AST 426 :Sensing Technologies for Precision Farming I

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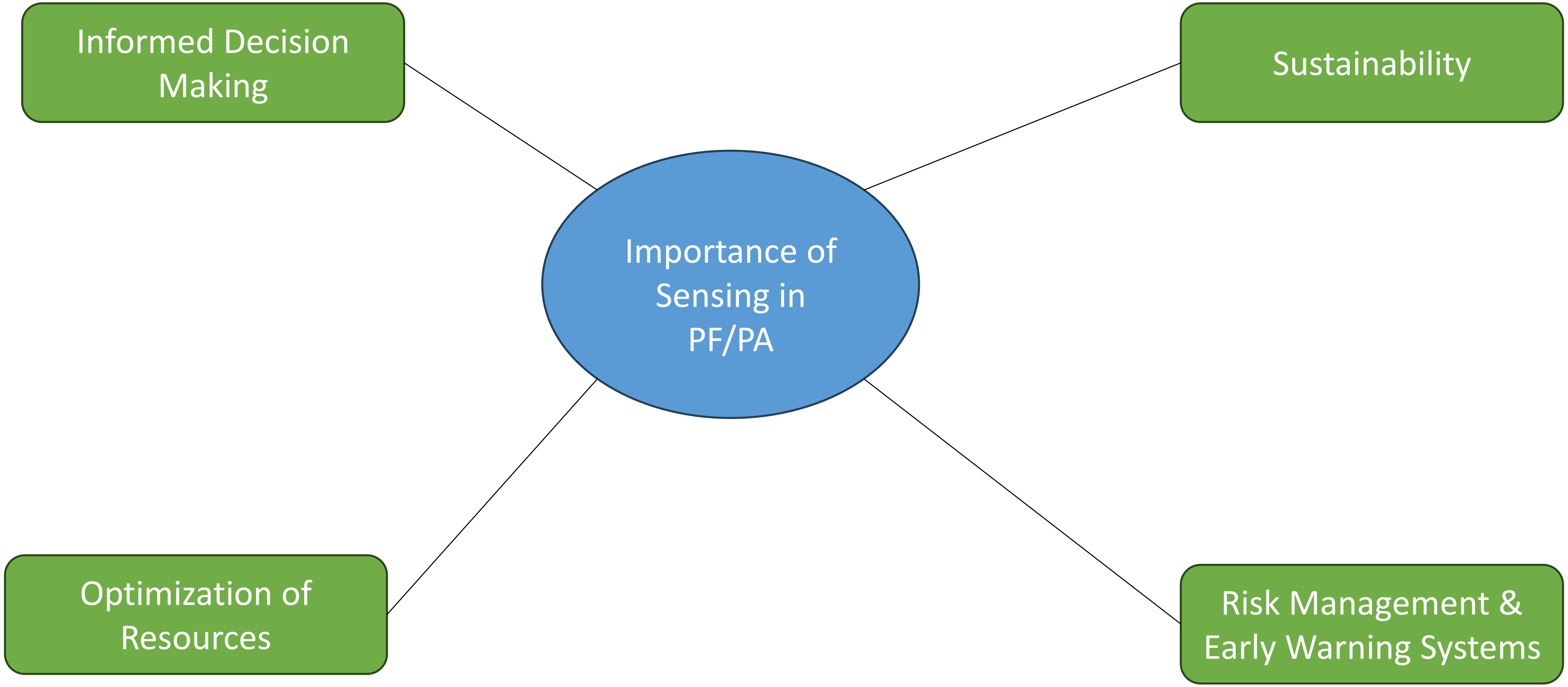
Role of Sensing in Precision Farming

- Sensing technologies are a critical component of **precision agriculture**, as they enable the **continuous collection of data** about field conditions, crops, and environmental factors
- Provide farmers with **precise and up-to-date information** about their fields that helps in making **data-driven decisions** on where and how to apply inputs, improving efficiency and reducing waste
- Helps in observing and responding with management actions to **spatial and temporal variability** in crops
- Based on the associated **time delay between sensing and management action** two fundamentally different precision agriculture (PA) techniques exist : **real-time sense and apply (RTSA),** and **conventional georeferenced PA**

