SoilSense

Kernefrugt temadag 2022

2 ZERO HUNGER

6 CLEAN WATER AND SANITATION

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Vanding ud fra jord sensorer

1. SoilSense, hvem er vi
2. Hvorfor optimering af vanding
3. Hvordan måler man vand i jord
    a. Matrix potentiale (SMP)
    b. volumetrisk vandindhold (VWC)
    c. Plantetilgængeligt vand (PAW)
4. Hvordan bruges data i praksis
    a. Vanding, eksempler fra kunder
    b. Temperatur og regndata

Hvem er jeg

Jesper Alkestrup

Ingeniør fra DTU

Arbejdet med udvikling af jord-sensor teknologi siden 2017, skift af fokus til software

Projekt implementering af sensor-baseret vanding i Peru, Kenya og Europa i 5 år

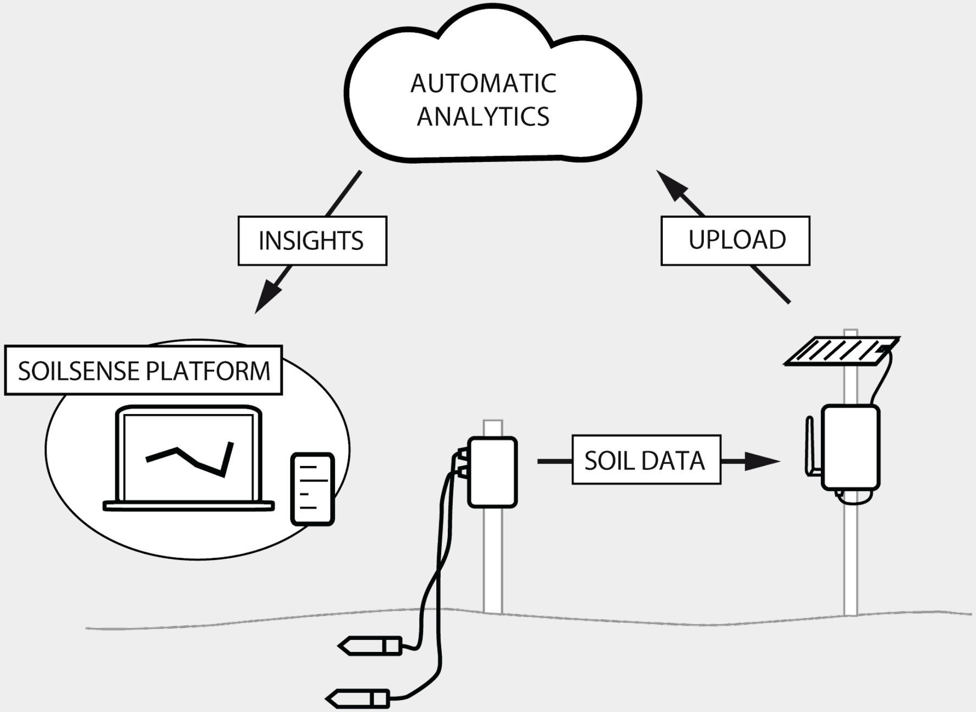
SoilSense: Hvem er vi?

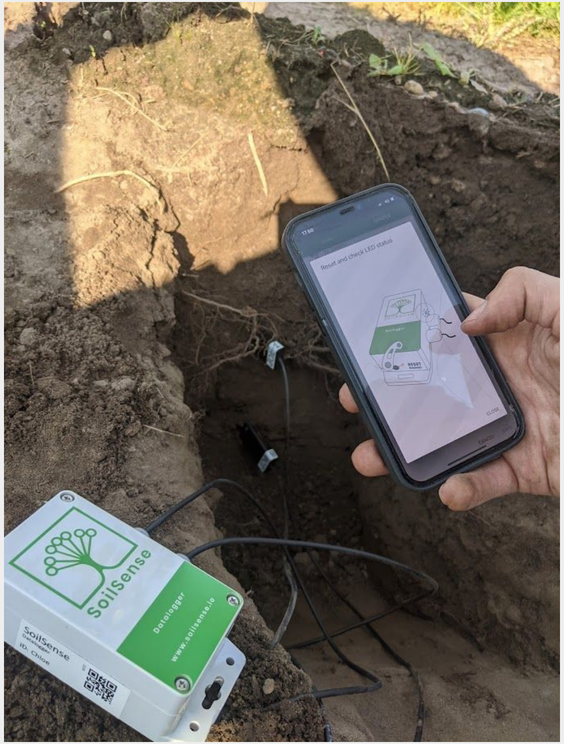
Teknologivirksomhed på 7 mand, fokuseret på at gøre præcisions vanding let.

Kunder i skandinavien og 5 andre lande.

Finansieret af private investorer, bl.a. Af Aarstiderne.

SoilSense: Hvad laver vi?





Hvorfor?

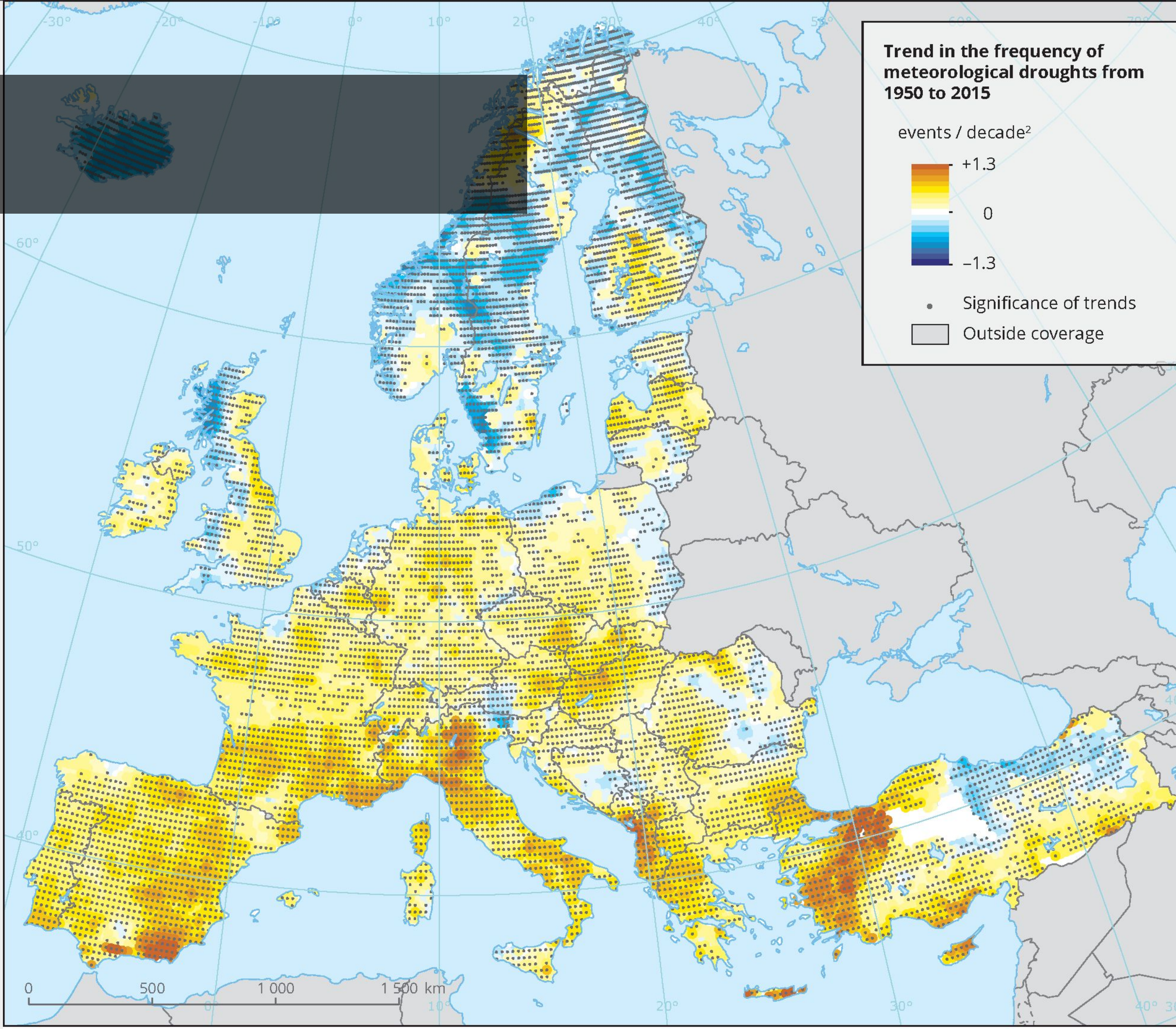
Stort potentiale for optimering

2018 og 2019, de tørreste år i træk i Europas historie

Vanding i landbrug ansvarlig for 40% af EU's vandforbrug

Øget politisk regulering og tilgængelighed af vandressourcer påvirker landbrug i dag

Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming (2020)
https://www.nature.com/articles/s41598-020-68872-9
FAO, Aquastat (2015), http://www.fao.org/aquastat/en/



Reference data: ©ESRI

Hvorfor bruge sensorer til vandstyring?

Præcis vanding giver mulighed for

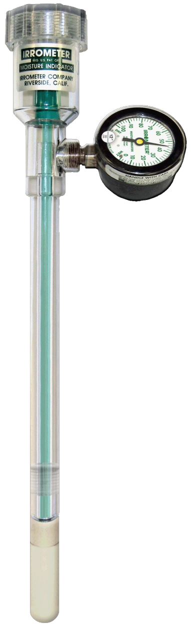
- Kontrollere vækst
- Øge kvalitet og udbytte af frugter
- Reducerer det samlede vandforbrug markant

"Field sensors that map irrigation needs allow water savings of 45 to 50 % for fruits and vegetables"

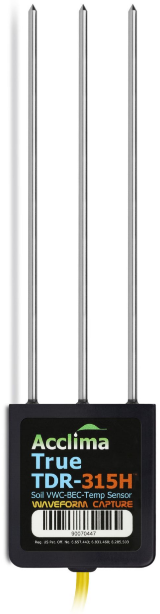
-Irrigation in EU agriculture, 2019

Forskellige måle-enheder

Matrix-potentiale (kPa / cb)



Volumetrisk vandindhold (%)

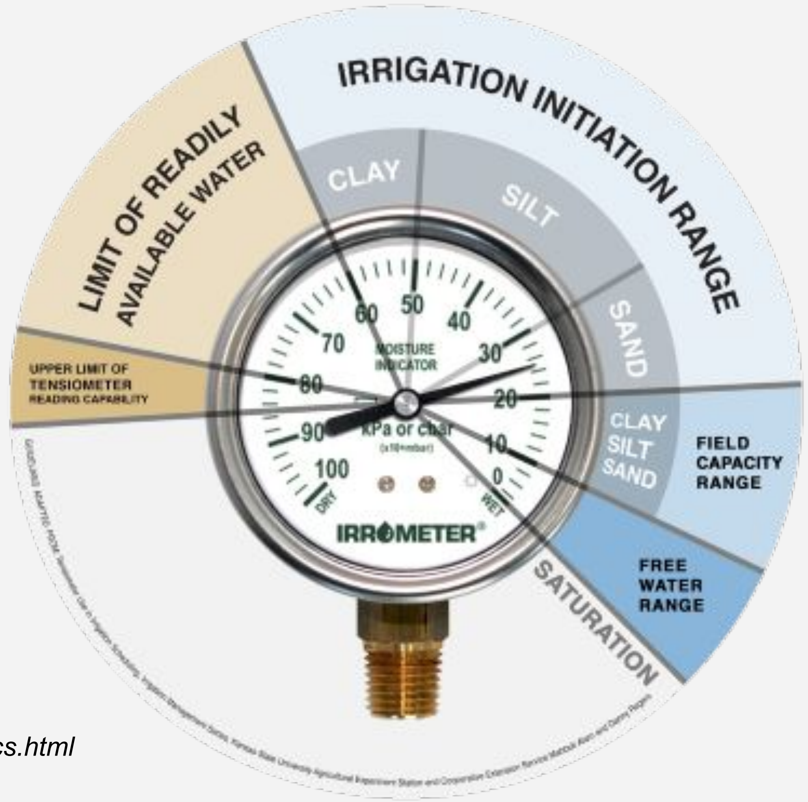


Matrix potentiale

Estimering af den energi som planten skal udøve for at optage vand.

