

## UNIT II - ENVIRONMENT CONTROL SYSTEMS

Artificial light systems, management of crop growth in greenhouses, simulation of CO<sub>2</sub> consumption in greenhouses, on-line measurement of plant growth in the greenhouse, models of plant production and expert systems in horticulture.

**Discuss various types of artificial lighting used in controlled plant production environments.**

### ARTIFICIAL LIGHT SYSTEMS

#### Why is Artificial Light Important?

- Plants need light to make their food through a process called photosynthesis.
- In indoor farming or during cloudy or short daylight seasons, there is not enough sunlight.
- Artificial lights replace or supplement natural sunlight to keep the plants growing.

#### What Should Artificial Lights Provide?

- **Correct Light Spectrum:** Different colors of light are used at different stages:
  - Blue Light (400–500 nm): Helps in making leaves and stems (vegetative growth).
  - Red Light (600–700 nm): Helps in producing flowers and fruits (reproductive stage).
  - Green Light: Less useful but helps overall balance.
- **Right Intensity:** Too much or too little light can damage plants.
- **Right Duration (Photoperiod):** Some plants need longer days, some shorter.

| Light Type   | Used For        | Good At          | Common Use   |
|--------------|-----------------|------------------|--------------|
| Fluorescent  | Leafy growth    | Blue light       | Seedlings    |
| LED          | All stages      | Custom spectrum  | Indoor farms |
| HPS          | Flowering/Fruit | Red light        | Greenhouses  |
| MH           | Early stages    | Blue-white light | Big farms    |
| Incandescent | Rare use        | Decorative only  | Experiments  |

#### Types of Artificial Light

##### A. Fluorescent Lights

- Tube-shaped or compact bulbs.
- Emit more blue light – good for early plant stages like seedlings.
- Pros: Cheap, low heat.
- Cons: Less powerful, not ideal for flowering.

##### B. LED (Light Emitting Diode) Lights

- Most advanced and efficient light for plant growth.
- Can be adjusted to give exact colors (red, blue, full spectrum).
- Pros:
  - Energy-saving (up to 70% less power).
  - Long life (50,000+ hours).
  - Low heat – safe for plants.
- Cons: High initial cost.

##### C. High-Pressure Sodium (HPS) Lamps

- Produce strong red/yellow light.
- Best for flowering and fruiting.
- Pros: Strong light, cheap for large farms.
- Cons: Produces a lot of heat, needs cooling.

**D. Metal Halide (MH) Lamps**

- Produce blue-white light.
- Best for leaf and stem development.
- Often used in early growth stages.
- Cons: Also generates heat.

**E. Incandescent Bulbs**

- Mostly outdated.
- Low light quality, high heat.
- Used rarely for ornamental plants or experiments.

**How Artificial Lighting is Used in Agriculture**

- **Indoor Vertical Farms**
  - Plants grown in shelves/layers with LED lights at each level.
  - Used in cities to grow lettuce, herbs, strawberries.
- **Greenhouses**
  - Supplementary lighting during cloudy days or at night.
  - Improves yield by providing extra growing hours.
- **Plant Factories**
  - Fully closed systems with no sunlight.
  - 100% artificial light, temperature, and water control.
  - Efficient but expensive.

**Lighting Control Systems**

To save energy and optimize plant growth:

- Timers: Automatically switch lights on/off (e.g., 16 hours on, 8 off).
- Light Sensors (LUX/Photometers): Measure light and adjust intensity.
- IoT & Automation:
  - Use mobile apps or computers to change light settings.
  - Use feedback from plant sensors to change lights.

**Smart Lighting System Features**

| Feature                  | Benefit                              |
|--------------------------|--------------------------------------|
| Customizable Color       | Match growth stage                   |
| Remote Monitoring        | Check from mobile or PC              |
| Scheduling               | Automate light periods               |
| Integration with Sensors | Change light based on plant response |

**Real-Life Use Cases**

- Japan: Indoor lettuce farms using 100% LED lights.
- NASA: Growing crops in space using red & blue LED arrays.
- Netherlands: Smart greenhouses using AI to control lights, temp, and humidity.

**Advantages**

- Grow crops without sunlight.
- Year-round farming.
- Energy-efficient (especially LEDs).
- Useful in urban farming.
- Control over crop growth stages.

**Disadvantages**

- Initial setup cost is high.
- Some lights produce heat – needs ventilation.
- Power consumption is high if not managed.
- Needs technical know-how to operate.

**Explain how environmental control and cultural practices are used to regulate crop growth in greenhouses.**

## **MANAGEMENT OF CROP GROWTH IN GREENHOUSES**

### **What is a Greenhouse?**

- A greenhouse is a structure made of transparent material (like glass or plastic) that allows sunlight in and traps heat. It provides a controlled environment for plants to grow efficiently.
- Main Goal: To provide ideal growing conditions (temperature, humidity, light, water, nutrients) all year round — even when outside conditions are poor.

### **Objectives of Crop Management in Greenhouses**

- \* Maximize crop yield and quality.
- \* Ensure efficient use of resources (water, nutrients, energy).
- \* Protect crops from pests, diseases, and weather extremes.
- \* Monitor and adjust environmental conditions using technology.

### **Key Components in Managing Crop Growth**

#### **1. Temperature Control**

- Ideal temperature range is 20°C to 30°C for most crops.
- Tools used:
  - Heaters – Used in cold weather.
  - Fans and vents – Let hot air out.
  - Cooling pads and foggers – Reduce temperature using water.
- Automation:
  - Temperature sensors detect changes.
  - Controller turns on/off fans or heaters.

#### **2. Humidity Control**

- Humidity = Amount of water vapor in the air.
- Too much → fungus, disease.
- Too little → plant stress and wilting.
- Tools used:
  - Humidifiers or misting systems.
  - Ventilation fans or dehumidifiers.
- Monitored using: Humidity sensors (RH sensors).

