Teaching Ag Tech: Managing Soil Moisture with Sensors

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SOIL AND CROP SCIENCES

COLORADO STATE UNIVERSITY

Outline

- Introductions
- Agriculture in the 21st century: How did we get here and where are we going?
- The role of the Internet of Things (IoT) and open-source electronics in Agriculture
- Measuring soil water status directly and indirectly (using sensors!)
- Soil-Plant-Water relationships
- Developing a sensor-based irrigation system
- Introduction to Arduino

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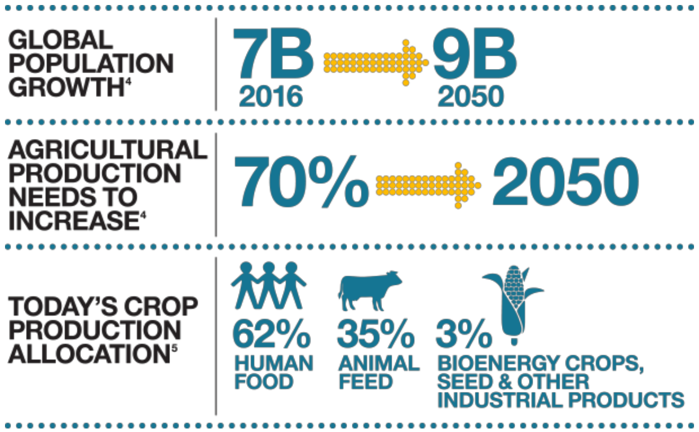
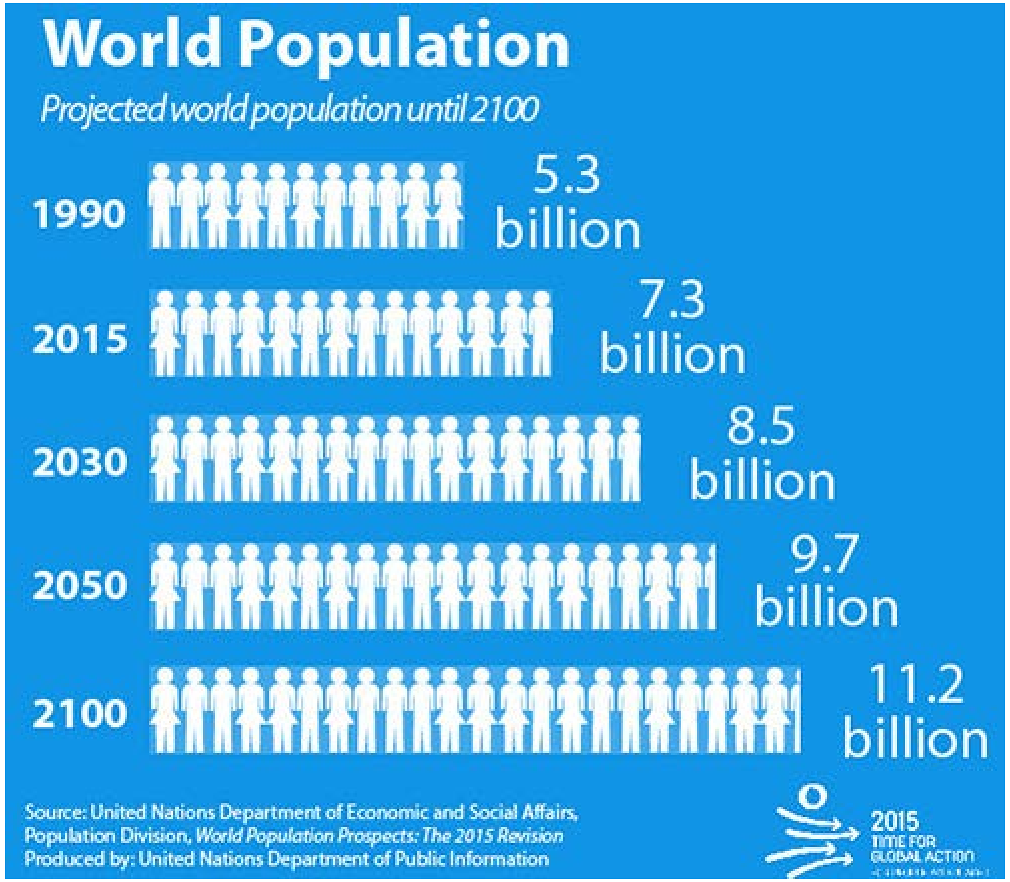
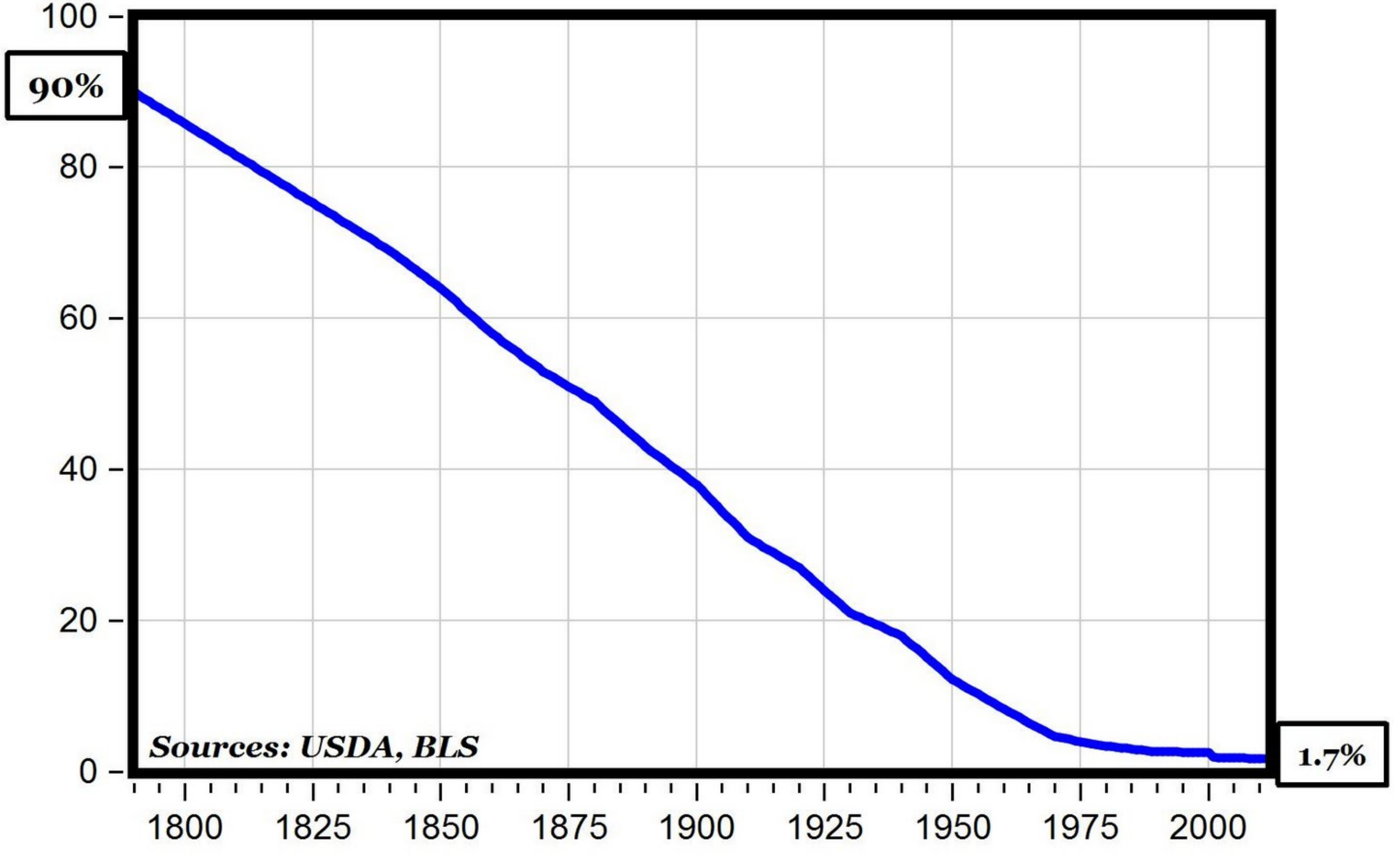
Meeting the needs of a growing population

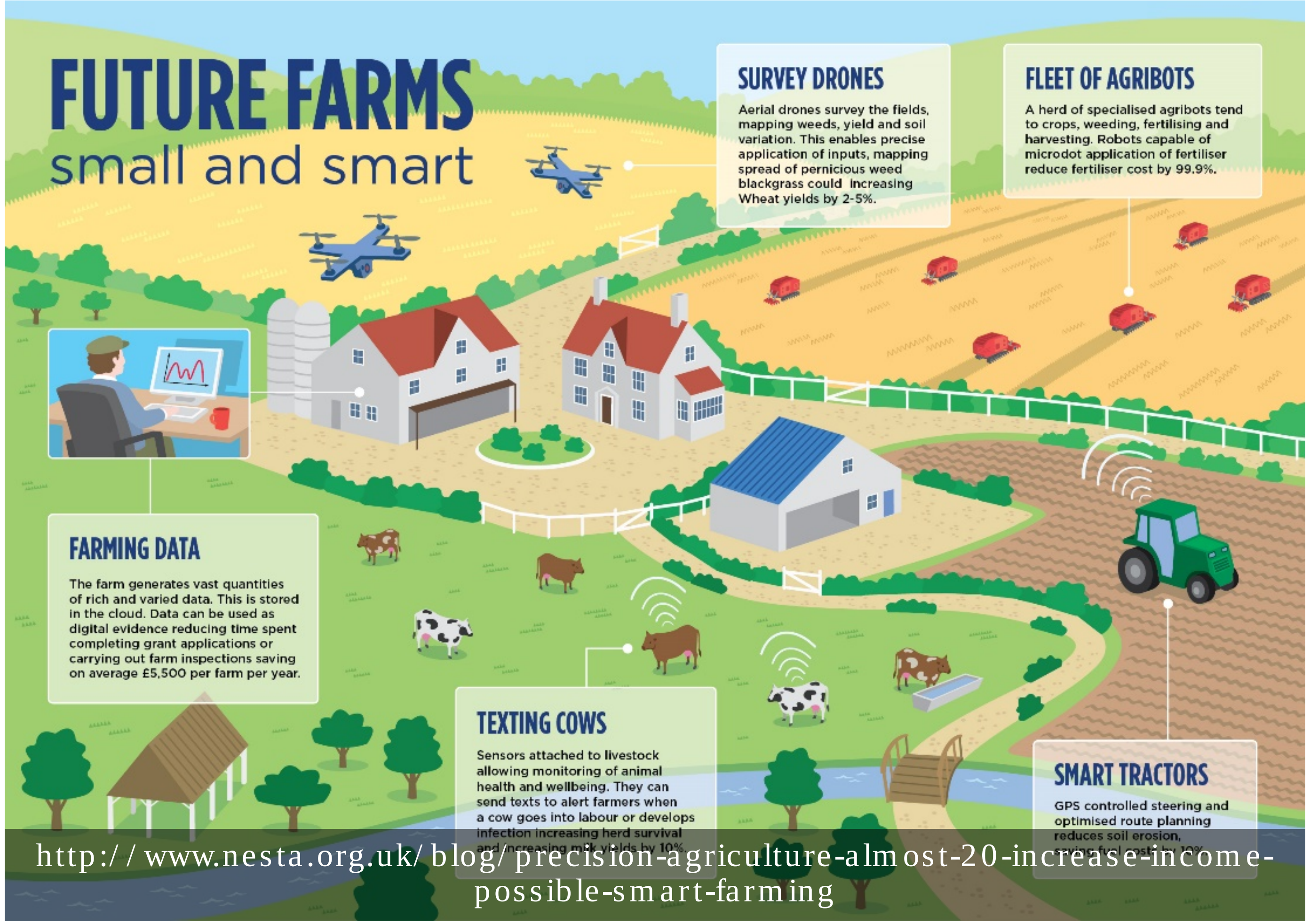


Land expansion will not fulfill crop production needs



Farm Jobs, % of Total U.S. Jobs 1790 to 2011





http://www.nesta.org.uk/blog/precision-agriculture-almost-20-increase-income-possible-smart-farming

Smart Farming

- Farms of the future will leverage sensor technology, the internet of things, and big data to improve decision making and increase efficiency.

An Internet of Things

"In the next century, planet earth will don an electronic skin.

It will use the Internet as a scaffold to support and transmit its sensations." - *Neil Gross 1999*

What is the Internet of Things?