Ift. vandingsstyring skal grænseværdier sættes efter jordtype og afgrød.

Omtalt SMP - Soil Matric Potential



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

De fleste sensorer er ikke gode nok

Få sensorer på markedet anbefales af videnskabelige studier til vanding

TDT & TDR

FDR & Capacative

Field Estimation of Soil Water Content, 2008
https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-30_web.pdf

Soil water sensors for agriculture - Theory and issues (2016)

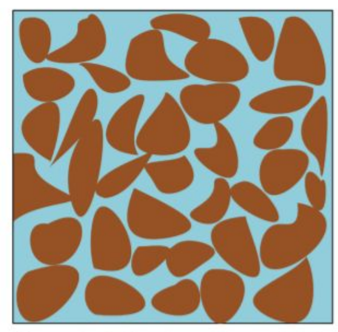
Volumetrisk vandindhold (VWC)

Hvor mange % af jord volumen, er vand. Ex. Et glas vand, 100%, luft 0%.

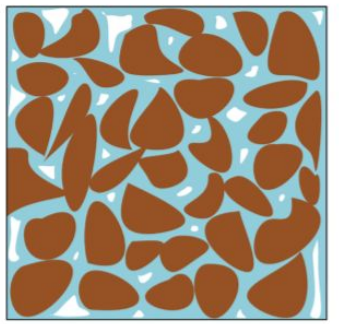
Mætning
Alle porer er fyldt med vand,
Vand dræner frit pga. tyngde

Mark kapacitet
Efter fri afdræning
Max. vand som fastholdes

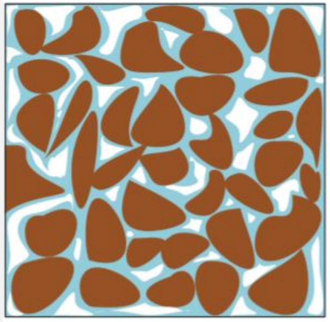
Visnegrænsen
Planter kan ikke optage
vand længere



Ex. 40% VWC



Ex. 20% VWC



Ex. 8% VWC

Plante tilgængeligt vand (PAW)

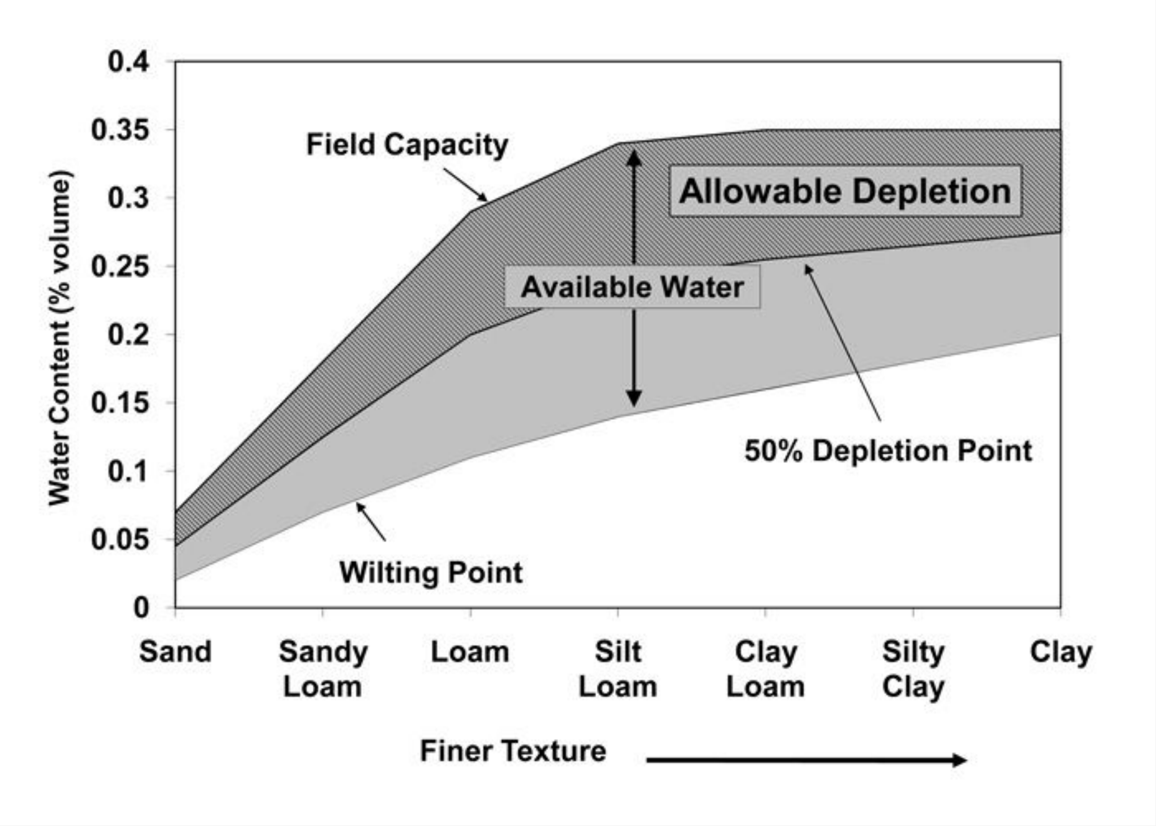
Enhed på tværs af jordtyper, kræver kalibrering:

100% plantetilgængeligt vand = markkapacitet

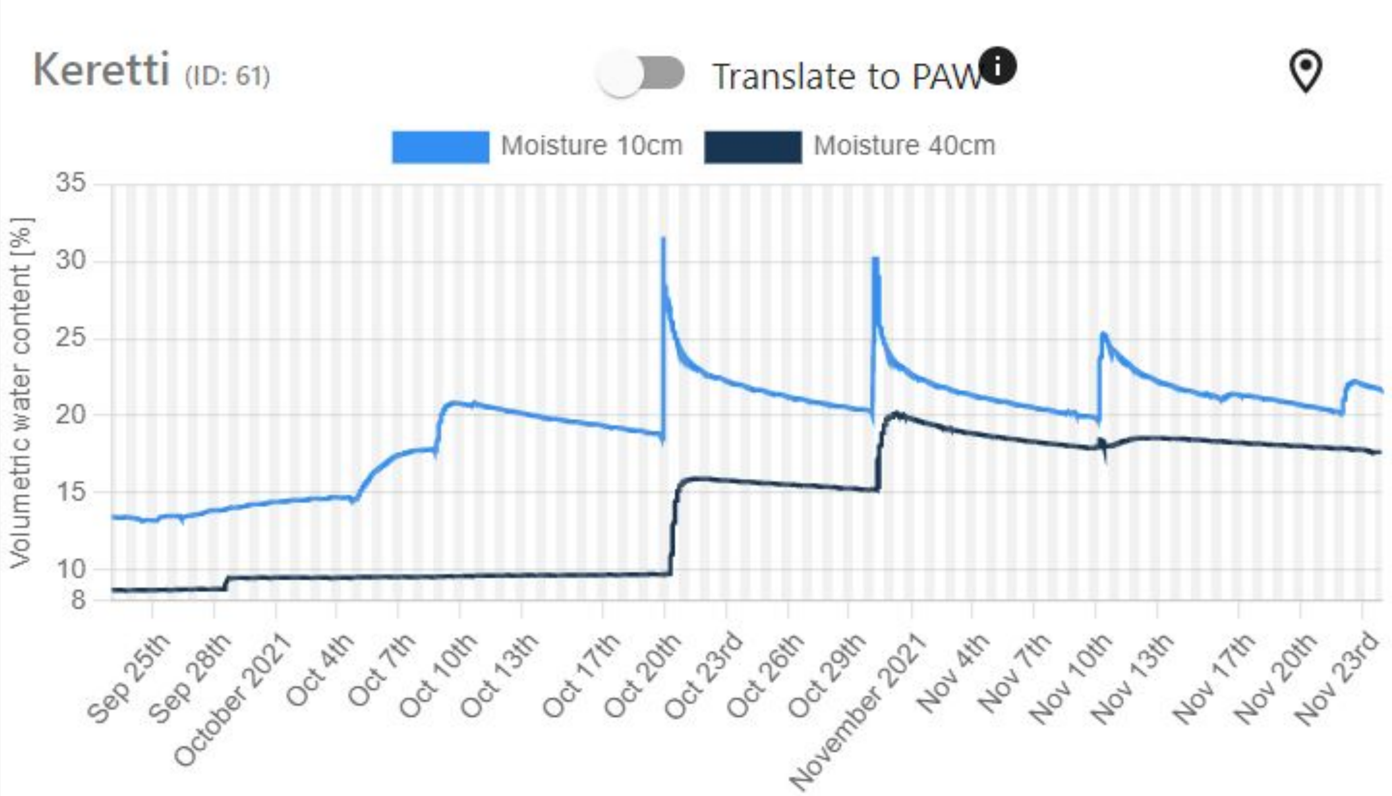
0% = visnepunkt

Vandingspunkt afhængigt af afgrøde og stadie,
for frugttræer typisk ved 50% PAW

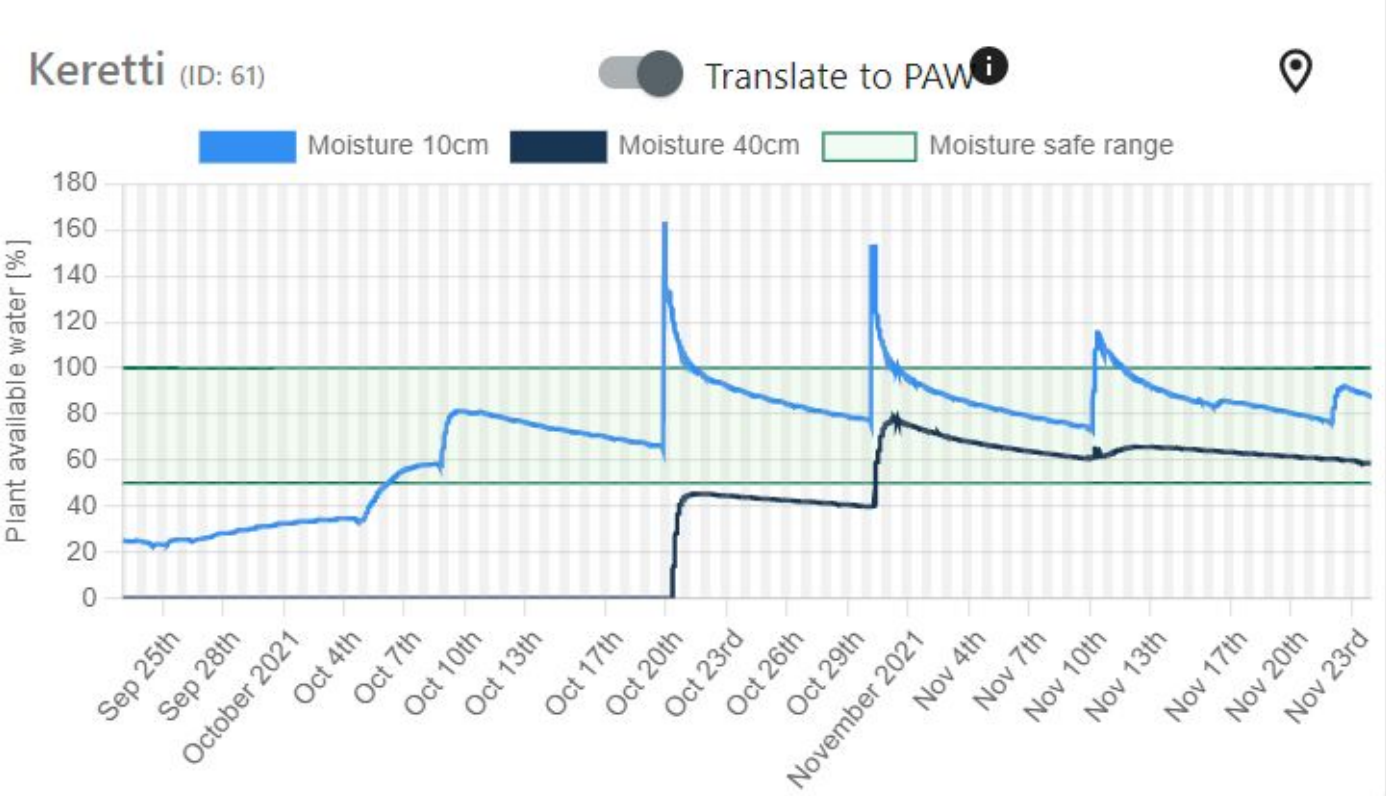
Plante tilgængeligt vand (PAW)