#### **3. Light Management**

- Light affects photosynthesis and growth rate.
- Types of management:
  - Shading nets or curtains: Reduce sunlight in hot conditions.
  - Artificial lights (LEDs): Used when sunlight is low.
- Controlled using:
  - Light sensors (Lux meters).
  - Timers and IoT devices.

#### **4. Irrigation Control**

- Watering must be accurate (not too much or too little).

- Irrigation Systems:
  - Drip Irrigation – Delivers water to plant roots slowly.
  - Sprinkler Systems – Sprays water like rain.
- Controlled using:
  - Soil moisture sensors.
  - Timers and automatic valves.
  - Fertigation systems – Mix fertilizer with water.

## 5. Nutrient Management

- Plants need NPK (Nitrogen, Phosphorus, Potassium) and other nutrients.
- Fertigation system: Fertilizers are mixed with water and given to plants.
- pH and EC (electrical conductivity) sensors monitor water quality.

## 6. Pest and Disease Control

- Greenhouses help reduce pests, but not eliminate them.
- Controls used:
  - Sticky traps for insects.
  - Mesh screens to block entry.
  - Biopesticides and natural predators.
  - Sensors or cameras can detect pest movement in smart systems.

## 7. Monitoring and Automation

| Tool             | Function                                     |
|------------------|----------------------------------------------|
| Sensors          | Measure temp, humidity, light, soil moisture |
| Microcontrollers | Arduino, Raspberry Pi for automation         |
| IoT Devices      | Connect to apps, monitor remotely            |
| Software         | Display graphs, alerts, and suggestions      |

## Crop Growth Stages to Monitor

| Stage      | What to Manage                                 |
|------------|------------------------------------------------|
| Seedling   | Warm temp, low light, soft misting             |
| Vegetative | More light, nutrients, water                   |
| Flowering  | Control humidity, increase red light           |
| Fruiting   | Strong light, balanced nutrients, pest control |

## Benefits of Controlled Crop Management

- Increased yield with less space.
- Saves water and fertilizer.
- Grow crops in off-seasons.
- Reduces chemical pesticide use.
- Smart farming with remote control.

## Example: Tomato Greenhouse Management

1. Temperature: 24°C day / 18°C night
2. Humidity: 60–70%
3. Drip irrigation with fertigation
4. Pollination managed by bumblebees
5. Red & blue LED lighting for flowering

**Discuss the simulation of CO<sub>2</sub> consumption in greenhouses. Include factors affecting CO<sub>2</sub> uptake and any models used.**

## **SIMULATION OF CO<sub>2</sub> CONSUMPTION IN GREENHOUSES**

### **Why is CO<sub>2</sub> Important for Plants?**

- Plants use Carbon Dioxide (CO<sub>2</sub>) during photosynthesis to make their food (glucose).
- More CO<sub>2</sub> (within limits) = faster growth and higher yield.
- CO<sub>2</sub> in air = around 400 ppm (parts per million), but ideal for crops = 800–1200 ppm in greenhouses.

### **What Happens in a Greenhouse?**

- Plants absorb CO<sub>2</sub> during the day (for photosynthesis).
- Over time, CO<sub>2</sub> levels drop in closed greenhouses.
- Low CO<sub>2</sub> = slower photosynthesis = reduced growth.

Solution: Monitor and simulate CO<sub>2</sub> usage, and then add CO<sub>2</sub> if needed.

### **What is CO<sub>2</sub> Simulation?**

- A computer-based model or system that:
- Calculates how much CO<sub>2</sub> is being consumed by plants.
- Predicts future CO<sub>2</sub> demand.
- Helps in automating CO<sub>2</sub> supply systems (like CO<sub>2</sub> tanks or burners).

### **Inputs Needed for Simulation**

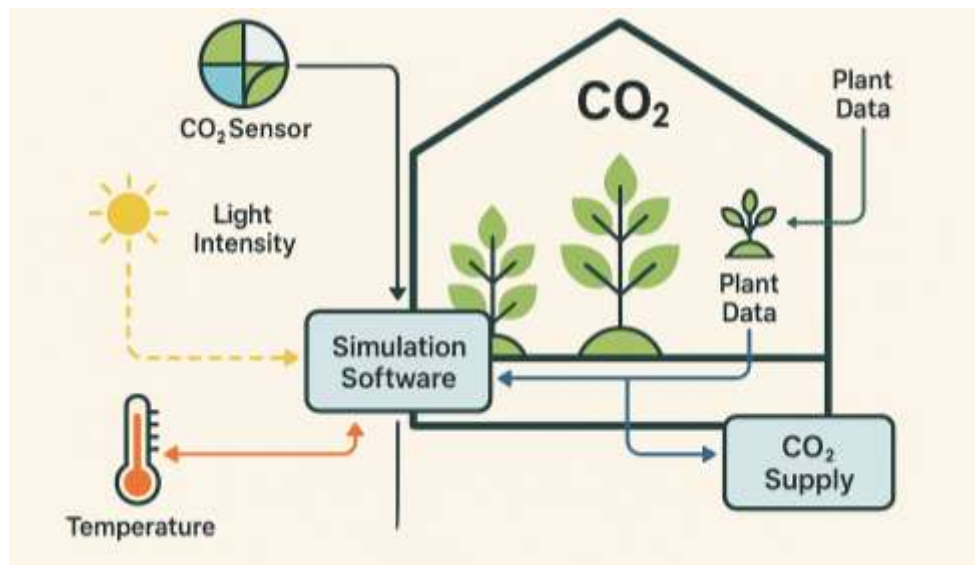
To simulate CO<sub>2</sub> consumption, the system takes in:

| Input                 | Description                                                          |
|-----------------------|----------------------------------------------------------------------|
| Light intensity       | More light = more photosynthesis = more CO <sub>2</sub> needed       |
| Temperature           | Affects plant metabolism and CO <sub>2</sub> uptake rate             |
| Plant type & age      | Young plants need less CO <sub>2</sub> than mature ones              |
| Plant density         | More plants = more total CO <sub>2</sub> consumption                 |
| Time of day           | CO <sub>2</sub> used mostly during daytime (when light is available) |
| Leaf Area Index (LAI) | More leaf area = more CO <sub>2</sub> absorption                     |

