Water Use Efficiency

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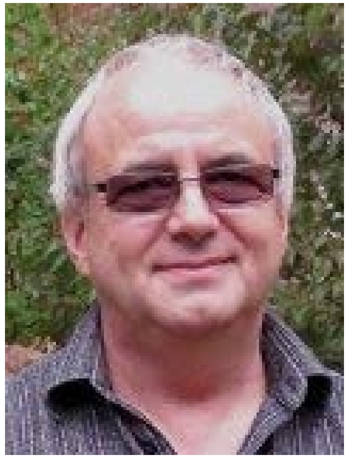
Speakers

2010-2016 - BSc and MSc – plant physiology and biochemistry
biological faculty
Saint-Petersburg State University, Russia
2014 – 2015 - MSc training – bioinformatics
2017-2021 - PhD – remote sensing of plant productivity and evaporation
ITC faculty of geoinformation science and earth observation
University of Twente, the Netherlands
2022 - Assistant professor, ITC + R&D at eLEAF

Egor Prikaziuk

eleaf FEED THE WORLD



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UNIVERSITY OF TWENTE.

ITC

What shall we talk about?

1. Leaf level processes governing WUE
2. Field (crop) scale WUE
3. Global scale (gross) WUE
4. Climate change and WUE
5. Summary
6. Exercise

Water use efficiency

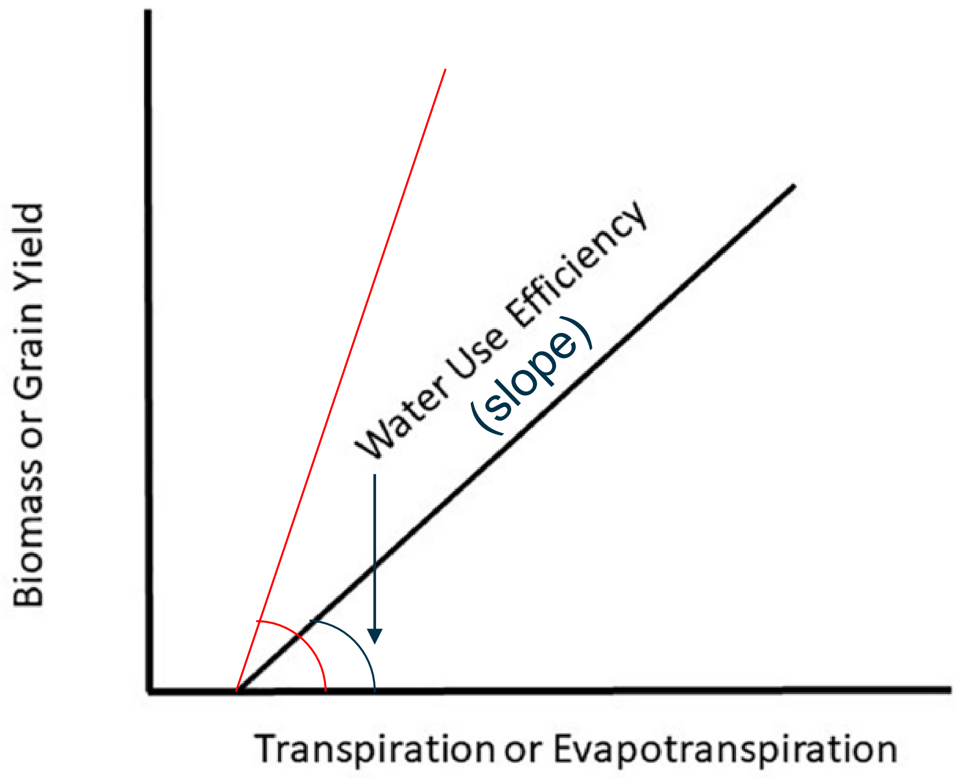


FIGURE 1 | Generalized view of water use efficiency as a function of the water use by a crop relative to biomass or grain production.

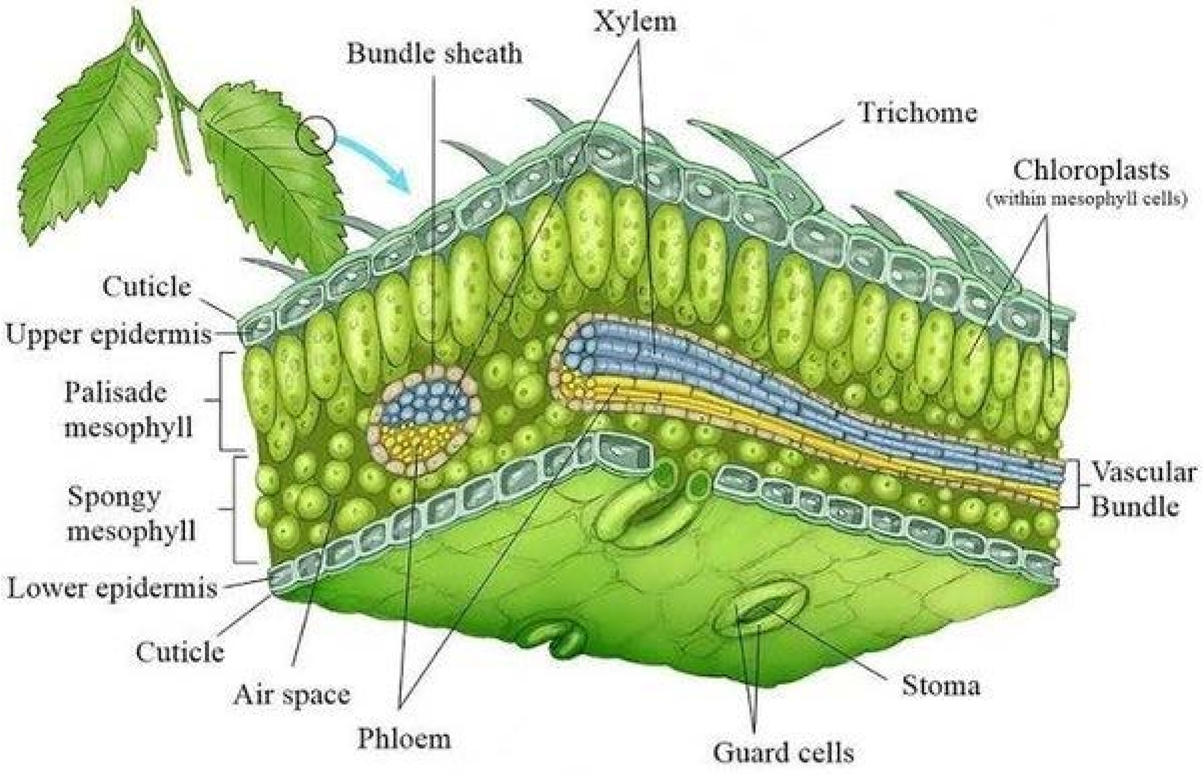
(Hartfield & Dold, 2019)

Water use efficiency (WUE) is the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop. (Hartfield & Dold, 2019)

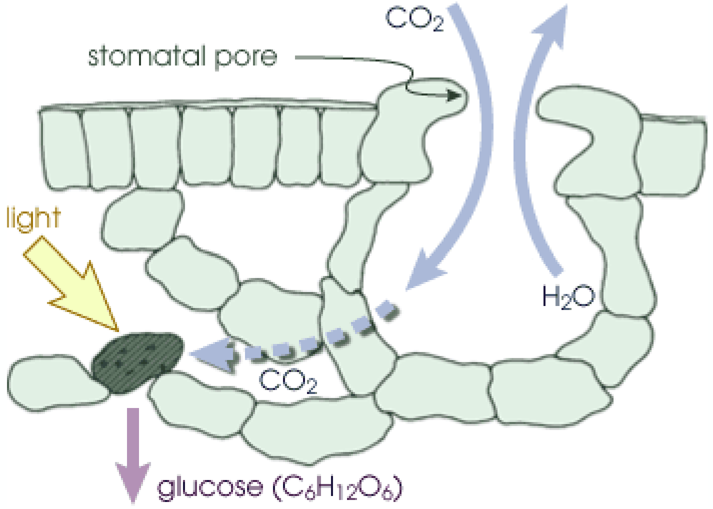
1/6 Leaf level processes governing WUE

1/6

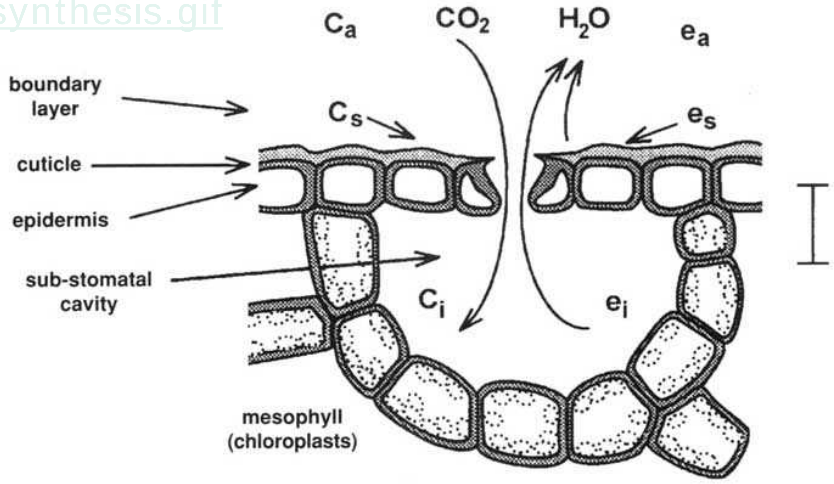
Leaf structure and gas exchange



https://qph.cf2.quoracdn.net/main-qimg-4f3ec585765cfcb3c57e7f50952a238a-lq



https://earthobservatory.nasa.gov/ContentFeature/LAI/Images/photosynthesis.gif



https://www.fao.org/3/W5183E/w5183e04.jpg

C4 plants have higher WUE

https://www.world-grain.com/ext/resources/2022/06/22/Wheat_photo-cred-Adobe-stock_E-2.jpg?t=1655908254&width=1080

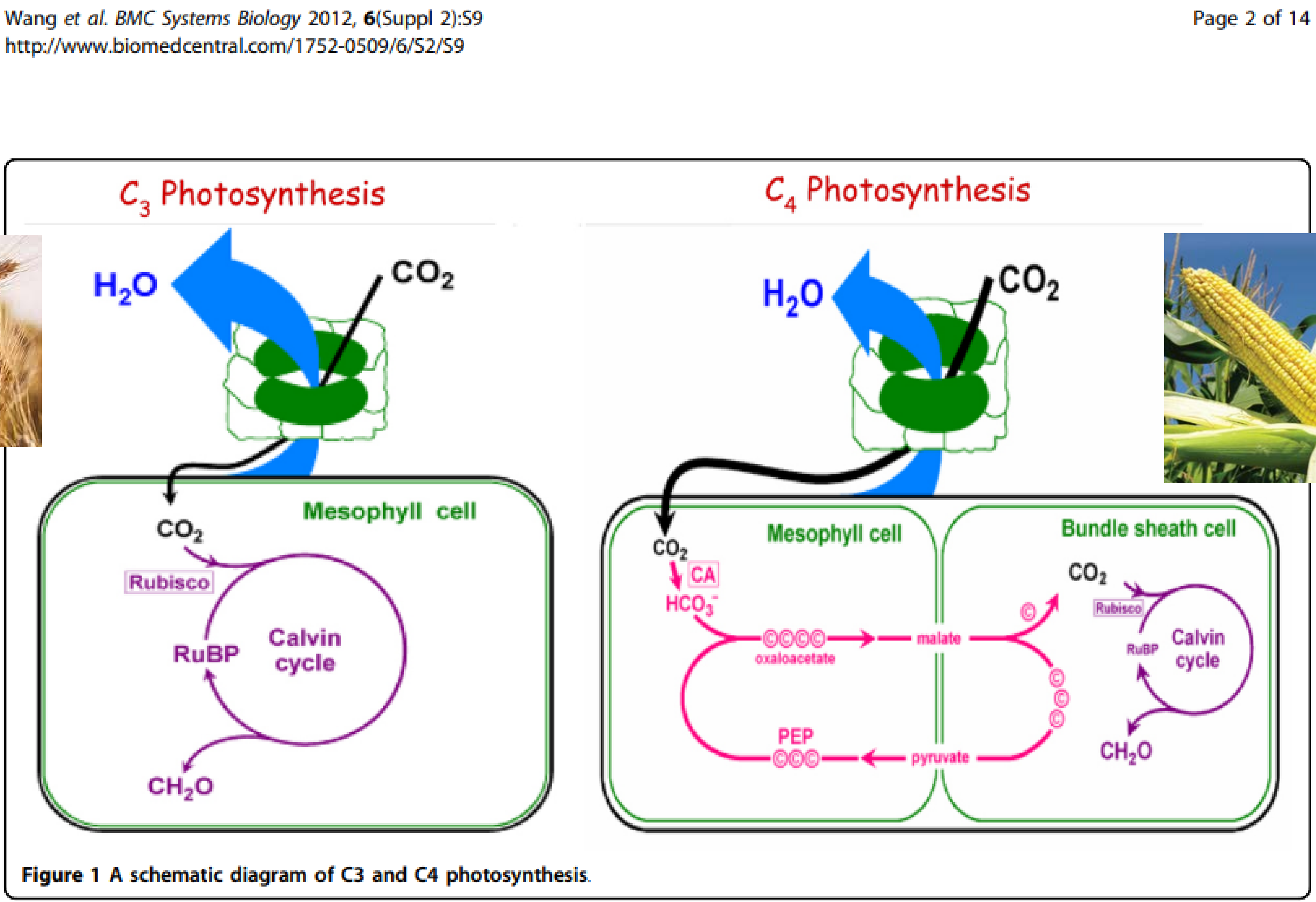


Figure 1 A schematic diagram of C3 and C4 photosynthesis.

