AI AgriBrain – Coffee Farming

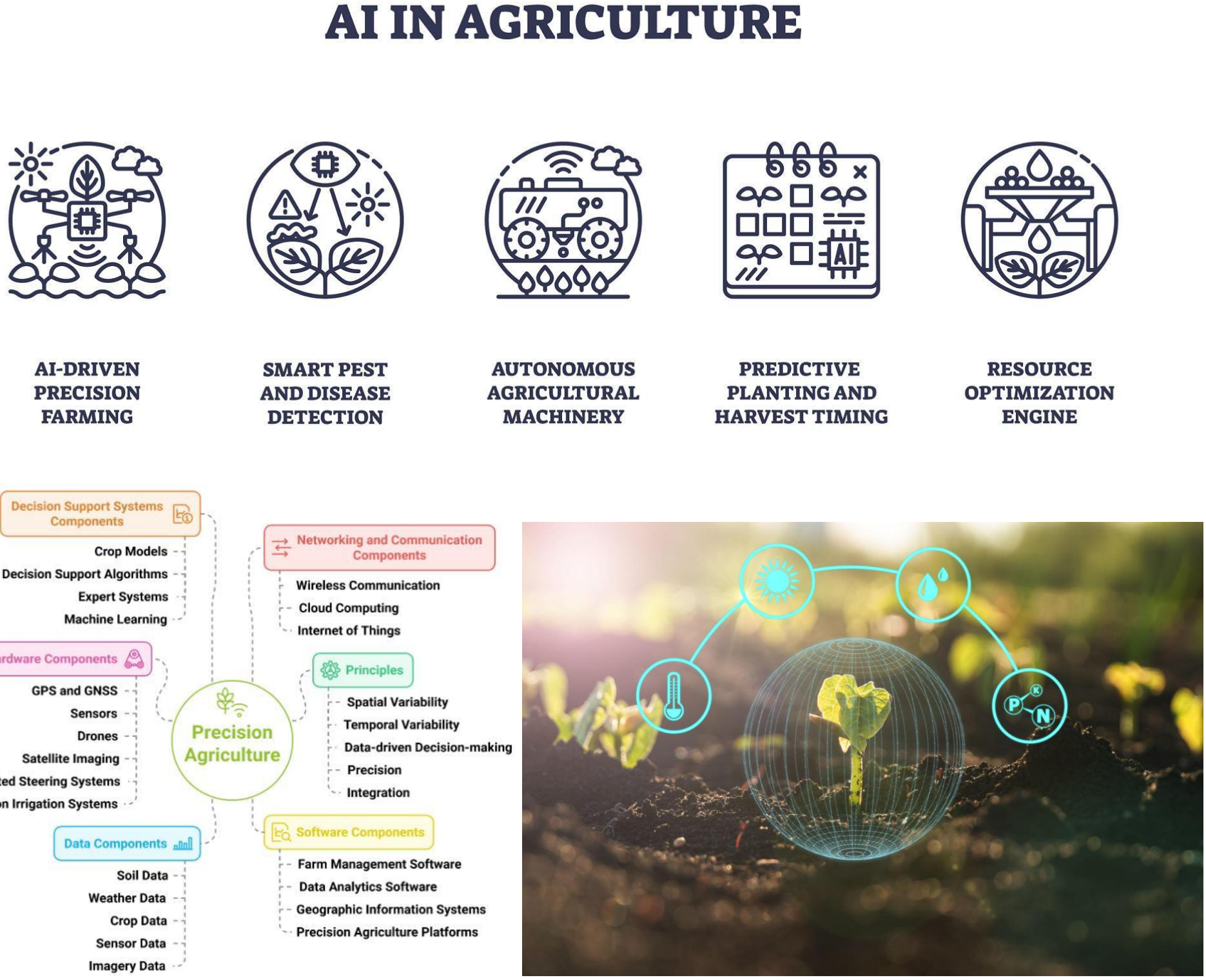
Abstract

The increasing demand for sustainable and high-yield coffee production necessitates the integration of intelligent technologies into traditional farming practices. This research proposes the design and development of AI AgriBrain, an AI-driven, IoT-enabled precision agriculture system tailored for coffee plantations. The system aims to optimize irrigation, nutrient management, and plant health monitoring through real-time data acquisition and intelligent decision-making.

AI AgriBrain is structured as a multi-layered architecture comprising field data acquisition, edge communication, cloud connectivity, AI-based analytics, control and actuation, and user monitoring modules. The system collects critical soil parameters such as moisture, temperature, pH, electrical conductivity (EC), and nutrient composition (NPK), along with environmental and visual data. These data streams are integrated with periodic laboratory soil analysis and processed using AI models to generate actionable insights.

The proposed system enables automated irrigation and fertigation, early detection of plant stress and disease, and optimized resource utilization. A mobile-based interface provides real-time monitoring and control, enhancing farmer interaction and decision support. The modular design ensures scalability and adaptability across varying farm sizes and conditions.

The implementation of AI AgriBrain is expected to improve coffee yield and quality, reduce water and fertilizer consumption, and promote sustainable agricultural practices. This research contributes to the advancement of intelligent farming systems by integrating multimodal sensing, AI analytics, and cyber-physical automation into a unified framework for precision coffee farming.



AI AgriBrain – Smart Coffee Farming

Transforming Coffee Cultivation through Intelligence, Precision, and Sustainability

AI AgriBrain is an advanced, AI-driven smart farming platform designed specifically for coffee plantations. It integrates real-time field sensing, intelligent analytics, and automated control systems to enable farmers to make precise, data-driven decisions that enhance productivity, optimize resource usage, and improve crop quality.

How AI AgriBrain Works

AI AgriBrain operates through a seamless integration of field sensors, connectivity systems, and artificial intelligence:

- **Real-Time Field Monitoring:**
  Sensors deployed across the farm continuously capture critical parameters such as soil moisture, temperature, pH, nutrient levels (NPK), and environmental conditions.
- **Smart Data Connectivity:**
  Data is transmitted securely to the AgriBrain control system through robust communication networks, ensuring reliable access from anywhere.
- **AI-Powered Intelligence:**
  The system analyses sensor data, integrates laboratory soil reports, and processes plant health images to generate precise recommendations for irrigation, fertilization, and crop management.
- **Automated Action & Control:**
  AI AgriBrain can directly control irrigation systems, nutrient delivery, and field devices, ensuring the right action is taken at the right time.
- **Mobile Monitoring & Alerts:**
  Farmers can monitor their entire farm through a user-friendly mobile application, receive alerts, and take manual control when needed.

