Probing the Benefits of Soil Moisture Sensors

Daran R. Rudnick, Ph.D.
Assistant Professor: Irrigation Specialist
Department of Biological Systems Engineering
West Central Research and Extension Center
University of Nebraska-Lincoln
Phone: (308) 696-6709, Email: daran.rudnick@unl.edu

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Importance of Irrigation

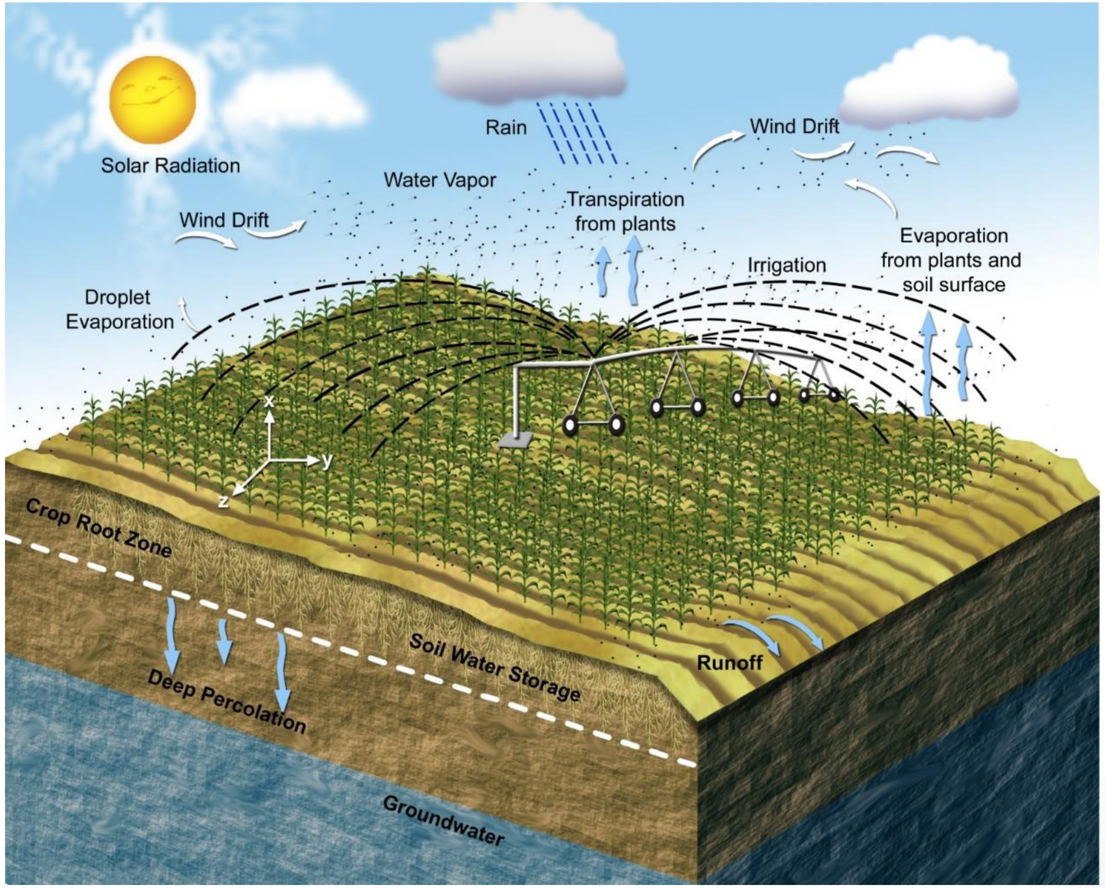
When precipitation and soil water storage in the crop root zone cannot supply the root system with enough water to meet crop evapotranspiration (ET) demand, irrigation is required.

Insufficient Irrigation can reduce:

- Total Biomass
- Grain Yield
- Grain Quality
- Net Return ($ per acre)

Excessive irrigation can result in:

- Runoff
- Soil Erosion
- Deep Percolation of Water (and Nutrients)
- Environmental Degradation
- Anaerobic Soil Conditions (Yield Penalty)
- Increased Pumping Cost (i.e., energy cost)



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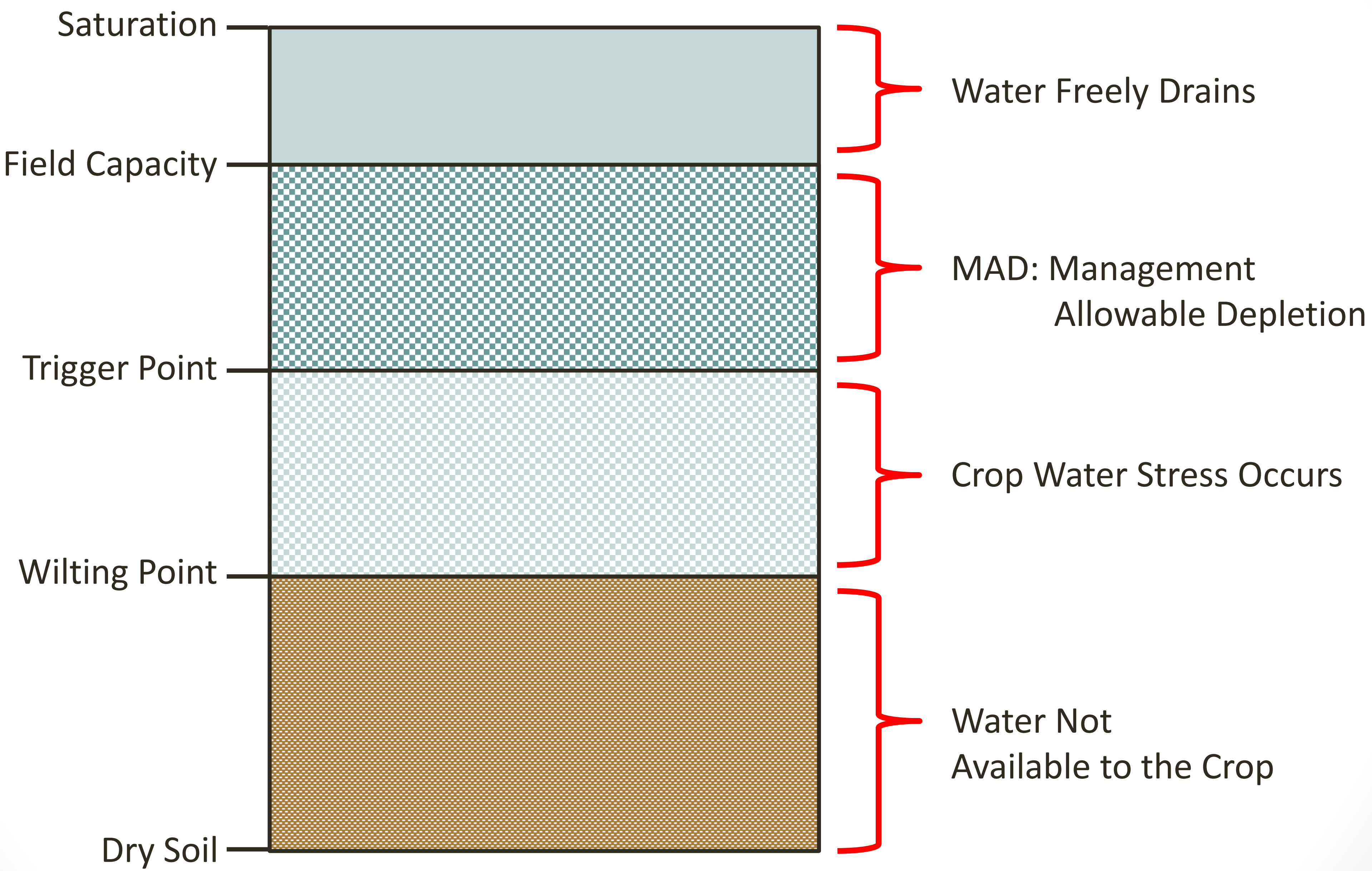
Concepts for Managing Irrigation with Soil Moisture Sensors

Soil Water Diagram for Irrigation



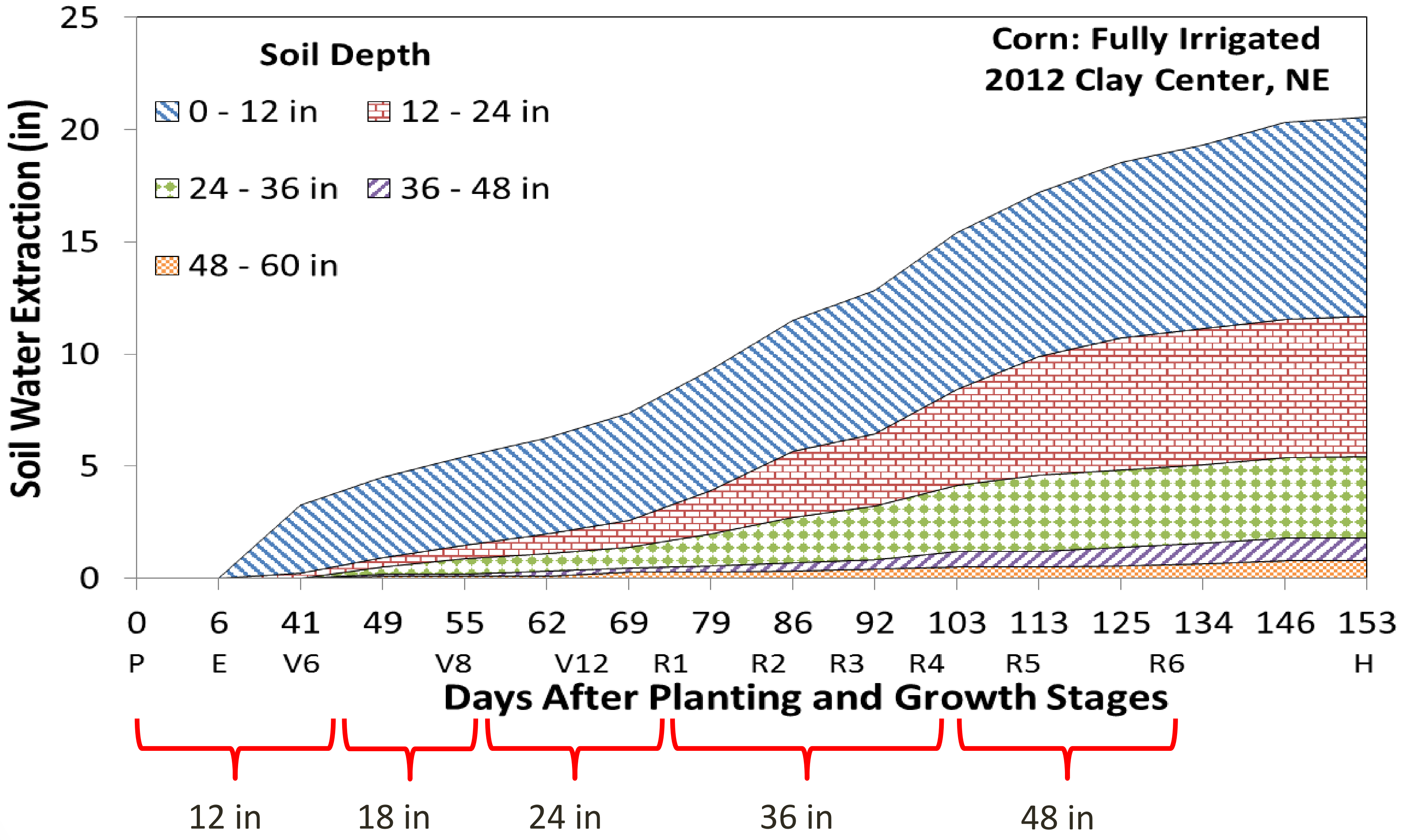
MAD: Management Allowable Depletion

- Lower limit of available soil water that the crop can use before water stress occurs.
- Taken as a percentage of available water holding capacity (AWHC)
  - AWHC = Field Capacity – Permanent Wilting Point
- MAD is typically set at 45 to 50%; however, irrigation should be triggered earlier to allow the system to complete the revolution prior to the last portion of the field dropping below MAD.

Soil Type	AWHC (in/ft)	MAD @ 50% (in/ft)
Silt Loam	2.5	1.25
Sandy Clay Loam	2.0	1.00
Silty Clay Loam	2.0	1.00
Silty Clay	1.6	0.80
Sandy Loam	1.4	0.70
Loamy Sand	1.1	0.55
Fine Sand	1.0	0.50

Source: Irmak and Rudnick (2014)

Effective Rooting Depth



Soil Depth Used for Scheduling Irrigation

Direct Measurement of Soil Water Content

- The success of irrigation management is, in part, contingent upon the accuracy of soil moisture data.
- Direct soil moisture measurements
  - Labor intensive
  - Time consuming
  - Non-continuous in nature
- Soil Water Content (θv)
  1. Remove known volume of soil
  2. Dry Soil @ 221°F until constant wt.
  3. Calculate Vol. of Water Removed
  4. $\theta_v = \frac{Volume\ of\ Water}{Bulk\ Volume}$

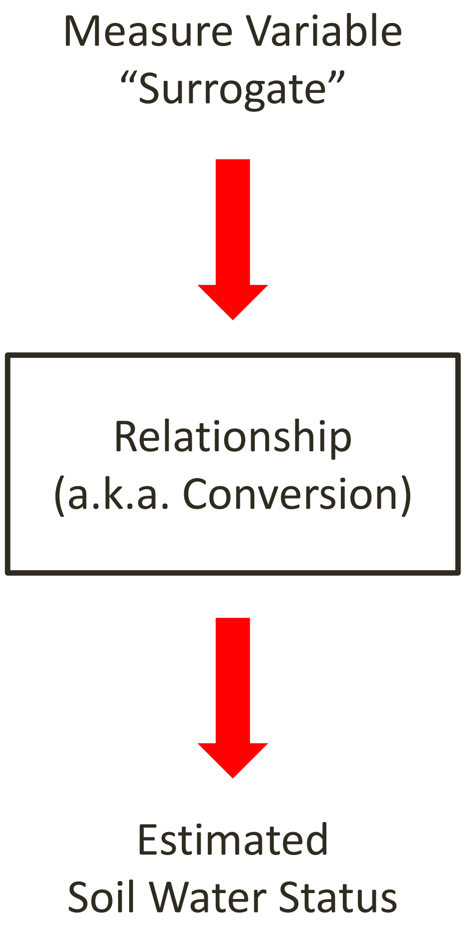
Direct Measurement




Indirect Soil Moisture Monitoring Methods

- Indirect methods measure a surrogate property and relate it to soil water content or potential.