https://cdn.britannica.com/167236-050-BF90337E/Ear-corn.jpg

Leaf measurements

https://nasatlabs.com/wp-content/uploads/2020/12/Photosynthesis-Rate-and-Chlorophyll-a-Fluorescence-Measurement.jpg

$$WUE\_instantaneous = \frac{An}{E}$$

An – CO_2 assimilation rate
[umol CO2 m-2 s-1]
E – evaporation (transpiration) rate
[mol H2O m-2 s-1]

$$WUE\_intrinsic = \frac{An}{g_s}$$

An – CO_2 assimilation rate
[umol CO2 m-2 s-1]

g_s – stomatal conductance
[mol H2O m-2 s-1 or
umol CO2 m-2 s-1]

leaf WUE (of C3 plants) in response to CO2

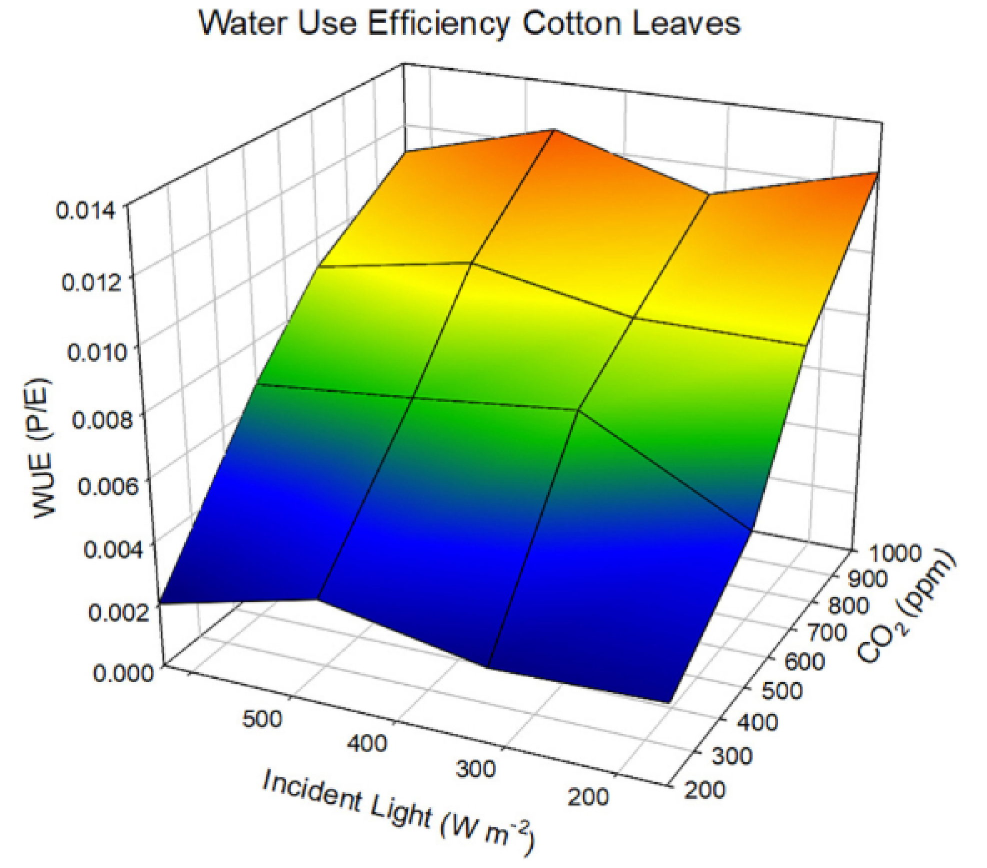
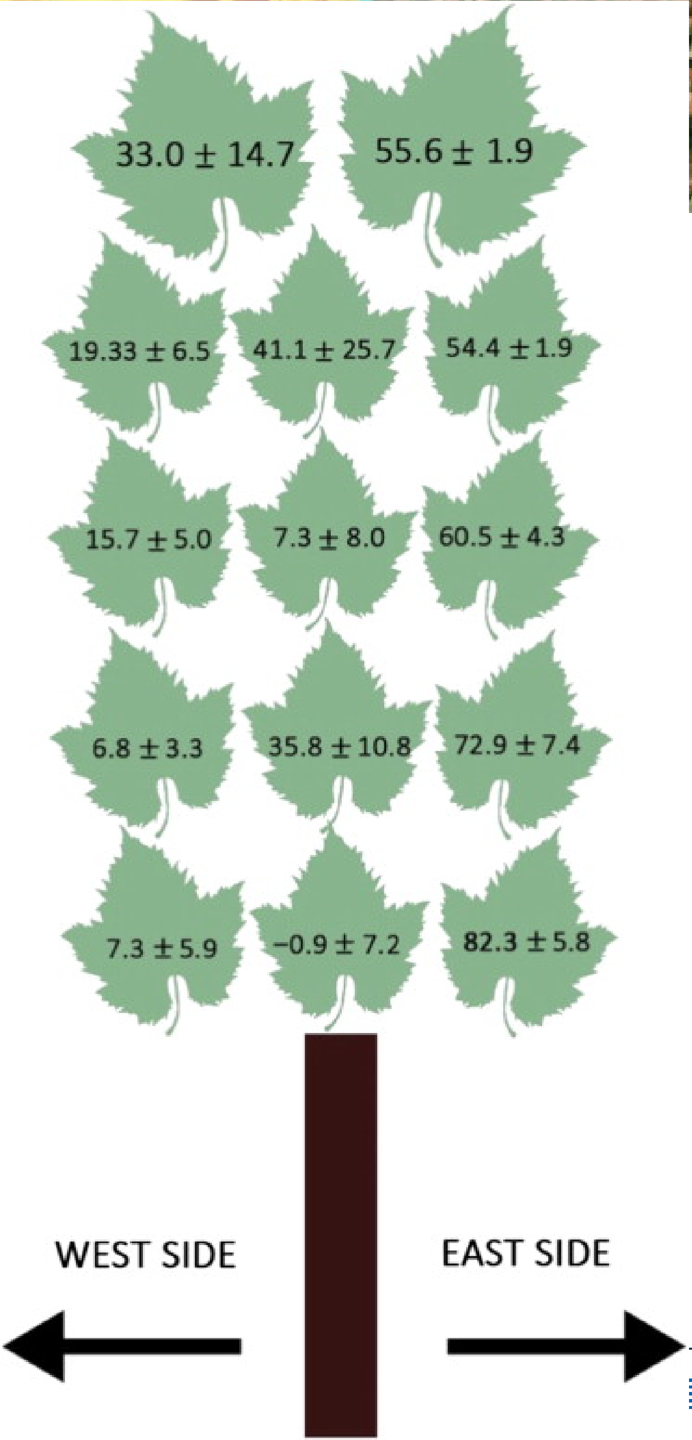
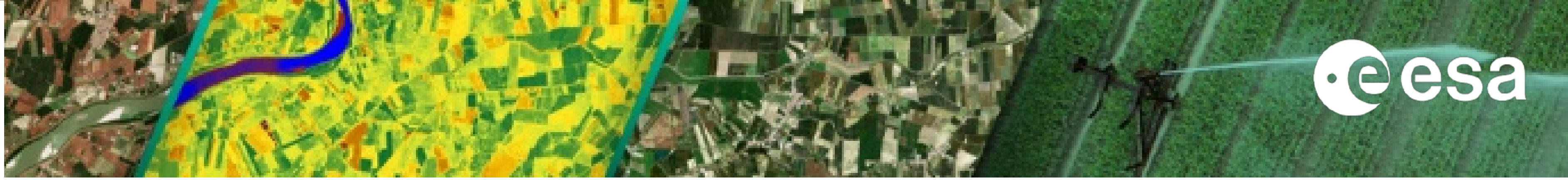


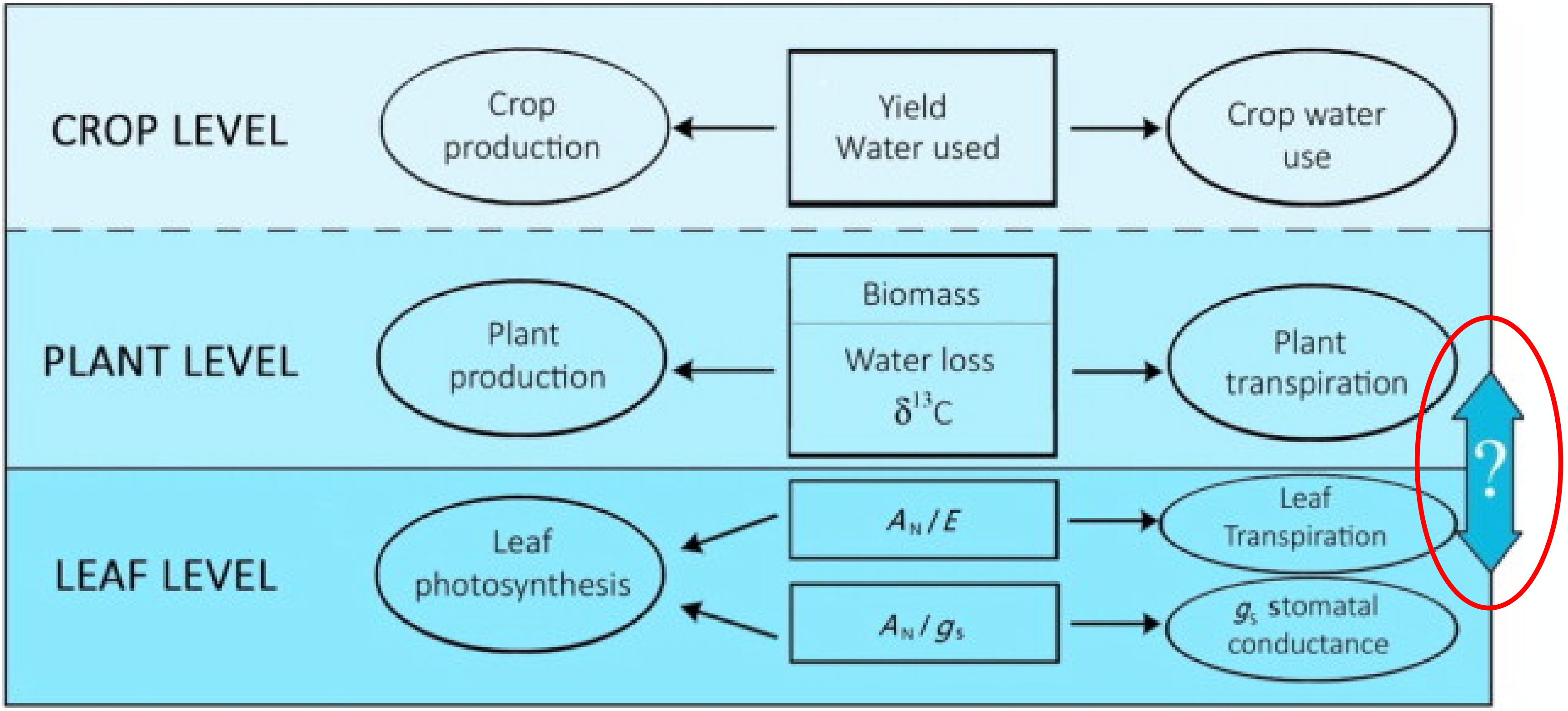
FIGURE 3 | Response of water use efficiency in cotton leaves as a function of changing CO_2 and incident light levels at a constant wind speed of 2.4 cm sec^{-1}. Data redrawn from Bierhuizen and Slatyer (1965).

