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REVISITING CROP WATER STRESS INDEX BASED ON POTATO FIELD EXPERIMENTS IN NORTHERN GERMANY

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TUDOR Project "Water stress detection, evapotranspiration and crop water requirement analysis to support irrigation scheduling"

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Revisiting crop water stress index based on potato field experiments in Northern Germany

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Highlights

Does CWSI work in humid regions?
CWSI works in humid regions at high radiation and dry air conditions.

Does CWSI relate to a measure of plant available water?
CWSI allows the estimation of soil water content with acceptable errors.

Compare the different CWSI methods (theoretical, empirical, hybrid)
Hybrid CWSI combines the advantages of the empirical and theoretical CWSIs.

Assess the ability of UAV drought stress indices to capture differences in irrigation treatments and spatial variation of drought stress
UAV-based CWSI and soil moisture maps can well capture irrigation patterns.

CROP WATER STRESS INDEX (CWSI)

The crop water stress index (CWSI) defines the relationship between actual (ET_{act}) and potential (ET_{pot}) evapotranspiration (Idso et al., 1981, Jackson et al., 1981):

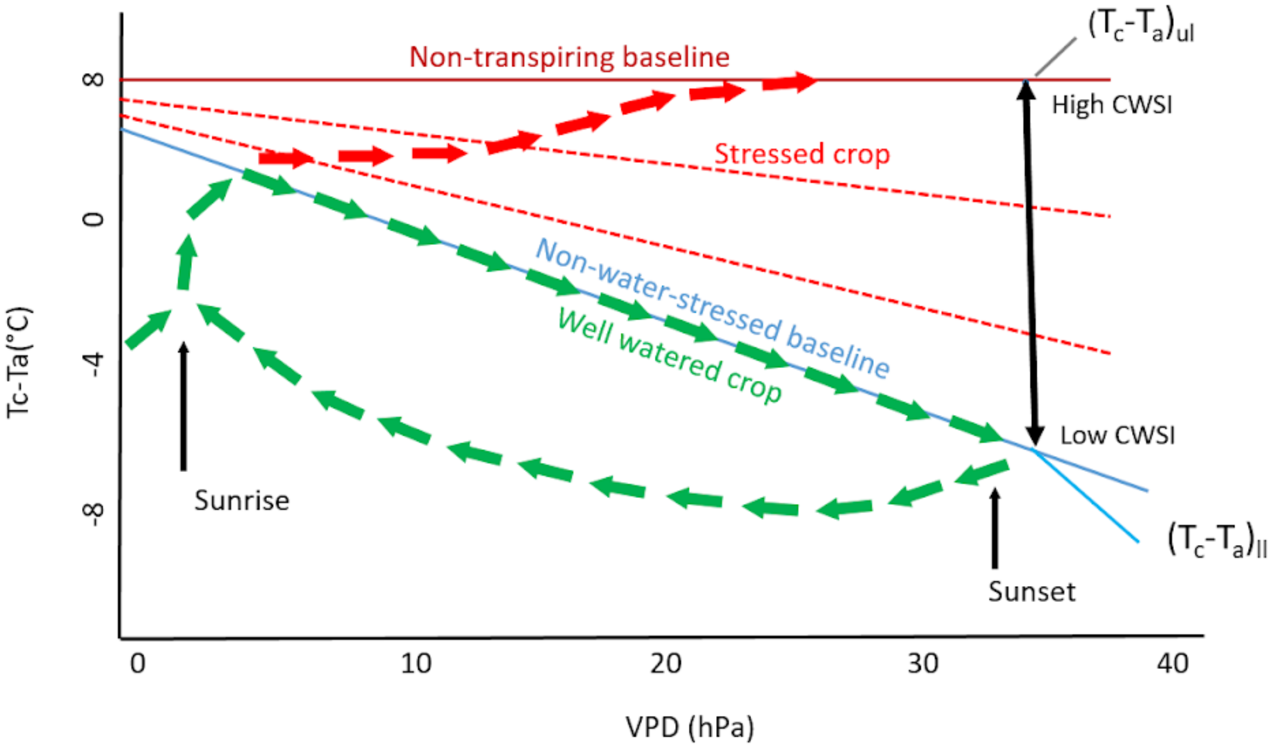
$$CWSI = 1 - \frac{ET_{act}}{ET_{pot}} = \frac{(T_c - T_a) \quad - (T_c - T_a)_{UL}}{(T_c - T_a)_{UL} - (T_c - T_a)_{LL}}$$