### **How Simulation Works (Simple Steps)**

1. Sensors measure current CO<sub>2</sub> level in the greenhouse.
2. Software Model uses formulas to:
  - Estimate how much CO<sub>2</sub> is being used based on plant data and conditions.
3. If CO<sub>2</sub> level < target (e.g., 800 ppm), the system:
  - Activates CO<sub>2</sub> generators or tanks.
  - Opens vents or adjusts airflow if too much CO<sub>2</sub>.
4. Continuously updates in real-time.
5. Sample Formula (Simplified Concept)
  - If > CO<sub>2</sub> uptake rate = f (Light Intensity × Leaf Area × Time × Temperature Factor)
  - This function is calculated using mathematical models built into simulation software.

A CO<sub>2</sub> simulation system in a greenhouse is like a plant breathing monitor – it watches how much "air" (CO<sub>2</sub>) the plants are using and makes sure they never run out of it!



### Tools and Technologies Used

| Tool/Tech                          | Function                                      |
|------------------------------------|-----------------------------------------------|
| CO <sub>2</sub> Sensors            | Measure actual CO <sub>2</sub> level (in ppm) |
| Temperature/Light Sensors          | Help estimate plant activity                  |
| Leaf Area Sensors                  | Estimate surface area for photosynthesis      |
| Simulation Software                | Runs model calculations                       |
| Controllers                        | Decide when to release more CO <sub>2</sub>   |
| CO <sub>2</sub> Generators / Tanks | Devices that add CO <sub>2</sub> to the air   |

### Examples of Simulation Software

- HORTISIM
- Virtual Grower (by USDA)
- GroSens
- GreenhouseManager

These simulate crop environment and CO<sub>2</sub> balance to make suggestions or automate control.

### Benefits of CO<sub>2</sub> Simulation in Greenhouses

- Maintains optimal CO<sub>2</sub> level for plant growth
- Improves yield and quality of crops
- Prevents wastage of CO<sub>2</sub> (and money)
- Helps in energy-efficient greenhouse operations
- Can be automated and remotely monitored

### Real-Life Example

- Tomato Greenhouse in the Netherlands:
  - Uses real-time CO<sub>2</sub> simulation + LED lighting.
  - Increases yield by 15–20%.
  - CO<sub>2</sub> supplied using flue gas (cleaned) from nearby industries.

**Explain how CO<sub>2</sub> consumption in a greenhouse can be predicted using simulation models.**

## ONLINE MEASUREMENT OF PLANT GROWTH IN GREENHOUSES

Online measurement of plant growth in a greenhouse refers to real-time, automated monitoring of plant development using sensors, imaging systems, and data analytics. This method enables precise and continuous tracking of plant health, biomass, and environmental interactions without manual intervention.

### Key Techniques for Online Measurement

#### 1. Digital Imaging Systems

- RGB Cameras: Capture images to analyze leaf area, color (indicating health), and size.
- 3D Stereo Cameras or LiDAR: Measure plant height, volume, and structure in 3D.
- Thermal Cameras: Detect water stress by measuring leaf temperature.

#### 2. Hyperspectral and Multispectral Imaging

- Analyzes plant reflectance at various wavelengths to assess:
  - Chlorophyll content
  - Nutrient status
  - Early signs of stress or disease

#### 3. Ultrasonic Sensors:

- Measure plant height by calculating the distance between the sensor and the canopy top.

#### 4. Laser Scanning (LiDAR):

- Provides detailed 3D models for growth rate, leaf angle, and plant density analysis.

#### 5. Weight-Based Systems (Load Cells):

- Monitor plant or pot weight changes to infer biomass gain and water uptake.

#### 6. Plant Sap Flow Sensors:

- Monitor water usage and transpiration in real-time.

#### 7. Internet of Things (IoT) & Wireless Sensor Networks (WSNs)

- Combine environmental data (light, humidity, CO<sub>2</sub>, temperature) with plant growth metrics.
- Enable remote access and control of greenhouse conditions.