Key Capabilities

✓ Precision irrigation based on real soil conditions
✓ Intelligent nutrient management (NPK, pH, EC-based decisions)
✓ Early detection of plant stress and disease through AI
✓ Automated control of pumps, valves, and fertigation systems
✓ Real-time monitoring via mobile and web dashboards
✓ Integration with solar-powered, energy-efficient systems

Benefits to Coffee Farmers

- **Higher Yield & Better Quality:**
  Optimized water and nutrient delivery improves coffee bean development.
- **Reduced Costs:**
  Minimizes wastage of water, fertilizers, and energy.
- **Sustainable Farming:**
  Promotes efficient use of natural resources and soil health management.
- **Data-Driven Decisions:**
  Replaces guesswork with scientifically validated insights.
- **Scalable Solution:**
  Suitable for small farms to large plantations.

From Soil to Smart Decisions

AI AgriBrain bridges the gap between traditional farming and modern intelligence by combining:

Soil Data + Climate Data + Plant Health + AI Analytics = Smart Coffee Farming

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Our Vision

To empower coffee farmers with intelligent tools that enhance productivity, ensure sustainability, and build a future of precision agriculture driven by AI.

Ownership of Work

All content, concepts, system architecture, designs, diagrams, methodologies, software components, and documentation related to the **AI AgriBrain – Coffee Farming System** are the original intellectual property of the author(s) and are protected under applicable copyright laws.

This includes, but is not limited to:

- System architecture and modular design
- AgriBrain AI decision framework
- Sensor integration models and deployment strategies
- Data processing and analytics workflows
- Graphical diagrams, visualizations, and GGIS frameworks

- Software logic, algorithms, and control systems
- Documentation, reports, and research outputs

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Third-Party Components

This project may incorporate third-party hardware, platforms, or technologies (e.g., sensors, microcontrollers, IoT platforms). All such components remain the property of their respective owners and are used in compliance with their licensing terms.

Disclaimer

The AI AgriBrain system is a research and development initiative. While every effort has been made to ensure accuracy and reliability, the authors do not guarantee performance under all environmental or operational conditions. Users are advised to validate the system before large-scale deployment.

Contact for Permissions

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Contents

Coffee Specifications

Age: 3 years

Height: 3.5 Feet

Root Dimensions

(3-YEAR COFFEE PLANT)Depth (Vertical Root Zone)

- **30 cm to 60 cm (1 to 2 feet)**
- **Majority of active roots:**
  Top 20–40 cm (this is the critical zone)

Spread (Horizontal Root Zone)

- **60 cm to 120 cm radius** (2 to 4 feet from stem)
- Roots spread **wider than canopy in many cases**

Root Structure Breakdown

1. Tap Root (Primary)

- Goes downward
- ~40–60 cm at this stage

- Helps anchoring

2. Lateral Roots (Most Important)

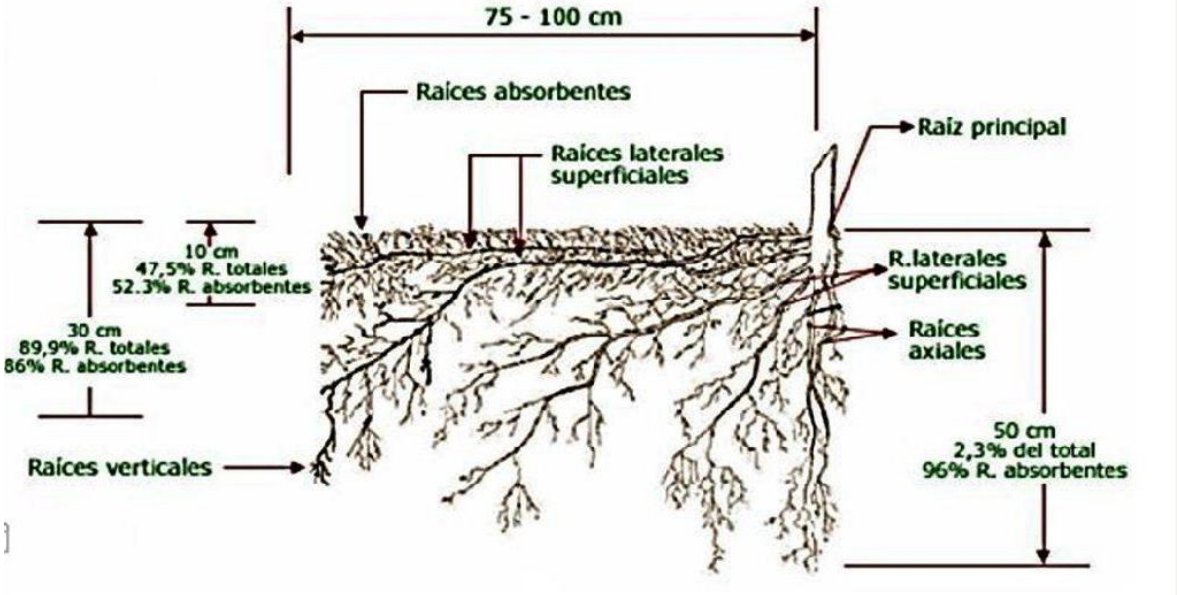
- Spread sideways
- Carry water & nutrient absorption
- Located in:
  top 15–30 cm soil layer