ET_{act} is the actual latent heat flux (W m^{-2})
ET_{pot} is the potential latent heat flux (W m^{-2})

T_c-T_a is the difference between canopy temperature (T_c, °C) and air temperature (T_a, °C),
$(T_c\text{-}T_a)_{UL}$ is the upper level boundary condition representing non-transpiring condition
$(T_c\text{-}T_a)_{LL}$ is the the lower level boundary condition representing actively transpiring condition

CWSI = 0 for well watered crop at maximum transpiration
CWSI = 1 for a crop at severe water stress

EMPIRICAL CWSI (CWSI-E)



Adapted from Liu et al. 2020

Vapour-pressure deficit (VPD): the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated

Non-transpiring baseline:

$(T_c-T_a)_{UL}$ = max. Tc-Ta

Non-water stressed baseline:

$$(T_c - T_a)_{LL} = a * VPD + b$$

coefficients a and b are determined by linear regression of the scatterplot between (Tc-Ta) versus VPD

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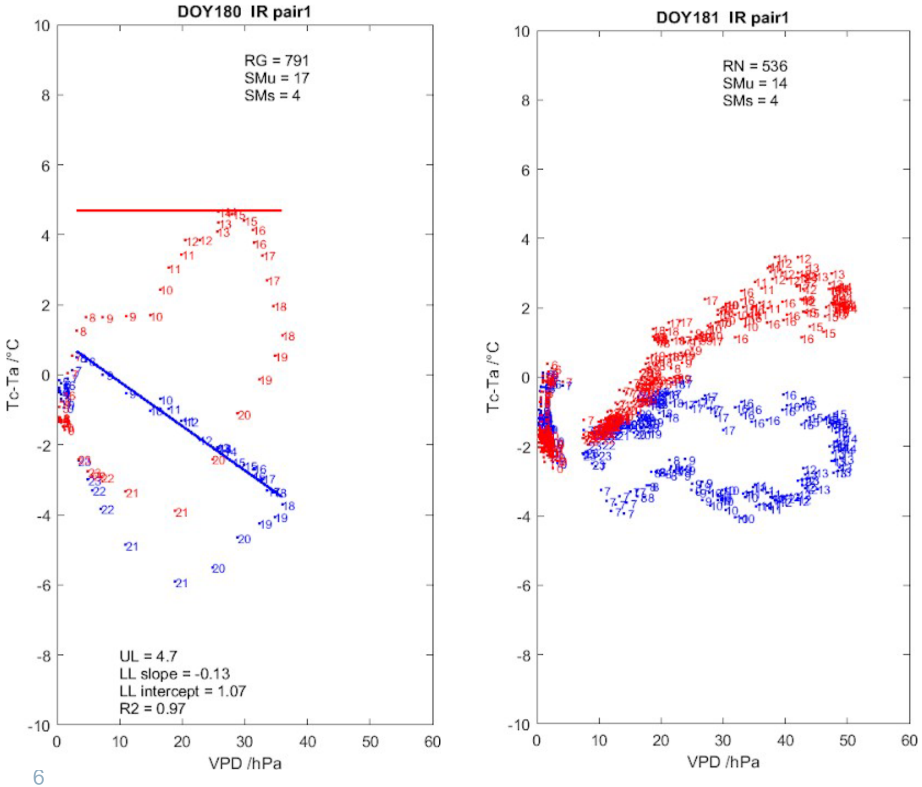
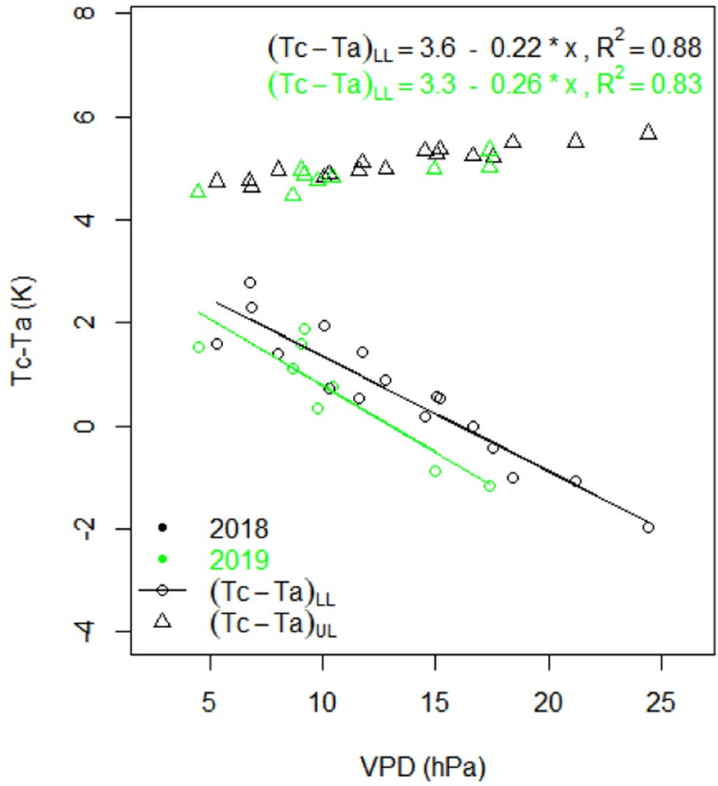
CWSIE: SINGLE-DAY VS MULTI-DAY METHOD

