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SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE

Unravelling Sugarcane Plant Response to a Future Climate

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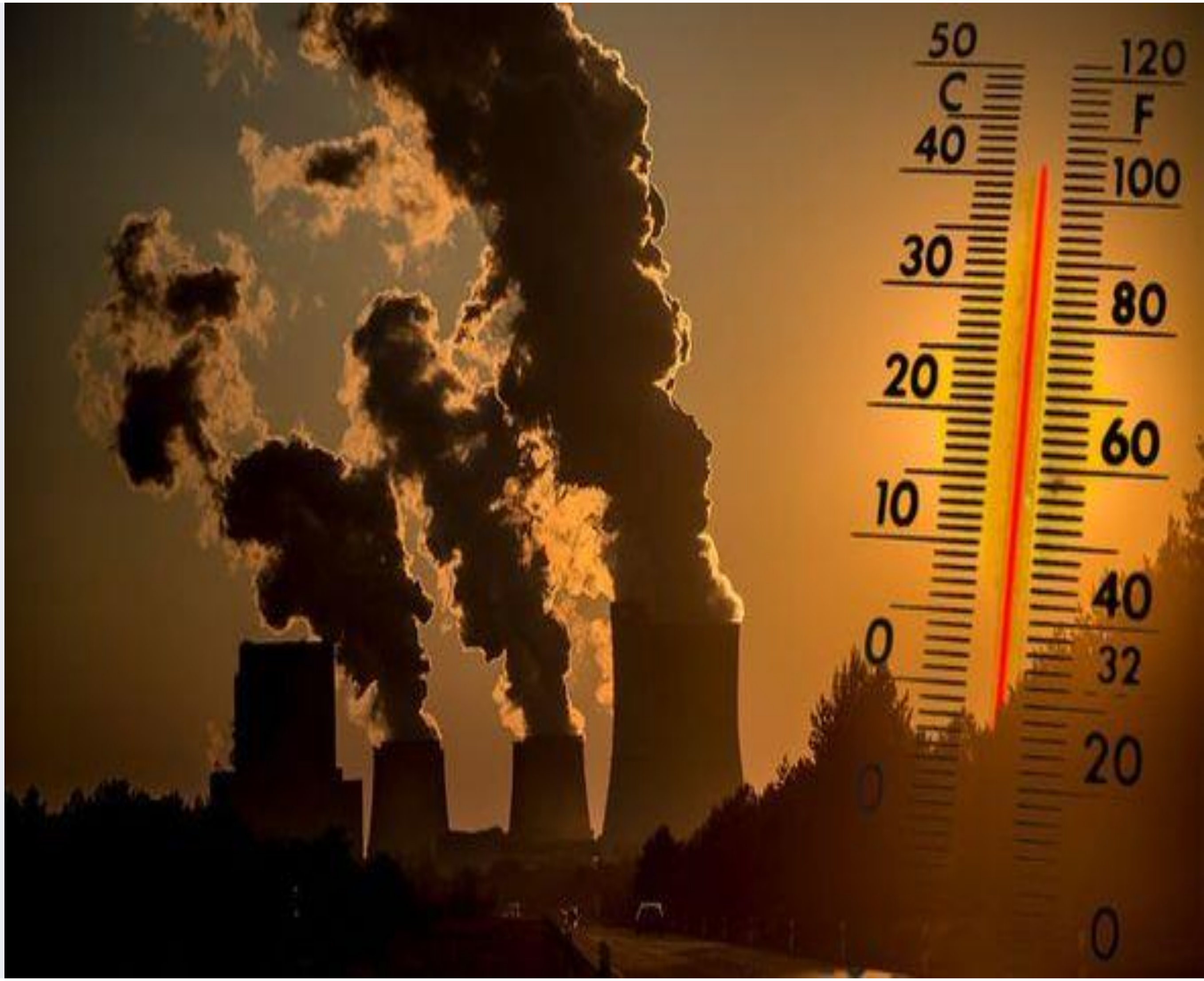
Introduction

- Climate change :
  - CO_2 emissions (Meehl et al., 2007; de Souza et al., 2008; IPCC., 2014; Tans & Keeling., 2016)
  - raised ambient temperature (arid and semi arid regions) aggravating plant heat stress
  - alterations in precipitation patterns



