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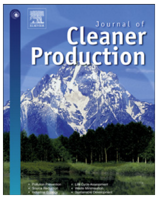

Integrated assessment of water–energy–GHG emissions tradeoffs in an irrigated lucerne production system in eastern Australia

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ABSTRACT

Robust understanding of possible trade-offs and synergies between climate change, energy and water sector policies is critical to achieving economically viable and environmentally sound agricultural production systems in a low-carbon water-constrained economy, in which greenhouse gas (GHG) emissions are penalized and water savings rewarded. Accurate assessment of the potential costs/benefits of investment decisions can help to optimize the economic efficiency of agricultural production while minimizing environmental impacts. This paper presents a novel integrated framework, based on carbon and water accounting, which enables analysis of potential trade-offs between water savings, energy consumption, GHG emissions and economic costs/benefits associated with the adoption of new water efficient irrigation technologies. The framework was applied to an irrigated lucerne cropping system in eastern Australia and compares the costs/benefits of old roll-line sprinkler irrigation systems against new pressurized systems. Positive synergies were found with the adoption of the new technology, which saved both water and energy use, reduced total GHG emissions and resulted in net economic returns across a range of carbon prices. The results of this study provide support for an integrated evidence-based approach to policy development and strategic decision-making and for the prioritization of investments on both economic and environmental grounds.

1. Introduction

The interconnectivity between water, energy and climate change is driving calls for integrated water- and energy-efficient low-carbon solutions (Ahmad and Khan, 2009; Bazilian et al., 2011). Irrigated agriculture provides a valuable example by which to test the extent to which this is occurring. The irrigation industry is under significant and increasing pressure to adopt water efficient practices to improve productivity (Howell, 2001; Zwart and Bastiaanssen, 2004). Modern irrigation technologies are designed to decrease irrigation water use and at the same time deliver significant gains in crop yield (Playán and Mateos, 2006; Ghorbani et al., 2011), thereby contributing to both water and food security, two of the most important challenges facing modern society. However, while investments in more efficient pressurized irrigation systems have been heralded as an integral way to increase water use efficiency and to save water (Green et al., 1996; Lal, 2004), these systems are often more energy intensive than conventional irrigation systems (Lal, 2004) and there is significant potential for tradeoffs between water use efficiency and energy use. This paper presents a new approach to assessing such tradeoffs, using an integrated economic framework.

New irrigation technology adoption decisions are generally made on the basis of perceived benefits from water savings and the costs related to the technology change (Mackinnon et al., 2009) without considering issues of energy dependency and greenhouse

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Abbreviations: APSIM, Agricultural Production Systems sIMulator; BCA, Benefit cost analysis; BCR, Benefit cost ratio; BE, Break even; CO_2, Carbon dioxide; CO_2-e, Carbon dioxide equivalent; CSIRO, Commonwealth Scientific and Industrial Research Organisation; GHG, Greenhouse gas; IRR, Internal rate of return; N_2O, Nitrous oxide; NPV, Net present value; SWAP, Soil, Water, Atmosphere and Plant.

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gas (GHG) emissions (Zillman et al., 2008). However, these are increasingly important considerations with the rising costs of fossil fuel use and the implementation of a carbon pricing mechanism in Australia. As well as saving water, modern irrigation technologies generate change in the pattern of on-farm energy consumption, crop production practices, inputs and soil carbon dynamics (Asgharipour et al., 2012; Soto-Garcia et al., 2013). Many of these changes may result in considerable additional GHG emissions. For example, recent research by Mushtaq et al. (2013) shows that replacing 43% of the total area of surface irrigation systems in Australia by drip irrigation (40%) and sprinkler irrigation (60%) systems, while saving an estimated 869 ML/yr of water, would increase irrigation pumping related GHG emissions by about 2 million tonnes CO_2-e/yr. However, when a more integrated approach is taken, which considers the net impact on GHG emissions of irrigation technology adoption plus associated changes in farm practices (e.g. fertigation, altered cultivation practices), the overall effect may be a reduction in total GHG emissions (Mushtaq and Maraseni, 2011; Maraseni and Cockfield, 2012).

Developing effective and complementary water and climate change mitigation and adaptation policies are challenging tasks facing all governments (Hermann et al., 2012). This is particularly so in the water sector where there is a reciprocal relationship between such policies: policies for water management may lead to increased GHG emissions while mitigation measures may influence water resources and their management (Dubreuil et al., 2013). Hence, a critical evaluation of energy-intensive responses to scarcity in the water sector is imperative to determine their impact on climate protection. A better understanding of potential trade-offs between water savings and energy use will inform policy, planning and management decisions at national, industry and farm level. While the energy efficiency of crop production has been previously analyzed in a number of studies (e.g. Asgharipour et al., 2012; Ramedani et al., 2011; Page et al., 2012), integrated frameworks in which the consequences of one policy on another policy area are evaluated rarely exist (Galli et al., 2011; Hermann et al., 2012).

