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Research Paper

Modelling economic impacts of deficit irrigated maize in Brazil with consideration of different rainfall regimes

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Deficit irrigation is often required to cope with droughts and limited water availability. However, to select an appropriate irrigation management, it is necessary to assess when economic impacts of deficit irrigation are acceptable. Thus, the main goal of this study was to evaluate economic water productivity for maize submitted to various levels of water deficits and different irrigation systems. The study was based on two different experiments conducted in Southern Brazil, one using sprinkler irrigation to supplement rainfall and the other using drip irrigation with precipitation excluded by a rainfall shelter to simulate cultivation under dry conditions. Water productivity indicators were calculated referring to: a) actual field collected data, including yields, commodity prices and production costs; and b) a sensitivity analysis to commodity prices and production costs. Alternative centre-pivot irrigation scenarios were also developed to assess their feasibility in terms of water use and productivity when irrigation is used to supplement rainfall or when rainfall is scarce. Results show that the feasibility of deficit irrigation is highly influenced by commodity prices and by the irrigation (and water) costs when the irrigation costs are a large part of the production costs. Results also show that deficit irrigation applied when rainfall is abundant is easier to implement than deficit irrigation where rainfall is very scarce, when only a mild stress is economically viable. For well-designed and managed centre-pivot systems, results confirm that adopting deficit irrigation when rainfall is scarce is less attractive than under conditions of irrigation to supplement rainfall. It could be concluded that farmers are unlikely to choose a deficit irrigation strategy unless they are facing reduced water availability for irrigation.

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Nomenclature

A_{inv}	investment annuity, BRL year^{-1}
BWU	beneficial water use, m^3
BWUF	beneficial water use fraction, dimensionless
C_a	investment annuity per unit of irrigated area, BRL ha^{-1} year^{-1}
C_d	energy demand tax, BRL kW^{-1}
C_{en}	annual energy costs, BRL ha^{-1} year^{-1}
C_{inv}	investment costs, BRL
C_m	annual maintenance costs, BRL ha^{-1} year^{-1}
CRF	capital recovery factor, dimensionless
CU	Christiansen coefficient of uniformity, %
DU	distribution uniformity, %
ET_o	reference evapotranspiration, mm
ET_a	actual crop evapotranspiration, mm
EWP	economic water productivity, BRL m^{-3}
EWP_{BWU}	economic water productivity relative to beneficial water use, BRL m^{-3}
EWP_{Irrig}	irrigation economic water productivity, BRL m^{-3}
$EWPR_{full\text{-}cost}$	economic water productivity ratio considering all production costs, dimensionless
$EWPR_{irrig\text{-}cost}$	economic water productivity ratio considering only irrigation costs, dimensionless
$f_{r\ mulch}$	fraction of the ground surface covered by mulch, dimensionless
$f_{eff\ mulch}$	fraction of the ground surface that is effectively covered by mulch, dimensionless
IWU	irrigation water use, m^3
NIR	net irrigation requirements, mm
TAW	total available soil water, mm
TWU	total water use, m^3
WP	water productivity, kg m^{-3}
WP_{BWU}	water productivity relative to beneficial water use, kg m^{-3}
WP_{Irrig}	irrigation water productivity, kg m^{-3}
Y_a	actual crop yield, kg ha^{-1}

Acronyms

ISR	irrigation in supplement to rainfall
ILR	irrigation with very low rainfall
BRL	Brazilian Real

1. Introduction

At present, more than 1.5 billion ha are used worldwide for crop production and there is little scope for further expansion of agricultural land; increasing land productivity, mainly adopting irrigation, is definitely required. According to FAO (2012), the world agricultural production has grown between 2.5 and 3 times over the last 50 years while the cultivated area has grown only 12%. More than 40% of the global increase in food production came from irrigated areas. However, at global level, agricultural water use represents 70% of all water use. Thus, and because water scarcity is increasing, the need to optimise water withdrawal is also increasing, mainly for irrigation purposes (Pereira, Cordery, & Iacovides, 2009). Consequently, farmers are forced to adopt an optimised irrigation management in order to decrease the water demand while increasing land and water productivity.

One commonly used technique that aims to decrease water use is deficit irrigation. This approach consists of deliberately applying irrigation depths smaller than those required to fully satisfy the crop water requirements, thus affecting evapotranspiration and consequently yields, but keeping a positive return from the irrigated crop (Pereira, Oweis, & Zairi, 2002). By avoiding water stress during drought-sensitive stages, deficit irrigation also aims to maximise water productivity (Geerts & Raes, 2009; Kang, Shi, & Zhang, 2000). However, particularly in arid regions, appropriate management is necessary to control effects of reduced irrigation on soil salinity (Pereira, Gonçalves, Dong, Mao, & Fang, 2007; Xu et al., 2013). Moreover, depending upon water management and available rainfall during the crop season, the impacts of deficit irrigation on yields and related farmer incomes may or may not be negative, also depending upon the adopted irrigation scheduling, production costs and yield values (Lorite, Mateos, Orgaz, & Fereres, 2007; Rodrigues & Pereira, 2009). Katerji, Mastrorilli, and Chernic (2010) have shown that maize water productivity (WP) varies with total available soil water (TAW), with a high TAW favouring crop responses to deficit irrigation. Various studies have been developed to assess impacts of deficit irrigation on maize yields and economic returns (Domínguez, de Juan, Tarjuelo, Martínez, & Martínez-Romero, 2012; Farré & Faci, 2009; Payero, Melvin, Irmak, & Tarkalson, 2006; Popova, Eneva, & Pereira, 2006). These studies clearly demonstrate that the feasibility of deficit irrigation strategies depends greatly upon the crop variety and the adopted crop and irrigation management, mainly referring to when those deficits are applied, e.g., Grassini et al. (2011) referred to the possibility of reducing irrigation depths by 25% throughout the crop cycle except for a −14 to +7 d window around silking, during which crops must be fully irrigated.

Another way to achieve efficient water use is through increasing WP, including the related economic results; however the term WP may be used with different meanings and at various scales, which may lead to contradictory interpretations. Various studies (Abd El-Wahed & Ali, 2013; Bouman, 2007; Grassini et al., 2011; Molden et al., 2010; Playan & Mateos, 2006; Zwart & Bastiaanssen, 2004) refer to factors influencing WP, including irrigation management (e.g., supplemental and deficit irrigation), irrigation systems and their performance, crop varieties, soil fertility and TAW, pest and diseases, and soil–water conservation practices (e.g., tillage and mulching). Pereira, Cordery, and Iacovides (2012) defined WP in agriculture as the ratio between the actual yield achieved (Y_a) and the total water use (TWU). These authors, and also van Halsema and Vincent (2012), emphasised that WP enables an appropriate thinking about both the numerator and the denominator, i.e., on both crop growth and yield and