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INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

# Working Group on Modernization and Revitalization of Irrigation Schemes (WG-M&R)

Web page: https://icid-ciid.org/inner_page/117

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# eDiscussion on Crop Water Productivity Performance Outcome of Irrigation System Modernization

**Period of discussion: 1-31 May 2023**

## Concept Note

### 1. Purpose

This Concept Note (CN) provides background information for an ICID eDiscussion and Summary Report preparation on crop water productivity concepts in irrigation modernization. The 25th International Congress on Irrigation and Drainage theme is: *tackling water scarcity in agriculture.* Its Question 65 is: *which on-farm techniques can increase water productivity?*

Compared to potential values, the present productivity of water consumed (CWP), by global cereal crops, varies from low to very low (*well established*). For example, present irrigated wheat CWP gaps vary from 0.55 kg $m^{-3}$ (25% of upper potential) to 1.40 kg $m^{-3}$ (70% of lower potential). Therefore, there is considerable potential to increase present CWP appreciably. FAO, ADB and ICID have specified similar outcome *objectives* in their definitions of irrigation modernization. In summary, these are to: *optimize irrigated agricultural system productivity and production performance*.

### 2. Basic CWP Concepts

Conceptually, CWP is deceptively simple. It is defined as actual crop yield (Ya) divided by water use. Actual crop evapotranspiration (ETa) is the fundamental water use and Ya/ETa is the basic CWP. If Ya and ETa were independent variables, CWP could be increased by either increasing Ya and/or decreasing ETa. However, Ya is dependent on ETa and “agronomy”.

Over a large range of actual crop evapotranspiration (ETa), from ETa = zero to ~ 0.85 of potential (maximum) crop evapotranspiration (ETc), both actual crop yield (Ya) and CWP (Ya/ETa) are positively associated with ETa. In other words, actual crop yield (Ya) and CWP (Ya/ETa) can be increased by increasing ETa up to the limit of ETa ~ 0.85ETc. When ETa exceeds this limit, crop yield continues to increase, but CWP decreases. This important but counterintuitive concept is referred to herein as the CWP *Paradox* (Box 1, Figure 1).

Colin Steley (c3steley@icloud.com) and Ian W Makin, March 2023

***Box 1: Crop - water productivity paradox***

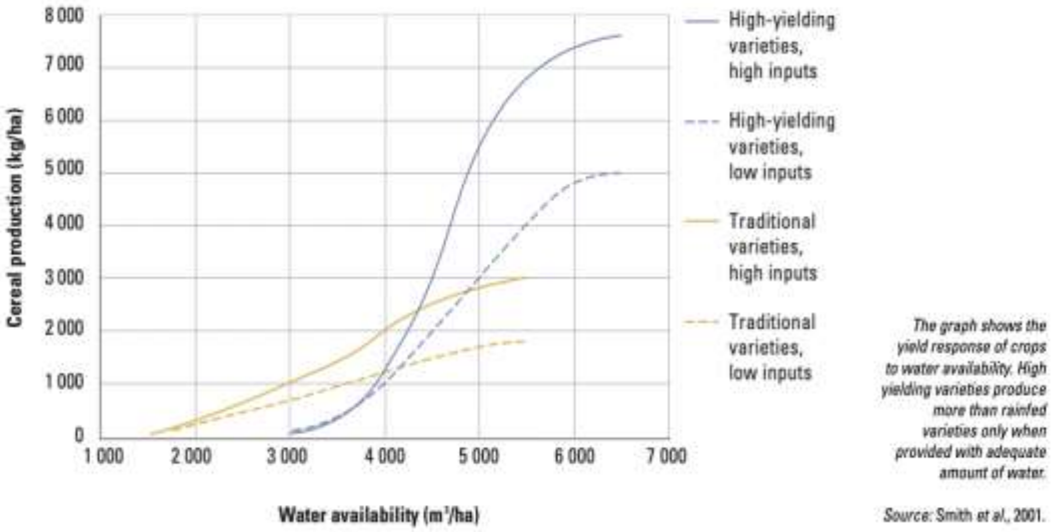
| |
|---|
| For a given climate (ETo) and crop (ETc), agronomy and ETa are the only independent variables that determine the Ya dependent variable. Increasing ETa: (i) increases Ya but (ii) depending on the ETa/ETc ratio and crop-water production function, may either decrease or increase CWP (Ya/ETa). |