Previous studies have investigated either: the water use efficiencies and economics of new pressurized irrigation systems; or energy use (and GHG emissions) associated with crop production. For example, a number of studies (e.g. Sousa et al., 1999; Qureshi et al., 2001; Bethune, 2004; Wood et al. 2007) have investigated the water use efficiencies, productivity and profitability of furrow, pivot and drip irrigation systems. Other studies (e.g. Pimentel et al., 2002; Canakci et al., 2005; Chamsing et al., 2006; Chaudhary et al., 2006; Erdal et al., 2007; Pishgar-Komleh et al., 2012a) have quantified the energy consumption associated with crop production, including energy used for irrigation. With the notable exception of Jackson et al. (2010), no studies have provided an integrated assessment of both water and energy consumption.

This study considers water and energy consumption and productivity and, importantly, provides an economic evaluation which integrates all aspects of water, energy and GHG emissions into a common measure. This new integrated assessment framework, which is based on water and carbon accounting and economic modeling, analyses potential environmental trade-offs between water and energy use associated with investments to increase water security through the adoption of new pressurized irrigation technologies. The assessment framework is applied, using a case study approach, to an irrigated lucerne cropping system in eastern Australia.

2. General methods

Here we provide an overview of the analytical framework followed by its application to an irrigated lucerne cropping system in eastern Australia (Section 3).

2.1. Integrated modeling framework

The integrated economic framework was developed to evaluate trade-offs related to the adoption of new irrigation technologies in terms of (i) water use, (ii) energy use and related GHG emissions, and (iii) costs associated with irrigation equipment and its use. The concept behind trade-off analysis is that, for a specified set of resources and technology, an increase in one preferred outcome may result in a reduction in another equally preferred outcome (Stoorvogel et al., 2004). In the case of new generation irrigation technologies such as large center pivot and lateral move sprinklers and trickle/drip systems it is assumed that, as these require increased pressurization to deliver greater water use efficiencies and water savings, they require more energy to operate and hence represent an increased GHG emissions burden on the environment.

The framework comprises three key elements: hydrological modeling; energy and GHG emission modeling; and economic cost/benefit analysis (Fig. 1). It provides robust estimates for water savings, associated GHG emissions and costs, and quantifies trade-offs between water and environmental security by converting these estimates to a common economic value. This framework has also been applied at the national crop level to investigate different irrigation technology adoption scenarios (Mushtaq et al., 2013).

2.2. Hydrological modeling

The hydrological modeling component of the framework targets the quantification of water savings resulting from the adoption of new water efficient irrigation technologies and can be used to validate primary water use efficiency data (i.e. farmers' estimated water savings). Significant improvement in water application efficiency, thus water savings, can be achieved by modernization of surface and older inefficient pressurized irrigation systems. While estimation of potential water savings can best be achieved through field experiments (Wood and Finger, 2006), these are costly and time and labor intensive. Reliable estimates are also able to be derived from robust crop models such as Agricultural Production Systems sIMulator (APSIM) and Soil, Water, Atmosphere and Plant (SWAP) (Khan et al., 2008a; Kroes et al., 2008). SWAP models simulate water and solute balances for the unsaturated and saturated zones of the cropped soils and have been used to estimate potential water savings due to changes in water management and irrigation technologies under a range of relevant climatic and soil conditions (Khan and Abbas, 2007; Khan et al., 2008a, 2008b). Details of the hydrological modeling methodology used in these analyses are provided in Mushtaq and Maraseni (2011).

2.3. Energy and greenhouse gas emissions modeling

The GHG modeling element of the integrated framework compares relative emissions from different irrigation systems considering: (i) the use and consumption of electricity and diesel for various farm operations, (ii) production, packaging, storage and transport of agrochemicals, (iii) soil-derived nitrous oxide (N_2O) from the application of nitrogen (N) fertilizer, and (4) production and use of farm machinery. Previous studies (e.g. Pimentel et al., 2002; Canakci et al., 2005; Chamsing et al., 2006; Chaudhary et al., 2006; Erdal et al., 2007) have sought to quantify energy consumption for various agricultural activities and farm inputs; however, these studies report energy use data in diverse forms, making it difficult to compare GHG emissions from different farm practices. The global warming potentials of CO_2, CH_4 and N_20 for 100 year are 1, 25 and 298, respectively (IPCC, 2007; Maraseni, 2007). Considering these multipliers, the present study converts all emissions data into a carbon dioxide equivalent (CO_2-e) value.

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