Single-day method

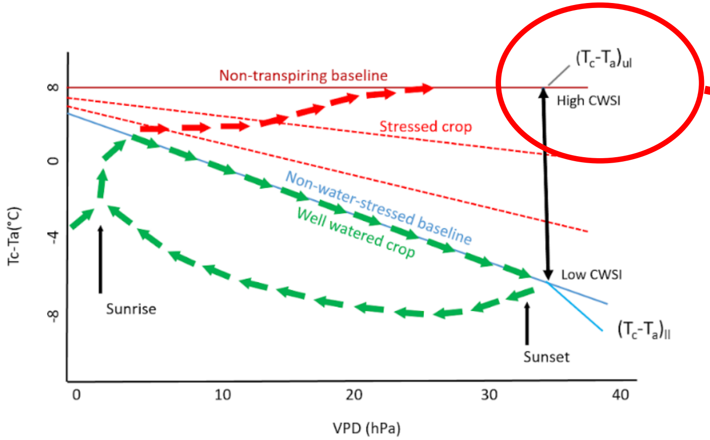
Multi-day method





HYBRID CWSI

Empirical CWSI



Theoretical CWSI

$$(T_c - T_a)_{UL} = \frac{r_a(R_n - G)}{\rho C_p}$$

$$(T_c - T_a)_{LL} = \frac{r_a(R_n - G)}{\rho C_p} \cdot \frac{\gamma}{\Delta + \gamma} - \frac{VPD}{\Delta + \gamma}$$

C_p = heat capacity of air (J kg^{-1} K)

ρ = air density

γ = psychrometric constant (Pa K^{-1})

r_a = the aerodynamic resistance (s m^{-1})

Δ = change (slope) of saturation vapour pressure with temperature (Pa K^{-1})

R_n = net radiation (J m^{-2} s^{-1})

G = heat flux consumed by soil (J m^{-2} s^{-1})

VPD = vapour pressure deficit (hPa)

Ta = air temperature (°C)

Tc = canopy temperature (°C)

Hybrid CWSI

Combines theoretical and empirical CWSI:

- LL from theoretical CWSI calculation
- UL from empirical CWSI, e.g. Ta + 5°C

$$(T_c - T_a)_{LL} = (T_c - T_a)_{UL} \cdot \frac{\gamma}{\Delta + \gamma} - \frac{VPD}{\Delta + \gamma}$$