3. Feeder Roots (Critical Zone)

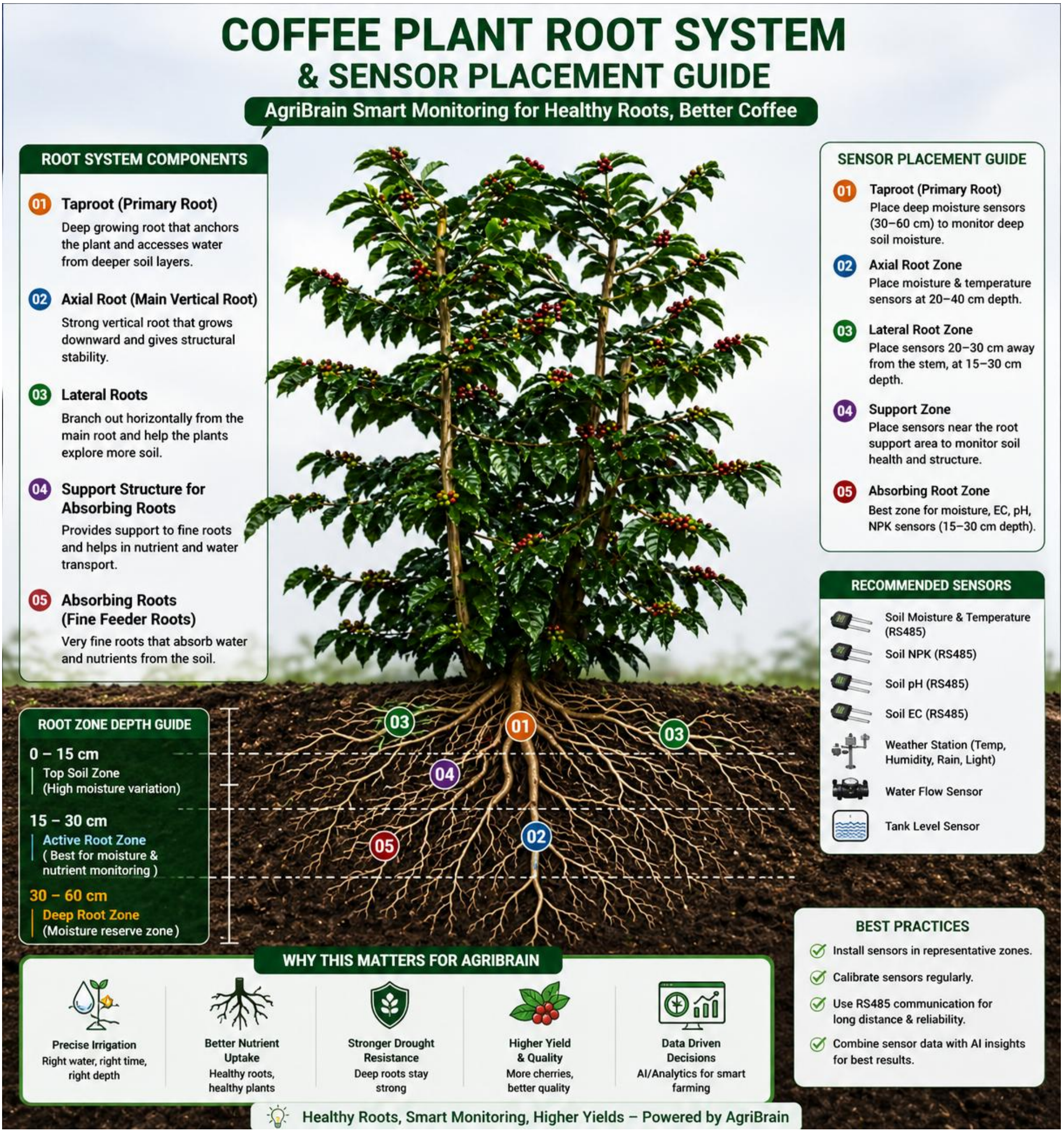
- Very fine roots
- Found near surface
- Responsible for:
  ✓ water uptake
  ✓ nutrient absorption

Coffee Plant – Root Structure Formation

Age: 3 years



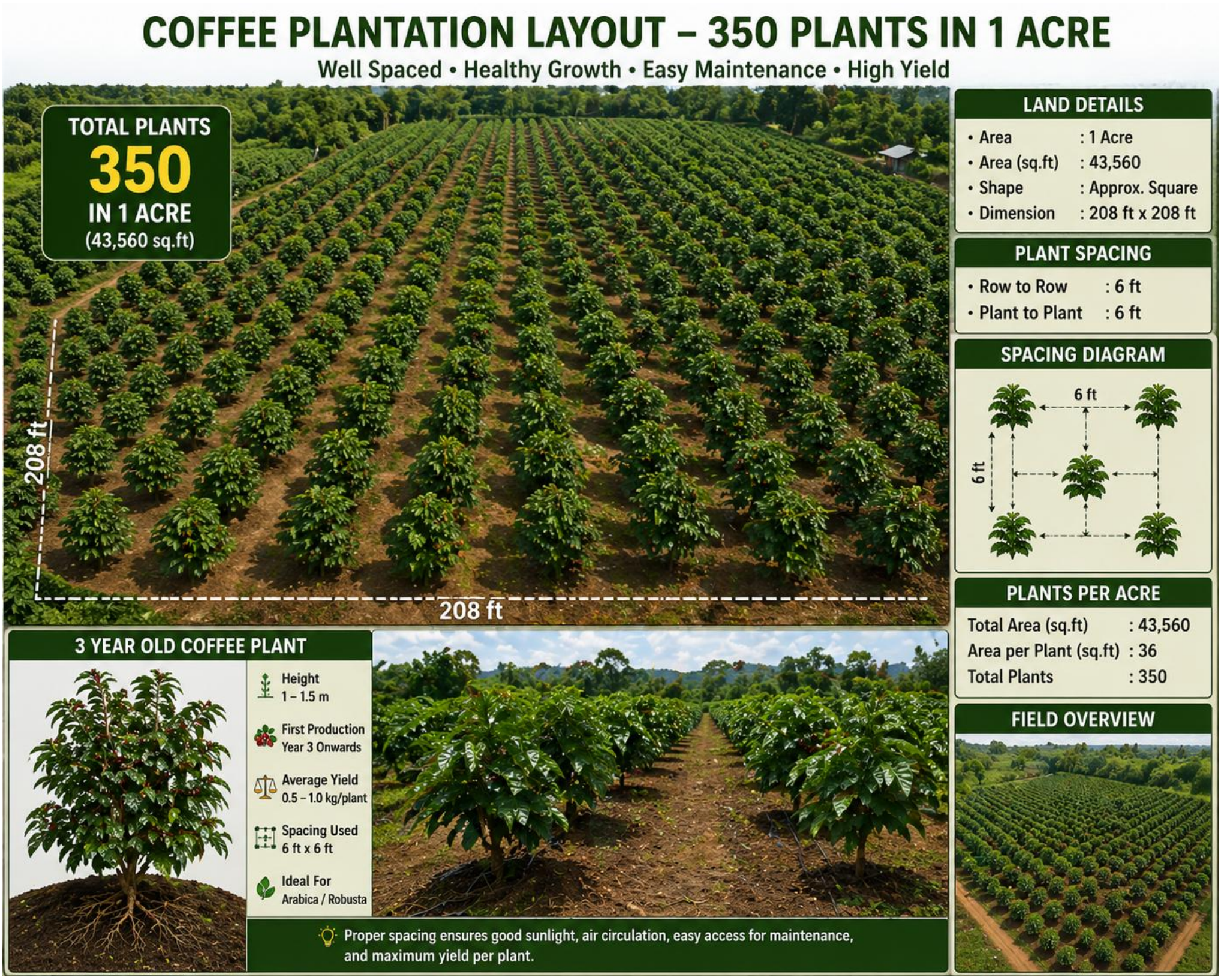
Coffee Plant Root System & Sensor Placement Guide