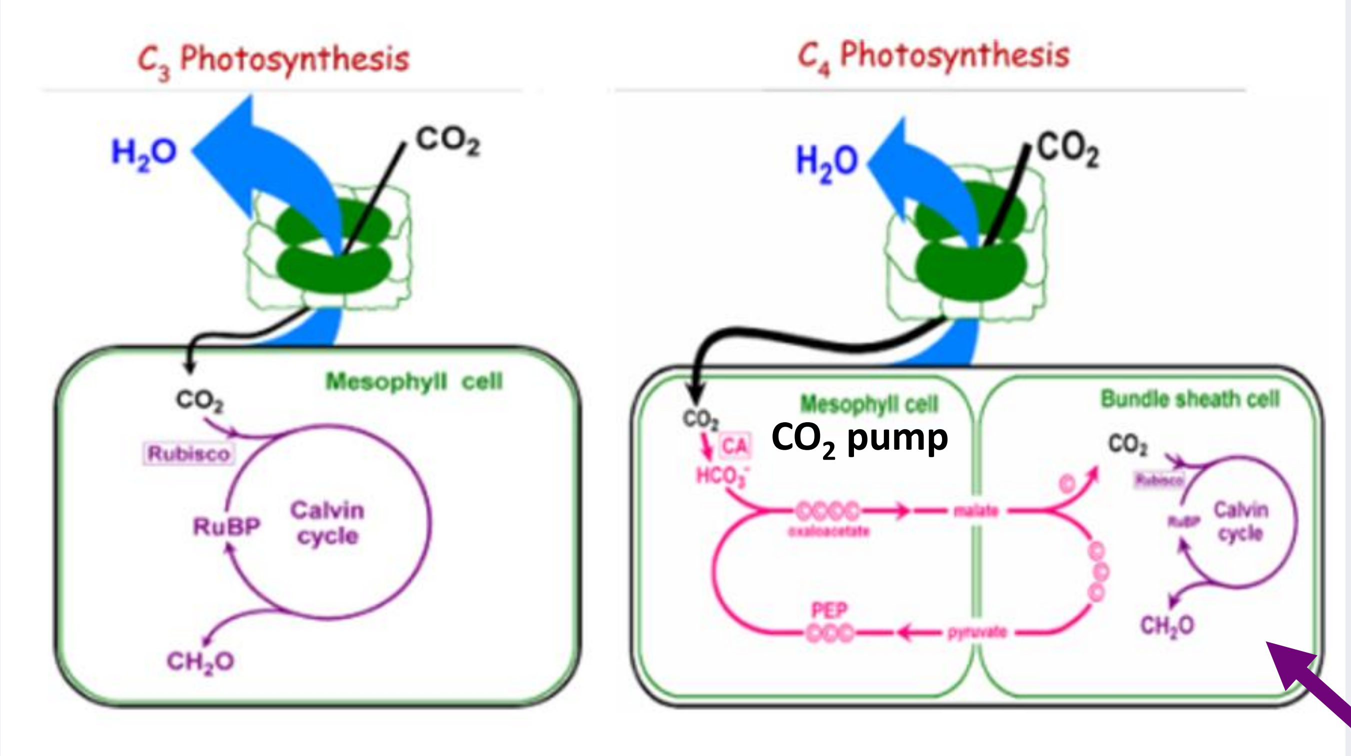
Introduction

- Interactive effect of CO_2 concentration (c_a) and soil water deficit (SWD) on sugarcane
- Sugarcane productivity under elevated c_a could possibly increase through:
  - Direct effects:
    - ✓ enhanced photosynthetic rate (A)
  - Indirect effects:
    - ✓ reduced stomatal conductance (g_s)
    - ✓ lower transpiration rate (E)
    - ✓ improved water use efficiency (WUE)

Introduction

- C_3 and C_4 type of photosynthesis:

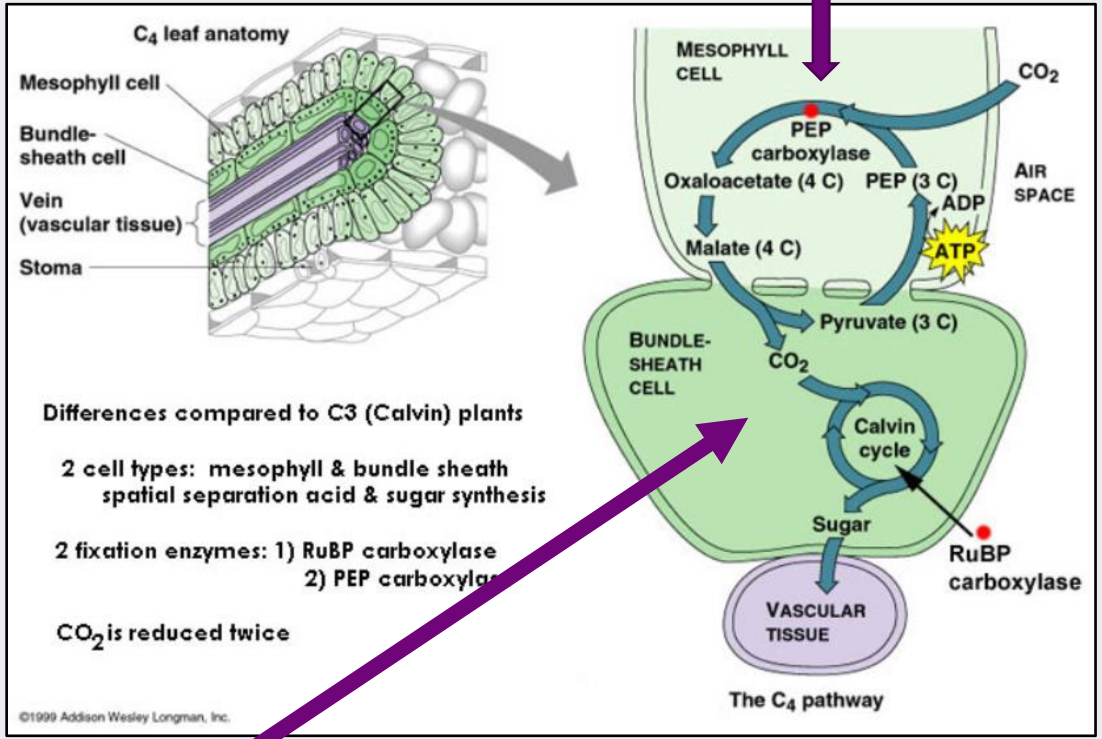
e.g. macadamia trees **e.g. maize and sugarcane**