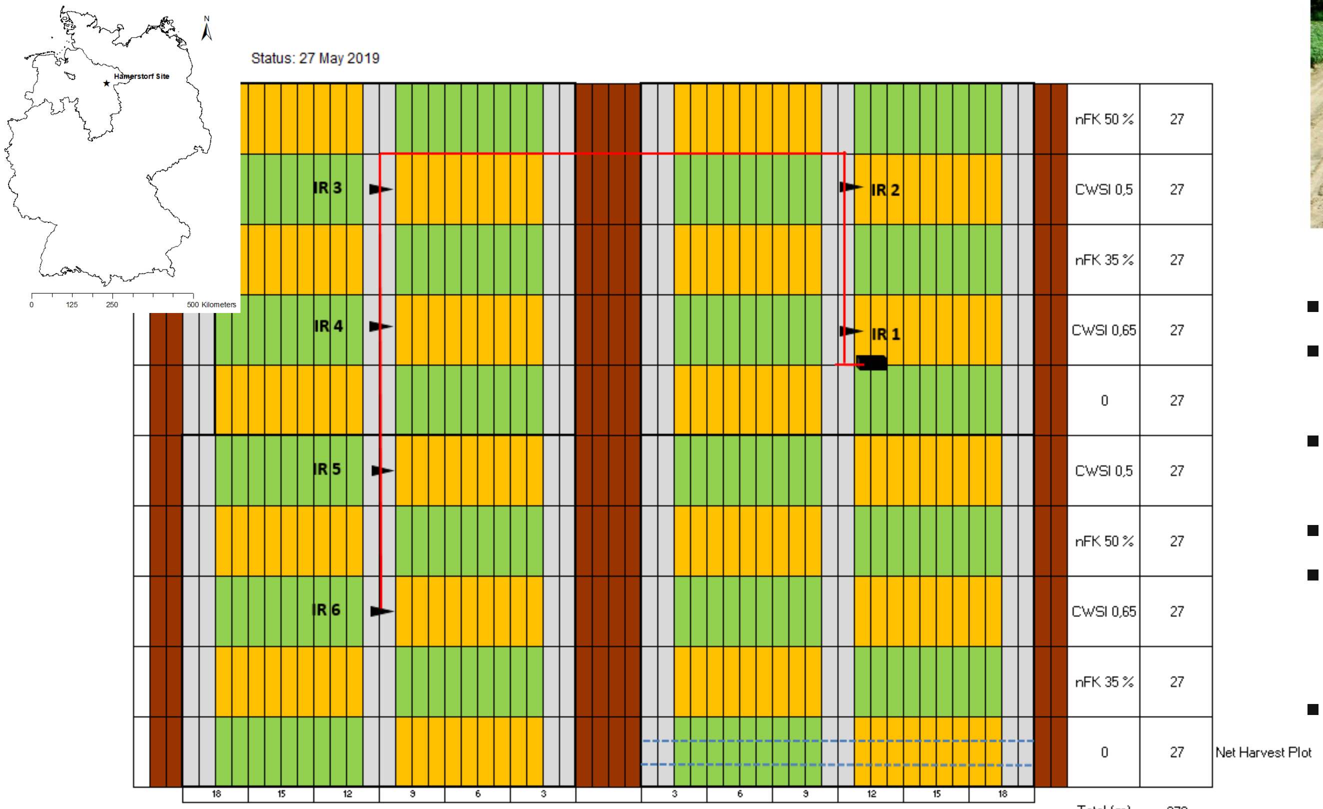
Advantage over CWSIt:

- No need to measure R_n, G, w, r_a

Advantage over CWSIe:

- No need to wait until end of season to calculate LL

EXPERIMENTAL SETUP



nFK 50 %	27
CWSI 0,5	27
nFK 35 %	27
CWSI 0,65	27
0	27
CWSI 0,5	27
nFK 50 %	27
CWSI 0,65	27
nFK 35 %	27
0	27
Total (m)	270

No irrigation
Reduced Irrigation (from 35 % nFK)
[Reduced Irrigation (CWSI 0,65)]
Optimal Irrigation (from 50 % nFK)
[Oprimal Irrigation (CWSI 0,5)]

- Sandy soils, irrigation is a must
- 3 irrigation levels:
  full (OP), half (RD), none
- 6 IRT sensors (3 in full, 3 in half)
- IRT sensors looked at 45°
- Soil water content (soil moisture) probes at positions IR1 and IR2
- (Colours green and orange have no meaning here)

