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SUSTAINABLE USE OF WATER RESOURCES FOR FOOD SECURITY

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Presentation outlines

1. **Development of Agriculture and Irrigation in last 50 years in Italy**

2. **The current contex and the new objectives**

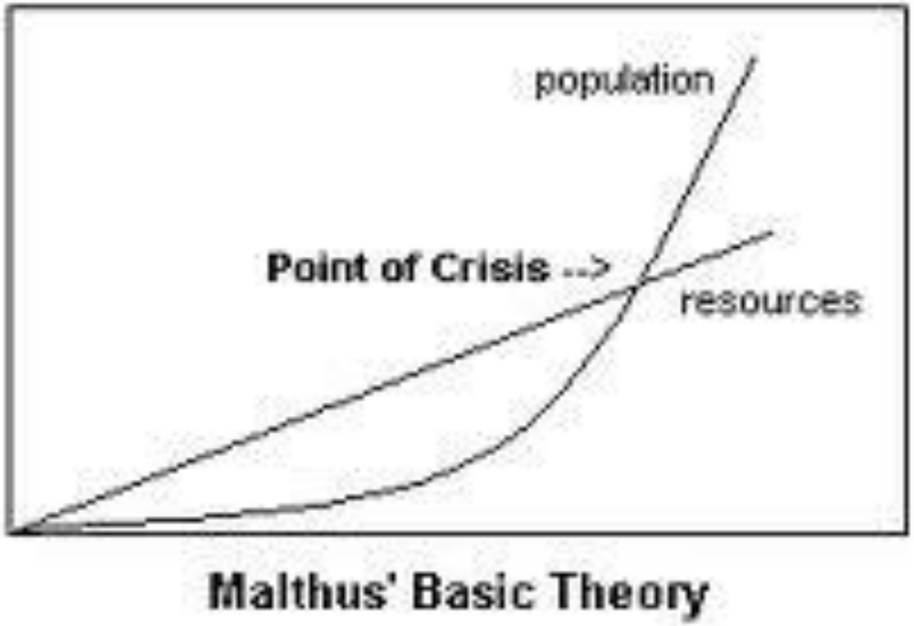
3. **The main strategies to improve crop productivity and water use efficiency**

1. Development of Agriculture and Irrigation in last century in Italy

A bit of recent history:

In 1798, Thomas Malthus argued*: "the community will reach the point of crisis, that is, a block of economic development, when population growth that accompanies the development is not accompanied by adequate production of food"*

Where do we come from? Who are we? Where are we going?
Paul Gauguin, 1897

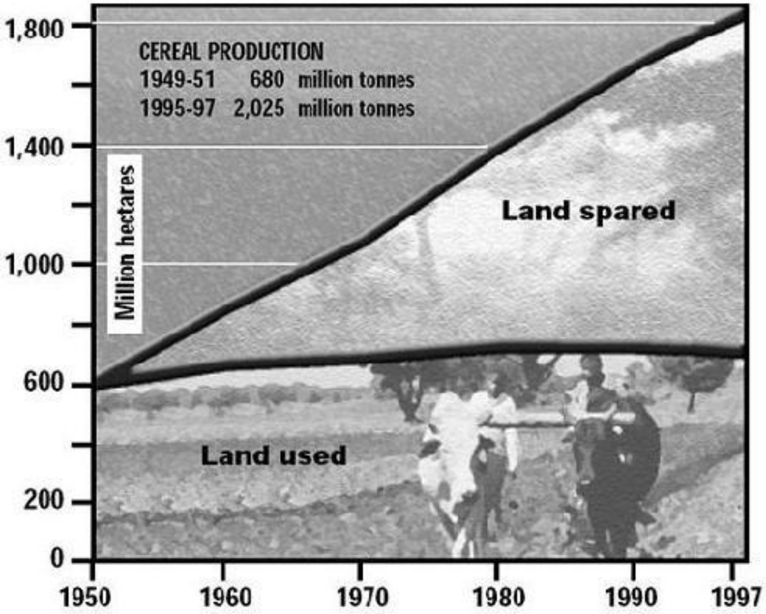


How we have faced food crisis after the last mondial war:

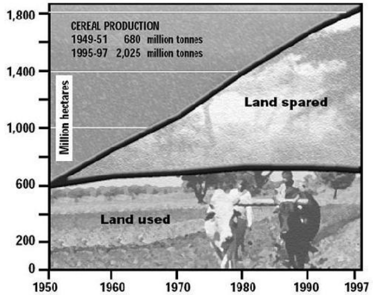
The green revolution, with large process and product innovations, has allowed a great increase in production (with an average growth rate of 2% per year), providing enough food to meet the growing population after the war and denying the pessimistic predictions of Malthus:

- Genetic improvement
- Fertilizers and manure
- Pest management
- Weeds control
- Progress in mechanization and more efficient tilling practice
- More efficient cropping systems
- **Increase of irrigated areas**
- **Irrigation scheduling and more efficient irrigation methods**
- **Soil reclamation and efficient drainage tecniques**
- Etc..

The period from 1950 to about 2000 was the fastest in the history of agriculture. Production more than doubled, the demand for labor required has dropped to one-tenth.



Norman Borlaug (the green revolution)



The increase in production has on the one hand calmed the Malthusian fear of unsustainable growth, on the other hand the increase in supply has led to a positive decline in prices of food.

The Green Revolution was made possible thanks to strong investment in research, services and facilities (farm modernization) and a clear political action (CAP).

Achieved the goal of food for all at low prices, dropped both political interest and investment in the agricultural sector. Result:

The growth in food productivity stopped thanks also to a reversal trends in the use of fertilizers, plant protection safeguards, use of water resources in agriculture.

Two constraints to growth in food productivity were then placed:
- **On the one hand the need for a low-input agriculture**
- **On the other hand the belief that it has reached a technological level too high and difficult to improve.**

2. The current contex and the new objectives

The context

- Population growth has not stopped: from the current 6.9 billion people (31-8-2011), the estimates provide a world population of 9 billion in 2050 *(Population Reference Bureau, 2006)*

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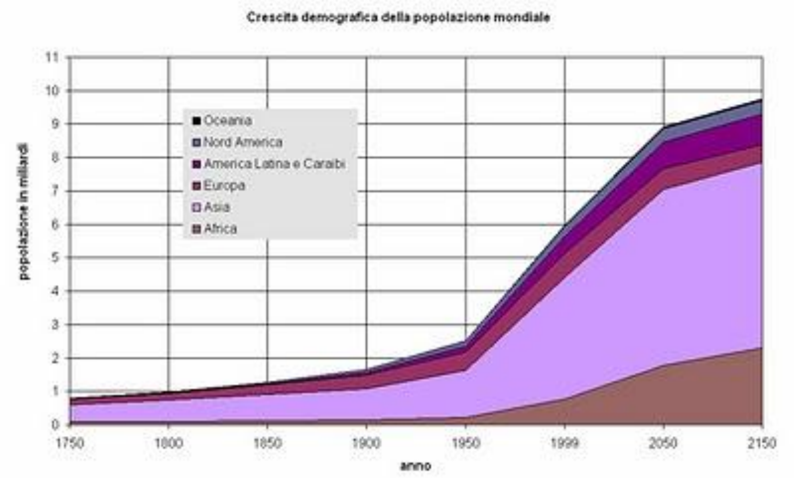