CO_2 pump

Source: https://openi.nlm.nih.gov

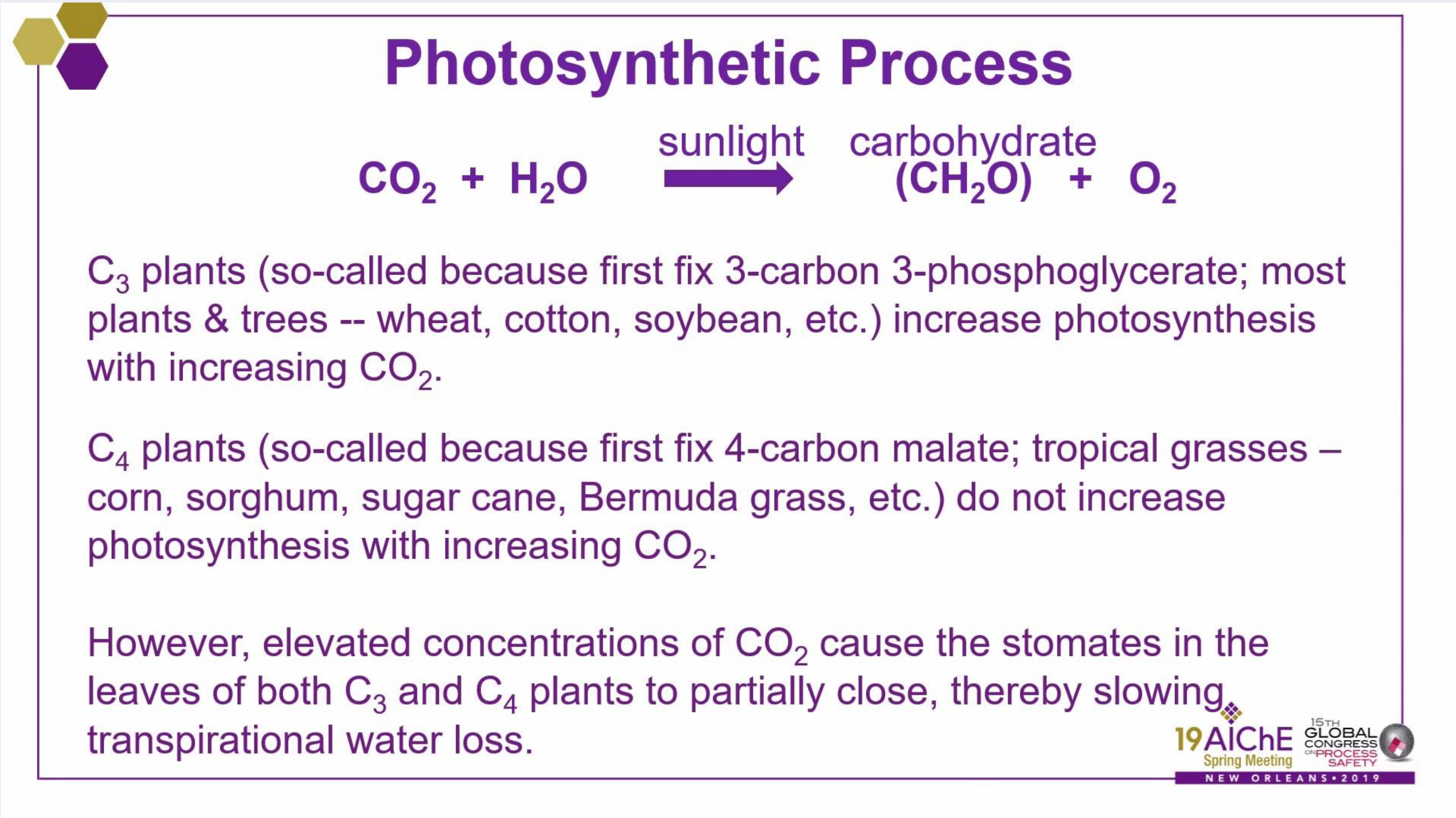
CO_2 pump



CO_2 pump in mesophyll cells concentrates CO_2 for Rubisco enzyme in bundle sheath cells

