A close-up of a metal faucet in a desert landscape. The faucet is on the left, and a small green plant is growing in the foreground. The background is a vast, flat, sandy desert under a clear blue sky.

How to Assess Agricultural Water Productivity: Looking for Water in the Agricultural Productivity and Efficiency Literature

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Outline

- 1. Rationale: Why Agricultural Water Productivity?**
2. Concepts and Methods
3. Findings of Literature Survey
4. Conclusions

1. Rationale

It is widely believed that we are facing **two emerging and unprecedented crises** involving agricultural water management:

- global water crisis
- global agricultural crisis

In order to at least partially respond, it is increasingly recommended that efforts should **focus on improving agricultural water productivity.**

Why Agricultural Water Productivity?

Given the large amounts of water involved, and the widely held belief that water use in agriculture is relatively inefficient, it is thought that even small improvements in agricultural water productivity could have large implications for local and global water budgets.

Such improvements would allow

- **higher** agricultural production with the **same** amount of water, or
- the **same** amount of agricultural production with **less** water, thus lead to **water savings** that could be reallocated to other higher-value uses.

Improving Agricultural Water Productivity as Important Policy Goal

Global Water Partnership (2000)

An important global water security target is the increase in water productivity for food production by 30% in 2015.

World Water Council (2000)

To avoid intensification of the water crisis, about half of the increased demand for agricultural water use in 2025 should be met by increases in water productivity.

United Nations World Water Assessment Programme (UNESCO, 2009)

Crop water productivity increases are called for with the aim of reducing pressure to develop new supply sources or increase water allocation to agriculture.

Food and Agriculture Organization of the United Nations (2012)

Demand management is an important option to cope with water scarcity, with increasing agricultural water productivity as the single most important avenue for managing water demand in agriculture.

Problems with Agricultural Water Productivity

- Most reports and public communications are **vague on the meaning of “agricultural water productivity”**. If a definition is given or implied, it is usually along the lines of “more crop per drop”, emphasizing water as if it were the only agricultural input that mattered.

For example:

“...we need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water, or ‘more crop per drop’”.

(Kofi Annan in an address to a summit of the Group of 77 developing countries, 2000)

- There is **little discussion about the instruments** available for improving agricultural water productivity, and which interventions may be suitable and feasible in a particular situation.
- **Little attention is paid to monitoring and measuring the results** of the different interventions, and thus measurements showing positive results of interventions (such as water savings) continue to be rare.

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2. Concepts and Methods

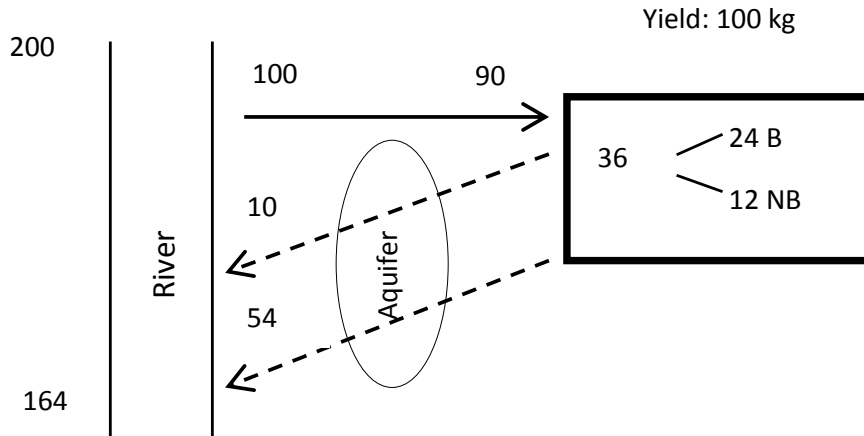
Different disciplines, such as irrigation engineering and economics, use the concepts (irrigation water) productivity and efficiency in different ways.

There is little communication across disciplines.