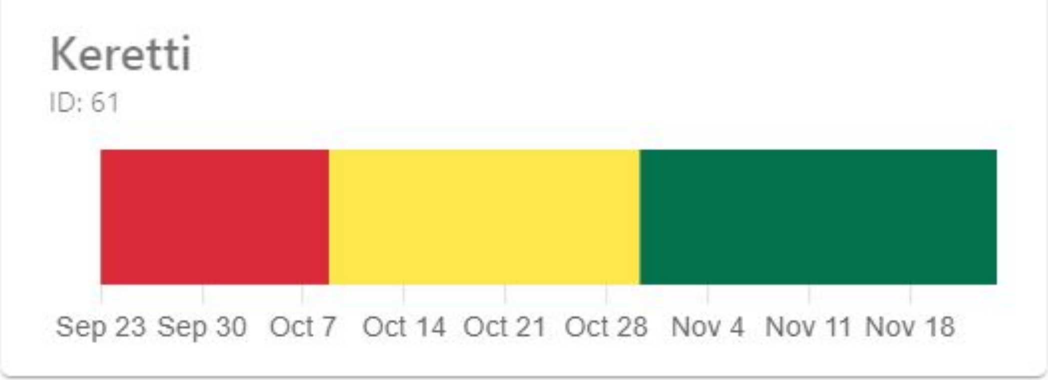


SoilSense – fra VWC til PAW

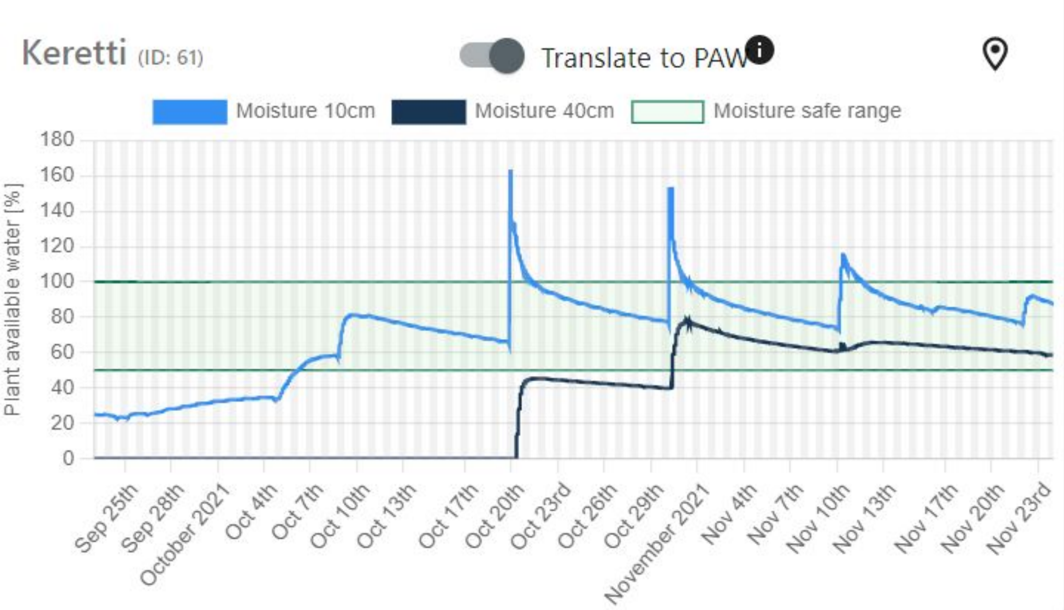


SoilSense – Automatisk kalibrering



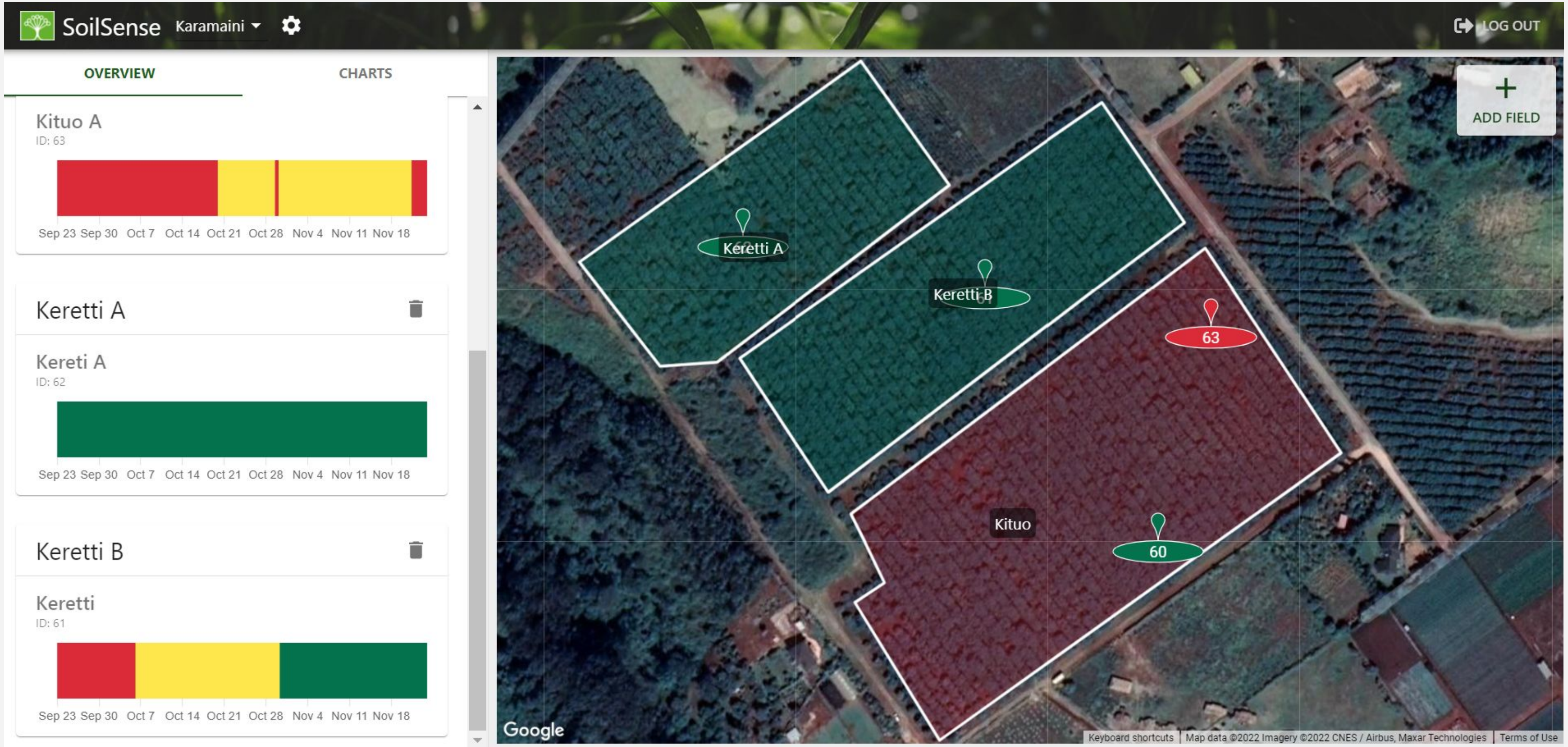


Keretti
ID: 61
Sep 23
Sep 30
Oct 7
Oct 14
Oct 21
Oct 28
Nov 4
Nov 11
Nov 18

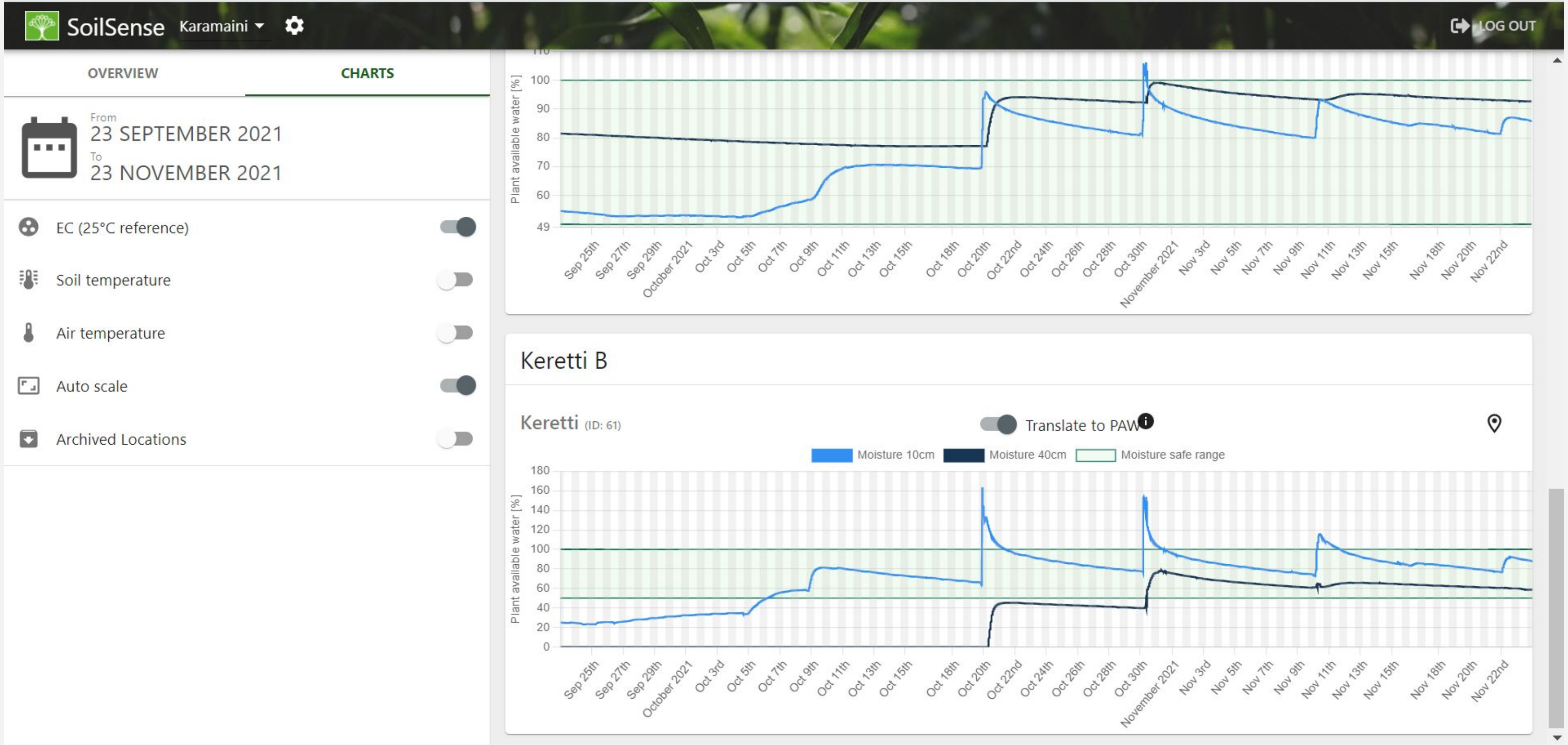


Keretti (ID: 61)
Translate to PAW
Moisture 10cm
Moisture 40cm
Moisture safe range
Plant available water [%]
180
160
140
120
100
80
60
40
20
0
Sep 25th
Sep 28th
October 2021
Oct 4th
Oct 7th
Oct 10th
Oct 13th
Oct 17th
Oct 20th
Oct 23rd
Oct 26th
Oct 29th
November 2021
Nov 4th
Nov 7th
Nov 10th
Nov 13th
Nov 17th
Nov 20th
Nov 23rd

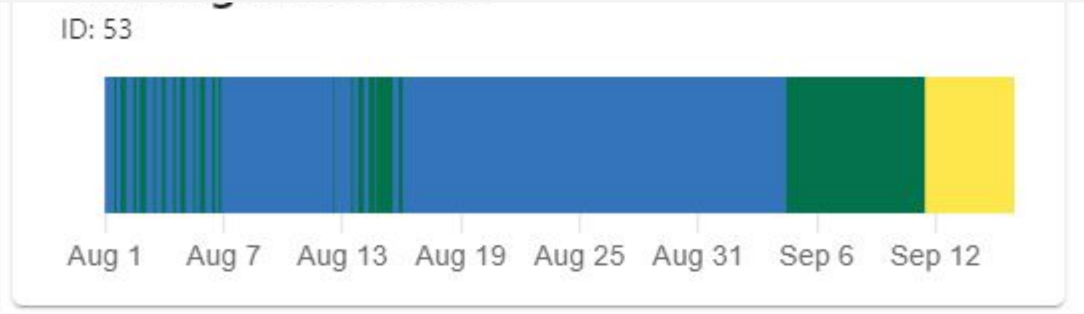
SoilSense – I praksis

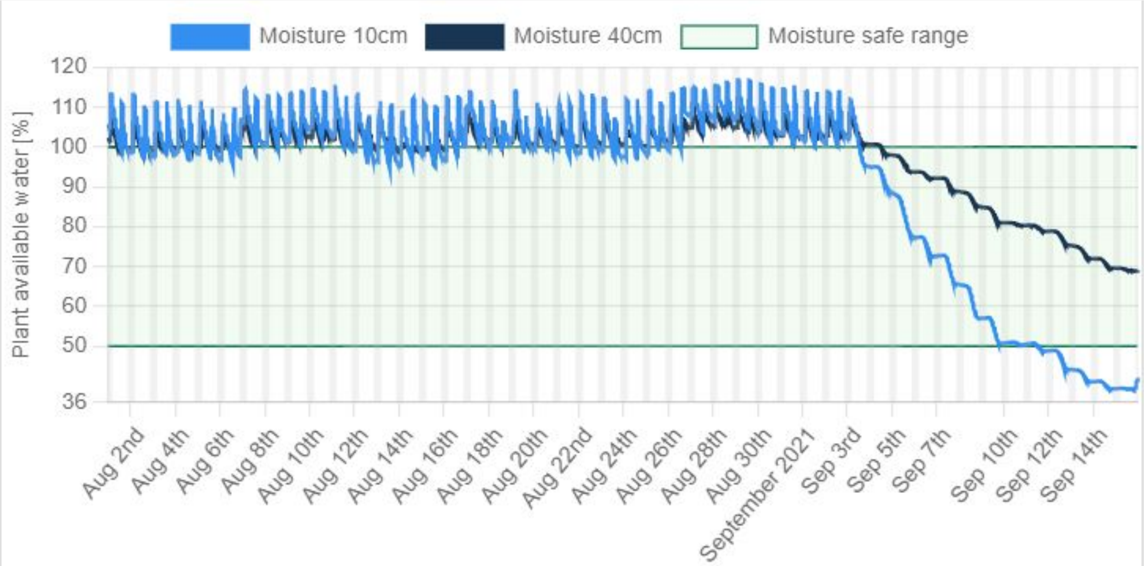


SoilSense – I praksis



Eksempler: Clara Friis 1. August til 15. Sept



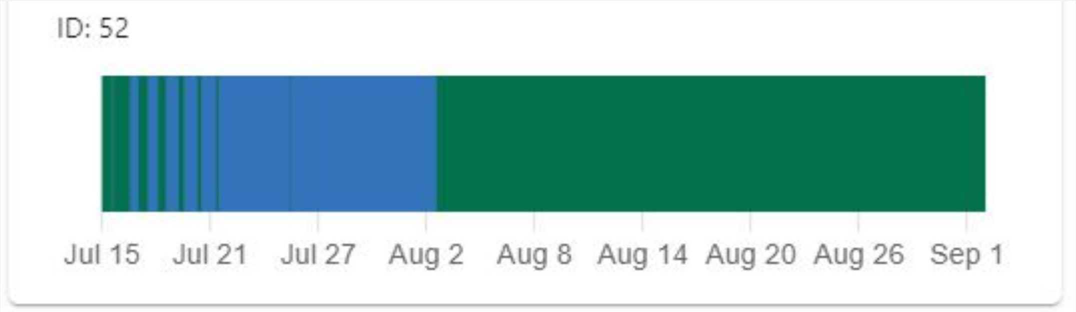


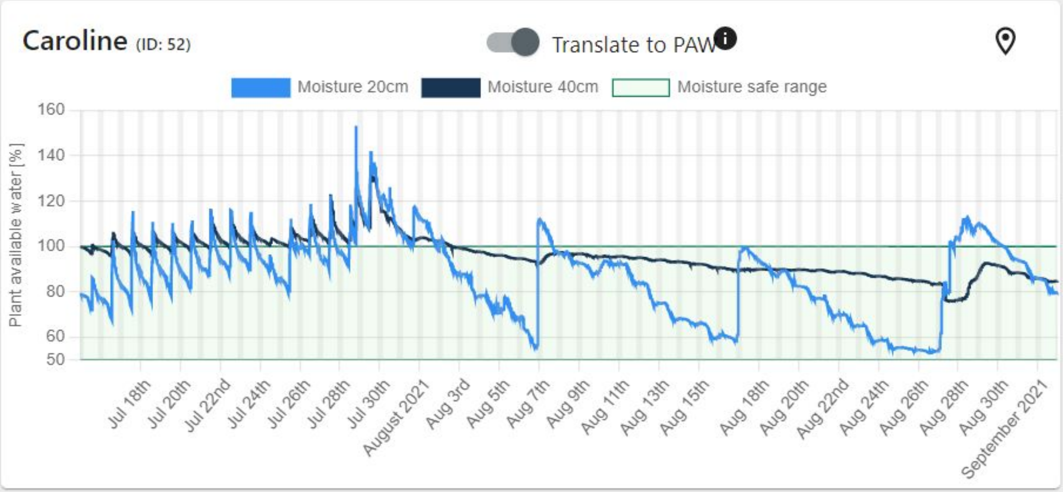
Intention: Tilstrækkeligt vand i vækstfase af pærer

Sensor data:
Klar overvanding ved sensor lokation

Potentiel
Udvaskning af Næringsstoffer, plantesygdomme og stort vandspild

Eksempel: Caroline æbler (nyplant)



