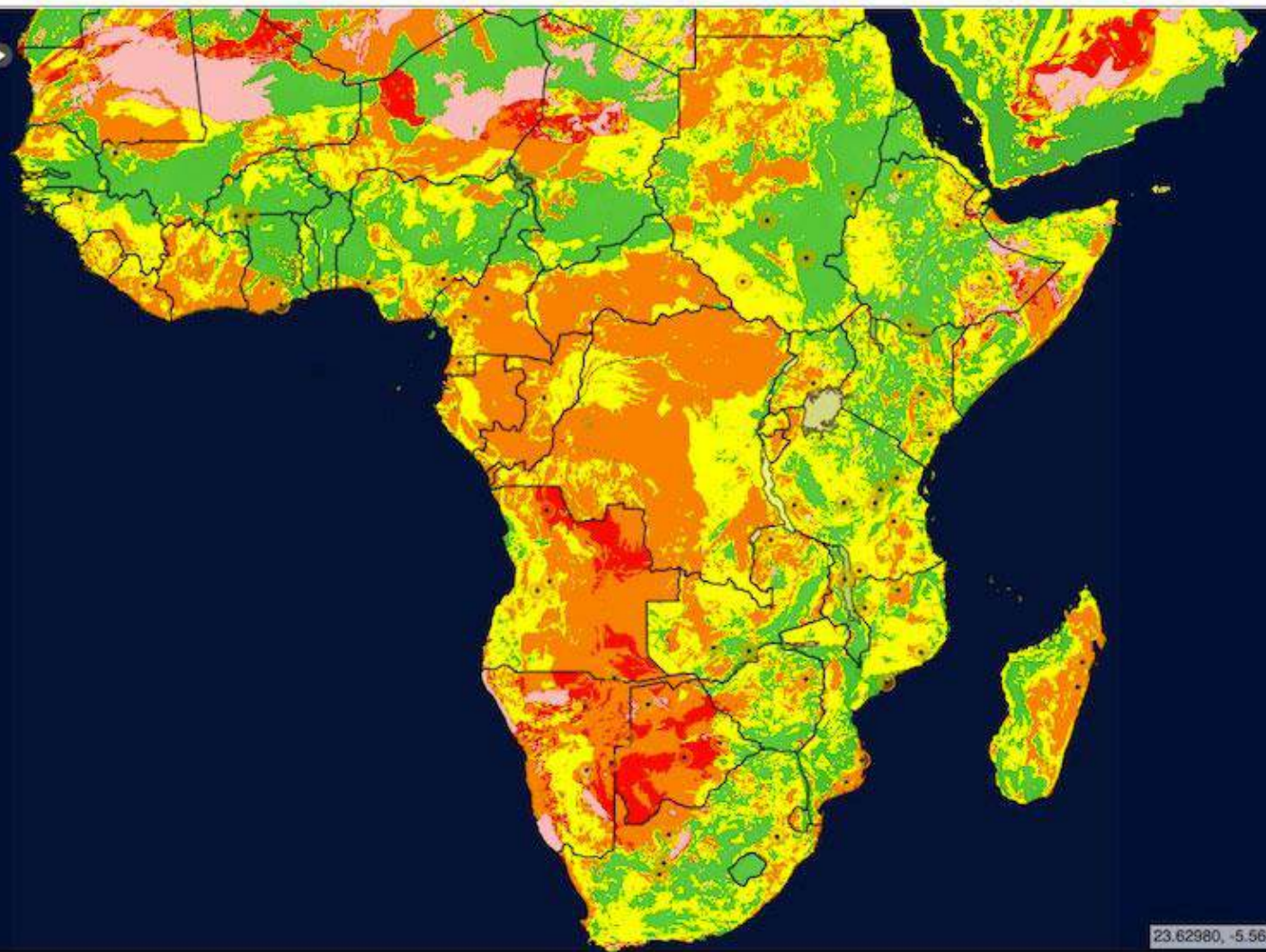
Grids for Digital Soil Mapping

- Maximum Temperature Warmest Month
- Annual Mean Temperature
- Anthropogenic Biomes v1
- AfSIS Land Cover-MERIS
- Tree Cover
- Global Carbon Biomass
- Watersheds