- For example, irrigation engineers tend to focus on physical aspects, and often use “**irrigation efficiency**” --in its basic form defined as ratio of water consumed by crops to water applied (on-farm irrigation efficiency).
- The concept of “**more crop per drop**” (in its common and widespread use) partly relates to this.
- Various problems are associated with this conceptual framework.

“Irrigation Efficiency” and “Crop per Drop”

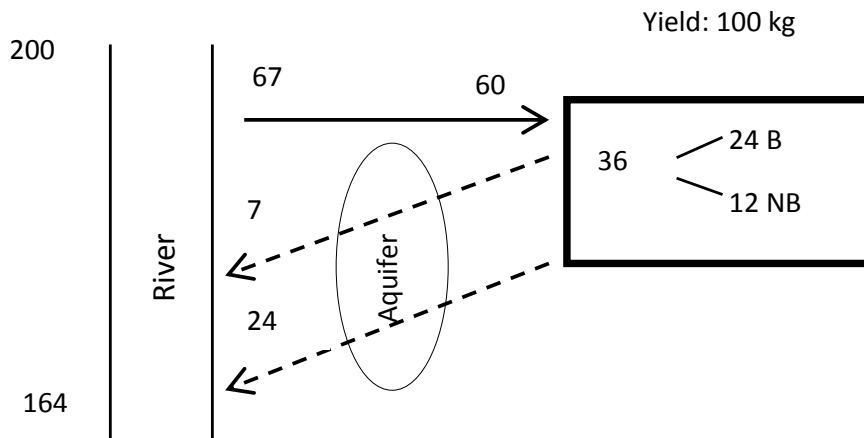
Case (i): 40% (On-Farm) Irrigation Efficiency



	Water Measure (m ³)	AWP (kg/m ³)
Water withdrawn	100	1
Water applied	90	1.1
Water consumed	36	2.8

“Irrigation Efficiency” and “Crop per Drop”

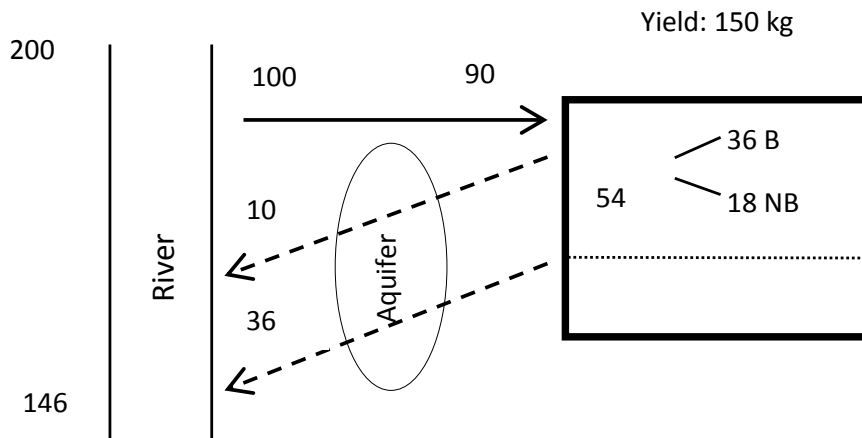
Case (ii): 60% (On-Farm) Irrigation Efficiency, no Water Spreading



	Water Measure (m³)	AWP (kg/m³)
Water withdrawn	67	1.5
Water applied	60	1.7
Water consumed	36	2.8

“Irrigation Efficiency” and “Crop per Drop”

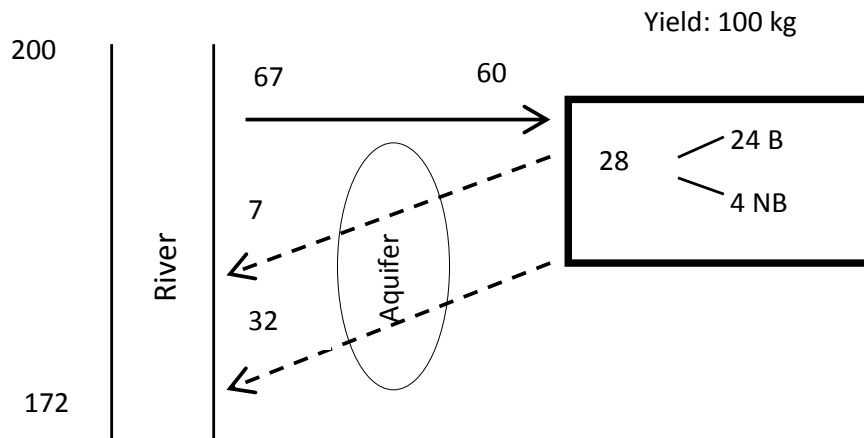
Case (iii): 60% (On-Farm) Irrigation Efficiency, Water Spreading