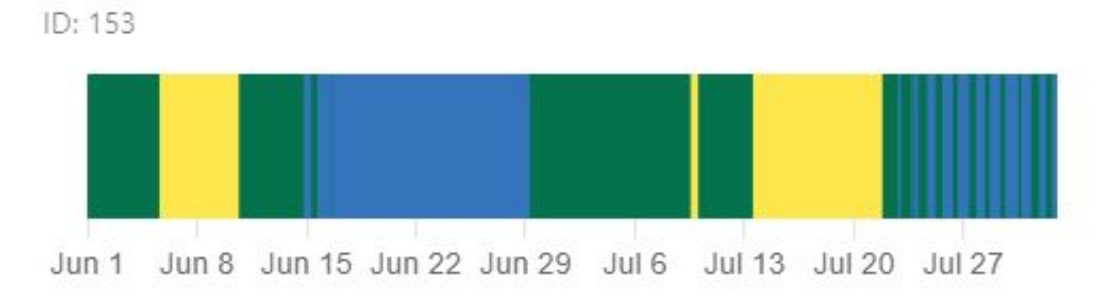


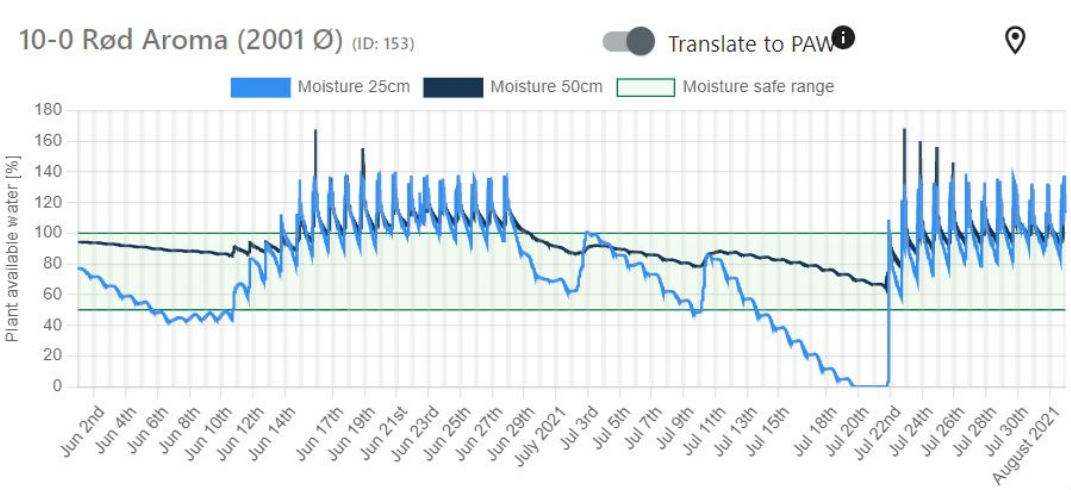
Intention: Tilstrækkeligt vand for "nyplantede" æbler (2. sæson)

Sensor data:
Overvanding justeret til optimal vanding

Potentiel
Sparret vand, fremmer udvikling af rodvækst nedad, mindre risiko for sygdomme

Eksempel: Rød Aroma, reducer vegetativ vækst



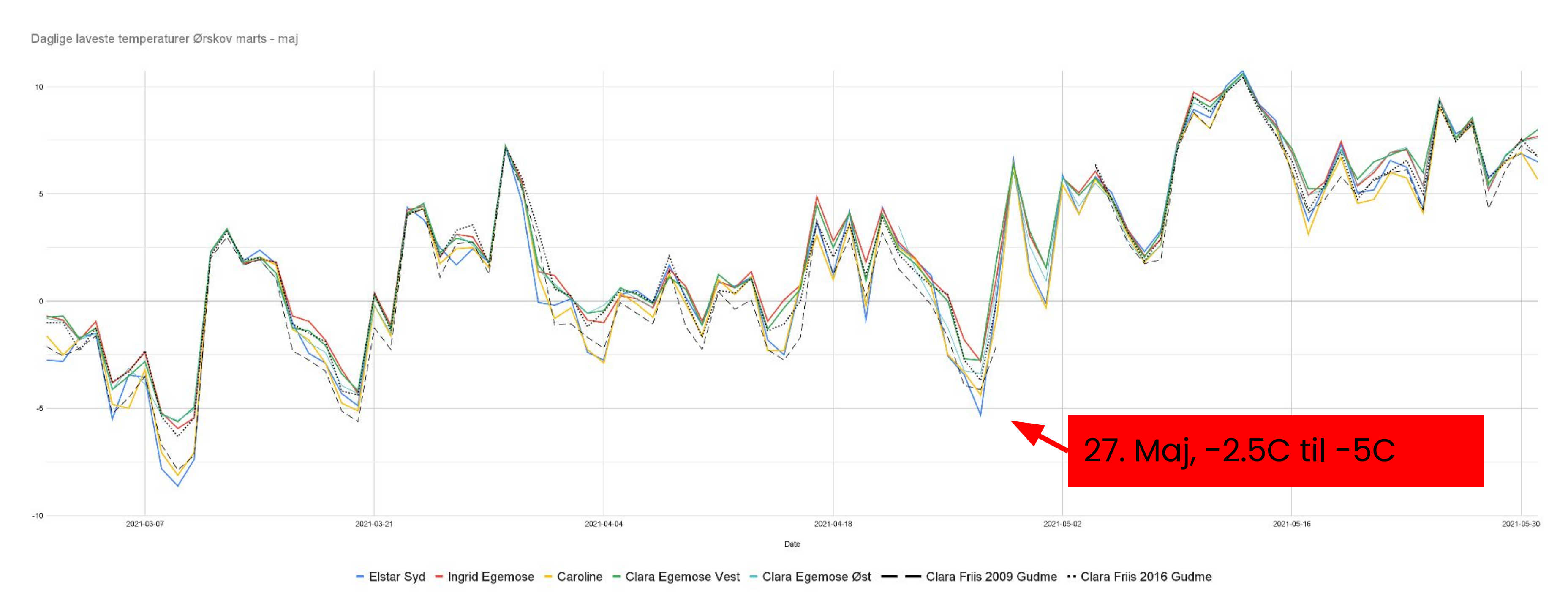


Intention: Reducere vegetativ vækst i sommermåneder

Sensor data:
Kraftige vandinger justeret til at reducere plantetilngængeligt vand, derefter opvanding i vækstfase

Potentiel
Kontrolleret vækst af vegetativ og tilstrækkelig vand i vækstfase

Temp eksempel: Nat temperatur marts - maj

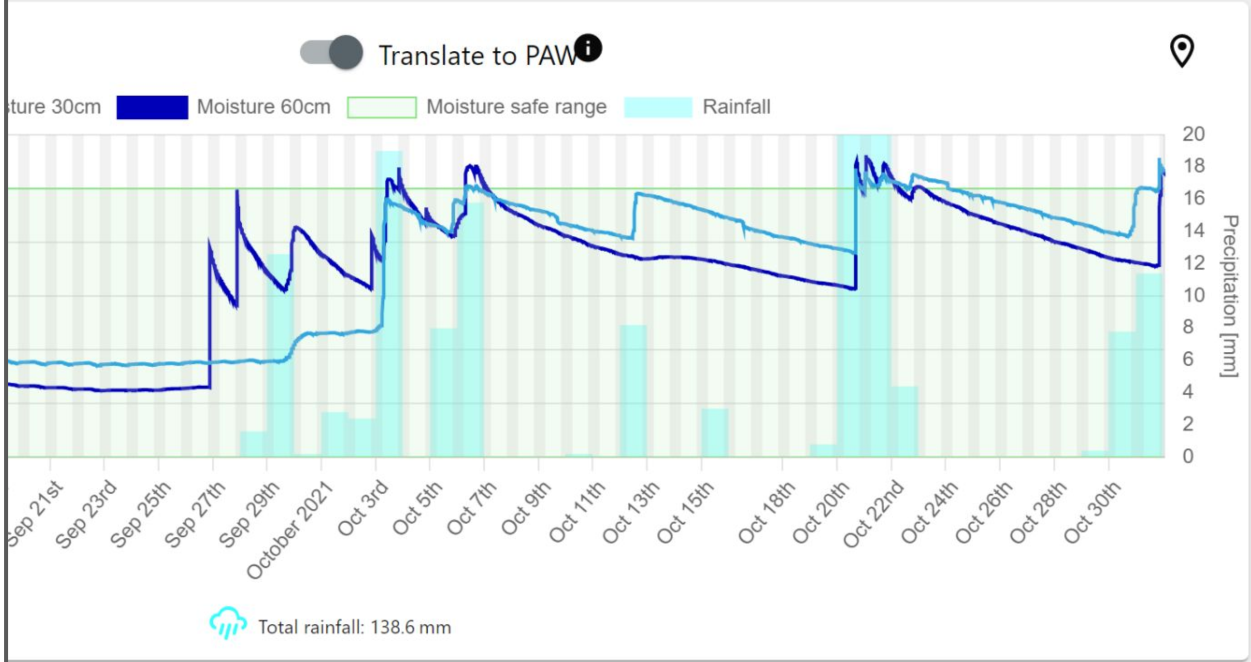


Frostalarmer og variation i plantage

Date	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7
2021-04-17	3.69	4.88	3.06	4.5		3.81	3.69
2021-04-18	1.25	2.81	1	2.5		1.25	2.06
2021-04-19	4.19	4.12	3.62	4.12		2.94	3.56
2021-04-20	-0.88	1.81	-0.25	0.94		0.19	1.19
2021-04-21	4.38	4.31	4.06	4.06		3.19	3.88
2021-04-22	2.62	2.75	2.5	2.38	3.5	1.5	2.19
2021-04-23	1.94	2	1.94	1.75	1.5	0.69	1.38
2021-04-24	1.19	1	0.62	0.81	0.12	-0.19	0.69
2021-04-25	-2.56	0.25	-2.5	0	-1.25	-1.69	0.31
2021-04-26	-3.44	-1.81	-3.31	-2.69	-3.25	-3.94	-2.75
2021-04-27	-5.31	-2.81	-4.38	-2.75	-3.38	-4.12	-3.69
2021-04-28	0.31	1.25	-0.69	2.06	0.81	-2	0.06
2021-04-29	6.62	6.44	6.38	6.38	6		
2021-04-30	1.5	3.06	1.25	3.25	2.56		

Reg eksempel: Udstyr hos Fruitconsult

Nu: Regndata integreret



SoilSense

Nemt og robust sensorsystem til at hjælpe med at tage de bedste beslutninger om vanding