Role of Sensing in Precision Farming

- RTSA is based on sensing a parameter and immediately using that information for a management action (e.g., **see and spray technology**)
- Geolocation is not required for RTSA
- Conventional georeferenced PA technology employs sensing and association of location with sensed data, a map of the sensed information
  - management action is not performed immediately but at a later time

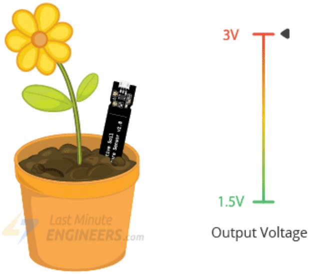
Importance of Sensing in Precision Farming



Types of Sensing Technologies

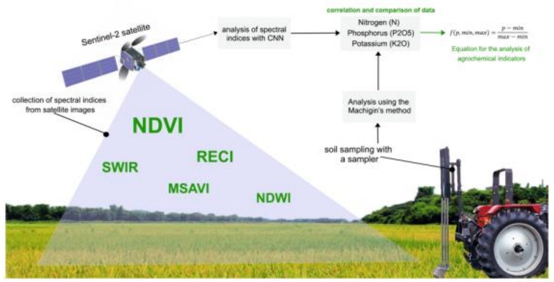
Sensing Technologies

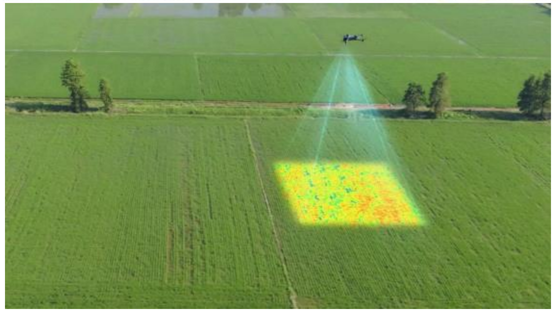
- In-Situ Sensing
- Proximal Sensing
- Remote Sensing




Veris soil EC mapping

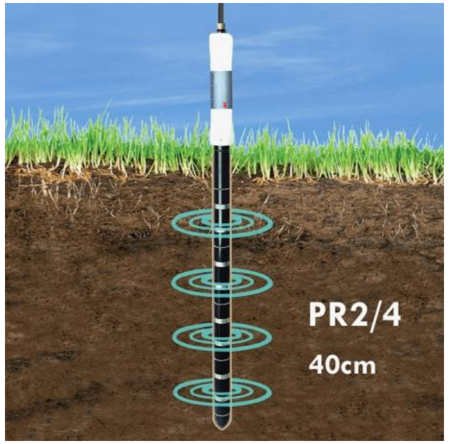

Leaf chlorophyll meter





In-Situ Sensing : Soil Moisture Sensor

- Soil moisture sensors are devices placed directly into the soil to **measure** or **estimate** the **water content in the soil** (usually volumetric water content)
- Provide real-time data about soil moisture levels, helping farmers make informed decisions about **irrigation scheduling** and **water management**



Volumetric water content Soil Moisture Sensors

- Volumetric water content (VWC) is the volume of water per volume of soil
- It is usually expressed as a percentage (%) and represented by **θ**
- Mathematically, it is given by:

$$\boldsymbol{\theta}(\%) = \frac{\boldsymbol{V_w}}{\boldsymbol{V_s}}$$

where $\boldsymbol{V_w}$ is volume of water in soil in m^3 or L and $\boldsymbol{V_s}$ is volume of soil in same unit.

