Water, soil and salinity management

Smart agriculture and use of instrumentation

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ACACIA WATER

Introduction

- Acacia Water and me
- Web platform for sharing of information
- Water balance, crop water use, moisture measurement methods and instruments
- Importance of monitoring
- Soil water sampling and analysis
- Improving agricultural production through monitoring and planning

Acacia Water

- 2003: Acacia Institute foundation established at VU University in Amsterdam. Start Acacia Water BV in 2008, based in Gouda
- Objective: Achieve improved availability and use of water resources for water supply, agriculture and industry. Both in quantity and quality!
- Over 30 academically trained hydrologists and environmental economists

Not such a typical company

We aim to promote and achieve sustainable, applicable solutions to urgent water problems

We combine applied research and scientific knowledge to arrive at practical and sustainable solutions

We value knowledge transfer

We are passionate, pragmatic and impact driven

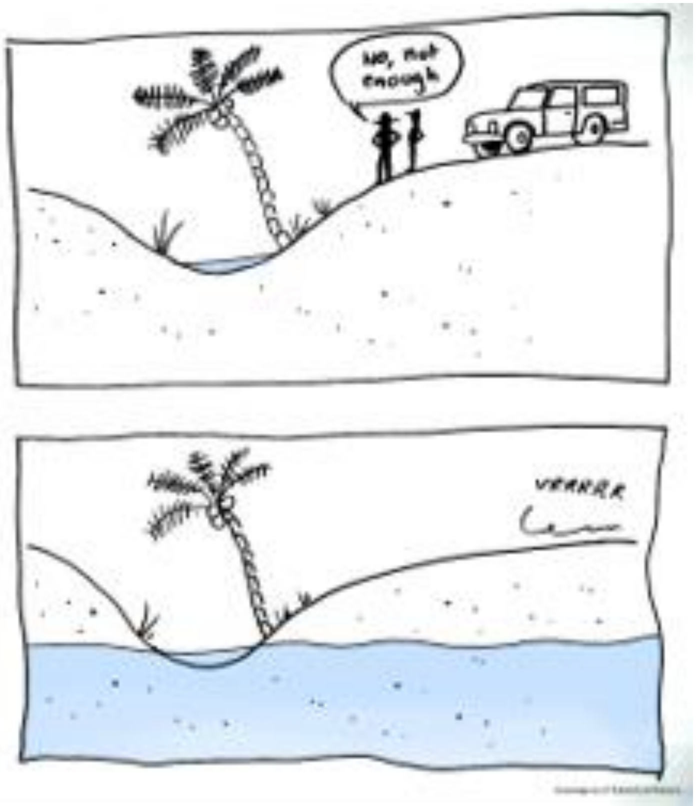
Our project locations

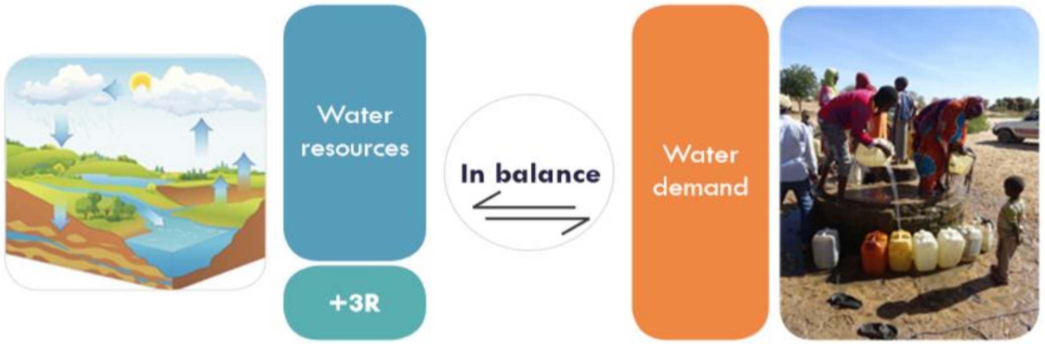
- Main office in Gouda, The Netherlands
- Branch office in Leeuwarden, The Netherlands
- Branch office in Addis Ababa, Ethiopia

National 50% - international 50%

What we do

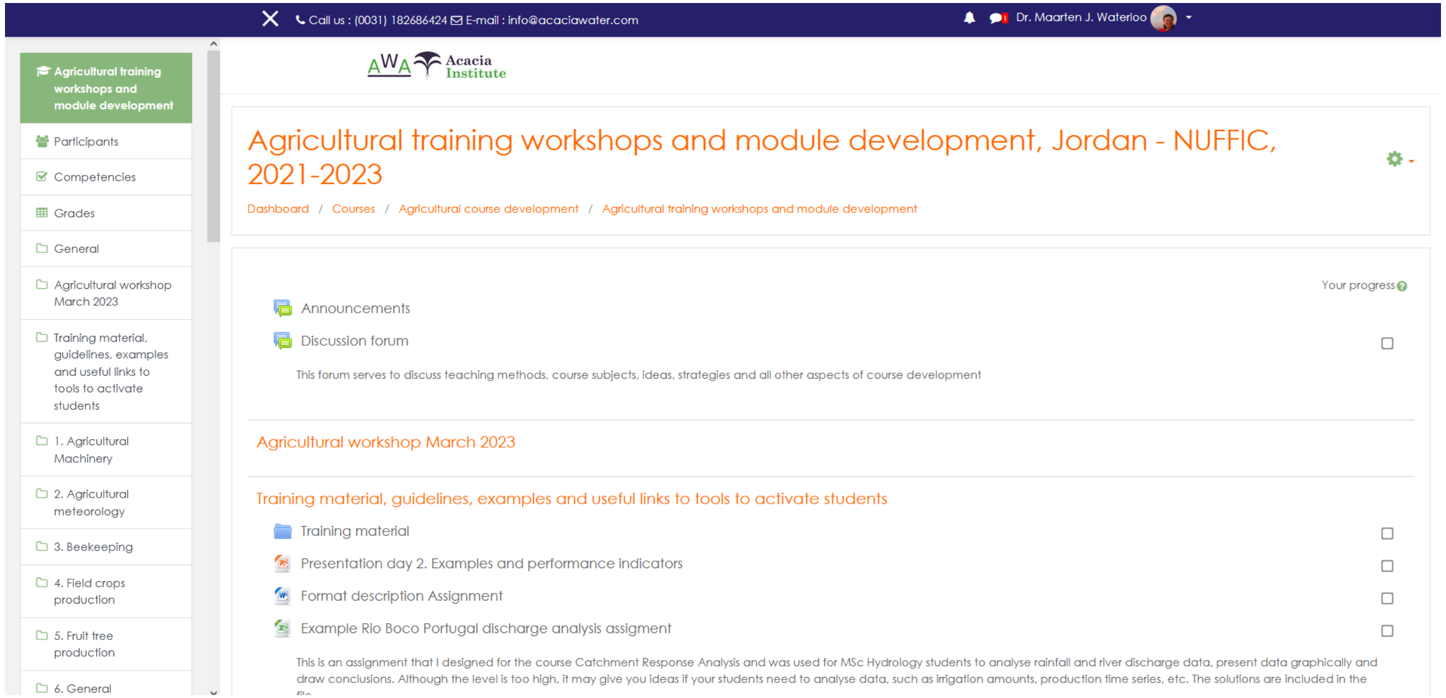
- Develop sustainable (ground)water management strategies
- Making physical and institutional landscapes more resilient to climate and land use change
- Provide facts about (ground)water, and its potential
- Mapping landscape potentials for water supply potential, water buffering and development of water resources
- Combine of ‘hard’ and ‘soft’ interventions
- Provide capacity building and training





Acacia Water Moodle platform for info sharing between partners

- Access through https://awa2.acaciadata.com
- Participants receive e-mail with credentials upon request
- Provides forum, programme, background information, presentation, literature, info on sensors, etc.