Introduction

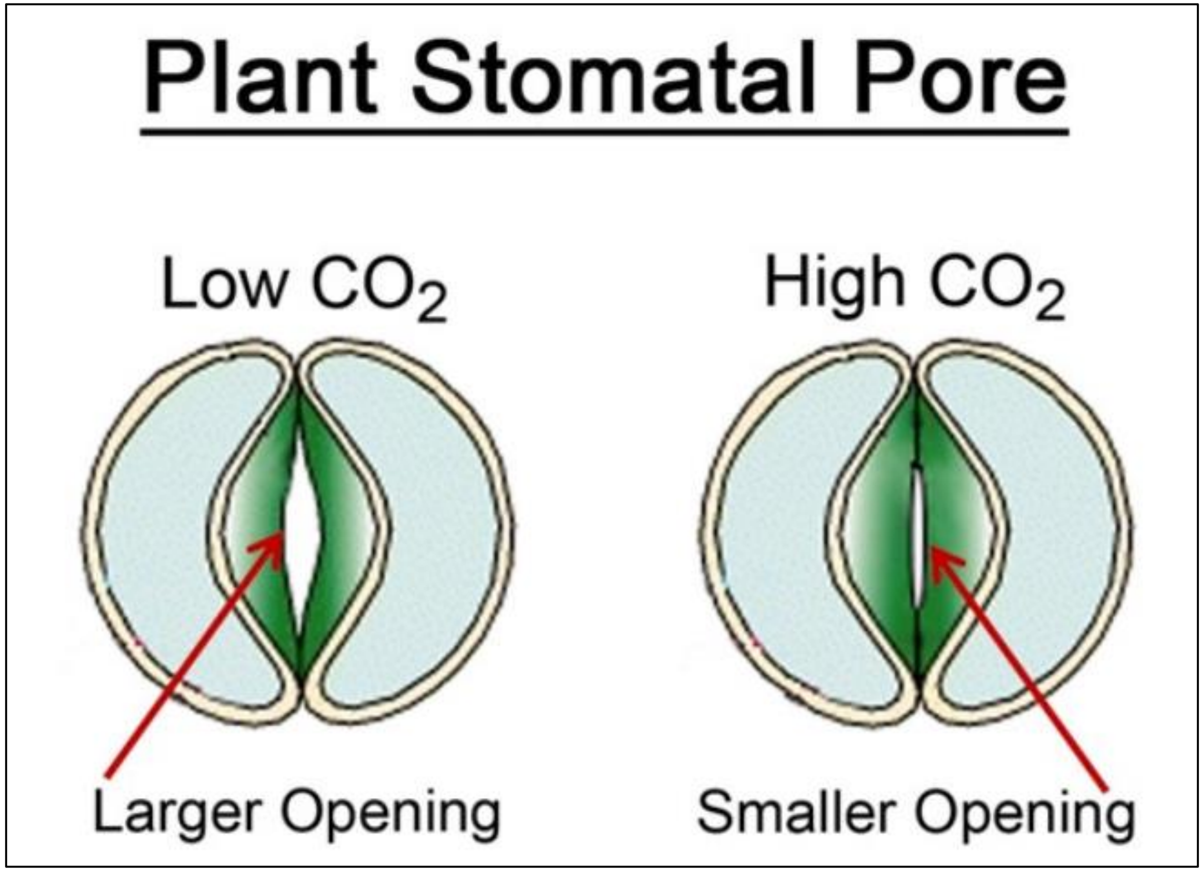
- Interactive effect of CO_2 concentration (c_a) and soil water deficit (SWD)



Introduction

- WUE is the amount of biomass produced per unit of water used

- Elevated CO_2 increase WUE because of reduced water loss by transpiration



Introduction

- Crop simulation model
  - Canesim® sugarcane model (Singels., 2007)
  - The Canesim® sugarcane crop model assumes that elevated c_a will cause no additional yield benefit, but that crop WUE will increase. Improved WUE may buffer transient periods of SWD (Wall et al., 2001; Stokes & Inman-Bamber., 2014).
  - Crop model testing
  - Thus this research was aimed at generating a novel empirical data set that could be used to test the Canesim® sugarcane model`s simulation capabilities.
  - Continuous model improvement will enable more precise exploration of sugarcane productivity under predicted future climate, which holds direct relevance for local sugarcane production into the future.

Objectives

- To gain insight into the phenological response of sugarcane to elevated c_a and SWD interaction.
- To critically assess elevated c_a and SWD interaction on sugarcane photosynthetic gas exchange and WUE.
- To evaluate the interactive effect of elevated c_a and SWD on sugarcane yield and quality parameters.
- To test the Canesim® crop model`s simulation capability of the noted effects.

