Unit 6: IRRIGATION

Potato water requirements, partial root-zone drying irrigation and effective use of water

David A. Ramírez & Javier Rinza, 5th July 2022

Objectives

1. To learn about the importance of saving water in agriculture.

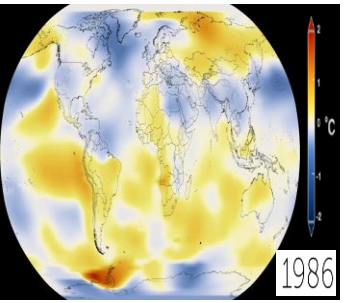
2. To analyze the methods to optimize irrigation in potatoes through water demand assessment and the appropriate irrigation timing.

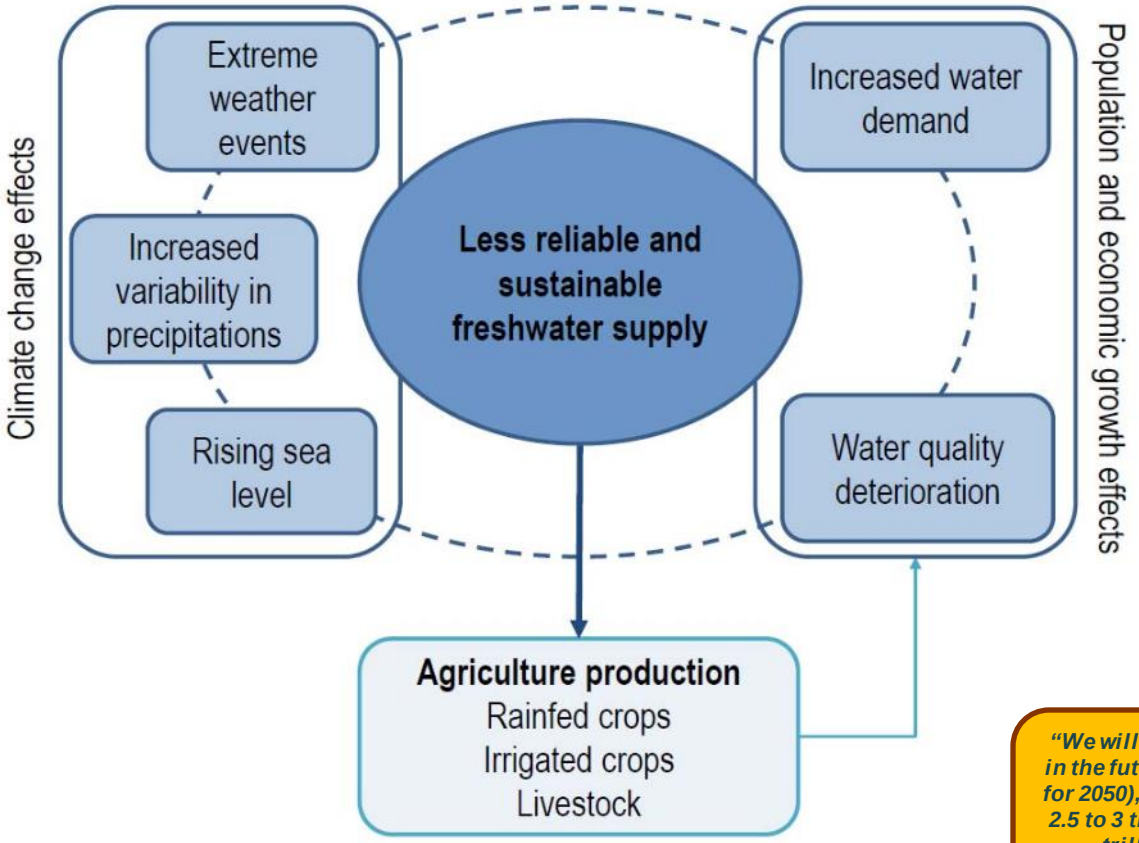
3. To share some research experience from CIP regarding water management in potato.

Program

1. Introduction
2. Potato Water Requirements
3. Partial Root-Zone Drying (PRD)
4. Effective Use of Water
5. Final Remarks

Global Problems in relation to water resources





"We will must feed more people in the future (9 billions predicted for 2050), we will require between 2.5 to 3 times more water (10-13 trillions m3 for 2050)"

Lal, (2013)

Source: OECD Studies on Water (https://doi.org/10.1787/9789264279551-en)

Climate Change

Water Deficit

Agriculture

Vulnerable Crops

↓ Yield

↑ Costs

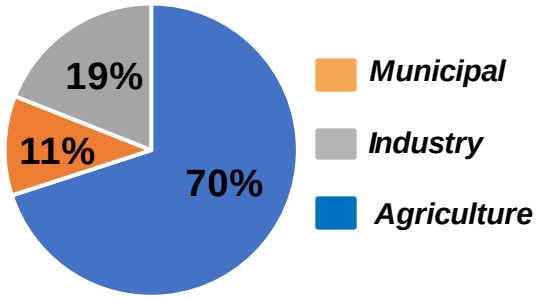
↑ Temperatures

↑ Aridity

↓ Appropriate areas for agriculture

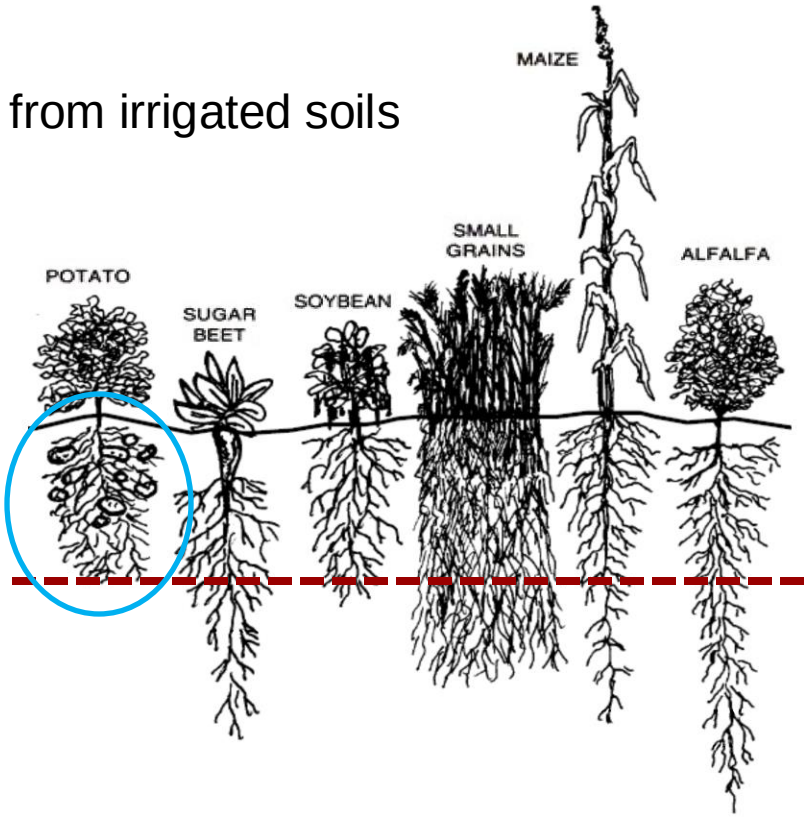
↓ Water availability

Fresh water global use (FAO 2016)



70% globally fresh water

40% of globally food come from irrigated soils



→ **Potato**

3er edible crop

85% harvest index

Drought sensitive

2. POTATO WATER REQUIREMENTS

0.35 to 0.8 m^3 of water to produce 1 kg of tuber dry matter

350 - 650 mm (L/m^2) (during the growing period)