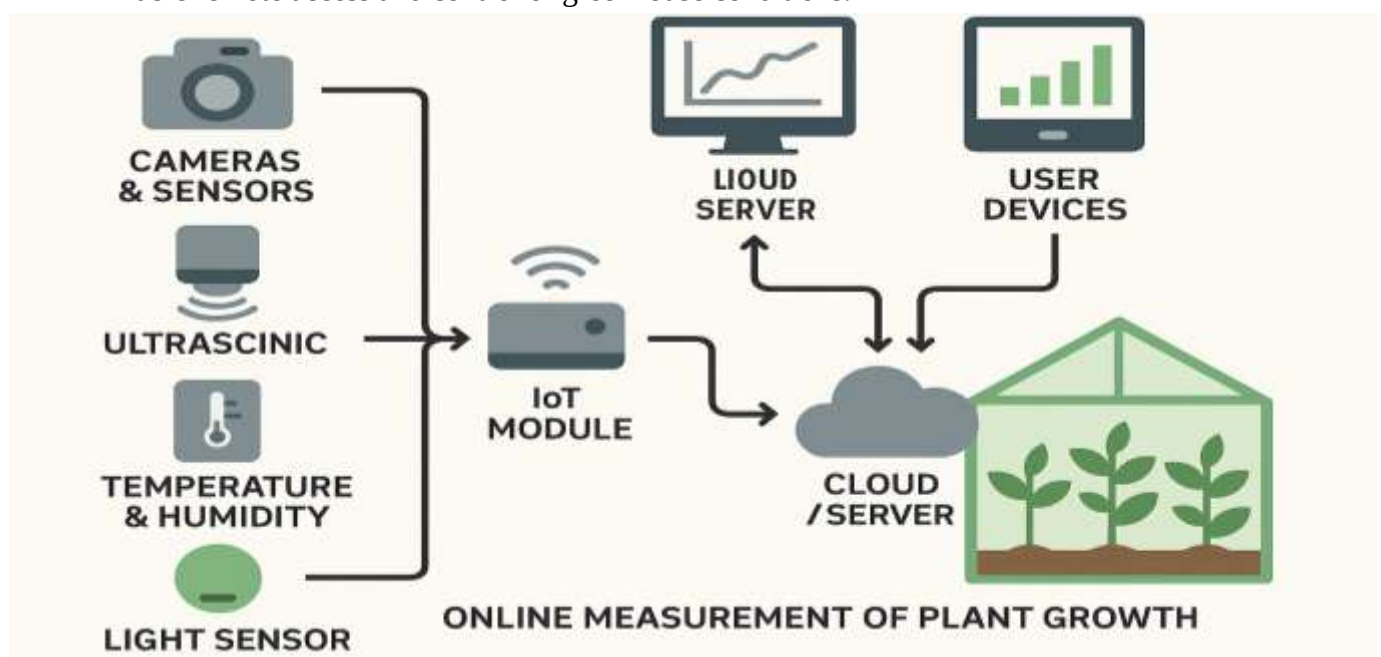


Figure: system architecture for online measurement of plant growth in a greenhouse

**Parameters Measured Online**

| Parameter            | Sensor Type                    |
|----------------------|--------------------------------|
| Plant height         | Ultrasonic, LiDAR              |
| Leaf area            | Digital camera, image analysis |
| Biomass              | Load cells, image-based models |
| Transpiration        | Sap flow sensors               |
| Temperature          | Thermal cameras                |
| Chlorophyll/Nitrogen | Multispectral imaging          |
| Light absorption     | PAR sensors                    |

**Workflow of Online Growth Monitoring**

1. **Sensor Deployment:** Cameras and sensors are installed above or near the plants.
2. **Data Collection:** Continuous measurements are taken at set intervals (e.g., every 10 min).
3. **Data Transmission:** Sent via IoT modules to a cloud/server.
4. **Analysis & Visualization:** Software processes the data into growth curves, heatmaps, etc.
5. **Decision-Making:** Automated systems can adjust irrigation, lighting, and nutrient supply.

**Benefits**

- Non-destructive and real-time monitoring
- Improved accuracy and frequency of data
- Early detection of stress or diseases
- Better resource use (water, fertilizers)
- Enhanced yield prediction

**Example Systems**

- PhenoBot (for robotic image capture)
- CropQuant (open-source phenotyping platform)
- Greenhouse Management Systems by Priva, Argus, or Netafim

**1. Sensor Layer (Data Acquisition Layer)**

This layer includes all the devices that gather real-time data from the plants and environment:

- i. Cameras & Sensors
  - RGB Cameras: Capture 2D images of plant canopy for leaf area and color analysis.
  - 3D Cameras / LiDAR: Measure height, volume, and shape of plants in 3D.
  - Thermal Cameras: Detect temperature variations indicating water stress.
- ii. Ultrasonic Sensors
  - Positioned above plants to measure height by bouncing sound waves.
  - Non-contact, fast, and reliable for vertical growth tracking.
- iii. Temperature & Humidity Sensors
  - Monitor microclimate to ensure optimal growth conditions.
  - Used for correlating environmental factors with plant health.
- iv. Light Sensors (PAR/Photodiode)
  - Detect light intensity and photoperiod exposure.
  - Ensure sufficient photosynthesis conditions.

**2. IoT Module (Edge Device / Gateway)**

- Functions:
  - Collects sensor data in real-time.
  - Preprocesses or filters data (optional).

- Transmits data wirelessly (via Wi-Fi, LoRa, Zigbee, NB-IoT).
- Examples: Arduino + ESP8266, Raspberry Pi, or dedicated IoT boards.
- Can support actuators too (e.g., automatic irrigation, fans, shade controls).

### 3. Cloud / Server (Data Storage and Processing Layer)

- Acts as a central hub for:
  - Storing large volumes of data securely.
  - Running analysis algorithms (AI/ML models, statistical tools).
  - Hosting dashboards or APIs.
- May include:
  - Databases: e.g., InfluxDB, Firebase, AWS DynamoDB.
  - Data pipelines: e.g., MQTT, HTTP, or REST APIs for transmission.
  - AI modules: for plant health prediction, disease detection, and growth modeling.

### 4. Cloud Dashboard / User Interface (Visualization & Control Layer)

- Accessible via PC, tablet, or mobile phone.
- Functions:
  - Visualize growth trends (graphs, 3D models).
  - Alert users in case of anomalies (e.g., poor light, high temperature).
  - Allow remote control of greenhouse devices (e.g., irrigation, ventilation).
  - Generate automated reports or yield forecasts.

### 5. Greenhouse Environment

- The physical environment where:
  - Plants grow and interact with external conditions.
  - Feedback from the monitoring system is used to adjust conditions (closed-loop).
  - Actuators may be installed to automate environmental control (optional).

## Case Study: Online Plant Monitoring in a Tomato Greenhouse - Wageningen University, Netherlands

**Objective:** To implement a real-time, non-invasive system for monitoring the growth and health of tomato plants in a greenhouse using imaging, environmental sensors, and AI models.