Existing Soil Maps

- Soil Rooting Conditions
- Soil Nutrient Availability
 - Ocean
 - No or slight constraints
 - Moderate constraints
 - Severe constraints
 - Very severe constraints
 - Mainly non-soil
 - Permafrost
 - Waterbodies

- Soil Salinity
- Soil Workability
- Soil Nutrient Retention Capability

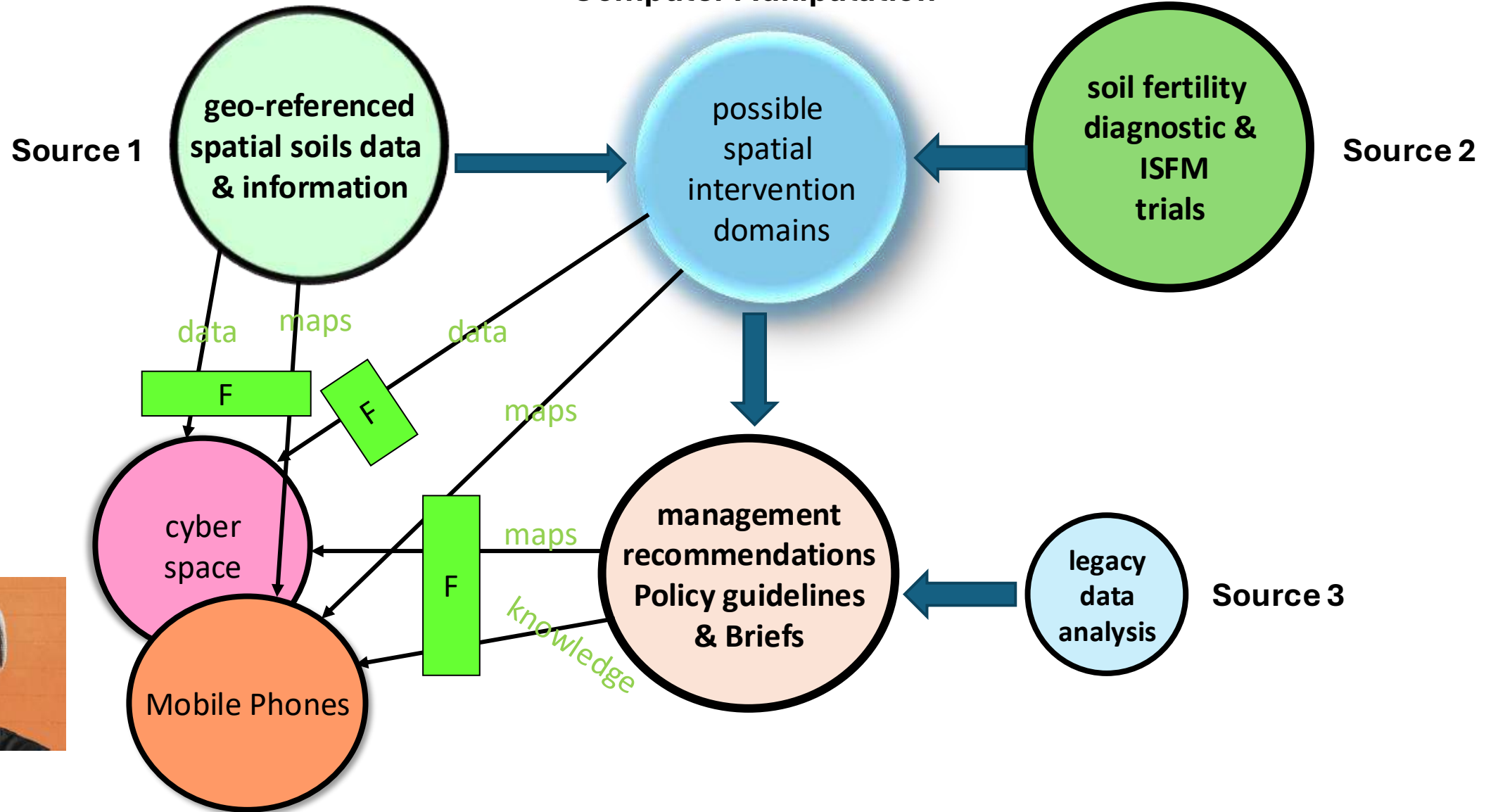


23.62980, -5.56845

Africa Soil Information Service

Data & Information Flows

Computer Manipulation



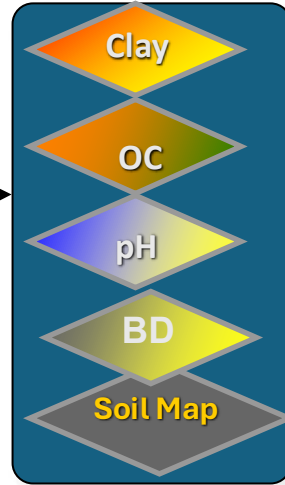