$1\ mm = 10\ m^3/ha$

tubers contains ~80 % of water

Water productivity for yield of fresh tuber is 4 to 11 kg/m^3

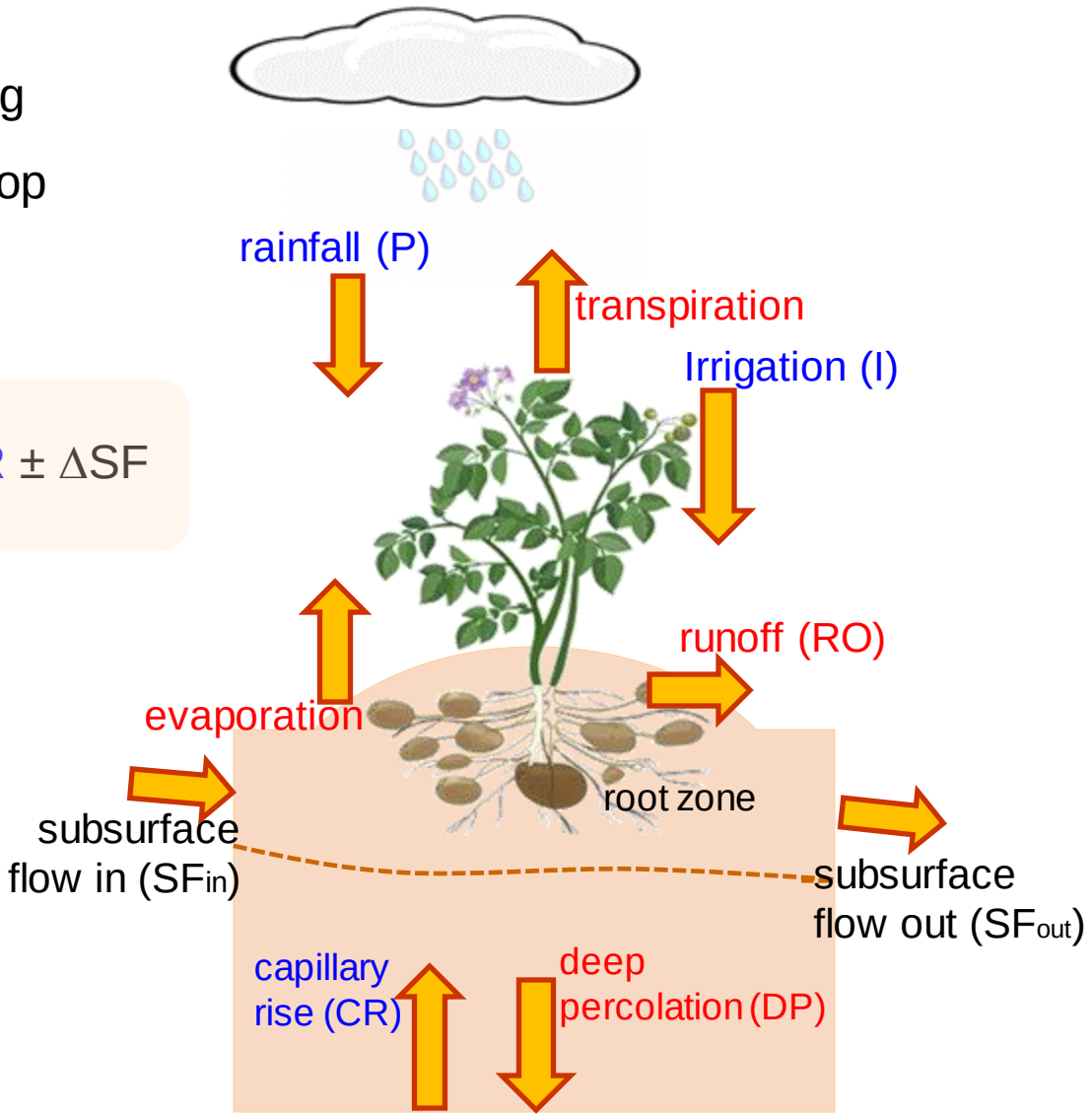
FAO 66

2. POTATO WATER REQUIREMENTS

Soil water balance:

Consists of assessing the incoming and outgoing water flux into the crop root zone over some time period

$$\Delta SW = I + P - ET - RO - DP + CR \pm \Delta SF$$



ΔSW: Stored soil water content

ET: evapotranspiration

$\Delta SF = SF_{in} - Sf_{out}$

2. POTATO WATER REQUIREMENTS

Evapotranspiration (ET):

ET is the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation (E) and on the other hand from the crop by transpiration (T).

2. POTATO WATER REQUIREMENTS

Reference evapotranspiration (ETo): FAO Penman-Monteith method

$$ETo = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T+272}\,U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \text{ (mm day}^{-1}\text{)}$$

$$ETc = \text{kc ETo (mm day}^{-1}\text{)}$$

Where:

R_n, net radiation on the crop surface (MJ m^{-2} $día^{-1}$)
G, soil heat flux (MJ m^{-2} $día^{-1}$)
T, average air temperature at 2 m height (°C)
U_2, wind speed at 2 m height (m s^{-1})
e_s, saturation vapor pressure (kPa)
e_a, actual water vapor pressure (kPa)
$e_s - e_a$, vapor pressure saturation deficit (kPa)
Δ, slope of the water vapor saturation pressure curve ($e_s = e_a$) (kPa°C^{-1})
γ, psychrometric constant (kPa °C^{-1})
ETc is the crop evapotranspiration
kc: is the crop coefficient

FAO 56

2. POTATO WATER REQUIREMENTS

Soil moisture: gravimetric water content (w, g/g or %)

$$w = \frac{Mw - Md}{Md}$$

Mw is wet soil mass (immediately weighted after sampling)

Md is dry soil mass after oven drying soil sample to get constant weight

Soil moisture: Volumetric water content (θ, cm³/cm³ or %)

$$\theta = \frac{Mw - Md}{Vt}$$

Bulk density (ρ_b, g/cm³)

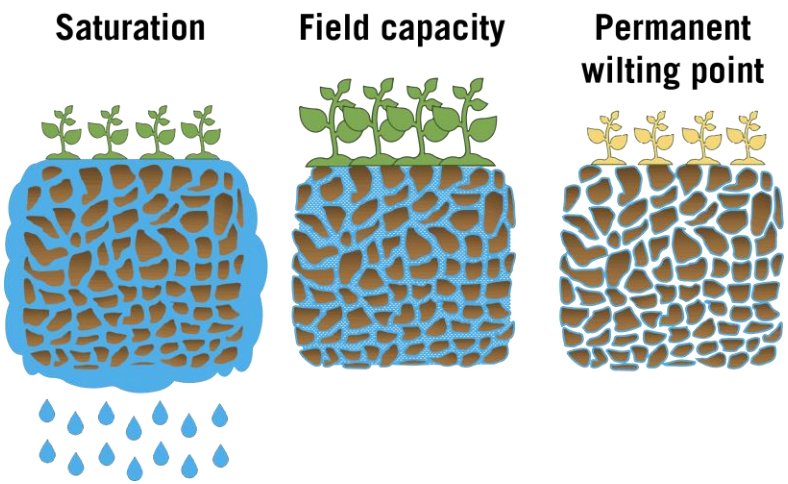
$$\rho_b = \frac{Md}{Vt}$$

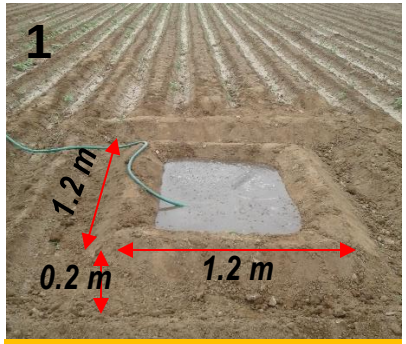
Vt is the volume of the container used for soil sampling. Usually, when w and ρ_g are available, θ can be calculated as follows:

$$\theta = w.\rho_g$$

Soil Field capacity: How to measure it?

Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased.