- Example: 35% VWC means 0.35 cubic inch of water per cubic inch of soil
- Alternatively,

$$\boldsymbol{\theta}(\%) = \boldsymbol{GWC} \times \boldsymbol{\rho_b}$$

Where ***GWC*** is gravimetric water content (mass of water/mass of dry soil) and $\boldsymbol{\rho_b}$ is soil bulk density (mass of dry soil/volume of dry soil)

Quiz

A soil sample has a volume of water (V_w) of 0.05 m^3 and a total soil volume (V_s) of 0.25 m^3. What is the volumetric water content (θ)?

a) 0.15

b) 0.20

c) 0.25

d) 0.30

Quiz

A soil sample weighs 2000 g when fully saturated. After drying, its weight reduces to 1600 g. If the total volume of the soil is 1000 cm^3, calculate the volumetric water content (θ). [Assume 1 g of water = 1 cm^3]

a) 0.30

b) 0.40

c) 0.20

d) 0.50

Quiz

If a soil sample has a gravimetric water content (GWC) of 0.15 and a bulk density (ρ_b) of 1.4 g/cm³, what is the volumetric water content (θ)?

a) 0.21

b) 0.18

c) 0.15

d) 0.10

Water Potential Soil Moisture Sensors/Tensiometers

- Tensiometers measure the tension (or potential) of water in the soil
- Porous ceramic tip is inserted into the soil, and water moves into or out of the tensiometer tube depending on the soil moisture creating a vacuum that is measured to determine soil moisture
- Provides accurate readings in **sandy soils**.
- Unlike VWC sensors that measure the amount of water in the soil, **water potential sensors measure the availability of that water to plants**
- Plants can only access water that is **not bound too tightly to soil particles**.

Water Potential Soil Moisture Sensors/Tensiometers

What is Soil Water Potential?

- Water potential (ψ) is a measure of the energy required to move water from the soil into plant roots.
- It is expressed in units of pressure, typically **pascals (Pa), bars/centibars, or kilopascals (kPa)**
- Water potential is commonly expressed in kilopascals (kPa), where **0 kPa** represents **water that is freely available to plants** (saturated soil)
- Lower the water potential (i.e., **more negative values**), the more energy plants must use to extract water from the soil i.e., **water is NOT freely available** to plants