(Hartfield & Dold, 2019)





MEASUREMENT LEVELS OF GRAPEVINE WATER USE EFFICIENCY



(Medrano et al., 2015)

Lessons learnt from leaf level

- leaf gas exchange through stomata:
    - CO_2 goes easily in as Ci << Ca (0.04%)
    - H_2O goes out ei > ea (0-4%)
    - single conductance, target of high WUE genotypes
- components are measured by gas exchange instruments
- instantaneous
- varies in a plant
- upscaling is questionable

2/6 Field (crop) scale WUE

Water use efficiency – Crop water productivity

Crop water productivity (CWP) is the ratio of crop yield to total actual evapotranspiration (ETa) in the growing season days in between *Start Of growing Season* (SOS) and *End Of growing Season* (EOS) (Blatchford et al., 2019, RSE)

$$CWP\ (kg\ m^{-3}) = \frac{Crop\ yield\ (kg\ ha^{-1})}{10 \times \sum_{i=SOS}^{EOS} ET_a\ (mm)}$$

this is fresh (not dry) yield

10 converts ETa from mm to $m^3\ ha^{-1}$

Plant productivity

M.L. Blatchford, et al.

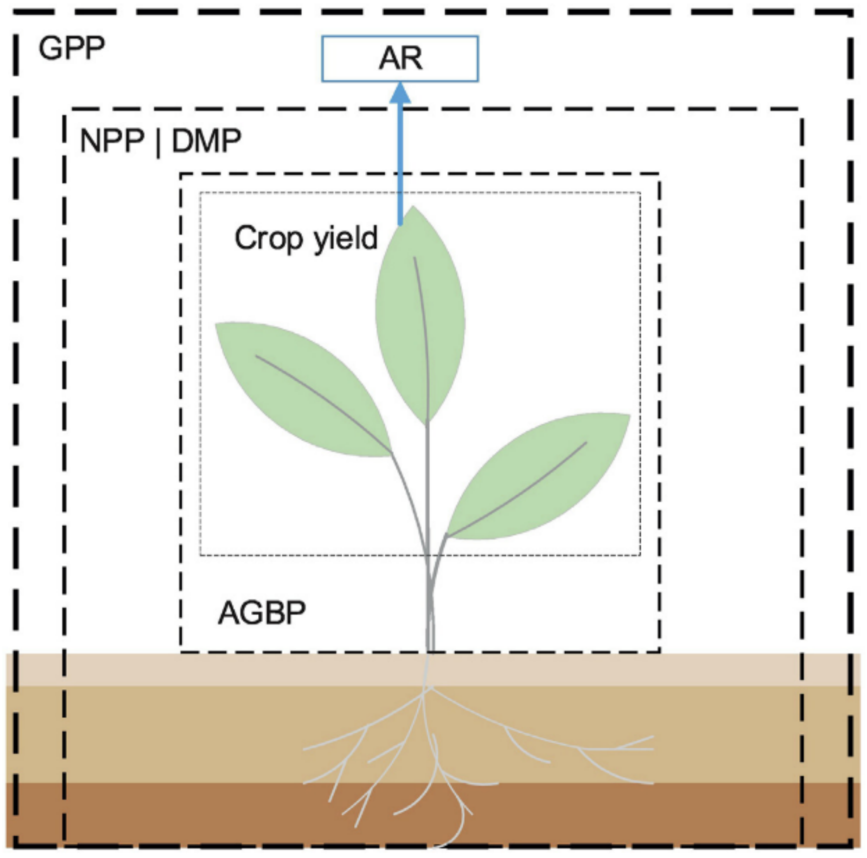


Fig. 1. Distinction between GPP, NPP, DMP, AGBP and crop yield products, where each box compares the plant parts associated with each product.

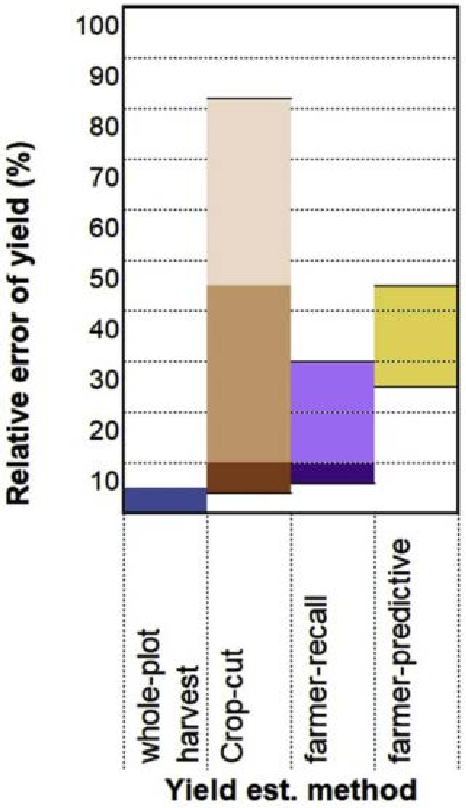
(Blatchford et al., 2019, RSE)

quantile	meaning	units
GPP	Gross primary productivity	µmol CO_2 m^{-2} s^{-1}
AR	Autotrophic (plant) respiration	µmol CO_2 m^{-2} s^{-1}
NPP (~DMP)	Net primary productivity	µmol CO_2 m^{-2} s^{-1}
DMP (~NPP)	Dry matter productivity	kg DM ha^{-1} day^{-1}
AGBP	Aboveground biomass productivity	kg DM ha^{-1} day^{-1}
Crop yield	yield	kg FW ha^{-1} $season^{-1}$

DM – dry matter – CH_2O or $C_6H_{12}O_6$
FW – fresh matter (weight)

In the exercise
- make the unit conversions
- make variable conversions

Measurement accuracy

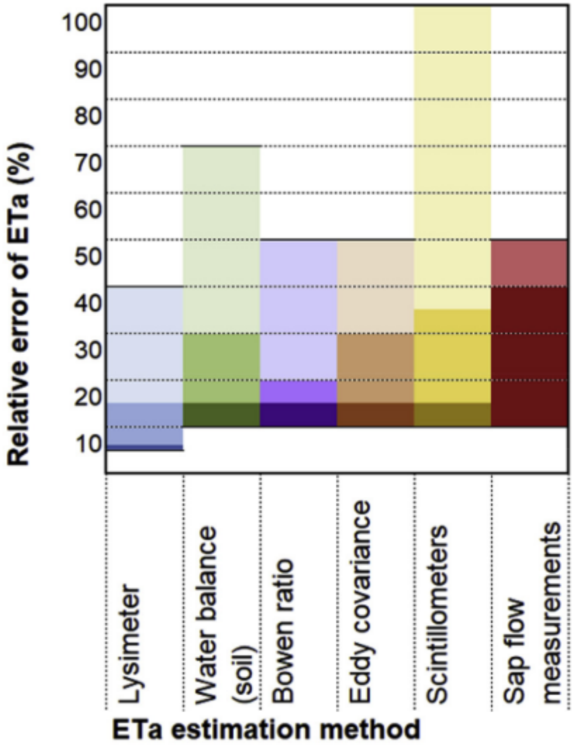


In-situ method	Novice	Typical	Expert
whole-plot harvest			
Crop-cut			
farmer-recall			
farmer-predictive			

Fig. 2. Relative error associated with in-situ methods of crop yield estimation. All methods provide estimates for at field scale for cropping season.

$$CWP\ (kg\ m^{-3}) = \frac{Crop\ yield\ (kg\ ha^{-1})}{10 \times \sum_{i=SOS}^{EOS} ET_a\ (mm)}$$

(Blatchford et al., 2019, RSE)

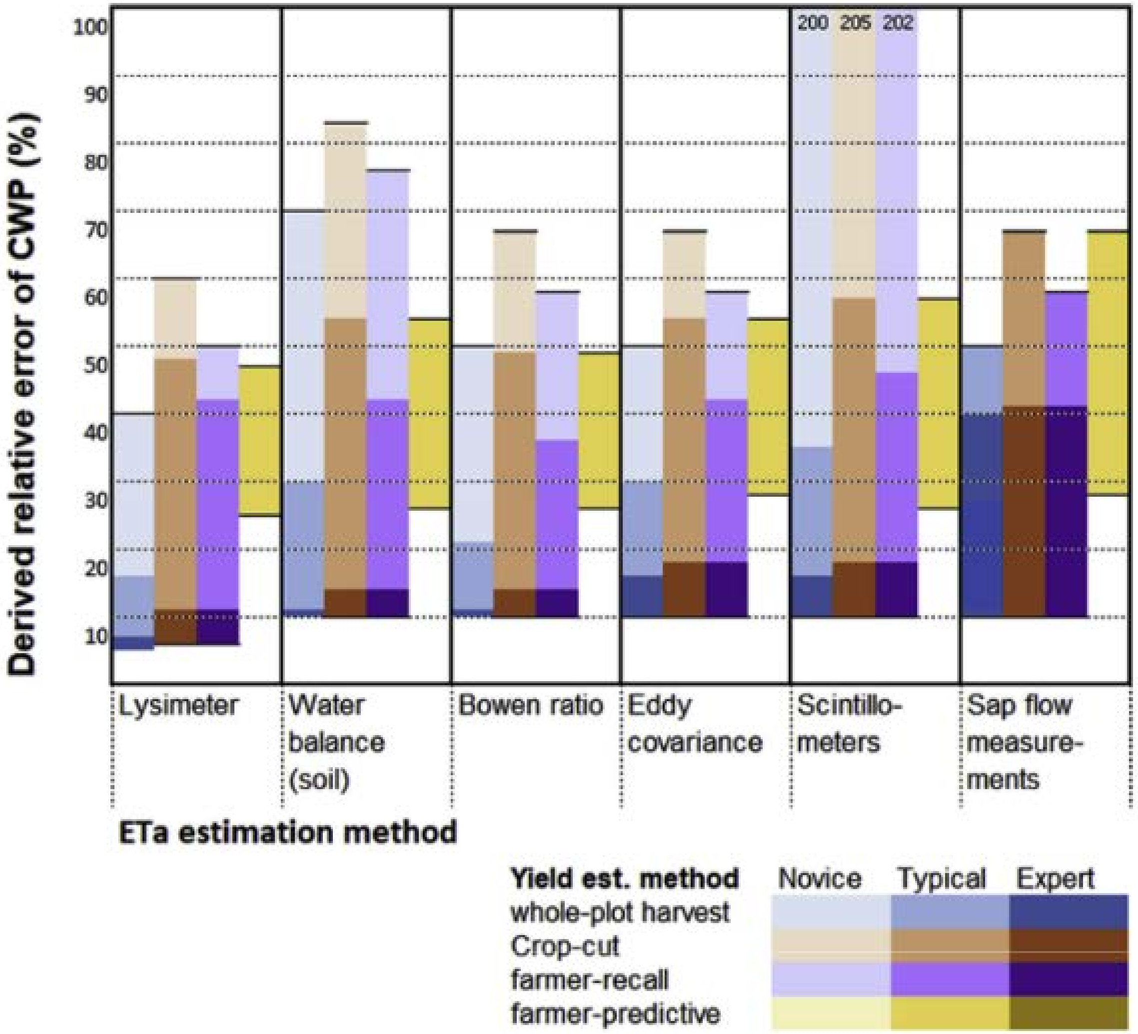


ETa	Novice	Typical	Expert
Lysimeter			
Water balance (soil)			
Bowen ratio			
Eddy covariance			
Scintillometers			
Sap flow measurements			

Fig. 3. Relative error associated with in-situ methods of ET_a estimation used for irrigation performance, adapted from Allen et al. (2011).