Water balance components

All water balance components are highly dynamic in space and time

$$\frac{dV}{dT} = \text{Inflow} - \text{Outflow}$$

Increased food production requires increase in ET through irrigation

Precipitation P	Liquid rainfall Snow/ice Other sources?
Evapotranspiration ET	Lake/river/ice evaporation Soil moisture evaporation Rainfall interception loss Plant transpiration
Runoff Q	Surface runoff Groundwater runoff
Storage change ΔS	Lake/river/ice storage Soil moisture storage Groundwater storage

Smart agriculture

- Objective: increase quality and quantity of crops while optimizing the human labour used and environmental impacts
- Focus on accessing and applying data
- Means to achieve objectives:
  - Application of precision irrigation and optimal plant nutrition (fertigation)
  - Use of smart sensors, Internet of Things (IoT)
  - Automatization and software platforms
  - GPS assisted agriculture
  - Application of predictive models for irrigation timing
  - Use of drones for crop monitoring
- Data provide means for precision farming

More water – nutrient efficient agriculture

- Irrigation efficiency optimization procedure
  1. Select most appropriate efficient irrigation technique
  2. Continuously measure soil moisture status in the field in root zone
  3. Estimate daily crop evaporation
  4. Measure and fine-tune water supply:
     - Place flow meter in water supply system
     - Measure pump capacity and hours (can be done using a datalogger in groundwater extraction well)
- Nutrient use optimization
  - Measure soil nutrient status at start of crop season
  - Register fertilizer / manure nutrient input
  - Measure removal of nutrients by harvest

Who should be driving innovation in agriculture?

- Government?
- Farmers?
- Technical colleges?
- Universities / research institutes?
- Irrigation and water quality hardware companies?

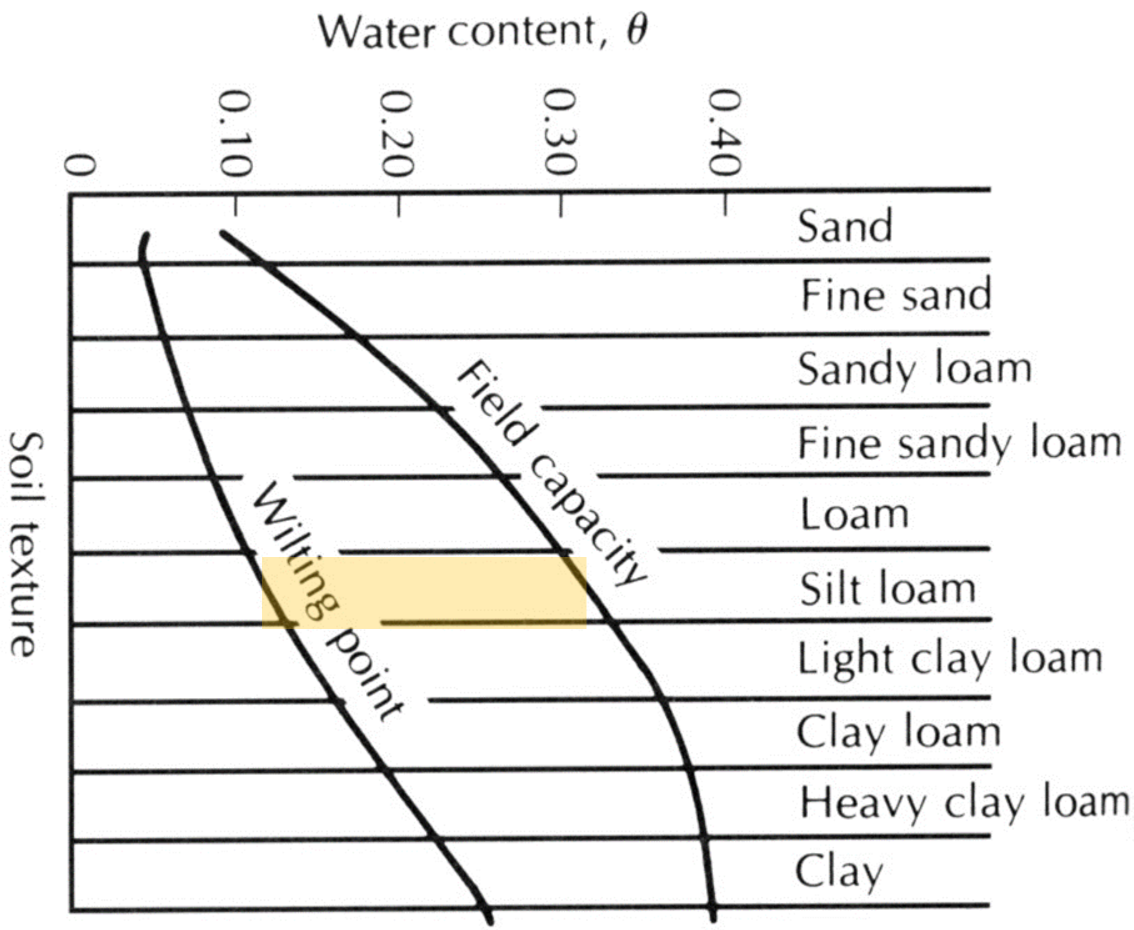
- What are the needs of farmers and TVETs with respect to more efficient use of resources
- What would you propose that the triple helix could do to bring innovation and what kind of innovation is urgent?

Field capacity and wilting point

- **Field capacity** is the tension with which water is held in the pores that do not drain under gravity force
  - Field capacity soil water tension -100 to -300 cm (pF = 2.0 - 2.5)
- **Permanent wilting point** is the tension in the soil when plants wilt and die
  - Soil water tension -15,000 cm (pF = 4.2)
- **Plant available water** is between pF = 2.0 and pF = 4.2
  - Crop stress occurs at pF > 3.5
- Optimal water supply: keep root zone soil moisture between pF= 2.0 and pF = 3.5

Plant available water

- Plant available water: difference in soil moisture content between field capacity and wilting point
- Depends on soil texture
  - *If we have a silt loam soil and grass rooting zone of 30 cm, how much is the plant available water expressed in mm?*
  - *If plant transpires 3 mm day^{-1}, when does crop wilting start?*
- Irrigation aims to keep soil sufficiently moist for optimal production

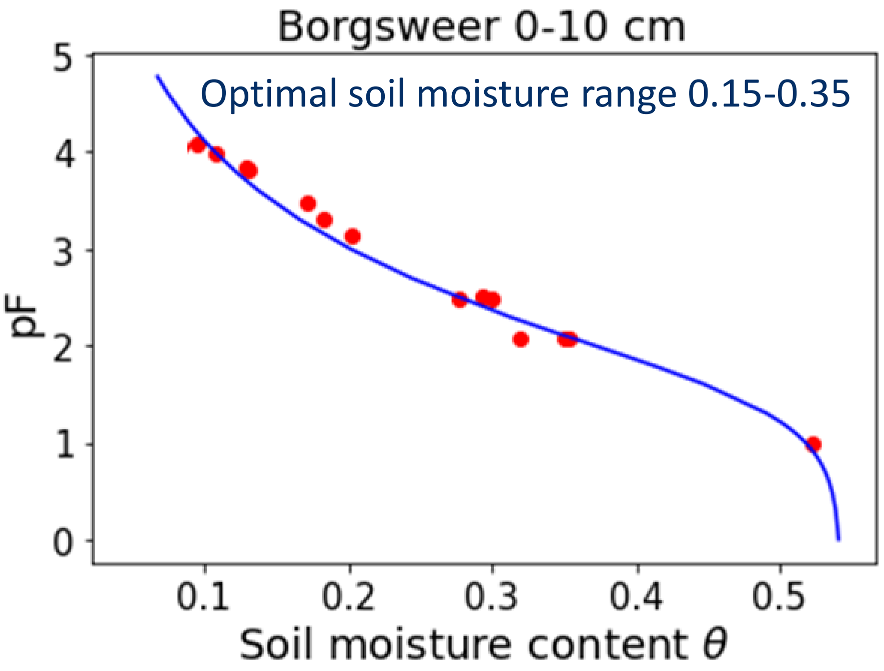


Soil moisture tension

- With drip irrigation, aim to keep pF soil moisture tension value between 2.0 and 3.0 (for most crops)
- Use tensiometer to monitor soil moisture tension, disadvantage, tensiometer stops working when tension above pF = 2.7 and needs refilling.
- Meter group Teros 21 can work from pF= 2 (field capacity) until pF = 4.2 (wilting point), needs connection to read-out unit (datalogger) and can be used to control irrigation