Methodology

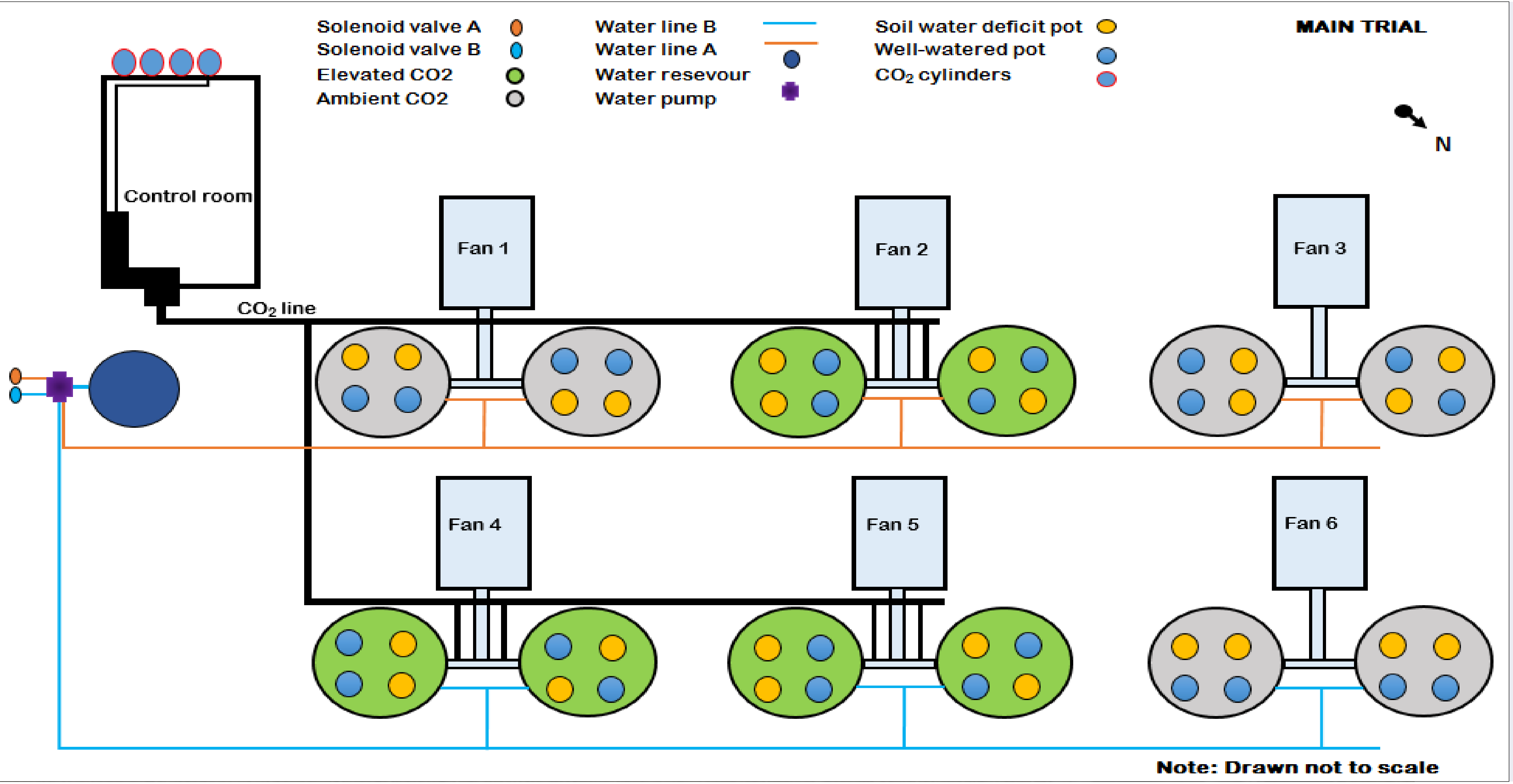
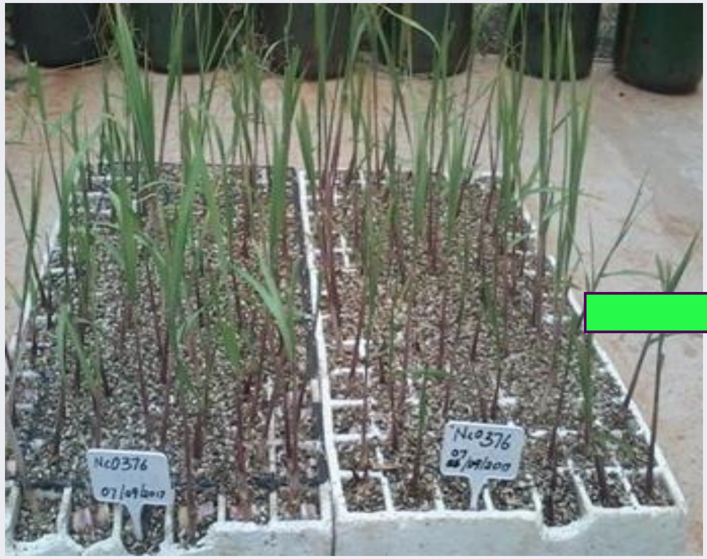


FIGURE: The layout of the main experiment for cultivar NCo376 grown under different CO_2 and soil water treatment conditions in the OTC facility at NWU (Potchefstroom)

Methodology

Planting	CO_2 fumigation	SWD treatment effected	Harvesting
12-Sep-18	02-Nov-18	22-Jan-19	22-Apr-19
400 (μmol mol^{-1})	400 (μmol mol^{-1})*8L/day	400 (μmol mol^{-1})*8L/day	
400 (μmol mol^{-1})	400 (μmol mol^{-1})*8L/day	400 (μmol mol^{-1})*4L/day	
400 (μmol mol^{-1})	750 (μmol mol^{-1})*8L/day	750 (μmol mol^{-1})*8L/day	
400 (μmol mol^{-1})	750 (μmol mol^{-1})*8L/day	750 (μmol mol^{-1})*4L/day	



NCo376 sugarcane speedlings ready for transplanting.