Crop water productivity (CWP) "measurement" accuracy

$$CWP\ (kg\ m^{-3}) = \frac{Crop\ yield\ (kg\ ha^{-1})}{10 \times \sum_{i=SOS}^{EOS} ET_a\ (mm)}$$



(Blatchford et al., 2019, RSE)

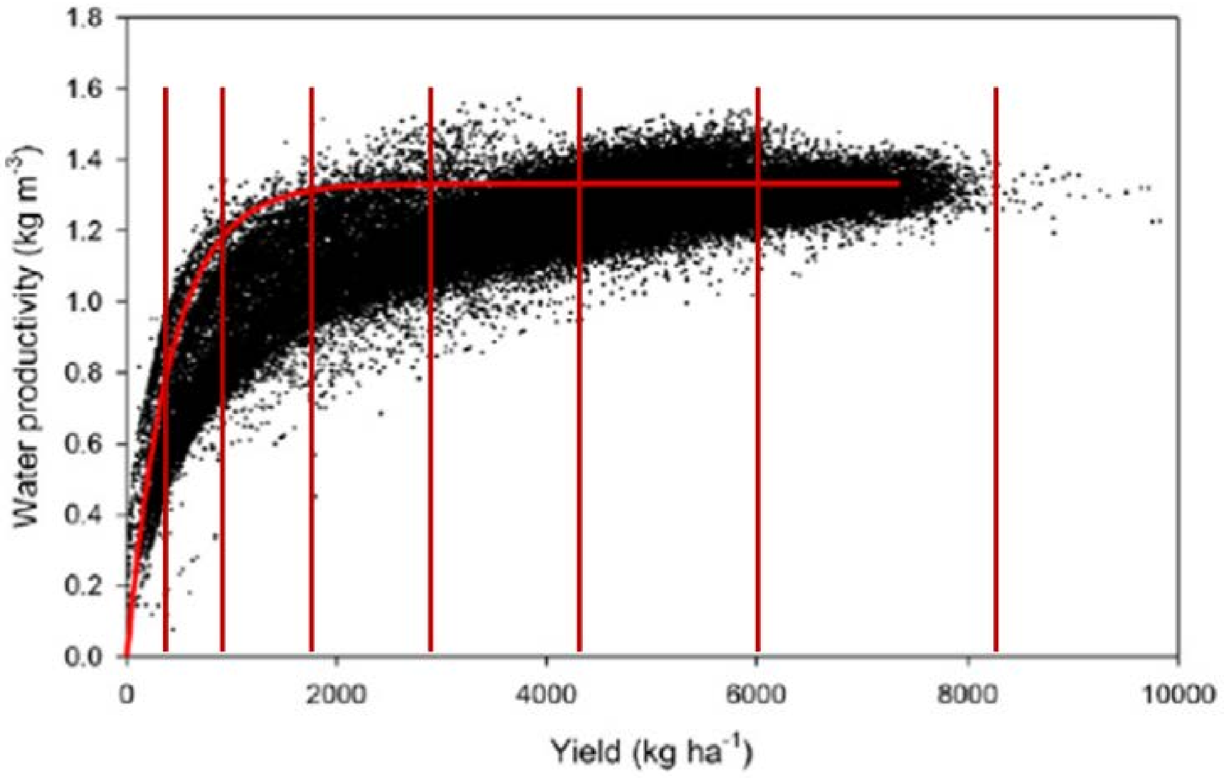


Fig. 3. Relationship between land and water productivity for maize fields in the Doukalla irrigation system, Morocco. The x-axis is subdivided in 'yield-zones' to reflect different local growing conditions and hence define a spectrum of target values of CWP (adjusted after Sadras et al., 2015).

(Bastiaanssen and Steduto., 2016)

Cultivation practices to maximize WUE

- mulching (plastic/straw)
- irrigation (furrow/drip)
- crop arrangement (row distance)
- crop rotation
- intercropping
- agroforestry

What is the best way to maximize
WUE = yield / ETa?

Cultivation practices to maximize WUE: mulching

straw

plastic

https://agriculturalinformation4u.com/advantages-and-disadvantages-of-mulching/

Cultivation practices to maximize WUE: irrigation

furrow (flood) 50%

https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/styles/search_result/public/thumbnails/image/wss-banner-irrigation-furrow.png?itok=vCvLvx3-

sprinkler – 70%

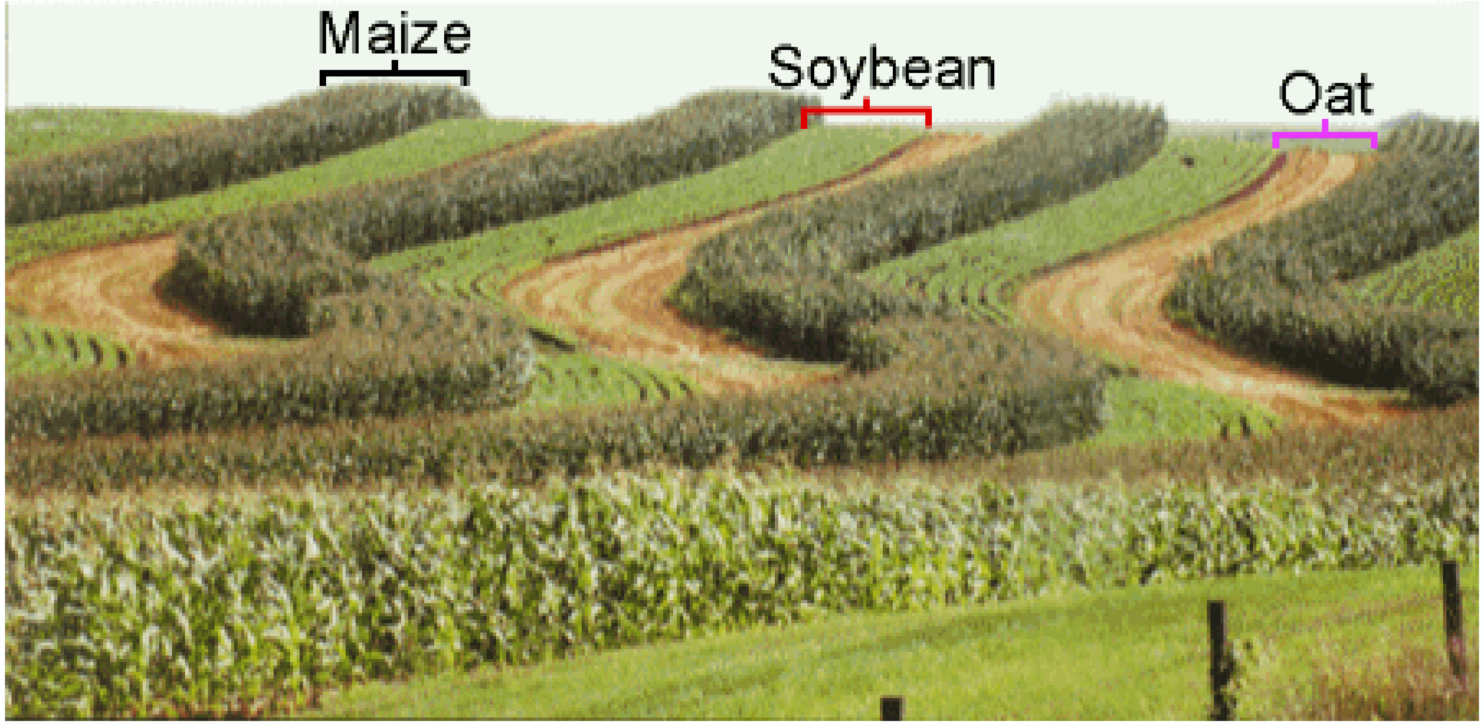
http://www.tyagiindustries.com/wp-content/uploads/2022/08/sprinkler-irrigation-system-500x500.jpg

drip – 95%

https://www.gardeningknowhow.com/wp-content/uploads/2022/07/drip-irrigation-duration.jpg

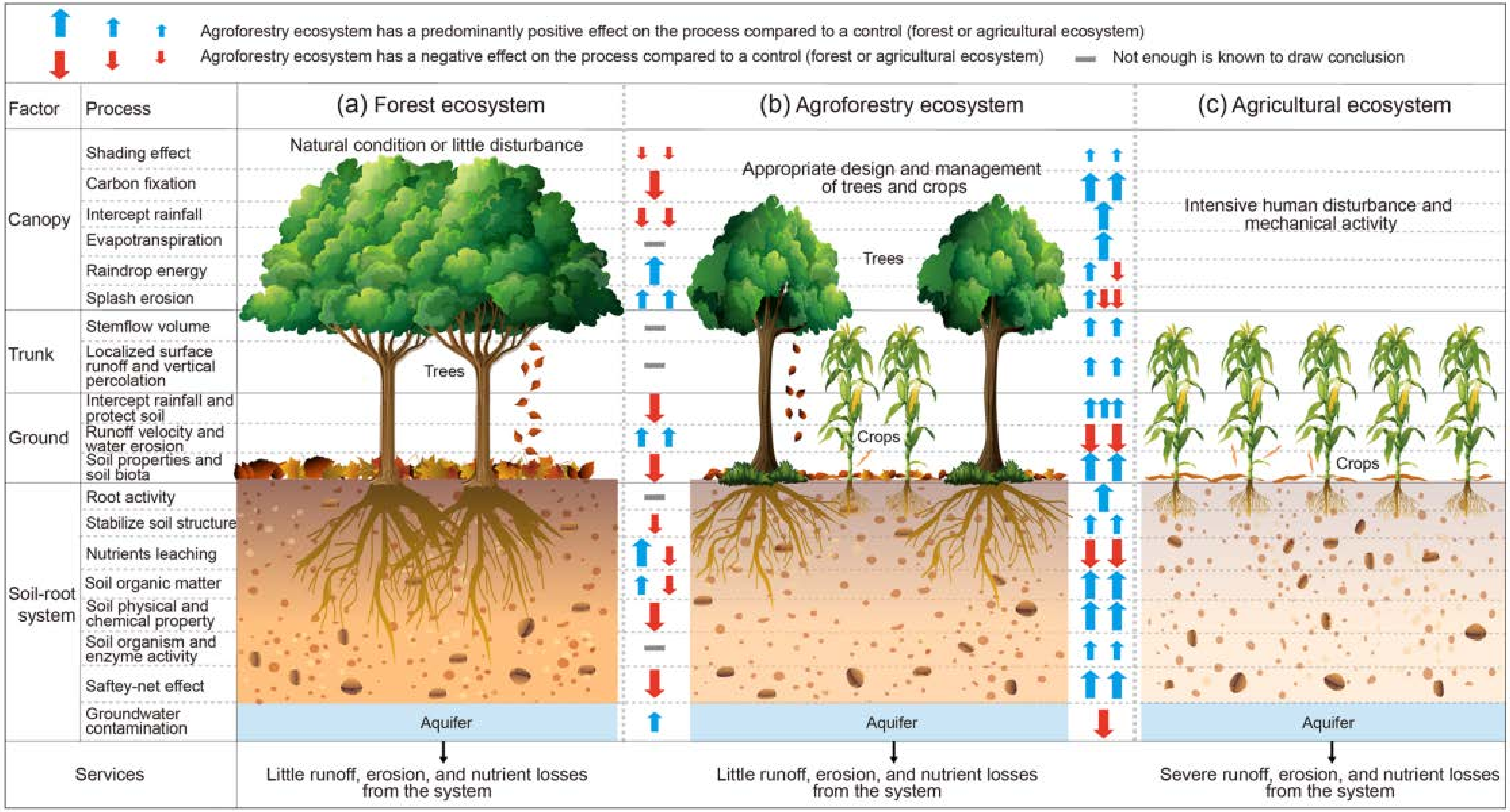
Cultivation practices to maximize WUE: intercropping

https://s3-us-west-2.amazonaws.com/agfuse-web/production/article_feature_images/aaf320dd674f4ee56c95e21225e05221.jpg



https://masters-sms.agron.iastate.edu/Content/Students/sample/classes/Sample/lesson09/images/stripcrop1.gif

Cultivation practices to maximize WUE: agroforestry



(Zhu et al., 2020)

Lessons learnt from crop (field) level

- we need the whole growing season
  - instantaneous does not work anymore as was with leaves
- many ways to measure yield and evapotranspiration
- cultivation practices reduce soil component of evapotranspiration
  - mathematically best way is to create a drought ☺ (but this is not a cultivation practice advice)

3/6 Global scale (gross) WUE

$$WUE = \frac{\sum GPP}{\sum ET}$$

GPP – gross primary productivity (g C m-2 s-1), annual sum

ET – evapotranspiration (kg H_2O m-2 s-1), annual sum

$$ET = \frac{LE}{heat\ of\ water\ vaporization}$$

how many grams of carbon are assimilated per 1 kg of transpired (evaporated) water

