UNCERTAINTIES AND MISCONCEPTIONS AS HIDDEN THREATS TOWARDS SUSTAINABLE IRRIGATION WATER MANAGEMENT

Graziano Ghinassi [1], Anna Dalla Marta [1], Leonardo Verdi [1] & Carmelo Maucieri [2]

(1) Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, Italy; (2) Department of Agronomy, Food, Natural Resources, Animals and Environment (DAFNAE), University of Padua, Legnaro, Padua, Italy.

KEY POINTS:

REWATERING project, Deficit irrigation, misconceptions

1 HOW IRRIGATION IS CURRENTLY PRACTICED

In the common practices, irrigation is carried out to achieve high to maximum crop yields without explicit assessment of the crop net irrigation water requirement (NIWR). In addition, farmers are not aware of the performance (i.e., precipitation rate, distribution uniformity, wetted fraction of the soil surface) of the systems they use to supply irrigation water (*Dichio et al.,* 2020). Actual applications, also called gross irrigation water requirement (GIWR), generally lead to over-irrigation with unavoidable loss of water and energy and possible harmful effects on the environment as a consequence. Improving the irrigation water use efficiency (IWUE) is required for ensuring long-term sustainability of irrigated agriculture (*Pereira et al.*, 2009). Major effort has been devoted to developing reliable tools for estimating crop water requirements, CWR (CWR= crop evapotranspiration, ETc) and NIWR (*Allen et al.*, 1998; *Steduto et al.*, 2012). Advisory services and remote sensing technologies provide timely information for optimal irrigation scheduling. These tools are generally based on simplifications of the processes that control water dynamics in the soil-plant-atmosphere continuum, as well as the plant response to meteorological conditions, nutrient availability, water quality and availability, and other potential sources of plant stress. Results provided are good estimates of CWR under optimal conditions, but they do not consider the crop responses to environmental stresses, which play an increasingly critical role under climate change (*Di Stasio et al.*, 2020; *Giorio et al.*, 2020). In order to overcome the forementioned limitations, the Rewatering project (Rp) was submitted and then financed as a PRIN in 2021.

2 THE REWATERING PROJECT

The Rp aims to create a reference databank of remote imagery and field data for processing tomato and soybean cultivated in representative pedoclimatic locations in Italy, reassess the CWR, develop new tools to assimilate remotely derived crop data into operational forecasting systems of the CWR, NIWR, and crop yield under different conditions. These objectives are expected to be achieved through activities such as recalibrate current procedures to assess CWR at the farm and territorial levels, refine Kc values for Mediterranean conditions under current climate and with modern cultivars, evaluate crop water use under stress conditions induced by deficit irrigation (DI), integrate advanced monitoring and modelling tools that better predict CWR in current and foreseen climatic scenarios. The activities envisaged by the Rp make use of techniques and tools already available. Therefore, given the paramount role of irrigation for the success of the project, particular attention was paid to design the irrigation systems, plan and carry out the irrigation events taking into account the characteristics of chosen method (i.e., drip and sprinkler) and treatments under investigation (i.e., full and deficit), quantify the needs and monitor the soil moisture. To support the project activity, a bibliographic review was carried out on the state of the art of soybean DI (*Morbidini et al.*, 2023).

3 DEFICIT IRRIGATION ON SOYBEAN

DI is a promising strategy (*Fereres & Soriano*, 2007; *Chen et al.*, 2023) defined as irrigation water amount less than 100% of the full CWR (DI= % < 100 of ETc). Suboptimal applications have proven to be effective to achieve the goals of modern irrigated agriculture, which includes the increase of IWUE, a condition to meet the FAO policy oriented to maximize the water productivity, WP, according to the motto *more crop per drop*. The higher the productivity, the lower the unitary impact on the climate and the environment, in accordance with the SDGs and the farmer's expectations. DI field trails are carried out in two sites located in Tuscany and

Veneto. Planned activity includes the assessment of the CWR through the season according to FAO procedure (ETc = ETo Kc), the monitoring of soil water content along a given soil profile, full and deficit applications using annual driplines. In support of the Rp, a literature review on DI of soybean was carried out in order to identify the impact of different DI strategies on grain yield, WUE, oil and protein content in seeds. Attention was paid to articles providing outputs similar to Rp, focusing on the methodologies used in trails and on the operational details provided. For the above, a huge part of the available bibliography showed critical issues regarding the way the tests were carried out. In particular, lexicon not shared can lead to confusions that may escape even the reviewers of high impact Journals.