Pilot Project Details

Land Size: 1 Acre

Number of Coffee Plants : 345 to 350 plants ~ 350 plants for the pilot project



Coffee Plant – Growth and Yield Nutrient Composition

Nutrient composition is a core AgriBrain parameter , the following nutrients and soil conditions to be measured

Nutrient Group : Coffee Plant	
Nutrient Group	**Parameters**
Primary macronutrients	Nitrogen (N), Phosphorus (P), Potassium (K)
Secondary nutrients	Calcium (Ca), Magnesium (Mg), Sulphur (S)
Micronutrients	Iron, Zinc, Boron, Copper, Manganese
Soil condition indicators	pH, EC, organic matter

First Level – Practical Automation

For automation, the most practical first level is:

NPK + pH + EC

Nitrogen (N) : Supports leaf growth and plant vigour.

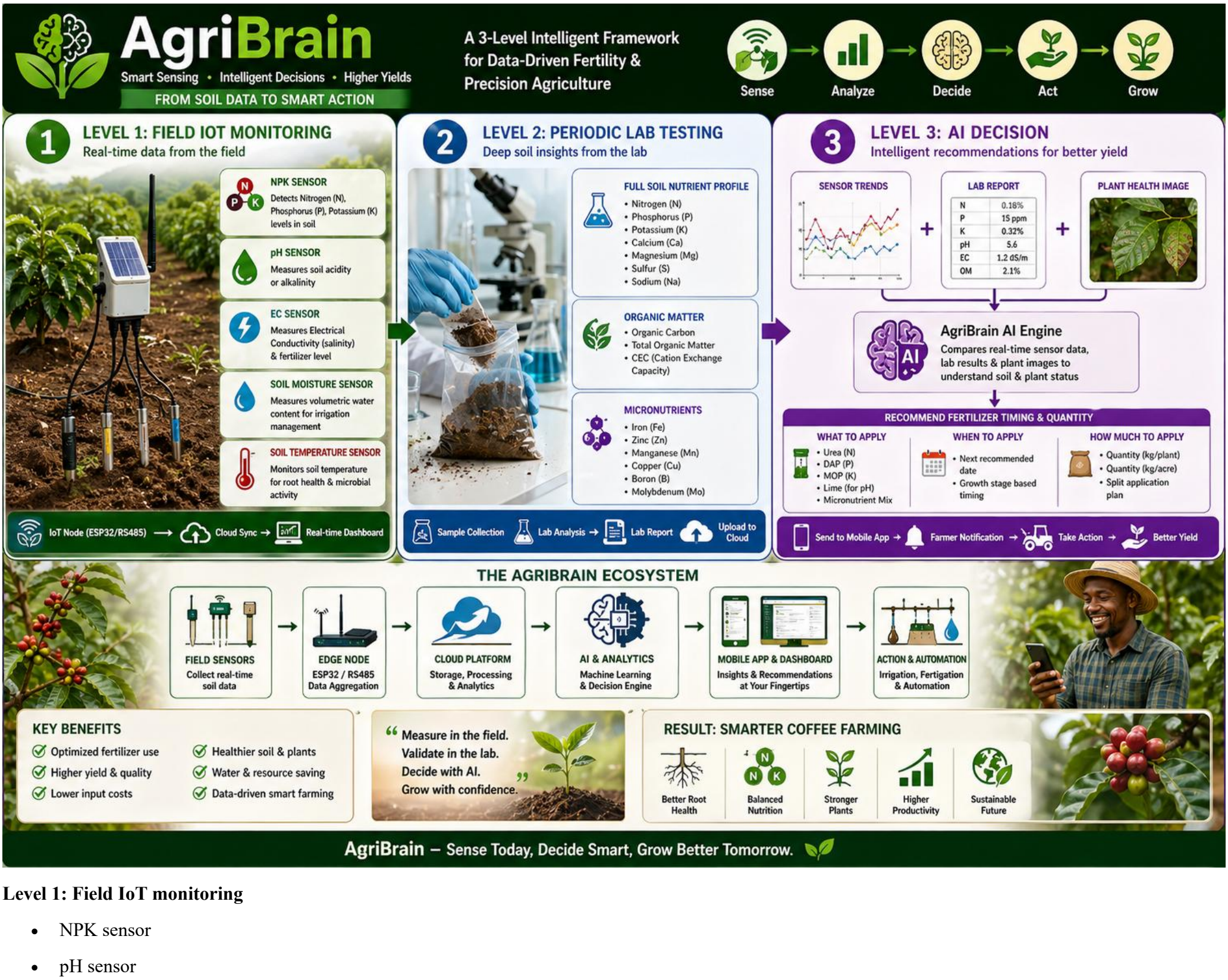
Phosphorus (P): Supports root development and flowering.

