Concept and application of water productivity
Introduction

- Demand for food, feed and fiber is increasing
- Fewer and fewer resources (water, land, P) are available for crop production
  - Climate change, resources degradation, fierce competition between sectors
Definition

Water productivity?

\[ WP = \frac{\text{Output}}{\text{Water consumption}} \]

- Biophysical (Biomass, grain, meat, protein)
- Economic (money)
- Jobs (employment)
- Consumptive water use (ET and I)
  - Beneficial (T), and non-beneficial consumption (E, I)
  - Green and blue water consumption

(Molden et al., 2010; Van Halsema et al., 2012)
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Definition

Green and blue water consumption

Green water consumption is evapotranspiration of the green water, which is water from precipitating that is stored in the root zone. Thus, the green water consumptions include green water that is evaporated, transpired or incorporated by plants.

Blue water consumption in irrigated agriculture is evapotranspiration of blue water, which is water sourced from surface or groundwater resources and evaporated, transpired or incorporated by plants.

Chukalla et al. (2015)
Biomass or crop yield (which is used to define Land productivity) is calculated as:

\[
NPP_{\text{max}} = R_s \cdot \varepsilon_p \cdot \varepsilon_T \cdot \varepsilon_{\text{co2}} \cdot \varepsilon_{AR}
\]

\[
NPP = NPP_{\text{max}} \cdot f\text{APAR} \cdot SM \cdot \varepsilon_{\text{LUE}} \cdot \varepsilon_{RES}
\]

\[
NPP_s = \sum_{SOS}^{EOS} NPP
\]

\[
\text{Biomass (}B\text{)} = AOT \cdot f_c \cdot \frac{NPP_s \cdot 22.222}{(1 - MC)}
\]

\[
\text{Crop yield} = HI \cdot B
\]

Where:
- \(SC\): Scaling factor from DMP to NPP [-]
- \(R_s\): Total shortwave incoming radiation [GJ/ha/day]
- \(\varepsilon_p\): Fraction of PAR [0.4 – 0.7μm] in total shortwave 0.48 [IP/IT]
- \(f\text{APAR}\): PAR-fraction absorbed (PA) by green vegetation [JPA/IP]
- \(SM\): Soil moisture stress reduction factor
- \(\varepsilon_{\text{LUE}}\): Light use efficiency (DM=Dry Matter) at optimum [kgDM/GPA]
- \(\varepsilon_T\): Normalized temperature effect [-]
- \(\varepsilon_{\text{CO2}}\): Normalized CO₂ fertilization effect [-]
- \(\varepsilon_{AR}\): Fraction kept after autotrophic respiration [-]
- \(\varepsilon_{RES}\): Fraction kept after residual effects [including soil moisture stress][-]
- \(NPP\): Net primary production [gC/m²/day]
- \(NPP_s\): Seasonal NPP [gC/m²/season]
- \(SOS\): Start of season
- \(EOS\): End of season
- \(B\): (Above-ground) biomass [ton/ha/season]
- \(AOT\): Above ground over total biomass [-]
- \(f_c\): Crop light use efficiency correction factor
- \(MC\): Moisture content of fresh biomass/crop yield [-]
- \(HI\): Harvest index [-]
**Definition**

**Satellite Methods for Estimating ET:**

Energy Balance Methods

These methods for estimating ET are grounded in the theory behind the surface energy balance model, where available energy at the surface from shortwave and longwave radiation is balanced by fluxes from surface heating (e.g., sensible heat flux) and exchange of water vapor (e.g., latent heat flux).

\[
ET_a_s = \sum^{EOS}_{SOS} ET_a
\]

\[
ET = R_n - G - H
\]

ET is calculated as a “residual” of the energy balance

\(R_n = \text{net radiation [W m}^{-2}\text{]}, \ G = \text{soil heat flux [W m}^{-2}\text{],}\)
\(H = \text{sensible heat flux}\)

ETa is actual evapotranspiration
Application

- To compare productivity of water resources across space and time (in different parts of the same system or river basin)
- To compare productivity of water in different sectors (e.g. agriculture vs other possible uses of water)
- To compare the performance of a system with others or with the same system over time
- To assess progress against strategic goals (e.g. SDG goals 6.4 – Water use and scarcity and 2.3 – Double the productivity and incomes of small-scale food producers)
- To assess impacts of interventions
- To assess the general health of a system
- To improve system operations, resource use efficiency and assist performance-oriented management
Principles of WP improvement across scales

The key principles for improving water productivity at field, farm and basin level, under rainfed or irrigated conditions, are:

(i) increase the marketable yield of the crop for each unit of water transpired;
(ii) minimize evaporation
(iii) reduce all outflows (e.g. drainage, seepage and percolation) if this water is of no use downstream or if it generates further pollution from geological salt leaching; and
(iv) increase the effective use of rainfall, stored water, and water of marginal quality (RWW, BW).
Considerations for WP improvement