- A Network of Physical Devices: Sensors and Actuators
- With Embedded Electronics and Software
- Connected to the Internet
- Allowing exchange of information and interaction with the world

The Maker Movement

Open-Source Technology

ARDUINO
OPEN-SOURCE
COMMUNITY

open source
hardware

MySQL
odoo
The Apache Software Foundation
Joomla!
...because open source matters
Apache OpenOffice™
WordPress
open source initiative®
Magento™
Open Source eCommerce
Java
ubuntu
android

Open-Source: Making Technology Accessible to the Masses

Journal of open hardware

Pearce, JM 2017 Emerging Business Models for Open Source Hardware. *Journal of Open Hardware*, 1(1): 2, pp. 1–14, DOI: https://doi.org/10.5334/joh.4

ISSUES IN OPEN HARDWARE

Emerging Business Models for Open Source Hardware

Joshua M. Pearce[*,†]

The rise of Free and Open Source models for software development has catalyzed the growth of Free and Open Source Hardware (also known as "Libre Hardware"). Libre hardware is gaining significant trac-tion in the scientific hardware community, where there is evidence that open development creates

CHAPTER 1

Introduction to Open-Source Hardware for Science

1.1. INTRODUCTION

By any standard, the process of development and licensing for free and open-source software, which is discussed in Chapters 2 and 3, has been a success. Because of this success, the method is now being applied to hardware. Thus,

Modern Instrumentation, 2012, 1, 8-20
http://dx.doi.org/10.4236/mi.2012.12002 Published Online April 2012 (http://www.SciRP.org/journal/mi)

Scientific Research

Open-Source Hardware Is a Low-Cost Alternative for Scientific Instrumentation and Research

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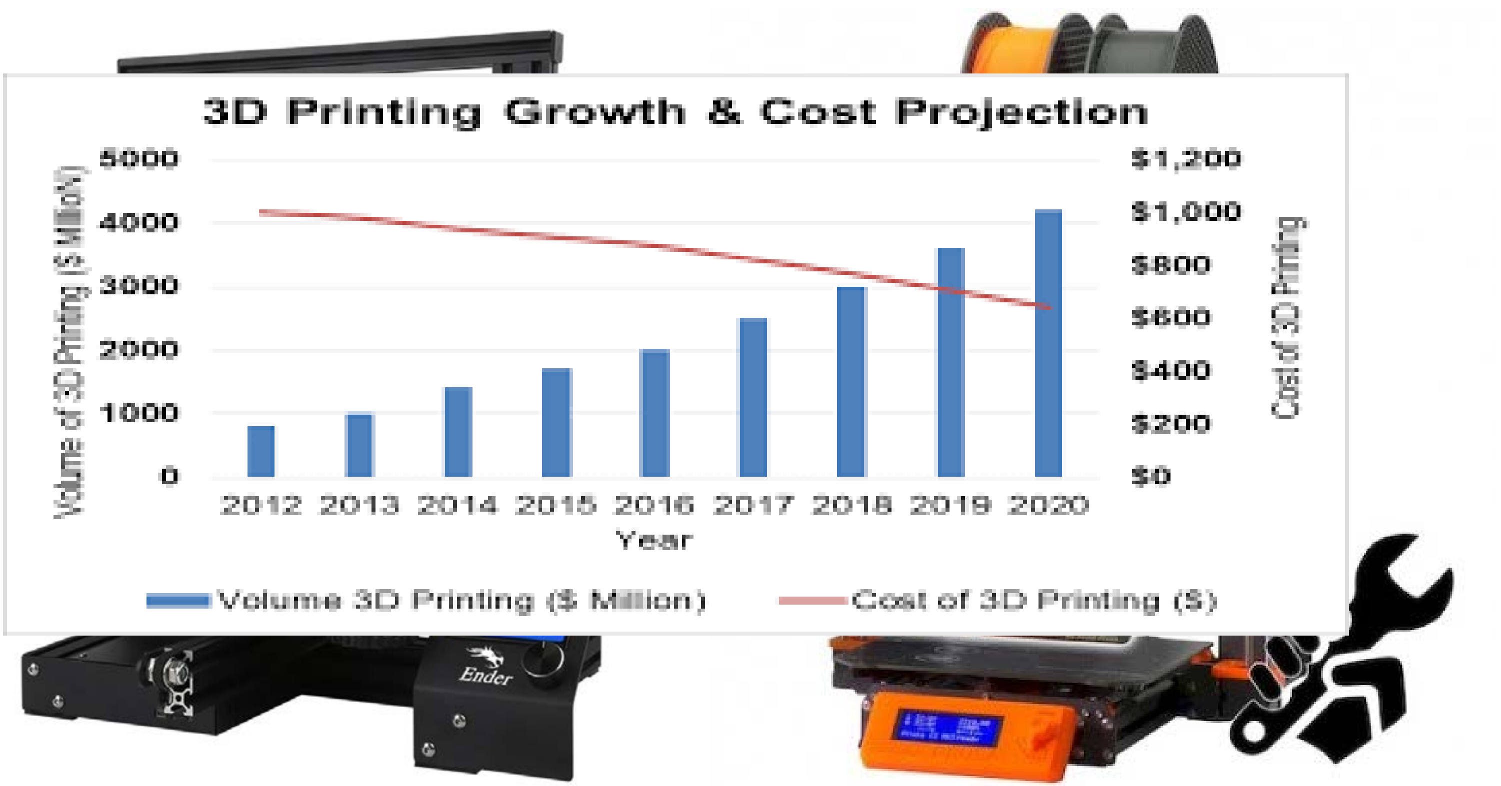
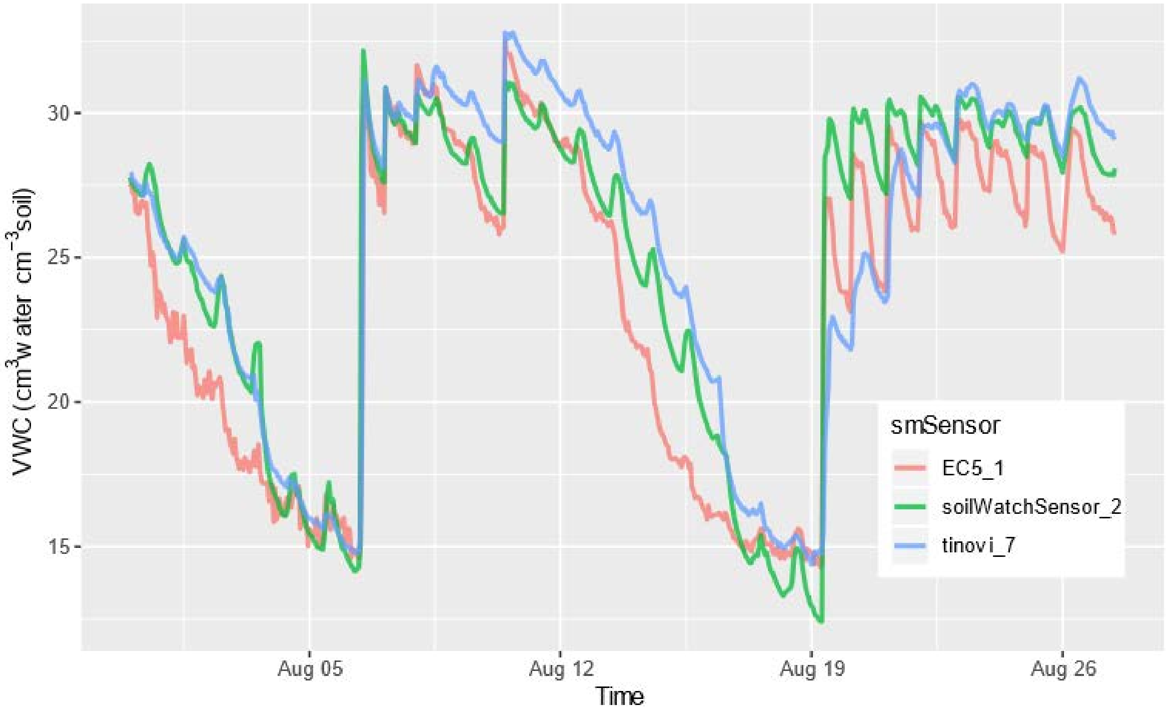
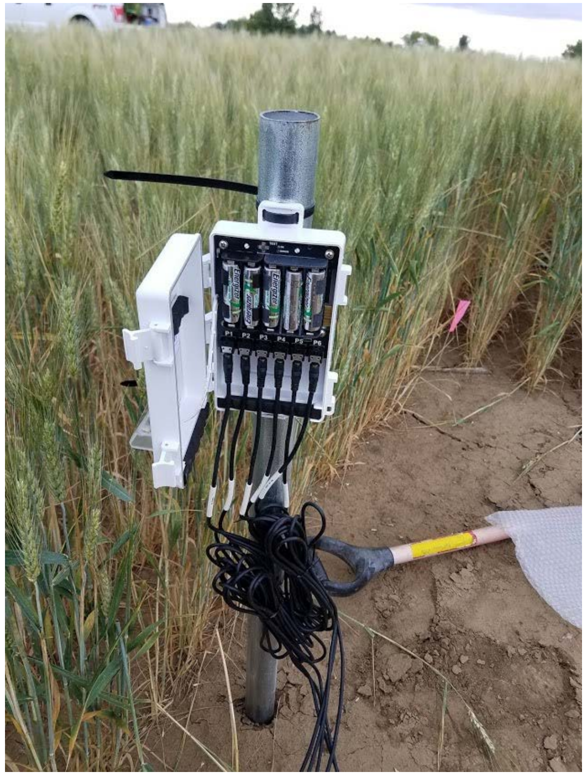
Open-Source: 3d printing

- Modern 3-d printing technology exemplifies the benefits of open-source development.
- The last decade has seen rapid advancement in 3-d printer technology as popularity increases and the cost of manufacturing decreases.



Open-Source: Making Technology Accessible to the Masses





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AGRICULTURE

Smart Agriculture - More sleep for growers

bosch.com

Add comment

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FARMING

Moo-ve fast and break things: Farmers are finding tech talent crucial for business

Lynsey Barber

Tech talent is becoming crucial for business, but its not just the hottest startups and forward thinking giants that are hankering after ...

Add comment

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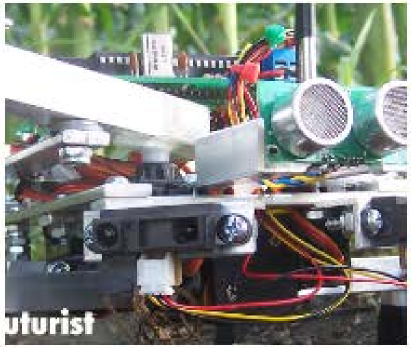

AGRICULTURE

Farmers in the future will “shepherd herds of robots”

Matthew Griffin

WHY THIS MATTERS IN BRIEF Robots sat in the doldrums for years without much happening but now, fuelled by AI and advance Machine vision capabilities ...

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BOULDER

CU Boulder researchers lead team using drone technology to map soil moisture

By Charlie Brennan Staff Writer

University of Colorado Boulder students and faculty make the claim

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QUANTUM MECHANICS

A wheeled robot to monitor grape growth

phys.org

Just like great wine needs time, great grapes require continuous

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AGRICULTURE

Transforming the bush: robots, drones and cows that milk themselves

The Guardian: Australia News · Paul Daley

Rural Australia is being progressively hollowed out of its people. Will it be reduced to a vast mechanised place of scant human

Add comment

Irrigation

- ~20% of total crop land is irrigated
- Irrigated land accounts for almost half of total crop production (~47%)
- ~60% of cereal production

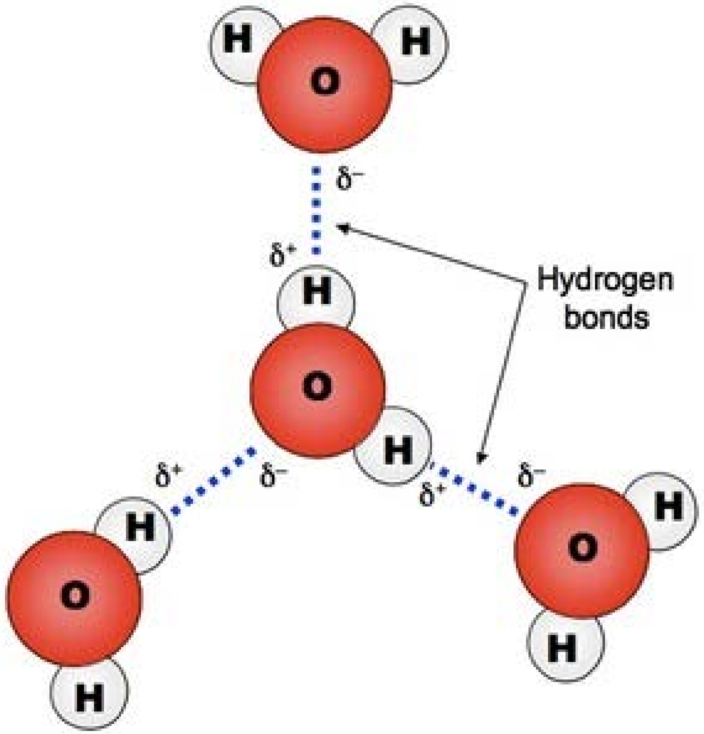
Why should we care?