- Indirect methods
  - Hand Feel
  - Neutron Attenuation
  - Capacitance
  - Time Domain Reflectometry
  - Frequency Domain Reflectometry
  - Time Domain Transmissometry
  - Electrical Resistance
  - Tensiometers
  - Thermal (i.e., Heat Dissipation)



Some In-Situ Soil Moisture Sensor Companies

Delta-T Devices

Sentek technologies

CPN
AN INSTROTEK® COMPANY

AquaCheck
SOIL MOISTURE MANAGEMENT

TROXLER
The Leader in Construction Testing Equipment

DECAGON DEVICES

AquaSpy®

JOHN DEERE

Acclima

Stevens®
Water Monitoring Systems, Inc.

CropMetrics™
Yield Optimization Technology

CAMPBELL® SCIENTIFIC
WHEN MEASUREMENTS MATTER

DELMHORST®
INSTRUMENT CO.
WHEN ACCURACY IS THE POINT.™

IRROMETER

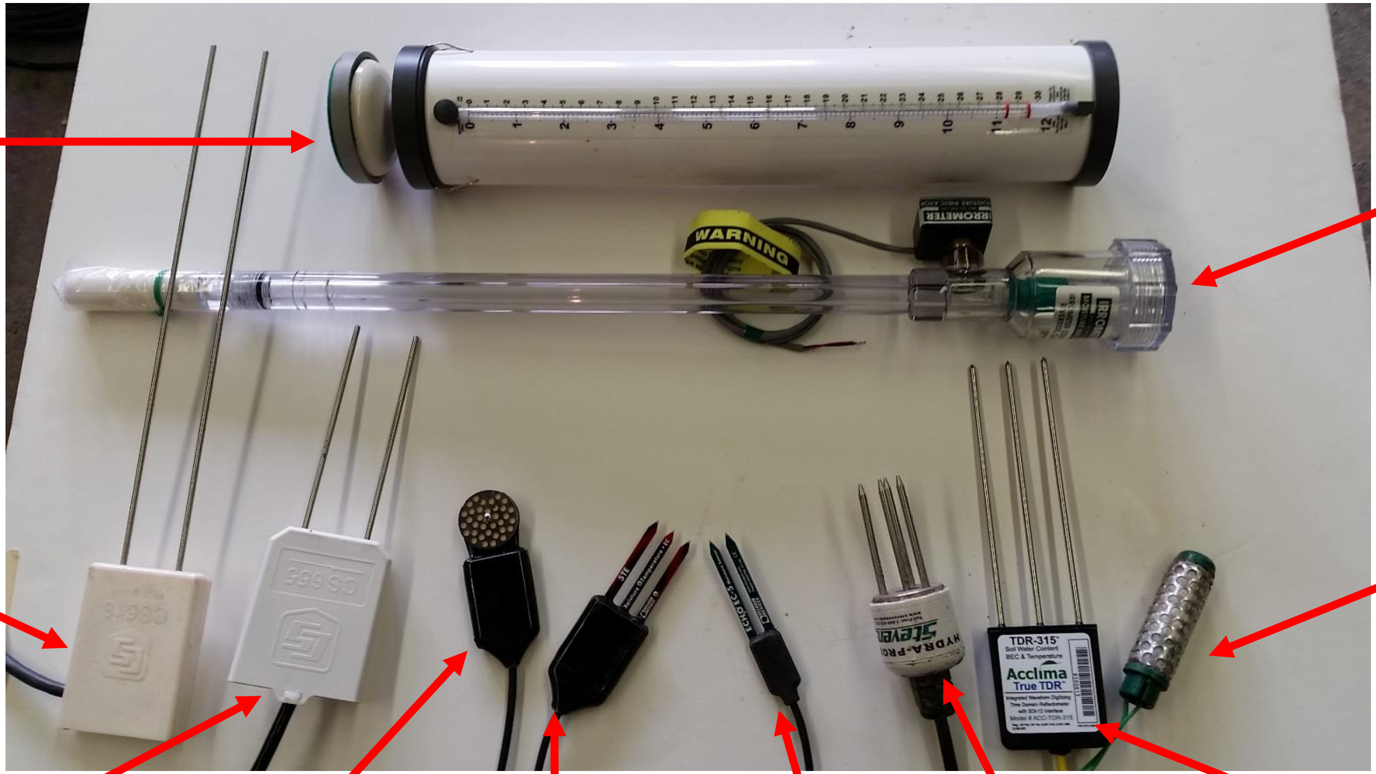
HORTAU
SIMPLIFIED IRRIGATION®

IMKO

Spectrum®
Technologies, Inc.

Soil Moisture Sensors & ETgage

Legend:
SWP: Soil Water Potential
SWC: Soil Water Content
Temp: Soil Temperature
EC: Bulk Electrical Conductivity



ETgage (Atmometer)
Reference ET

Irrometer Tensiometer
SWP

Campbell Scientific CS616
SWC

Irrometer Watermark
SWP

Campbell Scientific CS655
SWC, Temp, & EC

MPS-2 or MPS-6
SWP & Temp

5TE
SWC, Temp, & EC

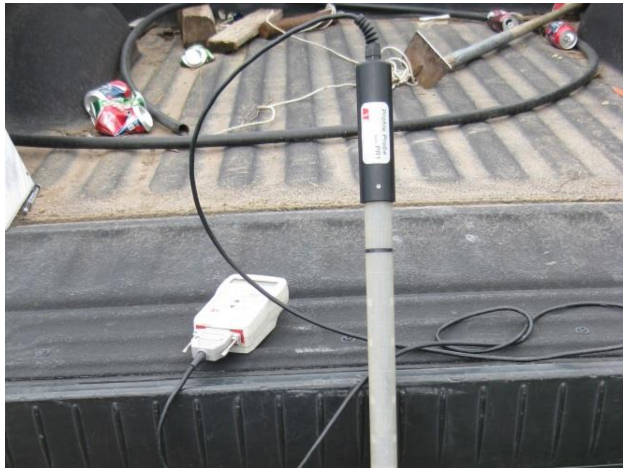
EC-5
SWC

---------- Decagon Devices ----------

Stevens Hydra Probe II
SWC, Temp, & EC

Acclima True TDR
SWC, Temp, & EC

Soil Moisture Sensors



Hand Feel Method

- Summary:
  - Viewing and feeling the soil to make an inference on soil water status to determine whether or not irrigation is required. It is often the least accurate method, because it does not provide a quantitative assessment of soil moisture, but rather a subjective qualitative assessment.
- Description:
  - Inexpensive
  - Relies on the ability of a user to view and feel the soil
  - Challenging when working with layered soils or different soil types due to differences in soil properties

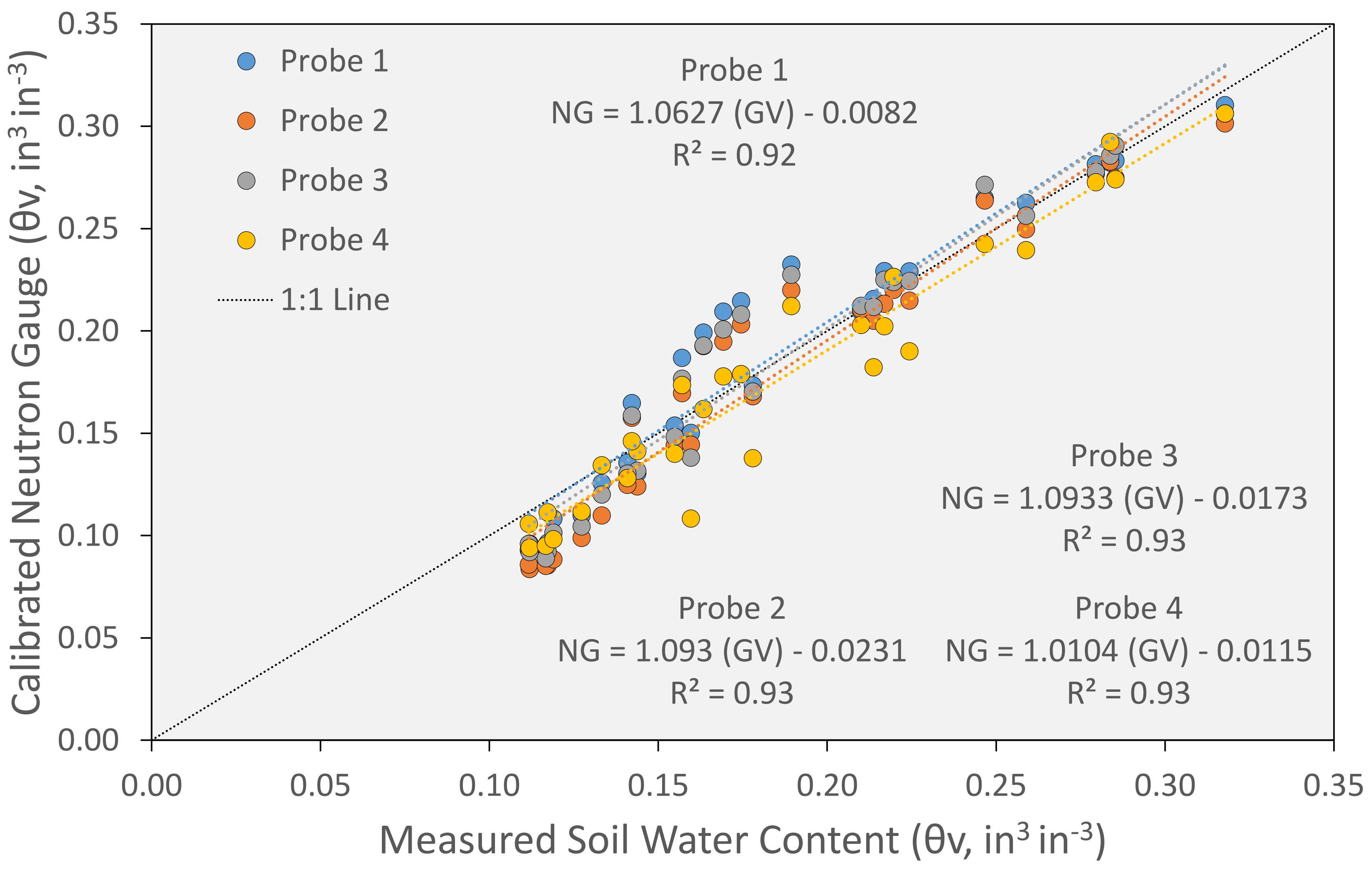
Not Recommended

Neutron Attenuation

- Summary:
  - Most accurate indirect soil moisture sensor available. Comprised of a neutron source and detector, which are lowered into access tubes. The source emits fast neutrons, approx. 17,000 neutrons per second, where they collide with hydrogen atoms (water) in the soil and slow down enough to be counted by the detector.