Flood the area selected for the sample

Cover with plastic to prevent evaporation

After ~6 days, when drainage is negligible due to percolation, dig a pit (width 0.4 x length 0.7 x depth 0.5 m^3)

Fix at different profile levels of 0, 10, 25, and 40 cm

Carefully take the samples in each level

Label and wrap with aluminum foil

2. POTATO WATER REQUIREMENTS

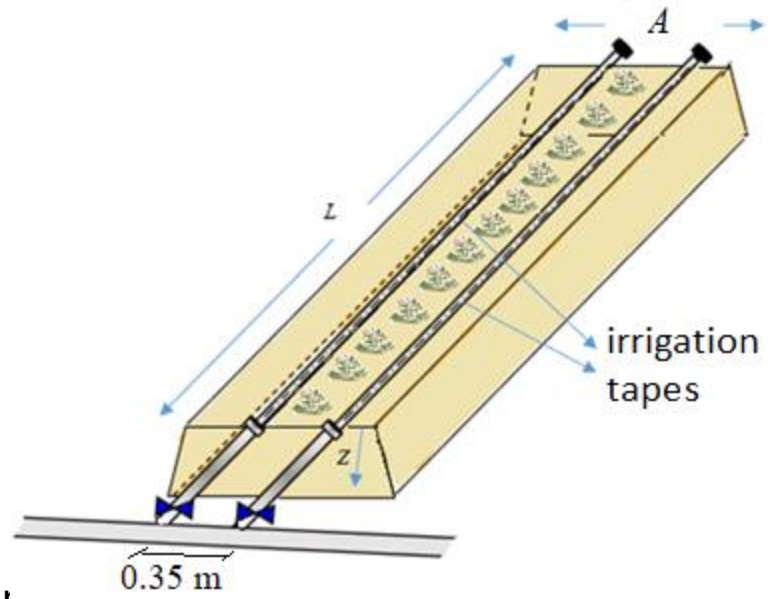
How long should we water under drip irrigation?

Irrigation lamina (RIL, in mm) are calculated as

$$RIL = 1000(\theta_{Fc} - \theta_{act}) * \mathrm{Z}$$

Irrigation time (IT, in minutes)

$$IT = RIL * \frac{A * L}{Q_s}$$



Where:

L (m): length of the irrigation tapes,

A (m): row bed width (side to be moistened)

Z (m): depth of the root system (0 - 0.35 m)

θ_{Fc}: volumetric moisture at field capacity

θ_{act}: volumetric moisture actual in cm^3/cm^3.

Q_s: irrigation flow per furrow (in L min^{-1}), resulting fro
multiplying the dripper flow with the number of drippers per row.

3. PARTIAL ROOT-ZONE DRYING (PRD)

Concept

Full Irrigation

Partial root-zone drying (PRD) or Alternated Irrigation

PRD + Siphons

Partial root-zone drying (PRD) benefits in potato

- ↑ Water Use Efficiency*
- 29-50% Water Saving *
- ↑ Marketable tuber — *Shahnazari et al. (2007)*
- ↑ Soil N Availability — *Shahnazari et al. (2008)*
- ↑ Anti-oxidants in tubers — *Jovanovic et al. (2010)*

PRD in Potato

Agricultural Water Management 123 (2013) 65–70

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

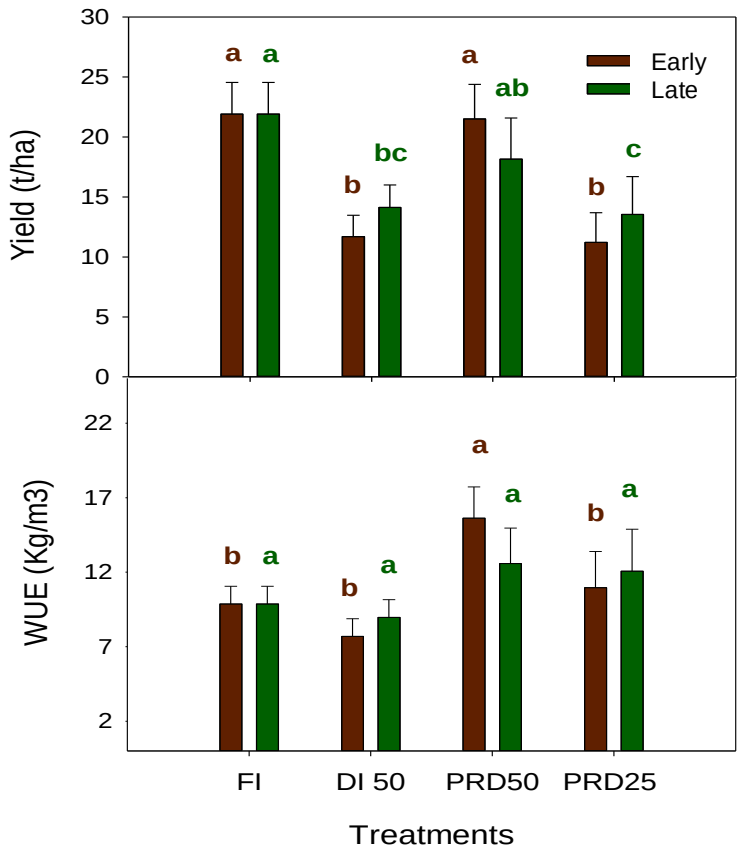
Effect of partial root-zone drying irrigation timing on potato tuber yield and water use efficiency

Wendy Yactayo, David A. Ramírez*, Raymundo Gutiérrez, Víctor Mares, Adolfo Posadas, Roberto Quiroz

International Potato Center (CIP), Apartado 1558, Lima 12, Peru

* Jovanovic et al., 2010; Liu et al., 2006; Saeed et al., 2008; Shahnazari et al., 2007; Xie et al., 2012

Yactayo et al. (2013)



FI = Furrow irrigation (control)
DI 50 = Deficit Irrigation 50 % FI water
PRD 50 = PRD with 50% FI water
PRD 25 = PRD with 25% FI water

How to establish a PRD irrigation system?

- At the entrance of the furrows, soil will be accumulated in those furrows, which should not receive irrigation water to stay dry.
- In the following irrigation interval, the previously dry furrows will be irrigated (removing the soil hill in the entrance) whereas the water flow will be blocked in the previously wet furrows.

Important Considerations !!:

1) Water flow (Litters/hour or m^3/minute, etc.) of channel which will provide water for the irrigation will be known.

$$\text{Water flow} = \frac{Volume\ (L)}{Time\ (s)}$$

2) PRD treatment initiation

Flower buds' presence in our plants (red arrows). It is necessary start our Partial root-zone drying treatment after the occurrence of this phenological state.

3). **It is important to register the time of the irrigation (starting time and end time).**

Starting time

End time

It is necessary to register the "starting time" in which the water enter to our target furrows and the "end time" in which all the furrow have been flooded and water entrance is finished.

DE GRUYTER OPEN

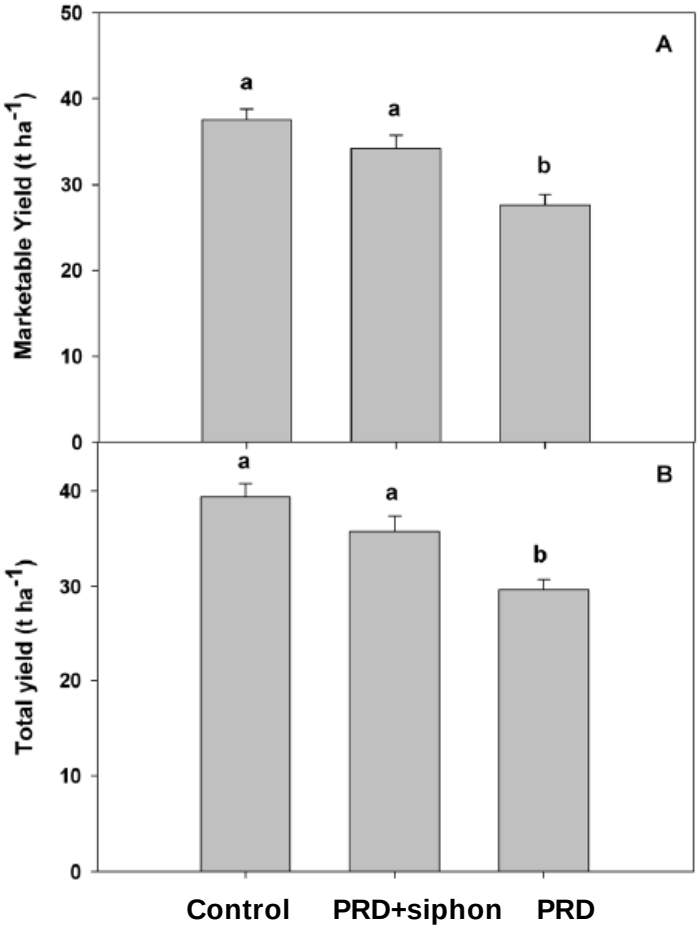
Open Agriculture. 2017; 2: 255–259

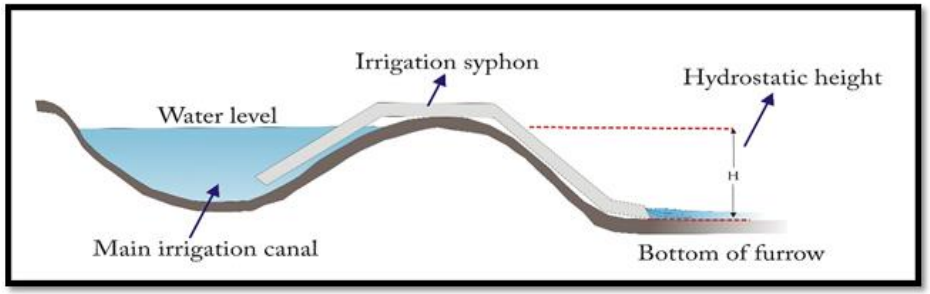
Rapid Communication

Open Access

Wendy Yactayo, David A. Ramírez*, Tigist German, Alemu Worku, Atklte Abeb, Dieudonné Harahagazwe, Victor Mares, Felipe De Mendiburu, Roberto Quiroz