Example of Gross Bomass Water Productivity

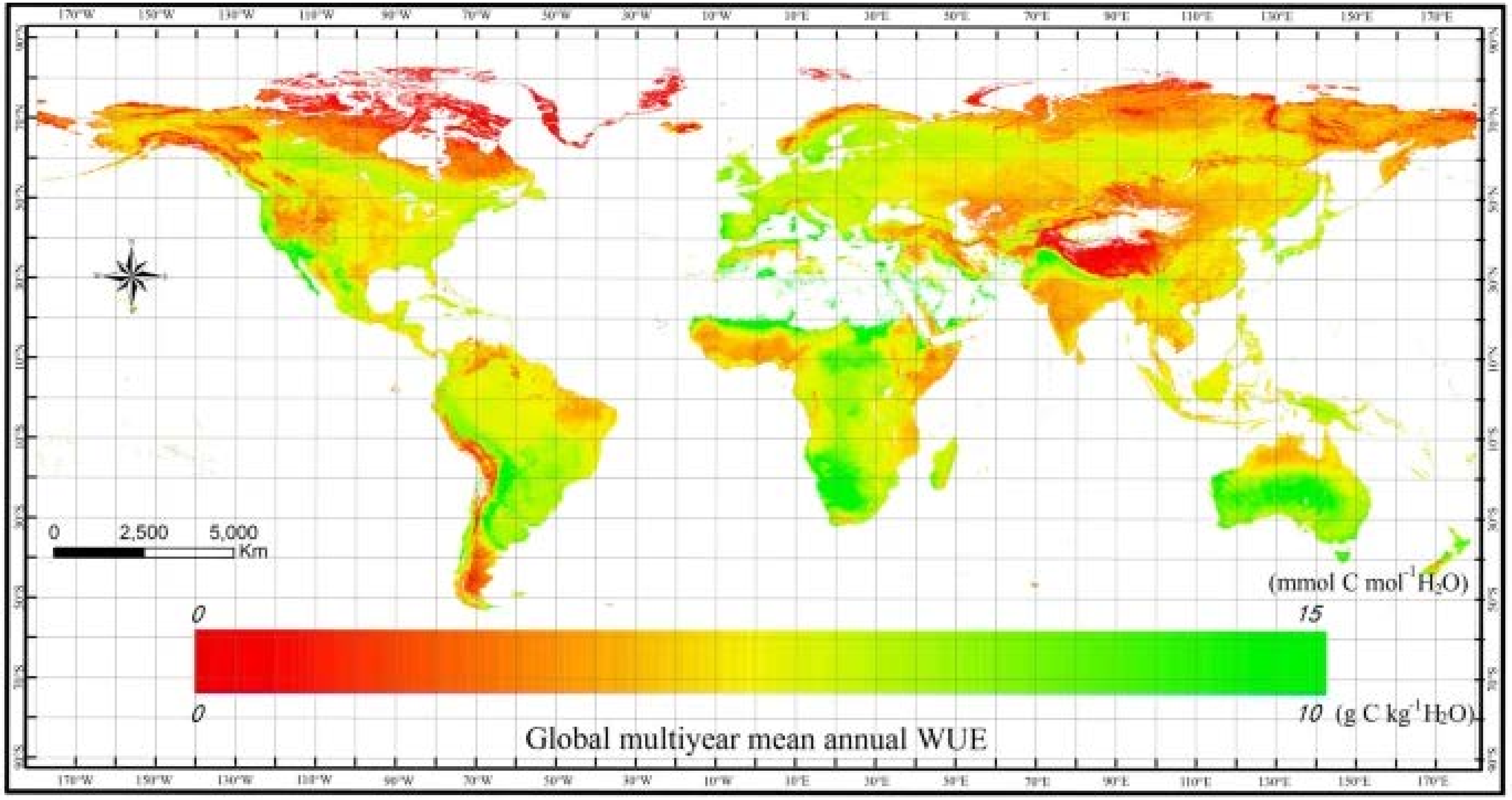
Gross biomass water productivity can also be referred to as ecosystem WUE (Tang et al., 2014). It's multi-year (2000-2013) mean global distribution is:

Based on:

MODIS-based GPP/ET

- GPP – from MOD17 product
- ET – from MOD16 product

Flux tower data for
 of the annual sum



Source: https://www.nature.com/articles/srep07483/figures/4

FAO WaPOR portal (Africa + Middle East)

wapor.apps.fao.org/catalog/WAPOR_2/1

Food and Agriculture Organization of the United Nations

WaPOR

The FAO portal to monitor WAter Productivity through Open access of Remotely sensed derived data

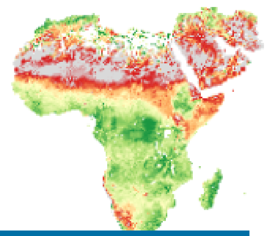
Back to map > Catalog

WaPOR 2.1 | My WaPOR | Info | Feedback

CONTINENTAL (250m) | NATIONAL (100m) | SUB-NATIONAL (30m)

☑ Water Productivity ☐ Water ☐ Land ☐ Climate ☐ Ancillary

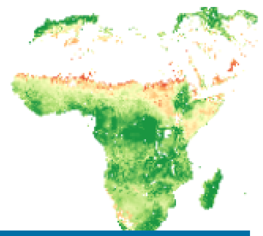
Gross Biomass Water Productivity



The annual Gross Biomass Water Productivity expresses the quantity of output (total biomass production) in relation to the total volume of water consumed in the year (actual evapotranspiration).

WATER PRODUCTIVITY

Net Biomass Water Productivity



The annual Net Biomass Water Productivity expresses the quantity of output (total biomass production) in relation to the volume of water beneficially consumed (by canopy transpiration) in the year, and thus net of soil evaporation.

WATER PRODUCTIVITY

Reminder: we need two components GPP and ET

$$WUE = \frac{\sum GPP}{\sum ET} \qquad \frac{\text{photosynthesis models}}{\text{evapotranspiration models}}$$

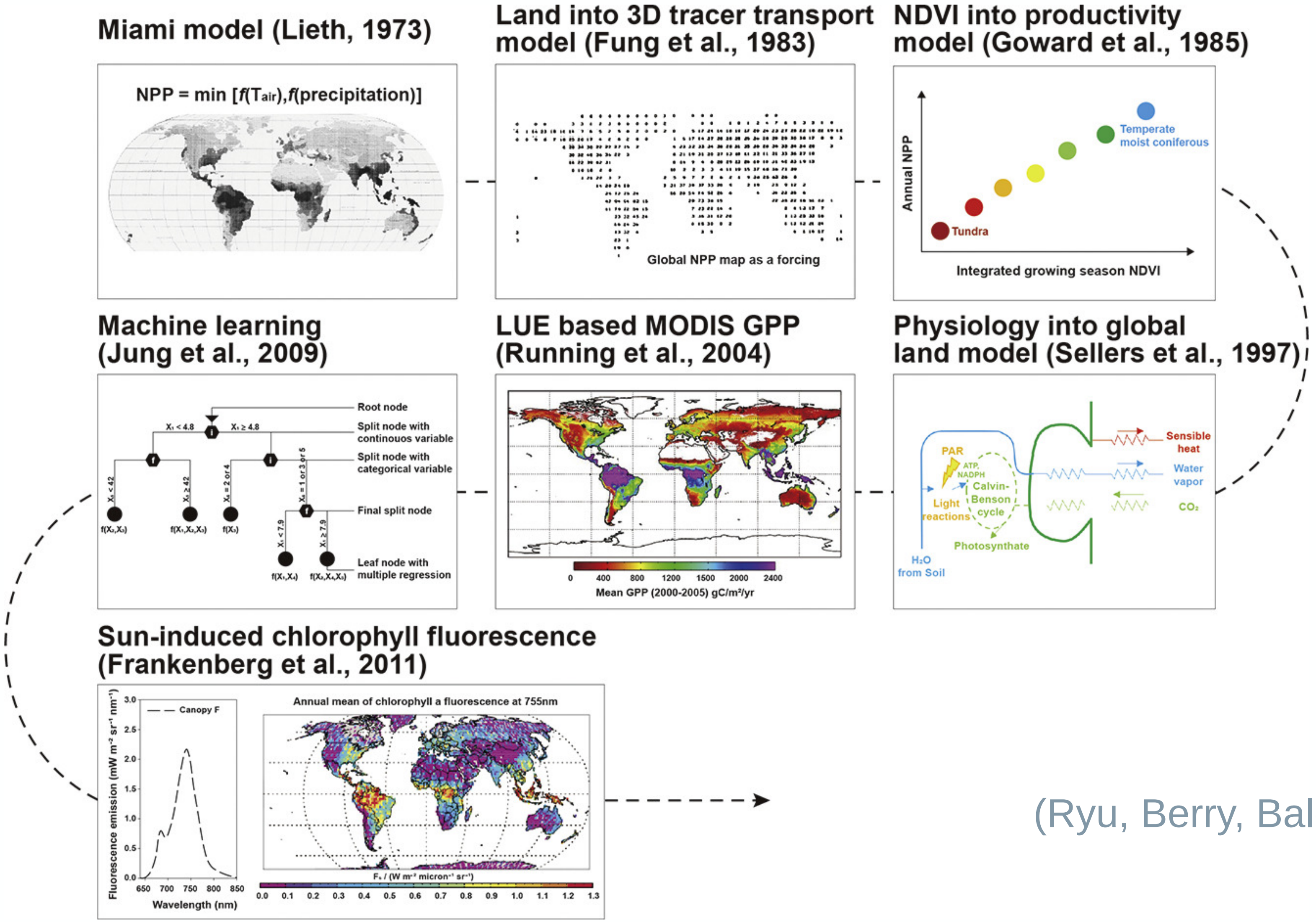
GPP – gross primary productivity (g C m-2 s-1), annual sum

ET – evapotranspiration (kg H_2O m-2 s-1), annual sum

$$ET = \frac{LE}{heat\ of\ water\ vaporization}$$

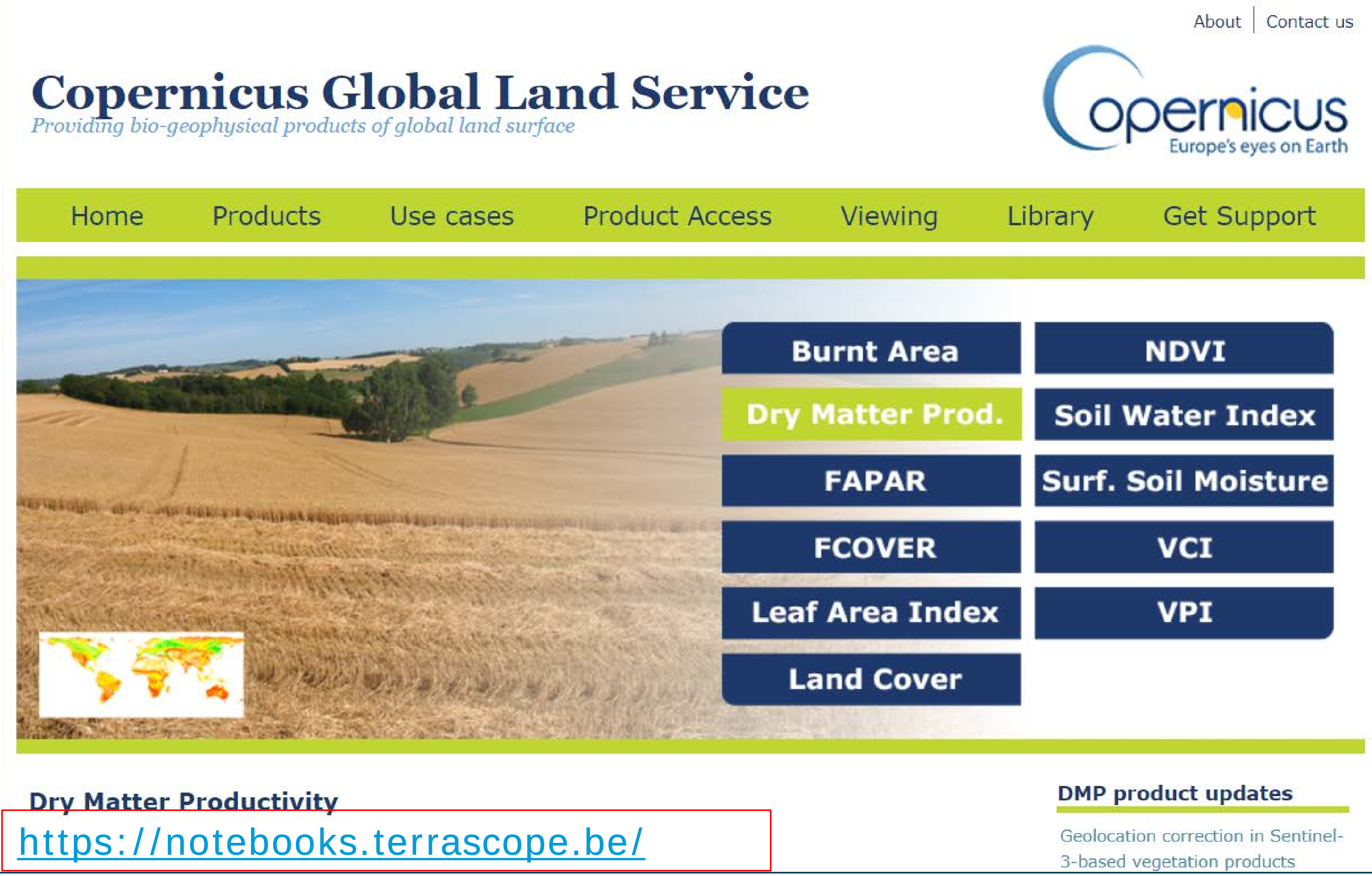
how many grams of carbon are assimilated per 1 kg of transpired (evaporated) water

What is global photosynthesis?