Sugarcane tiller initiation under OTC facility at 4 weeks after CO_2 fumigation.

Sugarcane crop at full canopy cover at 16 weeks after CO_2 fumigation (WAF)

Mulched sugarcane stalks at harvest (23 WAF)

Data Collection

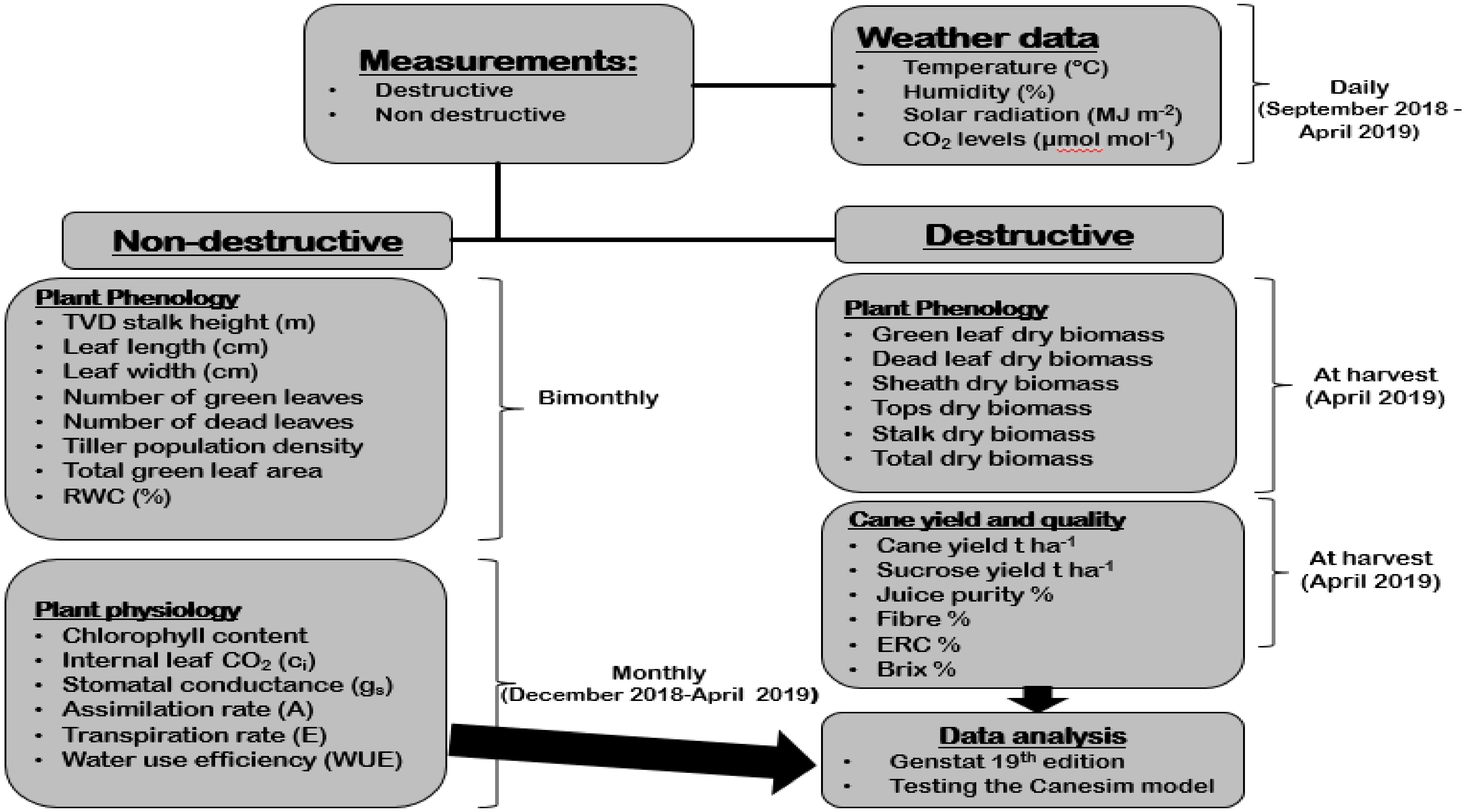


FIGURE: A summary of all measurements taken during the main trial.