Figure 1 plots actual cereal yield (Ya) against available soil water (ASW). [1] As ASW is an indicator of ETa, Figure 1 illustrates the CWP *Paradox* (Box 1). Figure 1 also plots crop (Ya) – water (ASW) production functions, for high and low agronomic inputs, and indicates that:

i. At ASW = 3,000 m$^3$ ha$^{-1}$ (ETa ~ 0.45ETc), there is no appreciable difference between Ya and CWP (Ya/ETa) with either high or low agronomic inputs. Therefore, high agronomic inputs are ineffective. Ya and CWP (Ya/ETa) can be increased by <u>increasing</u> ETa <u>only</u> and <u>not</u> by improving low agronomic inputs;

ii. Presumably, there is an ETa threshold, for example at ASW = 4,500 m$^3$ ha$^{-1}$ (ETa ~ 0.70ET) above which the increased yield ($\Delta$Ya) pays for the incremental cost of improving agricultural inputs from low to high. Ya and CWP can then be increased by <u>both</u> <u>increasing</u> ETa <u>and</u> improving agronomic inputs from low to high.

***Figure 1: Typical cereal responses to water*** [2, 3]




Crop water consumption (ETa) cannot exceed the total (effective rainfall and irrigation) water supply (TWS is the limiting resource). The productivity of TWS is a function of the productivity of water consumed (Ya/ETa) and the conventional irrigation efficiency (Annex A). Therefore, rather than improving CWP (Ya/ETa) <u>instead</u> of irrigation efficiency, improving CWP of TWS withdrawn requires improving <u>both</u> irrigation efficiency <u>and</u> the basic CWP (Ya/ETa).

[1] Available soil water (ASW) cannot exceed the soil water storage (SWS) capacity, where:
SWS capacity is defined as field capacity (FC) minus wilting point (WP). By definition, when ASW is less than allowable depletion (AD), actual crop evapotranspiration (ETa) and yield (Ya) are reduced.

[2] World Bank GWSP. 2023. *The Impacts of Irrigation: A Review of Published Evidence*, https://documents1.worldbank.org/curated/en/099514502242320808/pdf/IDU073231b050f334041090b9b003eb2ee76fdb8.pdf.

[3] FAO. 2003. *Agriculture, Food and Water*, https://www.fao.org/3/Y4683E/y4683e.pdf.

## 3. Empirical CWP Evidence

Some authors recently advocated moving *beyond more crop per drop*. [4] This implies that, the CWP concepts (Section 2) are well understood, widely disseminated and fully operational.

Of the six irrigation system CWP case studies reviewed, only one explicitly recognized and applied the CWP *Paradox*. Four other CWP case studies were indifferent (neither explicitly rejected nor accepted the CWP *Paradox*). By asserting that, *because CWP is a ratio of above ground biomass production (AGBP)* (or Ya) *over ETa, areas with low AGBP and low ETa will have a high CWP and vice versa*, the sixth CWP case study: (i) wrongly assumed that Ya and ETa are independent variables (Ya is dependent on ETa) and (ii) explicitly rejected the CWP *Paradox* (Table 1).

However, each of the six CWP case studies presents different positive circumstantial evidence that supports the basic CWP concepts and *Paradox* described herein. None presented any negative evidence to contradict the CWP concepts. This consistency (Table 1) confirms the CWP *Paradox* (Section 2). In summary, the review of the six case studies confirms that:

i. The sizeable crop water productivity (CWP) literature does not provide a complete operational overview of basic CWP concepts, particularly the CWP *Paradox*;

ii. None of six typical "CWP" case studies present complete and conclusive evidence, positive or negative, that basic CWP concepts are *empirically well established* or not;

iii. This indicates that, basic CWP concepts are not sufficiently well understood, widely disseminated and systemically applied in practice. Therefore:

iv. The basic CWP concepts are an *Opaque Spot* in the sizable CWP literature;

However, six typical "CWP" case studies consistently indicate that, in most irrigation systems, Ya and basic CWP (Ya/ETa) could be increased appreciably by <u>increasing</u> ETa (Table 1).

## 4. Irrigation System Modernization

In conclusion, we argue that economic cropping system productivity of total water supply per irrigable area should be the default *outcome* of irrigation system modernization (ISM) projects. However, *if you don't know where you're going, you're unlikely to get there.* Therefore, the eDiscussion will: (i) explain basic CWP concepts, (ii) review the empirical evidence, in the six "CWP" case studies, and (iii) consider their irrigation system modernization (ISM) implications.

Evidently, to achieve the proposed ISM project CWP performance *outcome*, optimum ETa (ETa ~ 0.85ETc) should be the generic annual irrigation water management (IWM) *strategy*, but what *solutions* and *outputs* are required to operationalize this *strategy*? [5] The eDiscussion will provide relevant insights to the proposed ISM project CWP *outcome* and ICID Question 65: *which* (main irrigation system and) *on-farm techniques can increase water productivity?* An irrigation system performance assessment and diagnosis (PAD) framework is in Figure 2.