### System Setup

#### 1. Greenhouse Type:

- Controlled-environment greenhouse
- Crop: *Solanum lycopersicum* (Tomato)
- Area: 500 m<sup>2</sup> under study

#### 2. Sensors & Hardware:

| Component            | Details                                                        |
|----------------------|----------------------------------------------------------------|
| RGB Cameras          | Time-lapse image capture every 15 min                          |
| 3D Stereo Vision     | Canopy structure and plant height                              |
| Thermal Cameras      | Detecting heat stress on leaves                                |
| Ultrasonic Sensors   | Installed overhead to track vertical growth                    |
| Light Sensors (PAR)  | Measuring photosynthetically active radiation                  |
| Temperature/Humidity | Multiple zones for microclimate tracking                       |
| Load Cells           | Monitoring plant pot weight for water uptake and biomass       |
| IoT Gateway          | Raspberry Pi + Zigbee modules for local control and data relay |

**Workflow**

- i. **Data Collection**
  - Every 15 minutes, the cameras and sensors collect:
  - Plant height, width, and leaf area index (LAI)
  - Environmental variables like humidity, temperature, CO<sub>2</sub>
- ii. **Transmission via IoT Gateway**
  - Data is sent to a central cloud server using MQTT protocol.
- iii. **Cloud Analytics**
  - AI models (trained on historical growth data) predict expected growth.
  - Image processing (OpenCV + Python) detects color changes for early stress signs.
  - Anomalies in plant weight or leaf color trigger alerts.
- iv. **Visualization**
  - Researchers use a web-based dashboard to view growth curves, thermal maps, and environmental trends.
  - Data exported to Power BI and Grafana for visualization.
- v. **Automated Control**
  - Irrigation and CO<sub>2</sub> systems are adjusted automatically based on real-time readings.

**Results & Impact**

- Yield Increase: ~18% higher than the control group using manual observation.
- Resource Efficiency: 25% less water used due to real-time irrigation feedback.
- Early Disease Detection: Yellowing from nitrogen deficiency was caught 5 days earlier than manual checks.
- Labor Reduction: Significant reduction in manual data logging and crop inspection.

**Precision agriculture through online plant monitoring not only improves yield and quality but also minimizes resource wastage and enables early decision-making.**

**Key Technologies Used**

| Tech Layer      | Example                                              |
|-----------------|------------------------------------------------------|
| Sensor Hardware | Basler RGB Cameras, FLIR Thermal Sensors, Load Cells |
| IoT Gateway     | Raspberry Pi + LoRa Node                             |
| Cloud Platform  | AWS IoT Core + S3                                    |
| AI Models       | Random Forests, Convolutional Neural Networks        |
| Analysis Tools  | OpenCV, TensorFlow, Pandas, Grafana                  |
| Communication   | MQTT, HTTP REST API                                  |

**Describe the concept and applications of plant production models in horticulture. Provide examples.**

**MODELS OF PLANT PRODUCTION IN HORTICULTURE**

A *plant production model* is a **mathematical, statistical, or simulation-based representation** of the growth and yield of a crop under specific environmental, biological, and management conditions.

These models help:

- Predict **yield** before harvest.
- Test **different management practices** virtually.
- Save resources by **optimizing inputs**.

## Classification of Models

### A. Empirical Models

- **Principle:** Based purely on observed data and statistical relationships (e.g., regression analysis).
- **Example:**  $\text{Yield} = a + b \times \text{N\_fertilizer} + c \times \text{Rainfall}$   
where  $a, b, c$  are constants derived from experiments.
- **Advantages:** Simple, fast, inexpensive.
- **Limitations:** Works well only under conditions similar to the data used for development.

### B. Mechanistic Models

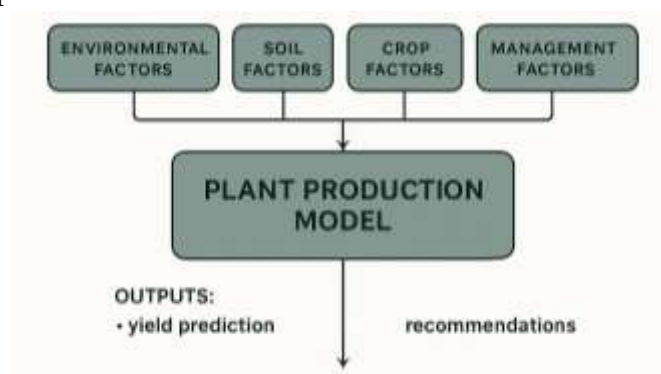
- **Principle:** Simulate actual plant physiological processes.
- **Factors considered:** Photosynthesis, respiration, transpiration, nutrient uptake.
- **Example:**  
CERES (Crop Environment Resource Synthesis) model.
- **Advantages:** Can be applied to multiple scenarios.
- **Limitations:** Requires large amounts of accurate input data.

### C. Simulation Models

- **Principle:** Integrates environmental, plant, and management data to simulate plant growth stage-by-stage.
- **Tools:** CropSyst, APSIM, WOFOST.
- **Output:** Graphs showing growth rate, yield prediction, and stress impacts.
- **Usage:**
  - Greenhouse tomato yield prediction.
  - Scheduling harvest dates.

### D. Decision Support Models

- Integrated into farm software.
- Often connected with **expert systems** to give recommendations.
- Example: DSSAT (Decision Support System for Agrotechnology Transfer) used in field and horticultural crops.



### Common Inputs for Plant Production Models

1. **Climatic Data:** Temperature, rainfall, solar radiation, humidity, wind speed.
2. **Soil Data:** Texture, structure, nutrient content, moisture levels.
3. **Crop Data:** Variety, growth stage, disease incidence.
4. **Management Practices:** Irrigation frequency, fertilizer application, pest control methods.

### Benefits

- Predict yield in advance.
- Optimize irrigation and fertilizer use.
- Reduce trial-and-error farming.
- Support precision horticulture.

