ARAB FUND FOR ECONOMIC & SOCIAL DEVELOPMENT

International Center for Agricultural Research in the Dry Areas

Economics of Water Productivity in Managing Water for Agriculture: Theoretical background

Training Course

Impact Assessment and Livelihood Analysis in Systems Research

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Economics of Water Use Efficiency and Productivity…WHY?

- ✓ 1/3 of the world’s population live in water scarce areas
- ✓ Many countries with chronic water scarcity
- ✓ Water for agriculture in dry areas is declining
- ✓ Climate change adds to the problems
- ✓ Energy competes

Agricultural Water

- ✓ Agriculture uses most of the water
- ✓ Agricultural water is declining
- ✓ Mostly used with low productivity

New Water.....Limited!!!

- ✓ Surface, mostly tapped
- ✓ Ground, over exploited
- ✓ Marginal-quality, small amounts, environment, health
- ✓ Desalination, costly, environment, transport
- ✓ Water transfer, cost and politics

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What does the future hold…?

<u>WATER</u>:

Water deficit is projected to increase from 50 BCM per year today to 150- to 235 BCM per year by 2050, based on the level of water use efficiency and wastewater reuse adopted, 2/3 times the physical volume of the Nile River flow…***scary!***

<u>ENERGY</u>:

Correspondingly, about 31 billion barrels of fuel is needed to desalinate about 150 BCM of water per year by 2050 (e.g., KSA today uses > 1.5 million bbls/day for desalinization)…***not sustainable***

<u>Environmental Impacts/GHG Emissions</u>:

Which corresponds to 9.6 GtC (gigatonnes of carbon) of CO_2 emissions per year by 2050….***not sustainable (global good)***

<u>And food security</u>…?

60 % of food from irrigated agriculture (21 Mha, consuming 251BCM+)

In some areas, fossil groundwater is being exploited for irrigation…***not sustainable***…rainfed plays a good role but threatened by Climate Change

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Conventional coping strategies: insufficient !!!

1. Increasing crop yield (land productivity)

Great !! but needs more water…..Which is not available

2. Improving Irrigation Efficiency

- Reflects the performance of irrigation system (engineering aspects)
- Ignores recoverable losses ???
- Nothing to do with the return to water (productivity)
- Wrongly used to judge the whole farm water management system
- Necessary to improve but will add a little at scale

3. Modernizing Irrigation Systems

- Meant for higher efficiency: not guaranteed
- Savings are not totally due to efficiency improvement

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Conventional coping strategies: insufficient !!!

4. Demand management: Pricing water

- Not working in this region
- Politically and socially infeasible
- Weak Institutions
- Innovative alternatives are needed

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Economics of Water Use Efficiency and Productivity…WHY?

Two key research questions in this area are:

- ✓ What are the best ways of allocating scarce water to the many users that need it? and
- ✓ How can we stimulate that agricultural technologies be used and/or adopted for use?

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Assessing Whole Farm Water Use Efficiency & Productivity: Approach by Indices

Key points:

1. Water use efficiency describes a relationship between system inputs and outputs;
2. Relating production outputs (such as $ or yield) to water input (M3) results in a water use index (WUI);
3. Relating water output (M3) to water input (M3) results in a dimensionless (%) irrigation system efficiency.

Note

It is important to understand the inputs and dimensions of indices and efficiency terms as well as the scale at which they are applied (Farm, Field & Crop)

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Indicators of Water Use Efficiency

What are the key indicators of water use efficiency?

Production indicators:

Increased production per unit of water

Increased value (income) per unit of water

Water conservation indicators:

Amount of water saved

Who benefits/looses from the saved/waster water?