4 COMMON UNCERTAINTIES AND MISCONCEPTIONS

Recent approaches on water management focus on saving water and improving IWUE and WP, sustainability, salinity control, remote sensing applications to estimate ETc, soil moisture, crop yield and land cover using models as water management tools (Ragab, 2024). The application of the concepts does not always match the intention. Examples of misunderstanding and misconceptions include, among the others, incorrect application of DI, IWUE used in place of WP, misunderstanding the water accounting system elements.

4.1. CWR and DI

Many publications on deficit irrigation provide yields at different percentages of full irrigation requirements, similar to or equal to the yield obtained when 100% is applied. These findings should prompt the question of whether DI actually causes a deficit or is simply the supplying of actual needs. If the latter option is true, then the CWR has been overestimated. CWR can be determined by equations based on meteorological data, soil measurements, plant measurements, lysimeters, direct and indirect measurements of the evaporation flux. Normally, CWR estimated from equations is different (higher) compared to CWR measured. Deviation can be large enough to explain why deficit irrigation even at 50% of full CWR can give the yield expected in full irrigation. One of the reasons can be found in the structure of Penman-Monteith (PM) equation, since in addition to weather data it takes into account stomata/canopy surface resistance to calculate CWR. The canopy resistance (CR) is a plant parameter difficult to get. The FAO and the International Commission on Irrigation and Drainage (ICID) yielded a simplified PM equation by assuming CR, rs, equal to 70 s m^{-1} as the average seasonal value for crops (*Ragab*, 2024). This simplification led to the modified PM, FAO-56 (*Allen et al.*, 1998). Studies carried out by several authors in different sites (*Han et al.*, 2022; *Lin et al.*, 2020; *Maruyama & Kuwagata*, 2008; *Zheng et al.,* 2022) report diurnal and seasonal variation in stomatal conductance depending on the plant type. Observed rs values were higher than that used in the modified PM equation (Figure 1a). Flux measurements through eddy covariance were carried out on different plant types (*Hsieh et al.*, 2023). Results showed that also for grassland CR varied during the day from larger values in the morning to lowest from noon to late afternoon (approximately 220 sm^{-1} and 150 sm^{-1} respectively, with an average of 163.36 sm^{-1}). Therefore, the assumption of a constant value of CR of 70 sm^{-1} cannot approximate the diurnal and seasonal variation of the CR. *Paço et al.*, 2006; *Ragab et al.*, 2017a, b using modern technologies (i.e., eddy covariance, scintillometry, cosmic ray) found that the FAO 56 PM equation overestimates actual ETo and ETc up to more than 50% (Figure 1b). The true DI represents a fraction or a % of actual ET reliably measured or calibrated against measurements.

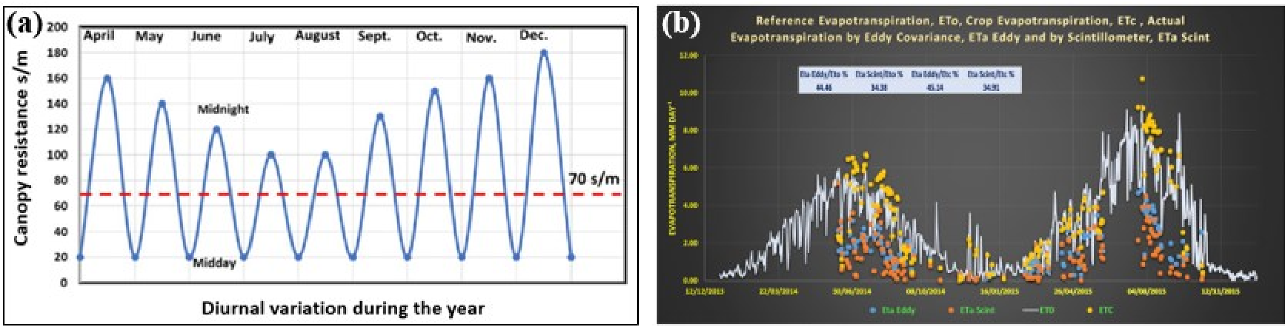

Figure 1. Panel (a) illustrates diurnal and seasonal variation of canopy resistance in the northern hemisphere (from: Ragab, 2024, modif.), panel (b) shows ETa measured (actual evapotranspiration, without use of Kc) through eddy covariance and scintillometry, indicating a rather relevant PM overestimation (about 50%) both for ETo and ETc (from: Ragab et al., 2017a).