- Eating habits are changing: emergent countries from a vegetarian diet are moving (for expanded purchasing power of the population) to a diet higher in protein and calories = consumption per capita increases *(OECD and FAO , 2010)*

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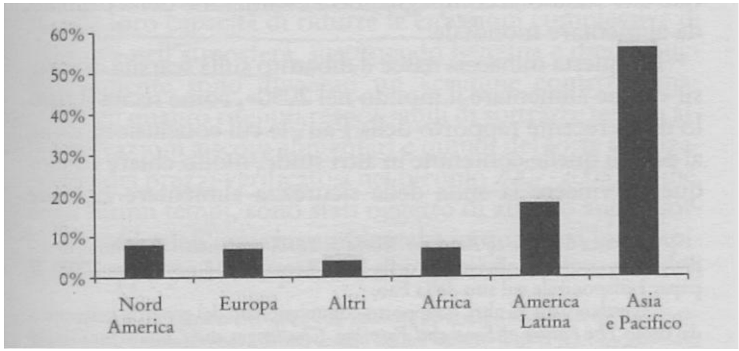


Projection on the increase in meat consumption. Projections 2010-2020. *Source OECD and FAO.*

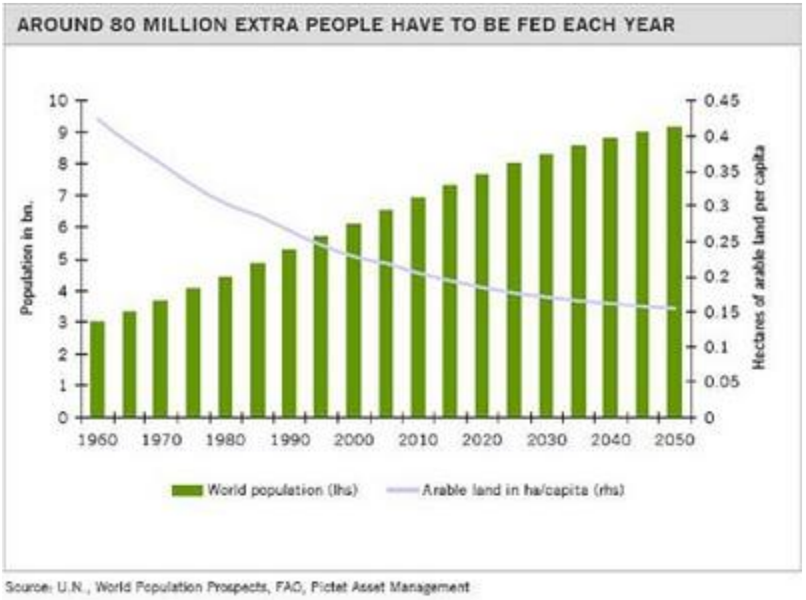
- **According to estimates by FAO (2010) the increase of the world population with rising per capita consumption will increase the demand for food by 70%**

=

The context

- arable land are reducing by urbanization, abandonment of marginal land, desertification, erosion and landslides, salinisation, etc.. (*Nellemann*, 2005)

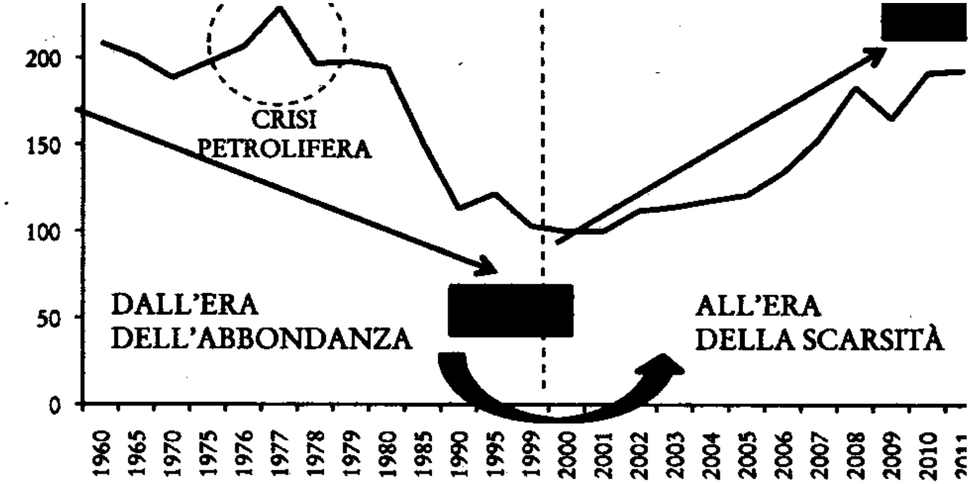
- The increase in population and the concomitant reduction of arable land, results in a reduction of arable land for food per capita (*FAO*, 2009).



AROUND 80 MILLION EXTRA PEOPLE HAVE TO BE FED EACH YEAR

Source: U.N., World Population Prospects, FAO, Pictet Asset Management

- **This contributes to an increase in demand and a reduction in the supply of agricultural commodities, with a consequent increase in the price of food (also favoured by speculative phenomena).**



Real price index of agricultural commodities (1960-2011).
Year 2000 = 100
Source World Bank.

The context

- Greater variability of production between the years because of extreme events from **climate change** (drought, Frost, hail, floods, heat waves) (*IPCC*, 2007)

+

- Reduction of availability of food reserves (*Tangermann*, 2011)

=

- Greater price volatility and uncertainty in farming management (*OCSE*, 2011)

The current context

- **Produce more food**

High-quality food: technological
nutritional
organoleptic
healthy
nutraceuticals

- Low environmental impact

- Soil, water and natural resources sustainable use

- Safeguard and maintainement of the rural landscape and territory

The goal for the near future:

produce more food polluting less

SUSTAINABLE INTENSIFICATION
(OECD, 2011*)*

PRODUCE MORE WITH LESS

Sustainable intensification:
Optimaize the resources use efficiency

$$\text{WUE} = \frac{\text{Biomass produced (Kg)}}{\text{Water transpired (m}^3\text{)}}$$