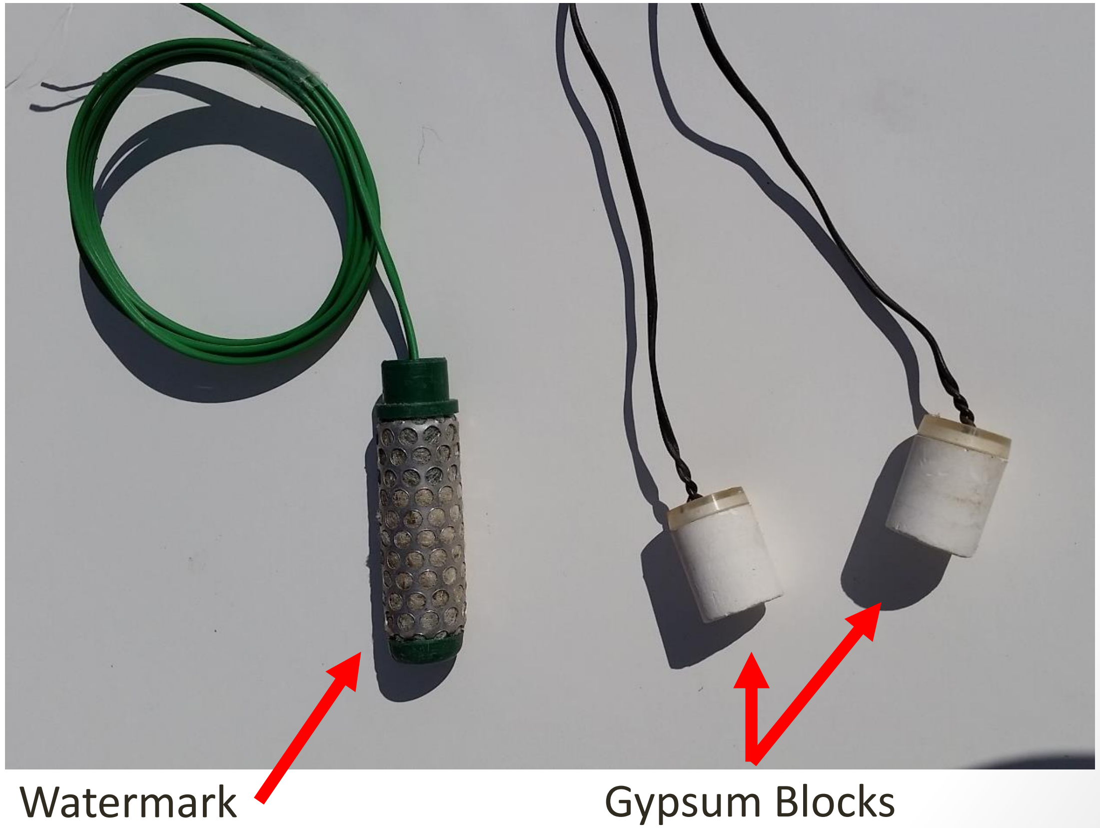
- Description:
  - Highly accurate
  - Not affected by temperature and salinity, but influenced by OMC, clay content, soil texture, & chemical elements
  - Field calibration still recommended
  - Radioactive source: Requires training, licensing, & safety measures when handling, storing, and transporting
  - Expensive (> $10,000)

Neutron Attenuation

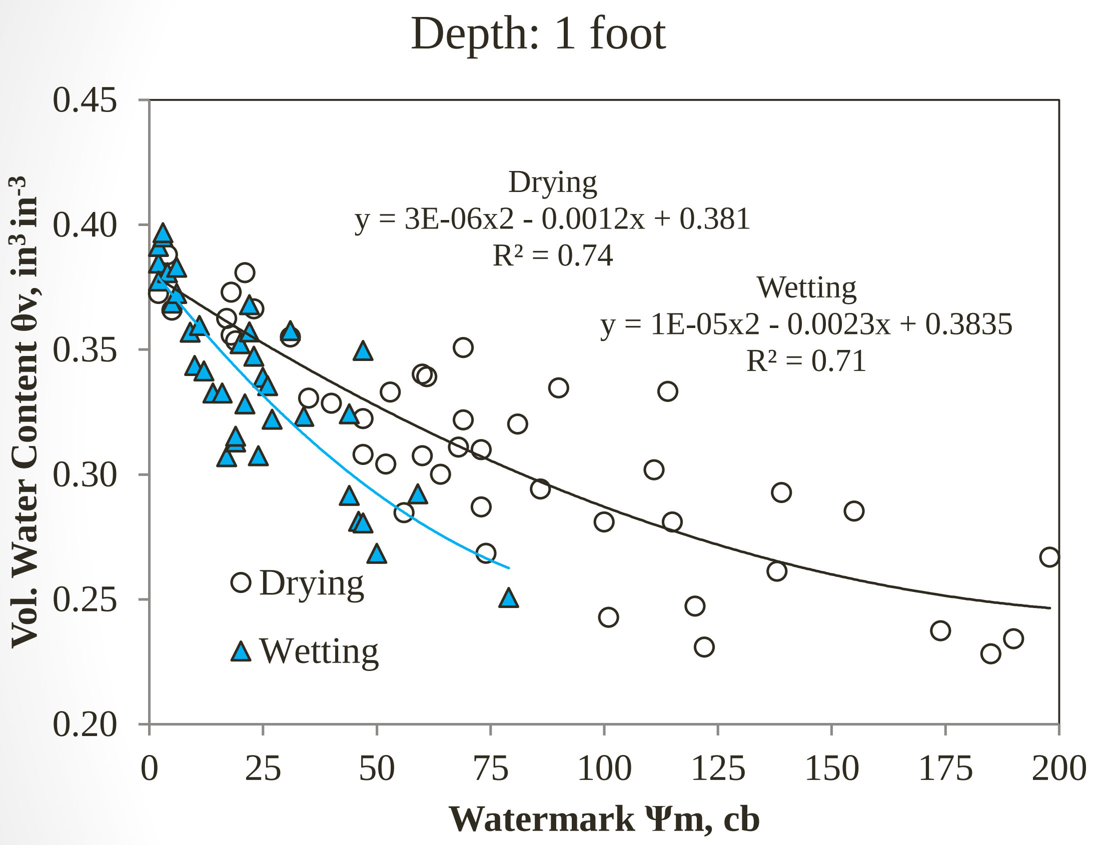


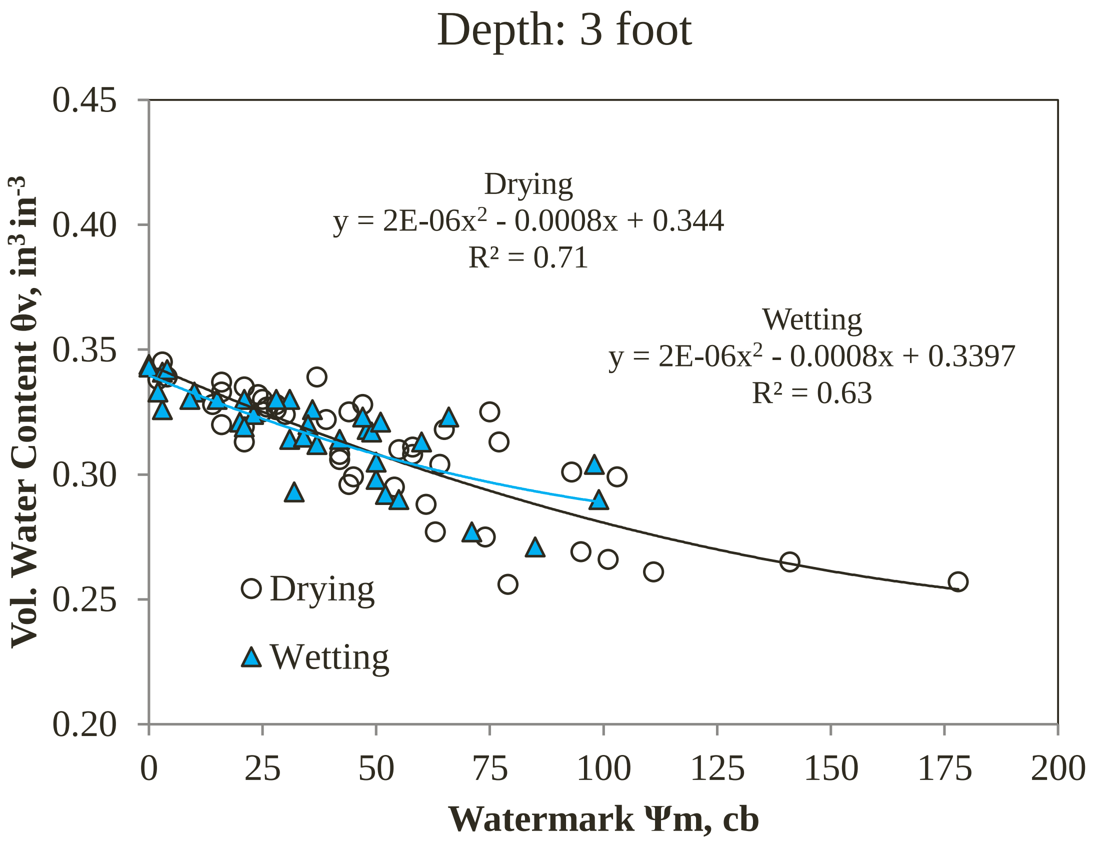
Electrical Resistance Sensors

- Summary:
  - Comprised of two non-connecting electrodes imbedded in a porous media (usually gypsum). A current is applied across the electrodes, which is affected by water content (θv); as θv increases, resistance decreases. The sensor outputs a voltage that is proportional to the resistance in the porous medium, which is converted to soil matrix potential via a calibration equation.
- Description:
  - Relatively low cost & easy to use/install
  - Reports "tension" not "water content"
  - Requires good soil contact
    - Some issues with high sandy soils at high tensions or swelling clays
  - Minor Temperature effects
    - Tension decreases by 1% for each 1°F increase above 70°F & vice versa
  - Response Time (potential lag)
  - Hysteresis Effects (i.e., wetting and drying curves are not the same)



Hysteresis Effects: Wetting versus Drying Cycles



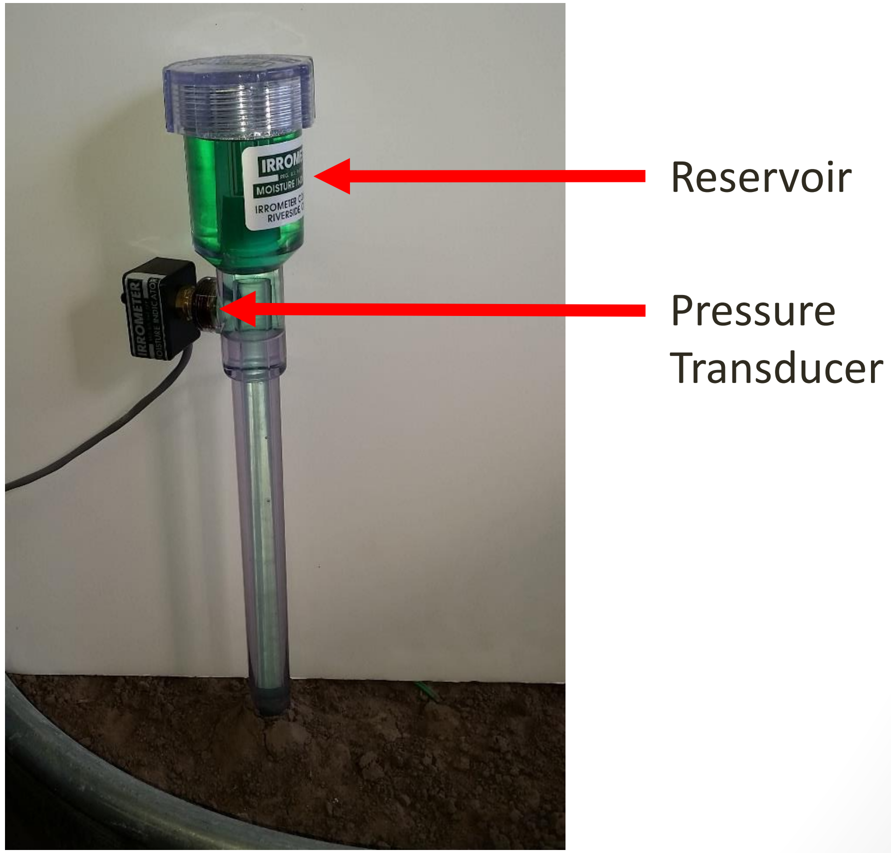


Drying Cycle: Previous 3 days experienced no precipitation and/or irrigation
Wetting Cycle: Previous 3 days experienced precipitation and/or irrigation

Tensiometers

- Summary:
  - A water filled tube with a hollow ceramic tip is placed in the soil at a desired depth. The sensor will equilibrate with the soil, by pulling water out of the tube while the soil dries and pulling water into the tube as the soil wets. This process creates tension within the access tube and the tension is measured using a vacuum gauge or pressure transducer.

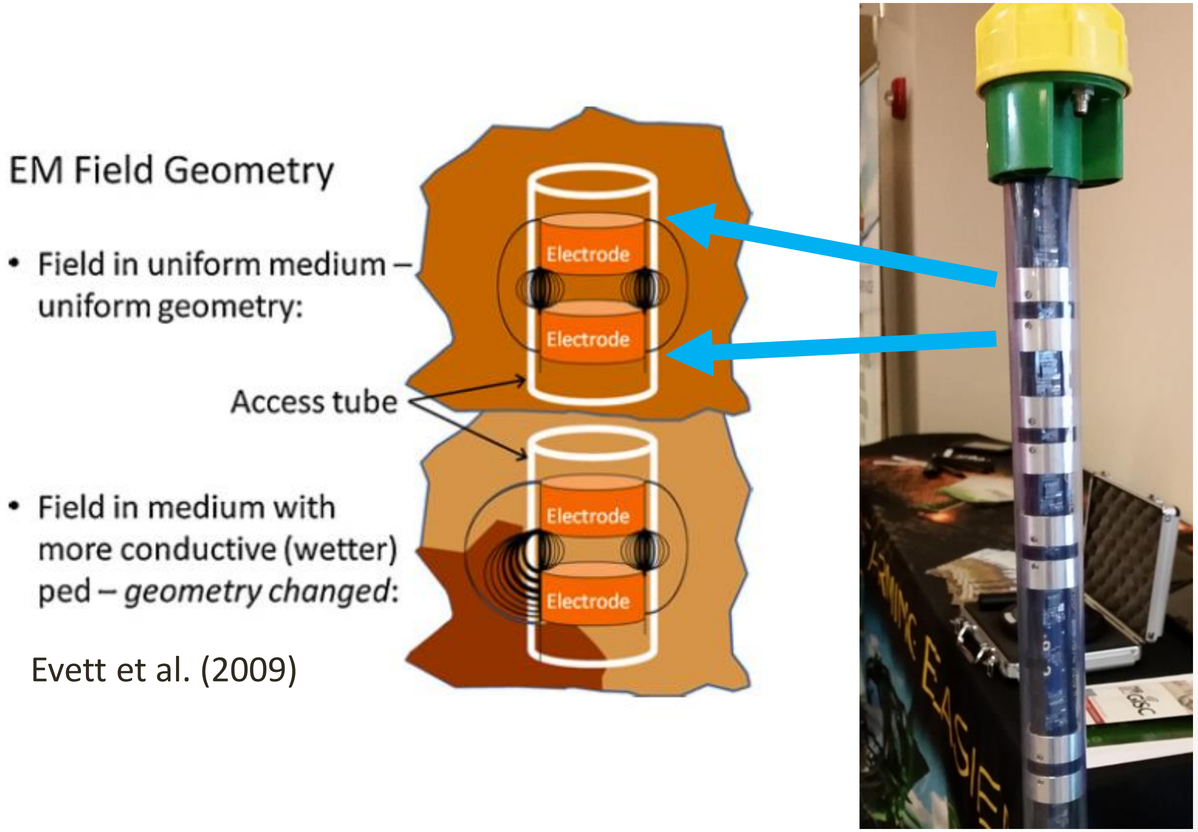
- Description:
  - Operational range: 0 to ~85 cb
    - Within irrigation range for sandy soils
    - Not within irrigation range for fine-textured soils
  - Limitation on depth of install
  - Reports "tension" not "water content"
  - Requires good soil contact
  - Response Time (potential lag)
  - Hysteresis Effects (i.e., wetting and drying curves are not the same)
  - Routine maintenance