Potassium (K) : Important for fruit development, stress tolerance, and coffee cherry quality.

pH : Controls nutrient availability. Even if nutrients exist in soil, wrong pH can block uptake.

EC : Shows dissolved salts/fertilizer strength. High EC may indicate over-fertilization or salt stress.

Proposed Best AgriBrain approach



Level 1: Field IoT monitoring

- NPK sensor
- pH sensor
- EC sensor
- soil moisture
- soil temperature

Level 2: Periodic lab testing

- full soil nutrient profile
- organic matter
- micronutrients

Level 3: AI decision

- compare sensor trend + lab report + plant health image
- recommend fertilizer timing and quantity

Recommended Nutrient Sensor Placement for 1 Acre Coffee Fram

Concept: Use nutrient sensors by zone, not per plant.

Suggested Recommendation :

- 5–7 nutrient sensing points per acre
- soil moisture sensors: 25–30
- pH/EC/NPK sensors: 5–7 points, rotated or fixed by zones

The Task for AgriBrain

The AgriBrain has to Monitor whether the soil is healthy enough to produce Quality Coffee.

Proposed Sensor Stack- Project AgriBrain

Level 1 Sensors

Core Sensor Stack - AgriBrain	
Sensor	**Purpose**
Soil Moisture	Irrigation control
Soil Temperature	Root activity
Soil pH	Nutrient availability
Soil EC	Fertilizer / salinity
Advanced Sensor Stack	
NPK Sensor	Nutrient Level
Soil Oxygen	Root Respiration

Level -2 Sensors: Weather Climate Sensors

Weather Sensors : AI AgriBrain	
Sensor	**Purpose**
Temperature (DHT11/DHT22)	Environment
Humidity	Disease + irrigation
Rain Sensor / Rain Gauge	Natural watering
Light Sensor (LDR / Lux)	Sunlight exposure
Advanced Climate Sensors	
Solar Radiation Sensor	Crop energy intake
Wind Speed (Anemometer)	Spray / stress
Wind Direction	Microclimate modelling

Level -3 : Plant Health (AI + Sensors)

AgriBrain - Plant Health Sensors	
Sensor	**Purpose**
Camera (Pi Camera / USB)	AI disease detection
Advanced Plant Health Sensors	
NDVI Sensor	Plant vigour
Leaf Wetness Sensor	Disease prediction
Growth sensor (height tracking)	Yield estimation

Level-4 Water System Sensors

AgriBrain- Water System Sensors	
Sensor	**Purpose**
Water Flow Sensor	Usage tracking
Tank Level Sensor	Water availability
Pump Current Sensor	Pump health
Pressure Sensor (optional)	Pipe health

Level-5 : Energy / Power Sensors

AgriBrain: Energy Sensors	
Sensor	**Purpose**
Battery Voltage Sensor	Power health
Current Sensor (INA219)	Energy usage
Solar Output Sensor	Solar efficiency

Level-6 Rover – Field AgriRobot (Mobility Sensors)

Agri Robot - Mobility Sensors	
Sensor	**Purpose**
Ultrasonic Sensor	Obstacle detection
IR Sensor	Close detection
Wheel Encoder	Distance tracking
IMU (MPU6050)	Orientation

AgriBrain- Phase Wise Sensor Implementation

AgriBrain- Phase Wise Sensor Implementation		
Phase	**Sensors**	**Task/ Role**
Phase-1	Soil moisture	**Irrigation & Energy**
	DHT11 (temp + humidity)	
	Pump control	
	Battery Voltage Sensor	
	Current Sensor (INA219)	
	Solar Output Sensor	
Phase-2	Soil pH	**Filed ready**
	Light sensor	
	Water level	
	Flow sensor	
Phase-3	NPK sensor	**AgriBrain**
	Camera (AI)	
	Weather station	
	Energy monitoring	
Phase-4	Camera (Pi Camera / USB)	**Plant Health**
	NDVI Sensor	
	Leaf Wetness Sensor	
	Growth sensor (height tracking)	
Phase-5	**Sensor**	**Core Climate**
	Temperature (DHT11/DHT22)	
	Humidity	
	Rain Sensor / Rain Gauge	
	Light Sensor (LDR / Lux)	

	Solar Radiation Sensor	
	Wind Speed (Anemometer)	
	Wind Direction	
Phase - 6	**Field robot**	**Farm Management & Surveillance**
	Ultrasonic Sensor	
	IR Sensor	
	Wheel Encoder	
	IMU (MPU6050)	

Sensor Requirement for 1 Acre Coffee Farm

Phase-1 Sensor Placement Requirement	
Category	**Quantity**
Soil moisture	25–30
pH / EC	5–7
Climate station	1–2
Water sensors	2–3
Camera nodes	2–4