Example

1. Data Input



Spatial inference models

2. Soil properties



GIS-Model

Conversion & Interpretation

3. Soil functions



Decision analysis

4. Management Inputs



Decision analysis

5. Management recommendations



Training
Dissemination
Cyber-Infrastructure
Mobile Tools

6. End Users



Spectroscopy scanning analysis

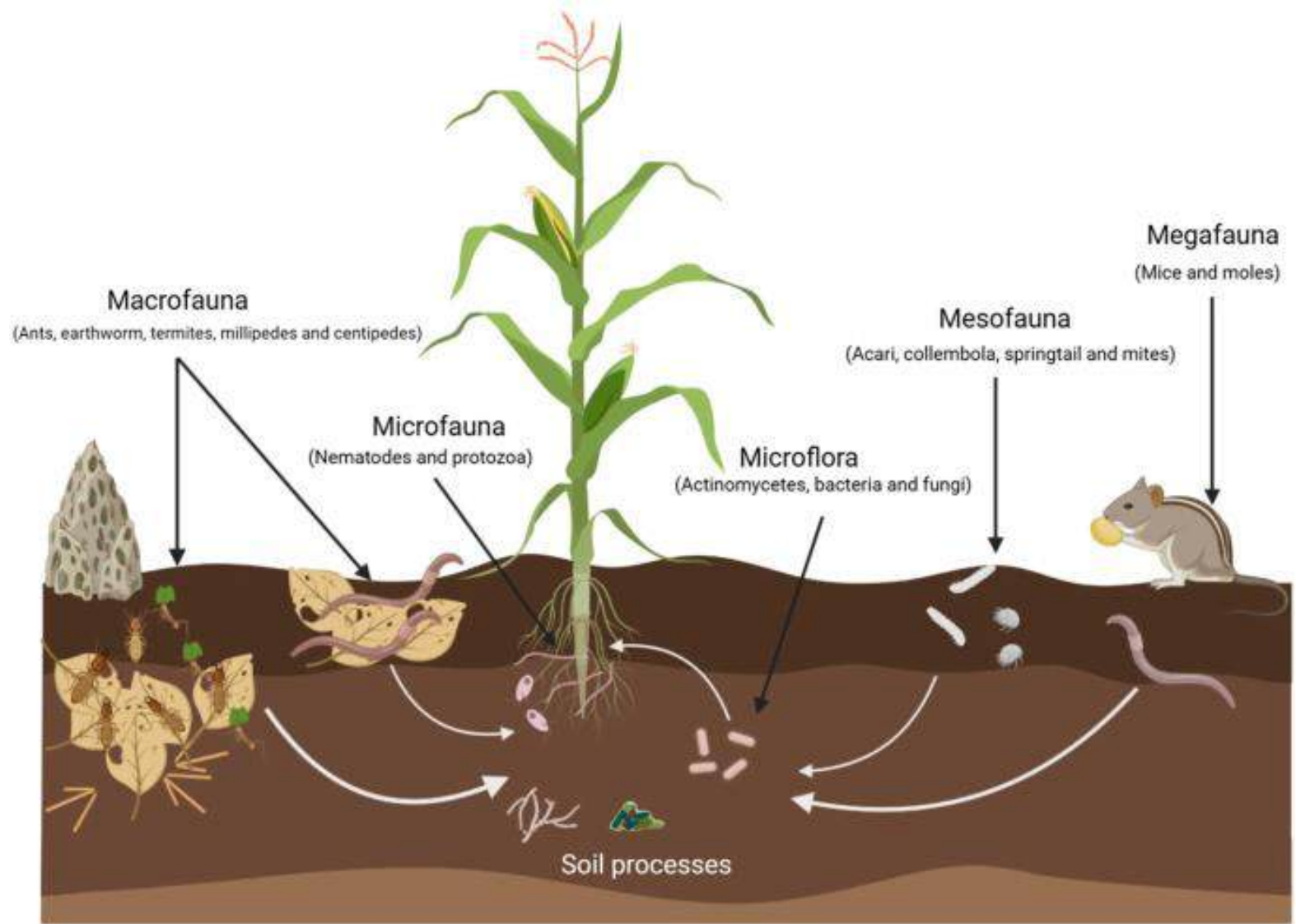
Sequential approach in soil fertility management-a digital approach (The AfSIS project)