Smart moisture monitoring

- Aim to keep soil moisture in optimal range 2.0 < pF < 3.5
- Tensiometer measurement in moist soils only (pF = <2.7)
- Relate tension to soil moisture content by making a field pF curve
- Automatic soil moisture content monitoring option - Huahuacaocao Flower Care smart sensor



Irrigation scheduling

- When should I give water?
  - Determined by soil moisture status (sensor data)
- How much water should I apply?
  - Not too much (pF < 2.0 for some time causes root rot because of lack of oxygen in the soil)
  - Enough to compensate for past irrigation losses and replenish the soil moisture storage
- Determination of crop evapotranspiration
  - FAO crop factor method
- Can be applied in open field agriculture, but also in tunnels and greenhouses

Empirical evaporation equations

- Radiation-based:
  - Penman open water evaporation E_0
  - Priestley-Taylor method reference E_{pt}
  - Makkink method (NL) reference E_m
- Temperature based:
  - Thornthwaite method reference PET
- Reference evaporation is that of well-watered short grass
- Note: Potential / reference evaporation is not actual evaporation!
- Need for meteorological data (weather station)
- Radiation based methods (e.g. Penman) can be used in tunnels tunnels, but need for measurements made in tunnels

$$\lambda E_0 = \frac{\Delta(R_n - G)/\gamma + \gamma E_a}{\Delta + \gamma}$$

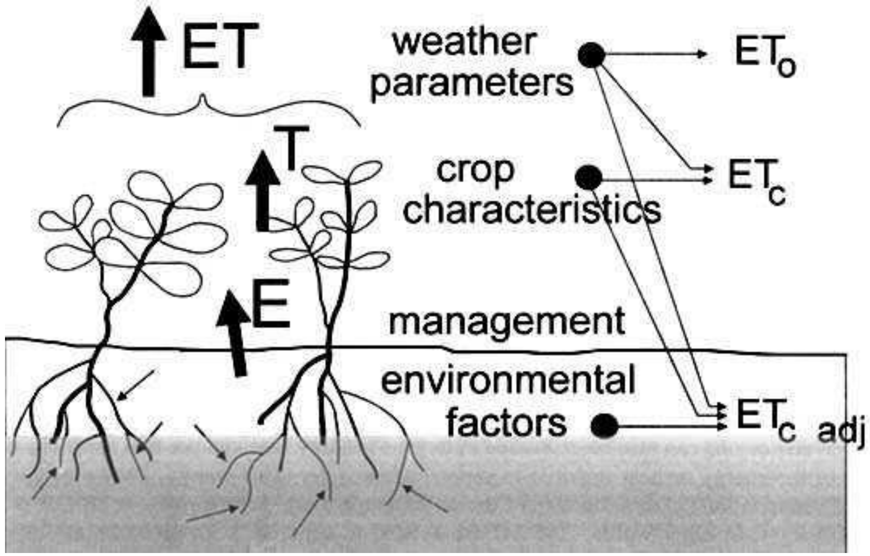
$$\lambda E_{pt} = \alpha R_n \frac{\Delta}{\Delta + \gamma}$$

$$\lambda E_m = 0.65\, R_s \frac{\Delta}{\Delta + \gamma}$$

$$\text{PET} = 1.6\left(\frac{10 T_i}{J}\right)^c$$

Importance of knowing actual evaporation rates

- To make optimal use of water in agriculture, we need to know the actual water use of the crop
- Irrigation is to provide extra water needed for optimal crop growth in dry periods
- Evaporation varies with land cover. With changing land use (*e.g.* deforestation or afforestation) we expect changes in river flow and groundwater recharge
- We can use potential/reference evaporation rates to estimate water using crop coefficients



Crop actual evaporation

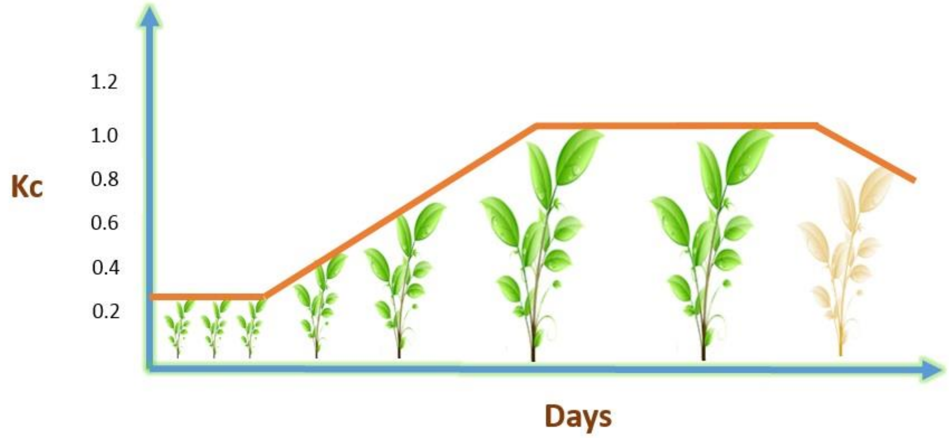
- Actual evaporation of crop estimated from the reference evaporation E_{ref} through the use of a crop factor K_c:

$$E_a = K_c \, E_{ref}$$

- K_c varies with vegetation type and cover, maturing stage, soil moisture availability, etc. The crop factor for bare soil is 0.2 - 0.4, for 50% cover 0.5 - 0.7 and for 100% cover 0.7 – 1.1. In case of water stress an additional K_s stress coefficient is used

Crop factors – seasonal variation

- Forest: transpiration K_c = 0.7 - 0.8, evapotranspiration K_c = 0.9 - 1.2



Crop	Crop Factors				
	Initial Stage	Development	Mid-Season	Late Season	At Harvest
Banana	0.50 – 0.65	0.80 – 0.90	1.00 – 1.20	1.00 – 1.15	1.00 – 1.15
Beans	0.30 – 0.40	0.70 – 0.80	1.05 – 1.20	0.90 – 0.95	0.80 – 0.90
Carrots	0.40 – 0.60	0.60 – 0.75	1.00 – 1.15	0.80 – 0.90	0.70 – 0.80
Citrus			0.65 – 0.90		
Grapes	0.35 – 0.55	0.60 – 0.80	0.70 – 0.90	0.60 – 0.80	0.55 – 0.70
Lettuce	0.30 – 0.50	0.60 – 0.70	0.95 – 1.10	0.90 – 1.00	0.80 – 0.95
Peppers	0.30 – 0.40	0.60 – 0.75	0.95 – 1.10	0.85 – 1.00	0.80 – 0.90
Pineapple			0.60 – 0.80		
Potatoes	0.40 – 0.50	0.70 – 0.80	1.05 – 1.20	0.85 – 0.95	0.70 – 0.75
Sugarcane	0.30 – 0.40	0.70 – 1.00	0.70 – 0.80	0.70 – 0.80	0.40 – 0.50
Tomatoes	0.40 – 0.50	0.70 – 0.80	0.80 – 0.95	0.80 – 0.95	0.60 – 0.65
Vegetables	0.40 – 0.50	0.70 – 0.80	0.80 – 0.90	0.80 – 0.90	0.60 – 0.70
Watermelons	0.40 – 0.50	0.70 – 0.80	0.95 – 1.05	0.80 – 0.90	0.65 – 0.75

Translate evaporation to irrigation water supply

- What we know now is:
  - Type of irrigation method and associated losses
  - Timing of irrigation from soil moisture measurements
  - Daily crop water use from evaporation estimates
  - Predictions of rainfall from weather service (open field)