Types of Water Potential Soil Moisture Sensors

i. Tensiometers
ii. Granular Matrix
iii. Gypsum Block

Tensiometers

Gypsum Block Sensors

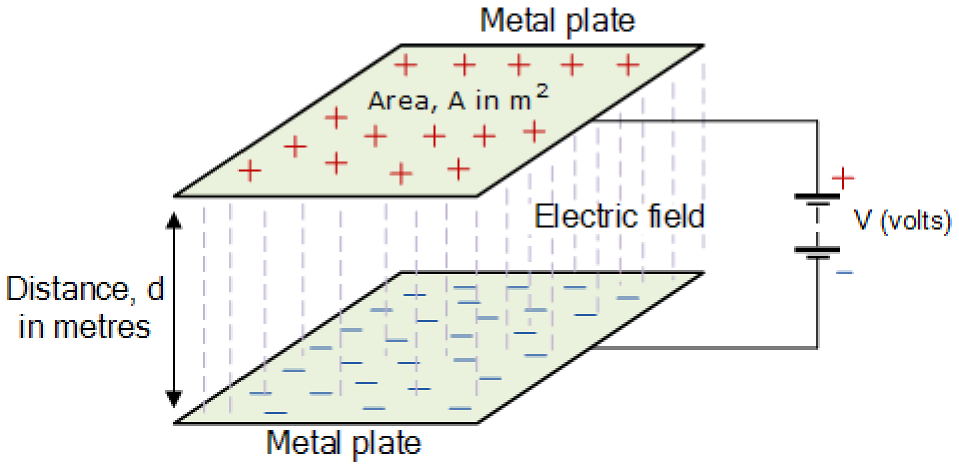
Granular Matrix Sensor

Key Soil Moisture Terms

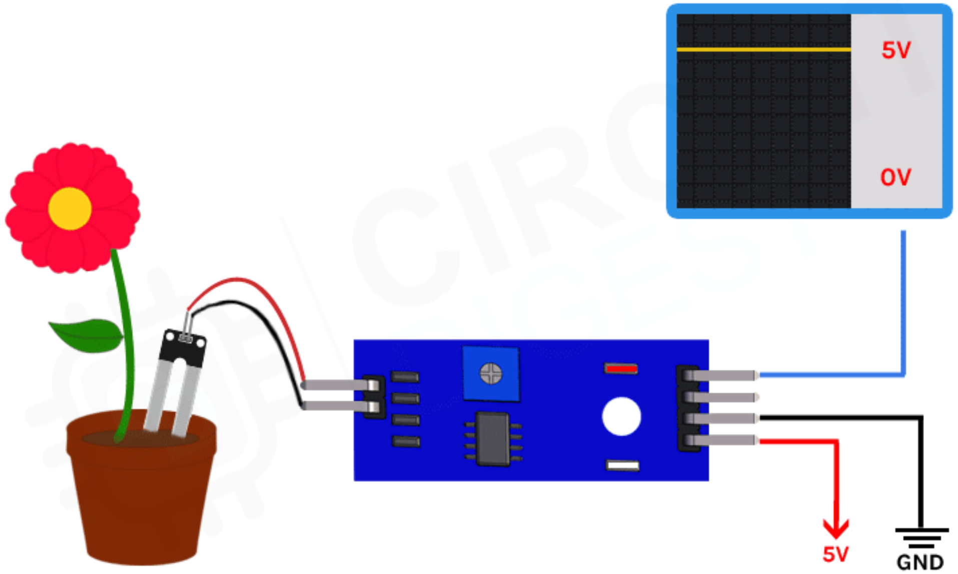
- **Field Capacity (FC)**
  - the amount of soil moisture remaining in the soil after excess water has drained away and the rate of downward movement has decreased
  - occurs **a day or two** after a rainfall or irrigation event when gravitational water has moved out of the root zone
  - benchmark for ideal soil moisture levels for plant growth
- **Saturated Soil**
  - saturated soil occurs when all the pore spaces in the soil are filled with water
  - usually happens immediately after heavy rainfall or irrigation
  - Plants cannot effectively absorb water in saturated soil because the lack of oxygen in the root zone restricts their ability to take up water and nutrients
- **Permanent Wilting Point (PWP)**
  - is the soil moisture level at which plants can no longer extract enough water to meet needs, causing them to wilt irreversibly
  - water is still present in the soil but is **held too tightly for plants to extract**

Soil Moisture Types Based on Technology

i. **Capacitance Sensors**
ii. **Resistance Sensors**
iii. **Time Domain Reflectometry (TDR) Sensors**
iv. Neutron Probe Sensors