Organic Fertilizers



Soil Biota & Life



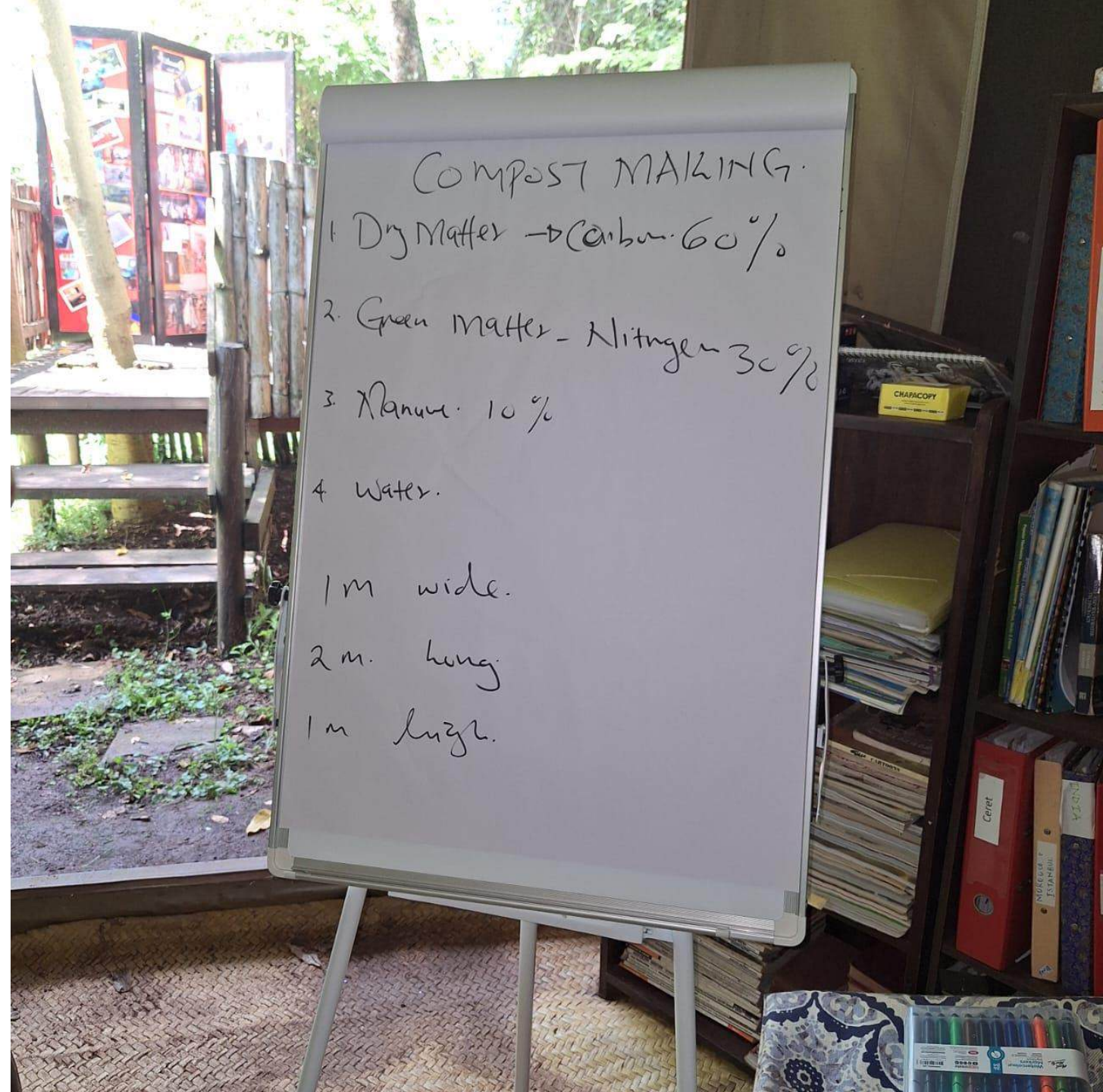
Soil Fertility Regeneration

Soil fertility regeneration is the process of restoring and enhancing the natural nutrients and organic matter within the soil. It involves practices like cover cropping, reduced tillage, and compost application to rebuild soil structure and biological activity.

The ultimate goal is to create a resilient, productive agricultural system that requires fewer synthetic inputs.