Improving potato cultivation using siphons for partial root-zone drying irrigation: A case study in the Blue Nile river basin, Ethiopia





4. EFFECTIVE USE OF WATER

Water Use Efficiency (WUE) Definitions in Potato

$$WUE = \frac{Y}{X}$$

Y → Photosynthesis, Tuber yield, Shoot biomass

X → Stomatal conductance, transpiration, evapotranspiration, amount of irrigated + rained water

Table 1
Range of values and kinds of water use efficiency (WUE) assessed at different scales in potato.

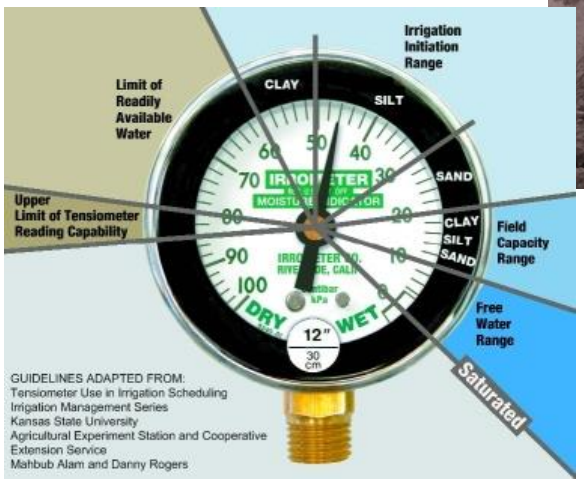
Scale	WUE type	Calculation	Range	Authors	Country
Leaves	Intrinsic WUE	A/g_s (mmol mol^{-1})	9.0–38.4	[13]	Denmark
Ideal	Transpiration efficiency	A/E (μmol mol^{-1})	2.2–11.4	[14]	Denmark
			0.9–1.0	[15]	Bolivia
Individual plants	Transpiration efficiency	Y/T (kg m^{-3})	4.3–5.1	Yactayo (*pers. comm.*)	Peru
	Transpiration efficiency	Y/W (kg m^{-3})	5.4–8.0	[16]	UK
Crop	Crop or irrigation WUE	Y/W (kg m^{-3})	0.6–2.5	[17]	China
			2.2–2.6	[18]	Peru
Water Productivity	Crop or irrigation WUE	Y/ET (kg m^{-3})	1.9–5.3	[19]	Iran USA
			4.9–9.3 5.0–9.8	[20] [13,14]	Denmark
			6.0–14.0	[21]	Tunisia
			7.7–15.6	Yactayo (*pers. comm.*)	Peru
			19.6–37.8	[22]	Denmark
	Crop or irrigation WUE	SB/T (kg m^{-3})	3.6–5.5	[23]	USA

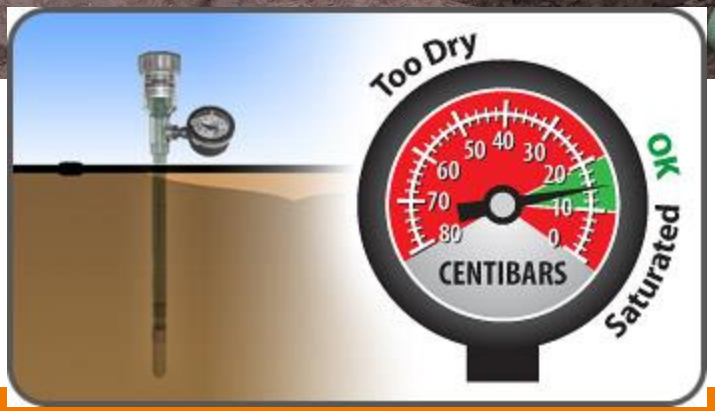
A = net photosynthesis, g_s = stomatal conductance, E = transpiration rate, T = individual transpiration, W = amount of water applied, ET = evapotranspiration or plant water used, Y = yield. SB = shoot biomass.

When irrigate? Optimization based on thresholds

I. Thresholds based on soil parameters

Tensiometers



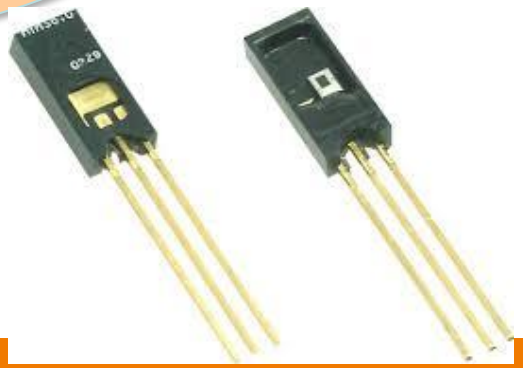


When irrigate? Optimization based on thresholds

I. Thresholds based on soil parameters

Soil Moisture Monitoring

Watermark Soil Moisture sensor (Item 6450)