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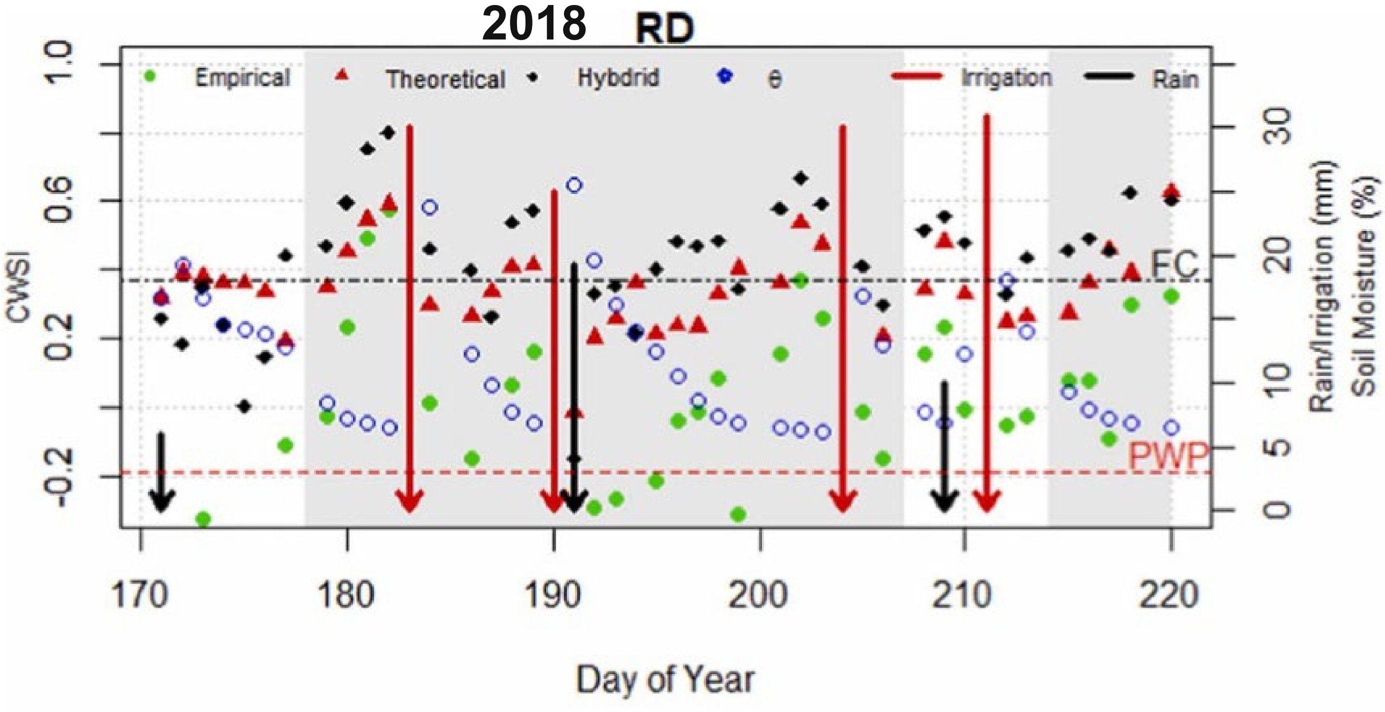
CWSI IN HUMID ZONES

Midday (11–15 h) CWSIe, CWSIt, CWSIh together with SWC at 10 cm depth (θ), irrigation events, and significant rain (> 5 mm). Grey background: high incoming solar radiation