MORE CROP PER DROP

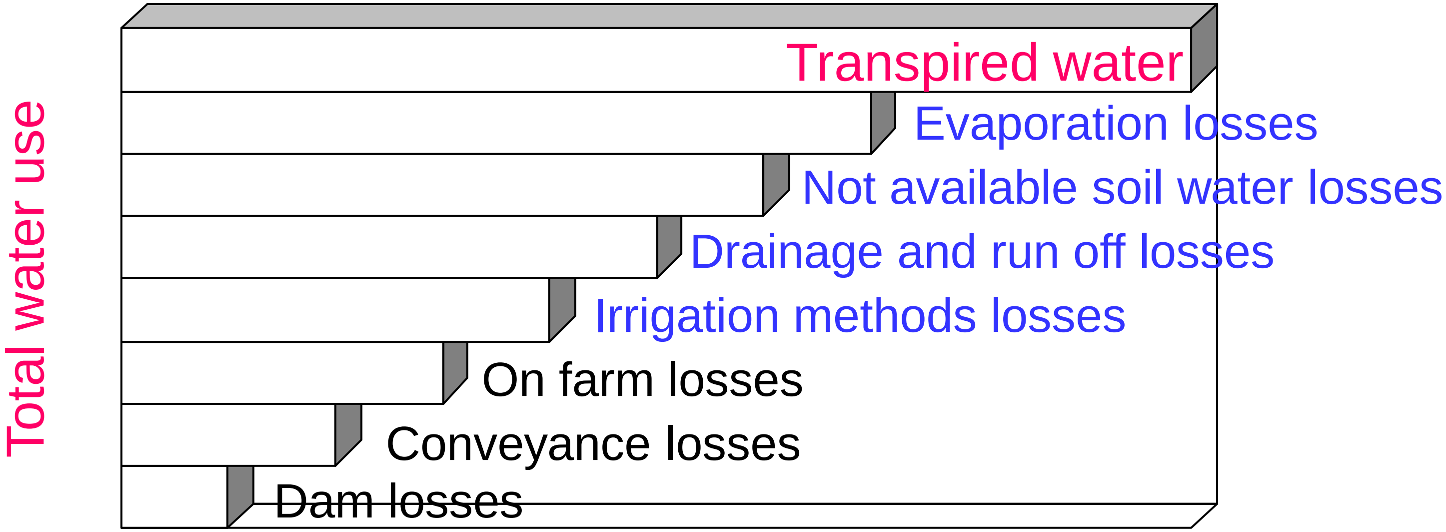
$$\text{Y} = \text{T} \times \text{WUE} \times \text{HI}$$

(Passiura, 2007) __

3. The main strategies to improve crop productivity and WUE

$$\textbf{WUE}\ (\textit{for physiologist}) = \frac{\textbf{leaf phothosynthesis}}{\textbf{leaf transpiration}}$$

$$\textbf{YWUE}\ (\textit{at field level}) = \frac{\textbf{Gross marketable yield}}{\textbf{Total water use (rain water+irrigation water)}}$$



Losses of water from dam to plant use. **(from Hsiao, 2003).**

YWUE (at field level)

$$\frac{\textbf{Gross marketable yield}}{\textbf{Total water use (rain water+irrigation water)}}$$

For **rain-fed** crops, the fraction of rainfall used for crop transpiration is from **15 to 30%** (*Wallace*) for **irrigated agriculture 13–18%** of irrigation water delivered is used for crop transpiration (*Wallace and Gregory*).

3. The main strategies to improve crop productivity and water use efficiency

Irrig Sci (2007) 25:209–231
DOI 10.1007/s00271-007-0063-2

WATER PRODUCTIVITY: SCIENCE AND PRACTICE

A systematic and quantitative approach to improve water use efficiency in agriculture

Theodore C. Hsiao · Pasquale Steduto · Elias Fereres

$$E_{conveyance} \times E_{farm} \times \underbrace{E_{application} \times E_{ET} \times E_{assimilation} \times E_{biomass\ conversion} \times E_{yield\ conv.}}_{\text{field level}} = E_{all}$$

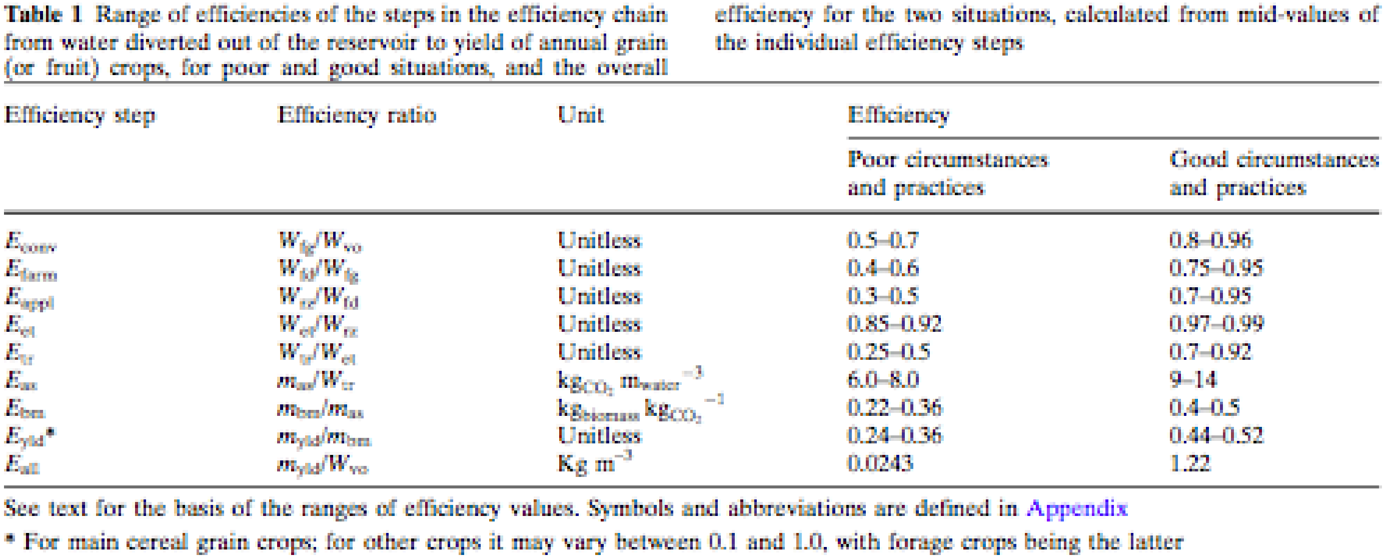


Table 1 Range of efficiencies of the steps in the efficiency chain from water diverted out of the reservoir to yield of annual grain (or fruit) crops, for poor and good situations, and the overall efficiency for the two situations, calculated from mid-values of the individual efficiency steps