Private and/or Social

Key Water Use Indices

✓ **Crop Water Use Index (Kg/ha/mm)**

$$= \frac{Yield\ (Tons\ per\ ha)}{Seasonal\ Evapotranspiration\ (mm)}$$

✓ **Gross Production Water Use Index (T/M3)**

= At field scale: $\frac{Total\ Yield\ (Tons)}{Total\ Water\ Applied (M3)}$

= At farm scale: $\frac{Total\ Yield\ (Tons)}{Total\ Water\ Used\ on\ Farm\ (M3)}$

✓ **Irrigation Water Use Index (T/M3)**

= At field scale: $\frac{Total\ Yield\ (Tons)}{Irrigation\ Water\ (M3)}$

= At farm scale: $\frac{Total\ Yield\ (Tons)}{Irrigation\ Water\ Supplied\ to\ Farm\ Gate\ (M3)}$

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Key Water Economic Indices

Economic Indices can be calculated by applying an economic production measure to any of the indices described before:

This measure could be:

- **Gross return**
- **Gross margin**
- **Marginal return**

✓ **Example: GPEconomicWUI ($/M3)**

=GPWUI * Crop price ($)

Other Indices

Other indices can be constructed as required, provided the inputs and dimensions are specified:

Examples:

- ✓ **Marginal Irrigation Water Use Index (T/M3)**

$$= \frac{Marginal\ Production\ due\ to\ Irrigation\ (Tonnes)}{Irrigation\ Water\ Applied\ (M3)}$$

- ✓ **Crop Economic Water Use Index ($/mm)**

$$= \frac{Gross\ Production\ (\$)}{Evapotranspiration\ (mm)}$$

Key Irrigation System Efficiency Terms

✓ **Application Efficiency (Ea-%)**

$$Ea = \frac{Irrigation\ water\ available\ to\ crop}{Water\ recived\ at\ field\ level}$$

✓ **Field Canal/Conduit Efficiency (Eb-%)**

$$Eb = \frac{Water\ recived\ at\ field\ level}{Water\ received\ at\ farm\ level}$$

✓ **Farm Efficiency (Ef-%)**

$$Ef = Ea * Eb = \frac{Irrigation\ water\ available\ to\ crop}{Water\ received\ at\ farm\ level}$$

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Other Efficiency Terms

- ✓ **Total Water Application Efficiency (%)**

$$= \frac{Irrigation\ water\ available\ to\ crop}{Total\ Water\ Applied\ (irrigation+rain)}$$

- ✓ **Farm Irrigation Efficiency (%)**

$$Ef = \frac{Irrigation\ water\ available\ to\ crop}{Water\ received\ at\ farm\ level}$$

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Assessing Whole Farm Water Use Efficiency: Quantitative (Econometric) Approach

Key points:

1. **Two types of functions can be used:**
   - **Production function:**

     $$Q\ (T/\$) = F\ (QL, QW, QS, QF, QC)$$

   - **Cost function**

     $$C\ (\$/ha) = F\ (CL, CW, CS, CF, CC)$$

2. **Type of technology**
   1. **Cobb-Douglass production and cost functions**
   2. ***Translog* production and cost functions**

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Assessing Whole Farm Water Use Efficiency: Quantitative (Econometric) Approach

Example

- **Cobb-Douglass Production function:**

  $Q = a\ L^{b}S^{c}F^{d}W^{g}e^{u}$ (1)

  Where;

  -Q: Yield of wheat (T);

  -L: Labor (mandays); S: Q of seed; F: Q of fertilizer; W: Q of water

  -**In log form:**

  $LogQ_i = \alpha_0 + \alpha_1 LogL_i + \alpha_2\ LogS_i + \alpha_3\ LogF_i + \alpha_4 LogW_i + Ui$

  $\alpha_4 = \frac{LogQ_i}{LogW_i}$: **Marginal Quantity Product (MQP):**

  The quantity (in physical units) of the additional yield obtained from the marginal increase in water quantity

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Measurement of Water Use Efficiency: Advanced Analysis
Definitions & Concepts

Definitions

Technical efficiency (TE):
Expressing the possibility of obtaining maximum production as much as possible by using fixed inputs from the technical view.