When irrigate? Optimization based on thresholds

I. Thresholds based on plant parameters

Stomatal conductance as key indicator to establish water status in plants

Medrano et al. — *Regulation of Photosynthesis of C_3 Plants Under Drought*

Annals of Botany 89:895-905, 2002

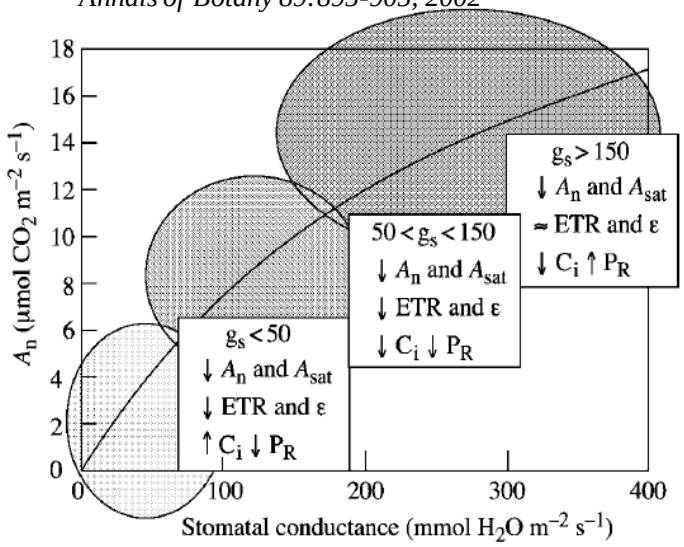
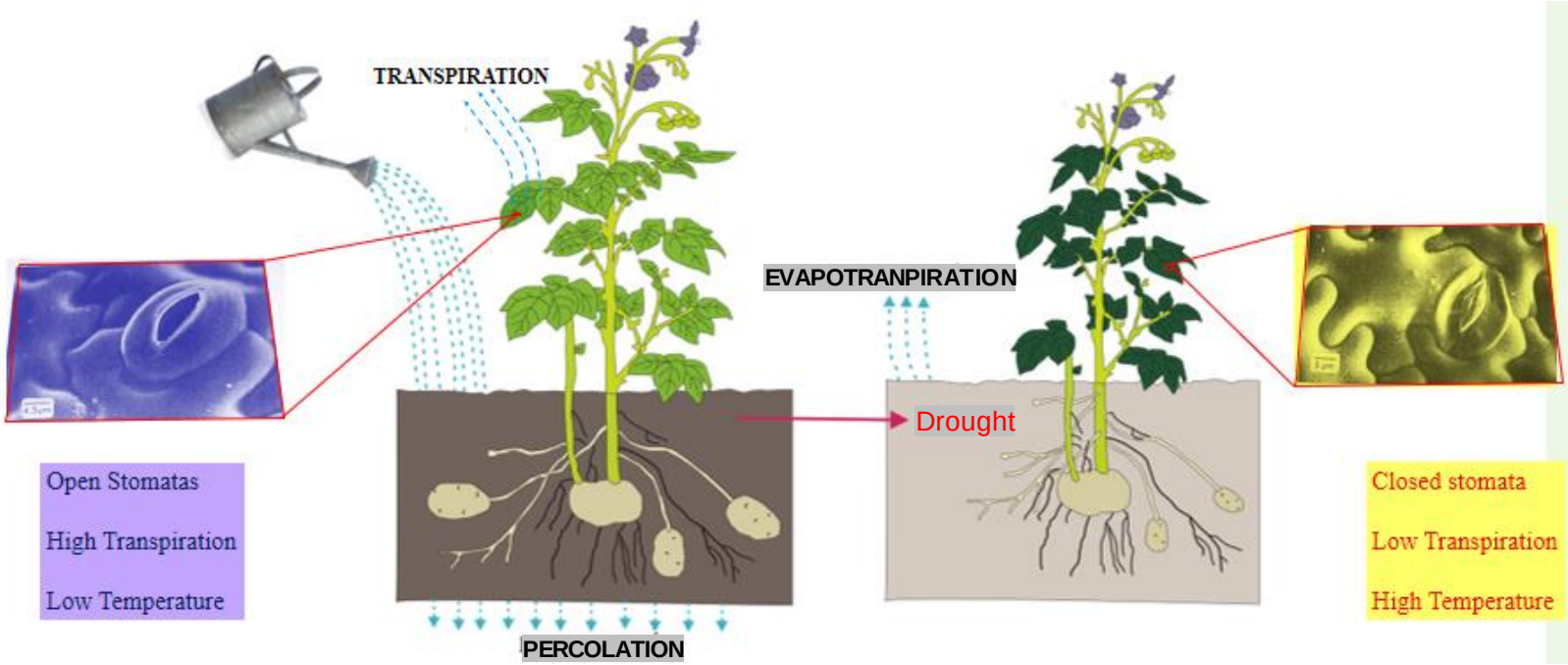
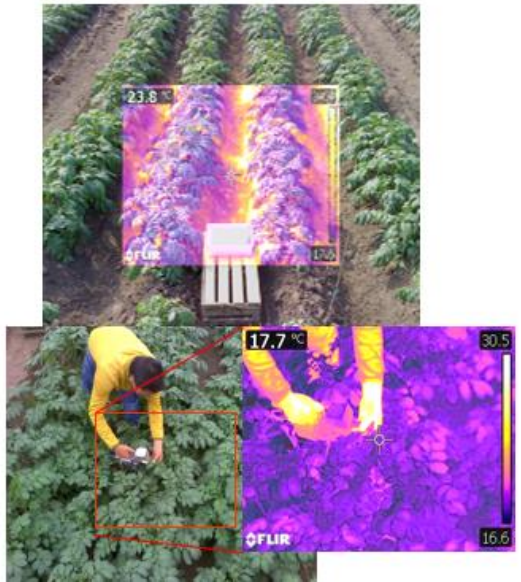


FIG. 3. Schematic pattern of response of photosynthesis in grapevines to drought, using g_s as a reference parameter. Three main regions are distinguished, and the down-regulation of different photosynthetic parameters is indicated for every region.



Stomatal Conductance

Infrared Thermography



Infrared thermal camera (FLIR- E60 Model)

Crop Water Stress Index (*CWSI*)

$$CWSI = \frac{(T_{canopy} - T_{wet})}{(T_{dry} - T_{wet})}$$

T_{wet}: *Wet temperature (humid reference surface)*

T_{dry}: *Dry temperature (+13°C of air temperature)*

Agricultural Water Management 177 (2016) 369–378

Contents lists available at ScienceDirect

Agricultural Water Management

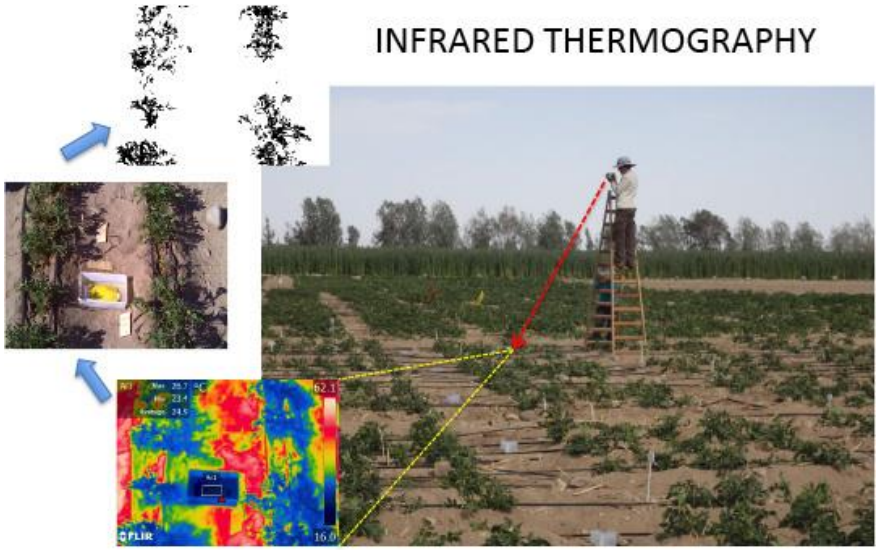
journal homepage: www.elsevier.com/locate/agwat

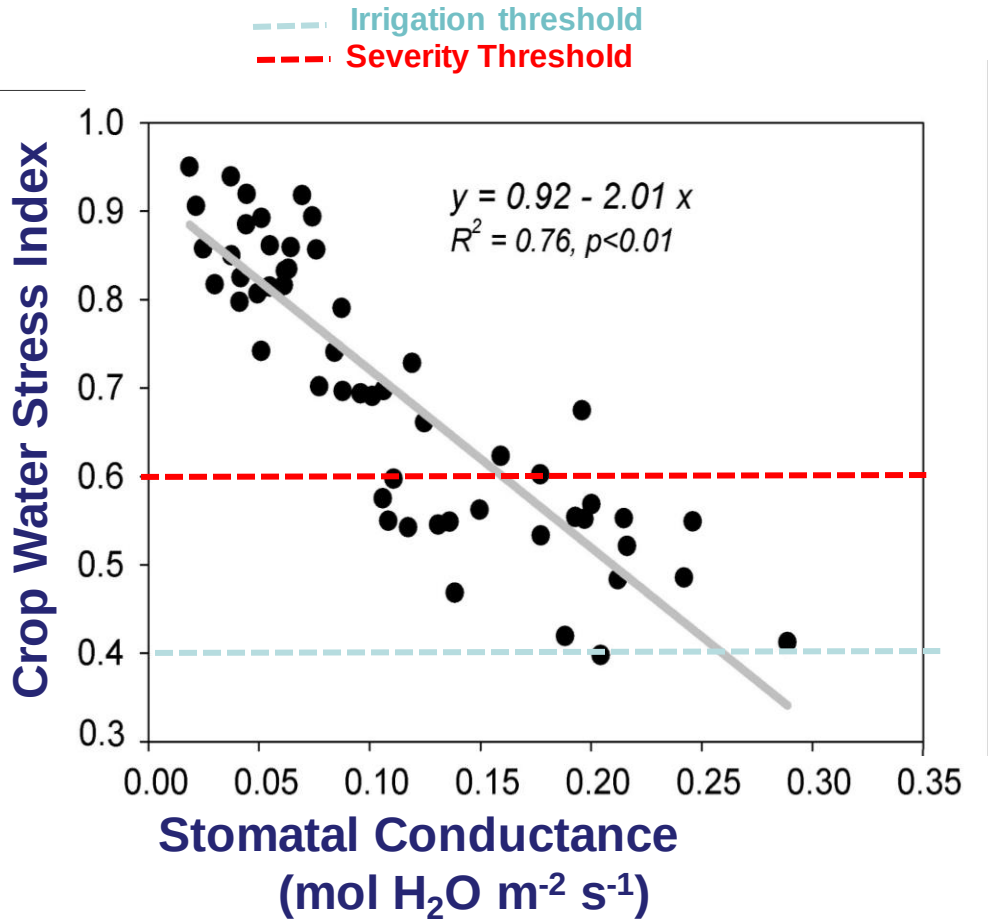
Early Stress Detection for Irrigation Purposes