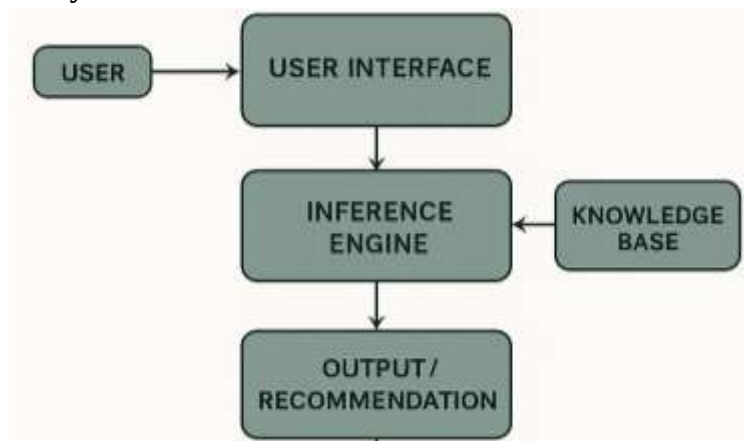
**Example – Greenhouse Tomato Model**

- **Inputs:** CO<sub>2</sub> concentration, light intensity, soil nutrients, irrigation schedule.
- **Outputs:** Daily growth rate, estimated harvest time, predicted yield.
- **Impact:** 15% water savings, 10% increase in marketable yield.

**Illustrate the role of expert systems in improving horticultural practices with examples. (or)**  
**Explain expert systems in horticulture. Describe their components, working, and advantages.**

**EXPERT SYSTEMS IN HORTICULTURE**

- An **expert system** is an **AI-based software** that uses a database of expert knowledge and logical reasoning to solve agricultural problems and provide recommendations.
- An expert system is an AI-driven tool that simulates the decision-making ability of a human expert.

**Architecture of Expert Systems****Components**

- **Knowledge Base:** Contains factual and procedural knowledge about horticultural practices (e.g., how to manage tomato wilt or when to apply micronutrients).
- **Rules:** These are "if-then" statements that define actions or recommendations based on given conditions.
  - Example: If soil pH < 5.5 then apply lime at 2 t/ha.
- **Inference Engine:** This is the reasoning module. It interprets the facts and rules to draw conclusions (recommendations).
- **User Interface:** The platform where the user inputs problems and receives solutions. It could be a mobile app, computer program, or even voice assistant.

**Output:**

- **Decision Support:** The system provides suggestions based on expert knowledge, such as:
  - Disease identification and control methods
  - Fertilizer recommendations
  - Pest and weed management
  - Optimal planting time
  - Post-harvest storage and handling

### Example Scenario

A user is cultivating capsicum in a polyhouse:

- The plant model uses current and forecasted weather, soil nutrient levels, and the fertigation schedule to predict:
  - Fruit set period
  - Expected yield
- The expert system evaluates sensor input and farmer queries:
  - Detects signs of spider mite infestation
  - Recommends neem oil spray in the early morning
- Both systems help the grower take informed actions.

### Applications in Horticulture

- **Pest and Disease Diagnosis:** Example: Detecting powdery mildew in roses from leaf images.
- **Irrigation Scheduling:** Based on soil moisture, weather, and crop type.
- **Fertilizer Recommendations:** Suggesting nutrient plans using soil test data.
- **Harvest Forecasting:** Predicting optimal harvest time for fruits.
- **Greenhouse Climate Control:** Adjusting temperature, humidity, CO<sub>2</sub> levels automatically.

### Examples of Real Expert Systems

- **HORTEX** – Manages greenhouse crops.
- **CROPEX** – Advises on crop growth and pest control.
- **Agri-Info** – Cloud-based advisory for multiple crops.
- **RICE-EX** – Developed for rice pest/disease management (adaptable to horticulture).

### Advantages

- Provides accurate, location-specific advice.
- Reduces crop loss by early problem detection.
- Saves time and resources.
- Makes expert knowledge accessible to remote farmers.

### Limitations

- High initial setup cost.
- Needs constant updating to include new knowledge.
- Dependent on correct data input by the user.

### Case Study – Expert System for Tomato Cultivation

- **Problem:** Farmers losing yield due to late blight.
- **Solution:** Expert system with:
  - Symptom recognition (leaf image upload).
  - Rule-based diagnosis.
  - Control measures with dosage and spray intervals.
- **Result:** 20% reduction in crop loss, improved marketable yield.

### Comparison Table

| Aspect          | Plant Production Models         | Expert Systems                        |
|-----------------|---------------------------------|---------------------------------------|
| Purpose         | Simulate plant growth and yield | Provide decision-making support       |
| Input           | Environmental, soil, crop data  | Problem symptoms, soil tests, climate |
| Output          | Growth curves, yield prediction | Recommendations, solutions            |
| Technology Base | Math/statistics, simulations    | AI, rule-based reasoning              |

**PART A****1. What is controlled agriculture environment? (Nov / Dec 2024)**

A controlled agriculture environment refers to a farming system where environmental factors such as temperature, humidity, light, CO<sub>2</sub> concentration, and irrigation are regulated using technology to provide optimal growing conditions for crops throughout the year.

**2. What is the purpose of artificial lighting in greenhouses?**

Artificial lighting supplements or replaces natural sunlight to maintain photosynthesis, extend the photoperiod, and control flowering in greenhouse crops.

**3. Name the types of artificial light sources used in agriculture. (Nov / Dec 2024)**

The types of artificial light sources used in agriculture include:

- Fluorescent lights
- Light Emitting Diodes (LEDs)
- High Pressure Sodium (HPS) lamps
- Metal Halide (MH) lamps
- Incandescent bulbs

**4. Define photosynthetically active radiation (PAR).**

PAR refers to the range of light (400–700 nm) used by plants for photosynthesis.

**5. What are the main environmental factors controlled in a greenhouse?**

Temperature, humidity, light intensity, CO<sub>2</sub> concentration, and irrigation.

**6. What is CO<sub>2</sub> enrichment in greenhouse farming?**

It is the process of artificially increasing CO<sub>2</sub> levels to enhance photosynthesis and crop yield.

