SHORT NON-REFEREED PAPER

MODELLING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON YIELD AND WATER USE OF SUGARCANE AND SUGAR BEET: PRELIMINARY RESULTS BASED ON THE AQUACROP MODEL

KUNZ R[1], SCHULZE R[1], MABHAUDHI T[2] AND MOKONOTO O[1]

[1]*Centre for Water Resources Research, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, P/Bag X01, Scottsville, South Africa*
[2]*Crop Science Discipline, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, P/Bag X01, Scottsville, South Africa*
kunzr@ukzn.ac.za schulzer@ukzn.ac.za
mabhaudhi@ukzn.ac.za 208510256@stu.ukzn.ac.za

Abstract

The FAO AquaCrop model was used to estimate the attainable yield of sugarcane and sugar beet, in relation to their seasonal water use. The AquaCrop model has been re-calibrated for sugarcane using the AgMIP La Mercy dataset (1989-1991). Similarly, the model was also re-calibrated for sugar beet using field data collected during the 2013 growing season at the Ukulinga research farm in Pietermaritzburg.

Future climate projections were obtained from the Council for Scientific and Industrial Research and based on six atmosphere-ocean General Circulation Models (GCMs) for the 'business-as-usual' A2 emission scenario. The six climate projections were dynamically downscaled using the conformal-cubic atmospheric model of the Australian Commonwealth Scientific and Industrial Research Organisation.

The grid-based output from the six GCMs was further 'spatially downscaled' to the Quinary catchment level, where a Quinary is a topographically based sub-division of each Quaternary catchment (originally delimited by the Department of Water Affairs). Daily reference crop evaporation estimates (FAO Penman-Monteith approach) were derived from the GCM temperature output. Soils information required by AquaCrop was obtained from the Quinary sub-catchment database.

The AquaCrop model was run for each Quinary sub-catchment to determine the attainable yield and water use of both sugarcane and sugar beet, for each growing season over the period 1950-2099, with the exercise repeated for all six downscaled GCMs. The results allow for the calculation, at the national scale, of each feedstock's water use efficiency. This knowledge may help guide decisions regarding which ethanol feedstock is better suited to South Africa's water-stressed catchments.

Keywords: sugarcane, climate change, yield, water use

Introduction

Global interest in and use of biofuels has grown rapidly over the past few years, due to their importance in reducing 1) use of fossil-based fuels and hence, 2) greenhouse gas emissions. According to South Africa's national biofuels industrial strategy (DME, 2007), sugarcane

(*Saccharum officinarum* L.) and sugar beet (*Beta vulgaris*) are 'preferred' feedstocks for ethanol production. However, the draft position paper on the biofuels regulatory framework (DoE, 2014) indicated that only one biofuel manufacturer (at Jozini, KwaZulu-Natal) intends to produce ethanol from sugarcane. Furthermore, the use of sugar beet has been delayed to a second phase of the proposed Cradock ethanol facility. Both Cradock and the proposed facility at Bothaville have indicated that grain sorghum is the 'preferred feedstock'. Thus, the majority of ethanol required for satisfying the minimum E2 (i.e. 2% ethanol) blend will be produced from grain sorghum.

Regardless of which feedstocks are used for ethanol production in South Africa, there is a need to grow feedstocks that have minimal water use and high yield potential, especially in the water-stressed catchments of South Africa. As noted in the draft biofuels regulatory framework, biofuel manufacturers are eligible for a government subsidy if the use of irrigation for feedstock production is controlled. Hence, biofuel manufacturers must obtain written permission from the Department of Water Affairs (DWA) to use irrigated water. In addition, they must provide detailed motivation that the country's water resources are not negatively impacted. However, Jewitt and Kunz (2011) reported that the DWA has taken the position that South Africa is a water-scarce country which can, "ill afford the use of current or potential irrigation water for fuel production rather than growing crops for food".

In this study, the Food and Agriculture Organisation (FAO) AquaCrop model was used to estimate the attainable yield of these two feedstocks, in relation to their seasonal water use. Modelled output was then used to calculate water use efficiency (yield per unit water use). This metric was then used to assess which feedstock uses water more efficiently (i.e. gives 'more crop per drop'). The main goal of this study was to estimate the potential effects of climate change on the water use efficiency of sugarcane and sugar beet.

Procedures

AquaCrop is a crop model developed by the FAO (Steduto *et al*., 2012) and designed to simulate yield response of several crops to water availability. It is particularly suited to addressing conditions where water is a key limiting factor in crop production. The AquaCrop model (version 4.0) was re-calibrated for sugarcane using the AgMIP La Mercy (1989-1991) dataset. It was also re-calibrated for sugar beet using field data collected in 2013 at Ukulinga research farm in Pietermaritzburg.

To date, AquaCrop has been applied successfully at different scales, ranging from the plot to the watershed. The model was linked to the Quinary sub-catchment database that exists for southern Africa. This database consists of 50 years (1950-1999) of daily climate data (e.g. rainfall, maximum and minimum temperature as well as reference crop evaporation) for each of the 5838 Quinary sub-catchments (Schulze *et al*., 2011).