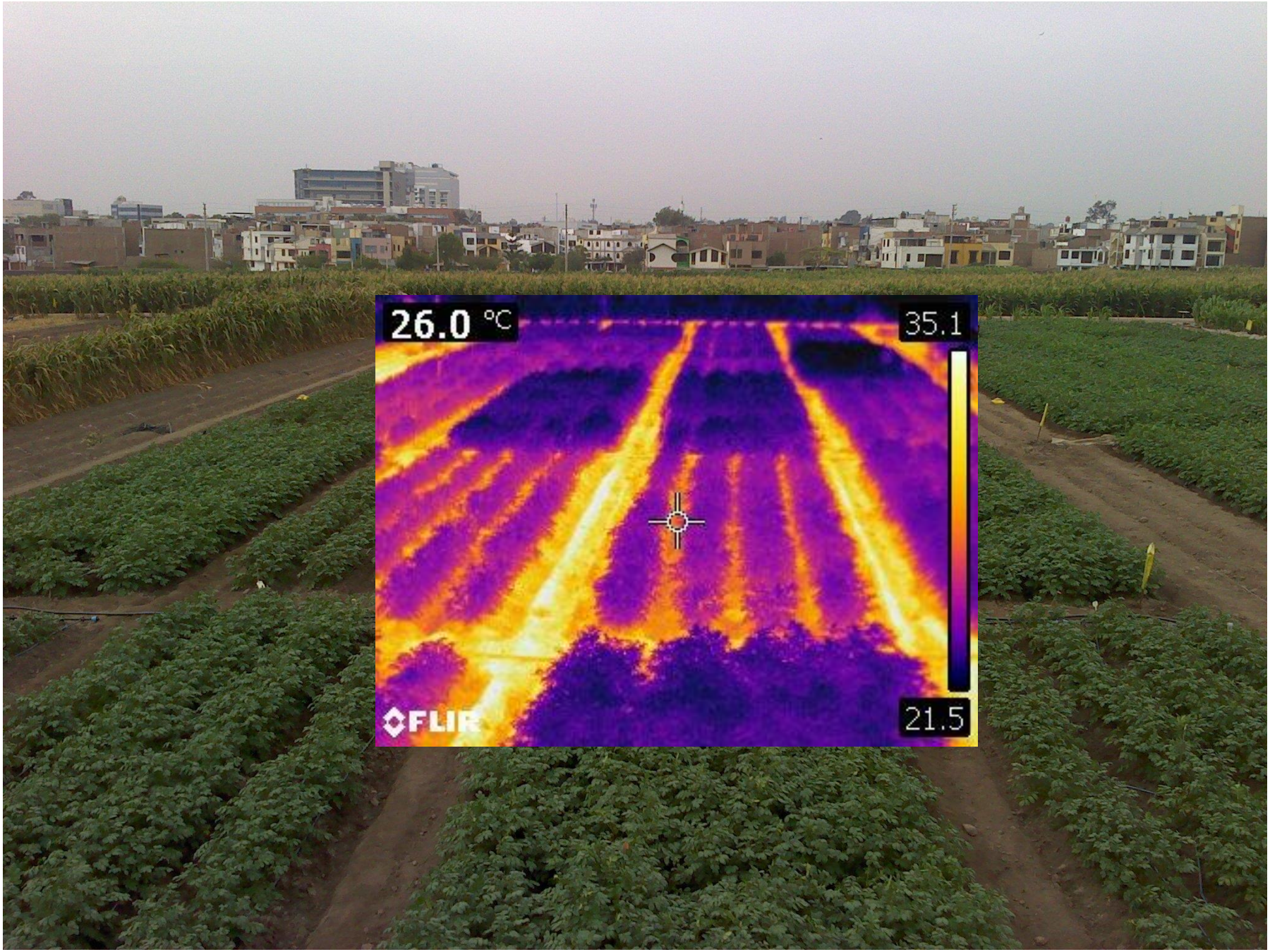
Defining biological thresholds associated to plant water status for monitoring water restriction effects: Stomatal conductance and photosynthesis recovery as key indicators in potato

David A. Ramírez[a,b,*], Wendy Yactayo[a], Libby R. Rens[c], José L. Rolando[a], Susan Palacios[a], Felipe De Mendiburu[a,b], Víctor Mares[a], Carolina Barreda[a], Hildo Loayza[a], Philippe Monneveux[a], Lincoln Zotarelli[c], Awais Khan[a], Roberto Quiroz[a]

[a] International Potato Centre (CIP), P.O. Box 1558, Lima 12, Peru
[b] Universidad Nacional Agraria La Molina, Av. La Molina s/n, Lima, Peru
[c] Horticultural Science Department, University of Florida, 241 Fifield Hall, Gainesville, FL 32611, USA

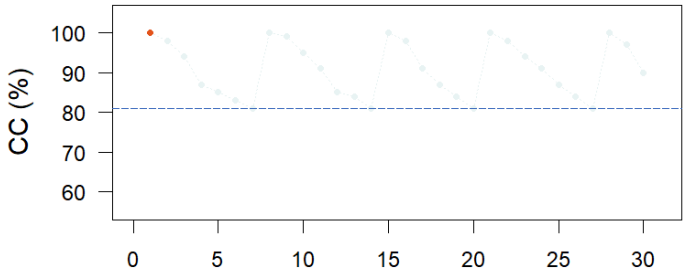





26.0 °C
35.1
21.5
FLIR

Water restriction treatments

Treatment 1 (T1)

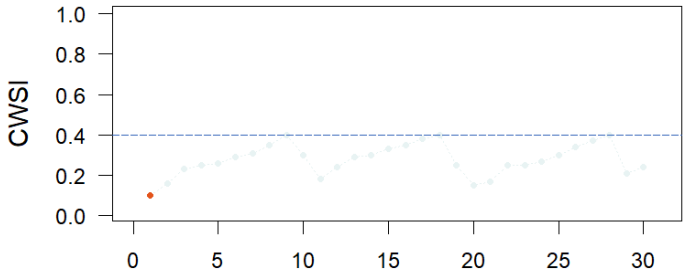


Control (CWSI ≈ 0.30-0.35)

Field Capacity (CC)

Irrigation timing: ≈ 4 days

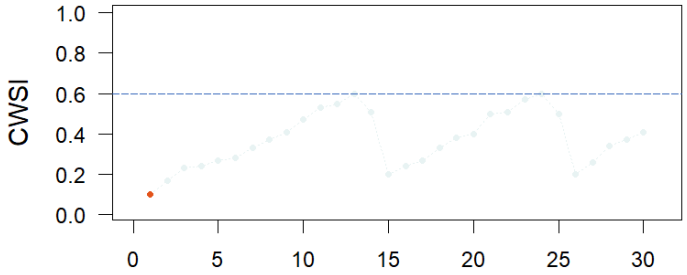
Treatment 2 (T2)



CWSI = 0.4

Irrigation timing : ≈ 6 days

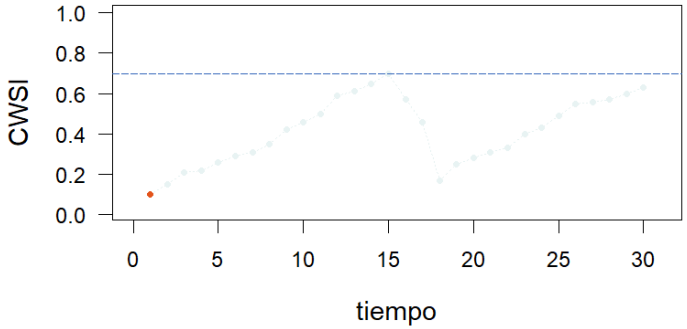
Treatment 3 (T3)