Allocative efficiency (AE):
Expressing the possibility of obtaining optimal mix, or the lowest cost of inputs used to produce a certain amount of production.

Economic efficiency (EE = AE*TE) :
Reflect the possibility of obtaining the lowest-cost mix of production inputs to obtain the possible maximum output from the use of fixed amount of inputs.

The value of the three previous efficiencies is between (0-1).

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Definitions & Concepts…cont'd

Water Use Efficiency (WUE):
The ratio of the amount of water actually utilized by the crop to the total water applied.

Water Productivity (WP):
The ratio of the amount of yield production per unit of water used.

The increase of WUE would lead to better WP

What are the objectives of water use efficiency/productivity research?

- **Increase output, Increase income**
- **Conserve water**
- **Reduce salinity**

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Measurement of Water Use Efficiency

Technical Efficiency Measures (TEM)

Output-Oriented Technical Efficiency: is a composite measure of the efficiency in the use of all inputs together for producing a given level of output.

Input Specific Technical Efficiency: measures the efficiency in water use of farm *i* relative to the most efficient user(s) of water keeping the application rates of all other inputs at their current levels.

Input Specific Technical Cost Efficiency: measures the cost efficiency in irrigation water application of a specific farm i relative to the most cost efficient user(s) of irrigation water keeping in mind the substitution possibilities between inputs as well as their relative costs.

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Assessing Whole Farm Water Use Efficiency: Quantitative (Econometric) Approach

TE Measurement: Theoretical Model

- **Production technology: Cobb-Douglass Production function:**

  $Q = a\, L^{b} S^{c} F^{d} W^{g} e^{u}$ (1)

  -**In log form:**

  $LogQ_i = \alpha_0 + \alpha_1 LogL_i + \alpha_2\, LogS_i + \alpha_3\, LogF_i + \alpha_4 LogW_i + Ui$

- **Battese and Coelli model (1995)specified for cross section data context:**

$$LnQ_i = Ln\, f\,(x_i\,;\beta) + v_i - u_i$$

$$u_i = \delta' z_i + \varepsilon_i$$

Assessing Whole Farm Water Use Efficiency: Quantitative (Econometric) Approach

TE Measurement: Theoretical Model

Technical Efficiency (TE)

$$TE_i = \exp(-u_i) = \exp(-\delta' z_i - \varepsilon_i)$$

The corresponding cost function

$$C_i = f(W_{hi}; y_i^*)$$

In this equation, C_i is the cost called "minimum" associated with the level of production Y^*_i of firm i and W_h is considered as the price of the h-th input.

Applying Shephard' lemma for the equation above, we obtain the following system:

$$\frac{\delta C_i}{\delta W_{hi}} = X_{hi}(W_i ; y_i^*)$$

Measurement of Water Use Efficiency

Efficiency Measures (EM)…cont'd

$$Y_i = f(x_i, w_i; a) \exp(\varepsilon_i \equiv v_i - u_i) \quad (1)$$

$TE_i = OB/OA$

$IWE_i = x_1C/x_1A = W_2/W_1 \quad 0 < IWEi \leq 1$

The proposed IWE measure determine both:

- The minimum feasible water use W_2
- The maximum possible reduction in water use ($W_1 - W_2$)

The farm (i) is efficient: The maximum possible reduction in water use is ($W_1 - W_2$)

Substitute $W_2 = W_1 * IWE_i$ into (1)