(Ryu, Berry, Baldocchi, 2019)

DMP 300m product



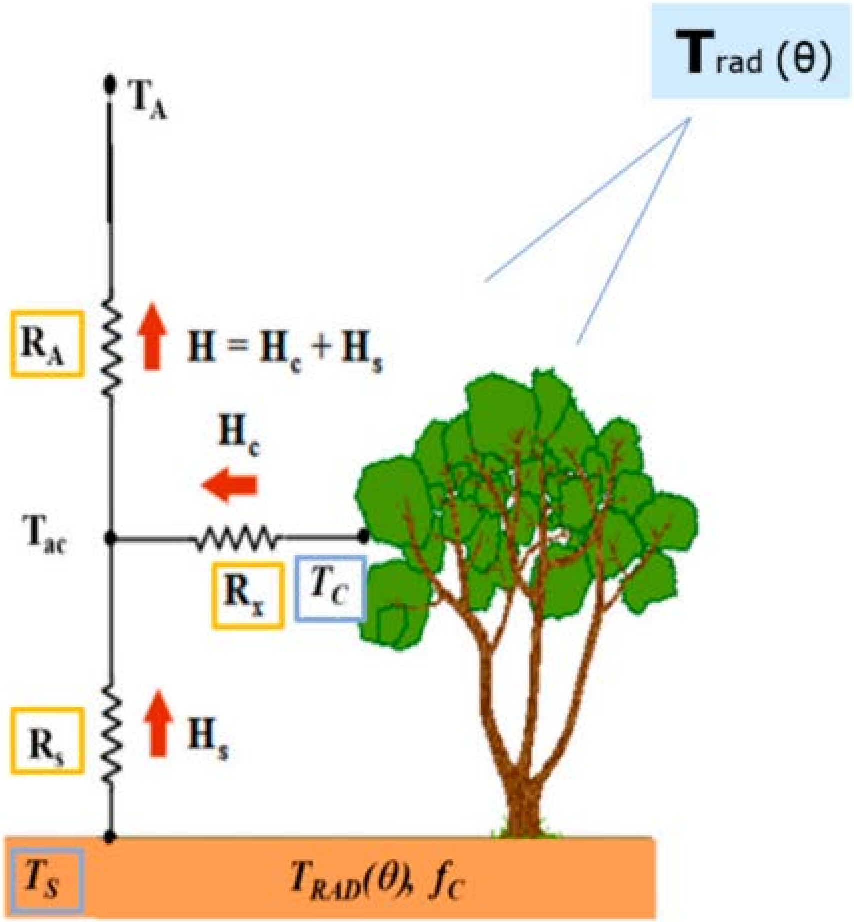
https://notebooks.terrascope.be/

How to estimate evapotranspiration with RS

1. Surface energy-balance models (SEB)
   - SEBS: Surface Energy Balance System (Su, 2002)
   - TSEB: Two-Source Energy Balance (Kustas and Norman, 1996)
2. Time rate of change in surface temperature [geostationary satellites]
   - ABL: Atmospheric Boundary Layer (Diak, 1990)
3. Combination: time rate of change + SEB
   - ALEXI: Atmosphere-Land Exchange Inverse (Anderson et al., 1997, 2007)
4. Spatial variability methods [wet (cold) / dry (hot) pixels]
   - SEBAL: Surface Energy BALance (Bastiaanssen et al., 1998)
   - METRIC: Mapping EvapoTranspiration with high Resolution and Internalized Calibration (Allen et al., 2007)
   - Vegetation indices (VIs):
     - as a proxy of FAO crop coefficient (Kc) or Priestley and Taylor alpha (α_{PT})
     - “triangle method” (Ts/VI)
5. Land surface models (LSM) + soil-vegetation-atmosphere transfer (SVAT) models

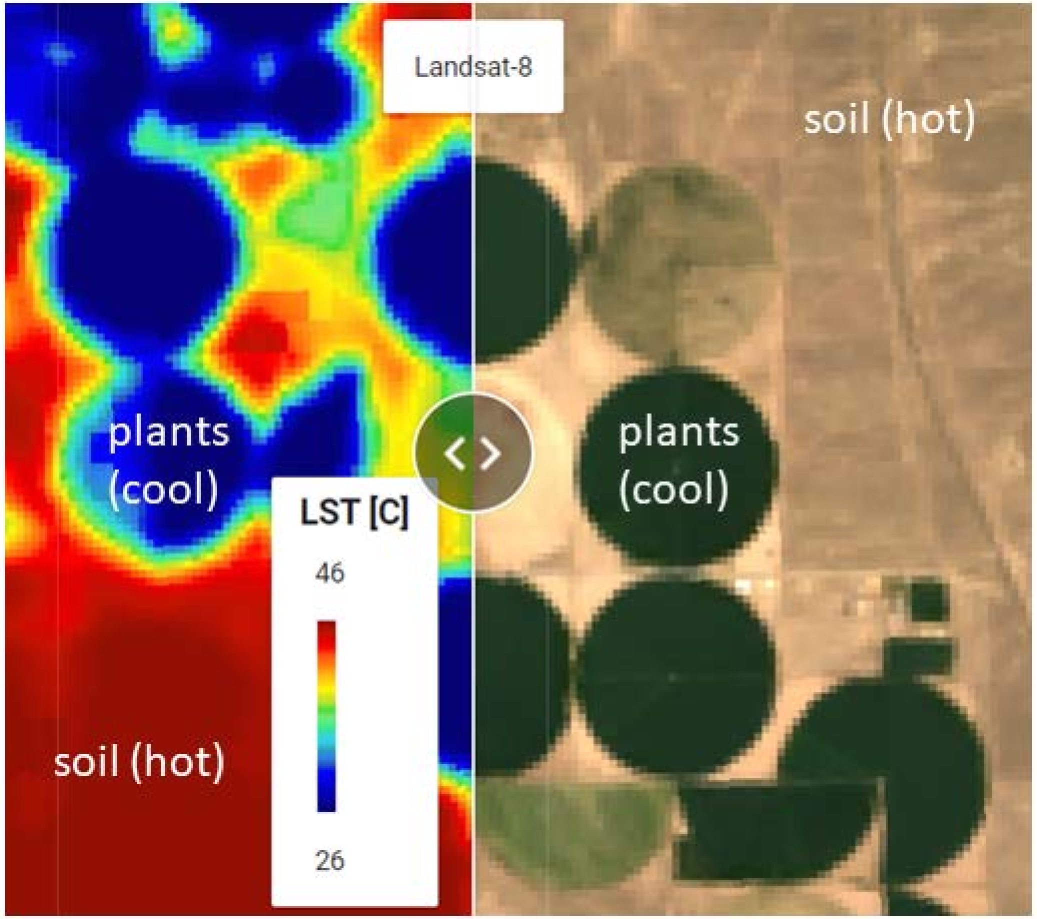
TSEB model (remember Hector's lecture on Tuesday)

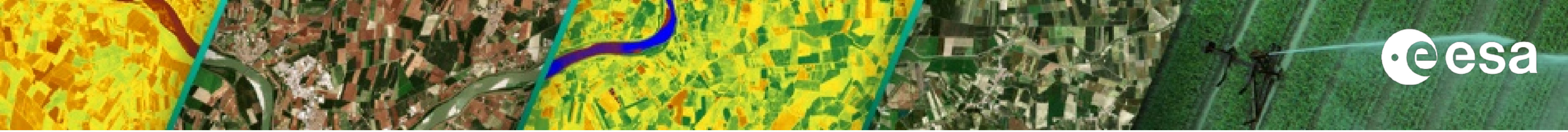
LE = Rn – G - H



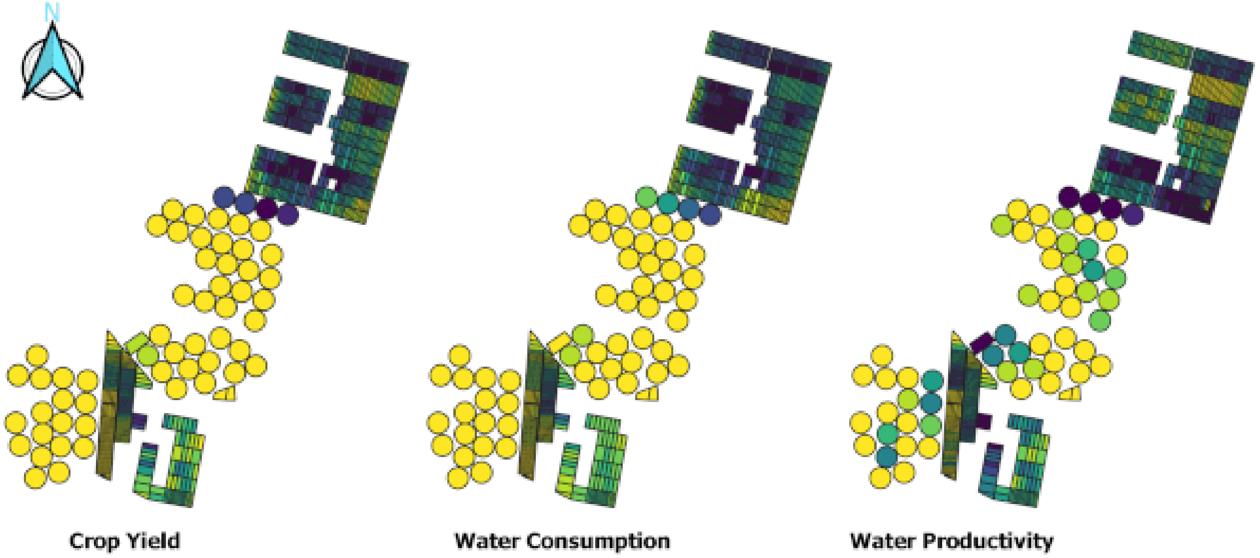
(Burchard Levine et al., 2020)

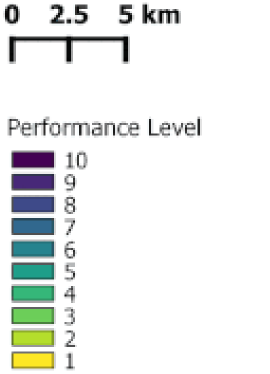
Transcripiration (sweating) cools plants down

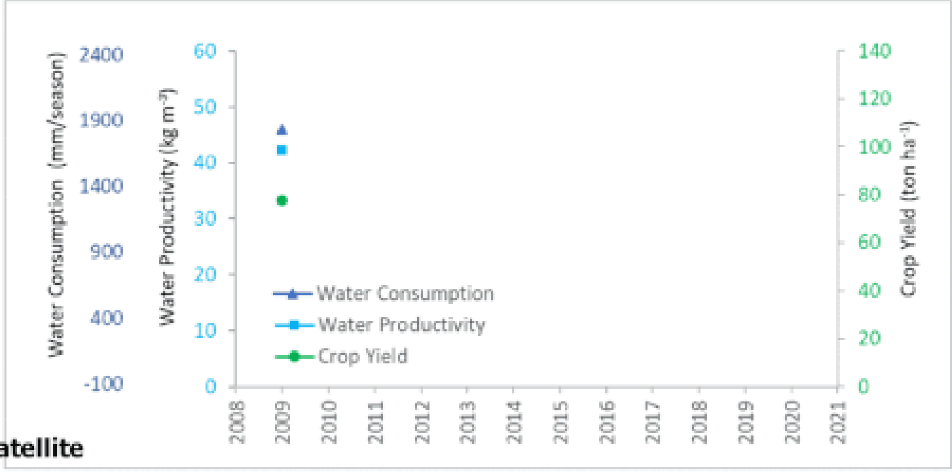




Irrigated Sugarcane, Office du Niger (Mali), 2009







Data Source: WaPOR
Background: Google Satellite

Lessons learnt from global level

- we need the whole growing season
    - instantaneous does not work anymore as was with leaves
- no ways to measure, only models and remote sensing
- several definitions (gross, net, dry mater)

4/6 Climate change and WUE

Climate change consequences

1. CO_2 concentration rise (420 ppm -> ?)
2. Air temperature rise (2.6 - 4.8 degrees)
3. Water holding capacity of air rise (7% per degree) => higher intensity of precipitation
    - Precipitation increase (?)
    - Global dimming => more diffuse radiation
    - Evaporation increase

factor	direction	GPP	ETa	WUE
CO_2	up	up	down	up
Air temperature	up (< optimum)	up	down	up
	up (> optimum)	down	up	down
Radiation	diffuse	up	down?	up