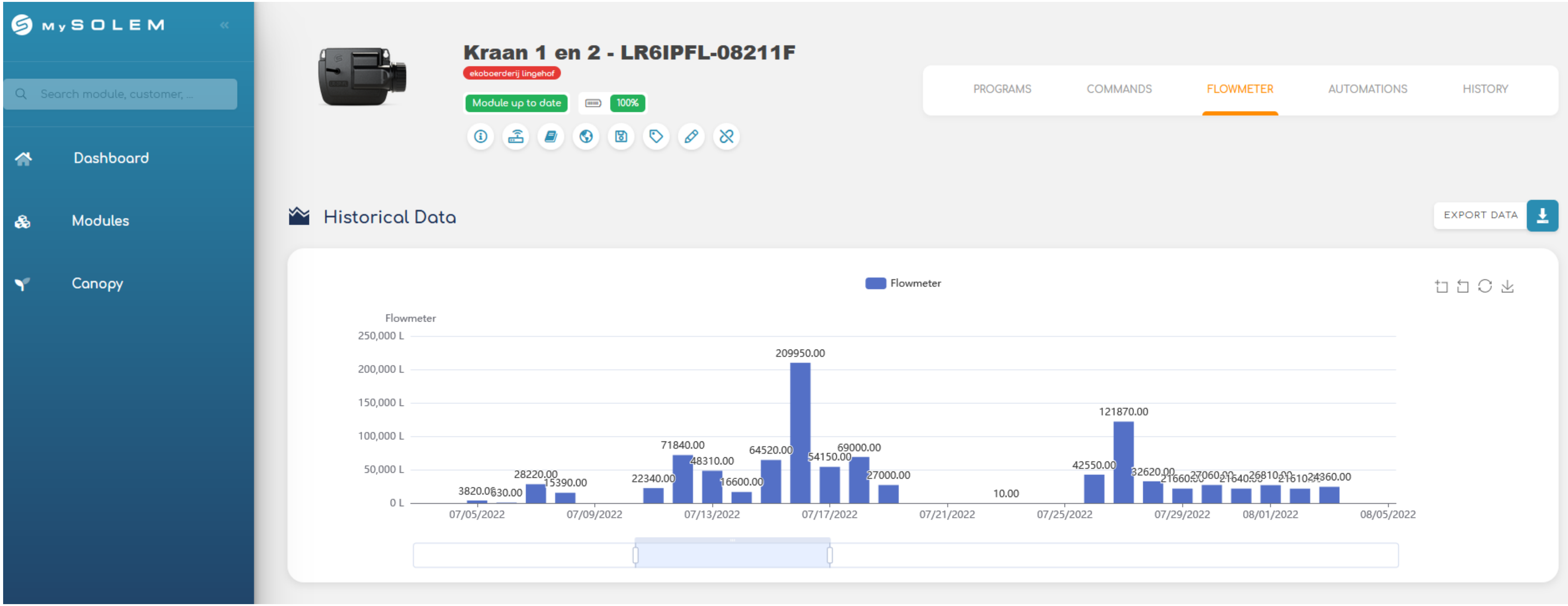
- It is time to give the appropriate amount of water:
  - Calculate volume from crop demand and field size
  - Irrigation water volume measurement to apply correct amount
    - Water meter in system, or
    - Pump capacity and running hours
    - Correct for water losses (e.g. sprinkler losses)

Monitoring irrigation in tunnels

1. Use known or measured plant water use in different stages of growth to calculate optimal irrigation needs
2. Use one or more flow meters per tunnel and crop to provide required amount of water such as not to give too much water
3. Apply irrigation return flow at end of season

Drip irrigation programming and remote control

Online irrigation amounts overview



https://www.solem.fr/en/

Importance of monitoring

- For optimal crop production water, soil and crop conditions need to be optimal. This requires frequent monitoring:
  - Monitoring of water demand and evaporation
  - Monitoring of soil moisture and irrigation amounts
  - Monitoring of water quality parameters
  - Monitoring of crop nutrient demands
  - Monitoring of soil nutrient content
  - Monitoring of growth
- This means that the farmer needs to have measurement and analytical equipment (or lab facilities) available to obtain information and needs to know how to act upon the information

Monitoring - obtaining time series

- Important to know soil moisture and fertility status over growing season
- Time series can be measured of soil moisture content, soil moisture tension, soil temperature and water quality parameters
  - Manually by noting down regular measurements (daily?)
  - By reading out the hourly values of a Xiaomi sensor
  - By using advanced programmable data logger systems with multiple sensors that can also send the data to a web site for near real-time viewing
  - Programmable data logger systems can also send SMS messages when alarms are set

pH, soil moisture, temperature and light intensity sensor

- Allows you to make quick measurements in the soil
- Simple to use, just insert in the soil of your preferred measurement location (about 10 cm deep)
- Display will give you information on:
  - Sunlight (9 levels): LOW-, LOW, LOW+, NOR-, NOR, NOR+, HGH-, HGH, HGH+
  - Moisture (5 levels): DRY+, DRY, NOR, WET, WET+
  - With switch:
    - PH value (12 levels): 3.5 - 9.0, best between 6 - 8
    - Temperature: -9 - 50°C

Soil moisture, light, temperature and salinity sensor

- Xiaomi Mi Flower Care Plant Sensor
- Can be used to measure EC of irrigation water or to monitor salinity in moist soil, comparison to EC_e
- Bluetooth reading on smartphone, timeseries given
- Needs some experience to know at what level there is sufficient water in the soil, say keep moisture content between 20 and 30%
- Cheap, price less than 20 euro
- https://www.xiaomiproducts.nl/en/xiaomi-mi-flower-care-plant-sensor.html

Huahuacaocao Flower Care smart sensor I

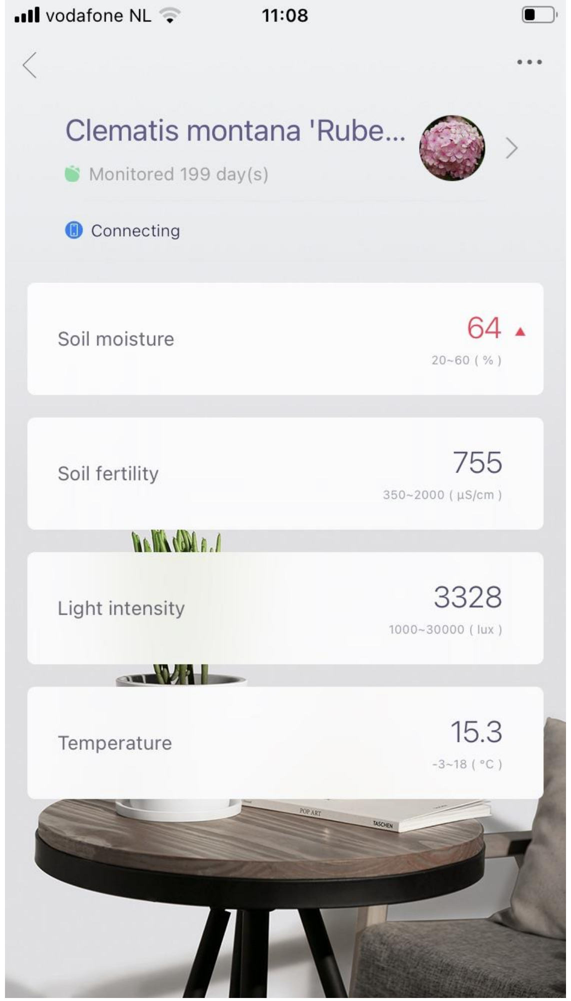
- Measures time series of soil moisture, light intensity, electrical conductivity (proxy for fertility) and temperature

Beijing HHCC Plant Technology Co., Ltd

1. Download the Flower Care app from the App store
2. Create an account (e-mail and password) and apply code that you received by e-mail
3. Remove the white cover part of the sensor and pull out the plastic battery protection
4. The light will go on briefly and you can scan for the device in the App, update firmware if asked (need access to phone storage)

Huahuacaocao Flower Care smart sensor II

1. Choose the crop from the database for the sensor
2. Insert sensor in the soil and see data readings
3. Leave the sensor in the soil for continuous measurements
4. Synchronise your smartphone with the sensor when you return to collect data
5. Note: the small sensor is not watertight, place an inverted transparent cap (water bottle bottom)with holes in the side to protect from rainfall (waterproof sensor available)