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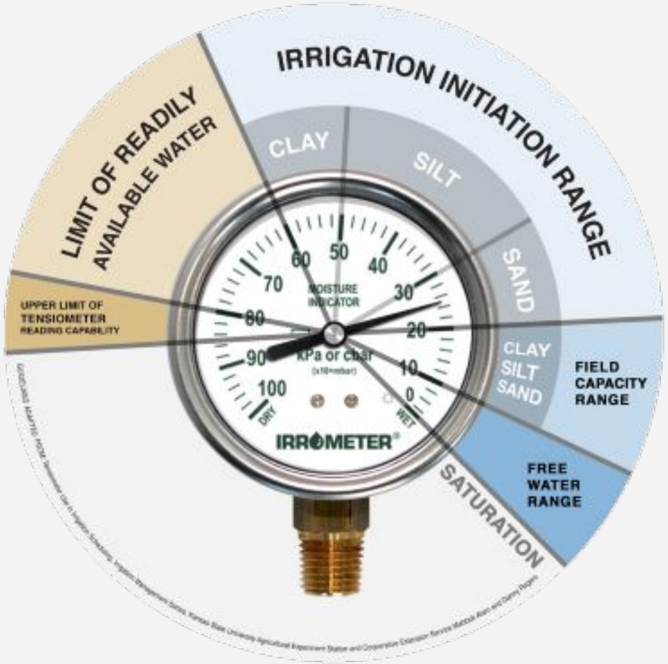
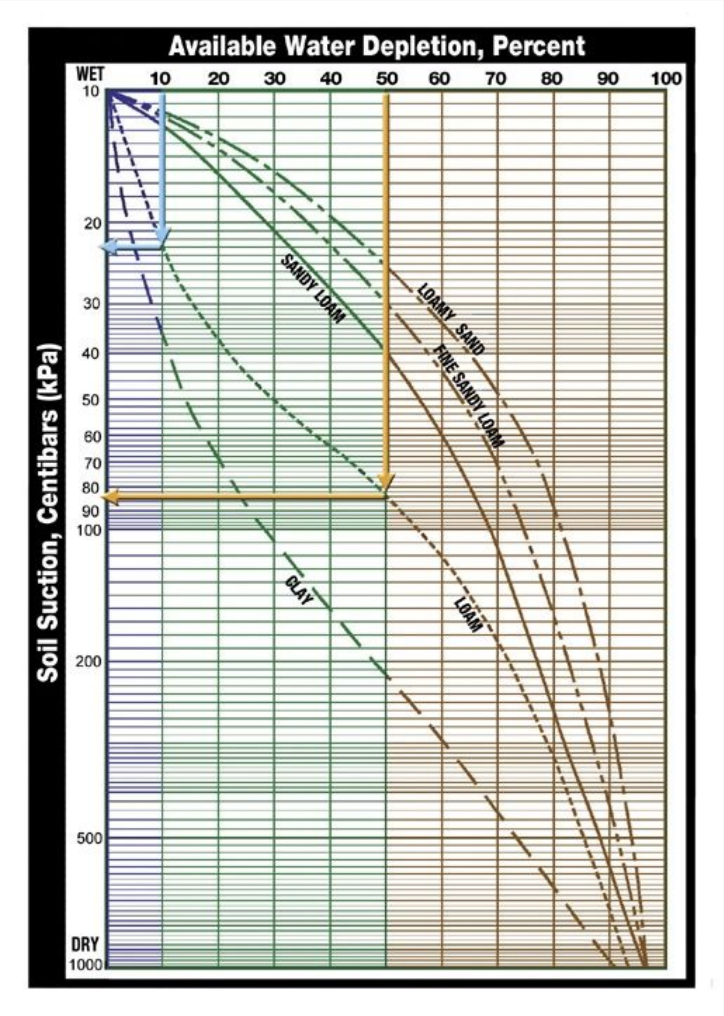
sebastian@soilsense.io

Matrix potentiale



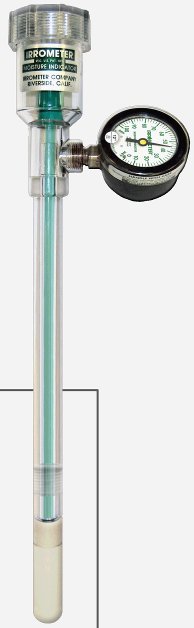
https://www.irrometer.com/basics.html



Soil Matric Potential

Tensiometer

- ❌ Meget vedligehold
- ❌ Sensitive for jordkontakt
- ❌ Manuel inspektion
- ✅ Billig
- ✅ Præcise under nogle forhold



*During the growing season, **all tensiometers should be topped off with distilled water periodically**.*

***All tensiometers should be removed from the soil every six months** or at the end of the growing season and washed to remove soil, algae, bacteria, and other debris from inside and outside the ceramic cup and plastic tube.*

https://www.irrometer.com/pdf/IFAS%20_ABE_326.pdf

Watermark - not measuring SMP directly

- ❌ Upræcis
- ❌ Sensitive for jordkontakt
- ❌ Skal udskiftes
- ❌ Langsom respons
- ✅ Billig
- ✅ Minimalt vedligehold

Watermark...

- Large RRMSE (%) 25-100% in studies
- ..more problematic: large variance in measurements
- Slow response time, issue in summertime and sandy soils

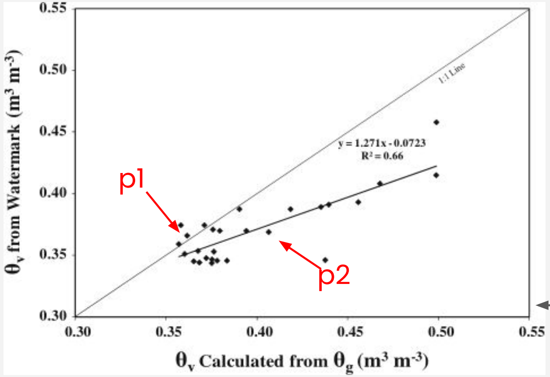
"Watermark sensor responds slowly to rapid increases in soil drying. In most irrigated agriculture in spring-summer cycles rapid soil drying is likely to occur, why it is recommended to be careful when using the Watermark sensor when detecting thresholds for SMP for irrigation management."

(R.B Thomson et. al. (2005), Evaluation of the Watermark sensor for use with drip irrigated vegetable crops)

Table 2 Values of relative root mean square error (RRMSE) comparing SMP measured with the Watermark sensor, using different calibration equations, to SMP measured with tensiometers

			Calibration Equation				
			In-situ	Shock et al. (1998)		Thomson and Armstrong (1987)	
				Original	Re-parameterised	Original	Re-parameterised
Crop	Range (kPa)	*n*	RRMSE (%)	RRMSE (%)	RRMSE (%)	RRMSE (%)	RRMSE (%)
Pepper treatment period 1							
	> −10	321	29.5	100.7	33.7	35.9	37.5
	−10 to −30	1,235	19.9	36.5	20.4	25.4	20.2
	−30 to −50	704	18.9	15.3	16.5	23.0	16.4
	−50 to −80	410	8.1	11.3	5.6	36.9	5.9
	0 to −80	2,670	16.9	28.8	15.1	37.0	15.2
Pepper treatment period 2							
	> −10	307	48.6	127.8	49.6	53.5	54.7
	−10 to −30	1,227	25.1	31.3	23.9	25.1	23.2
	−30 to −50	511	20.3	14.7	17.7	21.6	17.6
	−50 to −80	301	16.8	16.1	14.6	19.9	14.7
	0 to −80	2,346	23.3	25.7	21.1	25.3	20.9
Melon treatment period							
	> −10	1,009	51.5	130.9	67.7	49.3	46.4
	−10 to −30	263	55.6	28	49.6	49	47.3
	−30 to −50	152	59.4	40	46.6	48.1	48.1
	−50 to −80	160	60.4	51.3	46.6	45.6	49.8
	0 to −80	1,584	97.7	81.8	77.2	75.9	80.6

The calibration equations used are two published equations in their original form, and after re-parameterisation, and an in-situ calibration. RRMSE values were calculated for the given SMP ranges during the two treatment periods in pepper and one treatment period in melon. Continuous data collected every 30 min were used. *n* denotes the number of observations



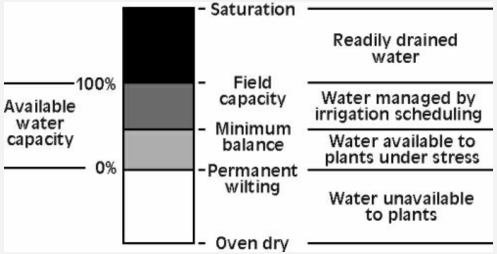
Issue of variance: Farmer reads 36% VWC, in measurement 1 it is correct, in measurement 2 the actual VWC is ~42%

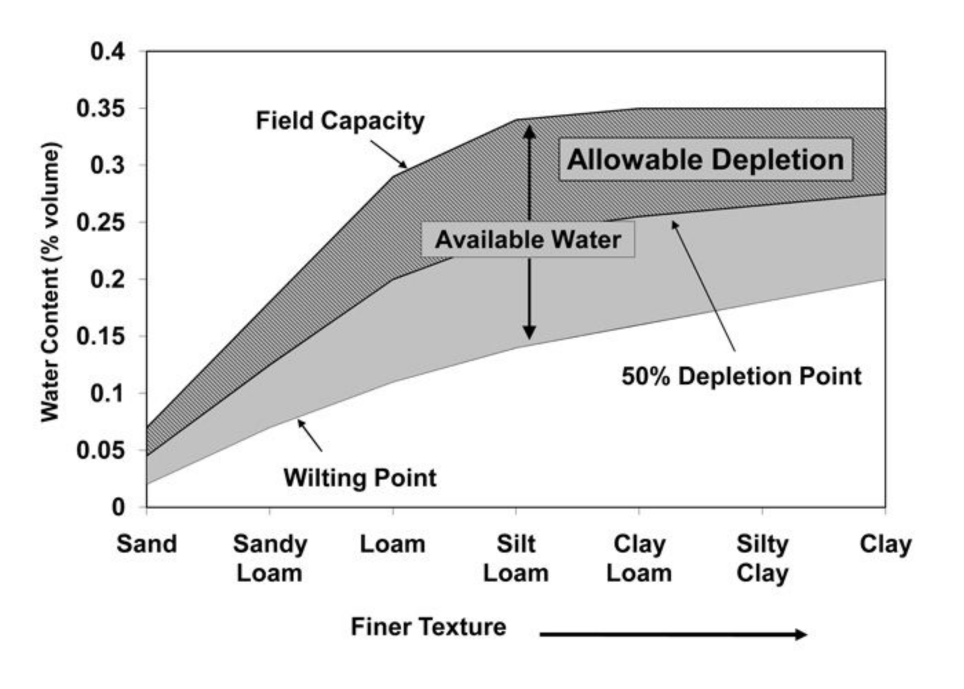
Comparison between soil water content measurements (hv, m3 m-3) by Watermark sensor and hv determined from gravimetric soil water content under field conditions. Pecan trees, without site-specific calibration (Ganjegunte et al, 2012)

Volumetric water content (VWC)

We work with the approach of mapping volumetric water content to **plant available water (PAW)**. To do so you need to know field capacity and wilting point of the soil.