Results

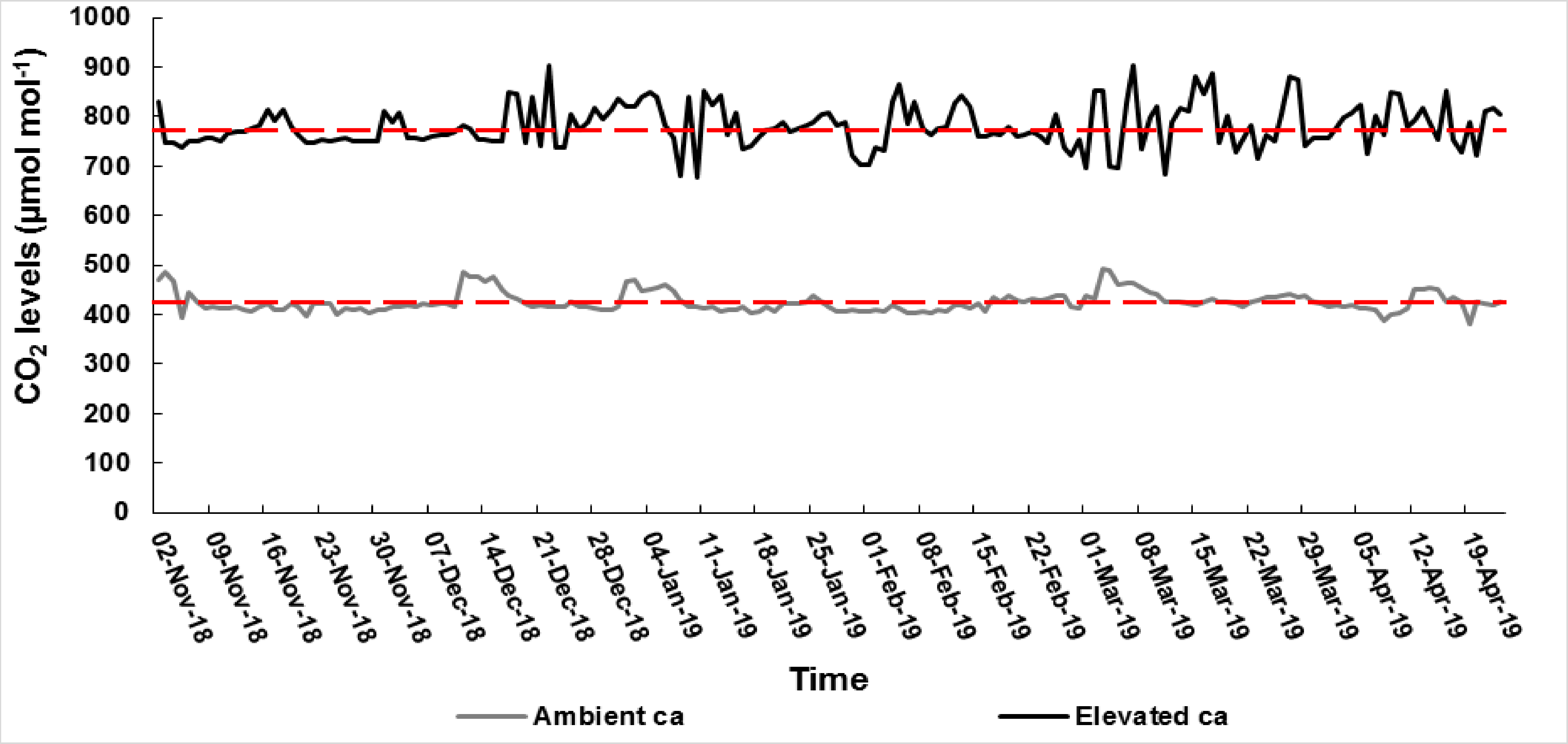


FIGURE: Daily measured c_a maintained in ambient and elevated OTCs. The target mean c_a for the elevated treatment was 750-800 µmol mol^{-1}. Dashed lines represent the average ambient and elevated c_a across measured time period.