Proceed to connect to sensor

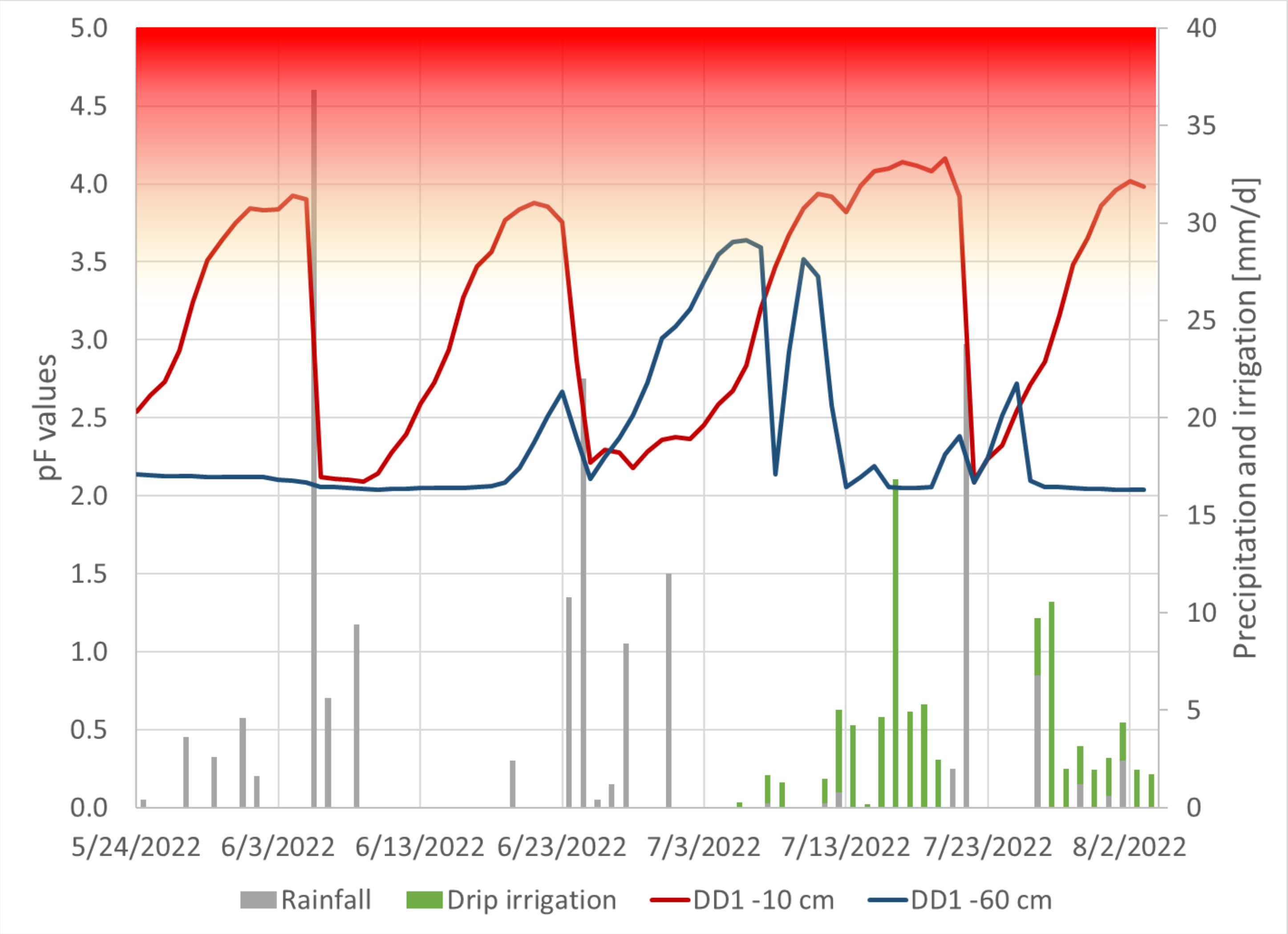
- Note that Bluetooth needs to be enabled
- Follow steps in Flower Care manual
- Installation of sensor in irrigated soil
  - What would you like to measure?
  - Where in the bed?
  - What depth in the soil?

Fixeau Aquapin

- An easy to install and relocatable modular pin for measurements of currently; groundwater level, soil moisture, temperature and salinity
- Pros
  - Simple install: drill, drop ready to start measuring
  - Modular and expandable with additional and/or new sensors
  - Location and height measurement in cm accuracy using advanced GPS algorithms
- Coupled to a dashboard with information and water management advice for farmers

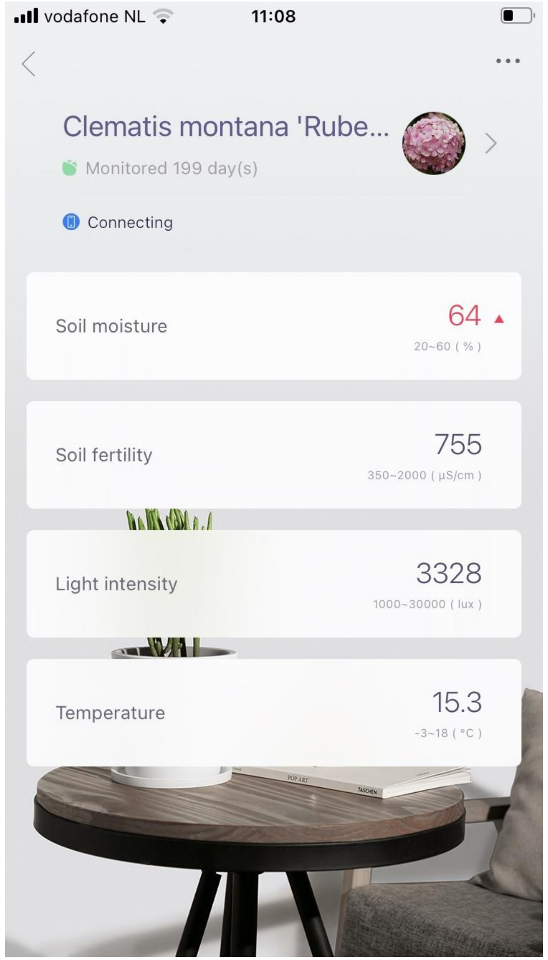
Soil moisture tension and irrigation

- Potato crop (organic)
- Drip lines 40 cm below soil surface
- Measurements at 10 and 60 cm below surface