Capacitance Sensors in Access Tubes

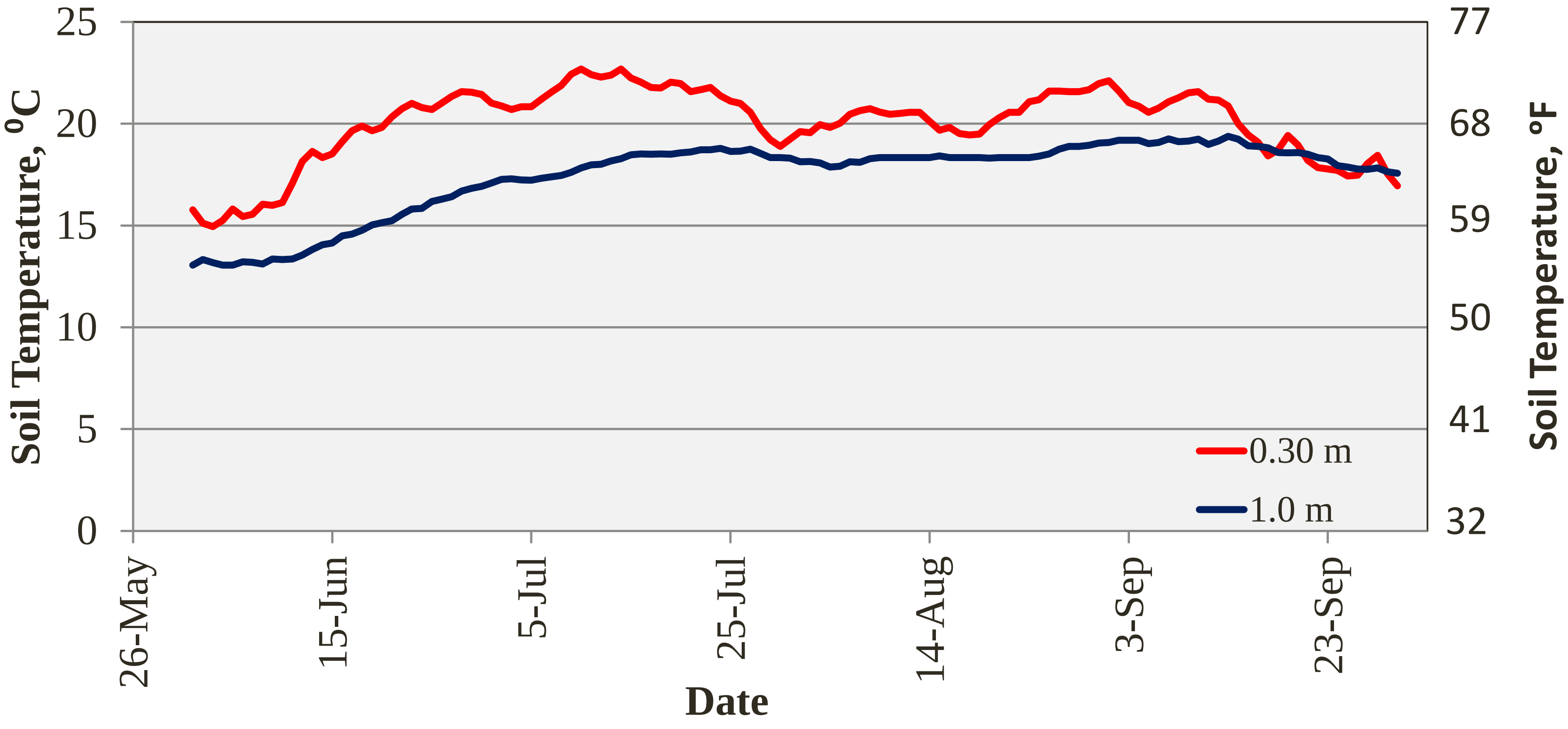
- Summary:
  - Electromagnetic (EM) sensors that estimate soil water content based on the dielectric properties of the soil. Usually consists of pairs of metal rings (i.e., capacitor), and the use of an electronic oscillator. The capacitor emits an EM field that extends out of the access tube into the soil, where the capacitance can be influenced by the soil bulk electrical permittivity, and therefore, soil water content.

- Description:
  - Capacitors can often be placed at various depths within access tube
  - Continuous monitoring capabilities
  - Fast response time
  - Susceptible to various factors: soil type and structure, temperature, wetting patterns, soil salinity, air gaps, clay content, among others
  - Proper installation is essential
  - Measurement frequency impacts on sensing volume



Evett et al. (2009)

Greater Fluctuations in Soil Temp near Surface



Factory Calibration Equations

- Factory calibrations are often performed under controlled laboratory conditions, which are not always representative of field conditions. The derived factory calibration equations (often imbedded into the sensor electronics) are typically developed by pooling a range of soil types together and fitting and/or parameterizing the curve. More recently, soil specific curves are being developed to improve performance of factory calibrations.

- Since “indirect” soil moisture sensors can be affected by influencing factors, such as soil temperature and soil physical and chemical properties, the manufacturer supplied calibration equations may not be suitable for all settings. Depending on sensor type and location the following are possible:
    1. The manufacturer calibration is appropriate and no adjustments are needed
    2. A site-specific calibration can be performed to correct the manufacturer calibration
    3. Additional sensors (e.g., temperature) are needed to adjust sensor output
    4. The sensor is not appropriate for the location and a different sensor technology should be adopted

Overview of Factors Effecting Sensor Performance

<u>Soil and Climate Related:</u>

- θv Range
- Salinity
- Ion Concentration
- Soil Temperature
- Particle Size Distribution
- Soil Layering
- Wetting and Drying Cycles

<u>Sensor Technology:</u>

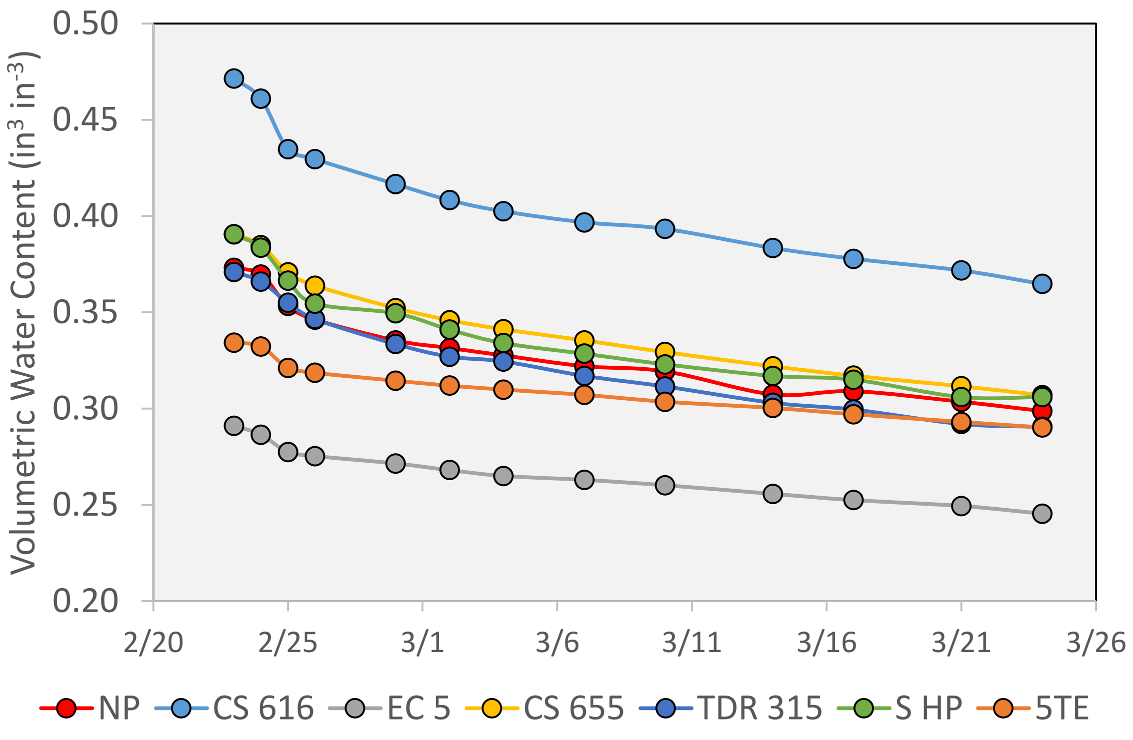
- Sensing Volume (Related to soil)
- Sensor Spacing (Vertical)
- Response Time
- Operational Range and Frequency

<u>Field Calibration:</u>

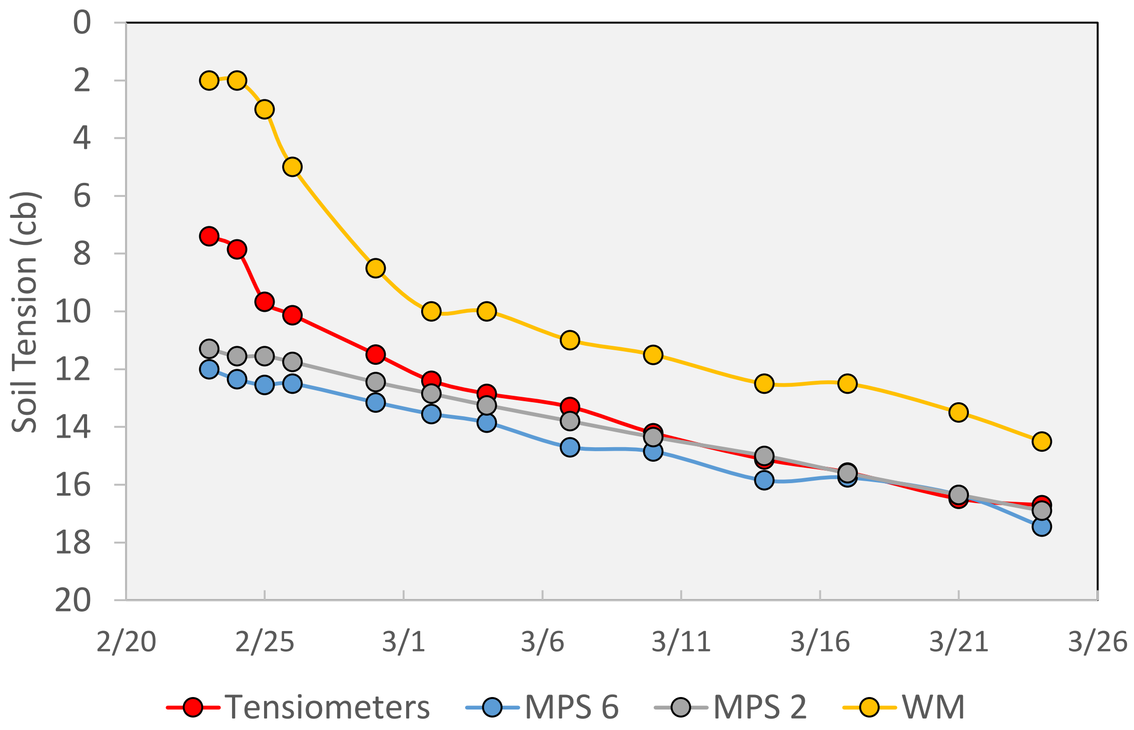
- Sensor technologies will not necessarily respond the same to the aforementioned
- Spatial and temporal variability of influencing factors, can require separate calibrations
- Soil layers closer to the surface can experience greater fluctuations in soil temperature and water content; which may consequently result in greater error if un-adjusted as compared to lower soil depths