Each of the 1946 quaternaries (4th level) catchment has been subdivided into three Quinary (5th level) sub-catchments according to altitude criteria (Schulze and Horan, 2011). The upper, middle and lower quinaries of unequal area (but of similar topography) were sub-delineated according to 'natural breaks' in altitude by applying the Jenks optimisation procedure. This resulted in 5838 Quinary sub-catchments deemed to be more homogeneous than the quaternaries in terms of their altitudinal range. The reader is referred to Schulze and Horan (2011) for further explanation on how the Quinary sub-catchments were delineated.

The database contains soils information derived from land types developed by the former Soils and Irrigation Institute. The land types identified in each Quinary were area weighted in order to derive one set of soils attributes (e.g. soil water retention parameters and soil depth) for the entire sub-catchment (Schulze *et al*., 2011). However, AquaCrop also requires the saturated hydraulic conductivity (K_{sat}) which is not available in the quinary database. A pedotransfer function approach was used to derive K_{sat} values for each sub-catchment.

Owing to the potentially large number of model runs (i.e. 5838 at the national scale), the plug-in[1] version of the AquaCrop model was used. This stand-alone version runs without a graphic user interface. The process was fully automated to reduce its computational complexity, thus reducing the time required to complete a national run. For sugarcane, a summer (i.e. October) planting with an 18-month growing season was assumed, which is typical for farms situated in the KwaZulu-Natal Midlands. A summer (i.e. September) and winter (i.e. May) planting of sugar beet was assumed, together with a seven month growing season. The winter planting should be the ‘norm’ for the Cradock region in the Eastern Cape.

AquaCrop was run nationally to estimate the attainable yield and water use under dryland conditions for a single season. This exercise was then repeated to obtain simulated data for the following season for both feedstocks. The seasonal yield and water use values were then analysed to calculate the mean and median statistics for each Quinary. These values represent the long-term yield and water use obtained under dryland conditions for the historical (or baseline) period.

The next step involved assessing the impact of climate change on feedstock yield and water use. Future climate projections were obtained from the Council for Scientific and Industrial Research and based on six atmosphere-ocean General Circulation Models (GCMs) for the ‘business-as-usual’ A2 emission scenario. Owing to the coarse spatial resolution of the GCM output, the scope for direct use in a crop model is limited, and downscaling is thus highly recommended. The six climate projections were therefore dynamically downscaled (Engelbrecht and Bopape, 2011), using the conformal-cubic atmospheric model (McGregor, 2005) of the Australian Commonwealth Scientific and Industrial Research Organisation.

The grid-based (0.5° grid size) output from the six GCMs was further ‘spatially downscaled’ to the Quinary sub-catchment level, Daily reference crop evaporation estimates (i.e. FAO Penman-Monteith) were derived from the GCM temperature output as described by Schulze *et al*. (2008). A wind speed of 2.0 m/s was assumed and solar radiation was derived by Schulze and Chapman (2008). The AquaCrop model was again run for each Quinary to determine the attainable yield and water use of both feedstocks, for each growing season over the period 1961-2099, with the exercise repeated for all six GCMs.

Results and Discussion

The AquaCrop model was pre-calibrated for both sugarcane and sugar beet using data obtained from South Africa and Turkey, respectively. For sugarcane, the pre-calibration was undertaken by Steduto *et al*. (2012) using the AgMIP La Mercy dataset. However, the model significantly under-estimated the observed yield in six of the eight treatments. Using the same dataset, a re-calibration of the model was undertaken which obtained better yield predictions (i.e. under-estimation of yield for one treatment only). The re-calibrated version was then

[1] http://www.fao.org/nr/water/docs/AquaCropPlugInV40.doc

validated using other AgMIP datasets for sugarcane, *viz.* Pongola (1968-1971), Komatipoort (2011) and Mt. Edgecombe (2011).

Preliminary results have indicated that AquaCrop performed fairly well in simulating sugarcane biomass and yield, despite the availability of limited growth data used in the re-calibration process. For sugar beet, the model performed well, with good correlation between observed and simulated canopy cover. Since AquaCrop is a canopy-based model, the accuracy of biomass and yield estimates depends on the model's ability to simulate canopy development.

Steduto *et al*. (2012) noted that long-term productivity estimates should be derived using at least 30 years of historical climate data. Hence, the present and future yields obtained from this study are deemed representative of each Quinary sub-catchment. The overlap period (i.e. 1961-1999) between the historical climate record and the future climate scenarios was also used to assess how well each GCM 'predicted' the present climate.

The spatial variability in sugar beet yields was high, due to the simulation of low yields which resulted from a winter planting in the summer rainfall region. Thus, the use of sugar beet for ethanol production is considered economically unviable, unless supplemental irrigation is used during establishment of the winter crop. A winter planting is desirable as it minimises disease incidence when compared to a summer planting.

For the purpose of this study, WUE was calculated as the attainable yield per unit of water use. Attainable yield refers to the usable portion of the biomass that contains sugar (i.e. stem or tuber). Water use is defined as total evaporation (transpiration + soil water evaporation) from the biomass, accumulated over the full productive cycle (i.e. growing season).

At the congress, the WUE of sugarcane and sugar beet will be compared at the national level. This knowledge may help guide decisions regarding which ethanol feedstock is better suited to South Africa's water-stressed catchments. The results also highlighted the difficulty in comparing the WUE of a perennial crop to that of an annual crop.

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