5/6 Summary

Summary

criteria	leaf	crop (field)	global
name	WUE	CWP	GWP
	Water use efficiency	Crop water productivity	Gross [biomass] water productivity
components are measurable	+	+	-/+
requires seasonal integration	-	+	+
Earth Observation	-	+/-	+

References

- Allen, Richard G., Luis S. Pereira, Terry A. Howell, and Marvin E. Jensen. 2011. "Evapotranspiration Information Reporting: I. Factors Governing Measurement Accuracy." Agricultural Water Management 98 (6): 899–920. https://doi.org/10.1016/j.agwat.2010.12.015
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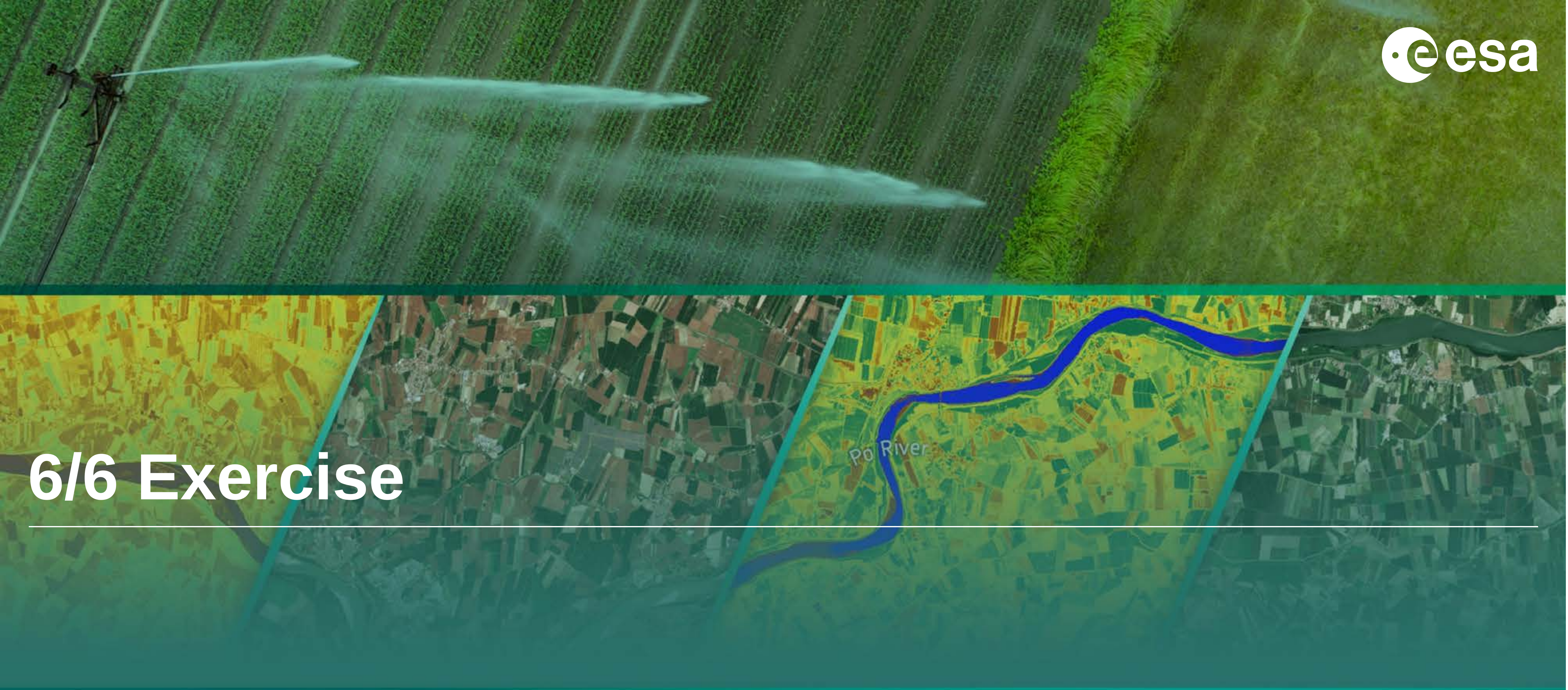
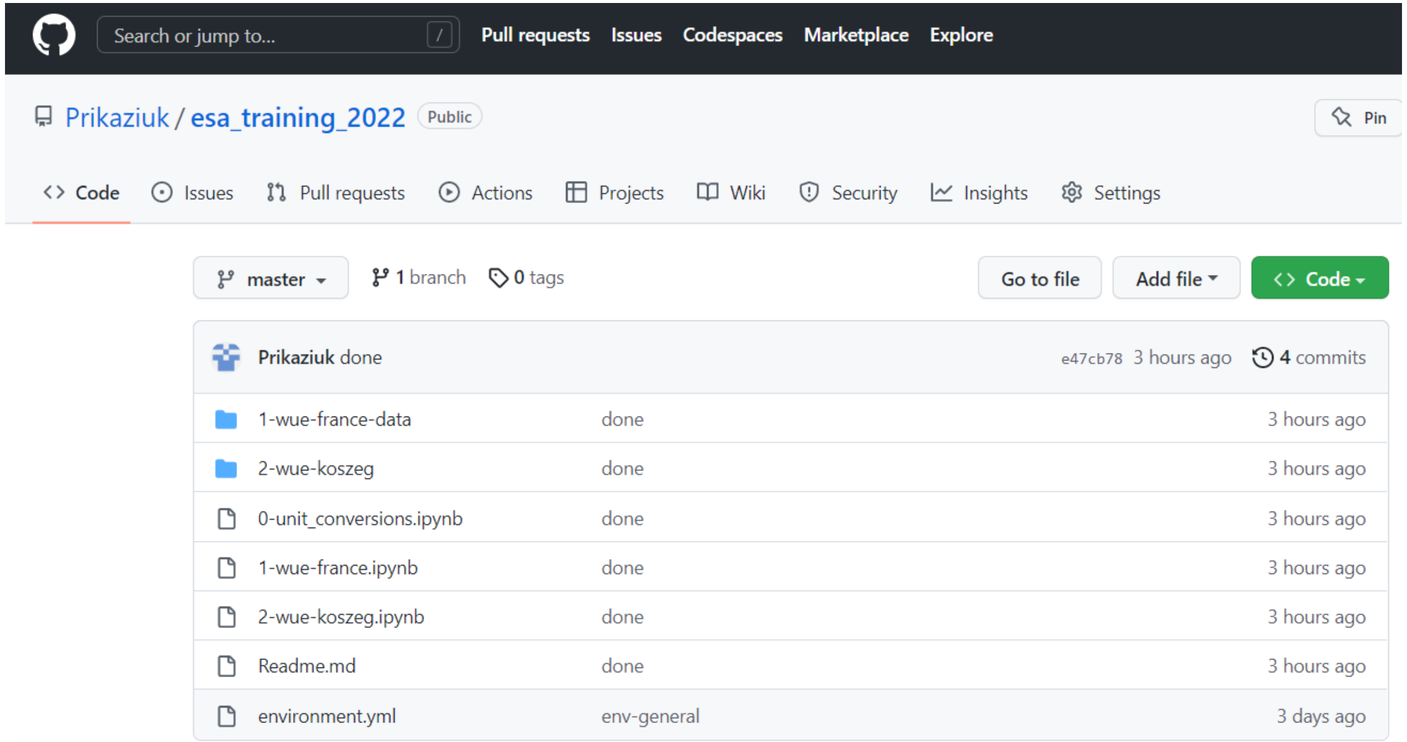


6/6 Exercise

3 tasks

- 0-unit_conversions.ipynb
- 1-wue-france.ipynb
- 2-wue-koszeg.ipynb

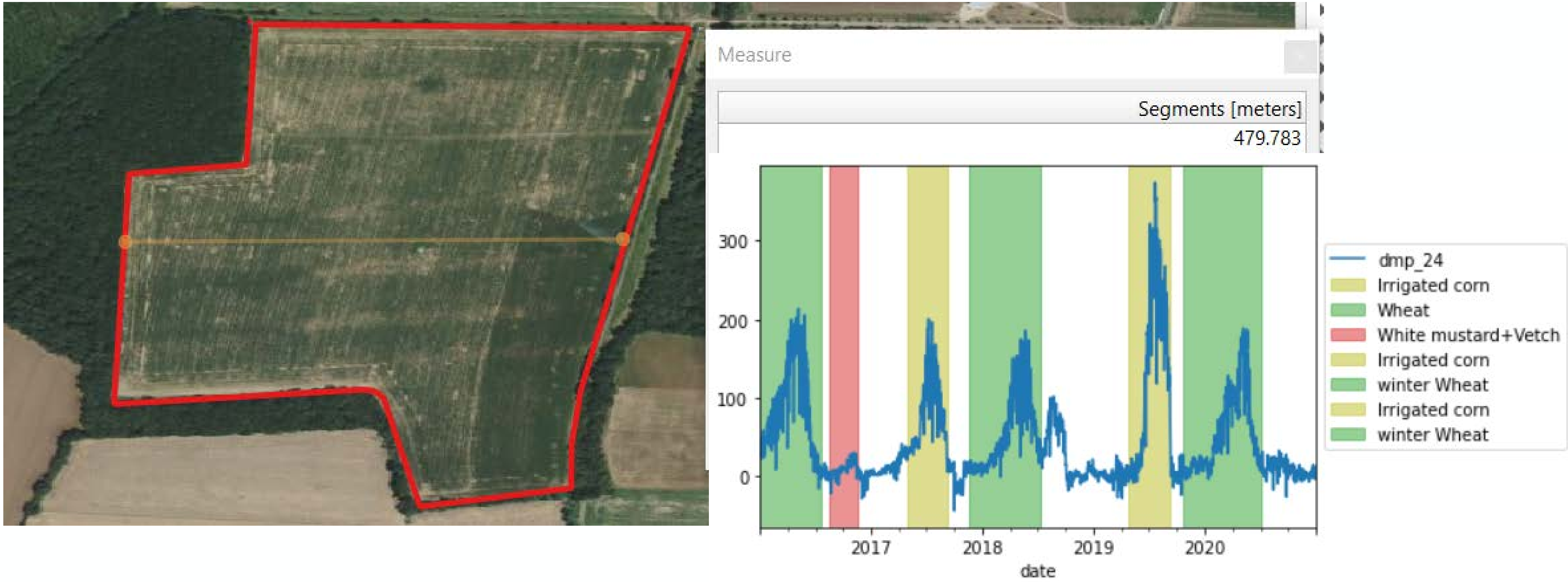
https://mybinder.org/v2/gh/Prikaziuk/esa_training_2022.git/HEAD



1-wue-france

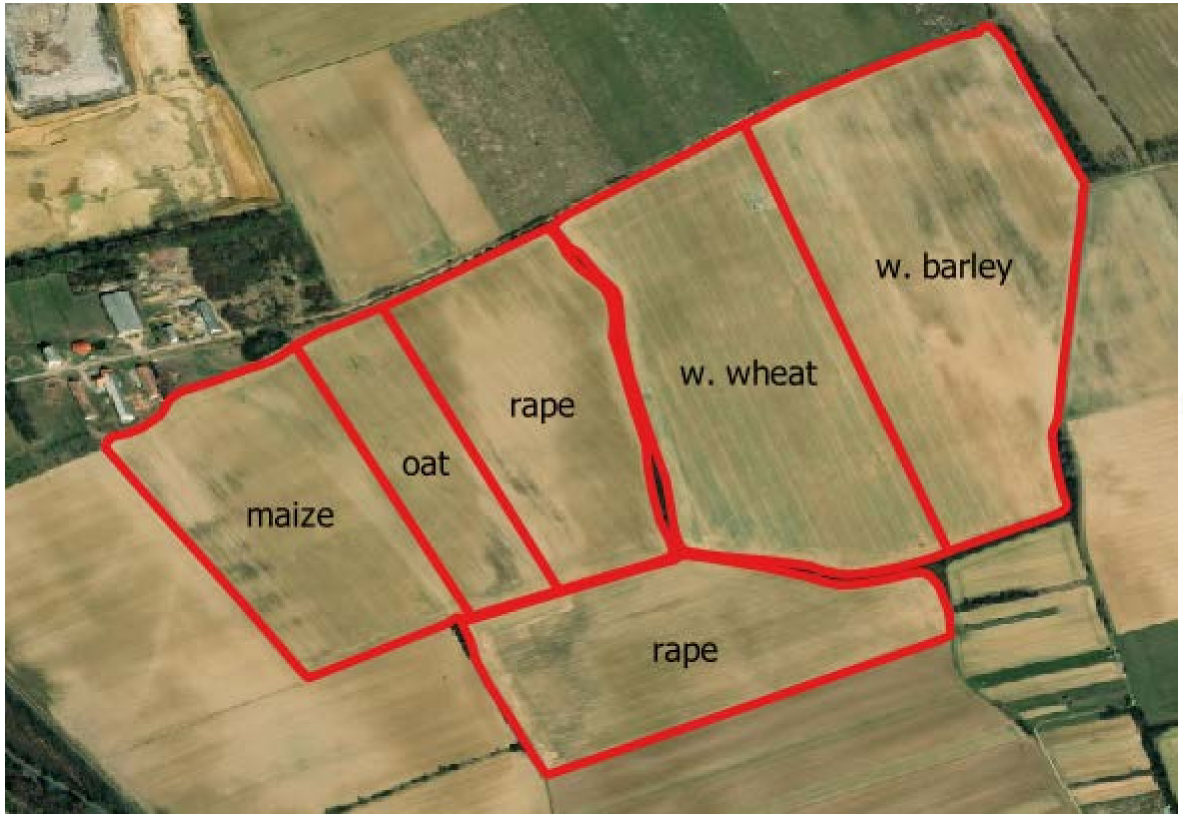
French eddy-covariance ICOS site (FR-Lam) – cropland with wheat-corn rotation measurements of GPP, ET and SOS and EOS