**7. Mention any two sensors used for online plant growth monitoring.**

RGB camera and ultrasonic sensor.

**8. What is the role of an ultrasonic sensor in a greenhouse?**

It measures the height of plants by calculating the distance from the sensor to the canopy top.

**9. What is meant by online measurement of plant growth?**

It is the real-time monitoring of plant growth using non-destructive technologies like cameras and sensors.

**10. Name two plant growth parameters that can be measured online.**

Plant height and leaf area index (LAI).

**11. What is a plant production model?**

A plant production model is a mathematical representation of crop growth under different environmental and management conditions.

**12. Give one example of a plant growth simulation model.**

DSSAT (Decision Support System for Agrotechnology Transfer).

**13. What is an expert system in horticulture?**

An expert system is an AI-based decision support tool that offers crop management advice similar to a human expert.

**14. State any one advantage of using expert systems in greenhouses.**

They help in making quick and informed decisions on irrigation, fertilization, and pest control.

**15. What is meant by fertigation?**

Fertigation is the application of fertilizers through the irrigation system.

**16. Name any one AI technology used in expert systems for agriculture.**

Rule-based logic or machine learning algorithms.

ADD-ON**1. Discuss the following common models and key components used in horticulture:**

- (i) Crop Growth Model
- (ii) Nutrient Management Models
- (iii) Pest and Disease Models
- (iv) Climate Control Model

(Nov / Dec 2024)

**(i) Crop Growth Model**

- Represents the growth and development of crops over time under specific environmental conditions.
- **Key Components:**
  - Environmental data: temperature, light intensity, CO<sub>2</sub> , humidity.
  - Crop parameters: variety, growth stage, leaf area index.
  - Mathematical/Simulation methods to predict yield and growth rate.
- **Example:** CERES model for simulating photosynthesis and biomass accumulation.

**(ii) Nutrient Management Models**

- Used to determine the optimal nutrient supply for plants, preventing deficiency or excess.
- **Key Components:**
  - Soil nutrient data: N, P, K levels, pH, EC.
  - Crop nutrient requirements for each growth stage.
  - Fertigation schedules linked with irrigation systems.
- **Example:** Models that integrate soil test results to recommend fertilizer dose and timing.

**(iii) Pest and Disease Models**

- Predict the occurrence and spread of pests and diseases based on environmental and crop conditions.
- **Key Components:**
  - Pest/disease life cycle data.
  - Weather and humidity patterns.
  - Crop susceptibility at different stages.
- **Example:** Powdery mildew prediction models using temperature and humidity thresholds.

**(iv) Climate Control Model**

- Maintains optimal microclimate conditions in greenhouses for maximum crop productivity.
- **Key Components:**
  - Sensors for temperature, humidity, CO<sub>2</sub> , and light.
  - Actuators: heaters, cooling pads, ventilation fans, shading systems.
  - Control algorithms for automatic adjustment.
- **Example:** Integrated greenhouse management systems adjusting climate parameters in real-time.

**2. Explain the three different methods that can be used to simulate CO<sub>2</sub> in greenhouses.**

(Nov / Dec 2024)

Three methods to simulate CO<sub>2</sub> consumption in greenhouses are:

**1. Sensor-Based Real-Time Monitoring**

- CO<sub>2</sub> sensors measure current levels in the greenhouse atmosphere.
- Data is fed into simulation software to calculate consumption and trigger CO<sub>2</sub> generators when levels drop below the target (e.g., 800–1200 ppm).

## 2. Mathematical Modelling

- Uses plant growth parameters such as light intensity, temperature, leaf area index (LAI), and plant density to predict CO<sub>2</sub> uptake.
- Models like HORTISIM or Virtual Grower calculate future CO<sub>2</sub> demand and adjust supply accordingly.

## 3. Integrated Environmental Control Systems

- Combines CO<sub>2</sub> simulation with other environmental controls (light, temperature, humidity).
- Uses historical and real-time data to optimize CO<sub>2</sub> levels, preventing waste and improving energy efficiency.

### CASE STUDY 1 – Artificial Light Systems

**Topic:** LED Lighting for Off-Season Capsicum Production in Bengaluru, Karnataka

#### Background:

A polyhouse farm in Bengaluru grows coloured capsicum for export. During monsoon months, natural sunlight is reduced, causing slow growth and poor fruit set. The farm installs **supplemental LED lighting** to maintain production.

#### Setup:

- **Lighting:** Red–blue LED panels (70% red, 30% blue).
- **Photoperiod:** 14 hours/day using timers.
- **Control System:** Light sensors adjust intensity.
- **Crop Cycle:** 120 days.

#### Results:

- Average yield increased from 5.2 kg/plant to 6.1 kg/plant.
- Fruit colour intensity improved.
- Energy savings of 25% compared to previous HPS system.

#### Questions & Answers:

##### 1. What was the ratio of red to blue light used?

70% red, 30% blue.

##### 2. Why was supplemental lighting needed during monsoon?

To compensate for reduced sunlight and maintain photosynthesis.

##### 3. Explain the role of red and blue light in capsicum growth.

Blue light promotes vegetative growth and leaf development, while red light encourages flowering and fruiting. The combination ensures balanced plant growth.

##### 4. Describe the LED lighting setup, working, results, and benefits in this case.

**Setup:** Red–blue LED panels, photoperiod control, light sensors.

- **Working:** Sensors maintain consistent light intensity, LEDs operate for 14 hours/day.
- **Results:** Yield +17%, improved colour, energy savings.
- **Benefits:** Year-round production, better quality, reduced power cost.

### CASE STUDY 2 – Management of Crop Growth in Greenhouses

**Topic:** Precision Climate Control for Tomato Production in Pune, Maharashtra

#### Background:

A tomato grower faced inconsistent yields due to fluctuating temperatures and pest attacks. The farm adopted **sensor-based climate control** to stabilise growth conditions.