TDR Sensor



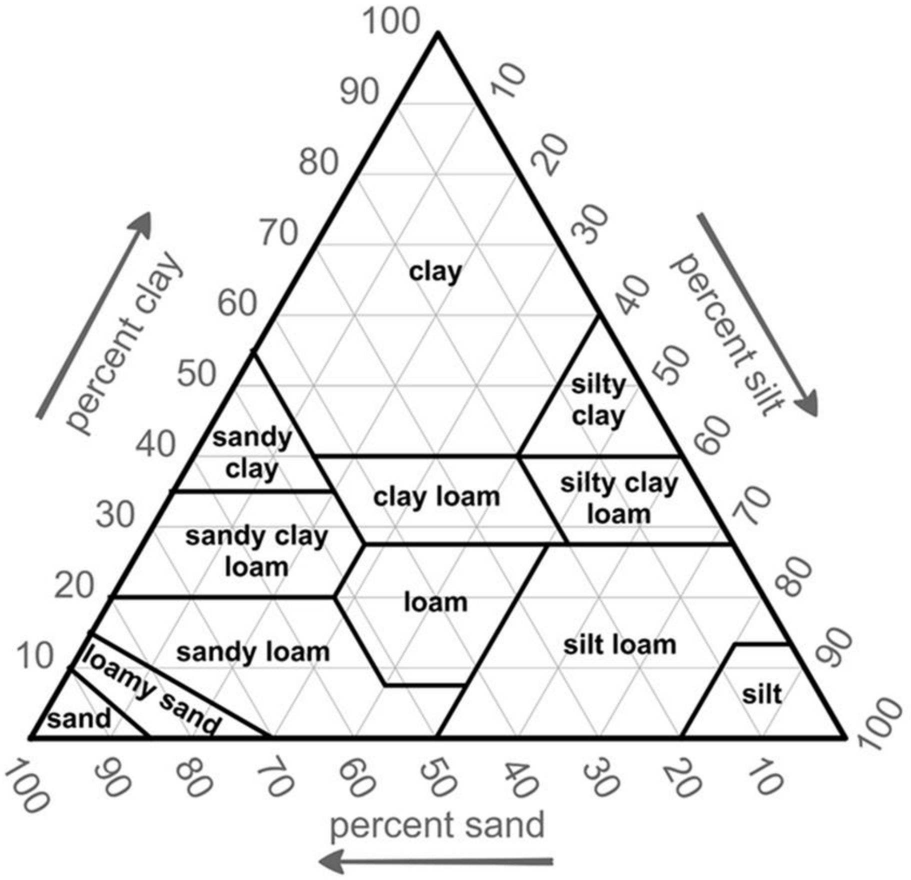
Resistance Sensors

Resistance Sensors

Soil Moisture Sensor for Irrigation Scheduling

Soil Texture Types

- Soil texture refers to the relative proportions of three primary soil particles: **sand, silt, and clay**
- Common Types: **Sandy, Silty, Clay, Loam, Sandy Loam, Clay Loam, Silt Loam**



Groenendyk, D. G., Ferre, T. P., Thorp, K. R., & Rice, A. K. (2015). Hydrologic-process-based soil texture classifications for improved visualization of landscape function. PloS one, 10(6), e0131299.

Soil Moisture Sensor for Irrigation Scheduling

Summary of Soil Texture Classes:

Soil Type	Sand %	Silt %	Clay %	Key Characteristics
Sand	> 85	< 10	< 10	Drains well, poor in nutrients
Sandy Loam	45-85	10-30	< 20	Good drainage, moderate water retention
Loam	25-50	30-50	10-30	Balanced texture, ideal for most crops
Silt Loam	0-20	60-80	0-20	Smooth texture, holds moisture well
Clay Loam	20-45	15-45	27-40	Retains water, risk of compaction
Clay	< 45	< 40	> 40	High water retention, poor aeration

Soil Moisture Sensor for Irrigation Scheduling

Soil Available Water (AW)

- The amount of water in the soil that is available for plant uptake, typically measured as the difference between the soil water content at field capacity and the permanent wilting point.

$$AW = FC - PWP$$

Available Water Depletion Percentage (AWD%)

$$\boldsymbol{AWD\%} = \left(\frac{FC - \theta}{FC - PWP}\right) \times 100 = \left(\frac{\boldsymbol{FC - \theta}}{\boldsymbol{AW}}\right) \times \mathbf{100}$$

θ : Current VWC (%) in soil

Soil Moisture Sensor for Irrigation Scheduling

Example: Let us say, you have sandy loam soil that has field capacity (FC) of 30%, PWP of 15% and your soil moisture sensor reads its current VWC (θ)as 22%. Then what is the AWD% of your soil?

Solution:

$$AWD\% = \left(\frac{FC - \theta}{FC - PWC}\right) \times 100 = \left(\frac{30-22}{30-15}\right) \times 100 = \mathbf{53.33\%}$$

Soil Moisture Sensor for Irrigation Scheduling

Irrigation Trigger Point/Management Allowable Depletion (MAD)

- Farmers typically aim to irrigate when a certain percentage of available water has been depleted, often referred to as the **Management Allowable Depletion (MAD)**
- This threshold can vary based on the **crop, soil type, and environmental conditions**.