A few quick stats:

- 0.02% of Earth's total water supply is available as fresh surface waters
- 70-80% of the world's freshwater withdrawal is used for agriculture
- 25-30% of U.S. soils are affected by drought
- 40% of annual crop losses in the US are attributed to drought and water limitation

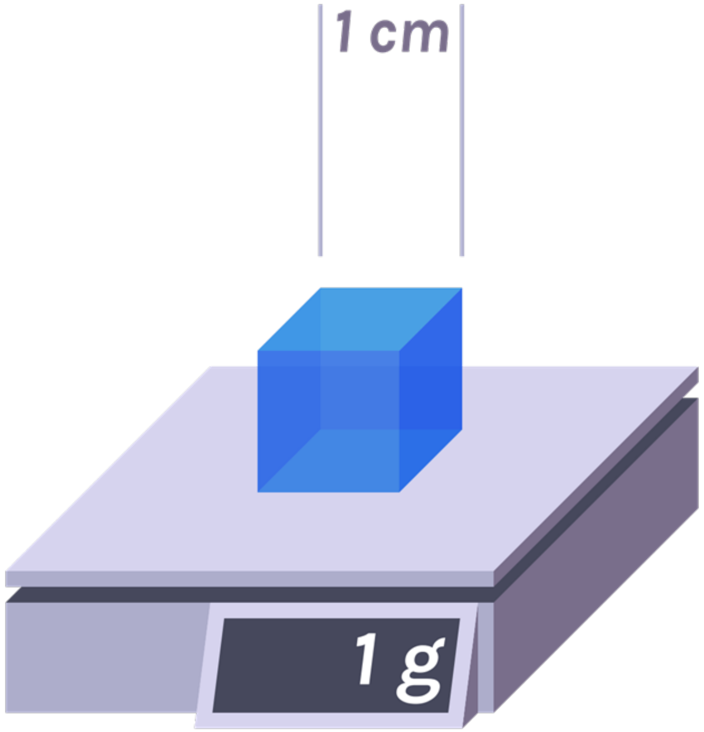
Properties of Water

- Water's unique chemical properties make it essential for life on Earth.
- Polarity (unequal distribution of charge) causes water molecules to stick together and form strong hydrogen bonds (called cohesion).
- Water molecules are also attracted to other charged surfaces (adhesion).



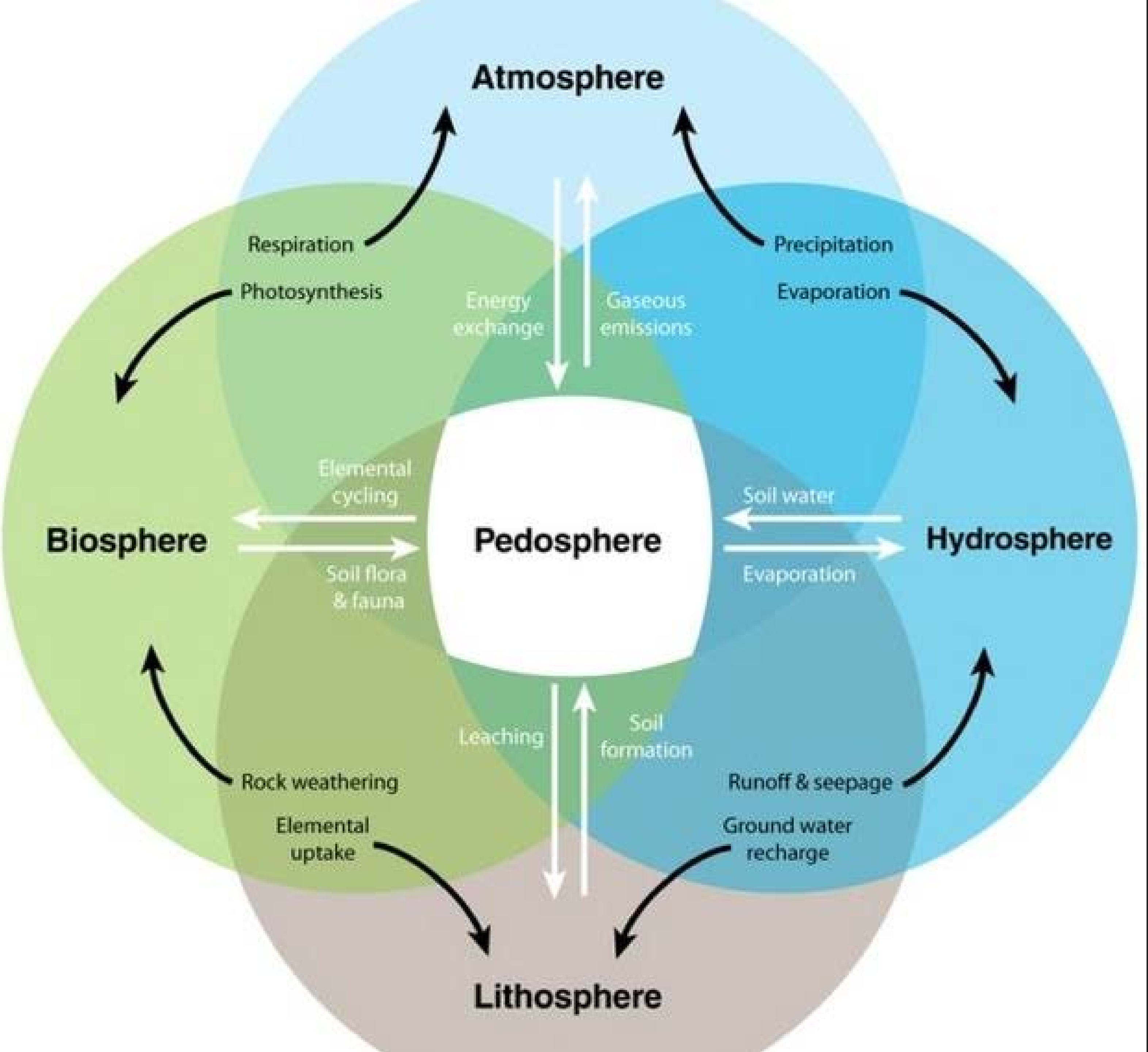
Properties of Water

- Water has a density of $1 g/cm^3$
- One gram of water occupies one cubic centimeter of space
- $1 cm^3 = 1 mL$

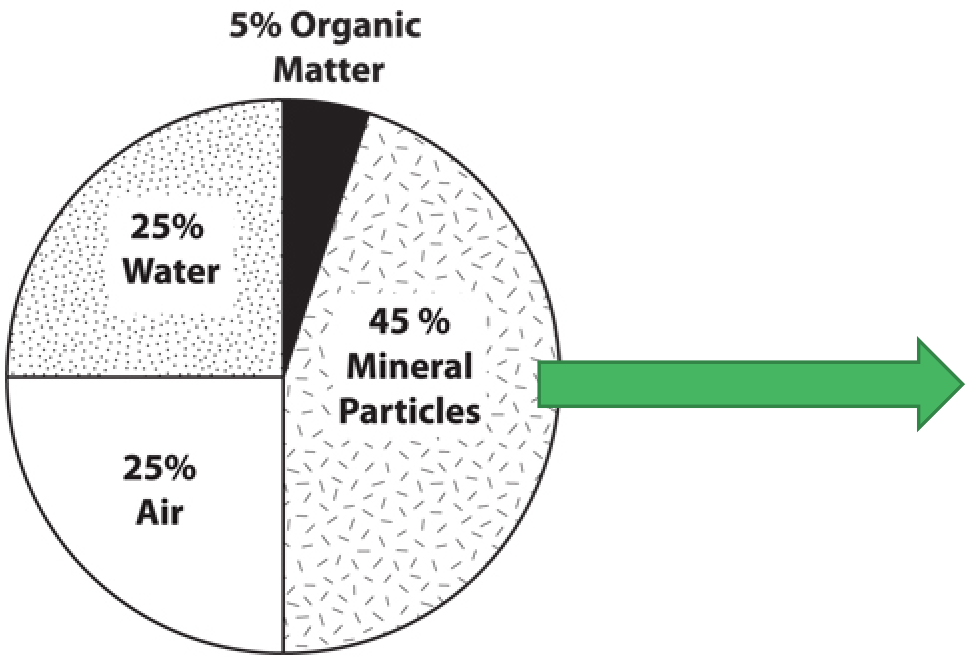


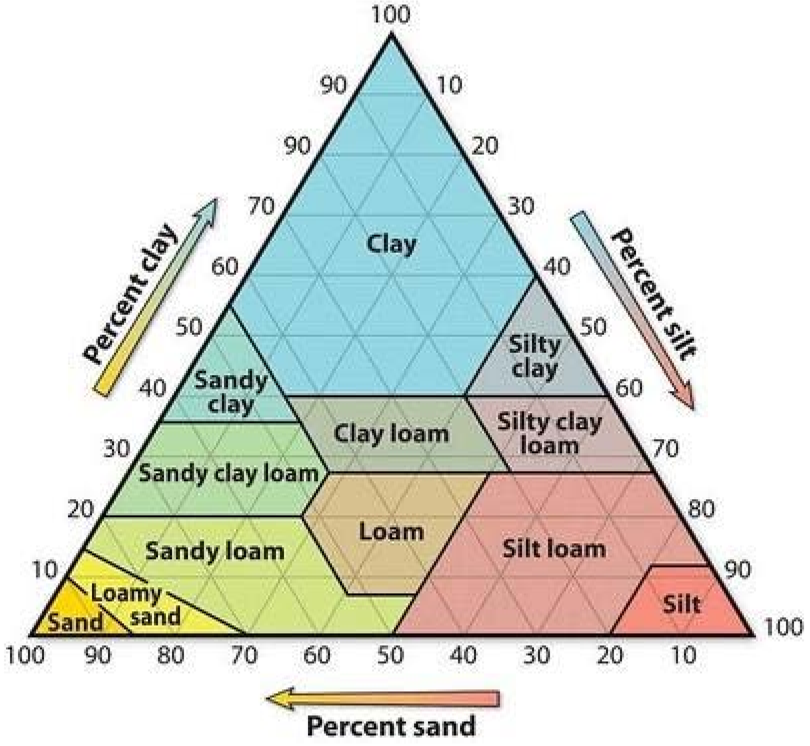
What is Soil?

- A porous mixture of decomposing rock and organic matter that exists at the intersection of the atmosphere, hydrosphere, lithosphere and biosphere.