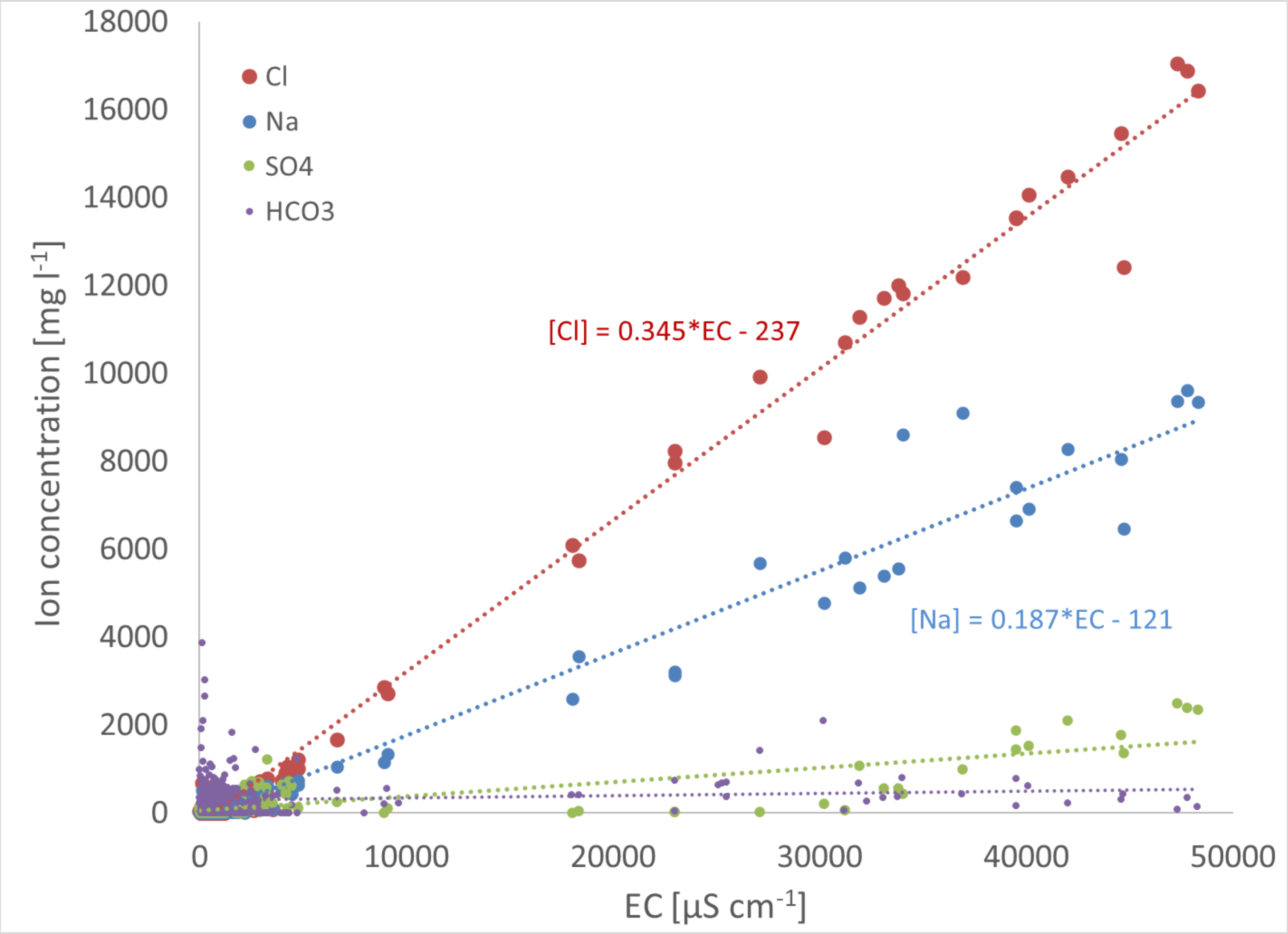
Electrical conductivity – soil fertility?

- What determines the electrical conductivity (EC) of a soil?
  - Moisture content
  - Ion concentrations in moisture
- If concentrations of fertilizer ions (nitrate, ammonium, urea, etc.) are much higher than those of natural ions (sodium, calcium, chloride, sulphate, bicarbonate) then EC relates to nutrient concentrations
- Can be used for fertility assessment in low EC source water conditions (< 500 μS cm^{-1})



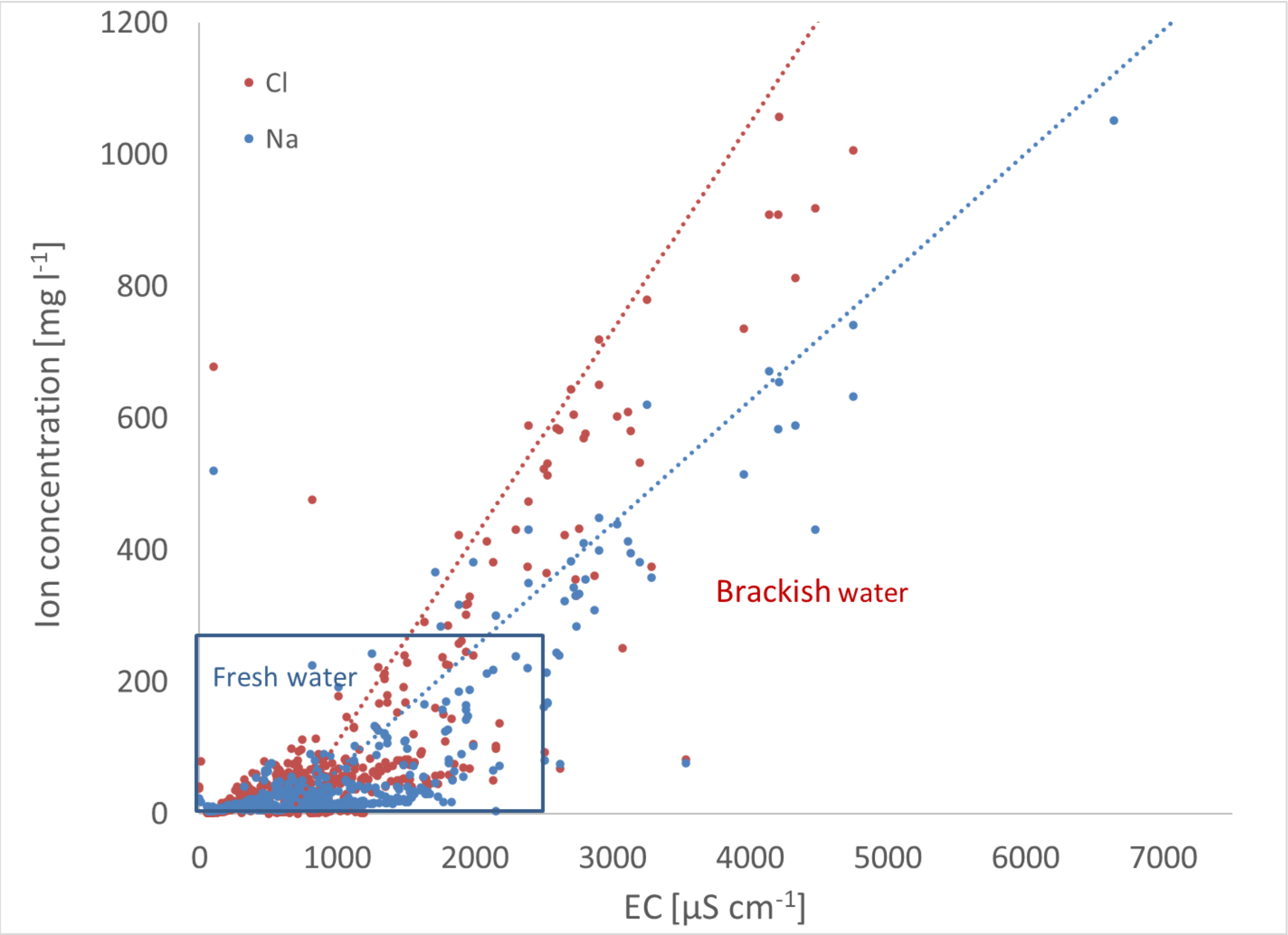
Electrical Conductivity (EC) and ion concentration

- EC can be measured to estimate concentrations of sodium and chloride
- EC measurement is easy to do
- Measurement in soil (lower) not the same as in water!



Fresh and brackish water

- Fresh water has an EC of less than 2500 µS cm^{-1} and a Cl concentration of less than 250 mg l^{-1}
- Crop production decreases when irrigated with brackish water or in saline soil
- Low to moderate risk up to 1000 mg l^{-1} and EC < 5000 µS cm^{-1}