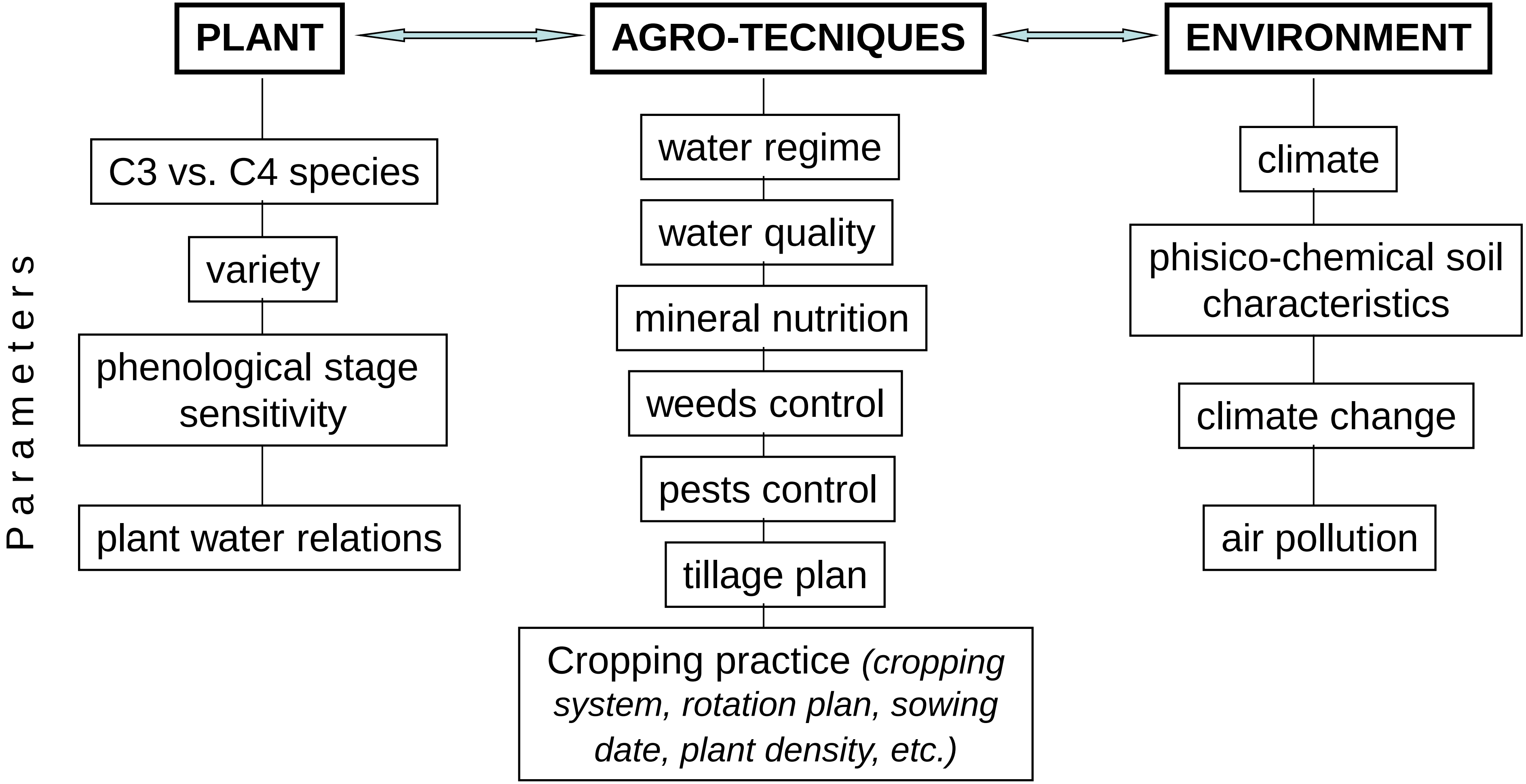
Efficiency step	Efficiency ratio	Unit	Efficiency	
			Poor circumstances and practices	Good circumstances and practices
E_{conv}	W_{lg}/W_{vo}	Unitless	0.5–0.7	0.8–0.96
E_{farm}	W_{fd}/W_{lg}	Unitless	0.4–0.6	0.75–0.95
E_{appl}	W_{rz}/W_{fd}	Unitless	0.3–0.5	0.7–0.95
E_{et}	W_{et}/W_{rz}	Unitless	0.85–0.92	0.97–0.99
E_{tr}	W_{tr}/W_{et}	Unitless	0.25–0.5	0.7–0.92
E_{as}	m_{as}/W_{tr}	$kg_{CO_2}\ m_{water}{}^{-3}$	6.0–8.0	9–14
E_{bm}	m_{bm}/m_{as}	$kg_{biomass}\ kg_{CO_2}{}^{-1}$	0.22–0.36	0.4–0.5
E_{yld}*	m_{yld}/m_{bm}	Unitless	0.24–0.36	0.44–0.52
E_{all}	m_{yld}/W_{vo}	Kg m^{-3}	0.0243	1.22

See text for the basis of the ranges of efficiency values. Symbols and abbreviations are defined in Appendix

* For main cereal grain crops; for other crops it may vary between 0.1 and 1.0, with forage crops being the latter

"Based on an equation quantifying the impact of changes in efficiency of component steps on the overall efficiency, it is concluded that generally, it is more effective to made modest improvements in several or more steps than to concentrate efforts to improve one or two steps."

sources of variability in the interaction between water and plant



Parameters

PLANT ⟷ **AGRO-TECNIQUES** ⟷ **ENVIRONMENT**

PLANT
- C3 vs. C4 species
- variety
- phenological stage sensitivity
- plant water relations

AGRO-TECNIQUES
- water regime
- water quality
- mineral nutrition
- weeds control
- pests control
- tillage plan
- Cropping practice *(cropping system, rotation plan, sowing date, plant density, etc.)*

ENVIRONMENT
- climate
- phisico-chemical soil characteristics
- climate change
- air pollution

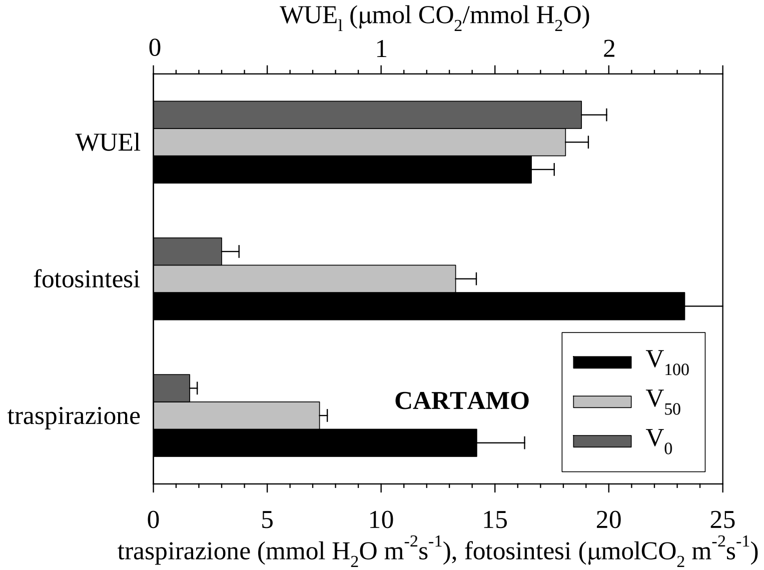
Schematic overview of the parameters involved in the determination of WUE at field level