Kashyap & Panda (2001) compared ETo calculated by using different procedures with the ETo obtained from lysimeters and found calculated ETo be higher than measured. Moreover, they also reported potato crop Kc measured values be lower than those suggested by FAO (*Allen et al.*, 1998). Therefore, estimated potato CWR was higher than measured CWR. *Amayreh & Al-Abed* (2005) reached the same conclusions on tomato by estimating ETc using eddy covariance and then calculating Kc as ETc ETo ratio obtained by modified FAO PM (*Allen et al.*, 1998). The Kc were 36% lower on average than those suggested by FAO.

4.2. Soil water status

Sensors used in the field measure the soil water content or potential. In addition to the limitation represented by the punctual information provided, sensors based upon the same principle (e.g., dielectric method) can provide different output values under the same working conditions. *Campbell et al.* (2022) carried out field tests on moisture probes using a calibration method derived from *Dane & Topp* (2002) and *Kizito et al.* (2008). They found no sensor performs within the manufacturer's published accuracy specification for all soil types and ECe. Results are reported in Table 1. A lower RMSE indicates a more accurate estimate of soil moisture. In spite most sensors provide good water content measurements in the field, soil specific calibration can improve the accuracy. Critical issues may occur when measuring in high shrink/swell clays.

Sensor	All Soil Types/ECe	Natural Soil Types	Natural Sand (all ECe)	Sandy Loam (all ECe)	Silt Loam (all ECe)	HB Clay (all ECe)
Hydra Probe	8.0	8.1	2.2	4.2	6.7	13.8
SM 100	8.6	4.7	3.7	14.4	4.7	8.4
SMEC 300	11.6	7.7	4.4	16.4	8.5	14.1
TDR-315	5.1	4.9	3.1	4.6	3.7	8.1
TEROS 12	4.0	3.6	2.4	3.2	3.1	6.4
Theta Probe	5.4	5.2	3.2	5.5	5.0	7.3
Wet-2	6.6	7.8	2.4	5.1	5.5	10.7

RMSE < 5% 5% < RMSE < 10% RMSE > 10%

Table 1. Root mean square error (RMSE) in percent volumetric water content (VWC) for each sensor for various soil type and electrical conductivity (EC_e) combinations (from: Campbell et al., 2022).

4.3. IWUE and WP

The efficiency of irrigation water at the field level, IWUE (dimensionless), is the ratio between the volume of irrigation water used, Vu, and the volume applied, Vp, in %. Effective rainfall has to be subtracted from Vu. Productivity refers to what you can produce from a unit of input. Input and output can have different units, as normally happens. WP in agriculture is defined as the crop yield produced per unit of water supplied, e.g., kg grains per m^3 water. Modern agriculture aims to increase yield production per unit of water used, both under rain-fed (WP) and irrigated conditions (IWP). Unlike efficiency, productivity could refer to multi-use/user benefits from water use. IWUE and WP have different meanings (*Kilemo*, 2022) and are interlinked, e.g., in order to increase the WP, the WUE needs to increase, not the other way around. Also, increase of WP follows the increase of IWUE and other efficiencies such as weed control, fertilization, pest and disease control.

4.4. Irrigation management under partial wetting of the soil surface

Water applications that do not consider the characteristics of the system in use can decrease IWUE, a frequent occurrence in micro irrigation where applications can result in dramatic excess when the GIWR to be applied is not calculated according to the wetted fraction (Wf) of the field (*Merkley & Allen*, 2004):

$$Wf = \frac{N_{ep} * a * W_s}{Cs_a Cs_b} \tag{1}$$

Where N_{ep} is the number of emitter per plant, a is the emitter spacing along the lateral, W_s is the width of the wetted strip, C_{sa} and C_{sb} are the crop spacing along and between the rows, respectively. In addition to the structure of the PM equation, incorrect use of the irrigation method can also explain yields in DI similar to those expected in full irrigation. The GIWR should be calculated as (*Capra & Scicolone*, 2016):

$$GIWR = \frac{Wf}{100} * \alpha * (\theta_{fc} - \theta_{wp}) * Z * \frac{1}{EU_d/100} \tag{2}$$

Where Wf is the wetted fraction, α is the allowed depletion fraction of the available water (0 to 1), θ_{fc} is the water content at field capacity, θ_{wp} is the water content at wilting point, Z is the active root depth, EU_d is the design emission uniformity.

5 CONCLUSIONS

All of the above is intended to draw attention to the risks associated with the incorrect use of techniques, technology and terminology currently used in research on the sustainability of agricultural water management.

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