C in figure lies on the frontier: $u_i = 0$

$$Y_i = f(x_i, w_i^E = (w_2); a) \exp(u_i) \quad (2)$$

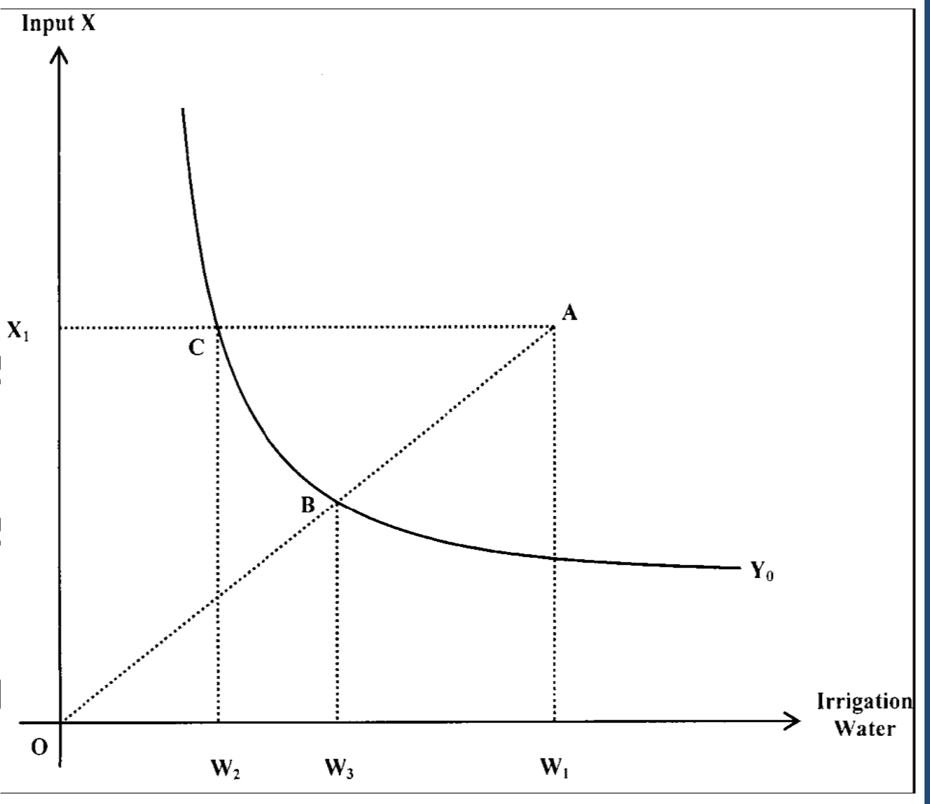

Fig.: Proposed measure of IWE

Measurement of Water Use Efficiency

Efficiency Measures (EM)…cont'd

IWE_i does not have a direct cost-saving interpretation.

According to Kopp (1981), $IWTCE_i$ is used to evaluate the potential cost savings from adjusting irrigation water to a technically efficient level.

Following Akridge (1989):

$$IWTCE_i = S_{wi} IWE_i + \sum_{j=1}^{J} S_{ji}$$

- S_{wi} : The observed cost share for irrigation water in farm i.
- S_{ji} : The observed cost share for inputs j in farm i.
- IWE_i: Irrigation water efficiency for farm i.

Measurement of Water Use Efficiency

Efficiency Measures (EM)…cont'd

The production frontier (1) is approximated by the following *translog* specification:

$$\ln y_i = \alpha_0 + \sum_{j=1}^{J} \alpha_j \ln x_{ji} + \frac{1}{2}\left(\sum_{j=1}^{J}\sum_{k=1}^{J} \alpha_{jk} \ln x_{ji} \ln x_{ki} \right) + \alpha_w \ln w_i + \frac{1}{2}\left(\alpha_{ww} \ln w_i^2 + \sum_{j=1}^{J} \alpha_{jw} \ln x_{ji} \ln w_i \right) + v_i - u_i$$

TE_i: Battese and Coelli (1995).

IWE_i: Reinhard *et al.,* (1999):

$$IWE_i = \exp\left[\left\{ -\xi_i \pm \left(\sqrt{\xi_i^2 - 2\alpha_{ww} u_i} \right) \right\} / \alpha_{ww} \right]$$

$$\text{where, } \xi_i = \frac{\partial \ln y_i}{\partial \ln w_i} = \alpha_w + \sum_{j=1}^{J} \alpha_{jw} + \ln x_{ji} + \alpha_{ww} \ln w_i$$

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Measurement of Water Use Efficiency

Efficiencies Measures (EM)…cont'd

Example:

TE=67.7%: This indicates that, on average, farmers could increase their production by as much as 32.3% through more efficient use of production inputs.