MASTER IDEA

DATA → INSIGHT → DECISION → ACTION

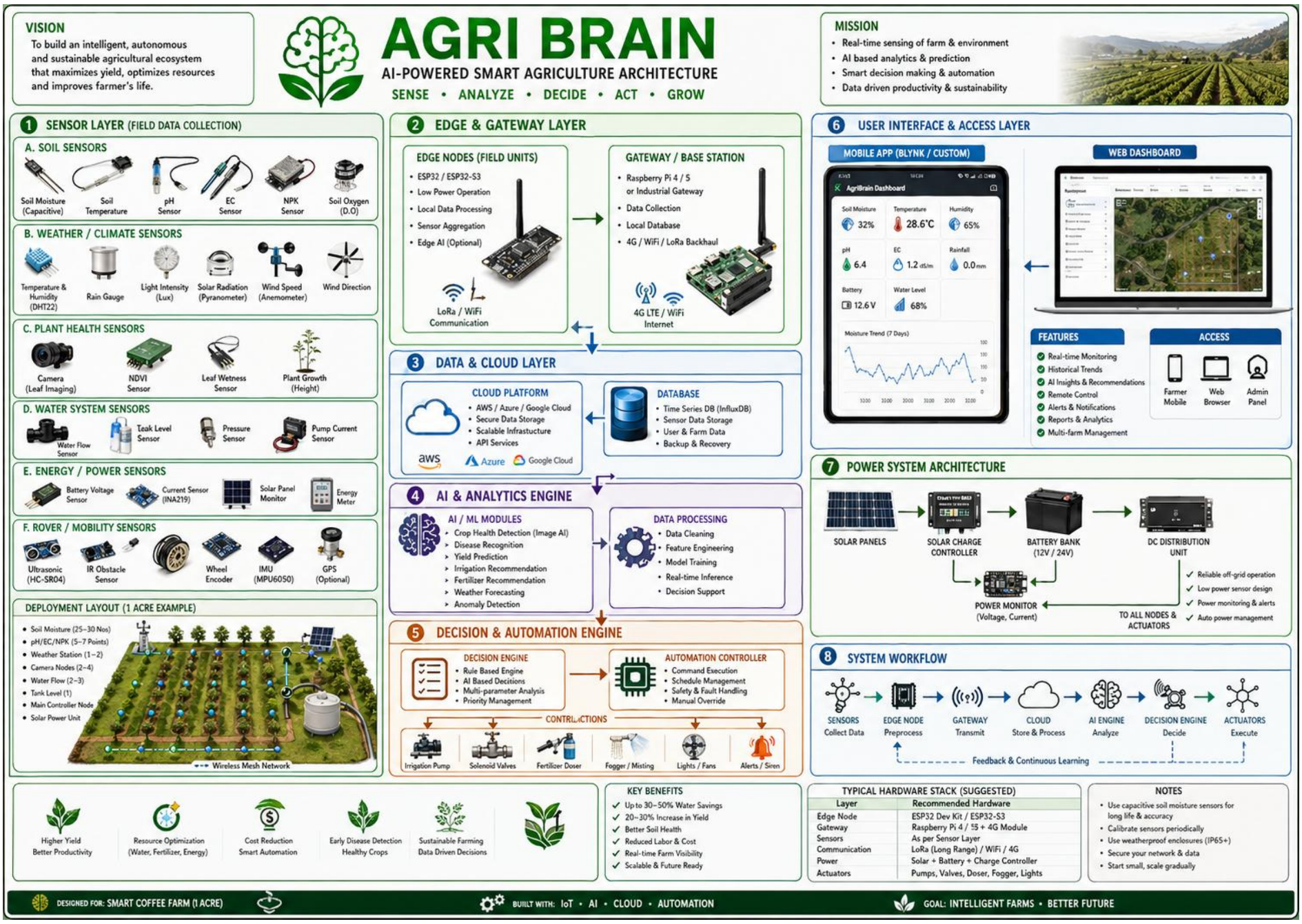
Sensors = Data

AI = Insight

Controller = Decision

Pump/Rover = Action

AgriBrain Architecture



Choice of Sensors for Implementation

Sensor choice from

https://roboticsdna.in

The RoboticsDNA page lists it as a **JXCT Soil Temperature and Humidity Sensor, 5V RS485**, with **IP68 protection**, **0–100% humidity range**, **-40 to 80°C temperature range**, and price around **₹3,863 inc. GST**. It also says it is meant for water-saving irrigation, meteorological monitoring, greenhouses, soil testing, and scientific experiments.

For the project, this is better than cheap DIY/resistive sensors because:

- **RS485** is excellent for long cable runs in a farm.
- **IP68** means it is waterproof/dustproof for field use.
- It gives more stable readings for automation.
- Multiple sensors can be connected in a network using RS485.
- It is suitable for solar-powered field nodes.

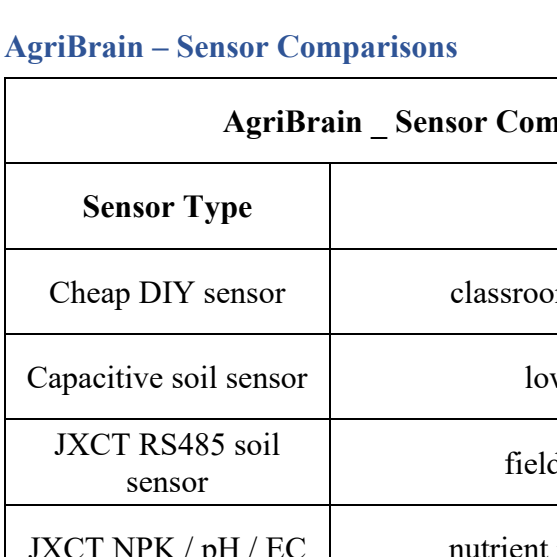
AgriBrain – Sensor Comparisons

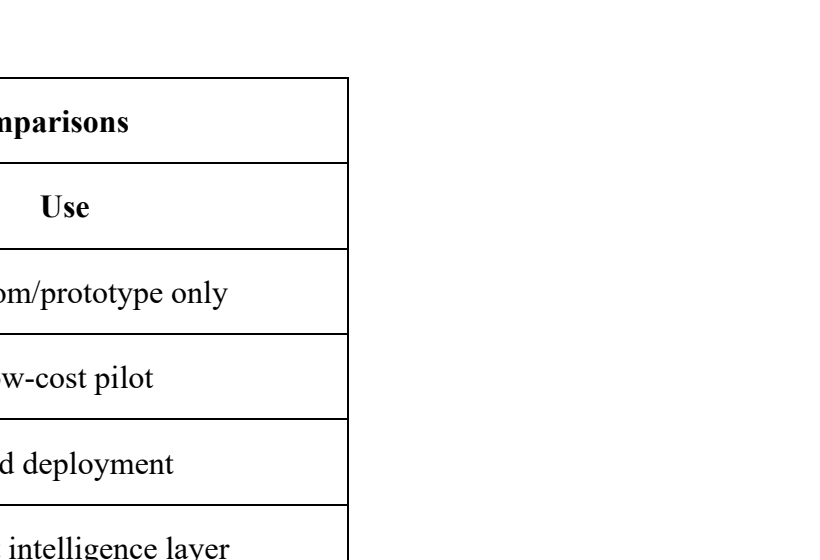
AgriBrain _ Sensor Comparisons	
Sensor Type	**Use**
Cheap DIY sensor	classroom/prototype only
Capacitive soil sensor	low-cost pilot
JXCT RS485 soil sensor	field deployment
JXCT NPK / pH / EC	nutrient intelligence layer

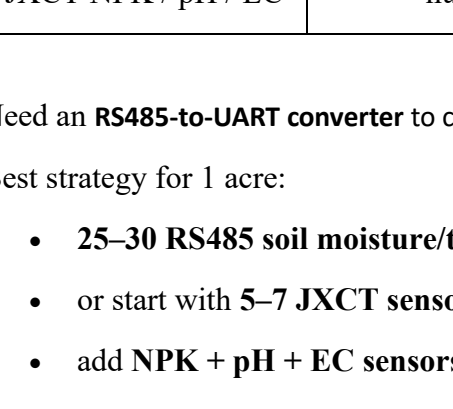
Need an **RS485-to-UART converter** to connect it to ESP32 or Raspberry Pi. RoboticsDNA also suggests a USB-to-RS485 converter for testing.