FAO guidelines on PAW thresholds for different crops, recommended apples, 50% PAW depletion under normal conditions





How to measure VWC

Electromagnetic sensors - all measure the dielectric permittivity of the surroundings

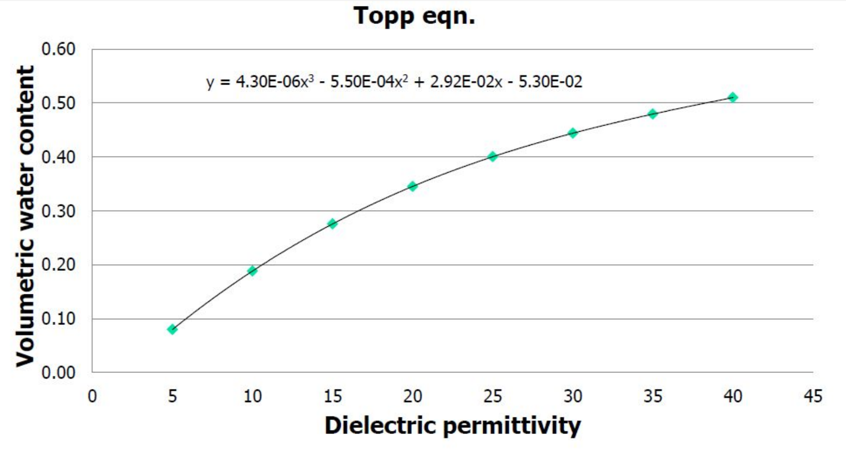
Capacitive, FDR, TDR, TDT & more...

Permittivity of dry mineral soil: ~3; pure water: 80

Translate dielectric permittivity to volumetric water content via manufacturer specific or general equations

Most widely accepted eq. ‘Topp equation’ - only works for high frequency sensor types.

Not accurate for high saline soils EC>4



Topp equation (1980)

Additional info on VWC via dielectric permittivity
http://manuals.decagon.com/Retired%20and%20Discontinued/Slicks%20and%20content/Presentations/SoilMoisture301.pdf

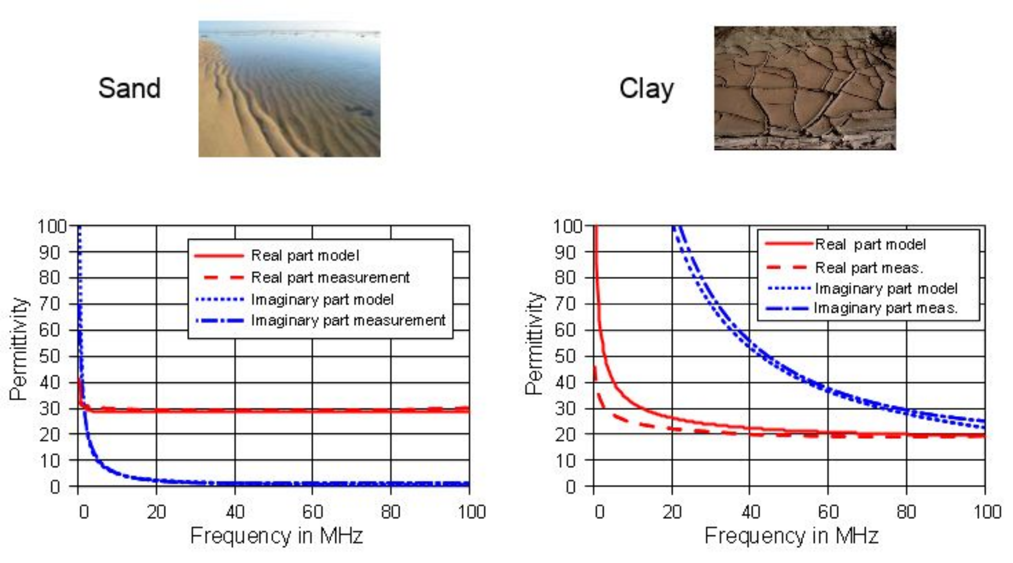
Frequency dependent

Dielectric permittivity: Affected by other factors such as salinity, bulk density, temperature etc.

Higher frequency, less variance. TDR accepted as highest accuracy. Measurements of sub 100 Mhz is affected by soil variance.

“The development of sensors operating in a broadband frequency range including frequencies higher than 100 MHz is advantageous for the purpose of minimizing the influence of clay content on the accuracy of soil moisture determination”

A Seven-Rod Dielectric Sensor for Determination of Soil Moisture in Well-Defined Sample Volumes (2019)
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6479481/pdf/sen



To have accurate measurements across soil types, a frequency where both the real and imaginary part of the permittivity is constant is desired Ie. 100> Mhz

Side-wall sensors

✅ Most accurate and robust sensor placement

✅ Installable in non-uniform soil

✅ No special tools needed

❌ Initial root & soil disturbance

Correct insertion in representative soil is crucial, most measurement errors occur due to poor installation where insertion have resulted in small air gaps around the sensor.

“Accuracy of the readings depends on the absence of air gap between the rods and soil, as this will result in underestimation in dry soil, and overestimation at saturation due to free water surrounding the rods. Installing by directly pushing the rods into the soil without preparing the hole with a drill rod is only recommended in wet and less compacted soils.” (Field estimation of soil water content: A practical guide to methods, instrumentation and sensor technology, 2008)

In-hole sensors

✅ Easy install in non compact, homogeneous soils

✅ Multi depth profile measurements

❌ Low accuracy

❌ Very sensitive to installation contact

“The effect of air gaps between capacitance probes and soil is large, causing a decrease in sensed permittivity of as much as 28% for a gap of 0.2 mm for one capacitance probe design” [edit, EnviroScan] (de Rosny et al., 2001).

“Soils irrigated with brackish or saline water, other salt affected soils, and soils irrigated non-uniformly (e.g. most drip irrigated soils) exhibit large variations in bulk electrical conductivity in both time and space. Typically, values of bulk electrical conductivity (BEC) will increase during an irrigation or crop growth season. Because all of the capacitance systems are sensitive to variations in BEC, and none of them provide for corrections for this problem, none can be recommended for use under such conditions” (Field estimation of soil water content: A practical guide to methods, instrumentation and sensor technology, 2008)

What makes a good sensor

- Frequency range, min 100 Mhz in wet soil
- Low inter-sensor variability
- Temperature compensated
- Robust materials for outdoor use
- Measurement volume

A bit of a jungle…trust the scientific community - if there was a 50$ sensor that was good enough, it would have been adopted.

For example: ICT International: https://ictinternational.com/products/soils/moisture-sensors/ (nov. 2020)

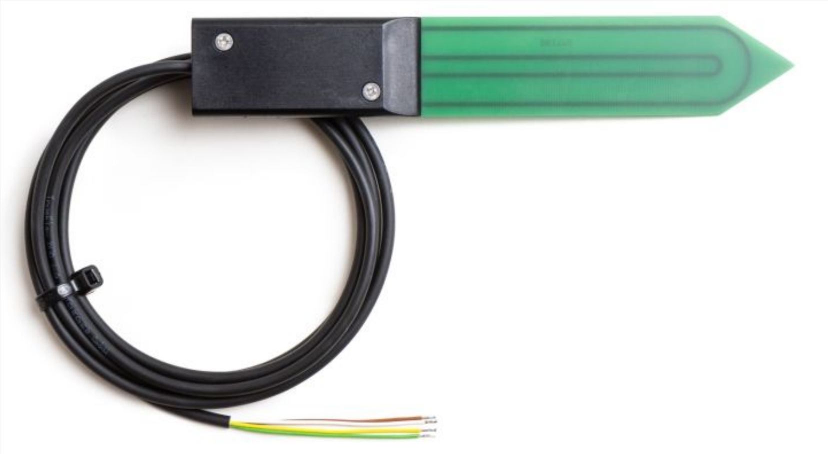
"**TDR does not require in-situ calibration to accurately measure VSW%.** " - Sells SMT100 in this category

"**Capacitance sensors require in-situ calibration for accurate measurement of volumetric soil water content (VSW%)**." - Sells decagon 5TE, Meter Teros12 in this category. Most commonly used sensor, not absolute accuracy.

Our selection

The SMT100 - the most affordable, accurate option

- TDT (TDR like) technology 150-300 Mhz frequency
- < 1% VWC inter-variability in a study involving 700 SMT's *
- Temperature compensated (0.1C accuracy)
- Robust materials, cable of anti-rodent plastic
- ~ 1.5L measurement volume
- Probe not suitable for insertion in very dry soil



*Effective Calibration of Low-Cost Soil Water Content Sensors. Sensors, Bogena, H. R., Huisman, J. A., Schilling, B., Weuthen, A., & Vereecken, H. (2017). https://doi.org/10.3390/s17010208

Where to put sensors?

- What do you want to control?
  - Position at representative area
    - Farmer’s experience
    - NDVI & topography
    - Consider micro-topography, where does surface water flow?
- 2-3 sensors per location: center of root zone, below root zone, potentially horizontally
- Recommend minimum 2 locations per irrigation zone

Correct placement of sensors is essential to provide effective measurement. Sensors should be located in representative zones of the crop e.g. avoiding border areas, non-representative patches of soil for reasons of depth, texture, compaction, non-representative plants etc. **At each measurement location, one sensor should be placed in the zone of maximum concentration of roots. Additional sensors can be placed at different depths e.g. below the roots to control drainage, and in case of drip irrigation to the side of the plants to control the size of the wetting bulb.** The most commonly-used sensor configurations are: (i) one sensor within the zone of major root concentration, and (ii) one sensor within the zone of major root concentration complemented by one or more deeper sensors. The use of deeper sensors is recommended to provide information on depth of wetting and water movement. To control drainage to limit nitrate leaching, two deeper sensors, one at the bottom of the root zone and another clearly beneath the root zone are recommended. Replication is necessary; sensors should be located in a minimum of 2-3 locations per field. The use of a single sensor per field in a nonrepresentative location could result in insufficient or excessive irrigation.
https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/6_mini-paper_soil_moisture_sensors_0.pdf

How to irrigate using VWC

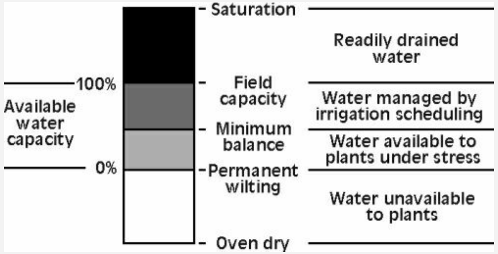
For accurate sensors (TDR-like) you generally don't need to know soil specific parameters to get an accurate VWC measurement (<2%).