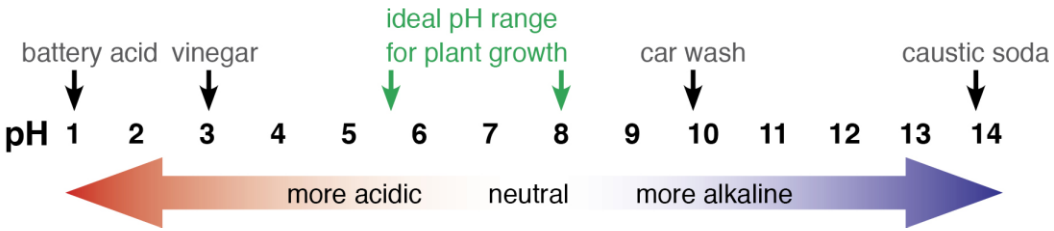


Soil salinity and sodicity

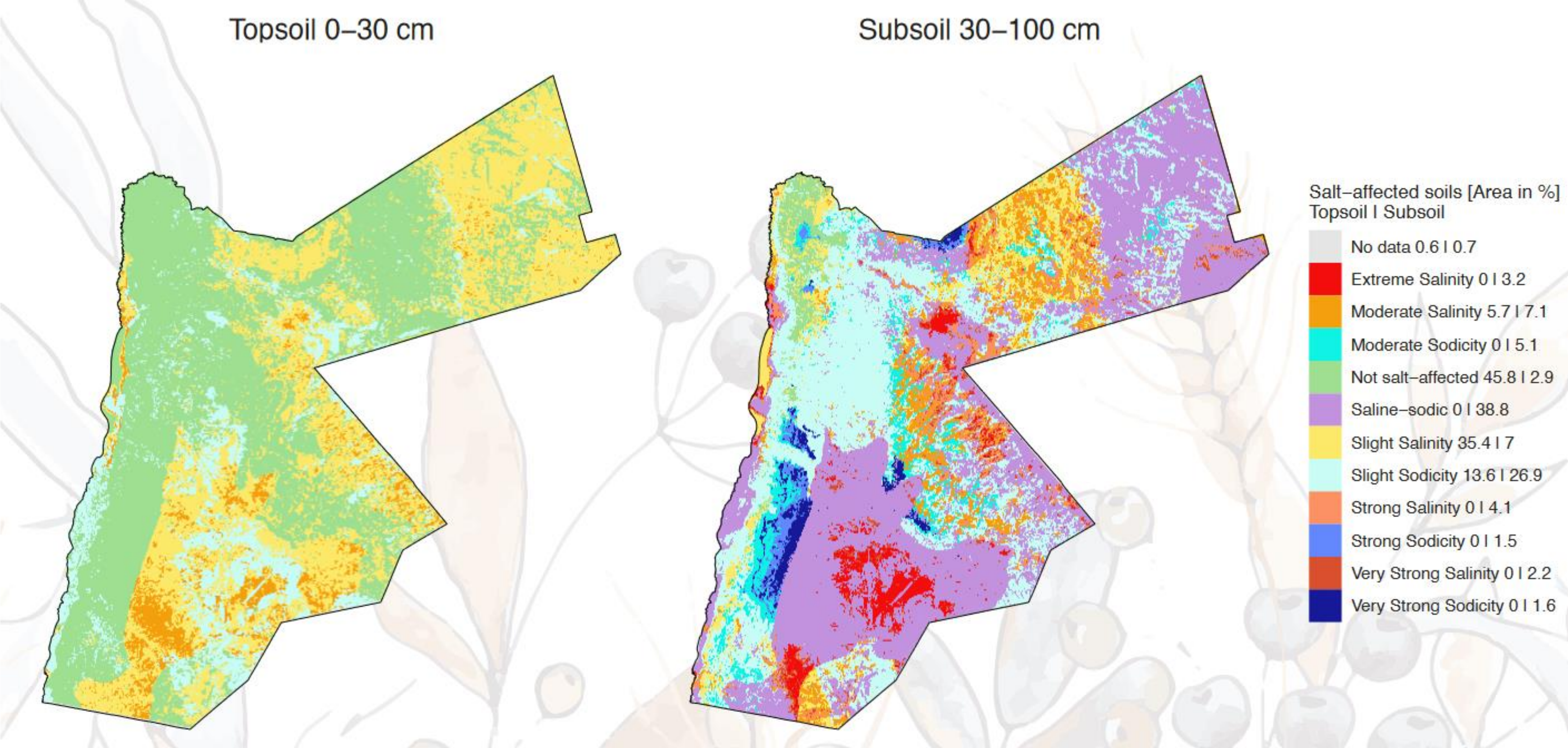
- Soil salinity - measure of the concentration of all soluble salts in soil water, usually expressed as Electrical Conductivity (EC) of pore water
- Soil considered saline when soil extract from a saturated paste (EC_e) equals, or exceeds 4000 µS/cm
- Sodicity is the dominance of sodium ions (Na^+) over other cations (Ca^{2+}, Mg^{2+}, etc.), expressed in the sodium adsorption ratio (SAR)
- Soils are considered sodic when the amount of sodium impacts soil structure (Na replaces Ca on clay surfaces causing structure degradation), SAR > 13 $(mmol\ l^{-1})^{0.5}$
- Sodicity affects soil permeability and surface sealing

Understanding of soil salinity and pH

- Soil salinity causes:
  - High surface evapotranspiration
  - Poor leaching / drainage
  - Capillary rise of saline groundwater
  - Cutting of vegetation causing rising groundwater table transporting salt from deeper levels upwards to root zone
  - Irrigation water salinity and too low irrigation return flow
  - Use of sewage sludge and/or treated sewage effluent
  - Excessive fertilizer use and use of soil amendments (lime and gypsum)
- Establish type of ions and dominance of cation (e.g. sodicity)
- Soil pH - most soil nutrients optimally available to plants within a soil pH range of 5.5 to 8.0. Use amendments to correct if outside of range



Distribution salt affected soils Jordan



https://www.fao.org/3/cc4726en/cc4726en.pdf

Estimating soil salinity

- Saturated paste method to determine EC_e
  - Take soil sample in the field and determine moist weight
  - Dry soil to 70 °C and determine dry weight and moisture content
  - Remove gravel particles and place in tube
  - Slowly add demineralized water to the soil and stir until saturation occurs
    - Saturation achieved when soil glistens and flows when the tube is held at angle of 45°
    - There should be no freestanding water on top of the soil!
  - Leave tube with soil and water standing for a day to equilibrate
  - Remove water through suction and filter
  - Measure the EC of the water using an EC meter

Alternatives

- Common with 1 : 5 volume method
  - Set your EC-meter to automatically correct EC value to 25 °C temperature
  - Add 10 g of finely crumbled well-mixed dried soil (70 °C) to a 60 ml test tube
  - Add 50 ml of distilled water (water with low EC)
  - Agitate the mix by shaking and leave standing for at least 3 h for to settle and for salts to dissolve
  - Measure the EC of the water in the tube and note the value down
  - Use soil salinity classification table to assess salinity status based on texture of soil
- 1 : 1 or 1 : 2.5 methods are alternatives to the 1:5 method
- Advantage is that EC can be measured in the water in test tube

Soil salinity classification 1:5 method

Salinity classes in electrical conductivity as $EC_{1:5}$ or EC_e^* for different soil textures				
Salinity class	$EC_{1:5}$ range SAND [µS/cm]	$EC_{1:5}$ range LOAM [µS/cm]	$EC_{1:5}$ range CLAY [µS/cm]	EC_e^* range pore water [µS/cm]
Non-saline	0–140	0–180	0–250	0–2000
Slightly saline	150–280	190–360	260–500	2000–4000
Moderately saline	290–570	370–720	510–1000	4000–8000
Highly saline	580–1140	730–1450	1010–2000	8000–16000
Severely saline	1150–2280	1460–2900	2010–4000	16000–32000
Extremely saline	2280	2900	4000	>32000

$^*Ec_e$ represents pore water EC or salinity

- Note that adding fertilizer (nitrate, ammonium, etc.) also increases the EC of the soil solution

Use rhizon to obtain soil water sample

- A rhizon can be used to obtain water samples from moist soils (https://www.rhizosphere.com/about_rrp)
- Cannot be used in dry soils
- Install in the soil at desired depth
- Extract water sample with syringe (may take some time)
- Measure:
  - Salinity (EC_e) of pore water
  - Nitrate concentration in pore water
  - Other ions…

EC meter for salinity measurement

- Handheld device, probe placed in water
- Needs calibration using calibration fluid, 0.01 M KCl would be 1413 $\mu S\ cm^{-1}$
- Always correct for temperature of water (automatic) to 25 °C
- Aquamobile smartphone EC meter developed by Fixeau company to measure surface and groundwater EC in salinity prone areas and transmit data to a web platform for display on maps.
- Provides information on spatial and temporal salinity variations