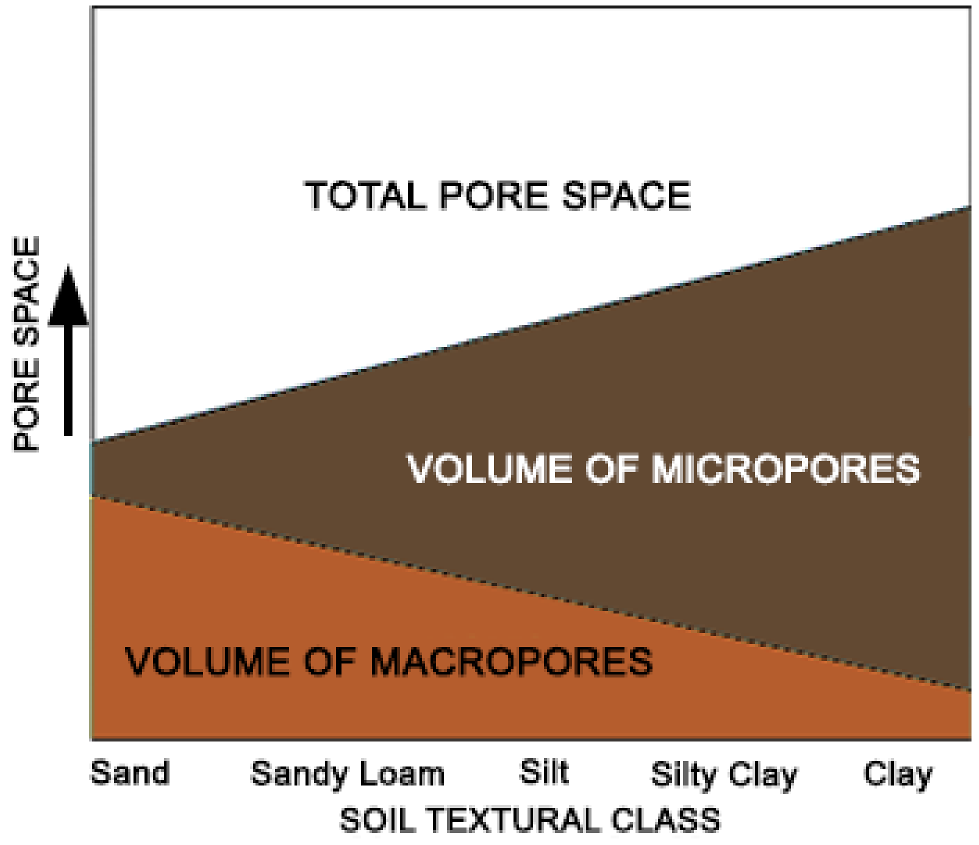
Soil Composition





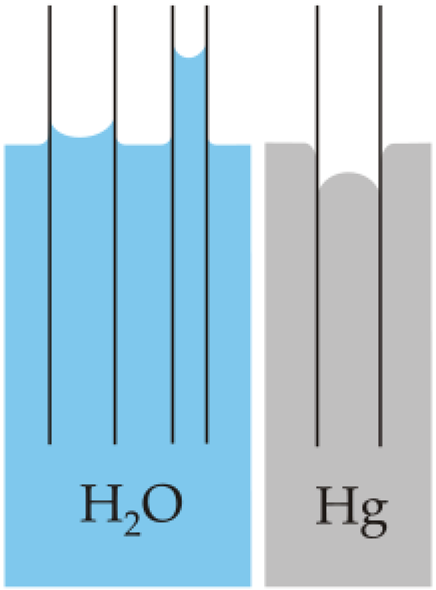
Soil Texture – Pore Space Relationships

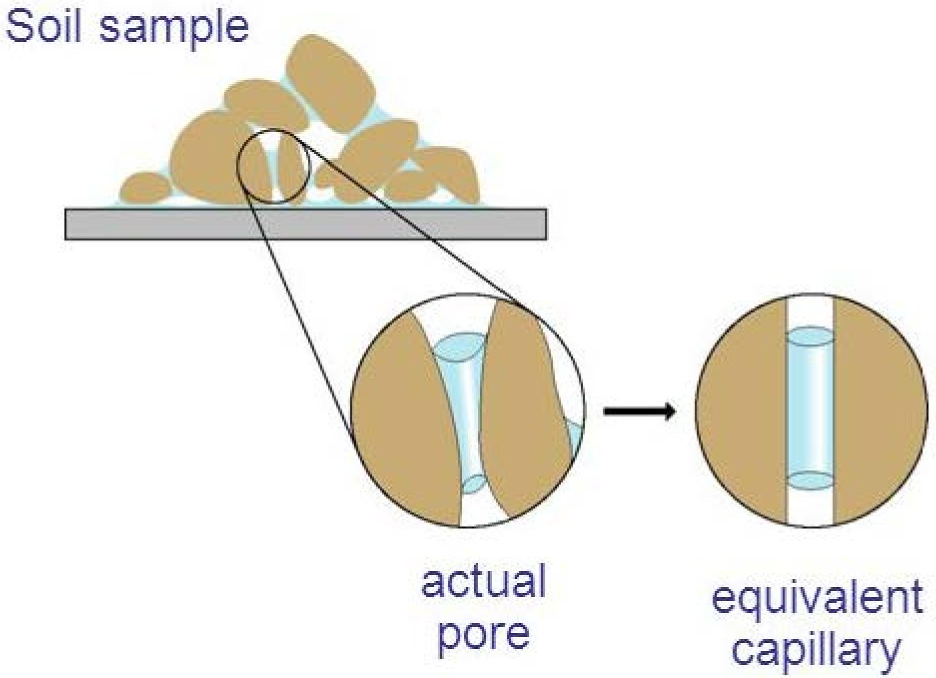
- Soil texture is a measure of particle size distribution in the soil; the relative amounts of sand, silt, and clay-sized particles that makes up a soil's mineral component.
- Texture is one of the most important soil properties that influences soil water storage and movement.



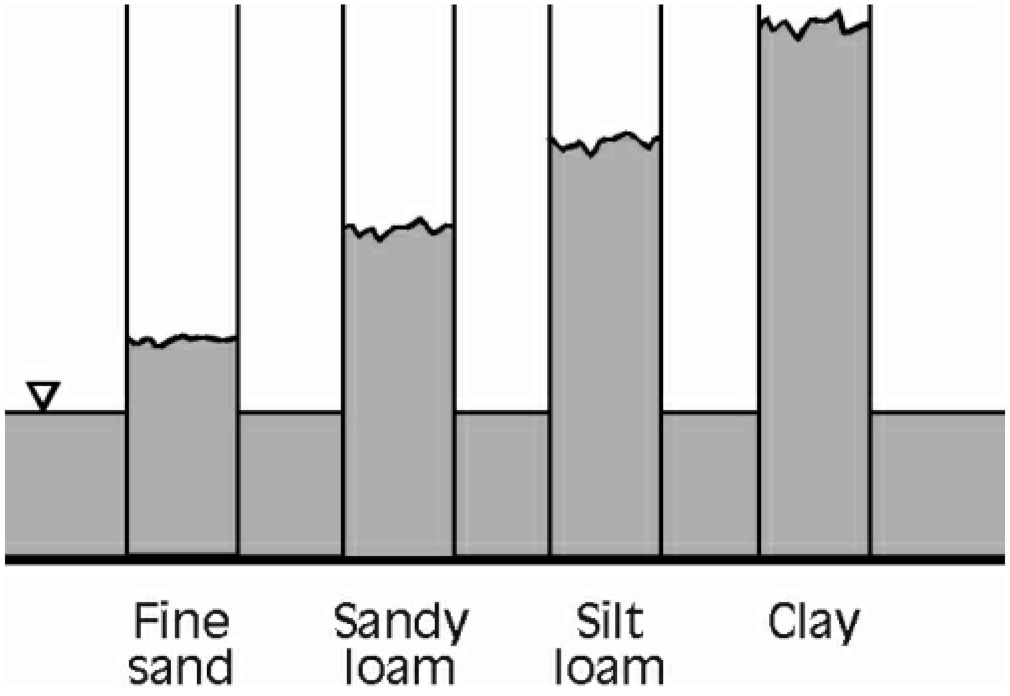
Soil Pores

- Soil pores are the void spaces in between soil particles.
- We can think of soil pores like a bundle of cylindrical capillary tubes.
- Height of rise in the capillary tube is inversely proportional to the tube's radius.





$$h = \frac{0.15}{r}$$



Bulk Density

Texture Class	Bulk Density (g cm^{-3})
Sand	1.65
Loamy sand	1.6
Sandy loam	1.55
Loam	1.5
Sandy clay loam	1.5
Silty clay loam	1.5
Silty loam	1.5
Clay loam	1.45
Silty clay	1.45
Sandy clay	1.4
Clay	1.35

Particle Density

$$Particle\ Density = \rho_p = \frac{mass\ of\ solids}{volume\ of\ solids}$$

Typically 2.65 g/cm^3 for mineral soils (the density of mineral quartz, an abundant mineral in soils)

Porosity

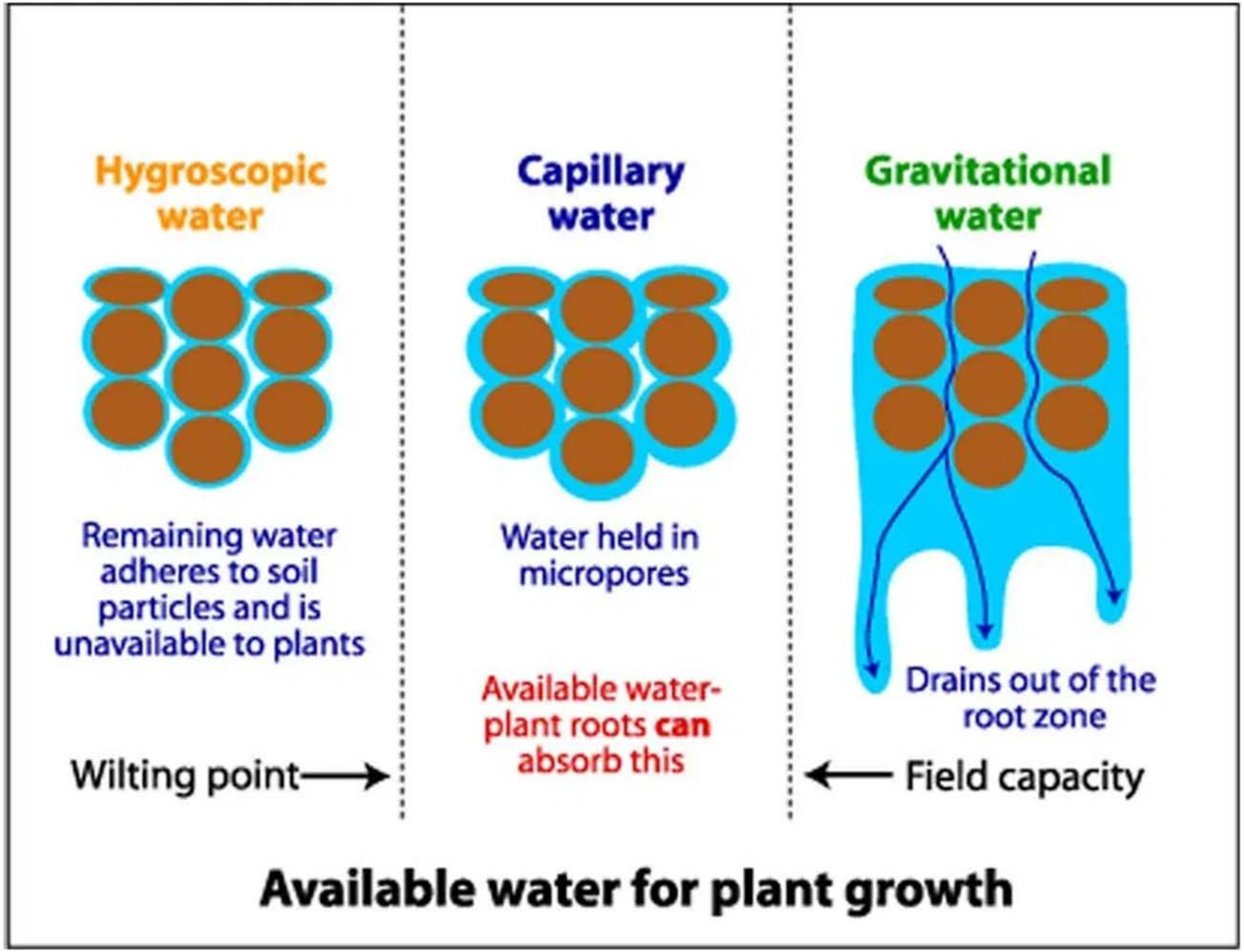
$$Porosity\ (\%) = \varphi = 1 - \frac{bulk\ density}{particle\ density}$$

Example: You have determined the bulk density of a soil to be 1.3 g/cm^3, what is its porosity?

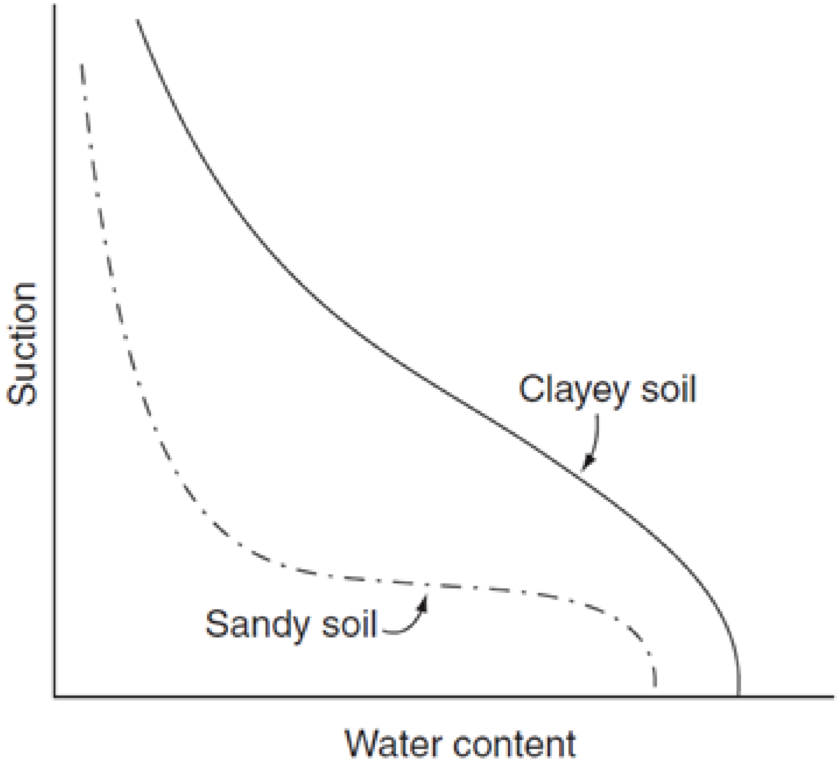
Follow-up: What is this soil's volumetric water content at saturation?