Figure: Scatter plot of grain yield and seasonal evapotranspiration of rainfed wheat in 4 mega-environments. The line uses French and Schultz (1984a) frontier concept, with $x$-intercept = 60 mm (Sadras and Roget 2004) and slope = 22 kg grain/ha.mm (Angus and van Herwaarden 2001) (Sadras and Angus, 2006)

Abiotic stresses:
- temperature stress
- Water and nutrient stresses
- Aeration and salinity stresses

Biotic stresses:
- weeds,
- diseases and pests
Quiz
#1: Why is improving land and water productivity important?

a) The availability of water and land resources for agriculture are declining
b) Increasing consumption due to population
c) Increasing consumption due to economic growth
d) Soil degradation
e) all
#2: Water productivity can be improved by increasing the crop yield per unit of water evapotranspiration.

True/ False?
#3: Water productivity can be expressed as

a) Output in Kg per meter of water use
b) Output in $ per cubic meter of water use
c) Number of jobs per cubic meter of water use
d) Output in Euro per millimeter of water use
e) all
#4: Green and blue water consumption is related to evapotranspiration from groundwater and surface water, respectively.

True/ False?
#5: Estimate the green and blue water consumption

Rainfed maize in an area with shallow groundwater consumes 500 mm per season. What is the blue and green water consumption if the water consumption from effective precipitation is 220 mm and capillary water is 55 mm per crop season?

a) 280 mm & 220 mm
b) 225 mm & 55 mm
c) 225 mm & 275 mm
d) 220 mm & 55 mm
#6: Which of the following inputs is not required to estimate crop yield from seasonal maximum net primary production?

a) Harvest index
b) Moisture content of the fresh crop
c) Biotic and abiotic stress factors
d) Heat stress
e) The ratio of above ground over total biomass
#7: A farmer applied optimal amount of fertilizer and water to grow maize on her field. The farmer harvested low yield though the crop grew free of diseases and pests. What could be the factor that led to low yield/productivity?

a) Salinity stresses 
b) Aeration stress 
c) Weeds 
d) CO$_2$ concentration 
e) All except one of the above

Which one of the above is not the factor for the yield reduction?
#8: Why farmers are not commonly managing their field to increase WP?

a) They manage to make their entire enterprise profitable

b) Low economic status of the farmer to pay for a management practice or technology

c) Market and climate risks to pay back

d) all
Exercise 1

**Self paced (Lecture videos):**
- Introduction to FAO WaPOR database
- WaPOR database components
- WaPOR quality assessment
- Quiz
- **Exercise 1:** Point time series in WaPOR portal

**Data analysis and download on WaPOR portal**
- Tutorial videos on
  - Data analysis in WaPOR portal
  - Data download from WaPOR

**[Quiz] WaPOR database**
- Check your knowledge on WaPOR database

**Exercise 1**
**Exercise 1**

**Example:** Retrieve time-series evapotranspiration on selected point over agricultural area in Kirkurk area (Lat:35.378, Lon:43.747)

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*Figure 1.* Time series of decadal actual evapotranspiration and interception from 01/01/2009-31/12/2020 (left) and from 01/01/2019-31/12/2020 (right).
Exercise 1

Question:

Report the answer for the following questions based on the point (Lat:35.378, Lon:43.747) that is assumed to represent a field in Kirkurk area:

1) Repeat step 1 to 3 above for annual precipitation, reference evapotranspiration, and actual evapotranspiration layers for a period of 2009 to 2020 and explain
   a) why the annual actual evapotranspiration is varying,
   b) what are the potential reasons for the discrepancy between annual actual evapotranspiration and annual precipitation.

2) Answer the following questions assuming irrigated wheat is grown during the dry season.
   I. identify the start and end of the irrigated crop season by plotting the point timeseries of
dekadal actual evapotranspiration, transpiration, reference evapotranspiration, precipitation for the period 01/01/2009 to 30/10/2020.
   II. estimate seasonal actual evapotranspiration, crop yield, and water productivity (WP) for
irrigated wheat that is sown in 2019. Optional [estimate seasonal crop water requirement (CWR), seasonal irrigation water requirement (IR)].

Upload your answer in short report on the OCW till 12 April
Exercise 1

Equations:

- Seasonal value is the sum of values from the start of the cropping season to end of the cropping season: $seasonal\ X = \sum_{i=SOS}^{EOS} x_i$
- $Biomass = AOT \times f_c \times \frac{NPP \times 22.222}{(1-MC)}$ and, (ii) $Y = B \times HI$
- $WP = \frac{Yield}{ET}$
- $CWR = \sum_{i=SOS}^{EOS} (kc_i \times ET_0)$
- $IR = CWR - \text{effective precipitation (Pef), Pef=80\% of the precipitation}$

![Diagram of crop coefficient curve of wheat](image)

Figure 2. Crop coefficient curve of wheat