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Greenhouse gas emission estimate in sugarcane irrigation in Brazil: is it possible to reduce it, and still increase crop yield?

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ABSTRACT

Irrigation increases sugarcane yield, especially in areas under restricted rainfall conditions. However, few studies have been carried out on the environmental impacts of this activity, mainly regarding greenhouse gas (GHG) emissions. Therefore, the aim of this study was to estimate the environmental impacts of sugarcane irrigation, contemplating GHG emissions at different production scenarios. For that, biomass production was simulated under rainfed conditions and different irrigation systems, comparing six Brazilian regions (Ribeirão Preto – SP; Araçatuba – SP; Paracatu – MG; Itumbiara – GO; Paranaíba – MS; and Petrolina – PE). After gathered, GHG emission estimates of each scenario were confronted with sugarcane production data. The results were expressed in “carbon (C) footprint” (kg CO_2eq t^{-1}). For all evaluated regions, irrigation intensifies and encumbers environmentally the agricultural practices by increasing GHG emissions (~7447.0 kg CO_2eq ha^{-1} yr^{-1}) compared with rainfed condition (~2154.6 kg CO_2eq ha^{-1} yr^{-1}). Irrigation systems require a large amount of electric power, diesel and other inputs such as synthetic nitrogen fertilizers. Surprisingly, this situation can change substantially if C footprint is considered. We observed that irrigated areas had a decrease C footprint of up to 59% (33.0 kg CO_2eq t^{-1}) against rainfed ones, as observed in Petrolina scenario. In other regions, C footprint reductions ranged from 23% (7.1 kg CO_2eq t^{-1}) in Ribeirão Preto to 37% (13.9 kg CO_2eq t^{-1}) in Paracatu. Thus, irrigated agriculture impact could be explored in terms of C footprint, which depends on regional biomass production as well as irrigation system efficiency towards a better water use.

1. Introduction

Human activities have rapidly increased worldwide, as consequence they brought environmental changes that resulted in short and medium-term influences on global agriculture and economy. Concerns about energy shortage, greenhouse gas (GHG) reductions and new income sources for farmers may explain why energy policies of many countries have considered biofuels as relevant alternative to fossil fuels (Demirbas, 2008; Tammisola, 2010).

Renewable energy use is one of the most efficient ways to reach sustainable development. Most of the “new renewable energy sources” are still undergoing large-scale commercial development; however, some technologies have already been established such as Brazilian sugarcane ethanol (Goldemberg, 2007). Brazil is the largest worldwide producer of sugarcane, with an output of 715 million tons within 9.6 million hectares, being 55% of that in São Paulo State (FNP, 2013). About 18% of the total consumed energy in Brazil comes from sugarcane ethanol, which makes it the second source of energy in the country (Jank, 2010). Nevertheless, recent crop's expansion has not considered the production potential based on weather conditions and management practices (Monteiro and Sentelhas, 2014).

Brazilian sugarcane production has grown substantially in recent years toward new agricultural areas, such as cerrado areas under critical climatic conditions, to satisfy the global demand for biofuels (Endres et al., 2010; Vianna and Sentelhas, 2015; Scarpare et al., 2015a). This growth, coupled with inter-annual climate variability and increasing mechanization, brought consequences to sugarcane growth patterns, maturation and crop yield in Brazil (Cardozo and Sentelhas, 2013; Scarpare et al., 2015b).

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Irrigation has emerged as one of the main alternatives to enhance sugarcane yield, especially in regions with limited water availability (Scarpare et al., 2015a). Several researchers have already shown the technical feasibility of irrigation with this crop resulting in considerable yield increases (normally above 140 t ha^{-1}). These researches have focused on economic efficiency, longer plant longevity (more than 10 harvests) and steady yield (reducing yield variation between harvests) (Freitas et al., 2009).

Despite to the higher yield gains, the intensification of agricultural practices results in higher consumption of energy and fertilizers, thereby increasing GHG emissions from irrigation systems (Mosier et al., 1998; Linn and Doran, 1984). Maraseni and Cockfield (2012) concluded that irrigated crops emit 700% more GHG because of a high consumption of fuel (diesel) and power for irrigation system as well as because of a large use of agricultural inputs like fertilizers and other agrochemicals.

According to Maraseni and Cockfield (2012), irrigation was responsible for a huge leap in agricultural yield in Australia. Over the last 30 years, Australian agricultural production has increased 2.8% per year, a rate higher than that achieved by country's economy. This increase is related to intensification of domestic farming allied to both irrigation and mechanization of agriculture (AGO, 2006). Nonetheless, Maraseni and Cockfield (2012) reported potential environmental impacts brought by such agricultural intensification (including irrigation). These authors also stated that larger energy and fertilizer consumptions could have promoted an increase in GHG emissions, which has not been taken into account so far.