Laboratory Sensor Evaluation

Laboratory Sensor Evaluation

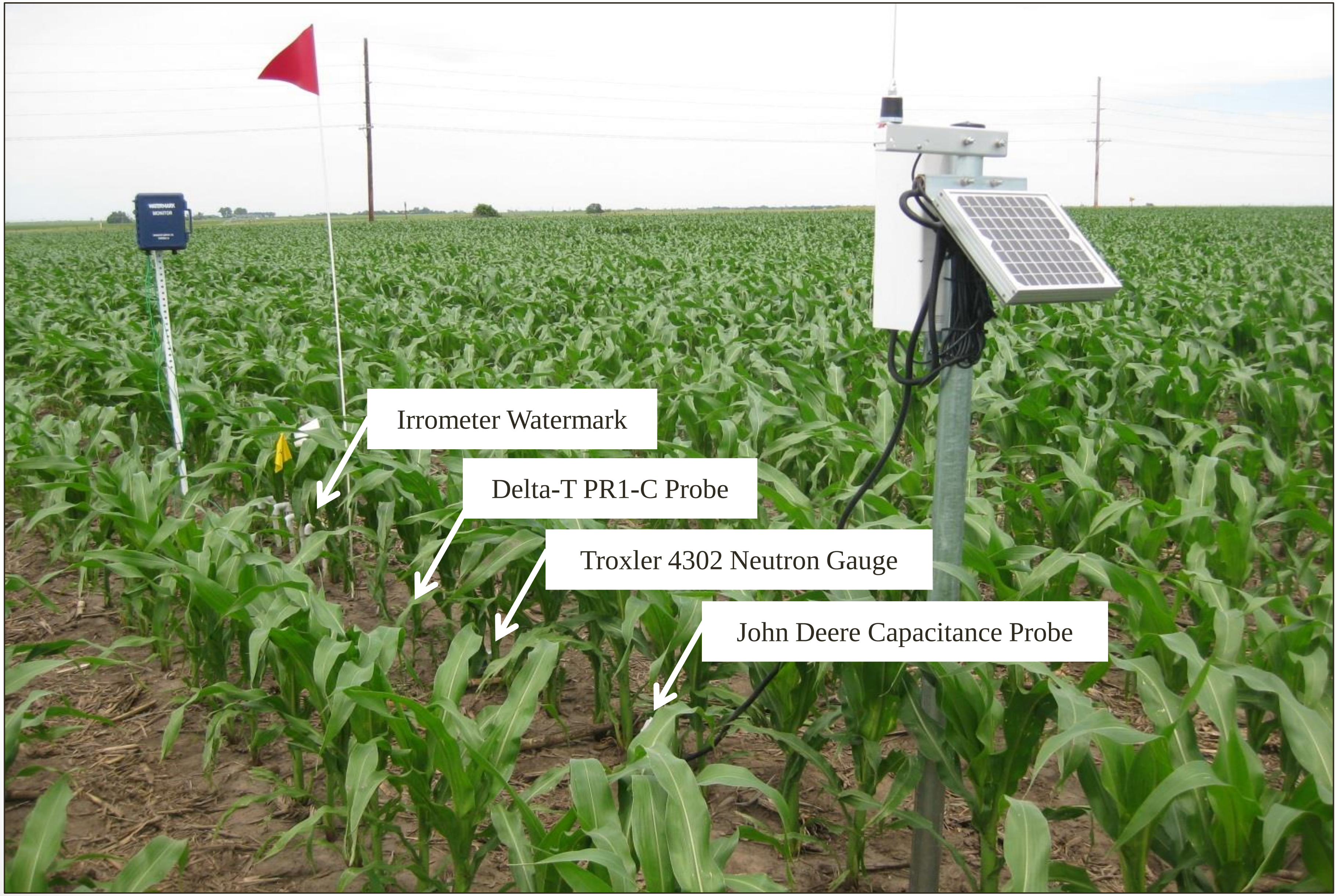


- Laboratory evaluation using site specific soils can help identify the accuracy and precision of the sensors.

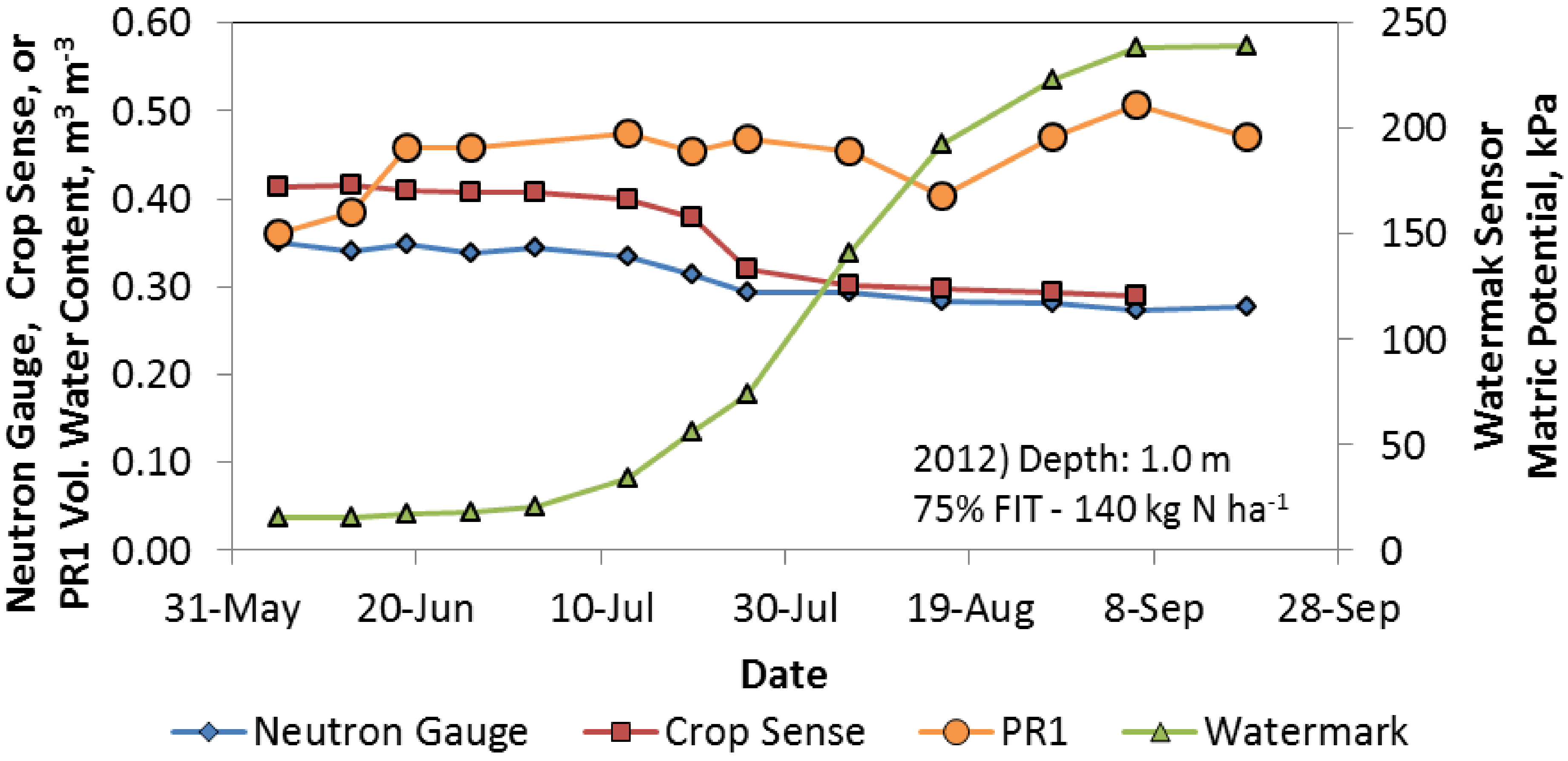


- Field evaluation is necessary to determine how well the sensors will perform under dynamic in-season conditions.

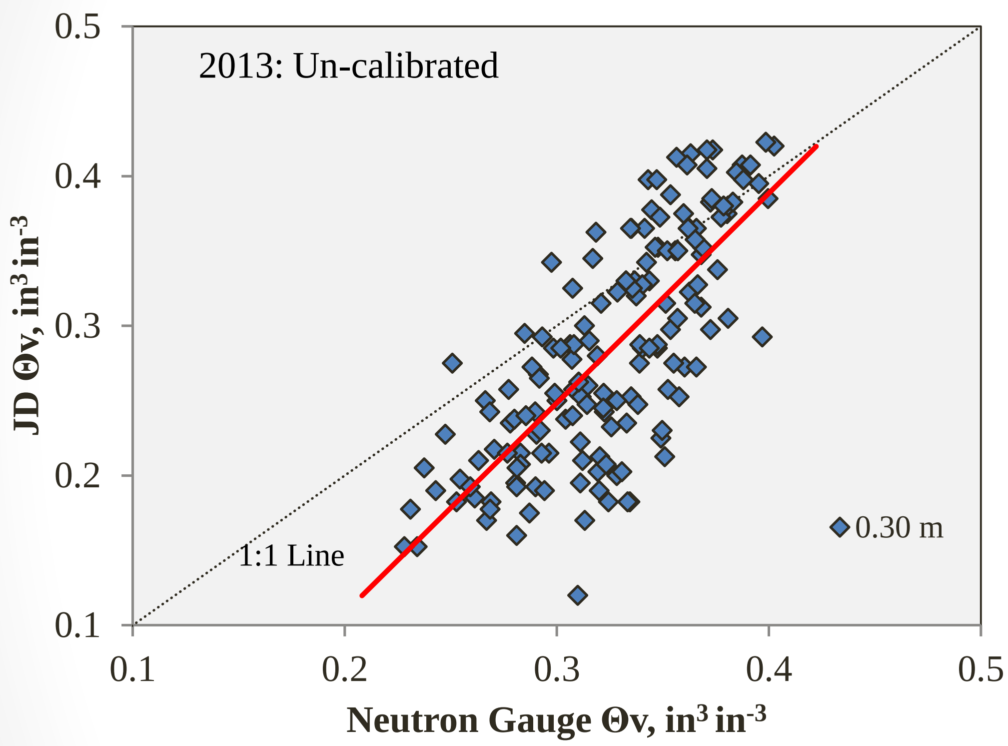
In-Field Sensor Comparison

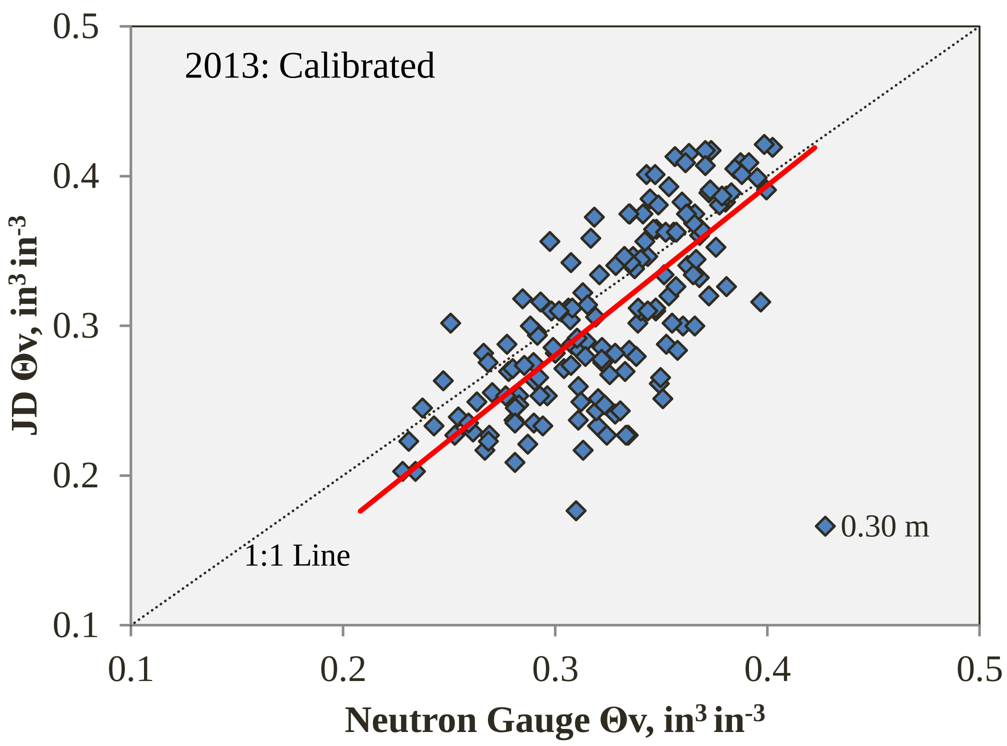


In-Field Sensor Evaluation



Field Calibration can Improve Sensor Performance





Root Mean Square Error (RMSE)

Unadjusted: 0.066 $in^3\ in^{-3}$

Adjusted: 0.043 $in^3\ in^{-3}$

Things to Consider When Selecting Soil Moisture Sensors

- Convenience
- Financial Cost
- Remote Access
- Sensor Accuracy
- Product Support
- Soil Type & Condition
- How Many are Needed
- Crop Type and Rooting Depth
- Integration with Other Sensors

Pros vs Cons → Select Sensor

How Accurate Do The Sensors Need To Be?

- Root Mean Square Error (RMSE)
  - Frequently used statistic for measuring the difference between sensor reading and actual value.