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[4] Crop water productivity, productivity of water withdrawn, delivered or consumed, *more crop with less water*, *more crop per drop* and *more cash per splash* are virtually synonymous (collectively CWP).

[5] FAO. 2012. *Crop Yield Response to Water, Irrigation and Drainage Paper 66,* indicates that most crops are more water consumption-sensitive during critical (yield-susceptible) growth stages (when peak ETa demand usually occurs as well). This requires crop growth stage *solutions* and *outputs*. https://www.fao.org/3/i2800e/i2800e.pdf.

*Table 1: CWP coverages of six typical case studies*

| Complete CWP Case Study Coverage | Typical "CWP" Case Study Contents | | | | | |
|---|---|---|---|---|---|---|
| | **CISP** | **ACI** | **GIW** | **KOIS** | **KPIS** | **CIS** |
| Sources | 6, 7, 8 | 9 | 10, 11 | 12, 13, 14 | 15 | 16 |
| CWP Paradox recognized | Ind | Ind | Ind | Ind | No | Yes |
| Potential (maximum) Yc values | No | [17] | Yes | [17] | [17] | RNP |
| Potential (maximum) ETc values | No | [17] | Yes | [17] | [17] | Yes |
| Multiple present Ya data | Av | [17] | Yes | [17] | [17] | RNP |
| Multiple present ETa data | Av | [17] | Yes | [17] | [17] | Yes |
| Present Ya gaps and potential increases | Yes | [17] | Yes | [17] | [17] | RNP |
| Present ETa gaps and potential increases | Yes | [17] | PPI | [17] | [17] | Yes |
| Crop – water production functions (CWPF) | PPI | [17] | Yes | [17] | [17] | RNP |
| Potential to increase Ya by increasing ETa | PPI | [17] | PPI | [17] | [17] | RNP |
| CWP of TWS and irrigation efficiencies | No | [17] | No | [17] | [17] | Yes |
| Confirms basic CWP concepts? | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

Legend: ACI = Australian Cotton Industry, Av = average irrigation system CWP values, CIS = Chubek IS, CISP = comparative IS performance, GIW = global irrigated wheat, Ind = indifferent (neither explicitly recognized nor rejected), IS = irrigation system, KOIS = Kirindi Oya IS, KPIS = Kamping Pouy IS, RNP = reported but not published (but mapped and/or analysed) and PPI = plausible positive interpretation.

The Australian Cotton Industry (ACI) provides a longitudinal historical record, dating from 1960-61, of actual increases in cotton lint yield (Ya) and the productivity of water withdrawn. The ACI literature coverage, of the basic CWP concepts, is in Table 1 in Section 3.

The ACI also provides a sizable record of the actual *solutions* and *outputs*, applied to achieve this impressive continuous CWP performance improvement. This is relevant to ICID Question 65. The ACI adapted an industry-wide *collaborative* research, development and extension (RDE) *process.* This inclusive RDE *process* is relevant to both the ISM *process*, to optimize irrigation system CWP performance, and ICID sub-question 64.3 on *empowerment of farmers*.

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[6] IFPRI. 1992. *A Framework for Assessing Irrigation Performance*, https://www.ifpri.org/publication/framework-assessing-irrigation-performance.
[7] IWMI. 1998. *Indicators for Comparing Performance of Irrigated Agricultural Systems*, https://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB020/REPORT20.PDF
[8] Sakthivadivel et al. 1999. *Indicators of Land and Water Productivity in Irrigated Agriculture*, https://www.researchgate.net/publication/40192826.
[9] Cotton Australia. 2014. *Sustainability Report*, https://cottonaustralia.com.au/sustainability-reports.
[10] Sadras et al. 2006. *Benchmarking Water-use Efficiency of Rainfed Wheat in Dry Environments*, https://www.researchgate.net/publication/230626148
[11] IWMI. 2007. *Water for Food, Water for Life: Comprehensive Assessment of Water Management in Agriculture*, https://www.iwmi.cgiar.org/assessment/Publications/books.htm.
[12] IWMI. 1999. *Multiple Uses of Water in Irrigated Areas: A Case Study from Sri Lanka*, http://www.iwmi.cgiar.org/Publications/SWIM_Papers/PDFs/Swim08.pdf.
[13] Bastiaanssen and Bandara. 2001. *Evaporative Depletion Assessments for Irrigated Watersheds in Sri Lanka*, https://www.researchgate.net/publication/225573320.
[14] Bandara. 2005. *Application of Satellite Remote Sensing for Irrigation Management Practices in Sri Lanka*, https://engineer.sljol.info/articles/abstract/10.4038/engineer.v38i2.7212/.
[15] IWMI. 2020. *Remote Sensing Based Water Productivity Assessment – Kamping Pouy, Cambodia*, https://www.wateraccounting.org/files/projects/adb/phase2/IWMI_WP_Cambodia_Final_Report_PartA.pdf.
[16] ADB. 2020. *Irrigation Performance Assessment Using Satellite Remote Sensing: Insights from Tajikistan*, https://www.adb.org/publications/irrigation-satellite-remote-sensing-tajikistan.
[17] To be completed.