CWSI = 0.6

Two irrigations

Treatment 4 (T4)



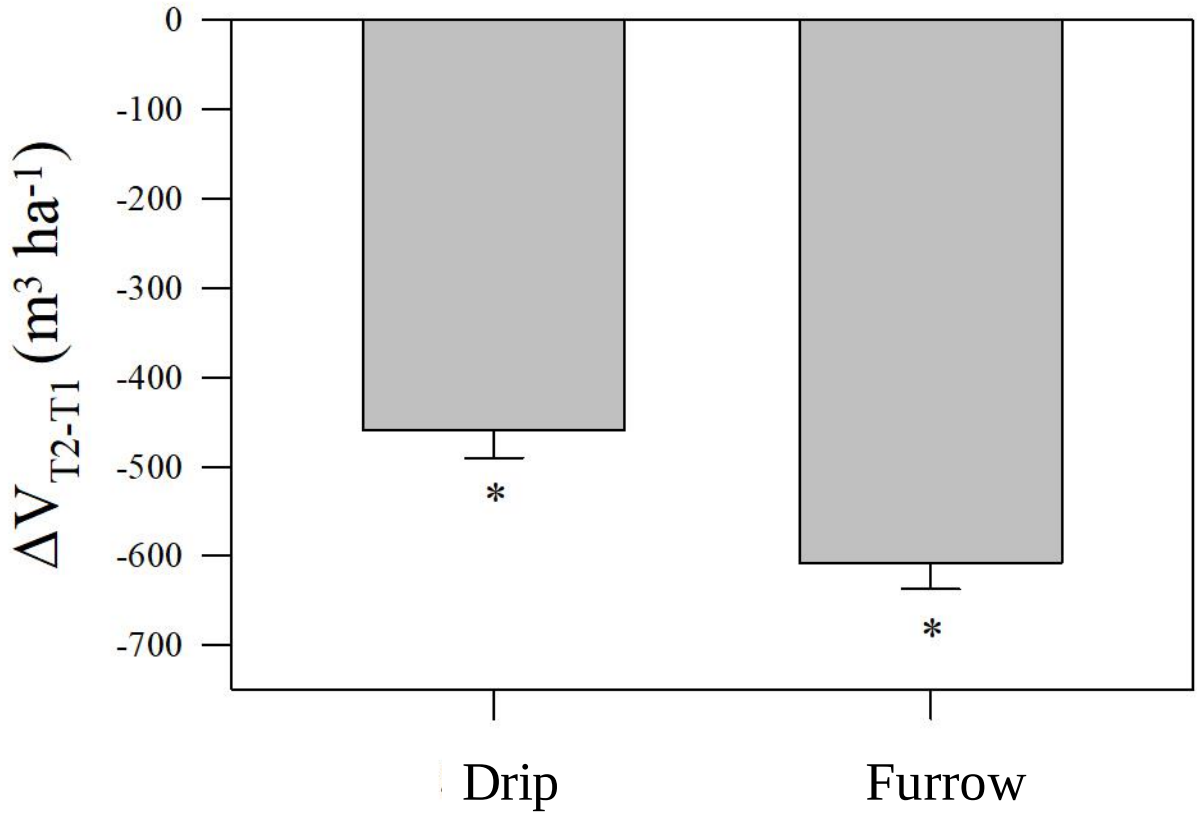
CWSI = 0.7

One irrigation

Furrow Irrigation

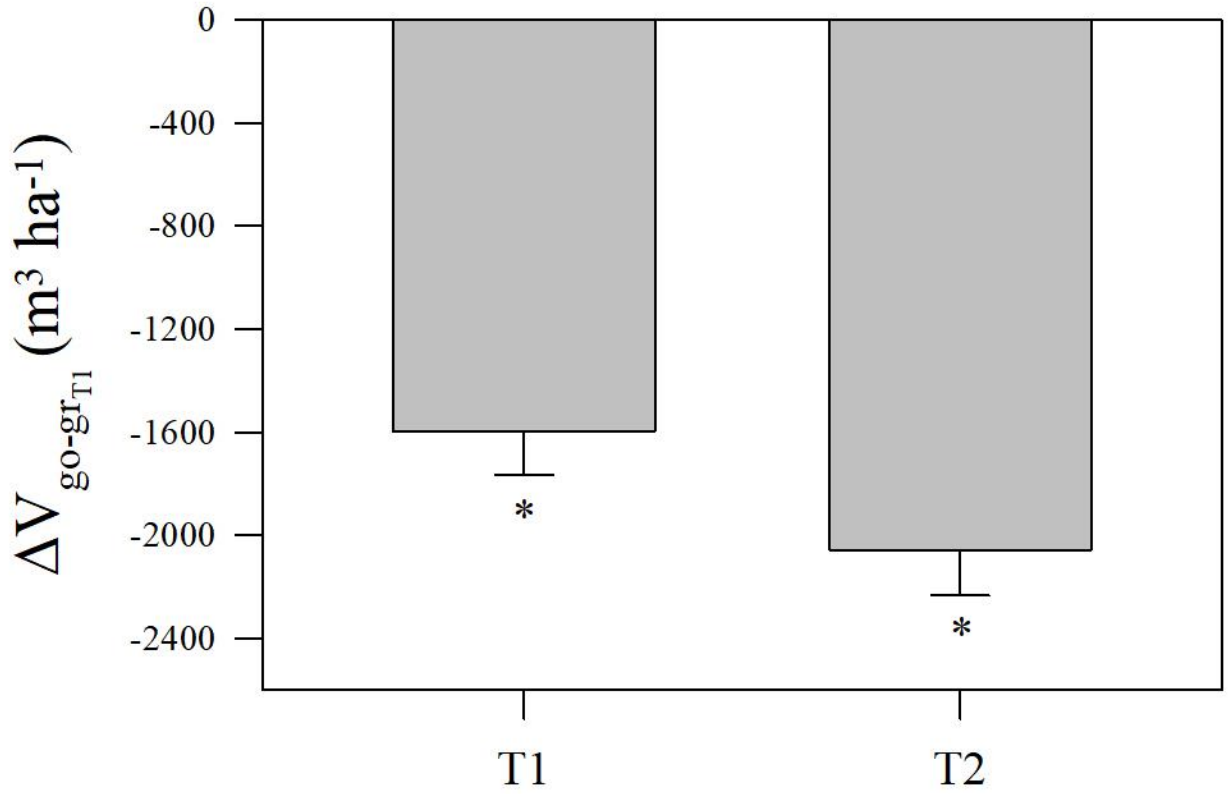
Drip Irrigation

How much water could we save using CWSI < 0.4 (T2)?