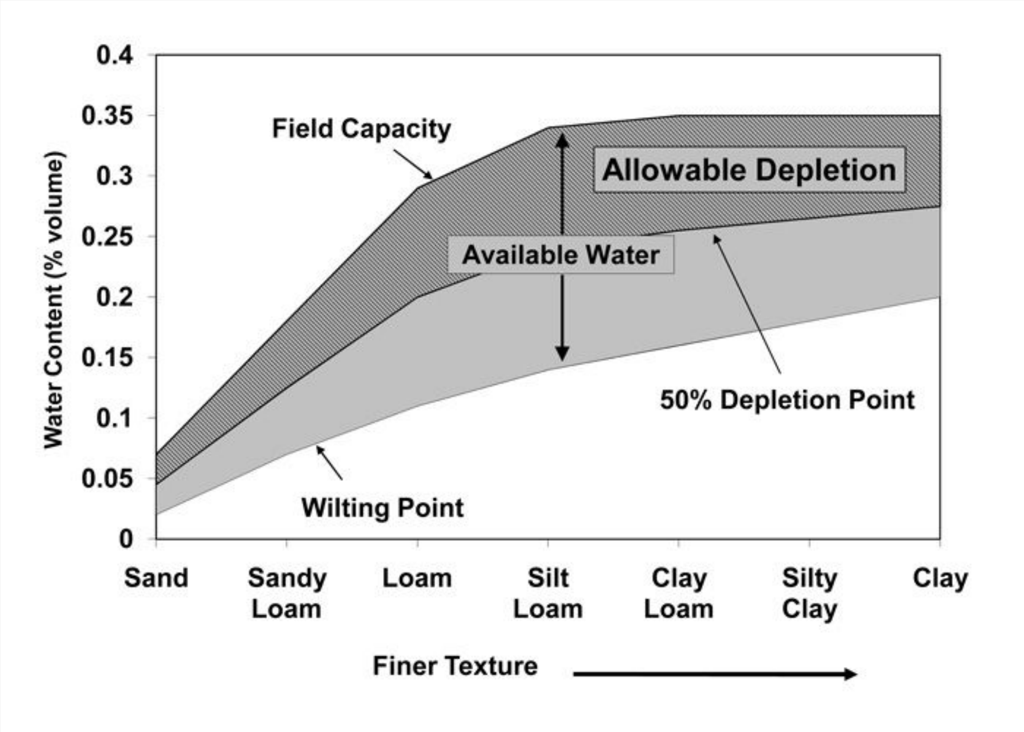
With just VWC you can understand the trend of soil water.

Plant available water

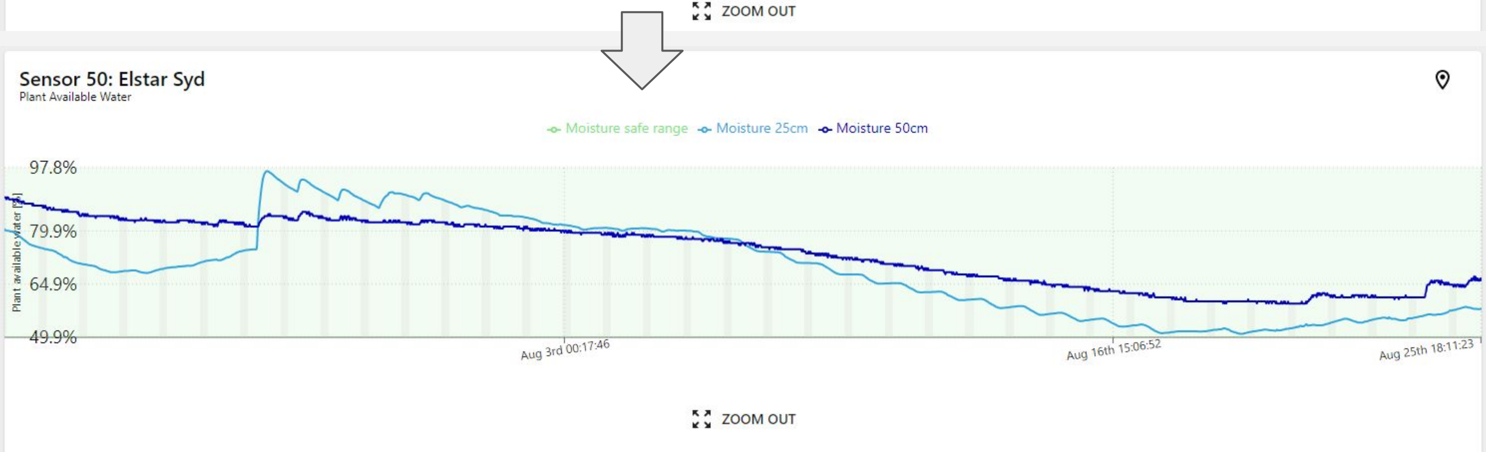
We work with **plant available water** instead of VWC. It's a universal measure across soil types, for how many % of the total water that's available to the plant.

In order to do so, you need to know the Field capacity (FC) and wilting point (WP) either via in field calibration (preferred) or knowing the soil type.





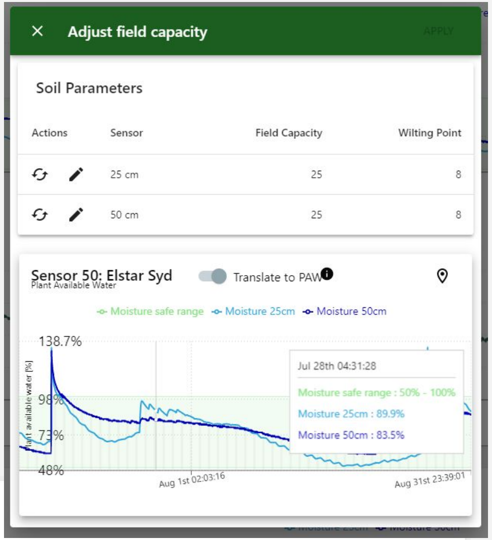
Plant available water

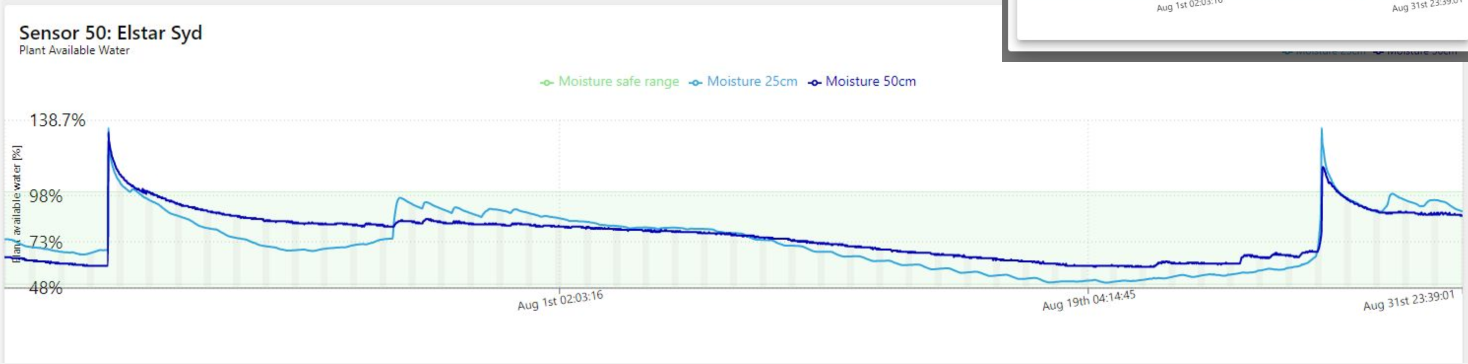


Plant available water

Our focus is on the translation of VWC to PAW and the use of PAW to schedule irrigation.

Adjustment of FC & WP either based on **automatic algorithmic detection** after heavy irrigation, soil composition or manual assessment.





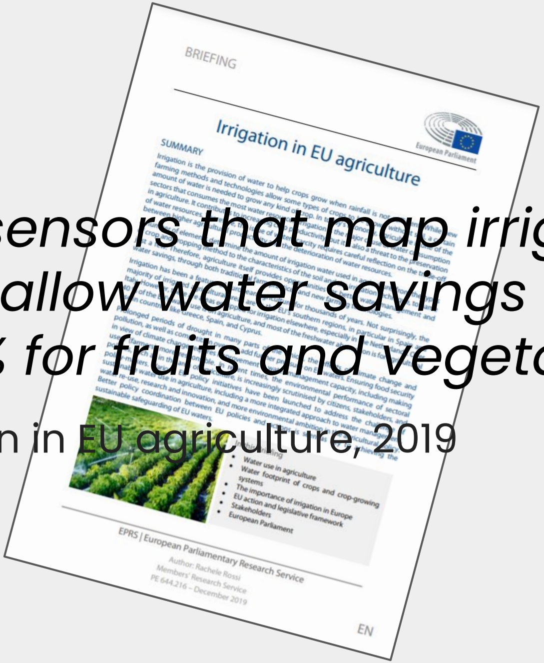
Plant available water

FAO guidelines on PAW thresholds for different crops

E.g. Apples, 50% PAW depletion under normal conditions

Crop	Maximum Root Depth [1] (m)	Depletion Fraction [2] (for ET ≈ 5 mm/day) p
a. Small Vegetables		
Broccoli	0.4-0.6	0.45
Brussel Sprouts	0.4-0.6	0.45
Cabbage	0.5-0.8	0.45
Carrots	0.5-1.0	0.35
Cauliflower	0.4-0.7	0.45
Celery	0.3-0.5	0.20
Garlic	0.3-0.5	0.30
Lettuce	0.3-0.5	0.30
n. Fruit Trees		
Almonds	1.0-2.0	0.40
Apples, Cherries, Pears	1.0-2.0	0.50
Apricots, Peaches, Stone Fruit	1.0-2.0	0.50
Avocado	0.5-1.0	0.70
Citrus		
- 70% canopy	1.2-1.5	0.50

Global vandmangel


BRIEFING

Irrigation in EU agriculture

European Parliament

SUMMARY

- Water use in agriculture
- Water footprint of crops and crop-growing systems
- The importance of irrigation in Europe
- EU action and legislative framework
- Stakeholders
- European Parliament

EPRS | European Parliamentary Research Service

Author: Rachele Rossi
Members' Research Service
PE 644.216 – December 2019

EN

"Field sensors that map irrigation needs allow water savings of 45 to 50 % for fruits and vegetables"

-Irrigation in EU agriculture, 2019

Irrigation strategies	Overall water use (inch)	Crop yield/tree (kg)
Soil moisture-based	8.7	28.2
ET-based	11	23.1
Conventional	9.2	18.8

Irrigation in EU agriculture, 2019
https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/644216/EPRS_BRI(2019)644216_EN.pdf

https://projects.sare.org/project-reports/lne19-378/

Our advice

Irrigation using soil moisture sensors can only be trusted if:

- **Accurate soil moisture sensor**
- **Careful installation**
- **Representative location selected**
- **Correct translation from VWC to PAW**

If you need to do your own study with a reference VWC sensor, get a high accuracy TDR sensor acknowledged by the scientific

Our recommendation Acclima TDR fairly budget friendly,