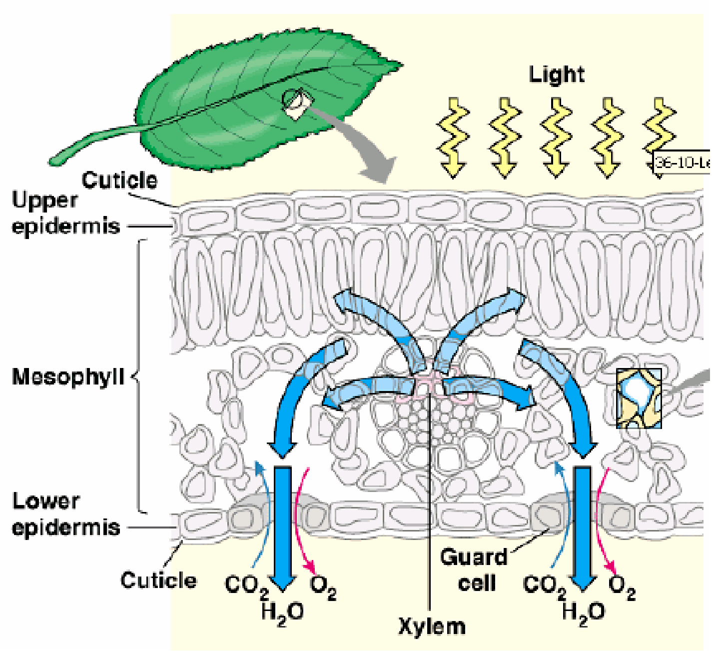
PLANT

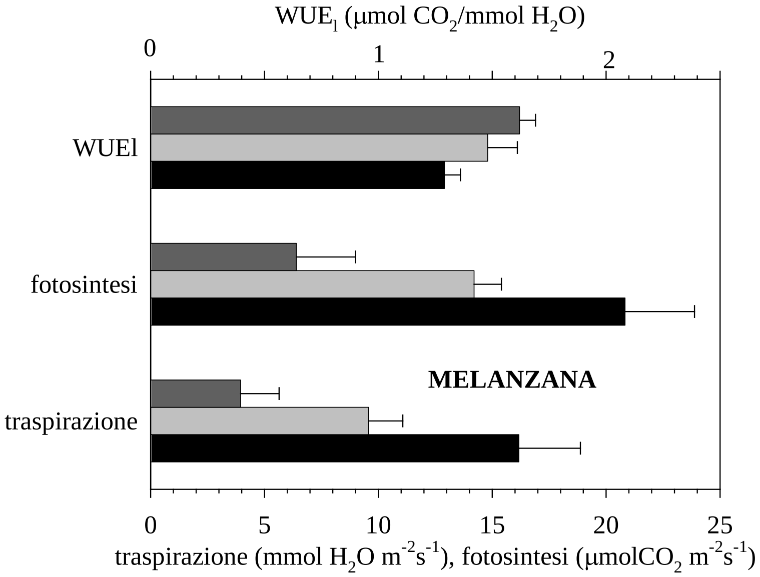
$$WUE_l = \frac{\text{Net Assimilation} \quad (\mu mol\ CO_2)}{\text{Transpiration} \quad (mmol\ H_2O)}$$

$$WUE_l = \frac{gc\ (Ca - Ci) \quad (\mu mol\ CO_2)}{gw\ (Wi - Wa) \quad (mmol\ H_2O)}$$

$$gc/gw = 0,6$$



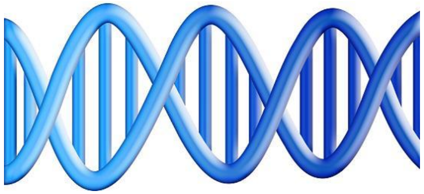


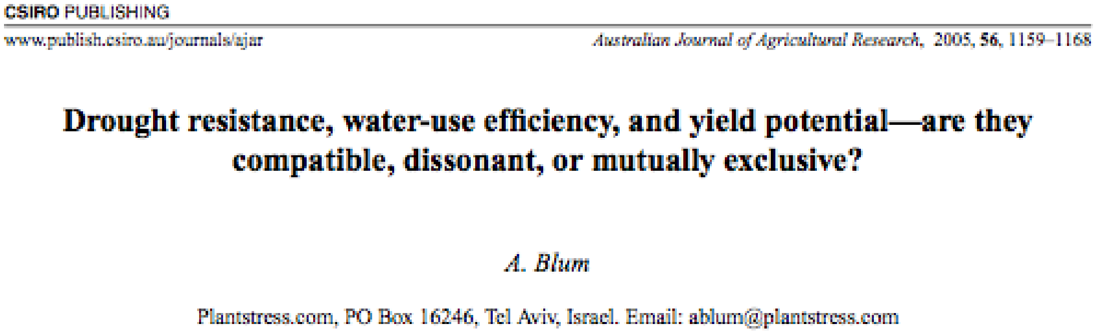


They are more water use efficient the old landrace varieties or the new high yielding cultivars?

?

PLANT BREEDING





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www.publish.csiro.au/journals/ajar
Australian Journal of Agricultural Research, 2005, 56, 1159–1168

Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive?

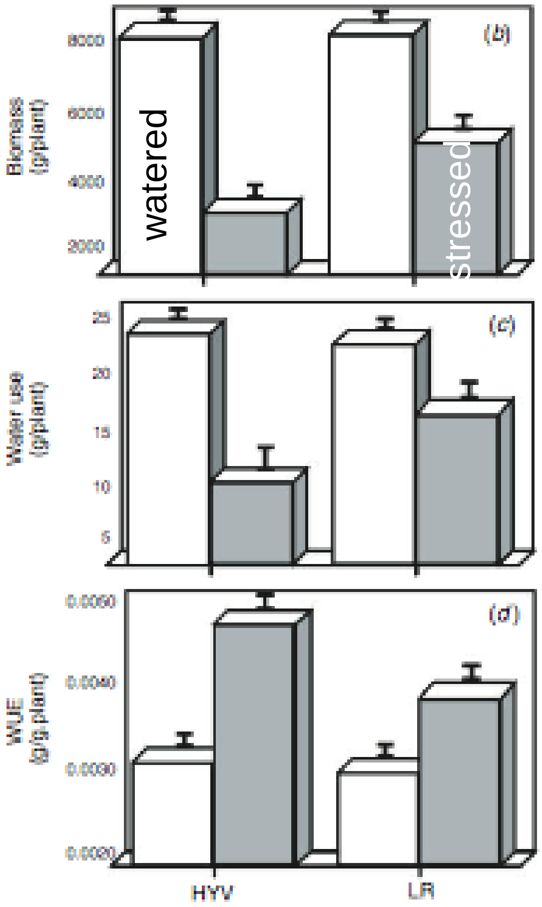
A. Blum

Plantstress.com, PO Box 16246, Tel Aviv, Israel. Email: ablum@plantstress.com

High productive cutivars mantein an higher YWUE both in well irrigated than in water stress conditions respect to landrace varieties

"Over the last century plant breeders have inadvertently selected for higher water use efficiency by selecting for higher yielding ability" (Hsiao)