	Water Measure (m³)	AWP (kg/m³)
Water withdrawn	100	1.5
Water applied	90	1.7
Water consumed	54	2.8

“Irrigation Efficiency” and “Crop per Drop”

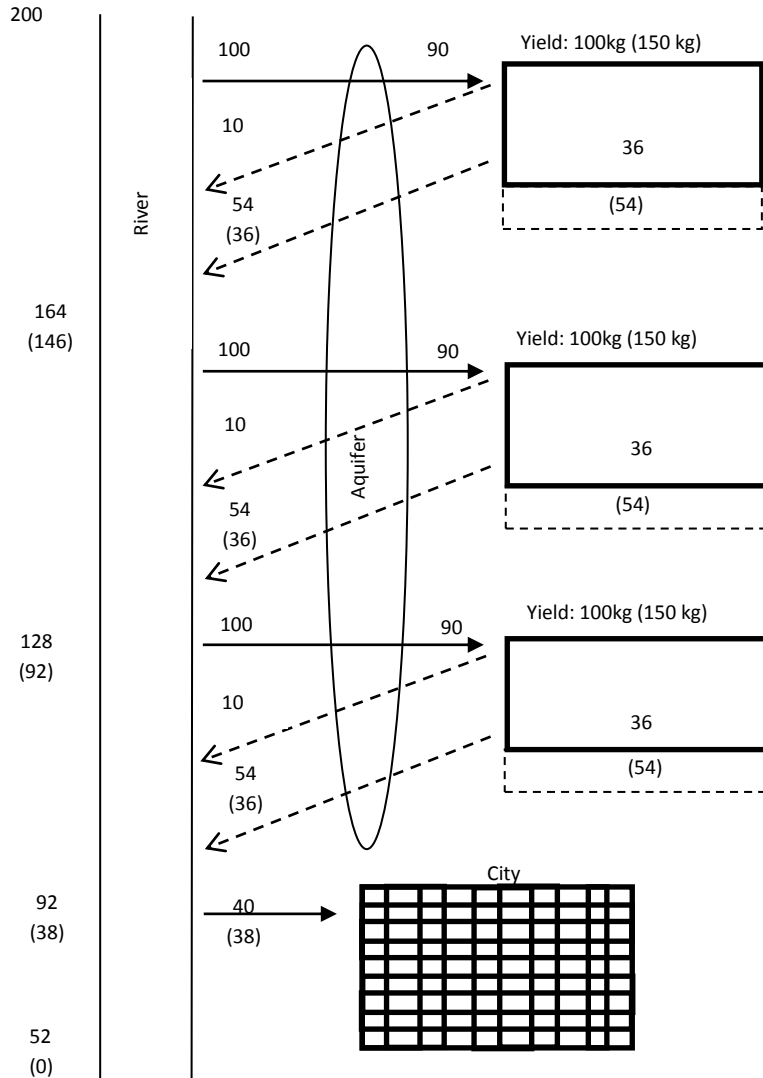
Case (iv): 60% (On-Farm) Irrigation Efficiency, no Water Spreading,
Reduction of Non-Beneficial Consumptive Use (NB) by Two-Thirds



	Water Measure (m ³)	AWP (kg/m ³)
Water withdrawn	67	1.5
Water applied	60	1.7
Water consumed	28	3.6

Basin-Wide Effects

(On-Farm) Irrigation Efficiency Increase from 40% to 60%, Water Spreading



Insights from Illustrations

Need to revisit the use of “crop per drop” ratios as

- productivity measures, and
- in particular for addressing productivity issues at the basin-level.

