SHORT, NON-REFEREED PAPER

AN EXPERIMENTAL AND CROP MODELLING ASSESSMENT OF ELEVATED ATMOSPHERIC CO_2 EFFECTS ON SUGARCANE PRODUCTIVITY

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Abstract

It is predicted that atmospheric CO_2 concentration could double by 2100. Sugarcane may respond favourably to elevated CO_2 by increased water use efficiency (WUE) and biomass, although contrasting reports exist.

The objectives of this study were to (1) determine the effects of elevated CO_2 on the physiology and yield of two sugarcane varieties; and (2) assess the simulation capability of the Canesim model to predict CO_2 effects on sugarcane.

Varieties NCo376 and N31 were grown for seven months in 12 open-top chambers under ambient (400 ppm) and elevated (750 ppm) CO_2 concentrations at Potchefstroom (South Africa). The effects of elevated CO_2 on stomatal conductance (g_s), CO_2 assimilation rate (A), WUE and stalk dry mass (SDM) and sucrose yields were assessed. The Canesim model was used to simulate the experiment in Potchefstroom, and the long-term (over 20 years) mean response of SDM yield to elevated CO_2 under rainfed (La Mercy) and irrigated (Komatipoort) conditions.

Under elevated CO_2 concentrations, g_s was significantly reduced by 30-40% in both varieties, while A was not affected. WUE was significantly higher in both varieties under elevated CO_2 conditions, with increases of up to 71%. No significant increases in SDM or sucrose yields were found for either variety as compared with the control, and this was corroborated by the Potchefstroom Canesim simulation. Canesim predicted a SDM yield benefit only in response to elevated CO_2 under rainfed conditions at La Mercy. These findings warrant further research into the impacts of elevated CO_2 and water deficit on sugarcane productivity.

Keywords: Canesim, climate change, elevated CO_2, sugarcane yield, water use efficiency

Introduction

Atmospheric CO_2 concentration has been predicted to double by 2100 (IPCC, 2013). C_4 plants, such as sugarcane, form a four-carbon compound during photosynthesis in order to minimise the energy losses associated with photorespiration. This internal CO_2 concentrating mechanism allows attainment of maximum photosynthetic capacity at current CO_2 concentrations, and C_4 plants are therefore less likely to be responsive to elevated CO_2 conditions compared with C_3 plants.

Contrasting reports exist regarding the response of sugarcane to elevated CO_2 conditions because the photosynthetic stimulation and reduced stomatal conductance observed in CO_2 rich environments may be variable and subject to environmental changes (Ainsworth & Rogers, 2007; Stokes *et al*. 2016). In the presence of elevated CO_2 levels, plants tend to regulate an increase in stomatal closure and it has been suggested that secondary benefits such as increased water use efficiency may be induced under elevated conditions (Stokes *et al*. 2016). The direct benefits of elevated CO_2 on sugarcane growth in South Africa requires further investigation in order to improve crop modelling capabilities and predict the effects of elevated CO_2 on future sugarcane growth and production.

The objectives of this study were (1) to determine the effects of elevated CO_2 in the absence of soil water deficit on the growth, physiology and yield of two South African sugarcane varieties; and (2) to assess the simulation capability of the Canesim® model (Singels & Paraskevopoulos 2017) to predict CO_2 effects on sugarcane.

Materials and Methods

A fully-irrigated pot trial was established at Potchefstroom (26.6905°S, 27.0932°E), in collaboration with North West University, from September 2015 to May 2016. Two varieties, namely NCo376 and N31, were grown for seven months in 12 open-top chambers under ambient (400 ppm) and elevated (750 ppm) CO_2 concentrations. Measurements of leaf-level stomatal conductance (g_s), transpiration rate (E) and CO_2 assimilation rate (A) were conducted on two occasions (February and April 2016) between 10h00 and 13h00 using a portable photosynthesis system (CIRAS-2, PP Systems, USA). Single leaf water use efficiency (WUE) was calculated as the ratio between A and E. Variety x treatment interactions of g_s, A and WUE were tested using ANOVA (p=0.05). Stalk dry mass (SDM) and sucrose (SUC) yields were measured at harvest.

The Canesim® crop model was used to simulate (1) the different treatments in Potchefstroom, and (2) the long-term (over 20 years, 1974-1993) mean response of SDM and SUC yield to elevated (750 ppm) CO_2 under rainfed (La Mercy, 29.6380°S, 31.1138°E) and irrigated (Komatipoort, 25.4510°S, 31.9587°E) conditions.