IWE=53%: This implies that the observed quantity of marketable crop could have been maintained by using 47% less irrigation water.

IWTCE= 70.8%: This suggests a potential reduction of 29.1% of the total cost if irrigation water is adjusted to its efficient level.

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Measurement of Water Use Efficiency

Explaining Efficiency Differentials

Example:

Regression analysis:

TE = F(Set of social, economic, environmental and institutional variables)

IWE = F(Set of social, economic, environmental and institutional variables)

IWTCE = FF(Set of social, economic, environmental and institutional variables)

Technology Evaluation

➢ **Basic Concepts:**

1. Identify the technology
2. Describe the advantages
3. Develop explicit and transparent budget to assess it economic feasibility
4. Identify constraints to adoption
5. Estimate adoption rates

➢ **Technology Assessment Tools**

1. Margin Rate of Return - MRR

2. Cost Benefit Analysis - CBA

Measurement of Irrigation Efficiency
Assessment of technology

Methodology:

1) Marginal Rate of Return (MRR)

The benefits of production increase can be analyzed by a procedure called MRR

MRR is an important indicator of potential technology adoption by farmers from financial point of view.

The value of saved water can be included in to MRR analysis to give it some economic dimension.

Marginal Rate of Return

Procedure for Measuring MRR

○ Productivity gain (YG)	= New yield-old yield
○ Price of the crop	= P
○ Gross additional income (GAI)	=YG x P
○ Cost of the technology	= CT
○ Net margin (NM)	= GAI-CT
○ MRR	= (NM/CT)*100

Rule of Thumb: MRR must be at least 40%

Practical Example

<u>Problem facing Water-use efficiency researchers?</u>

Assume that:
you developed a technology that improve water use efficiency in wheat

which have

an expected yield gain of 15%
and

will save 1000 cubic meters of water per ha.

Should the farmers adopt that technology?

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Practical Example

The answer depends on many factors:

1. Fixed cost of adoption
2. Price of wheat
3. Variable cost of the technology
4. Profitability of technology
5. Social acceptability of the technology
6. Economic value of water saved
7. Existence of other social or environmental benefits

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Cost Benefit Analysis (CBA)

- **Stages in the application process:**

1. Identify all costs and benefits
2. Measure them
3. Discount them back to common time period
4. Assess whether benefits>costs
5. Assess who bears the benefits and costs
6. Perform sensitivity analysis
7. Assess whether proposal is worth it

Benefit-cost analysis of technologies using Partial Budget Analysis

		Without technology					With technology option		
1	**Costs**	**A**	**B**	**C**		**Costs**	**D**	**E**	**F**
2	**Inputs**	**Quantity**	**Unit price**	**Total**		**Inputs**	**Quantity**	**Unit price**	**Total**
3	seeds					seeds			
4	Water					Water			
5	pesticides					pesticides			
6	labor					labor			
7	fuel					fuel			
8	machiney					machiney			
9	**Total**	**XX**	**XX**	**XX**		**Total**	**XX**	**XX**	**XX**
10									
11	**Revenue**					**Revenue**			
12	Main product					Main product			
13	Secondary product					Secondary product			
14	**Total revenue**	**XX**	**XX**	**XX**		**Total revenue**	**XX**	**XX**	XX
15									
16	**Indicators**								
17	Net returns			**C14-C9**					**F14-F9**
18	% change in NR							**(F17-C17)/C17**	
19	% change in TC							**(F9-C9)/C9**	
20	MRR						**Change NR/Change in TC**		
21	Benefit-cost Ratio			**C14/C9**					**F14/F9**

We Welcome Your Feedback!

Thank You!

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