Key shortcomings:

- Only one input (water) is considered.
- Productivity increases only stem from technological progress (possible efficiency gains are not considered).
- Prices are not accounted for.

Economic concepts are better suited to address some of the shortcomings.

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3. Findings of the Literature Survey

Findings are from a first attempt to survey the agricultural productivity and efficiency literature with regard to the explicit inclusion of water aspects in productivity and efficiency measurements.

The aim is to contribute to the discussion on how to assess and possibly improve agricultural water productivity.

Main Methods Surveyed:

- 3.1 Single-Factor Productivity Measures
- 3.2 Total Factor Productivity (TFP) Indices
- 3.3 Frontier Models
- 3.4 Deductive Methods

3.1 Single-Factor Productivity Measures

(i) Review of Studies

- SFP studies use various methods to measure ‘water productivity’ across locations and time periods for comparison to other studies and/or to identify factors causing the differences.
- Enormous differences in spatial and temporal water productivity values are documented; variations are often attributed to the water input.
- Authors use these findings to explain the potential scope for improvement and to make policy recommendations, e.g. increase international food trade or upgrade irrigation technologies.
- With a few exceptions, studies do not rigorously analyze the effect of various factors on water productivity values (e.g. via regression analysis as in Alauddin and Sharma, 2013; Belloumi and Mattoussi, 2006).

3.1 Single-Factor Productivity Measures

(ii) Typical Features

Factors: One input (water), one output (usually crop yield or revenue)

Scale: Any scale, from field and basin level (and global)

Water Variable: Water withdrawn, applied, consumed (as quantity)

Prices: Sometimes considered for output, not for input; variable and fixed costs are not taken into account

Economic Approach: Implicit water-crop production function (yet usually without consideration of other inputs); no underlying economic model

Focus: Partial productivity

Aim: Maximizing “crop per drop” ratios

3.1 Single-Factor Productivity Measures

(iii) Assessment

- Pros:**
- Simple approach
 - Ratios easy to compute and compare
- Cons:**
- All variations in output attributed to one input
 - Average, not marginal productivity
 - No consideration of possible input or output substitution
 - No prices or costs considered
 - No insight into variables that cause differences
 - Little value for policy analysis
- Further Development:**
- Few studies combine SFP with regression analysis for analysis of influencing variables. Possibly lessons from partial productivity research on labor and capital.

3.2 Total Factor Productivity (TFP) Indices

(i) Review of Studies

Empirical studies using TFP indices measure changes in agricultural productivity over time or across countries.

- Review focused on a number of studies published in two recent books: Alston *et al.* (2010) and Fuglie *et al.* (2012).

Only a few studies account (indirectly) for water.

- A recent review of agricultural productivity studies concluded that future studies should make an effort to investigate the effects of irrigation and rainfall (Darku *et al.*, 2013) .

3.2 TFP Indices

(ii) Typical Features

Factors: “All”/multiple inputs, “all”/multiple outputs

Scale: Usually whole agricultural sector at the national level

Water Variable: Water usually only indirectly taken into account (for example, by distinguishing between irrigated and non-irrigated cropland); irrigation fees are sometimes included

Prices: Used to aggregation of inputs and outputs (though prices are not required for some indices); for water only irrigation fees included (if at all)

Economic Approach: Growth theory

Focus: Technological progress

Aim: Gauging technological progress over time and/or across countries

3.2 TFP Indices

(iii) Assessment

- Pros:** - Analysis of overall performance of a country's agricultural sector across
- Cons:** - Difficulty of including water (data lacking at national level, both for quantity and price), and thus little insights into effect of water on productivity.
- Typical assumption of technically efficient firms may not be true. (Inefficiency can be tackled with Malmquist index.)

Further Development:

So far only few studies use TFP indices at subnational level (e.g. district) and include water (e.g. as dummy variable) to study the effect of water.