***Table 2: Irrigation system modernization outputs required to achieve the CWP* outcome**

| ICID Question 65 Sub–questions (SQ) | ISM *Output* to Optimize ETa (ETa ~ 0.85ETc) |
|---|---|
| SQ 65.1 Improving Management of Existing Facilities | Increase irrigation system efficiency, including field-level application efficiency, and water consumption (ETa) while maintaining or reducing water withdrawal |
| | If necessary, consider improved structures to improve system operation and water delivery performance? |
| SQ 65.2 Improved Agronomic Practices | For low ETa, high agronomic inputs are ineffective |
| | For high Ya, both high ETa and high inputs are required |
| SQ 65.3 Efficient Application of Irrigation Water | Improve irrigation application efficiency and ETa by applying the right amount of water at the right time |
| | Farmer-irrigator skill is more important than technology (precision surface, sprinkler or drip irrigation method) |

Cotton Research and Development Corporation (CRDC). 2012. *WATERpak* [18] exemplifies relevant RDE *outputs* including, but not limited to, farm planning (Section 1.1), water budgeting (accounting) (1.2) and water use efficiency (CWP) (1.2 and 1.3), metering (1.7), irrigation scheduling (2.1), crop and management decisions in limited water situations (2.2 and 3.3), plant water status measurement (2.4), cotton growth response to water stress (3.1), impact of waterlogging (3.4), selecting an irrigation system (5.1), surface irrigation performance and management (5.3) and catchment scale environmental impacts (Section 6).

## 5. eDiscussion Arrangements

To join the eDiscussion you are invited to register, before Friday 24 April 2023, at: https://www.linkedin.com/groups/9300326/

Participation will be via LinkedIn Group "ICID WG-M&R: e-Discussion on Crop Water Productivity Performance Outcome of Irrigation System Modernization".

The ICID eDiscussion will be jointly moderated and facilitated by:

Colin Steley <c3steley@icloud.com>, the originator and lead author of this CN

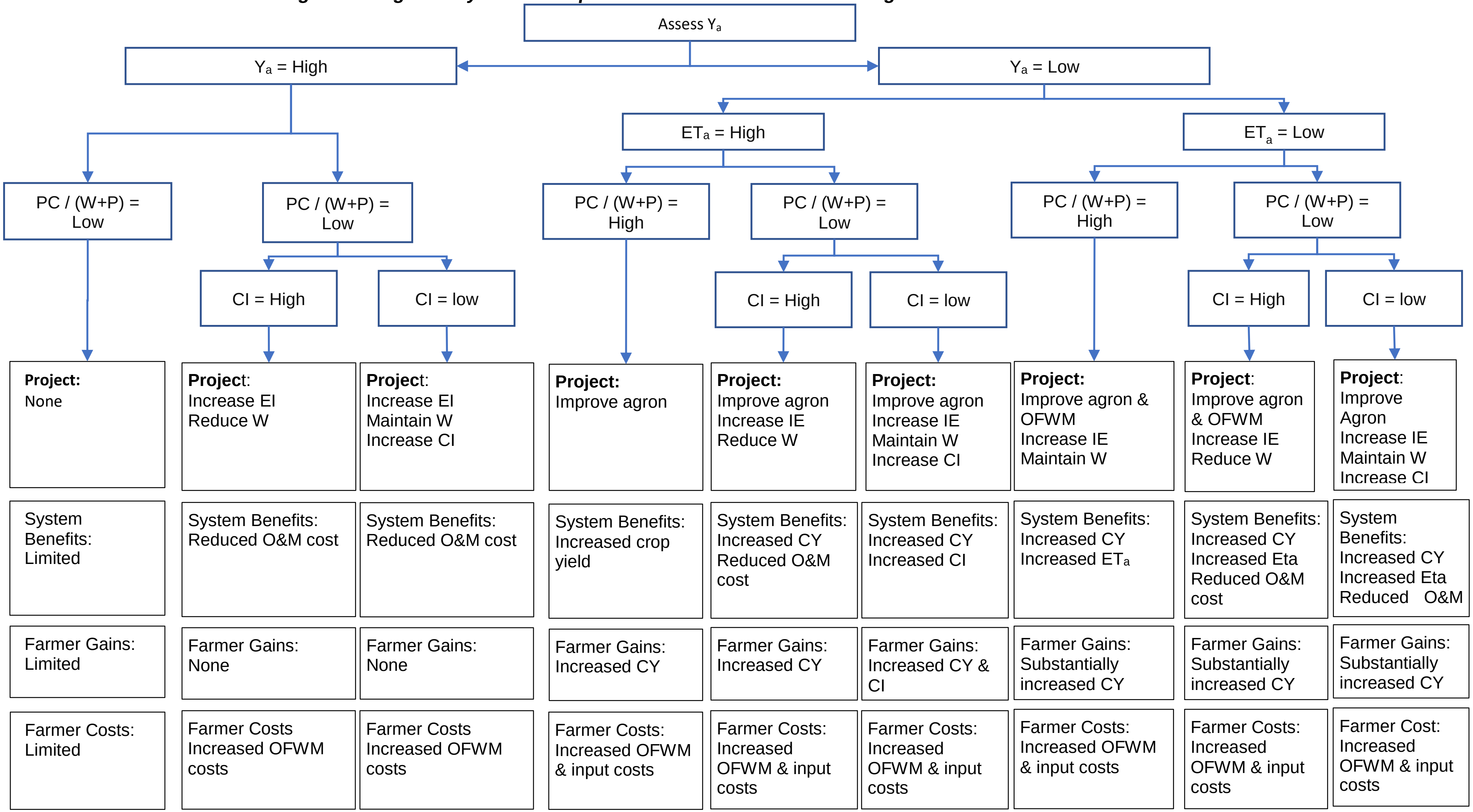
Ian Makin <ianwmakin@gmail.com>, ICID Vice President Honoraire and author of this CN