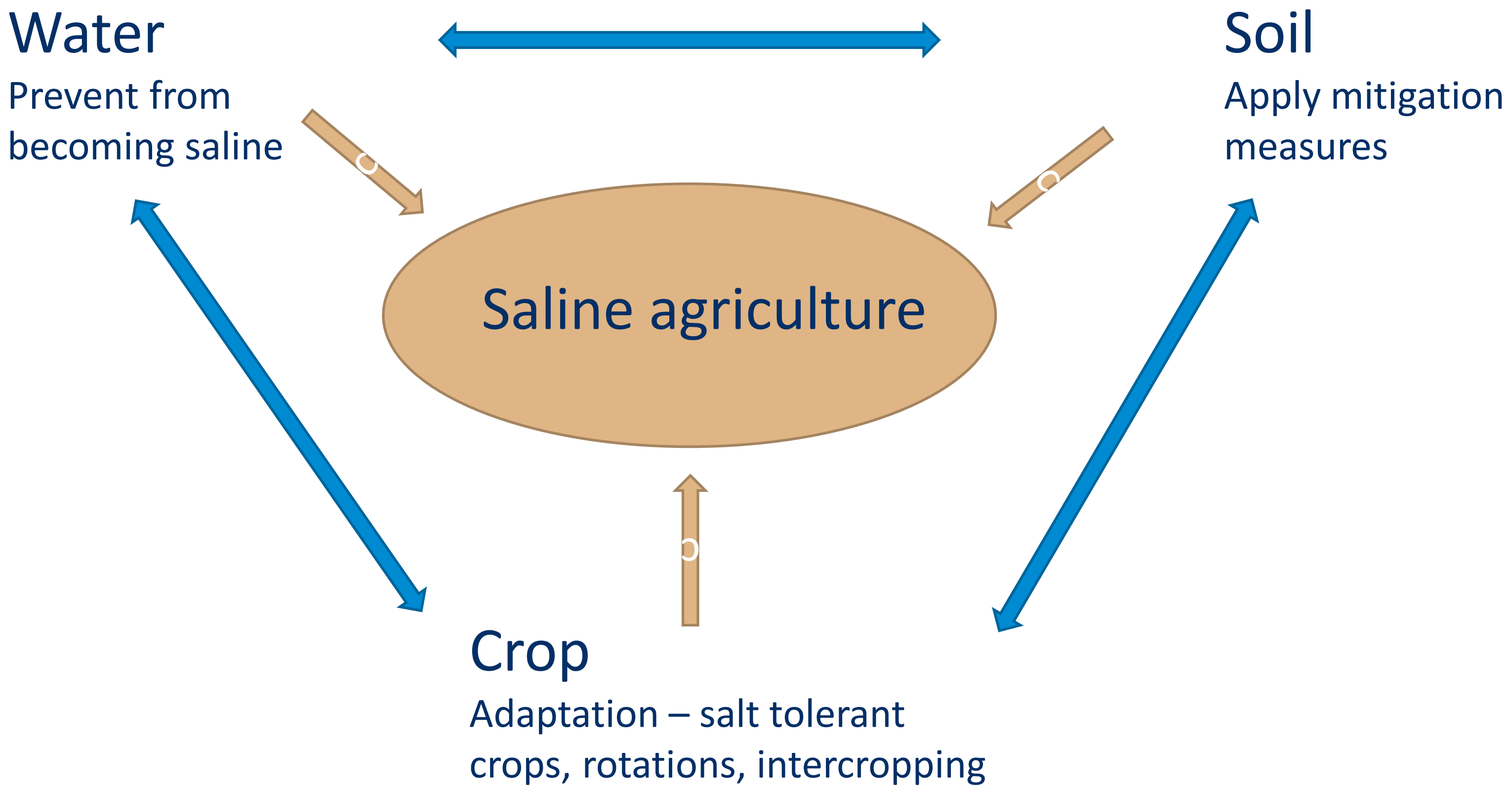
fixeau®

Nitrate concentration measurement

- Using strip tests in water (extracted from soil using rhizon)
- Readout visually against color scale or using the Nitracheck, range 0-500 mg l^{-1}
- Use ion selective electrode sensor (e.g. Horiba Laquatwin), range 6 – 10,000 mg l^{-1}
- Needs calibration and regular replacement of sensor depending on frequency of use
- Horiba also available for pH, Na, K, Ca, and EC
- https://www.horiba.com/int/water-quality/pocket-meters/

Improving crop yields under saline conditions

- Clever interplay between water, crop and soil can make relatively productive saline farming possible



Prevention, mitigation and adaptation

- Prevention: use of fresh water with low salinity, reverse osmosis, mixing, promote leaching of salts before planting, water harvesting to store more fresh water in the soil
- Mitigation: land preparation, soil amendments (gypsum, acid, organic), mulching (reduce soil evaporation), biostimulants, nutrients, increase infiltration capacity, drainage improvement, etc.
- Adaptation: transition to low water use crops, salt tolerant crops / varieties, crop rotation, intercropping, agro-forestry, open-field hydroponics to save water

Dilution of saline groundwater with surface water

- Create small reservoirs in wadis, water has an EC of 300-400 $\mu S\ cm^{-1}$
  Mix with more saline source water to reduce EC of irrigation water?

Soil health conservation

- Salt affected soil is degraded, need to improve soil by focus on chemical, physical and biological conditions
- Data required for assessment

Optimum soil health

Chemical properties
- EC
- pH
- Cations, anions
- ESP
- CEC
- (bi)carbonate
- SAR
- Nutrients

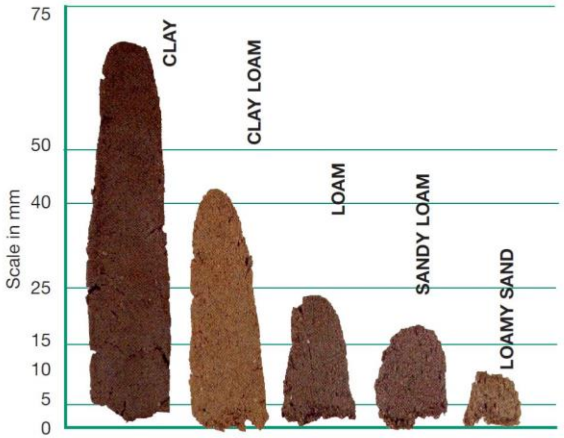
Physical properties
- Soil pan / rooting depth
- Bulk density
- Infiltration rate
- Water holding capacity
- Clay swelling
- Soil structure stability

Biological properties
- Organic matter
- Soil microbial activity
- Soil microbial diversity
- Soil fauna
- Nitrogen mineralization

Simple soil texture assessment

1. Dry and sieve your soil, remove stones and gravel > 2mm, estimate percentage of stones
2. Place some soil in your hand, add some water and try to form a ball. If impossible you have sand
3. Now try to make a hanging ribbon 2-3 mm thick, the longer the ribbon can be without breaking the higher the clay content

- https://www.agric.wa.gov.au/soil-constraints/soil-texture-estimating-hand



Activities and decisions before planting

- Determine soil type (texture), organic matter content, CEC, check EC and pH of soil and irrigation water, check ions / nutrients in soil and irrigation water
- Check the soil profile, are there any compact layers, tillage?
- Calculate nutrient availability in soil and crop needs. Add (organic) fertilizers when needed
- Decide on application of soil amendments (lime, compost, …) for pH correction
- Prepare and check irrigation system. If soil salinity is too high apply leaching before planting and check drainage status
- Decide on level field or planting in raised beds, use of organic mulch, intercropping or use of cover crops
- Select a salt tolerant crop variety
- Install soil moisture / water quality monitoring equipment (just after planting)

Monitoring during growing season

- Monitor EC of soil and water, crop development
- Decide on leaching if soil EC exceeds tolerance (taking crop stages into account)
- Apply smart irrigation based on soil moisture status
- Check crop performance, apply fertilizer (smart, fertigation) and decide on treatments
- Add biostimulants: substances or microorganisms that, when applied to the rhizosphere, stimulate natural processes to enhance or benefit nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, or crop quality and yield
- Carry out GAP / IPM activities
- Keep thinking and decide on future improvements and innovations

Summary

- Smart agriculture can lead to better production in saline conditions
- Estimation of crop evaporation to optimally provide water to the soil
- Subsurface drip irrigation most efficient
- Need to monitor soil EC and apply leaching if too saline
- Monitoring allows for better assessment of crop performance in view of soil and water properties. Start before planting!
- Monitoring requires technical skills and understanding
- Range of monitoring equipment and techniques available to farmers
- Rainwater harvesting can provide fresh water in soil or wadi storages to combat soil salinity

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