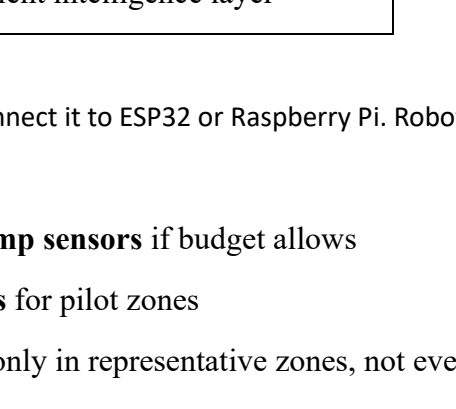
Best strategy for 1 acre:

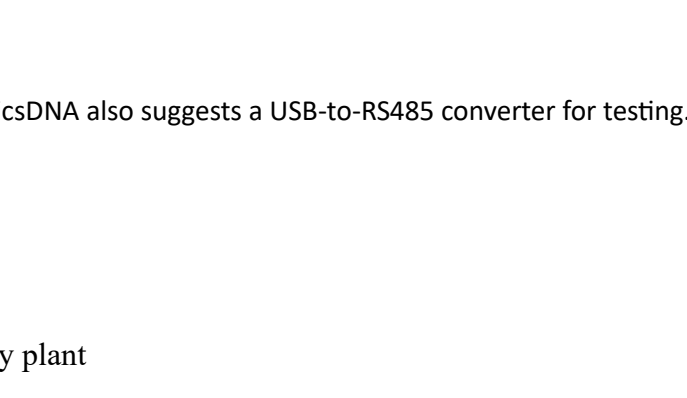
- **25–30 RS485 soil moisture/temp sensors** if budget allows
- or start with **5–7 JXCT sensors** for pilot zones
- add **NPK + pH + EC sensors** only in representative zones, not every plant











New Type Soil Humidity Sensor	Others
Capacitive soil humidity sensor	Resistive sensors
Longer service life	Short service life
Resist corrosion	Easily corroded

Resistive Soil Moisture Sensor (Fork Type with LM393 module)

Resistive Soil Sensors V/S – Capacitive Sensors – Comparison with Industry Sensors- JXCT RS485 Sensor

RESISTIVE Soil Senors	
Factor	**Rating**
Cost	★★★★★ (very cheap)
Accuracy	★★
Lifespan	✗ very low
Corrosion	✗ HIGH
Field use	✗ NOT recommended
Stability	✗ unstable

Capacitive Soil Sensor	
Factor	**Rating**
Cost	★★★
Accuracy	★★★★
Lifespan	★★★★
Corrosion	✓ low
Field use	✓ small farms
Stability	✓ good

JXCT RS485 Sensor (industrial)	
Factor	**Rating**
Cost	✗ expensive
Accuracy	★★★★★
Lifespan	★★★★★
Corrosion	✓ none
Field use	✓✓✓ BEST
Stability	✓✓✓ excellent

Proposed List of Sensors for AI AgriBrain

https://roboticsdna.in/product

JXCT Sensor Selection - AI AgriBrain	
Purpose	**Recommended sensor**
Irrigation decision	JXCT Soil Temperature & Humidity RS485 sensor
Nutrient monitoring	JXCT Soil NPK RS485 sensor
Soil acidity	JXCT Soil pH RS485 sensor
Fertilizer/salinity status	JXCT Soil EC RS485 sensor
All-in-one premium option	JXCT Soil 7-in-1 RS485 sensor
Water tank level	Float water level sensor
Water flow verification	Water flow sensor
Climate monitoring	DHT22 / temperature-humidity sensor
Light condition	Lux / light intensity sensor

Cost-effective Deployment plan for 1 acre / 350 coffee plants

Cost Effective JXCT Sensor Deployment Plan - 1 Acre	
Sensor	**Quantity**
Soil moisture/temp RS485	25–30
NPK RS485	5–7
pH RS485	5–7
EC RS485	5–7
Weather station/climate node	1–2
Tank level sensor	1
Water flow sensor	1–2