2



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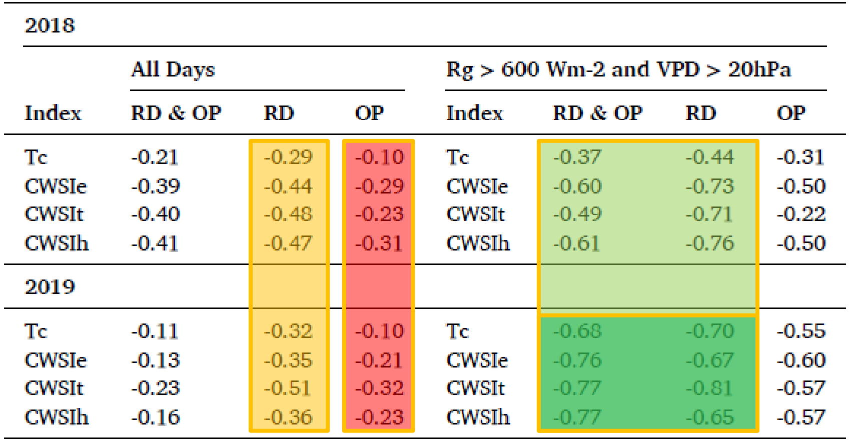
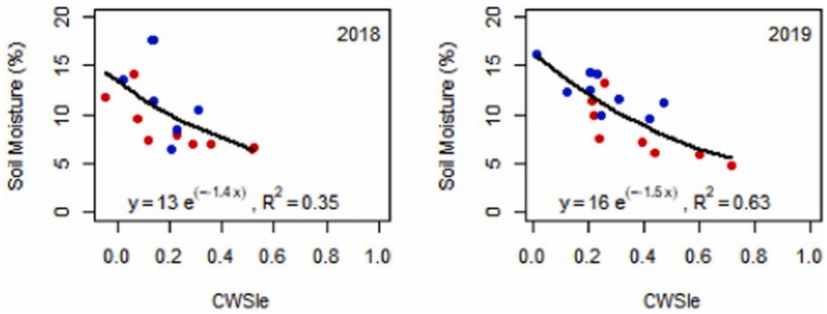
CWSI – SOIL WATER CONTENT



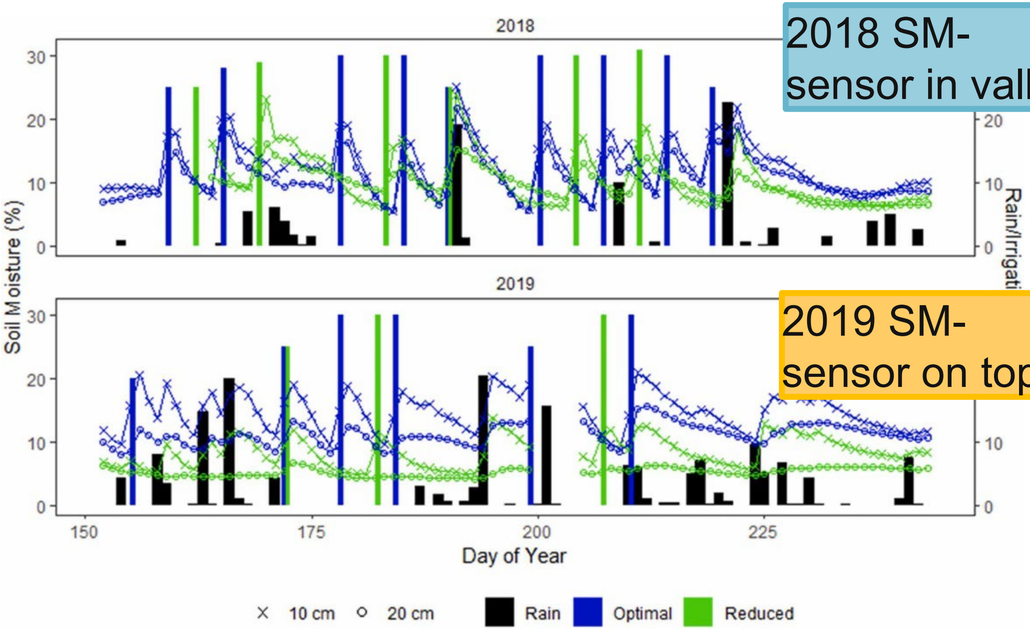
2018							
	All Days			Rg > 600 Wm-2 and VPD > 20hPa			
Index	RD & OP	RD	OP	Index	RD & OP	RD	OP
Tc	-0.21	-0.29	-0.10	Tc	-0.37	-0.44	-0.31
CWSIe	-0.39	-0.44	-0.29	CWSIe	-0.60	-0.73	-0.50
CWSIt	-0.40	-0.48	-0.23	CWSIt	-0.49	-0.71	-0.22
CWSIh	-0.41	-0.47	-0.31	CWSIh	-0.61	-0.76	-0.50
2019							
Tc	-0.11	-0.32	-0.10	Tc	-0.68	-0.70	-0.55
CWSIe	-0.13	-0.35	-0.21	CWSIe	-0.76	-0.67	-0.60
CWSIt	-0.23	-0.51	-0.32	CWSIt	-0.77	-0.81	-0.57
CWSIh	-0.16	-0.36	-0.23	CWSIh	-0.77	-0.65	-0.57