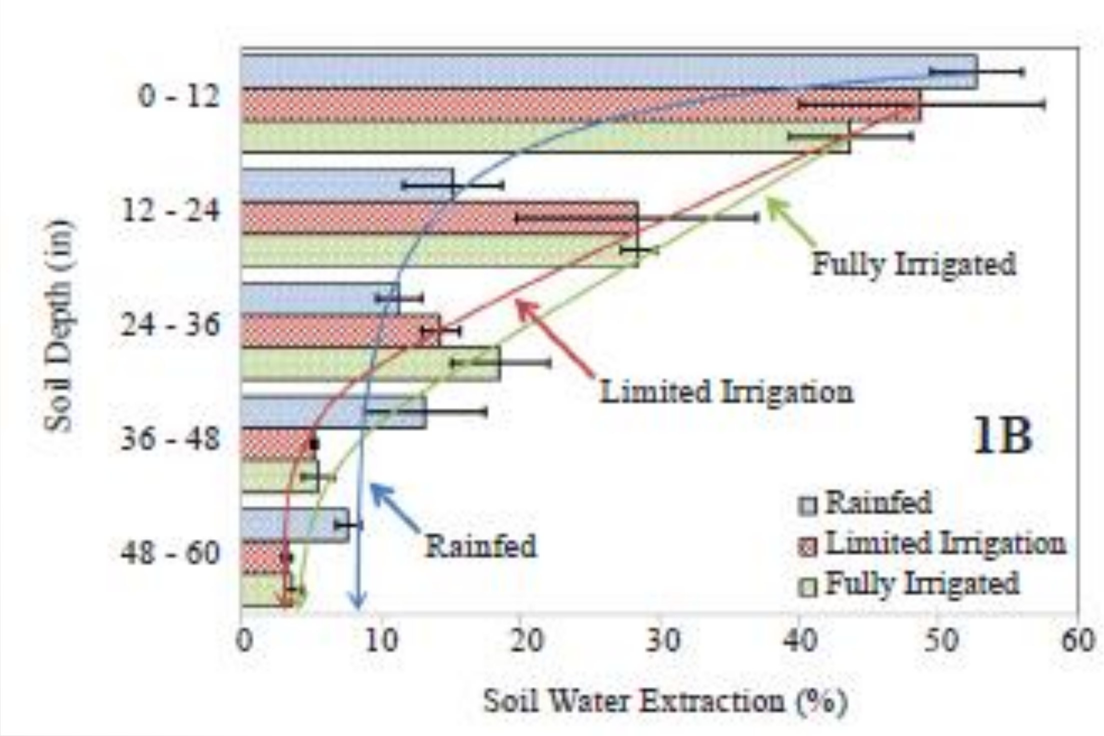
Accuracy level used by Fares et al. (2011)

Accuracy	RMSE ($in^3\ in^{-3}$)	RMSE (inches per foot)
Very Poor	RMSE ≥ 0.1	RMSE ≥ 1.20
Poor	0.1 > RMSE ≥ 0.05	1.20> RMSE ≥ 0.60
Fair	0.05 > RMSE ≥ 0.01	0.60> RMSE ≥ 0.12
Good	RMSE < 0.01	RMSE < 0.12

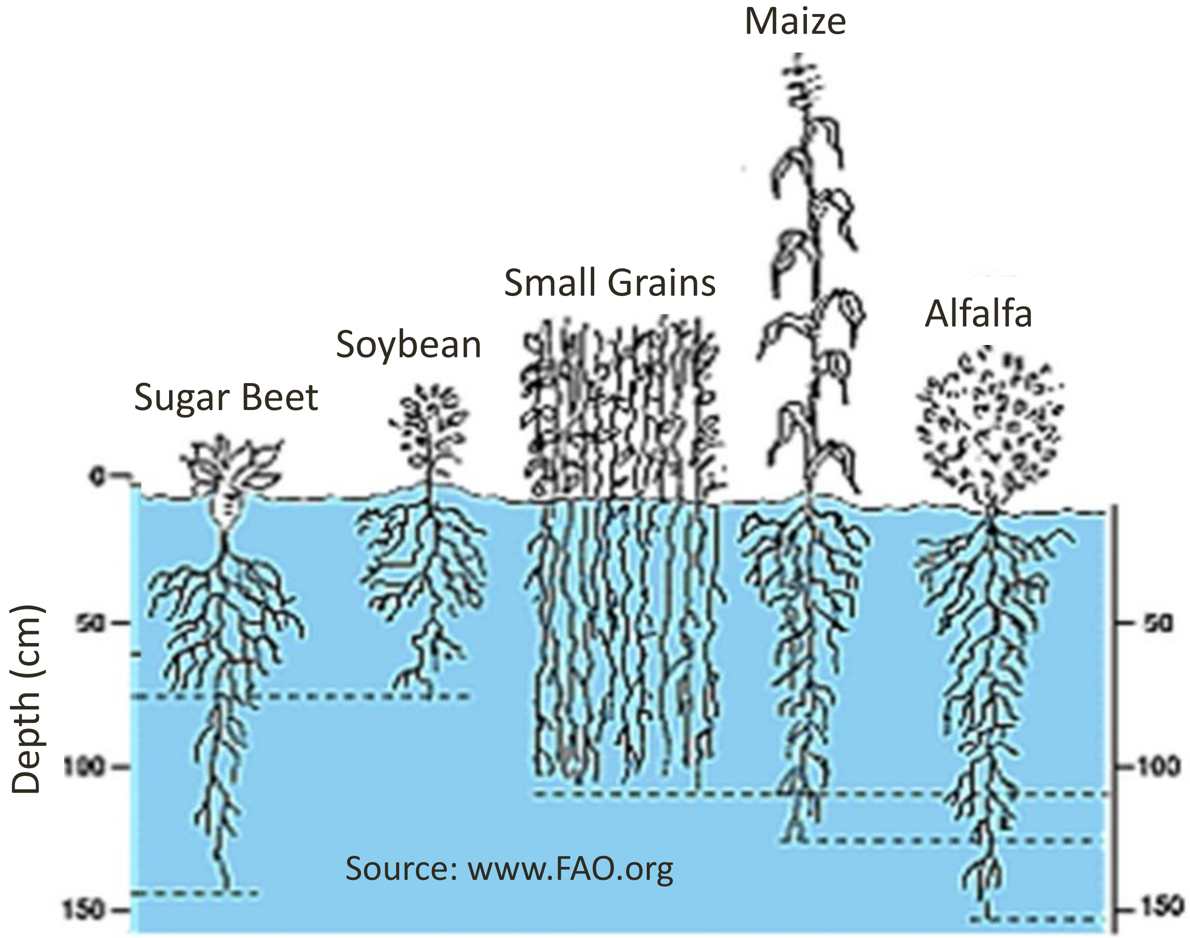
- Sensor might be consistently over-or-under estimating true value, resulting in poor accuracy.
  - Can occur as a result of interpolation between sensors along the probe
  - Evaluating trends may be an option

Effective Rooting Depth and Water Uptake Patterns

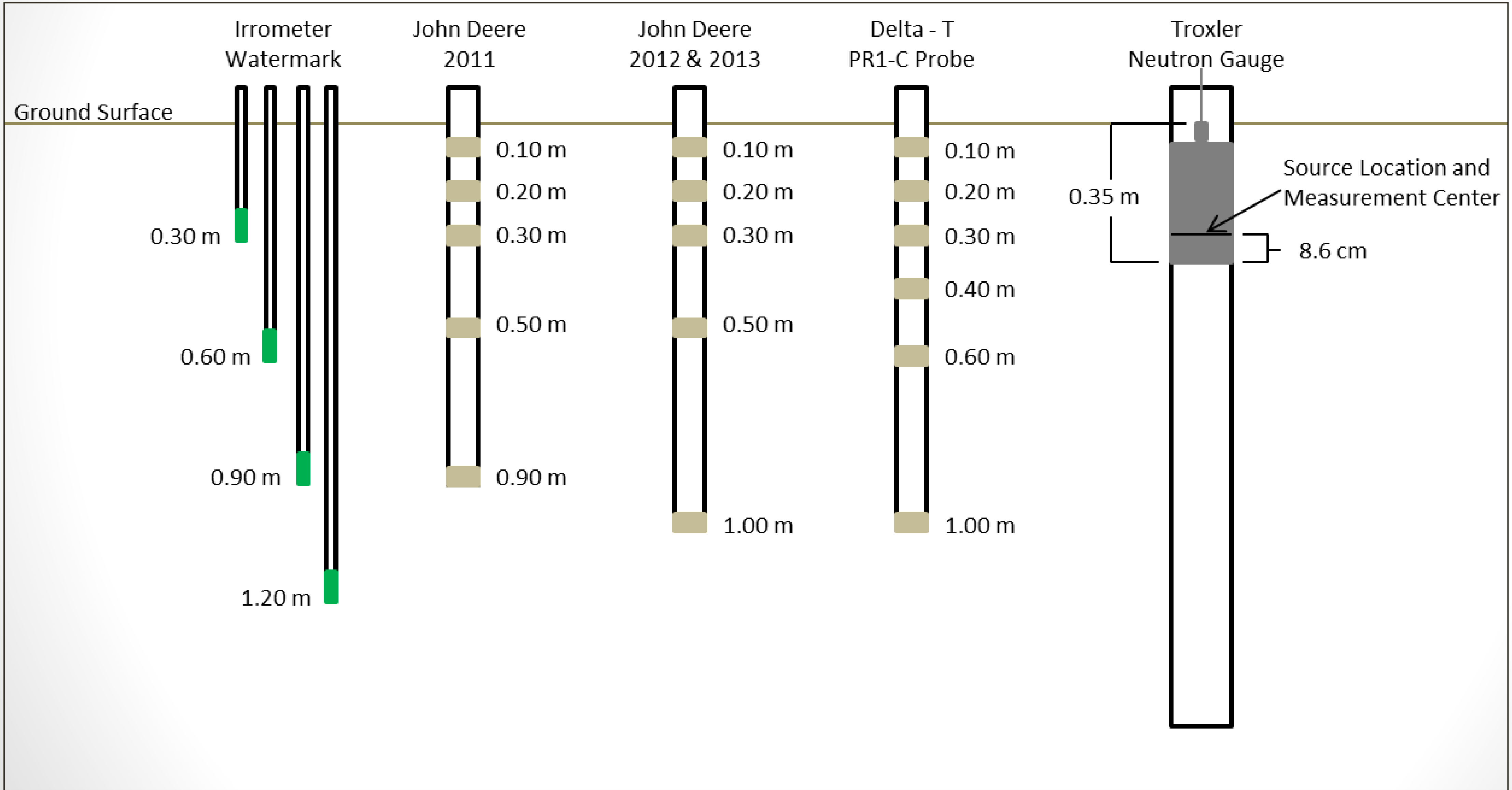
- Crops have different root architecture (e.g., density and depth), which can affect water and nutrient availability and uptake
- Consequently, soil moisture will have to be monitored at different depths.



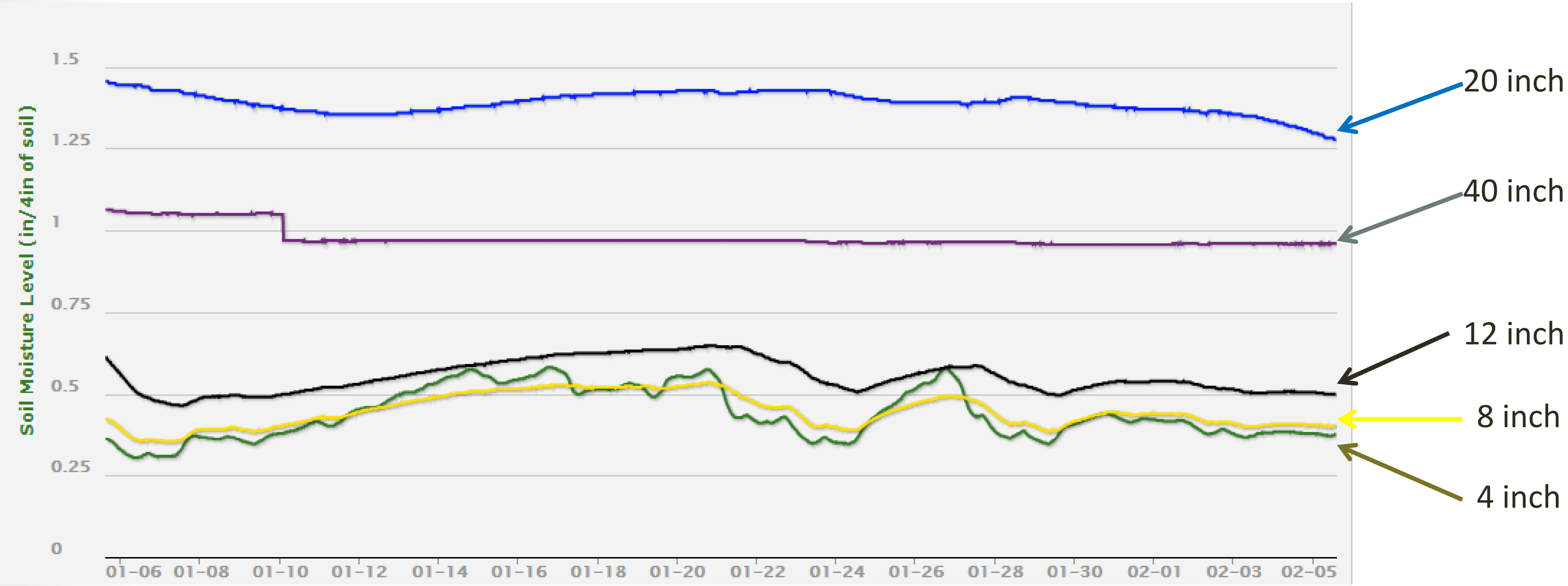
Source: Irmak and Rudnick (2014)