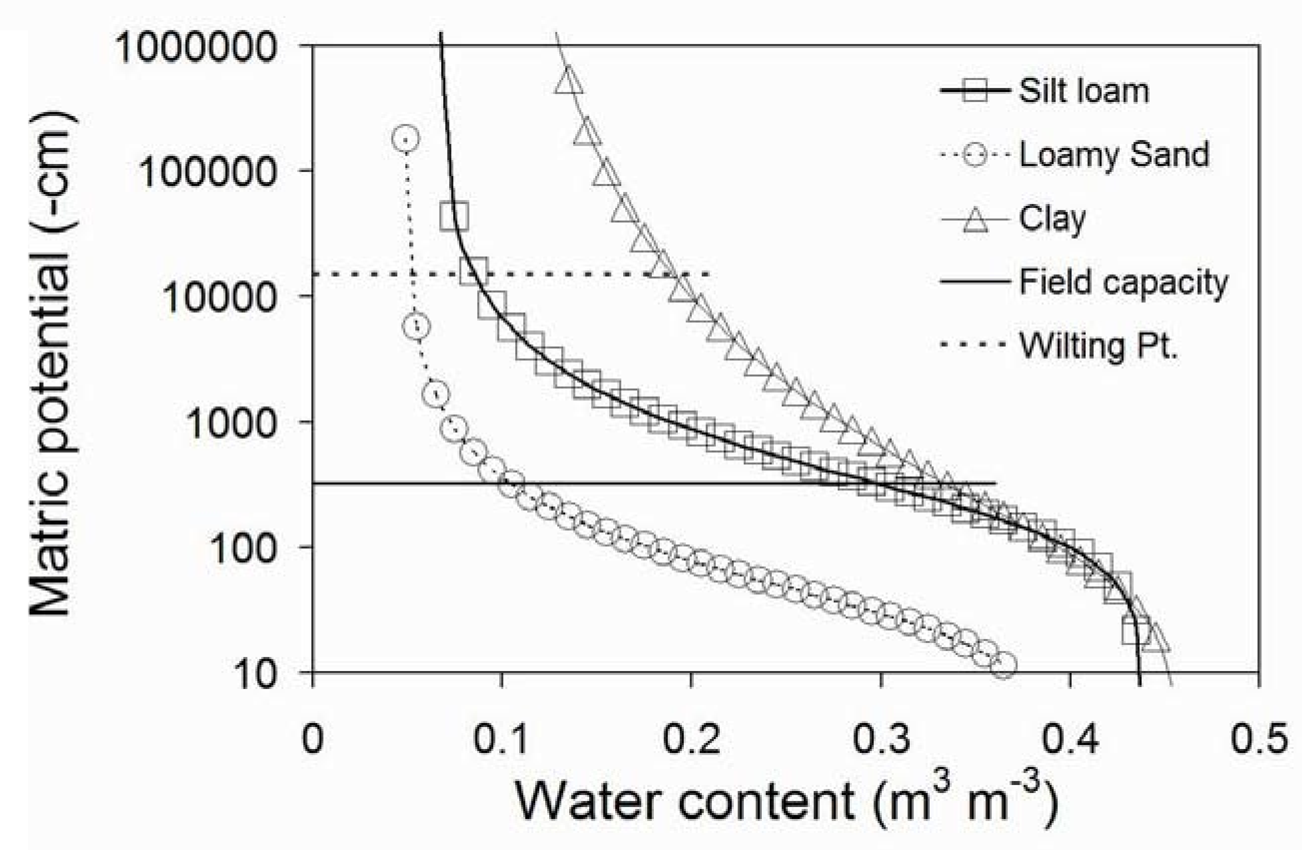
Visualizing Soil Properties with a Sponge

- Infiltration
- Wetting front
- Percolation
- Drainage
- Capillary Rise
- Surface Runoff


Hygroscopic water
Capillary water
Gravitational water
Remaining water adheres to soil particles and is unavailable to plants
Water held in micropores
Available water-plant roots can absorb this
Drains out of the root zone
Wilting point
Field capacity
Available water for plant growth

Measuring Soil Water Status





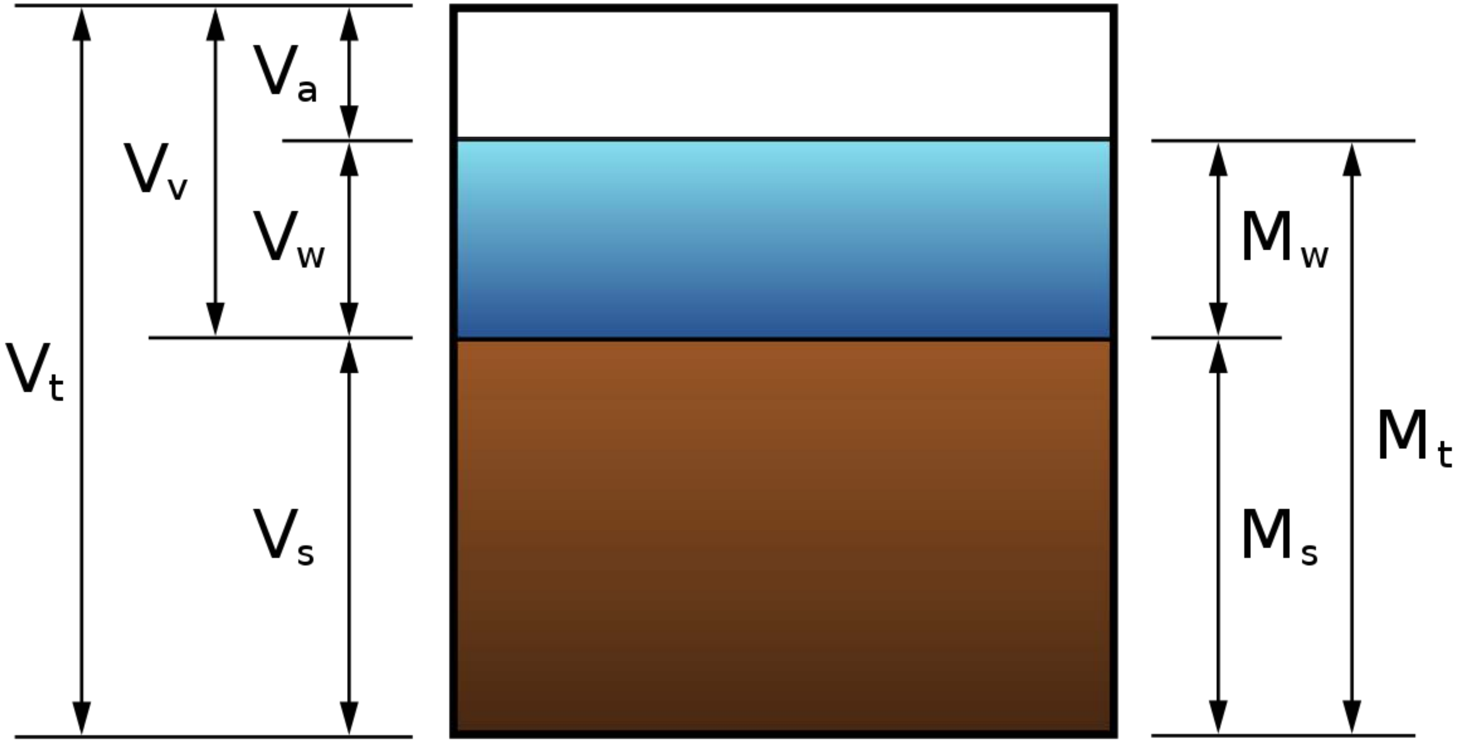
Soil Water Content

Gravimetric water content:

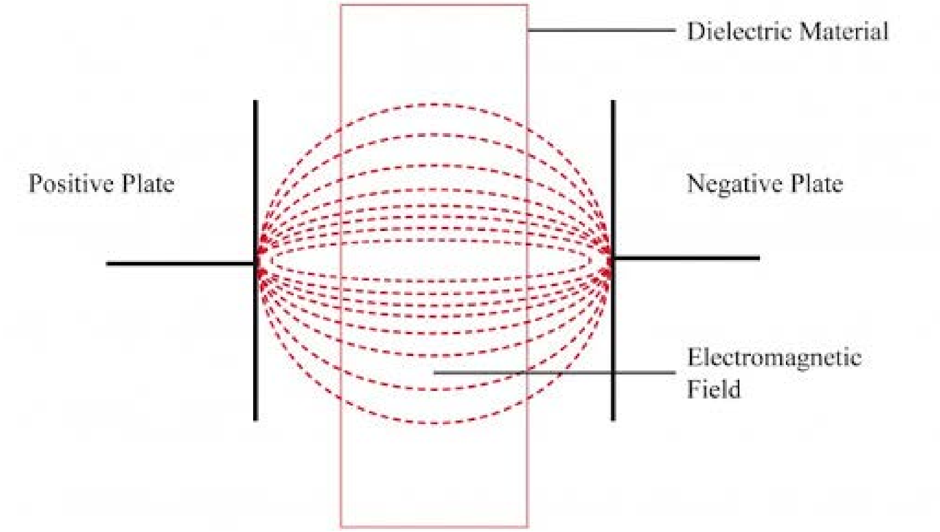
$$\theta_g = \frac{mass\ of\ water}{mass\ of\ soil} = \frac{mass\ wet\ soil - mass\ oven\ dry\ soil}{mass\ oven\ dry\ soil}$$

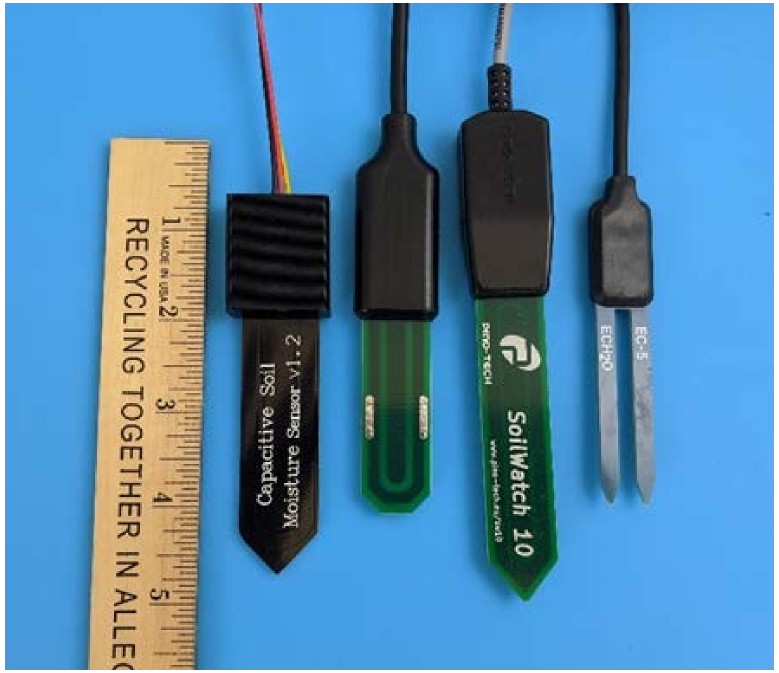
Volumetric water content:

$$\theta_v = \frac{water\ volume}{total\ soil\ volume} = \theta_g \times \rho_b$$