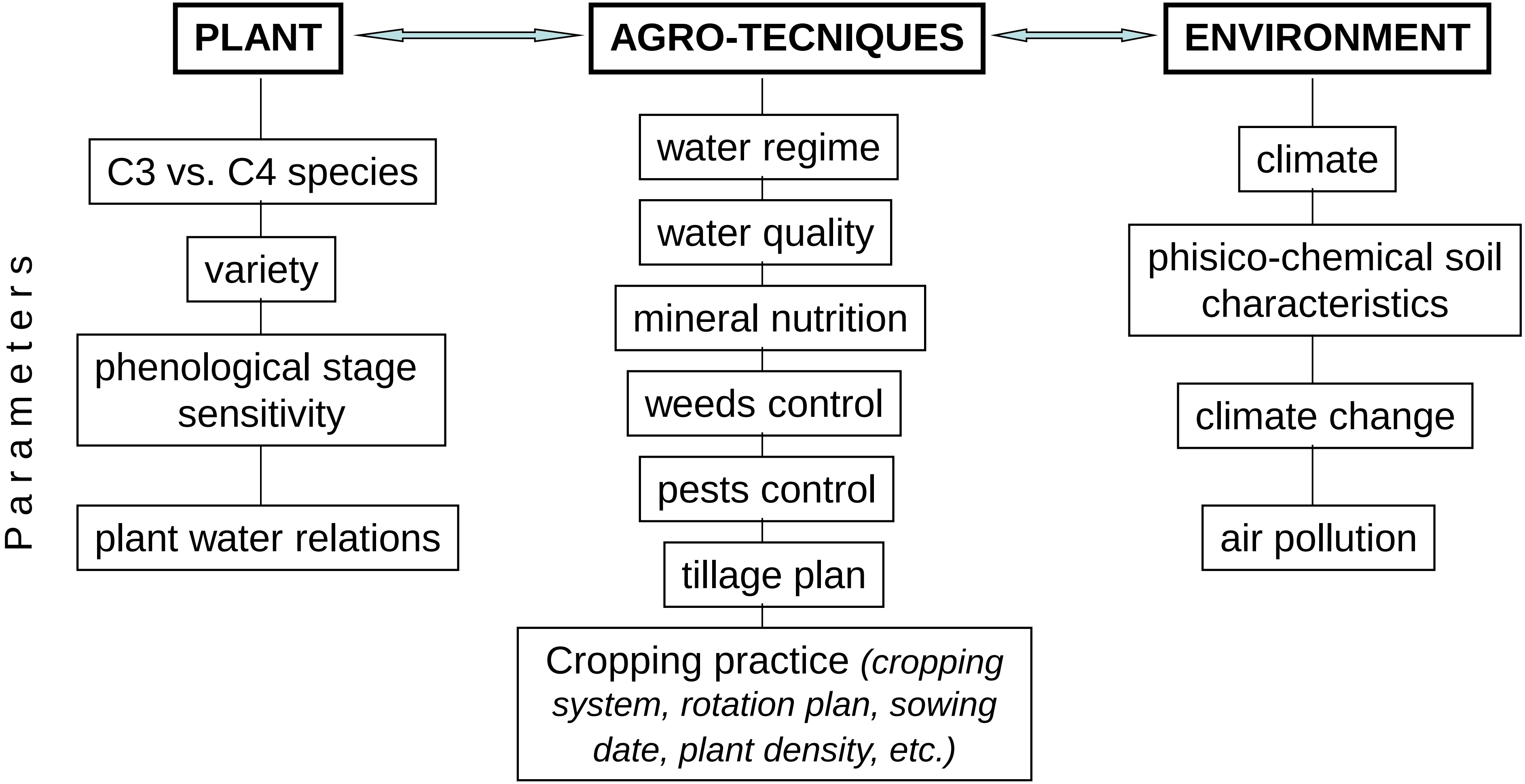
"WUE is often equated with drought resistance and improvement of crop yield in water shortage situations, without considering the fact that it is a ratio between two physiolgical (transpiration and photosynthesis) and agronomic (yield nad water use) entities.
As a ratio it is often susceptible to misinterpretation, especially when the dynamics of numerator and denominator are obscure" (LUM).



High Yielding cultivar

Landrace

sources of variability



PLANT ↔ **AGRO-TECNIQUES** ↔ **ENVIRONMENT**

Parameters

PLANT
- C3 vs. C4 species
- variety
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ENVIRONMENT
- climate
- phisico-chemical soil characteristics
- climate change
- air pollution

Schematic overview of the parameters involved in the determination of WUE at field level

If a limited amount of water is available for irrigation, is it more efficient a water regime of full irrigation on a reduced area or a water regime of supplementary irrigation on an expanded area?

Supplementary or full irrigation?

The FAO n. 33 “Irrigation & Drainage” (Doorenbos and Kassam, 1979) allowed to predict crop productivity as a response to their warter use by means of this equation (Stewart, 1997)

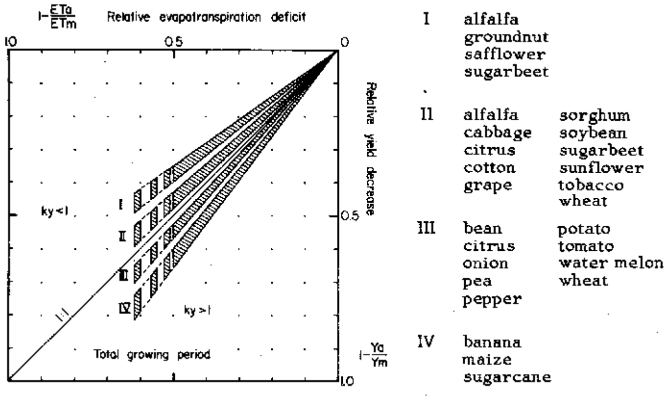
$$\left(\frac{Yx - Ya}{Yx}\right) = Ky\left(\frac{ETc - ETa}{ETc}\right)$$

(1) *Where:*

Yx *(kg ha^{-1}) and* ***Ya*** *(kg ha) are maximum and actual yield*

ETc *(m^{3} ha^{-1}) and* ***ETa*** *(m^{3} ha^{-1}) are maximum and actual evapotranspiration*

Ky is the correlation on proportionality factor between the related productivity loss and the related evapotranspiration reduction



Considering:

$$YWUE = \left(\frac{Ya}{ETa}\right) \qquad (2)$$

Kirda (2002) mathematically derived the YWUE from Eq 1 and 2 as:

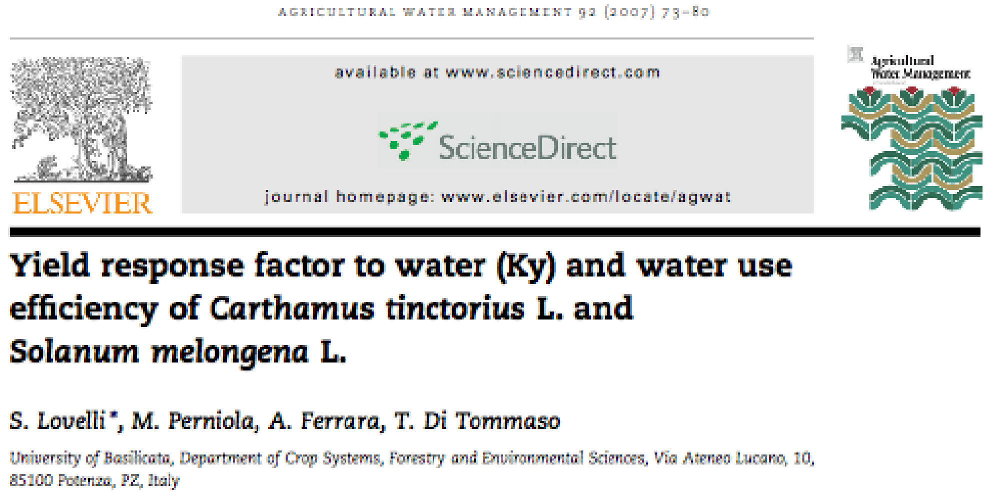
$$YWUE = \left\{Ky - \left[\frac{[Ky - 1]}{[ETa/ETc]}\right]\frac{xYx}{ETc}\right\}$$

$$YWUE = \left\{ Ky - \left[\frac{[Ky - 1]}{[ETa/ETc]} \right] \frac{xYx}{ETc} \right\}$$

Where:

Species which show a **Ky** smaller than 1 tolerate the water lack to a greater extent and they could be exposed to a water deficit; this determines a YWUE increase in water shortage conditions.

On the contrary species showing a Ky greater than 1 show a yield decrease more than proportional to the applied evapotranspiration decrease and this determines a YWUE decrease in water shortage conditions.



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Yield response factor to water (Ky) and water use efficiency of *Carthamus tinctorius* L. and *Solanum melongena* L.

