Agricultural Water Management 184 (2017) 28–35

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Review

An analytical review of irrigation efficiency measured using deterministic and stochastic models

Helga Pereira*, Rui Cunha Marques

CESUR, CERIS, Universidade de Lisboa, Avenida Rovisco Pais, n.°1, 1049-001, Lisboa, Portugal

ARTICLE INFO

Article history:
Received 20 September 2016
Received in revised form
26 December 2016
Accepted 31 December 2016

Keywords:
Water use efficiency
Technical efficiency
Data envelopment analysis
Irrigation
Literature survey

ABSTRACT

This article aims to provide a comprehensive review of the empirical literature on methodologies applied to measure irrigation efficiency.

Evaluating production unit efficiency is important for strategic purposes (comparison between production units), for planning purposes (evaluation of the use of different combinations of factors) and for decision making (to improve current performance, by analysing the differences between current and potential production).

We found more than thirty studies using deterministic and stochastic methods for measuring efficiency. These studies intended to measure efficiency and study its determinants and to compute efficiency as a tool for benchmarking or only estimating efficiency. Several methodologies were used, although the most popular technique adopted was data envelopment analysis (DEA). The DEA method is frequently combined with a second-stage analysis to better understand the source of inefficiency.

Several conclusions were drawn and discussed in this document. Of the thirty-two studies analysed, 87.5% determined efficiency using deterministic methods. Of these, the most frequently used methodology was DEA. These studies led to the conclusion that in general, farms are considerably inefficient with respect to water use, and some factors can contribute to its improvement, such as agricultural training, good crop choice, adoption of an extension advice service, not fragmenting the land or having larger farm sizes, a high education level, installing localized irrigation, being owners-operators and having access to better credit opportunities.

Contents

* Corresponding author.
E-mail address: helgapereira@tecnico.ulisboa.pt (H. Pereira).

http://dx.doi.org/10.1016/j.agwat.2016.12.019
0378-3774/

1. Introduction

"Agriculture is an activity (of Man), carried out primarily to produce food and fiber (and fuel, as well as many other materials) by the deliberate and controlled use of (mainly terrestrial) plants and animals" (Spedding, 1988). From the mid-20th century onwards, the concept of agriculture has changed substantially. It has become an economic activity and it is no longer a subsistence activity that produces food for the family who works the land. Between 1960 and 1995, the global use of nitrogen fertilizer increased and agriculture became an activity intended to maximize profit. The quality of the products, food safety and natural resources began to have a major impact on this activity in the 1990s.

Currently, both farmers and managers may work the land. The type of labor includes family labor, hired labor or a combination of both. The products are not aimed at the family's food needs but rather at the needs of larger markets.

Since this has become a relevant economic activity, agricultural producers want to maximize revenues by maximizing production and also aim to minimize costs and inputs (or resources) to ensure maximum profit. Inputs include labor, fertilizers, pesticides, machine utilization, plants or seeds and irrigation supply (Spedding, 2003).

The agricultural sector has a high risk that depends on many factors. Some of these factors are controllable, e.g. the inputs mentioned above. Other factors are not controllable, such as the soil and climate. Currently, it is possible to manage some soil characteristics, but the climate changes constantly and is becoming increasingly acyclic, with long periods of drought and periods of high intensity rainfall. It is also possible to control climatic instability using greenhouses, but their costs are very high, which may not be appropriate for most crops and farmers.

The current climatic trend is for dry periods to lengthen. However, the water needs of crops will remain the same; therefore, irrigation supply will become increasingly important. In addition, the water resources cannot increase to meet the increasing global demands. Therefore, water should be used with care, and we have to be efficient (OECD, 2014).

There are numerous studies on the efficiency of urban water use. However, little is known about agriculture, which uses 70% of the total amount of global water (Clay, 2004). There are some studies on this subject, however, few studies have measured irrigation efficiency or explained the methodology used.

Therefore, in this article, we intend to provide a comprehensive literature review of irrigation efficiency, using deterministic and stochastic methods, to understand the objectives of the studies conducted, the commonly used methodologies and the conclusions drawn by the authors. Consequently, we complied data in a database and extracted the required information to be analysed.