#### Setup:

- **Temperature Control:** Exhaust fans, cooling pads.

- **Humidity Control:** Foggers and RH sensors.
- **Irrigation:** Drip fertigation with moisture sensors.
- **Light:** Red–blue LEDs during cloudy days.

**Results:**

- Yield improved from 6.0 to 8.4 kg/plant.
- Water savings of 30%.
- Pest incidents reduced by 40%.

**Questions & Answers:****1. Name two systems used for temperature control.**

Exhaust fans and cooling pads.

**2. By what percentage did water use reduce?**

30%.

**3. Explain how humidity control reduced pest infestation.**

Proper humidity prevented excess moisture that promotes fungal growth and maintained conditions unfavourable to pests.

**4. Discuss the setup, operations, and outcomes of climate control in the Pune tomato greenhouse.**

**Setup:** Temperature, humidity, irrigation, light controls.

- **Operations:** Automated adjustments using sensors and IoT.
- **Outcomes:** Higher yield, water efficiency, fewer pests.
- **Benefits:** Consistent production, resource savings.

**CASE STUDY 3 – Simulation of CO<sub>2</sub> Consumption in Greenhouses**

**Topic:** CO<sub>2</sub> Simulation in Cucumber Polyhouse, Hosakote, Karnataka

**Background:**

High-density cucumber planting lowered CO<sub>2</sub> levels, slowing growth. The farmer adopted CO<sub>2</sub> simulation software to optimise enrichment.

**Setup:**

- **Sensors:** CO<sub>2</sub>, temperature, light, LAI.
- **Software:** HORTISIM.
- **Source:** Fermentation units as low-cost CO<sub>2</sub> source.

**Results:**

- Yield +12%.
- CO<sub>2</sub> wastage reduced by 20%.
- Faster fruit maturity by 4 days.

**Questions & Answers:****1. What CO<sub>2</sub> source was used?**

Fermentation units.

**2. How much did CO<sub>2</sub> wastage reduce?**

20%.

**3. Explain the role of LAI in CO<sub>2</sub> simulation.**

LAI indicates total leaf surface; higher LAI means greater CO<sub>2</sub> uptake potential, helping in accurate simulation.

**4. Describe the CO<sub>2</sub> simulation system setup, process, and benefits.**

**Setup:** Sensors, software, CO<sub>2</sub> release control.

- **Process:** Real-time monitoring, predictive CO<sub>2</sub> release.
- **Benefits:** Higher yield, cost savings, faster harvest.

**CASE STUDY 4 – Online Measurement of Plant Growth****Topic:** IoT-Based Capsicum Growth Monitoring in Nashik, Maharashtra**Background:**

Capsicum growers needed uniform fruit size for premium market sales. They implemented **online growth monitoring**.

**Setup:**

- **Sensors:** Ultrasonic for height, RGB cameras for canopy size.
- **IoT Gateway:** Sends data to mobile app.
- **Automation:** Adjusts irrigation/fertigation based on growth.

**Results:**

- Uniform fruit size improved by 15%.
- Reduced water usage by 18%.

**Questions & Answers:****1. Name two devices used in this system.**

Ultrasonic sensors, RGB cameras.

**2. How much did uniform fruit size improve?**

15%.

**3. Explain how ultrasonic sensors measure plant height.**

They emit sound waves and measure time taken for the echo to return from the plant canopy.

**4. Discuss setup, working, results, and benefits of the Nashik growth monitoring system.**

**Setup:** Height and canopy sensors, IoT link.

- **Working:** Continuous data collection and analysis.
- **Results:** Better uniformity, water savings.
- **Benefits:** Market value increase, resource efficiency.

**CASE STUDY 5 – Models of Plant Production****Topic:** Hydroponic Lettuce Production in Hyderabad, Telangana**Background:**

A hydroponic lettuce farm supplying supermarkets needed accurate harvest scheduling.

**Setup:**

- **Model:** Empirical model based on temp, nutrient EC, and light.
- **Output:** Predicts harvest within  $\pm 2$  days accuracy.

**Results:**

- Reduced wastage due to over/under maturity.
- On-time deliveries to buyers.

**Questions & Answers:****1. What type of model was used?**

Empirical model.

**2. What was the harvest prediction accuracy?**

$\pm 2$  days.

**3. Explain the benefit of accurate harvest timing in hydroponics.**

Prevents quality loss, ensures steady supply, and maintains buyer trust.

**4. Describe model inputs, working, and results in Hyderabad lettuce farm.**

**Inputs:** Temp, EC, light.

- **Working:** Uses regression-based formula.
- **Results:** Reduced losses, on-time delivery.
- **Benefits:** Efficient planning and marketing.

**CASE STUDY 6 – Expert Systems in Horticulture**

**Topic:** Mobile-Based Pest Control Advisory for Pomegranate in Solapur, Maharashtra

**Background:**

Bacterial blight reduced export quality in pomegranate orchards. Farmers adopted a **mobile expert system** for pest/disease management.

**Setup:**

- **Platform:** App in local language.
- **Function:** Farmers upload leaf images → AI diagnosis → Spray schedule provided.

**Results:**

- Disease severity reduced by 30%.
- Export-quality fruit increased by 20%.

**Questions & Answers:****1. What major disease affected the orchards?**

Bacterial blight.

**2. In what language was the app available?**

Local language (Marathi).

**3. Explain how the expert system reduced pesticide use.**

It recommended targeted sprays only when needed, avoiding blanket applications.

**4. Describe the expert system setup, operation, results, and benefits.**

**Setup:** Mobile app, AI engine, image upload.

- **Operation:** Farmer sends photo → system diagnoses → gives solution.
- **Results:** Lower disease, better quality.
- **Benefits:** Cost savings, eco-friendly, higher profits.