Correlation coefficients (r) between midday (11–15 h) 10 cm θ and Tc, CWSIe, CWSIt and CWSIh.

Relationship between mid- day index vs soil water content at 10 cm (%) when Rg > = 600 W/m² and VPD > = 20 hPa



SWC VARIATIONS AND SENSOR PLACEMENT

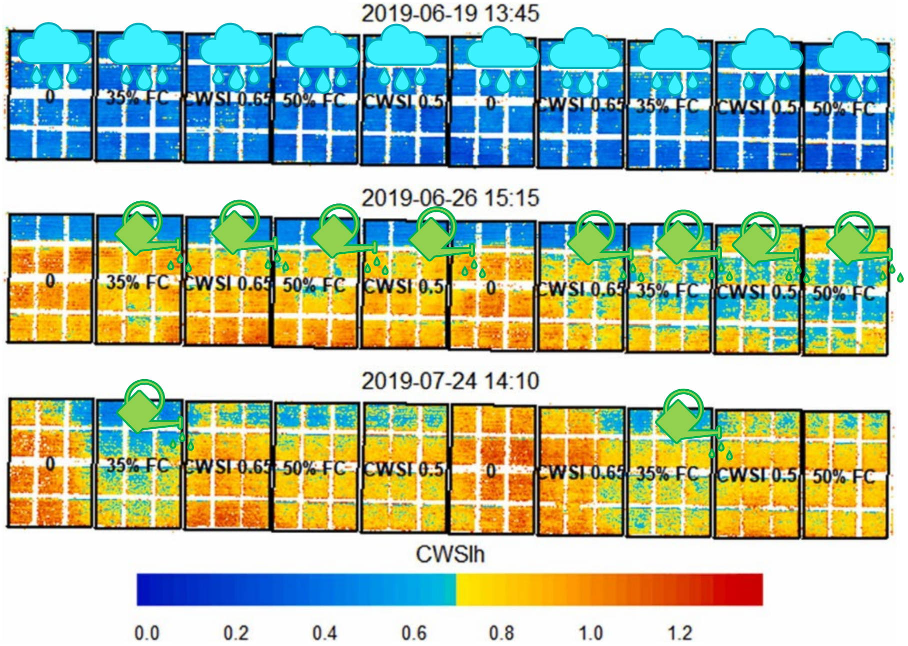


2018 SM-sensor in valley

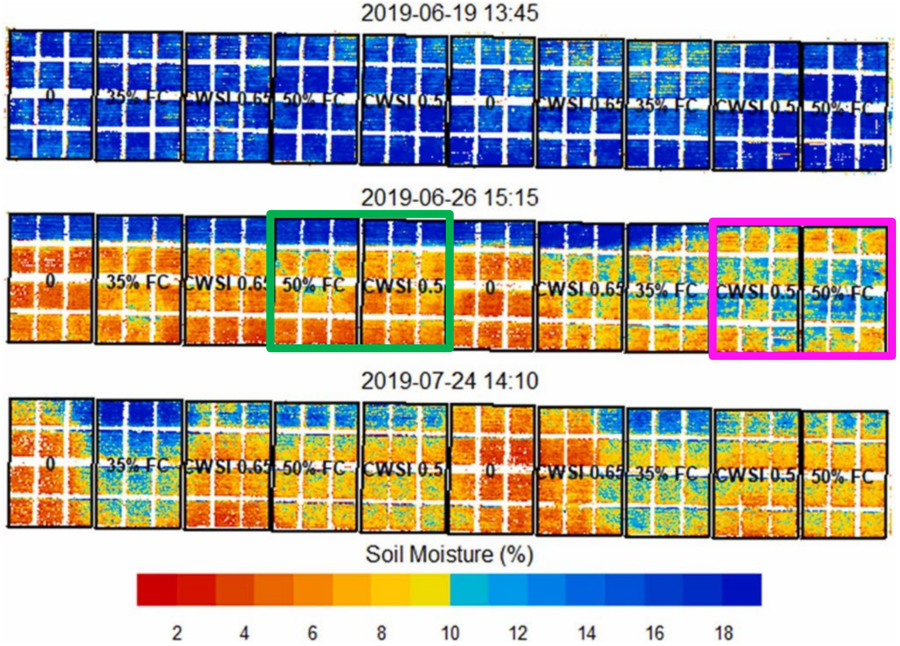
2019 SM-sensor on top

Temporal evolution of the midday soil water content in 10 cm and 20 cm depth together with rain and irrigation events in 2018 (top) and 2019 (bottom)

CWSI AND SOIL MOISTURE MAPS



CWSIh for potato field. Labels are irrigation treatments applied to the plots, i.e., **Reduced (CWSI 0.65, 35% FC)**, **Optimal (CWSI 0.5, 50% FC)**, and **No Irrigation (0).**

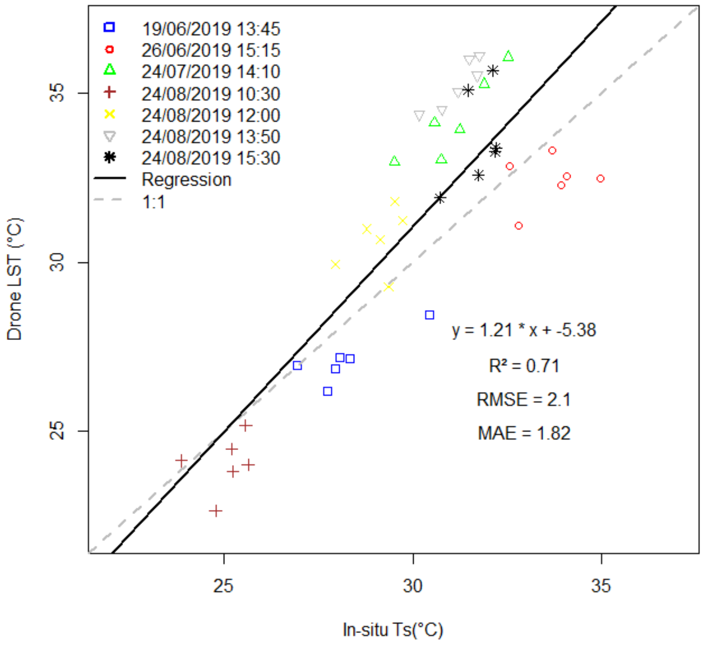


Estimated soil water content (%) based on the calibration between CWSIt and SWC at 10 cm. Approx. 3–4 Vol% corresponds to PWP, 15–18 Vol% to FC.

CONCLUSIONS

- CWSI models showed good relationships with volumetric soil water content only under meteorological conditions high radiative heating and high atmospheric demand
  - SM-sensor positions on top of potato ridge: favourable (valley unfavourable)
  - CWSIe models performed better than CWSIt and CWSIh (differences were small)
  - CWSI-θ relations calibrated in one year, could effectively predicted θ in another year with little errors of 1–2%
- For practical purposes, CWSIh could be a promising alternative to the traditional CWSI (CWSIe and CWSIt) models since it requires less amount of input variables than CWSIt and (Tc-Ta)LL can be computed before end of season
- CWSI applied to drone image can well capture spatial variations in water stress

Drone LST vs ground surface T



<u>Possible causes of difference:</u>

- Effect of atmosphere (downwelling & upwelling radiance, transmission)
- Anisotropy of the radiation (view and azimuth angles)
- Emissivity estimation (assumption)
- Heterogenous surface temperatures (ensemble of surfaces at different T, e.g. shaded and sunlit soil and leaves)
- Radiative versus aerodynamic temperature (thermal radiation stems from surface, not from canopy profile)

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