Soil Moisture Sensor for Irrigation Scheduling

Quiz

The field capacity (FC) of a soil is 30%, the permanent wilting point (PWP) is 15%, and the current volumetric water content (VWC) is 18%. The MAD value for the crop is set at 40%. Should irrigation be applied?

We know that : AW=FC-PWP=30%-15%=**15%**

This means that available water in the soil is 15%.

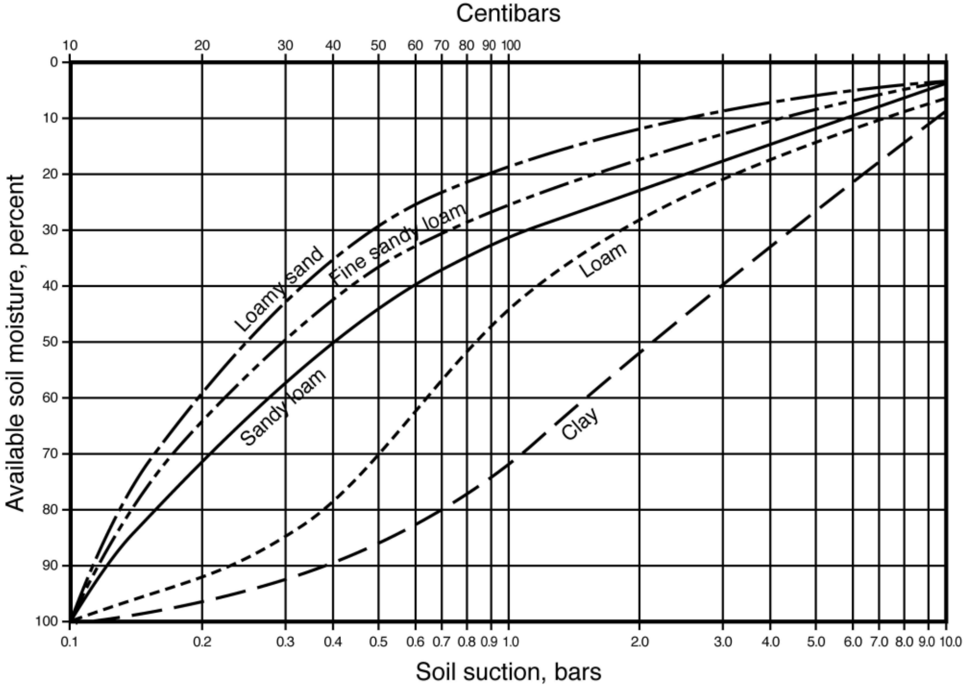
Given, MAD=40%

MAD threshold = 40% of AW = $\left(\frac{40}{100}\right) \times 15 = \mathbf{6}\%$