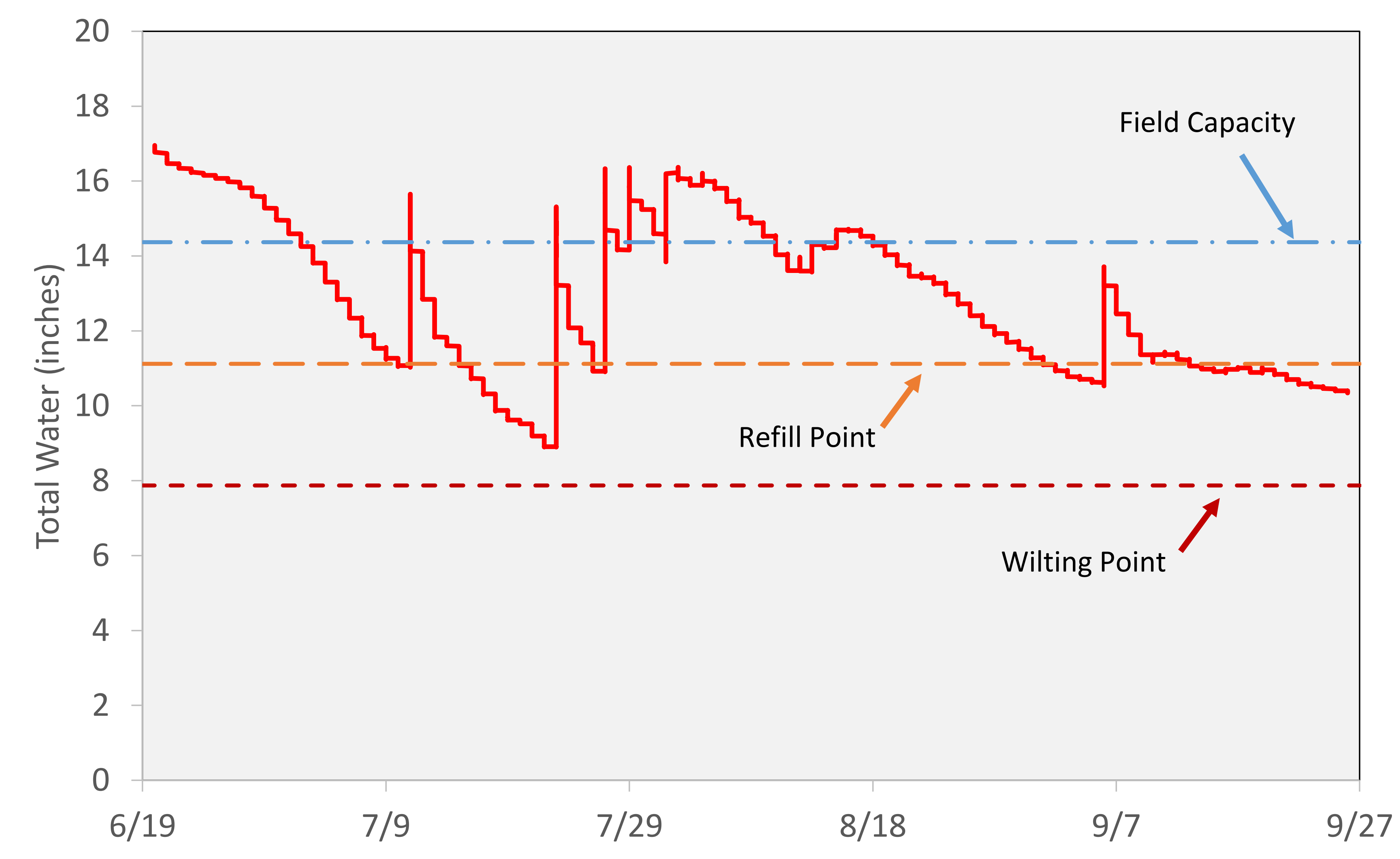
Sensor Installation Depth should Coincide with Effective Rooting Depth



Individual Sensors can Show Root Activity



Managing Trends Can Improve Irrigation Management



Integrating Sensors

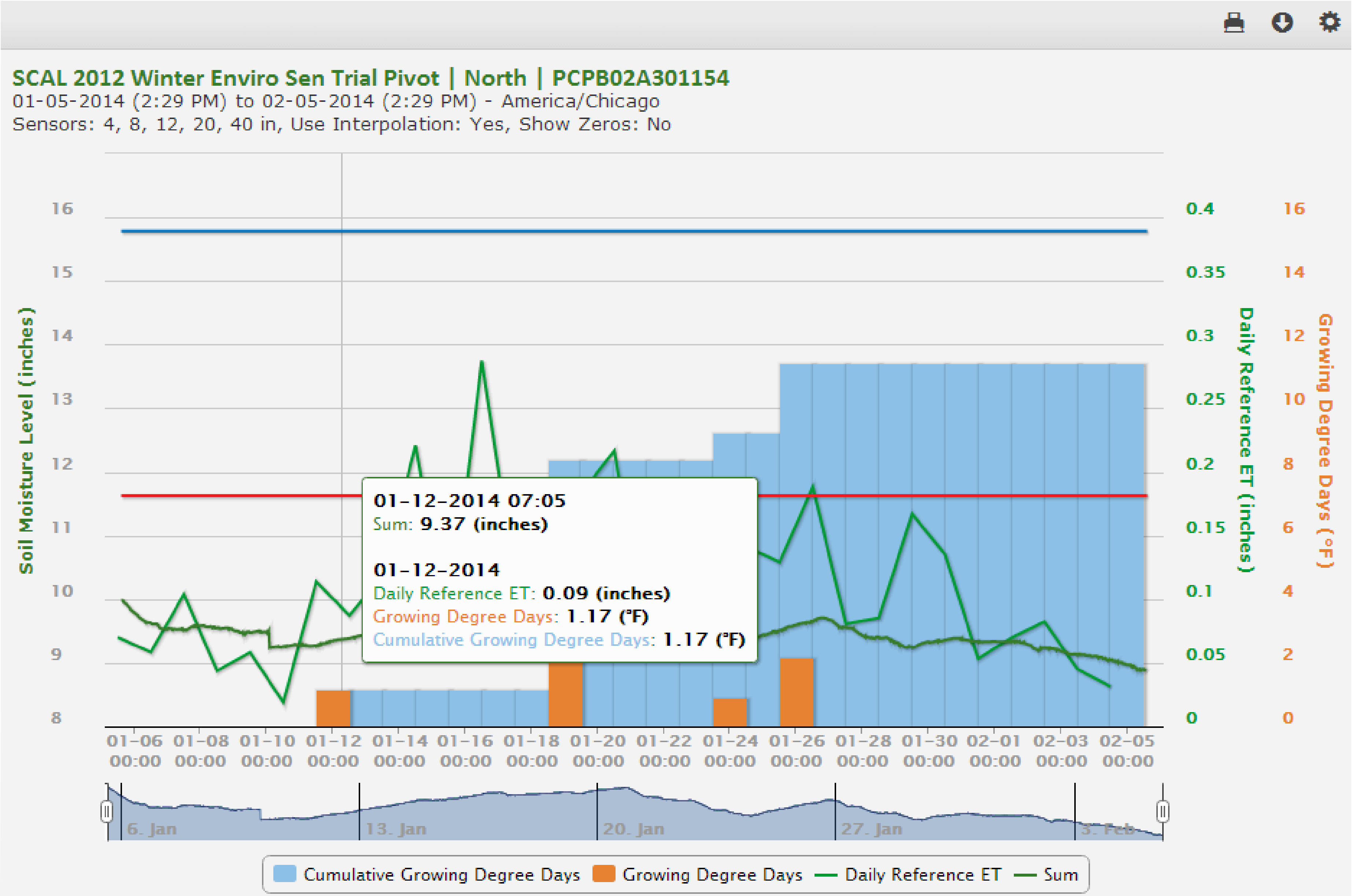
Weather Station Parameters:

- Soil Moisture
- Daily Moisture Change
- Battery Voltage
- Solar Radiation
- Rain Gauge
- Leaf Wetness
- Air Temperature
- Relative Humidity
- Wind Speed & Direction

Calculated Values:

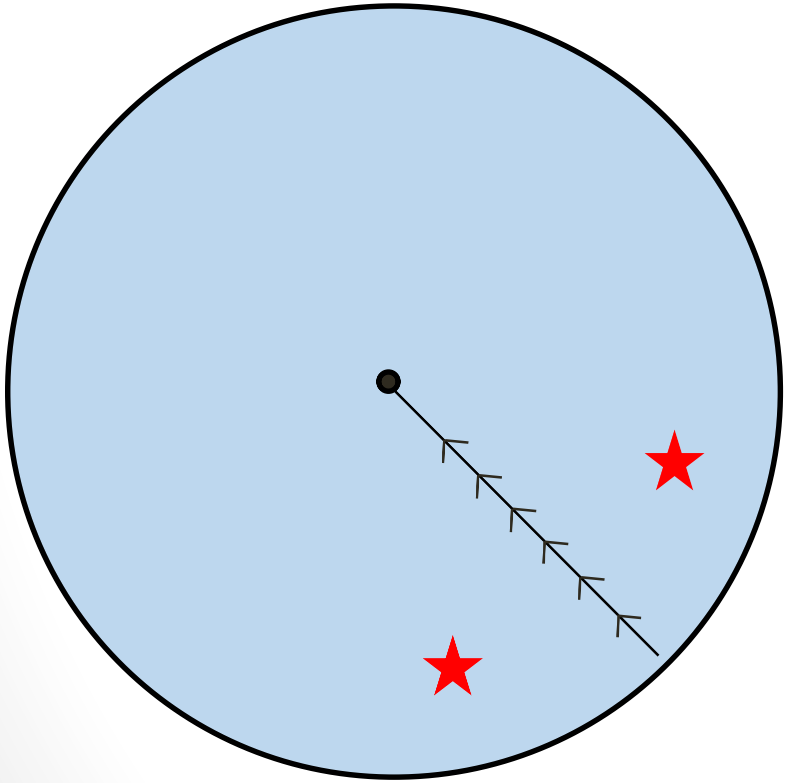
- Daily Reference ET
- Growing Degree Days

Example: John Deere Field Connect User Interface

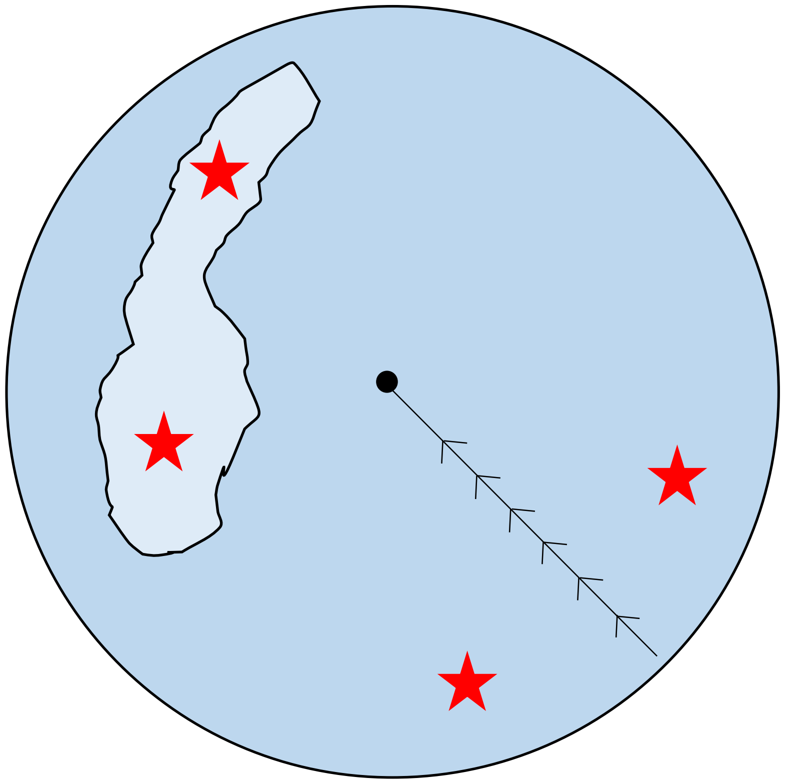


How Many Sensors Do I Need?

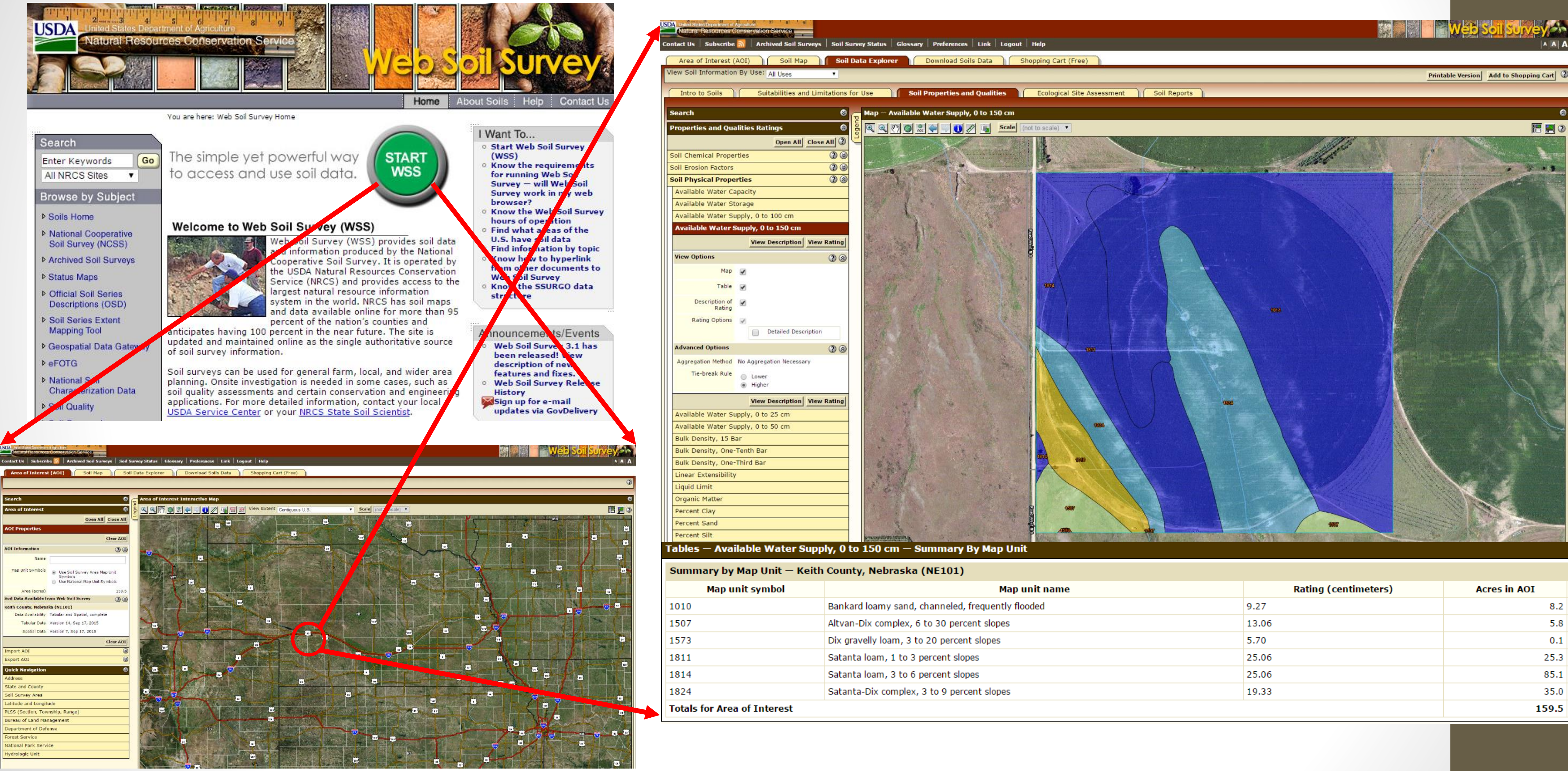
- Uniform Irrigation
  - Ideally 2 sets of sensors
    - 1 set at start of revolution and 1 set at end of revolution