Results and Discussion

Experiment results

Both varieties showed a significant decrease in g_s of 30% and 41%, and in E of 27% and 34% for NCo376 and N31, respectively, in response to elevated CO_2 (Table 1). A did not differ significantly between any of the treatments. As a result of the significant decrease in E when [CO2]=750 ppm, WUE increased significantly by 57% and 71% for NCo376 and N31 respectively, relative to that of the control treatment. These results are in agreement with those reported by Vu & Allan (2009), where g_s and E of sugarcane decreased by 34% and 25% respectively, and WUE increased by 35%, under elevated CO_2 conditions.

Despite the noteworthy response in terms of water use, no significant differences in SDM or SUC yield were found between treatments (Table 1). Stokes *et al*. (2016) also showed no increase in sugarcane biomass under elevated CO_2 conditions, and argued that the elevated CO_2-induced increases in sugarcane yield observed in other studies were most likely due to indirect mechanisms, where elevated CO_2 alleviated water stress during unintentional periods of soil water deficit.

Table 1: Experimental results of varieties grown under control (400 ppm) and elevated (750 ppm) CO_2 conditions. Parameters include leaf-level CO_2 assimilation rate (*A*, μmol/m²/s), stomatal conductance (g_s, mmol/m²/s), transpiration rate (*E*, mmol/m²/s) and water use efficiency (WUE, mmol CO_2/mol H_2O), as well as stalk dry mass (SDM, kg/pot) and sucrose yield (SUC, kg/pot).

Variety	Treatment	Parameters					
		A	g_s	*E*	WUE	SDM	SUC
NCo376	Control	15.4^a	130.5^a	2.68^a	5.62^a	1.91^a	0.67^a
	Elevated	17.3^a	91.4^b	1.95^b	8.83^b	1.66^a	0.63^a
N31	Control	13.4^a	125.0^a	2.54^a	5.15^a	1.32^a	0.49^a
	Elevated	14.5^a	74.0^b	1.67^b	8.81^b	1.42^a	0.56^a

Simulation results

The Canesim® model mimicked the observed response to elevated CO_2 conditions in Potchefstroom, with simulated crop water use (CWU) decreasing by approximately 7% for both varieties relative to that of the control treatment (Table 2). The measured reduction in g_s and *E* (Table 1) supports the simulation by the model that crop water use would decrease under elevated CO_2 growing conditions. Scaling up from the single-leaf WUE to crop-level WUE in species with complex canopies like sugarcane is difficult (Grantz, 2014). Although the measured increases in single-leaf WUE were significant, there was a much smaller decrease in crop-level water use when [CO_2]=750 ppm in model simulations (4 and 8% reduction under rainfed and irrigated conditions, respectively). Small differences (2%) in simulated SDM and SUC yield were also found for both varieties between ambient and elevated CO_2 concentrations.

Under irrigated conditions in Komatipoort, the long term simulated SDM and SUC yield were found to increase marginally (<2%) for [CO_2]=750 ppm, compared to [CO_2]=440 ppm. Under rainfed conditions in La Mercy, larger increases of 10-13% were found for simulated SDM and SUC yield for [CO_2]=750 compared to [CO_2]=400 ppm.

Table 2: Simulation results of varieties simulated at three sites under control (400 ppm) and elevated (750 ppm) CO_2 conditions. Parameters include stalk dry mass (SDM, kg/pot), sucrose yield (SUC, kg/pot) and crop water use (CWU, mm).

Variety	Treatment	Potchefstroom (irrigated)			La Mercy (rainfed)			Komatipoort (irrigated)		
		SDM	SUC	CWU	SDM	SUC	CWU	SDM	SUC	CWU
NCo376	Control	23.3	11.0	840	21.8	9.8	703.5	42.0	21.1	1236.7
	Elevated	23.8	11.3	780	24.0	11.1	677.0	42.6	21.4	1138.8
N31	Control	20.2	8.7	878	18.9	7.8	713.5	35.8	16.4	1280.2
	Elevated	20.6	8.9	819	20.8	8.8	686.6	36.2	16.6	1173.6

Conclusions

Despite significant measured increases in single-leaf WUE in both varieties at Potchefstroom, there was no yield benefit in response to elevated CO_2 under irrigated conditions. These results were corroborated by model simulations which showed that there was no yield benefit in response to elevated CO_2 with a small reduction in crop water use at the crop canopy-level, but only at irrigated sites (Potchefstroom and Komatipoort). Stalk and sucrose yield, when simulated in a rainfed environment at La Mercy, was shown to increase (10-13%) indirectly from elevated CO_2-mediated increases in crop water use efficiency as supported by Stokes *et al*. 2016. These findings therefore warrant further research into the interactions of elevated CO_2 and water deficit on sugarcane physiology, growth and yield in order to increase the mechanistic understanding of future climate change impacts and to verify current model predictions.

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