Capacitive Soil Moisture Sensors

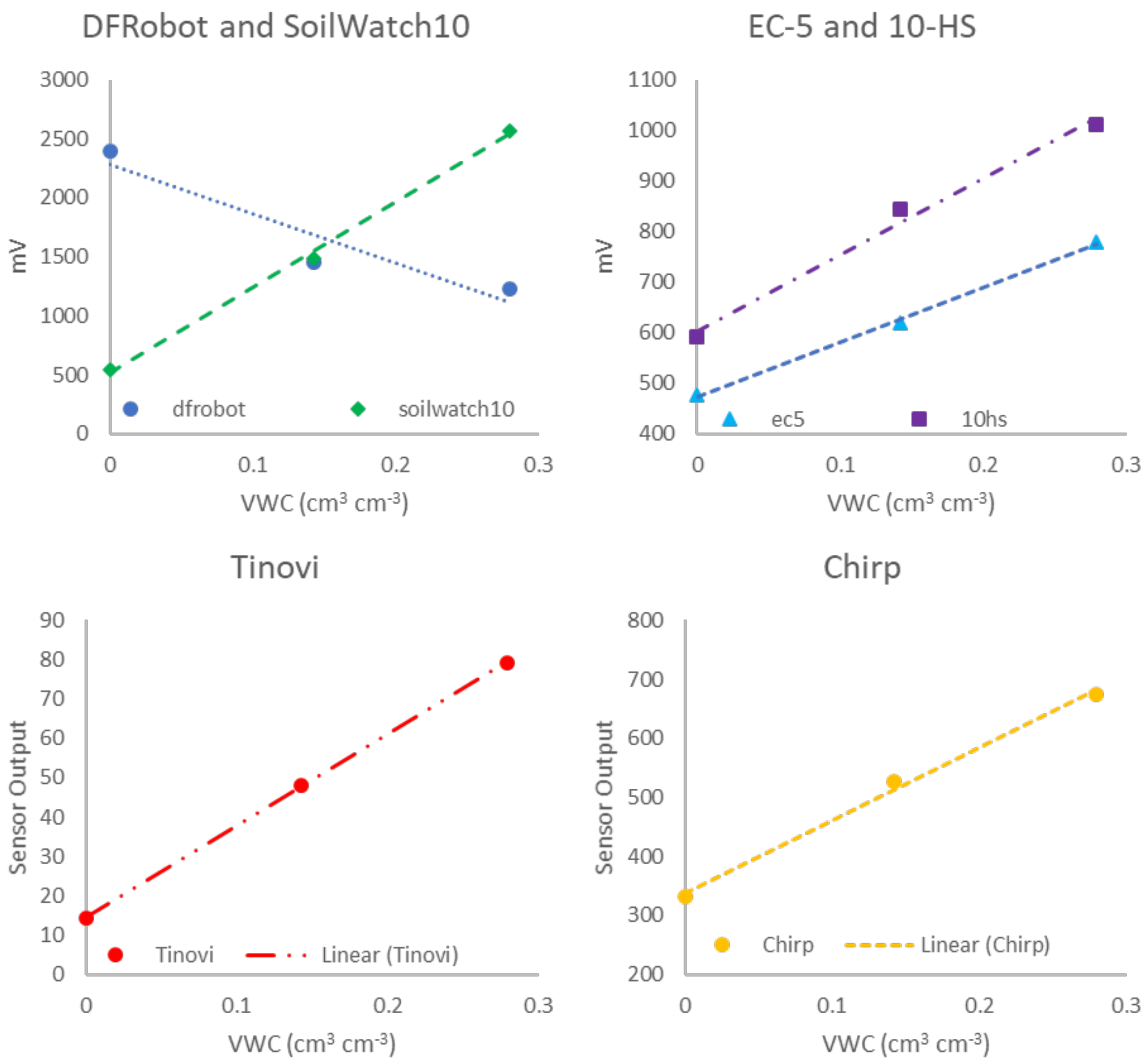


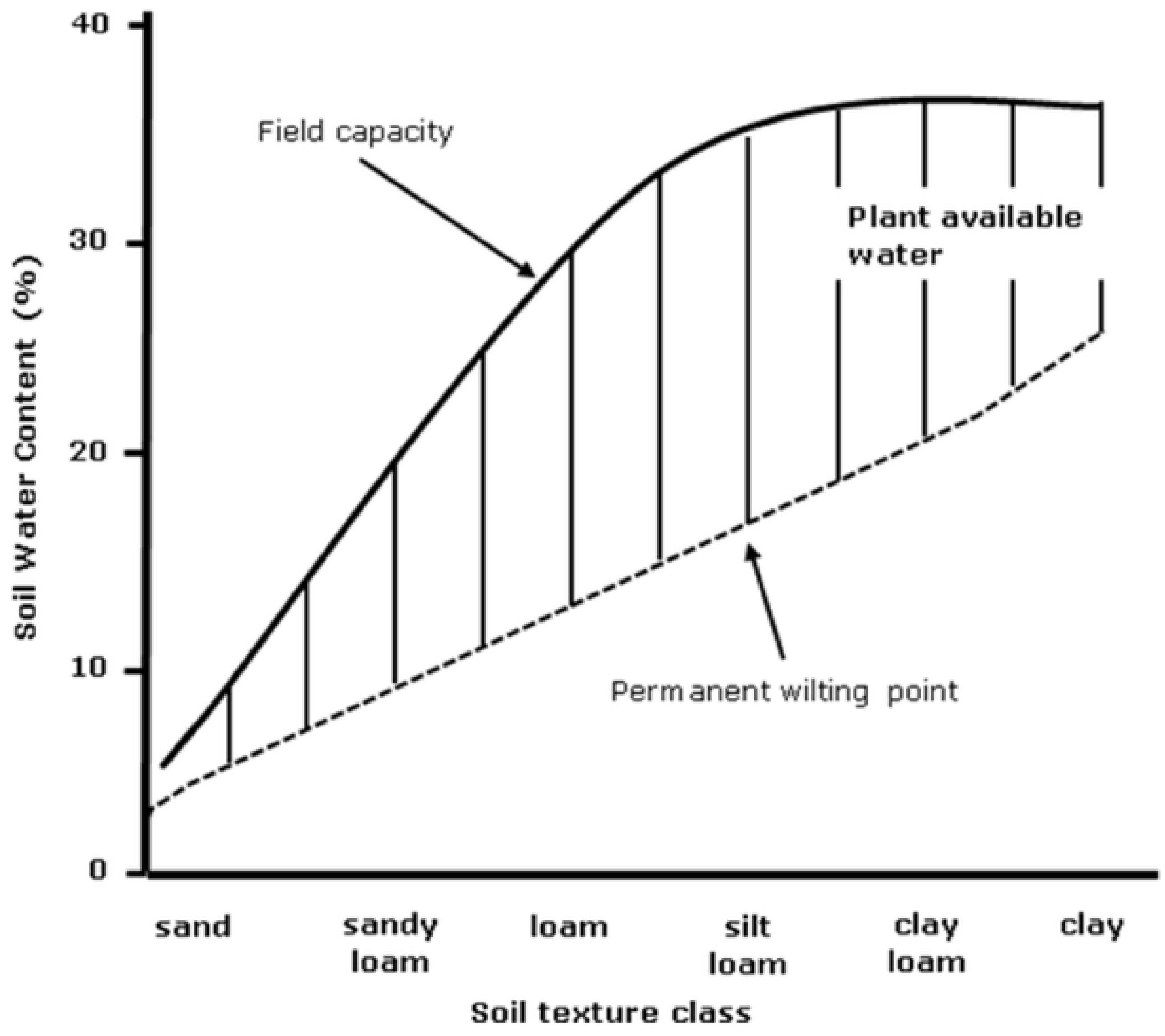


Capacitive sensors measure the dielectric permittivity of the material surrounding them—the dielectric constant of air is close to 0 F/m (Farads/meter), the dielectric constant of water is about 80 F/m

Calibrating Soil Sensors with Direct Measurement of Soil Water Content

- Many soil moisture sensors return a voltage.
- In order to convert this voltage to a meaningful measurement of soil water content, we need to calibrate the sensors against a direct measurement (GWC or VWC).



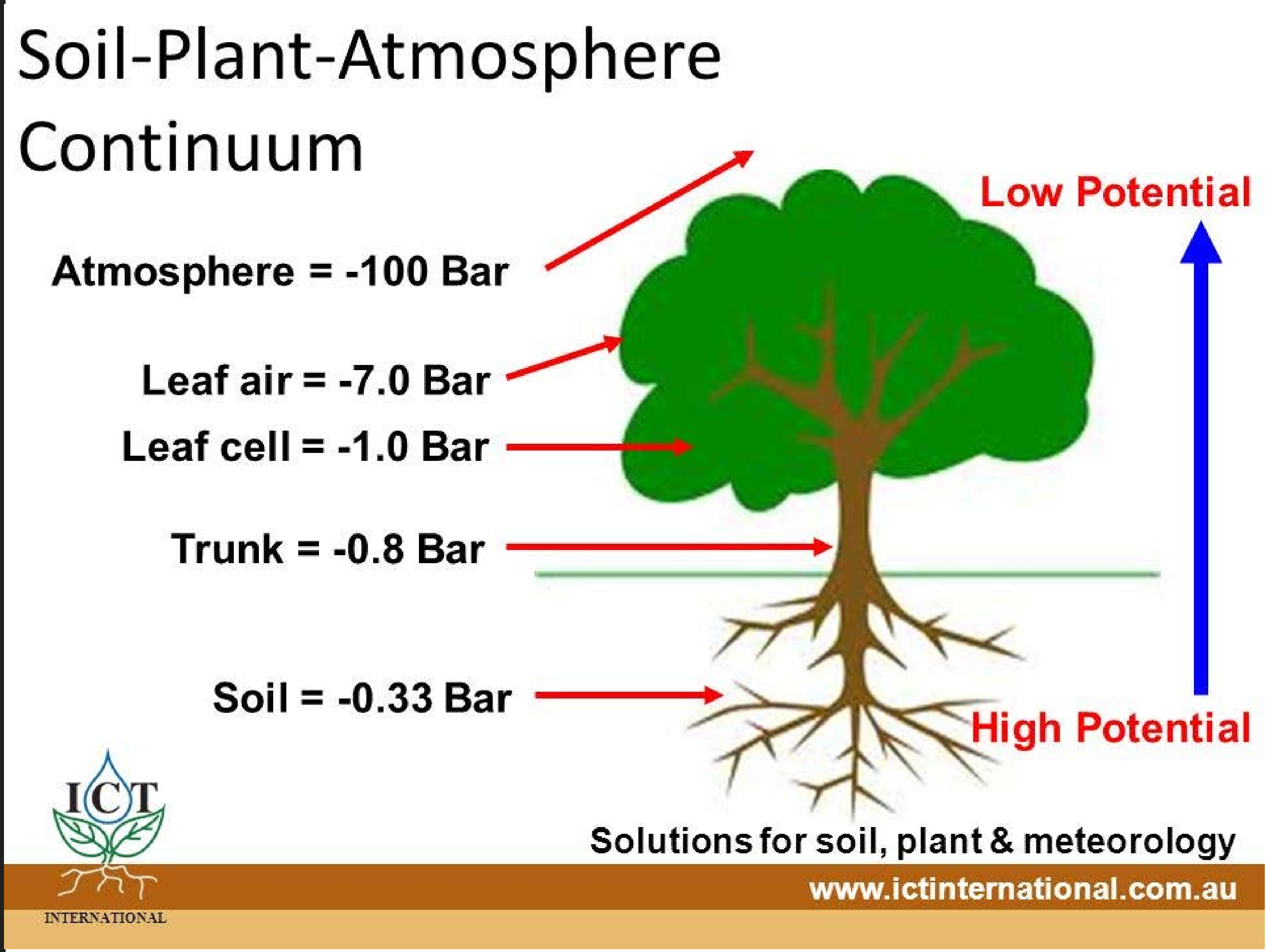


Plant Available Water

- Plant available water, or available water content (AWC), is the amount of water held in soil between field capacity (FC) and permanent wilting point (PWP)
- AWC = FC – PWP

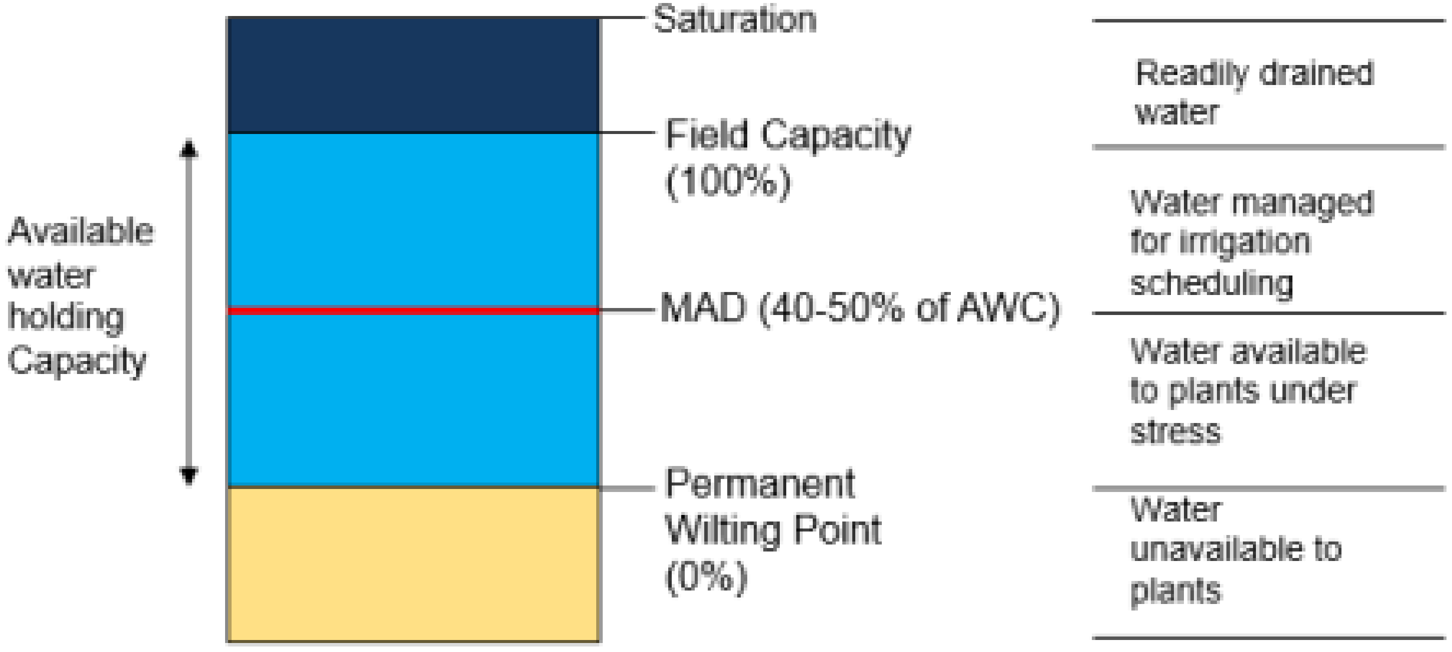
Evapotranspiration

- The sum of water lost from the soil by evaporation and transpiration processes
- Soil-Plant-Atmosphere continuum: Water moves along a gradient from high potential (wet soil) to low potential (dry air).