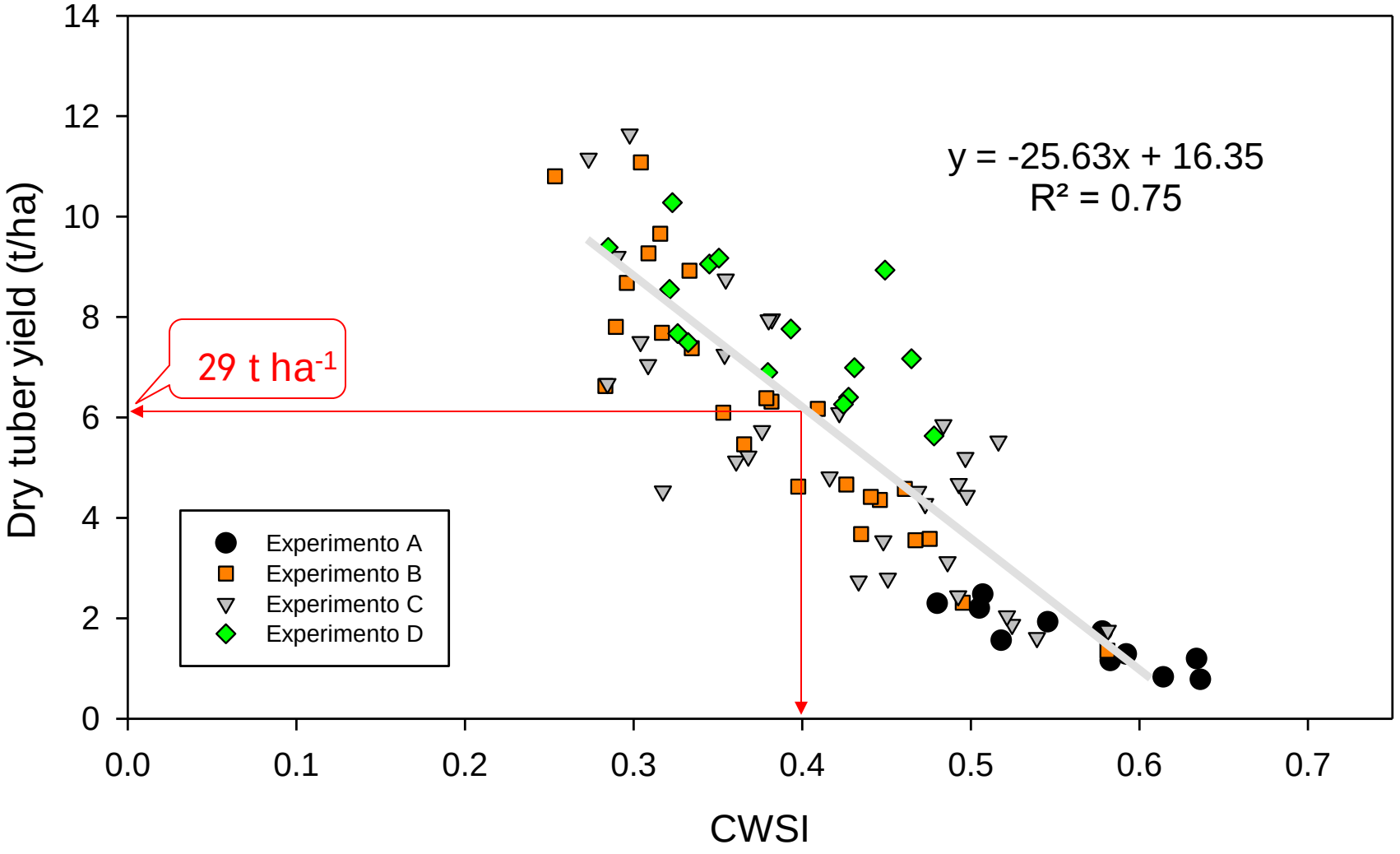
ΔV_{T2-T1}: Water amount difference between CWSI <0.4 (T2) and control (T1)

How much water could we save using CWSI < 0.4 (T2) under drip irrigation comparing to conventional furrow irrigation?



$\Delta V_{go\text{-}gr\ T1}$: Water amount difference between drip irrigation (under control –T1 or using CWSI <0.4 – T2) and normal furrow irrigation

Threshold values for Crop Water Stress Index (CWSI)



Precision Irrigation

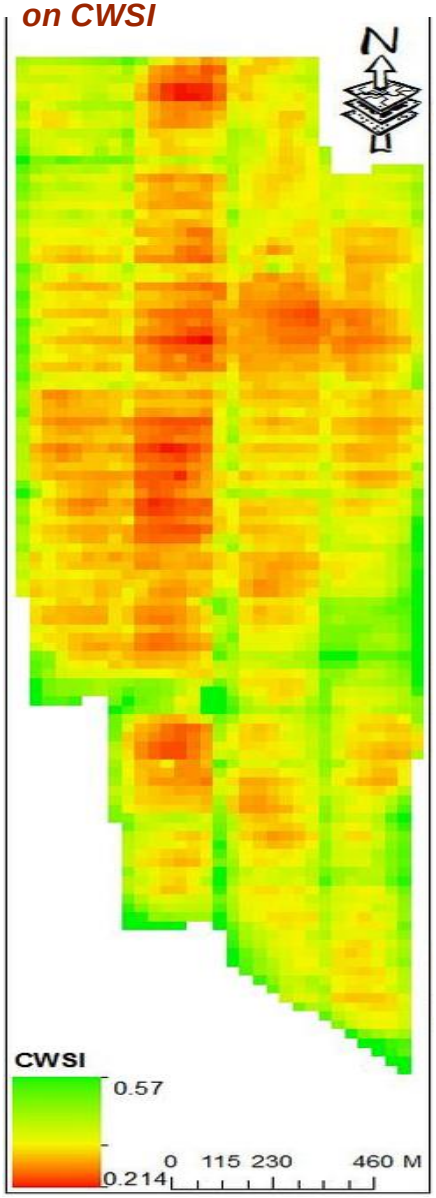
Low-cost technology to help improve crop yield prediction

TIPCIP Android APP

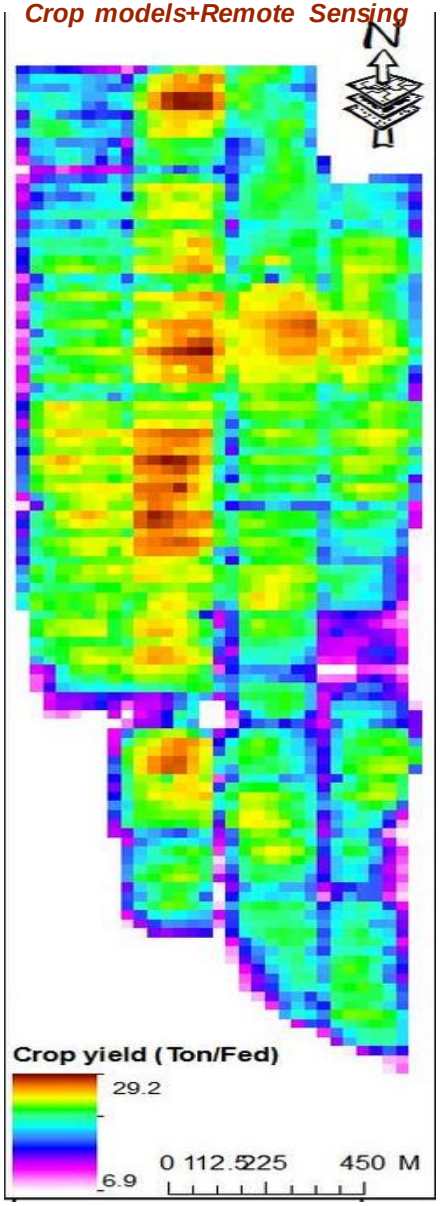
Thermal Camera FLIR ONE - USB

Foliage temperature sensors

Water stress maps based on CWSI



Yiel prediction– Crop models+Remote Sensing



6. FINAL REMARKS

- There is a global water crisis that encourages us to optimize water use, specially in agriculture.
- Irrigation based on crop water demand can help to save water.
- Water demand is assessed via evapotranspiration calculation or soil water moisture measurement. Based on that, it is possible to recommend the time for irrigation.
- Water management through PRD saves 50% of the water used conventionally.
- PRD must be initiated after tuber initiation onset to guarantee appropriate yield.
- Thresholds can help us optimize irrigation schedules to conserve water and don't reduce tuber yield.
- Thermal cameras in potatoes save ~450 and ~600 m^3 of water under drip and furrow irrigation.

USAID leads international development and humanitarian efforts to save lives, reduce poverty, strengthen democratic governance and help people progress beyond assistance. USAID leads international development and humanitarian efforts to save lives, reduce poverty, strengthen democratic governance and help people progress beyond assistance.

CIP is a research-for-development organization with a focus on potato, sweetpotato and Andean roots and tubers. It delivers innovative science-based solutions to enhance access to affordable nutritious food, foster inclusive sustainable business and employment growth, and drive the climate resilience of root and tuber agri-food systems. Headquartered in Lima, Peru, CIP has a research presence in more than 20 countries in Africa, Asia and Latin America. www.cipotato.org

CIP is a CGIAR research center, a global research partnership for a food-secure future. CGIAR science and innovation seeks to advance the transformation of food, land, and water systems in a climate crisis. Its research is carried out by 15 CGIAR centers in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector. www.cgiar.org

CIP thanks all donors and organizations that globally support its work through their contributions to the CGIAR Trust Fund:www.cgiar.org/funders

© May 2022. This publication is copyrighted by the International Potato Center (CIP). It is licensed for use under the Creative Commons Attribution 4.0 International License