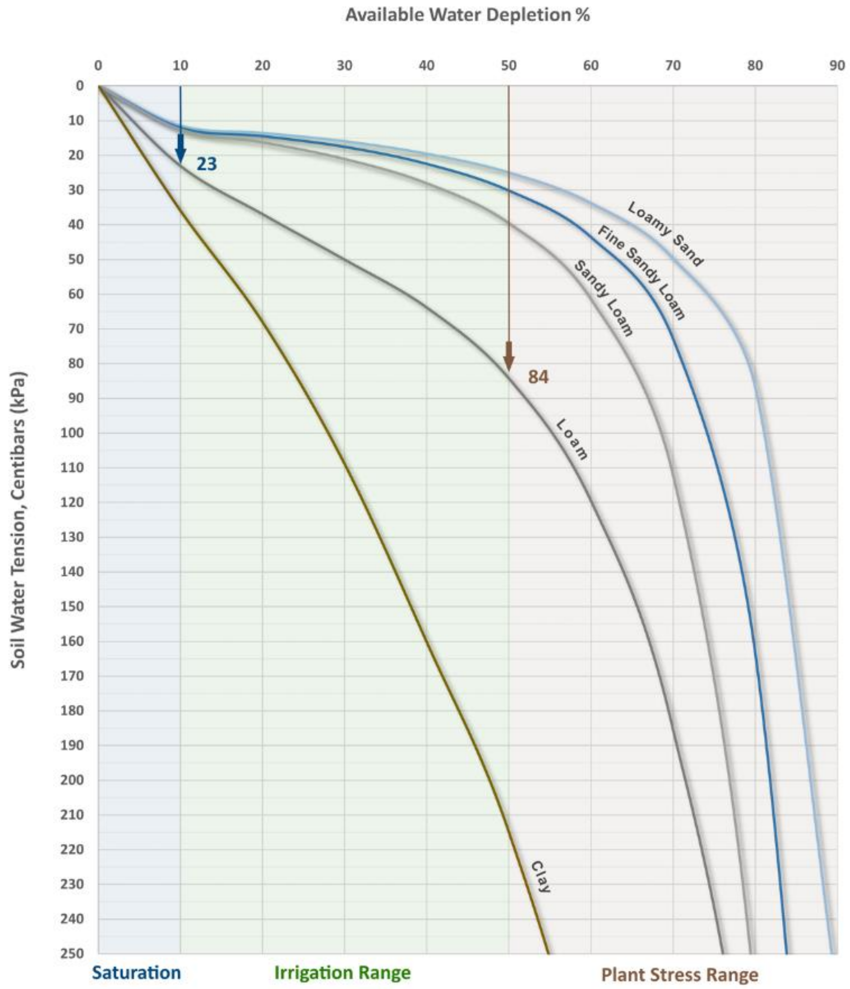
Therefore, Soil Moisture Threshold to trigger irrigation = 30%-6% = **24%.**

But current VWC is 18% which is below 24%, **therefore irrigation should be applied**.

Soil Moisture Sensor for Irrigation Scheduling



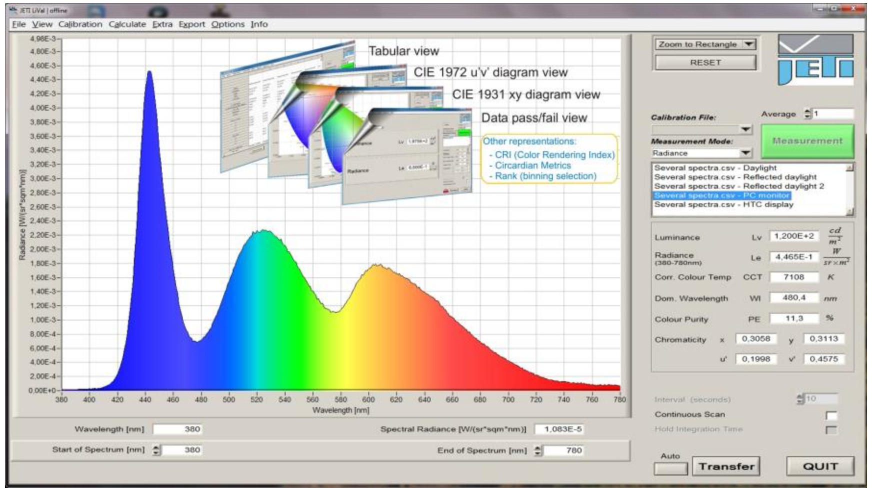
Adapted (with permission) from the *BC Trickle Irrigation Manual,* BC Ministry of Agriculture and Food, Irrigation Industry Association of British Columbia (T.W. Van der Gulik)
Note: 1 kpa = 1 centibar; 100 centibars = 1 bar