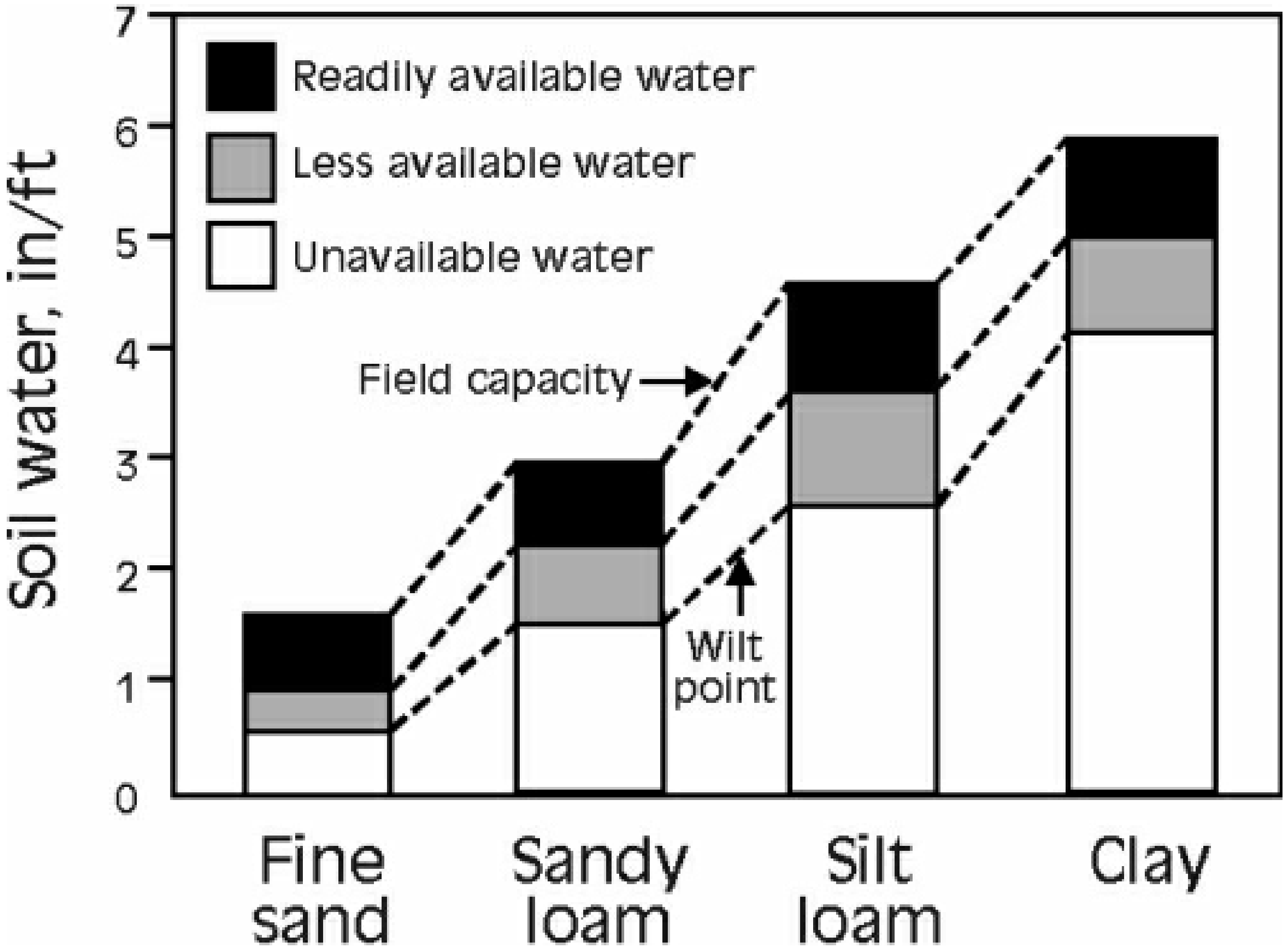
Management Allowable Depletion

- Management allowable depletion (MAD) is the amount of water that plants can extract from the soil before incurring a yield penalty from water stress.
- MAD is typically between 30-60% of field capacity, depending on plan species.
- FAO table for MAD by crop type



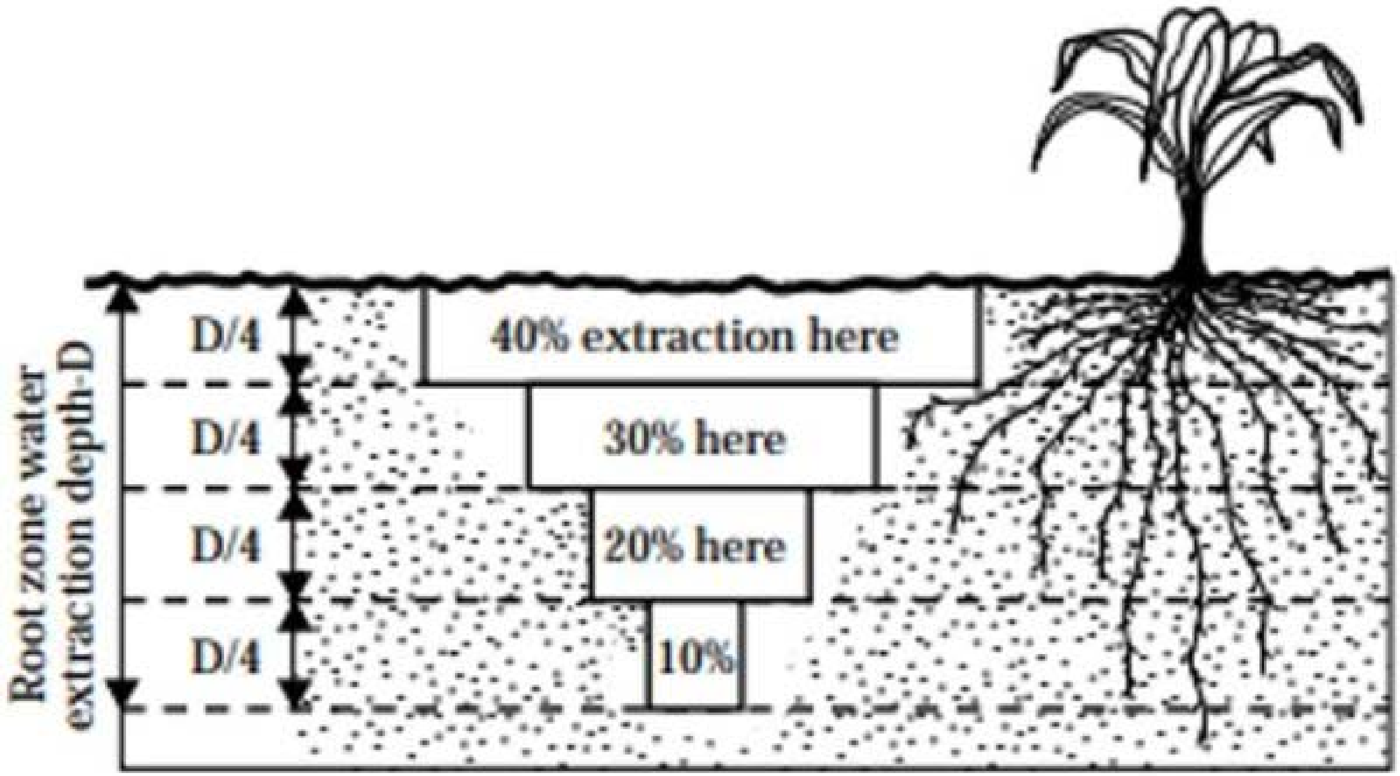
Readily Available Water

- Readily Available Water (RAW) is the fraction of AWC that a crop can extract from the root zone without suffering water stress (FAO)
- RAW = MAD x AWC



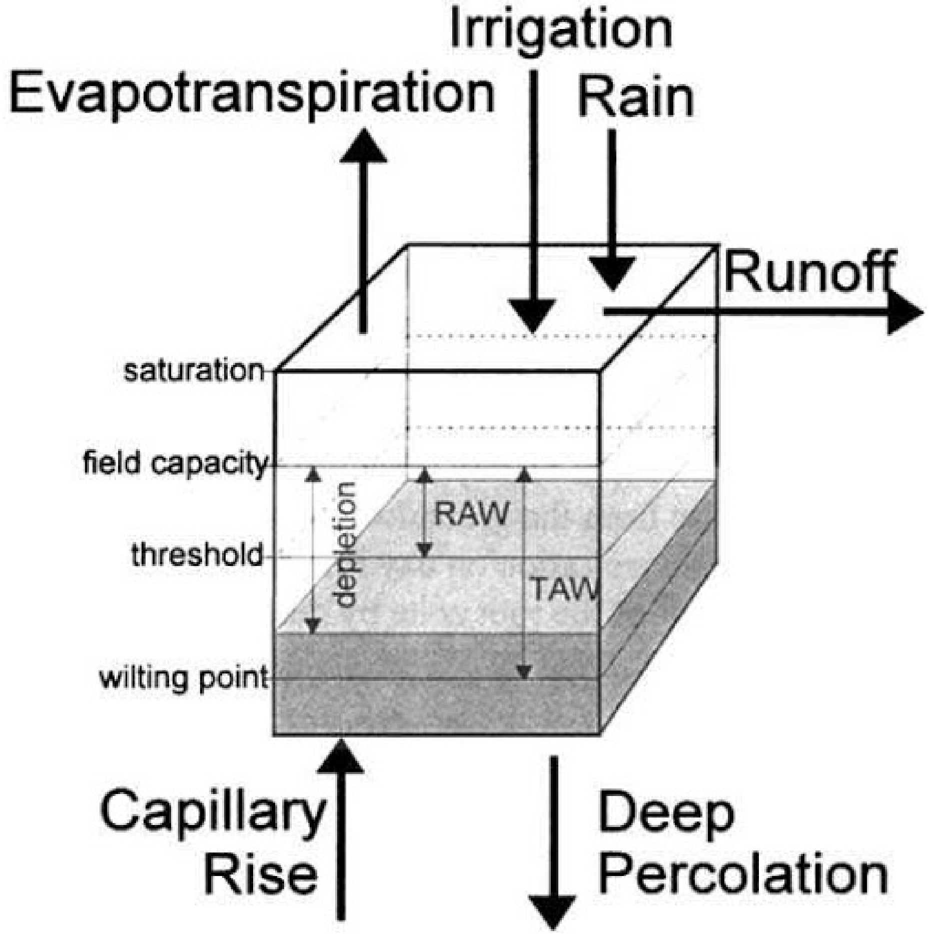
Gross Irrigation Water Depth and Root Zone Depth

- Gross irrigation water depth (IG) is how much water needs to be applied during irrigation to replenish the soil profile. IG is measured in length units (in/ft or cm/m)
- Root Zone depth is measured in length units (in/ft or cm/m) – FAO Table
- IG = MAD x AWC x RZ
- IG = RAW x RZ



Irrigation Scheduling

- Typically, we try to estimate soil water content using a water balance approach that is based on weather data.
- This approach works well if the weather data is accurate, but spatial variability in weather patterns (especially precipitation) leads to errors.



$D_{r,\,i} = D_{r,\,i-1} - (P - RO)_i - I_i - CR_i + ET_{c,\,i} + DP_i$ (85)

where

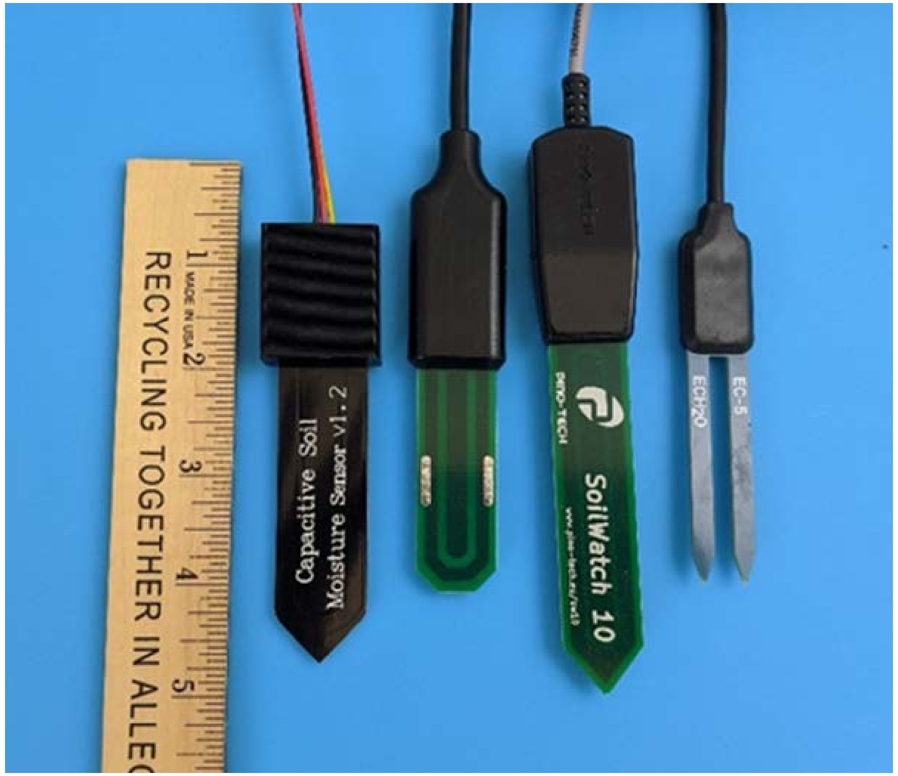
$D_{r,\,i}$ root zone depletion at the end of day i [mm],
$D_{r,\,i-1}$ water content in the root zone at the end of the previous day, i-1 [mm],
P_i precipitation on day i [mm],
RO_i runoff from the soil surface on day i [mm],
I_i net irrigation depth on day i that infiltrates the soil [mm],
CR_i capillary rise from the groundwater table on day i [mm],
$ET_{c,\,i}$ crop evapotranspiration on day i [mm],
DP_i water loss out of the root zone by deep percolation on day i [mm].