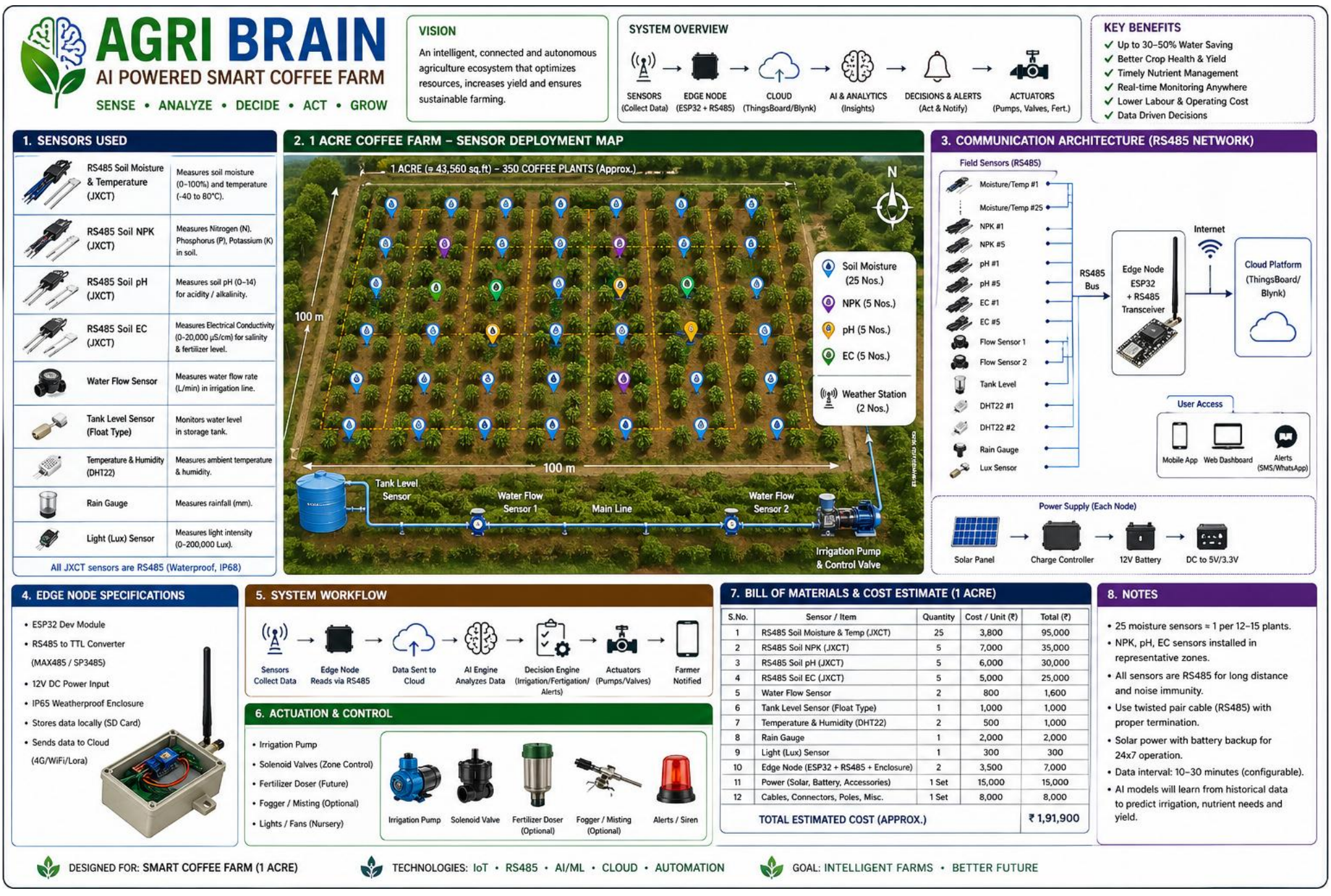
Sensor Deployment – Zoning Logic & Considerations

1. **Zoning logic:** 25 moisture sensors ≈ 1 per 12–15 plants (good balance of cost vs. accuracy).
2. **Representative zones:** NPK, pH, EC are **not needed everywhere** — 5 zones are enough to infer the field.
3. **Optional consolidation:** You can replace the separate NPK + pH + EC (₹90k) with **5× JXCT 7-in-1 sensors** (~₹12k each → ~₹60k), reducing cost and wiring.
4. **Network:** All JXCT sensors are **RS485** → use an RS485 bus (with ESP32 + RS485 transceivers) to reduce cable runs and improve reliability.
5. **Power:** Design for **solar + 12V battery**, duty-cycle reads (wake → read → sleep) to save power.

Core Soil System Deployment Budget 1 Acre in INR

Core Soil System - Sensor Deployment Budget -1 Acre in INR				
Category	**Sensor Type**	**Qty (1 acre)**	**Approx Cost / Sensor (₹)**	**Subtotal (INR)**
Soil (zones)	RS485 Soil Moisture + Temp (JXCT)	25	3,800	95,000
Soil (rep. zones)	RS485 Soil NPK (JXCT)	5	7,000	35,000
Soil (rep. zones)	RS485 Soil pH (JXCT)	5	6,000	30,000
Soil (rep. zones)	RS485 Soil EC (JXCT)	5	5,000	25,000
Water system	Water Flow Sensor	2	800	1,600
Water system	Tank Level Sensor (float/ultrasonic)	1	1,000	1,000
Climate	Temp + Humidity (DHT22 class)	2	500	1,000
Climate	Rain Gauge	1	2,000	2,000
Climate	Light (Lux) Sensor	1	300	300
	Total	47		190,900

Sensor Deployment – Plan



AgriBrain – Functional Modularisation

AgriBrain - functional Modularisation				
Module No.	**Module Name**	**Role**	**Sub-components**	**Output**
Module 1	***Field Data Acquisition & Sensing Module***	Capture real-time, multimodal data from the farm ecosystem	• Soil sensors (Moisture, Temp, pH, EC, NPK) • Climate sensors (Temp, Humidity, Rain, Light) • Water sensors (Flow, Tank Level) • Visual sensing (Camera, Rover imaging)	Raw environmental & plant data
Module 2	***Edge Communication & Transceiver Module***	Aggregate sensor data and transmit; receive control signals	• Sensor interfacing (RS485, Analog, Digital) • Edge controller (ESP32 / Raspberry Pi) • Communication protocols (UART, I2C, SPI) • Transceivers (RS485, LoRa, Wi-Fi)	Structured data packets ↔ command signals
Module 3	***Network & Cloud Connectivity Module***	Enable data exchange between field system and central platform	• Internet gateway (Wi-Fi, 4G, Ethernet) • Cloud server & database • APIs & middleware • IoT platforms (Blynk, MQTT, REST APIs)	Cloud-synced data streams
Module 4	***AgriBrain AI Analytics & Decision Engine***	Convert data into intelligence and actionable decisions	• Data analytics (trend, anomaly detection) • Soil–plant–climate models • Lab data integration • Computer vision (plant health) • Predictive models (irrigation, nutrients)	Optimized decisions (irrigation, fertilization, alerts)
Module 5	***Actuation, Control & Command Module***	Execute AI decisions through field actions	• Pump control • Solenoid valves • Fertigation system • Rover navigation • Alert systems (SMS/App)	Automated field operations
Module 6	***Monitoring, Visualization & User Interface Module***	Provide real-time monitoring and user interaction	• Mobile app (Blynk) • Web dashboard • Data visualization • Alerts & notifications • Manual override	User insights & control interface

AgriBrain: System Architecture