3.3 Frontier Models

(i) Review of Studies

Prevalent methods:

- deterministic frontier models
- stochastic frontier models
- Data Envelopment Analysis.

Review built on a meta-analysis of frontier models with a focus on farm-level studies: 167 studies from 1979 to 2005 (Bravo-Ureta *et al.*, 2007).

- Of these, 28 studies presented models that incorporated water. Yet most either included water as one of numerous inputs, or grouped water with other miscellaneous factors in a combined input, without explicitly analyzing water's role in technical efficiency.
- Only six studies incorporated water in more details.

Review also included studies beyond the meta-analysis. Of these, McGuckin *et al.* (1992) and Karagiannis *et al.* (2003) have a specific focus on water.

3.3 Frontier Models

(ii) Typical Features

Factors: One (or more) outputs, multiple inputs

Scale: Usually at farm level

Water Variable: Water used/applied

Prices: Usually not included

Economic Approach: Underlying economic model with SF

Focus: Technical efficiency (seldom allocative efficiency and/or technological progress)

Aim: Moving to production frontier

3.3 Frontier Models

(iii) Assessment

- Pros:**
- Analysis of extent of inefficiency and factors influencing inefficiency
 - Water-related policy recommendations possible
- Cons:**
- Aggregation beyond farm level difficult (thus return flows and basin level issues are not incorporated)
 - Bias from omitted variables
 - Time series analysis not possible (yet panel data can be used)
 - Deterministic frontier models assume any deviation from frontier to be due to inefficiency (yet stochastic frontier models allow the separation of random 'noise')
- Further Development:**
- So far few studies with an inclusion of water, and fewer with explicit conclusions with respect to water.
 - Move beyond production frontier approach to profit frontier approach is possible.

3.4 Deductive Methods

(i) Review of Studies

Applications comprise

- crop budgets
- mathematical programming methods (optimization models), and
- computable general equilibrium (CGE) models

Crop budgets and mathematical programming widely used in irrigation economics

Yet deductive methods are usually not mentioned in the productivity and efficiency literature (even though they can also examine technological change)

3.4 Deductive Methods

(ii) Typical Features

Factors: Inclusion of wide range of outputs and inputs possible

Scale: Variable from farm to irrigation scheme to basin level (CGE at national level)

Water Variable: Water withdrawn, applied, consumed (except CGE)

Prices: Included for inputs and outputs

Economic Approach: Normative (neoclassical) economics, welfare theory

Focus: Economic efficiency; possibility of including exogenous technological progress

Aim: Deriving producers' net income

3.4 Deductive Methods

(iii) Assessment

- Pros:**
- Well suited for policy analysis
 - Flexible for reflecting any desired future economic and technological conditions
 - Economic model can be linked with biophysical models (more limited with CGE)
- Cons:**
- Constructed empirical and behavioral models
 - Firms are assumed to be at production frontier
 - More realistic deductive methods may require extensive data collection and model-building proficiency
- Further Development:**
- Few studies so far include water consumption.

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4. Conclusions

- When looking for water in the agricultural water productivity and efficiency literature, it becomes apparent that numerous studies have examined the question of agricultural water productivity—using a wide range of definitions and methods (and also advocating a wide range of interventions).
- A key finding is that
 - most studies either incorporate field- and basin-level aspects but focus only on a single input (water), or
 - they apply a multi-factor approach but do not tackle the basin level.
- It seems that no study on agricultural water productivity has yet presented an approach that accounts for multiple inputs and basin-level issues.

4. Conclusions

Going forward, it will be important to achieve progress on several fronts:

- Studies should lay out much clearer the objectives they are pursuing, and be more transparent about their respective limitations (especially if partial approaches are used).
- More data need to be gathered on the different measures of agricultural water use (even though the special characteristics of water make this a more difficult and costly endeavor compared to most other factors involved in agricultural production).
- More intensive collaboration between the various concerned disciplines may well help to arrive at more comprehensive approaches.

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