***Table 3: eDiscussion schedule***

| From | To | Topic |
|---|---|---|
| 01 May | 07 May | 2. Basic CWP Definitions |
| 08 May | 14 May | 3. Empirical CWP Evidence<br>4. Irrigation System Modernization |
| 15 May | 21 May | eDiscussion Participant Feedback |
| 22 May | 31 May | Draft Summary Report |

[18] CRDC. 2012. *WATERpak: A Guide for Irrigation Management in Cotton and Grain Farming Systems*, https://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf

*Figure 2: Irrigation system CWP performance assessment and diagnosis framework* [19]




*Notes: Agron = Agronomy, CI = cropping intensity, CY = crop yields, $Et_a$ = actual crop evapotranspiration; IE = irrigation efficiency, O&M = operations and maintenance, OFWM = on-farm water management, P = precipitation, PC = productive consumption, W = withdrawal, $Y_a$ = actual crop yields.*

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[19] The present CN authors developed Figure 2 for ADB. 2011. *Innovations for More Food with Less Water: Task 1 - Technical Assistance Report*, https://www.adb.org/projects/45072-001/main.

## Annex A: CWP and Irrigation Efficiency

Crop water consumption (ETa) cannot exceed the limiting total water supply (TWS) where: [20]

$$TWS = Re + \frac{(Iw - Re)}{e} \qquad \text{(i)}$$

Where: Re = effective rainfall
Iw = irrigation withdrawal
e = overall irrigation system efficiency

The productivity of total water consumed ($CWP_{con}$) is:

$$CWP_{con} = \frac{Ya}{ETa} \qquad \text{(ii)}$$

Where: Ya = actual crop yield
ETa = actual crop evapotranspiration

And the productivity of total water withdrawn ($CWP_{with}$) [21] is:

$$CWP_{with} = \frac{Ya}{e\,.\,Iw + Re} \qquad \text{(iii)}$$

To improve the productivity of TWS withdrawn ($CWP_{with}$) requires: (i) system operators to improve irrigation services and delivery efficiencies, and (ii) farmers to increase ETa and CWP of consumed water (Ya/ETa).

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[20] FAO. 1977. *Crop Water Requirements*, *Irrigation and Drainage Paper 24*, https://pdf4pro.com/amp/download?data_id=2ffa1b&slug=fao-irrigation-and-drainage-paper-24, assuming negligible groundwater, change in soil moisture storage and leaching requirement.

[21] Similar lower-level CWPs and their irrigation efficiencies can also be defined, for example, for irrigation water delivered to either: (i) tertiary units (by government irrigation agencies), (ii) farms (by water user associations) and/or (iii) fields (delivered to and applied by individual farmers).