- Management Zones
  - Ideally 2 sets of sensors per zone



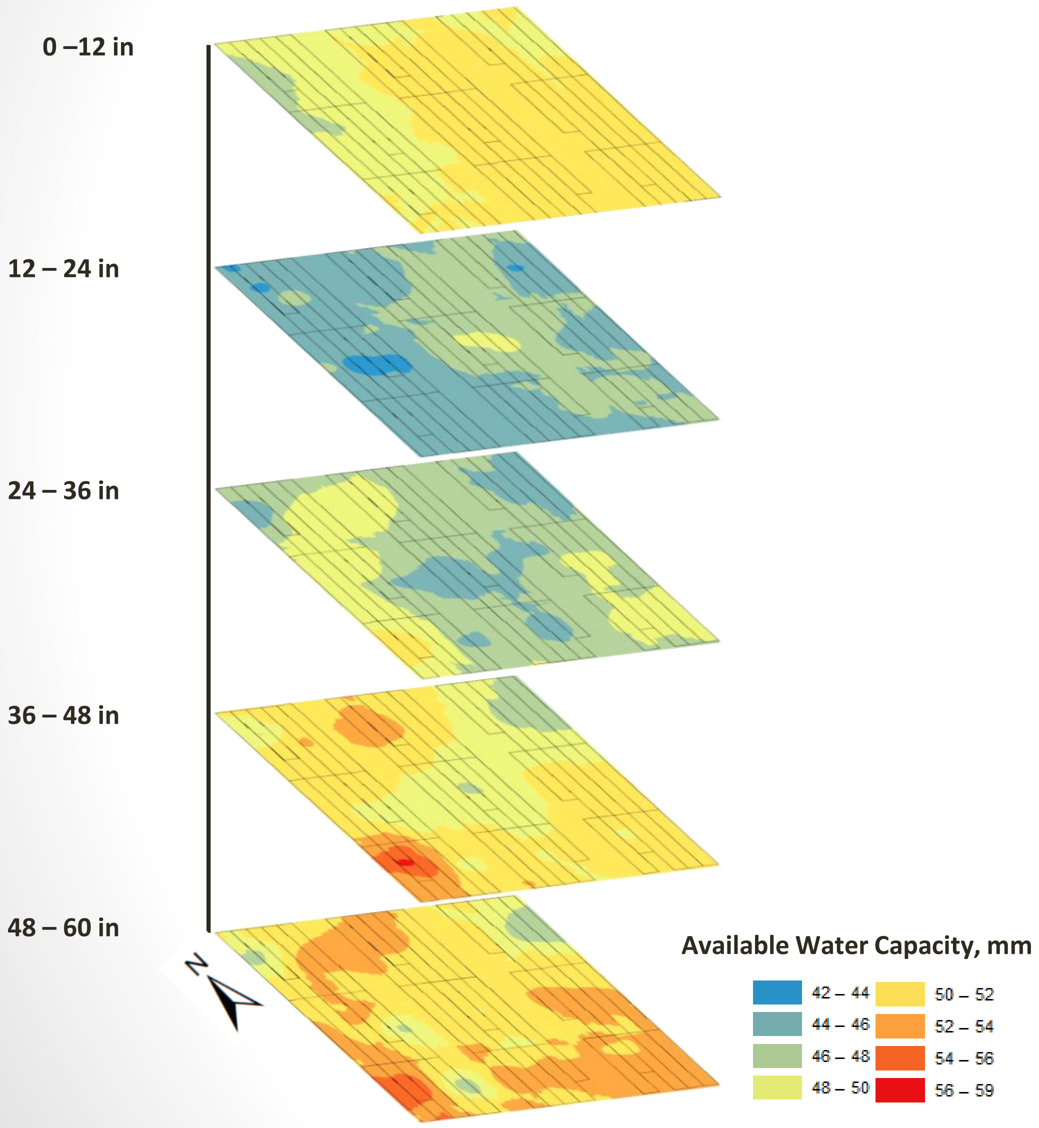
Soil Type: Web Soil Survey (websoilsurvey.nrcs.usda.gov)

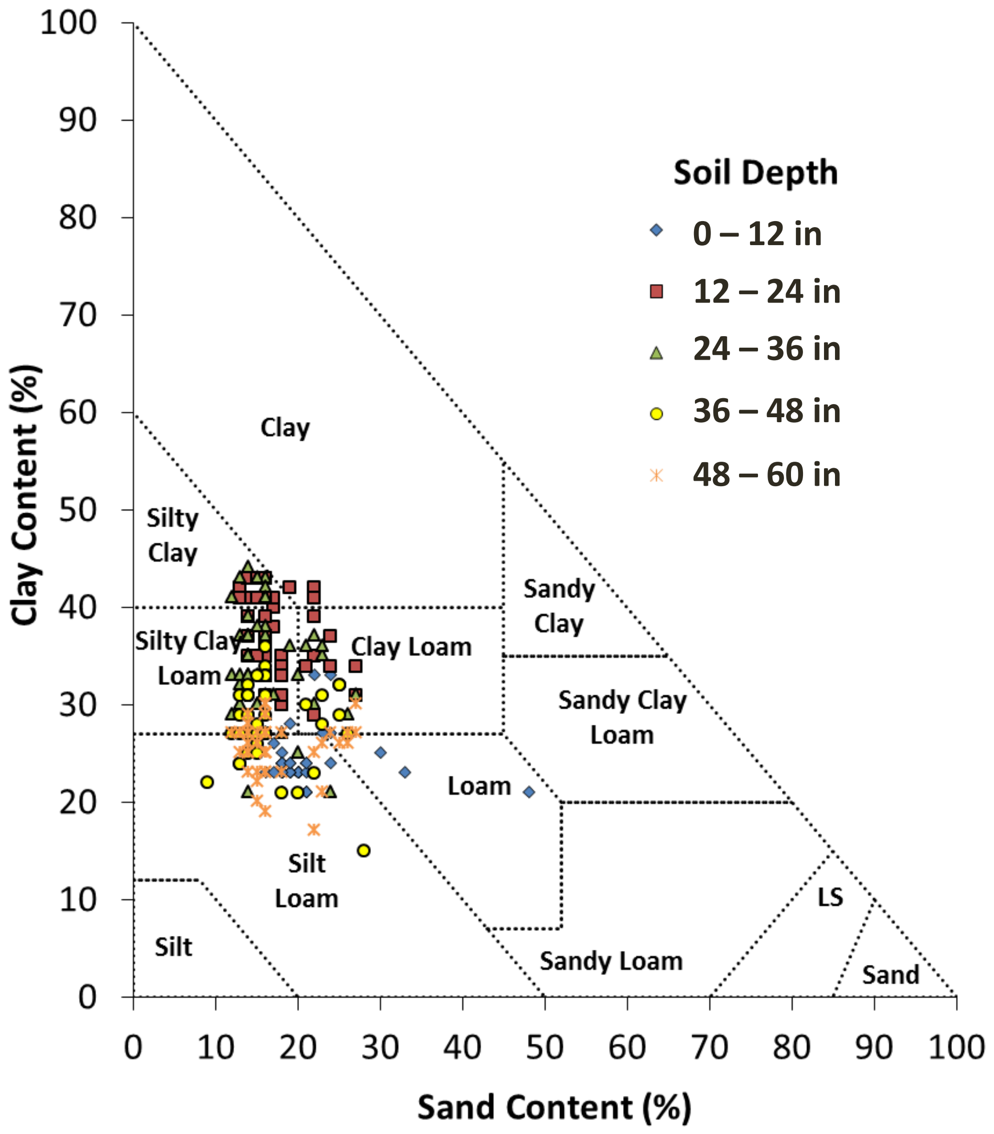


Summary by Map Unit — Keith County, Nebraska (NE101)

Map unit symbol	Map unit name	Rating (centimeters)	Acres in AOI
1010	Bankard loamy sand, channeled, frequently flooded	9.27	8.2
1507	Altvan-Dix complex, 6 to 30 percent slopes	13.06	5.8
1573	Dix gravelly loam, 3 to 20 percent slopes	5.70	0.1
1811	Satanta loam, 1 to 3 percent slopes	25.06	25.3
1814	Satanta loam, 3 to 6 percent slopes	25.06	85.1
1824	Satanta-Dix complex, 3 to 9 percent slopes	19.33	35.0
Totals for Area of Interest			**159.5**

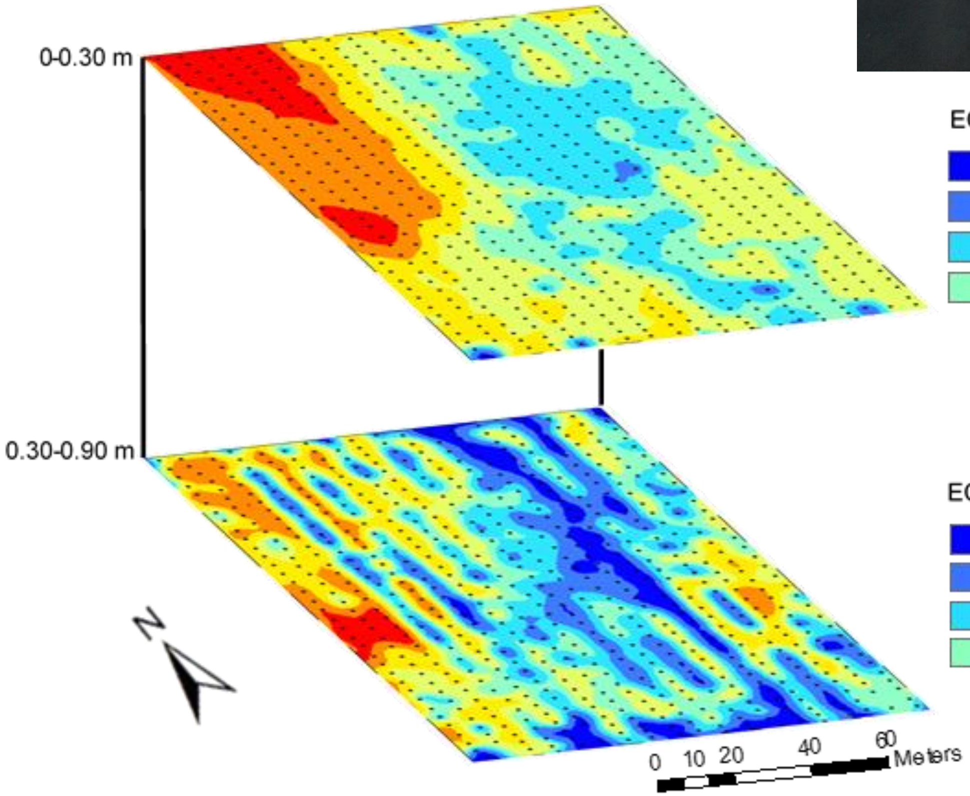
Field Soil Spatial Variability





Soil Physical and Chemical Properties

- Apparent Electrical Conductivity (ECa)
  - Easy to measure and relatively low cost
  - Indirect indicator of important soil physical and chemical characteristics
- Some Factors impacting ECa
  - Clay content and mineralogy
  - Soil salinity
  - Cation exchange capacity
  - Soil pore size distribution
  - Temperature
  - Organic matter content
  - Soil moisture content



Source: Rudnick and Irmak (2014)

Financial Cost, Convenience, and Support

- How much are the sensors?
- Is there a yearly subscription fee?
- Will someone install and remove the sensors?
- Do I have to purchase the installation equipment?
- Does the sensor have remote access for easy monitoring?
- Is there local product support incase the sensor malfunctions?
- Are there Cost Share or Leasing Opportunities
  - Natural Resource Districts
  - NRCS

Thank You!

The mention of trade names or commercial products in and during this presentation does not constitute an endorsement or recommendation for use by the University of Nebraska-Lincoln or the author.

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