Note that there are other approaches to reviewing articles on water management and/or irrigation efficiency. For example, Tarjuelo et al. (2015) reviewed the main technical aspects of irrigation modernization and improvement relative to water and energy management, and Iglesias and Garrote (2015) aimed to facilitate an improved understanding of the potential implications of climate change and adaptation options for agricultural water management, thereby assisting policy makers as they take up the adaptation challenge. In addition, Mei et al. (2013) reviewed studies on the physiological factors that affect water use efficiency at the individual plant level, and Ali and Talukder (2008) discussed the factors that may affect water productivity in irrigated and dry-land agriculture. Finally, Zoebl (2006) discussed the concept of water productivity and its use.

However, this literature review differs from the above-mentioned cases in the sense that we aim to identify the irrigation decision-making unit and to correspond this to an agriculture unit, i.e., a family, company, region or country. Our literature review aims to compile all the studies that analysed irrigation efficiency in this scope through deterministic and stochastic methods.

After this brief introduction, the paper is organized as follows. Section 2 addresses the definition of water efficiency used in our approach, while Section 3 consists of the narrative review, focusing on the types of publications, countries, data from the studies and the authors of those studies. Section 4 further explores the studies analysed, including their objectives, the methodology applied to achieve those objectives, the inputs and outputs used and the conclusions reached by the authors with respect to policy implications. Finally, Section 5 provides some concluding remarks.

2. The concept of efficiency

In 1957, Farrell stated that "when one talks about the efficiency of a firm, one usually means its success in producing as large as possible an output from a given set of inputs." This is a very general idea of efficiency but was remarkable at that time.

Later, Barrett Purcell & Associates, Pty, Ltd. (1999) stated that "efficiency, in the technical sense, is a dimensionless number, being an output/input ratio, usually expressed as a percentage.T̈he performance of a farm can be evaluated based on different efficiency measures namely: technical efficiency (TE), allocative efficiency (AE), economic (or cost) efficiency (EE), overall technical efficiency (OTE), pure technical efficiency (PTE), scale efficiency (SE), sub-vector efficiency, water use efficiency (WUE), irrigation water use efficiency (IWUE) and irrigation water technical cost efficiency (ITCE).

TE is defined as "the ability of the farm to use feasible amounts of inputs to produce a given level of output" (Coelli et al., 2002). AE "refers to the degree to which inputs are used in optimal proportions, given the observed input price and the value of the outputs produced" (Speelman et al., 2009). EE is calculated as the product of TE and AE.

OTE measures TE under the assumption of constant returns-to-scale (CRS) technology. Pure technical efficiency is obtained by estimating the efficient frontier under the assumption of variable returns-to-scale (VRS) technology. It is a measure of TE without SE and purely reflects the managerial performance to organize the inputs in the production process (Kumar and Gulati, 2008). SE is measured as the ratio between OTE and PTE.

The sub-vector efficiency estimates the relative input reduction potentials in based on individual inputs or a subset of the inputs, maintaining the other inputs and outputs constant (Chebil et al., 2012). In this specific case, the individual input is always irrigation water because of the importance of the growing water scarcity and the concerns about the future introduction of water pricing. Thus, in this case, we can say that the sub-vector efficiency is used to estimate the reduction potential, or excess, of the irrigation water used. This efficiency measure can be called WUE (Frija et al., 2009) or, in the case of irrigated production, it can be called IWUE. All the above measures are dimensionless. ITCE can be defined as the potential cost savings from adjusting irrigation water to a TE level while holding all other inputs at observed levels (Chebil et al., 2012).

Farmers and agronomists usually, use the term "Efficiency" not in a strictly dimensionless manner but rather as a performance indicator. Agriculturally speaking, many studies consider the TE of irrigation as the ratio of effective water used, i.e., the ratio of the plant water requirement and the actual amount of water applied to these plants (Barrett and Associates Purcell, 1999; Burt et al., 1997; Wang et al., 1996). It is a physical measure of a given irrigation technology presuming a level of management, and thus it is not