Irrigated agriculture requires heavy machinery (i.e., higher diesel consumption) for soil tillage besides more power for water pumping. Additionally, irrigated systems in general demand more agrochemicals, primarily nitrogen (N) fertilizers (Maraseni and Cockfield, 2012). It is estimated that more than half of that N is leached out of soil profile or released into the atmosphere as nitrous oxide (N_2O) (Vergé et al., 2007). This N form has 298 times more global warming potential than carbon dioxide (CO_2) (IPCC, 2007). In conclusion, the more the farmers attempt to enhance production levels through irrigation, the larger the contribution of fertilizers to GHG emissions.

Evaluating some winter crops (barley, chickpeas, and common and durum wheat) under irrigation, Maraseni and Cockfield (2012) concluded that these irrigated crops emit more amount of GHG into the atmosphere, especially because of prior soil tillage, higher diesel consumption during harvest, irrigation system power consumption and larger use of inputs such as fertilizers and other agrochemicals. However, when comparing rainfed and irrigated system, the first one emits only about 159 kg CO_2eq ha^{-1}, while the second one is in charge of around 4170 kg CO_2eq ha^{-1}; therefore, it requires increasing amounts of N fertilizers, whose emission factor is higher than other GHG sources. Furthermore, irrigated system generates an extra emission of 1974 kg CO_2eq ha^{-1}, arising from water withdrawal and transportation and may vary with the system. Overall, producing one kilogram of grain (on average) under irrigations demands twice the GHG emission level compared to rainfed production.

Even though agriculture contributes significantly to total anthropogenic GHG emissions, the sector has several strategies to mitigate those (Smith et al., 2007). For this purpose, detailed inventories of emission sources should be conducted to establish further feasible strategies in line with economic interests (Nguyen et al., 2010). The CO_2 flux between atmosphere and ecosystem is under natural conditions and is controlled by absorption via plant photosynthesis and emissions through respiration, decomposition and soil organic matter combustion.

The aim of this study was to estimate the environmental impacts of GHG emissions from irrigated sugarcane, through simulations in six producing-regions of Brazil. For that, crop yield was simulated under rainfed condition and different irrigation systems. The challenge was to assess implications of yield increase on GHG emissions and carbon (C) footprint over the different production scenarios. Therefore, our hypothesis is that the production enhancement by means of irrigation could result in increased sugarcane yield, thereby reducing the C footprint of sugarcane production.

2. Materials and methods

2.1. Evaluated locations

Soil and weather conditions of six of the most important sugarcane-producing regions in Brazil were considered to perform the current study. Fig. 1 shows these studied regions, which are: 1) Ribeirão Preto – SP; 2) Araçatuba – SP; 3) Paracatu – MG; 4) Itumbiara – GO; 5) Paranaíba – MS; and 6) Petrolina – PE.

2.2. Local soil and weather data

Daily data of rainfall (mm), air temperature (°C) and photoperiod (h) of a 32-year period (1982–2013) were obtained from local weather stations. The annual average values of these regions for the period between 1983 and 2013 are shown in Table 1. The data were provided by public agencies such as Instituto Nacional de Meteorologia (INMET), Escola Superior de Agricultura Luiz de Queiroz (ESALQ-USP), Universidade Estadual Paulista (UNESP) and Instituto Agronômico de Campinas (IAC). Table 2 shows the most representative soil types of each region, as well as their available water capacity (AWC) and sugarcane production environments.

2.3. Simulation of harvests and planting dates

Simulations comprised a period of 32 years (1982–2013), contemplating thus a wide range of climatic conditions. We agreed that plantings would be performed in April and harvests from the middle to the end of the season (September), when plants undergo water deficit stress (higher kc) and adverse weather conditions (Cardozo et al., 2014). Simulation results were expressed on average yield per year (t ha^{-1} yr^{-1}), which varied with region and irrigation system (Table 3).

2.4. Simulation of potential crop yield

The Agro-ecological Zoning model (AEZ) proposed by Doorenbos and Kassam (1979) was used to calculate potential sugarcane yield. Several other authors have already used this model for sugarcane, such as Monteiro and Sentelhas (2014) and Oliveira et al. (2012). The weather input variables used by the model were extraterrestrial solar radiation (MJ m^{-2} day^{-1}), photoperiod (h day^{-1}), sunlight (h dia^{-1}) and air temperature (°C), which were used to calculate the potential yield, as shown in equation (1):

$$PY = \sum_{i=1}^{m} (GPYp_i \times C_{lai} \times C_r \times C_h \times C_{sm}) \tag{1}$$

wherein: PY = dry matter (DM) potential yield in t DM ha^{-1}; m = time interval between simulations (10 days); G$PYpi$ = standard gross potential yield of dry matter in t DM ha^{-1} day^{-1}; $Clai$ = leaf area index correction factor; Cr = crop respiration correction factor; Ch = harvest index (stems); and Csm = stem moisture coefficient. All correction coefficients are dimensionless.