Why not just measure soil moisture?

- Soils a spatially and temporally heterogeneous, so many soil moisture sensors are needed to get a good estimate of soil moisture in a field.
- Sensors have historically been too expensive to be able to instrument fields with them in adequate numbers.

“Controlling an irrigation system without soil moisture sensors is like driving a car without a gas gauge” – Dana Lonn, Toro

“You can’t manage what you can’t measure!”- Peter Drucker



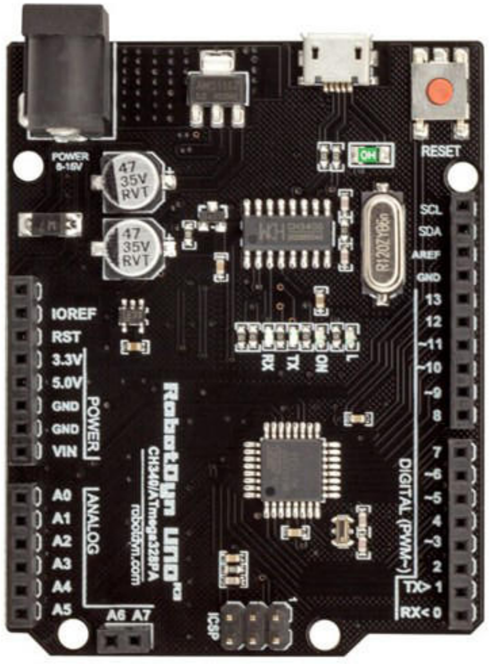
These sensors range in price from $1/unit to $120/unit.

We have found that mid-range sensors ($20) compare well with research grade alternatives.

Arduino is an Open-Source Microcontroller Platform

ATmega328

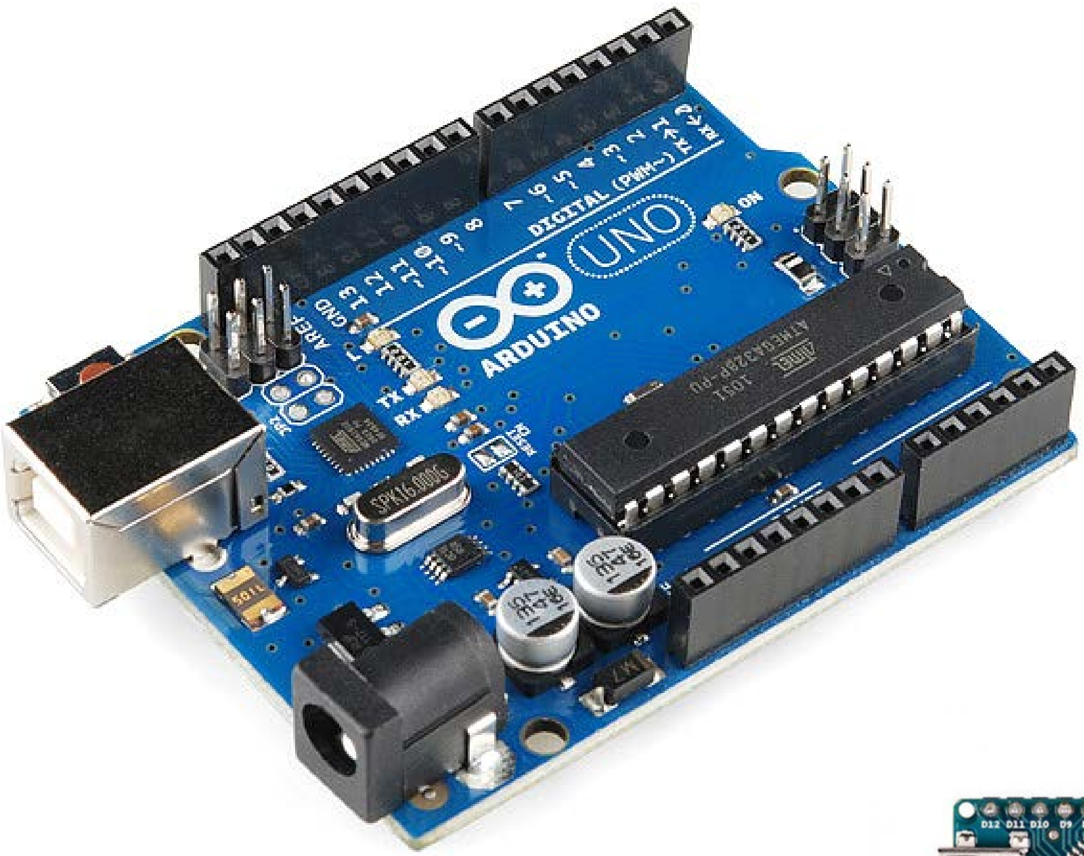
Footprint (board layout)

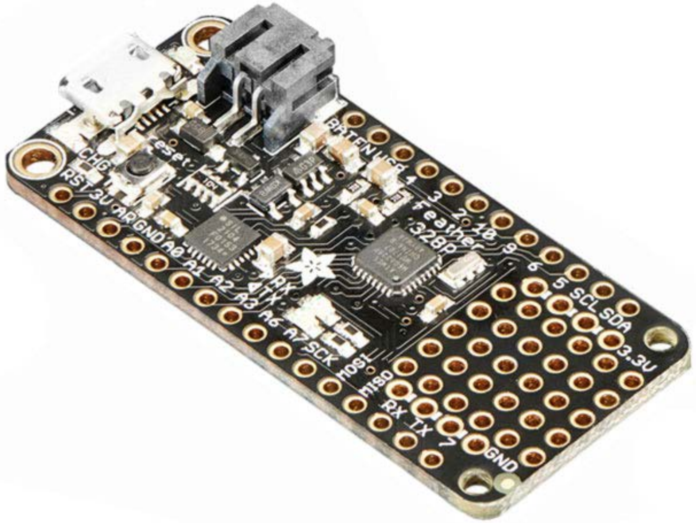


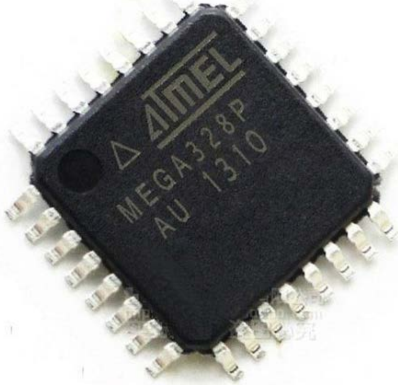
RobotDyn “Uno”

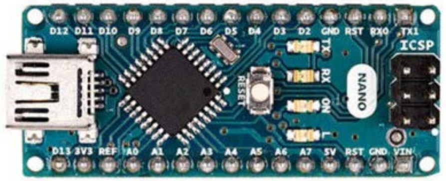
Official Uno

Comes in Many Different Shapes and Sizes

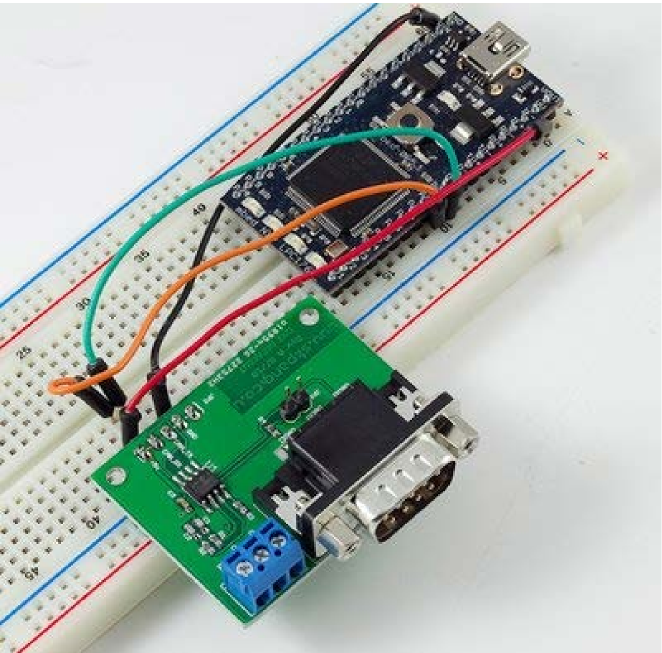






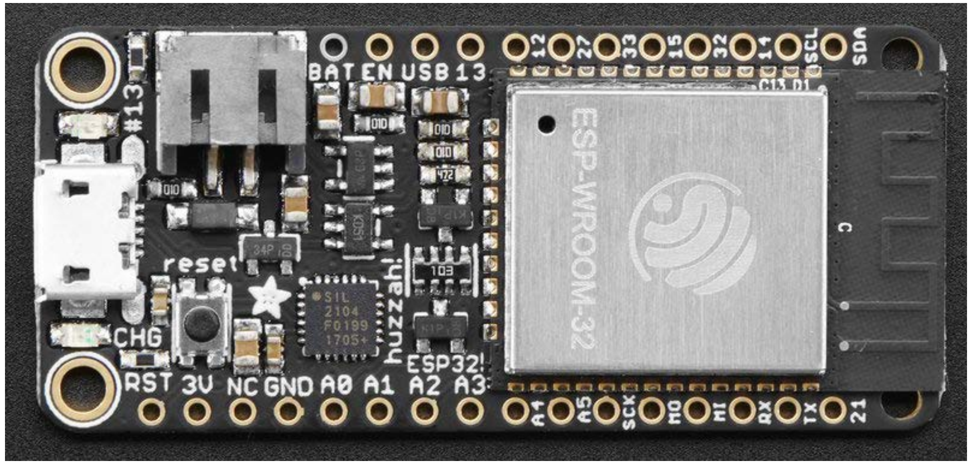


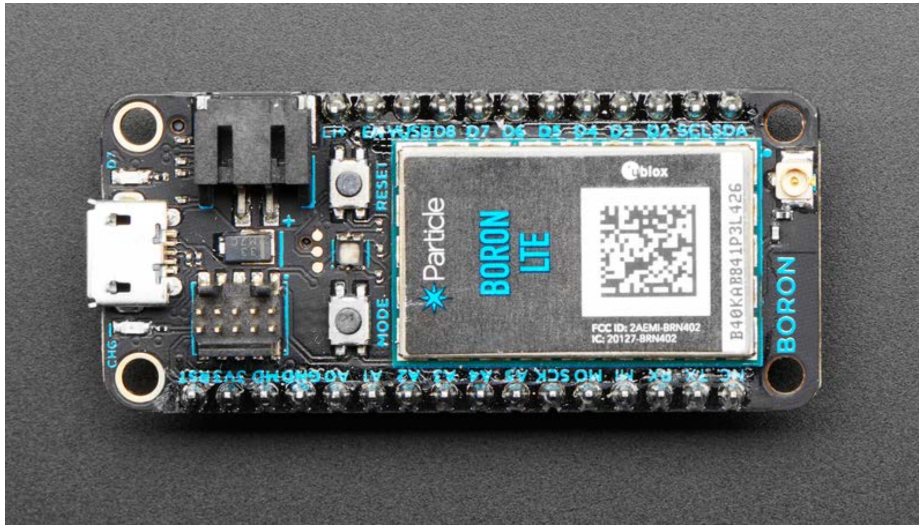
Breakout Boards and Shields



Connectivity Options with More Advanced Boards

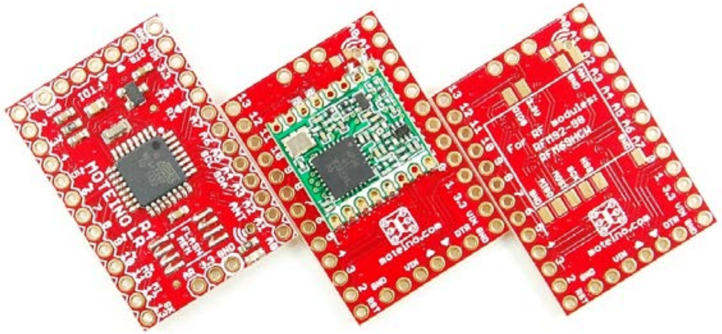
Processor: ESP32
Footprint: Feather
Connectivity: BLU and WiFi
Creator: Adafruit





Processor: ARM Cortex-M4F
Footprint: Feather
Connectivity: Mesh and Cellular
Creator: Particle

Processor: ATmega328p
Footprint: Custom
Connectivity: LoRa (Radio)
Creator: Moteino



Arduino Resources, References and Projects

- https://www.adafruit.com/
- https://www.sparkfun.com/
- https://www.arduino.cc/
- https://www.particle.io/
- https://www.dfrobot.com/
- https://www.seeedstudio.com/
- https://www.hackster.io/
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