https://www.irrometer.com/basics.html

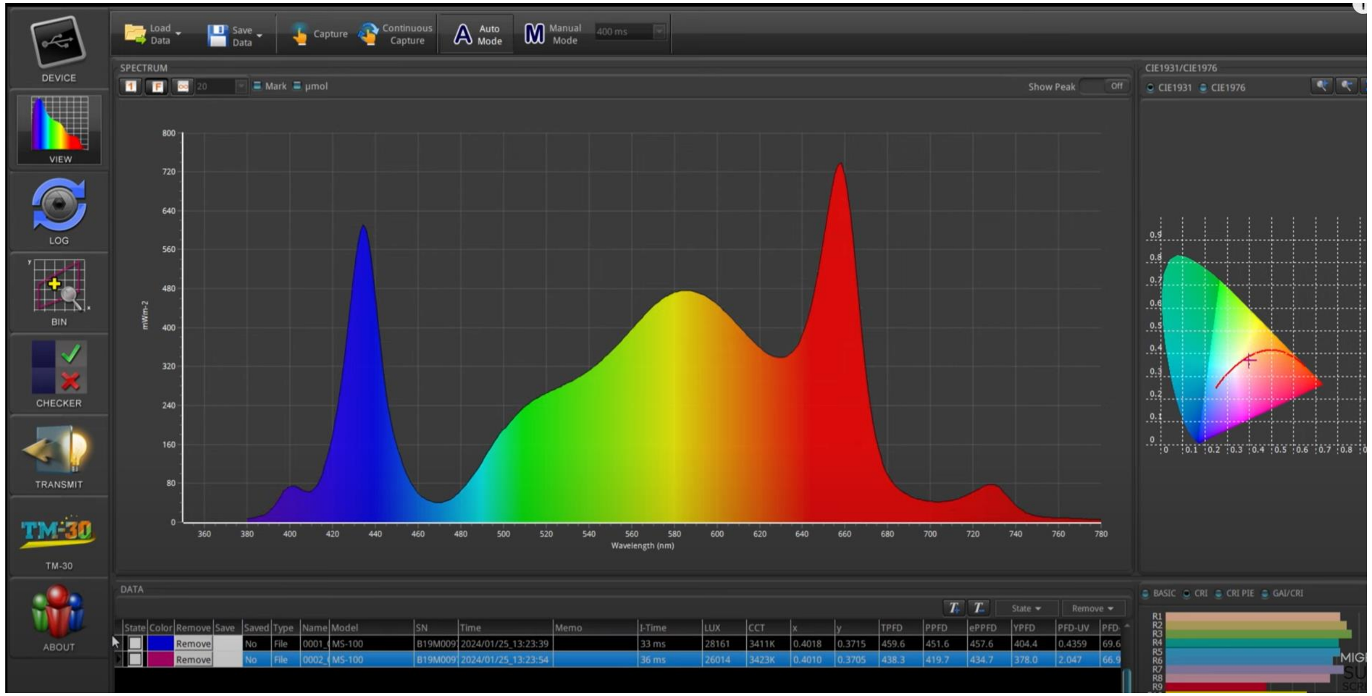
Proximal Sensing: Spectroradiometer

- Spectroradiometer is a device that measures the spectral power distribution of light across various wavelengths
- Captures spectral reflectance and absorbance data, helping to identify different materials based on how they reflect or absorb light.
- When used in **proximity to crops**, it collects detailed spectral data that can be used to **monitor plant health, stress, and growth**



Proximal Sensing: Spectroradiometer

- Spectroradiometer emits light onto a target (e.g., crop canopy) and measures the reflected light across a wide range of wavelengths, from visible light (400–700 nm) to near-infrared (700–2500 nm).



[Apogee M100 spectroradiometer | Grow Light spectrum analyser (youtube.com)]

Proximal Sensing: Spectroradiometer

Key Applications in Precision Agriculture

- Crop Health Monitoring
- Nutrient Management
- Water Stress Detection
- Yield Prediction

Next Lecture

- Sensing Technologies for Precision Farming II