S. Lovelli*, M. Perniola, A. Ferrara, T. Di Tommaso

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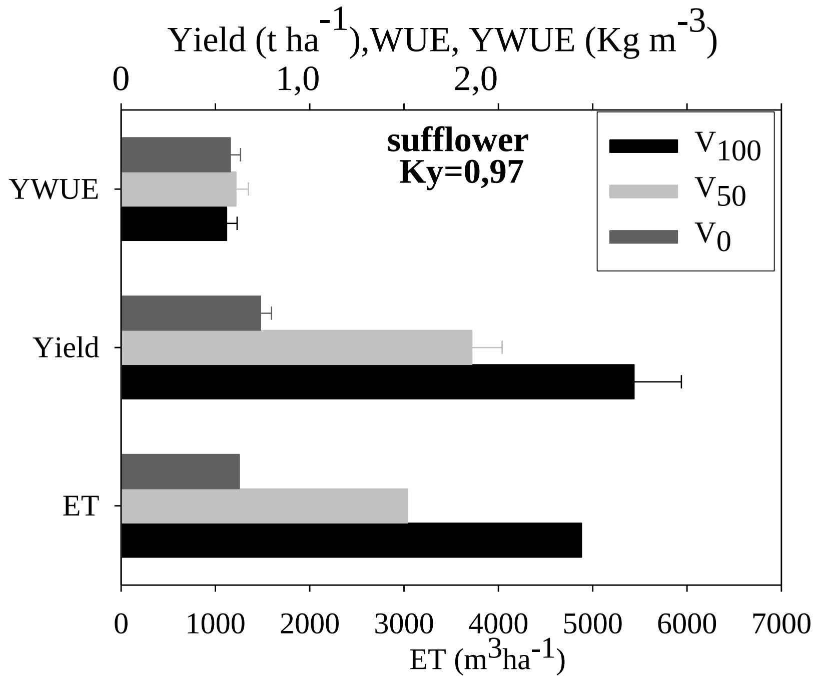

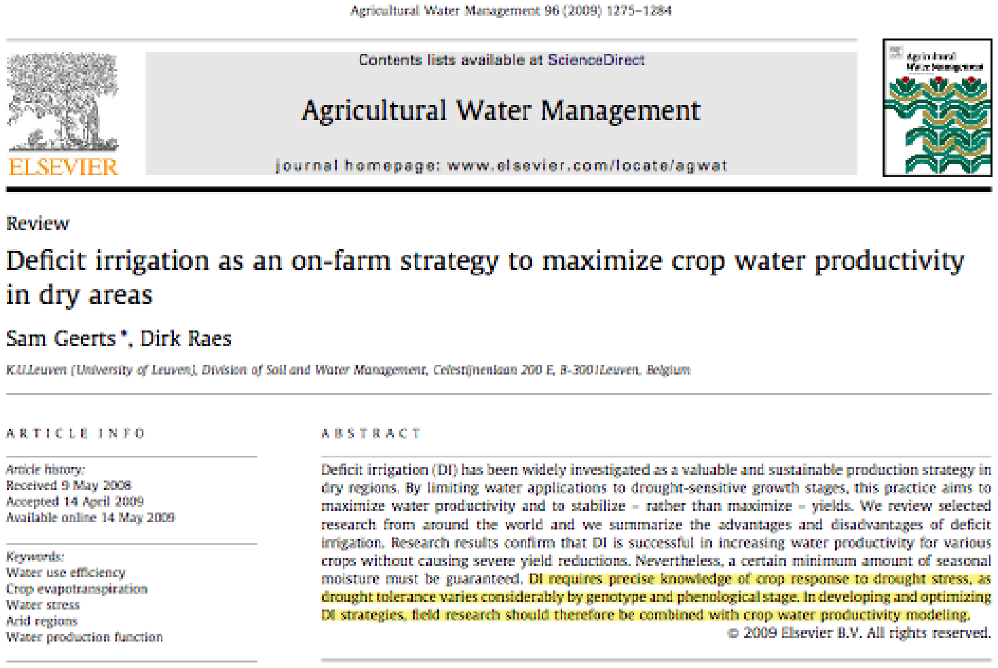

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Review

Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas

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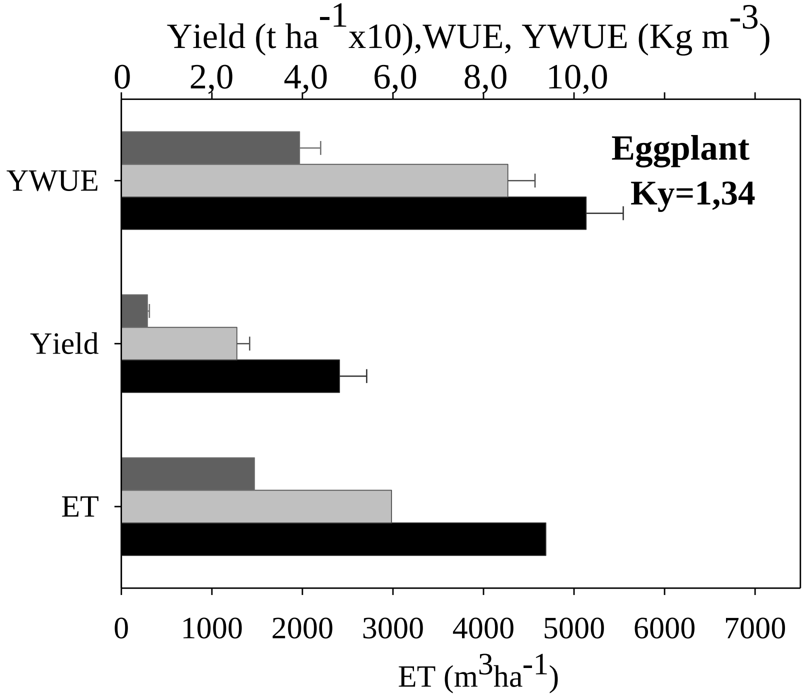
ABSTRACT

Deficit irrigation (DI) has been widely investigated as a valuable and sustainable production strategy in dry regions. By limiting water applications to drought-sensitive growth stages, this practice aims to maximize water productivity and to stabilize – rather than maximize – yields. We review selected research from around the world and we summarize the advantages and disadvantages of deficit irrigation. Research results confirm that DI is successful in increasing water productivity for various crops without causing severe yield reductions. Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed. DI requires precise knowledge of crop response to drought stress, as drought tolerance varies considerably by genotype and phenological stage. In developing and optimizing DI strategies, field research should therefore be combined with crop water productivity modeling.



$$YWUE = \left\{ Ky - \left[\frac{[Ky - 1]}{[ETa/ETc]} \right] \frac{xYx}{ETc} \right\}$$

Where:

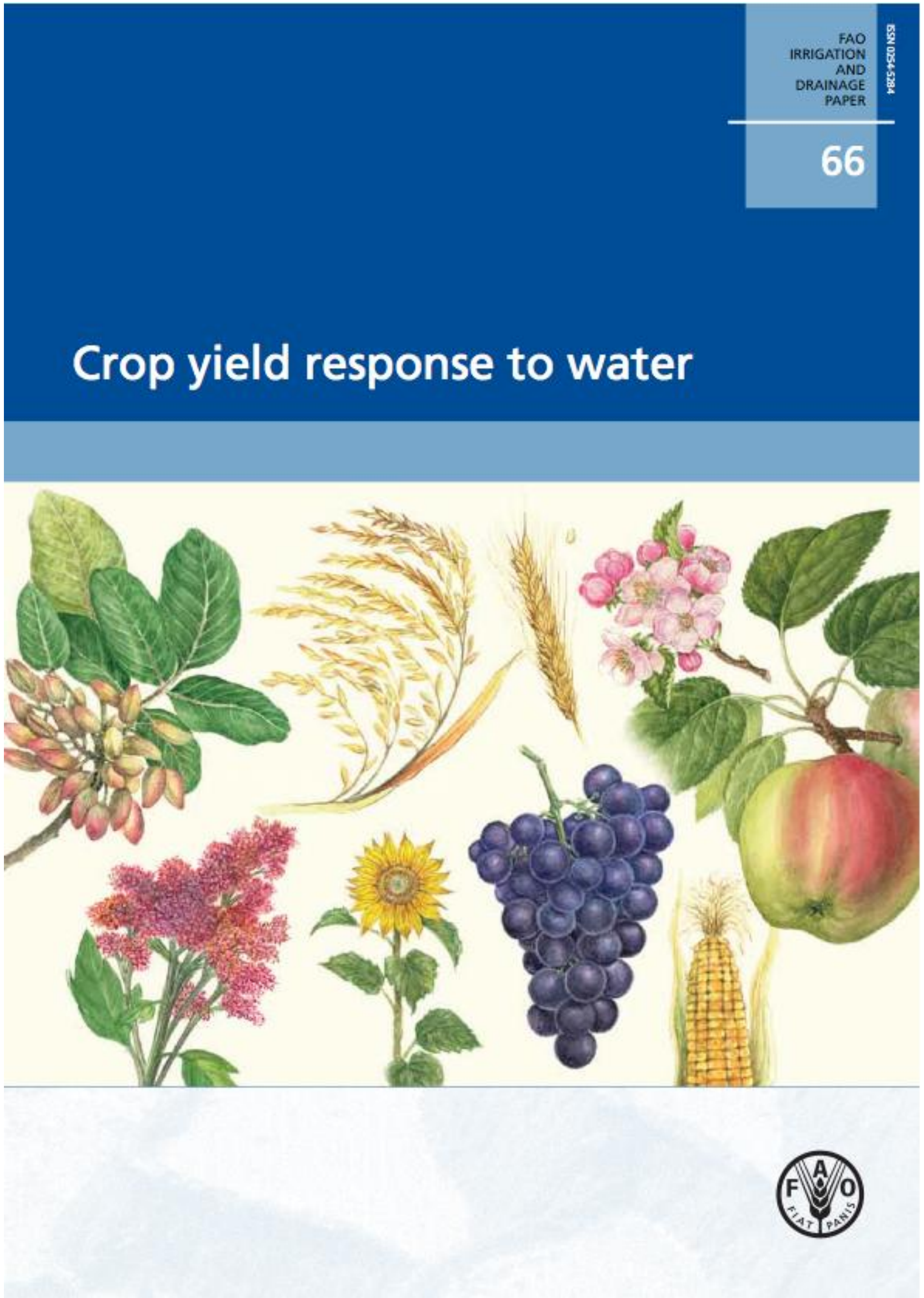
Species which show a **Ky** smaller than 1 tolerate the water lack to a greater extent and they could be exposed to a water deficit; this determines a YWUE increase in water shortage conditions.

On the contrary species showing a Ky greater than 1 show a yield decrease more than proportional to the applied evapotranspiration decrease and this determines a YWUE decrease in water shortage conditions.

“ While the FAO I&D No. 33 approach is solidly based on crop-water use principles, the simplification introduced by using one empirical yield response factor (Ky) to integrate the complex linkages between production and water use for crop production, ***limits its applicability for making accurate estimates of yield responses to water.”*** (Smith and Steduto, FAO #66, 2011)

As an example of the differences in Ky values from different studies, it is instructive to compare the results under a cooperative research programme carried out by the International Atomic Energy Agency (IAEA) against the original Ky values of the *FAO I&D No. 33*. Table 2 summarizes the comparison of Ky values as published in the *FAO Water Report No. 22*, *Deficit Irrigation*

Crop	Tr-0000			Tr-0111			Tr-1011			Tr-1101			Tr-1110		
	FAO	IAEA	(%)	FAO	IAEA	(%)	FAO	IAEA	(%)	FAO	IAEA	(%)	FAO	IAEA	(%)
Beans	1.15	0.59	-49	0.20	0.38	90	1.10	1.75	59	0.75	1.44	92	0.20	0.06	-70
	1.15	1.43	24	0.20	0.56	180	1.10	1.35	23	0.75	0.87	16	0.20	0.17	-15
Cotton	0.85	1.02	20	0.20	0.75	275	0.50	0.48	-4				0.25		
	0.85	0.71	-16	0.20	0.80	300	0.50	0.60	20		0.05				
	0.85	0.99	16				0.50	0.76	52						
Groundnut	0.70			0.20			0.80	0.74	-8	0.60			0.20		
Maize	1.25	1.33	6	0.40			1.50			0.50			0.20		
Potato	1.10			0.60	0.40	-33		0.33		0.70	0.46	-34	0.20		
Soybean	0.85			0.20	0.56	180	0.80	1.13	41	1.00	1.76	76			
Sugarcane	1.20			0.75	0.20	-73		1.20		0.50	1.20	140	0.10		
	1.20			0.75	0.40	-47		1.20		0.50	1.20	140			
Sunflower	0.95	0.91	-4	0.40	1.19	198	1.00	0.94	-6	0.80	1.14	43			
Spring wheat	1.15	1.32	15	0.20	0.55	175	0.65	0.90	38	0.55	0.44	-20		0.25	
Winter wheat	1.00	0.87	-13	0.20	2.54	1170	0.60	0.81	35	0.50	0.48	-4		0.62	



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PAPER

66

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Crop yield response to water

3. Yield response to water of herbaceous crops: the *AquaCrop* simulation model

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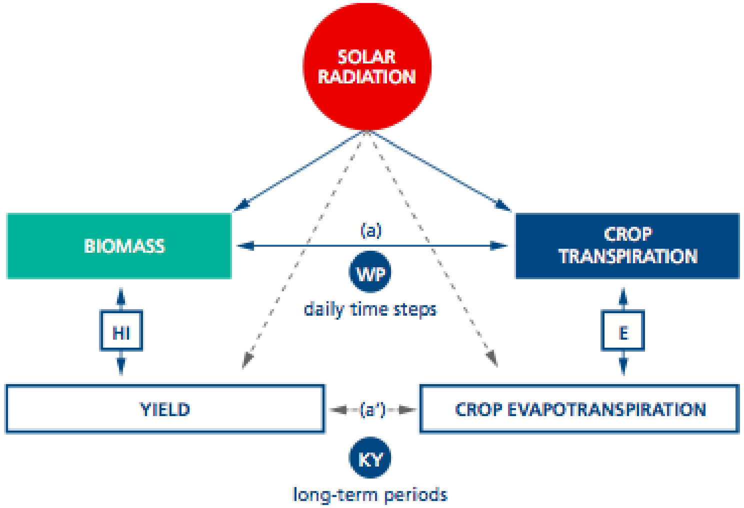

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Tanks for the attention