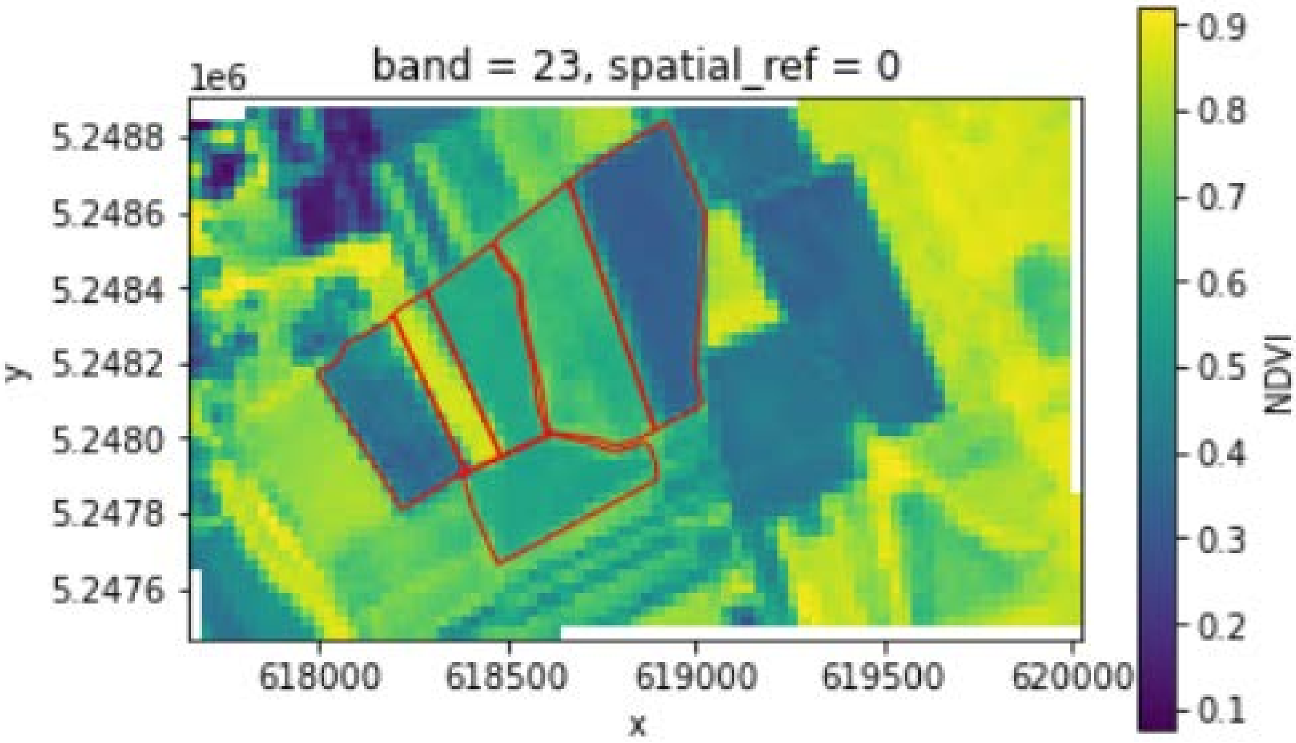
Compute WUE (GWP) for 5 seasons - point exercise



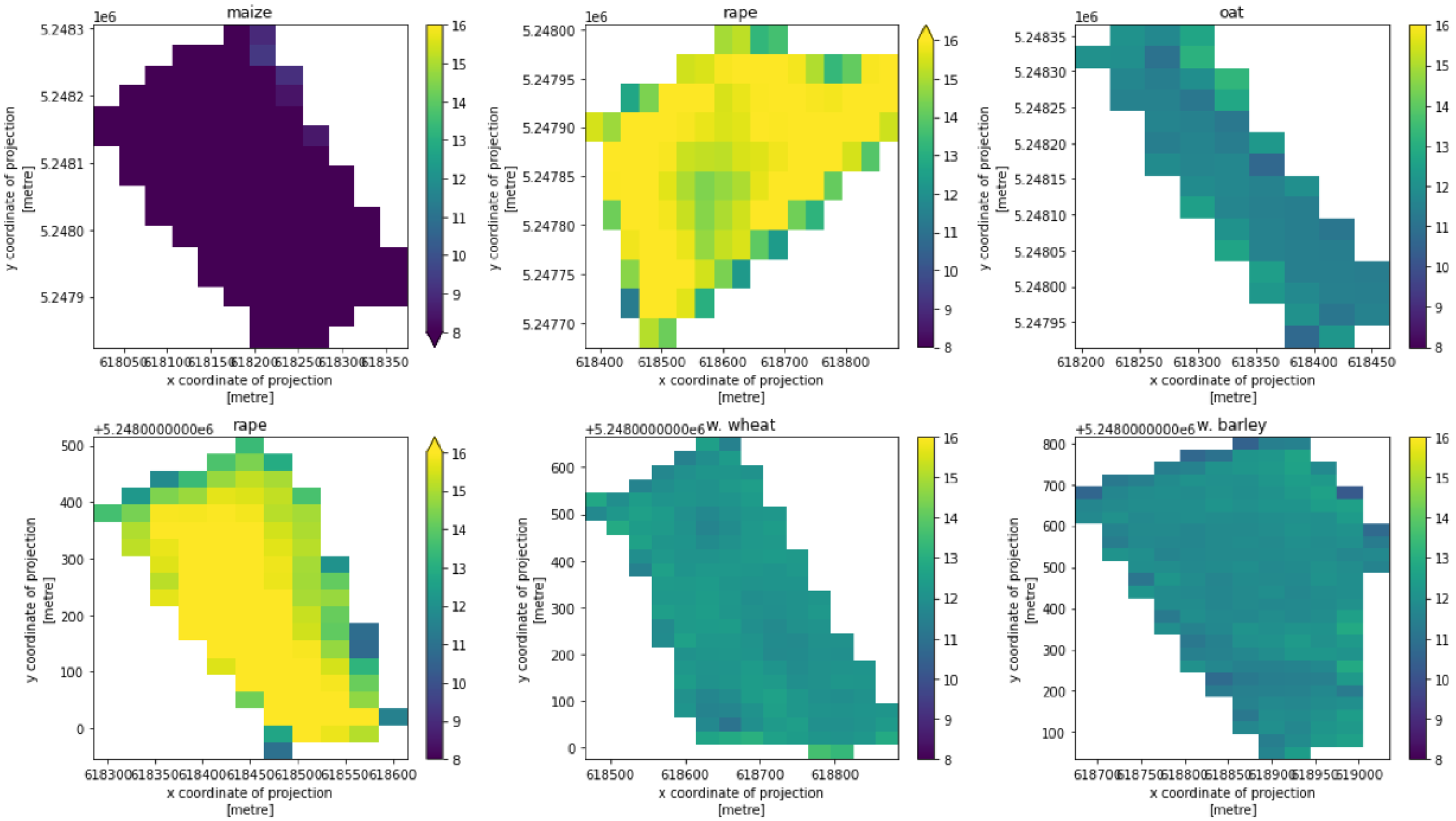
2-wue-koszeg

Compute a map of WUE (GWP) for 2022 growing season





2-wue-koszeg – result: WUE map for 2022



Merci!

Спасибо!

Danke!

Thank you!

شكريه

¡Gracias!

Köszönöm

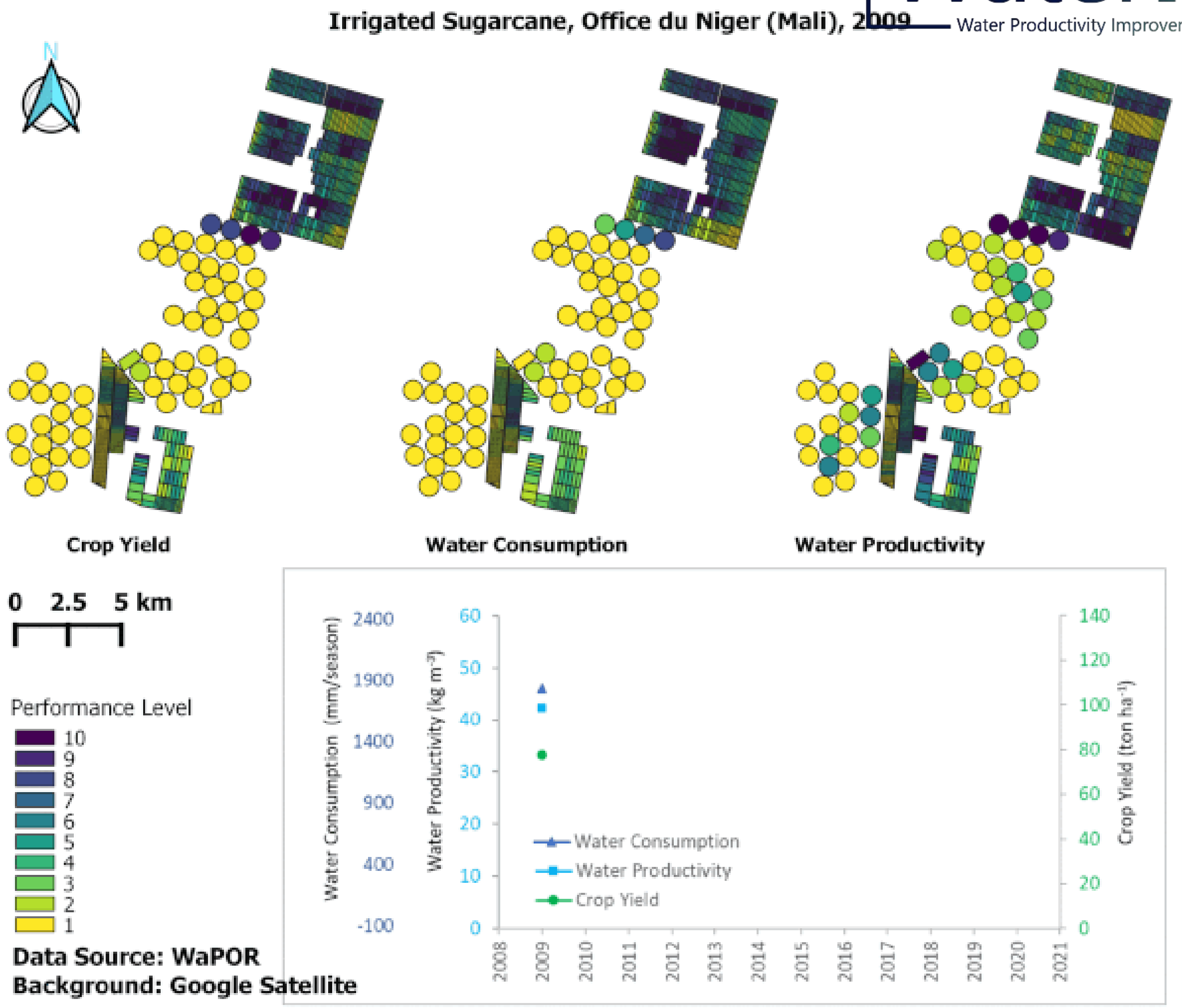
Ευχαριστώ!

Bedankt!

Grazie!

Application: longer term performance assessment

- Client: Policy and program design
- User pain: Unsustainable land and water resources management
- Proposed service: Long-term assessment of yield and water consumption
- Service helps to: Identify plots/area with low productivity (low sugarcane production per unit water and/or land area used), aiming toward sustainable use of water and land resources.



Longer term Irrigation performance assessment – Office du Niger, Mali (2009 – 2020)

→ THE EUROPEAN SPACE AGENCY