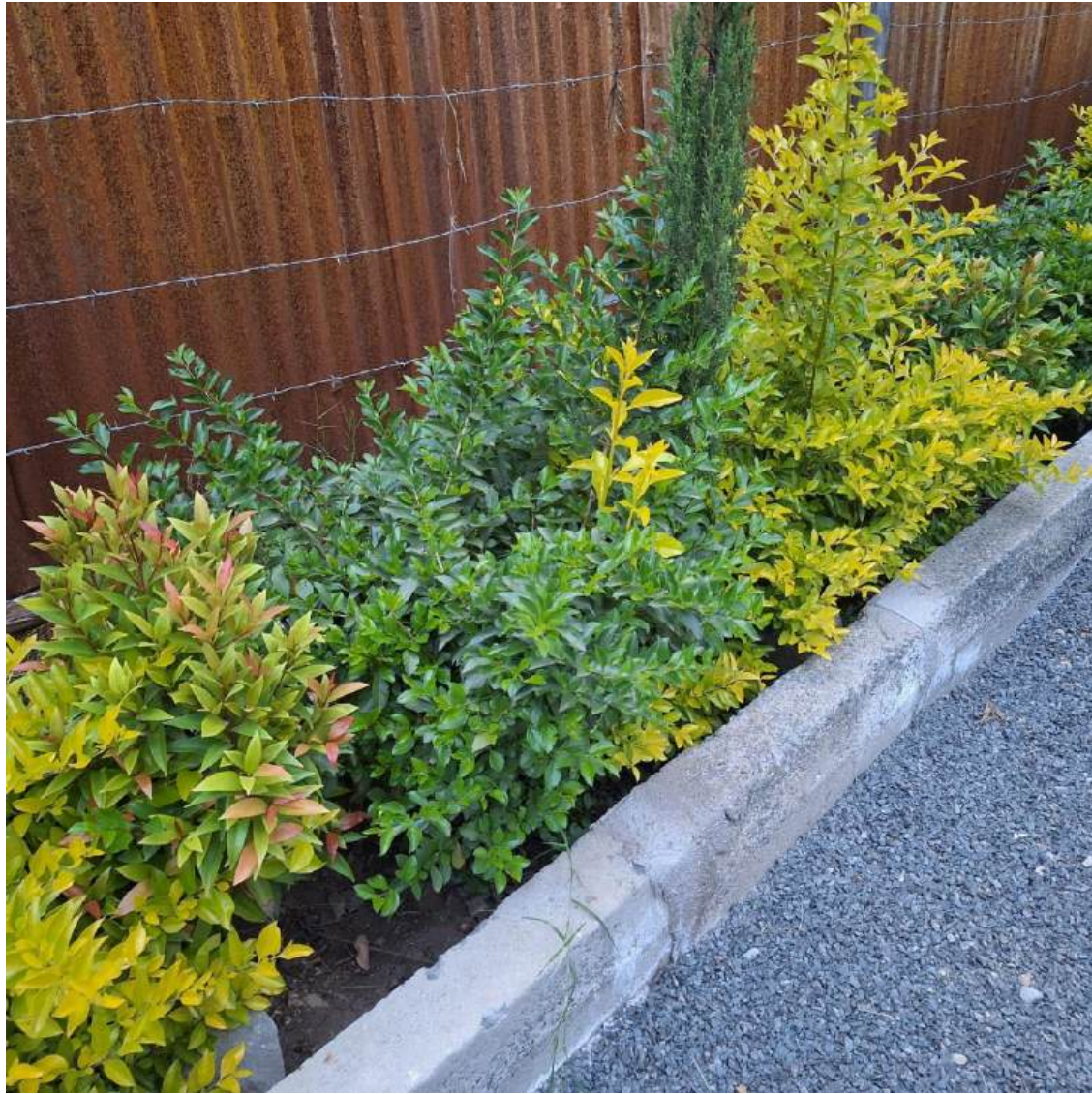


What is a good compost?



Video showing good compost manure





Solely Organic Plants

Challenges

Several challenges must be addressed to realize the full potential of digital tools.

- **Limited Technical Knowledge:** A skills gap exists among both extension agents and farmers in interpreting and using geospatial data and digital platforms.
- **Poor Coordination and Data Gaps:** Fragmented efforts between projects and institutions lead to data silos. Inconsistent data collection methods and a lack of centralized, interoperable data platforms hinder comprehensive analysis.
- **Accessibility by Farmers:** The "last-mile" delivery remains a hurdle. Issues of digital literacy, cost of devices, and lack of connectivity in rural areas limit direct farmer access to these tools.
- **Budgetary Constraints:** Acquiring high-resolution data, maintaining IT infrastructure, and running training programs require sustained funding, which is often limited.

Conclusion and Recommendations

1. **Strengthen Ground-Truthing Networks:** Invest in robust field data collection to validate and calibrate satellite-derived models, ensuring accuracy and reliability.
2. **Foster a Collaborative Ecosystem:** Actively build partnerships with identified projects and others to share data, resources, and best practices, creating a unified digital agriculture front.
3. **Prioritize Capacity Building:** Develop targeted training programs for all stakeholders, from technicians to farmers, focusing on practical use and interpretation of digital tools and AI.
4. **Develop Farmer-Centric Solutions:** Design simple, low-cost, and accessible applications (e.g., USSD or SMS-based services, simple mobile apps) that deliver clear, actionable advice directly to farmers.
5. **Advocate for Sustainable Investment:** Work with government and development partners to secure long-term funding for digital infrastructure and capacity-building initiatives.

Thank YOU

Q&A