Results

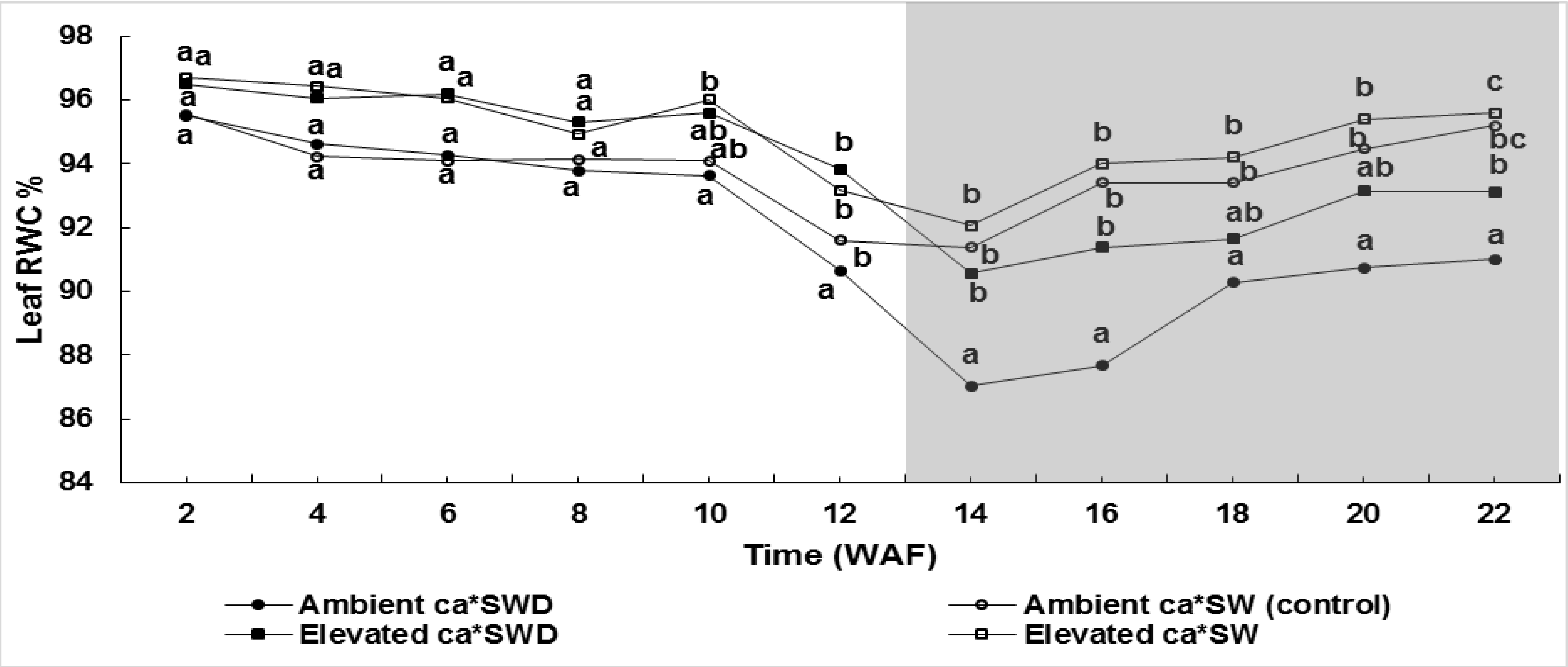


FIGURE: Bimonthly measurements of leaf relative water content (RWC) measured on top visible dewlap (TVD) leaves to monitor plant water status in well-watered (SW) and soil water deficit (SWD) plants both exposed to ambient c_a and elevated c_a treatments.

Results

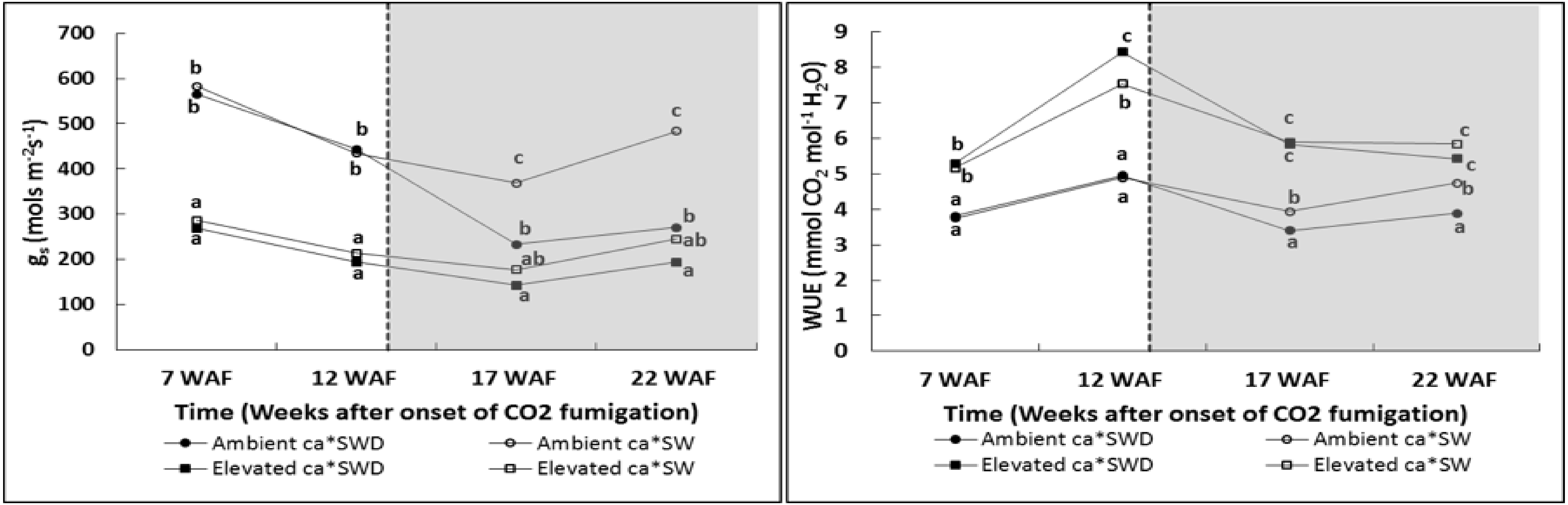


FIGURE: Stomatal conductance (g_s) and WUE of TVD leaves of sugarcane plants exposed to Elevated c_a (SW and SWD) and Ambient c_a (SW and SWD). From 7-12 WAF, all the potted plants were exposed to Ambient SW and Elevated SW conditions respectively, followed by the introduction of SWD treatments 12-22 WAF (grey shaded area). Data points with the same letter(s) are not significantly different at $P < 0.05$.

Results

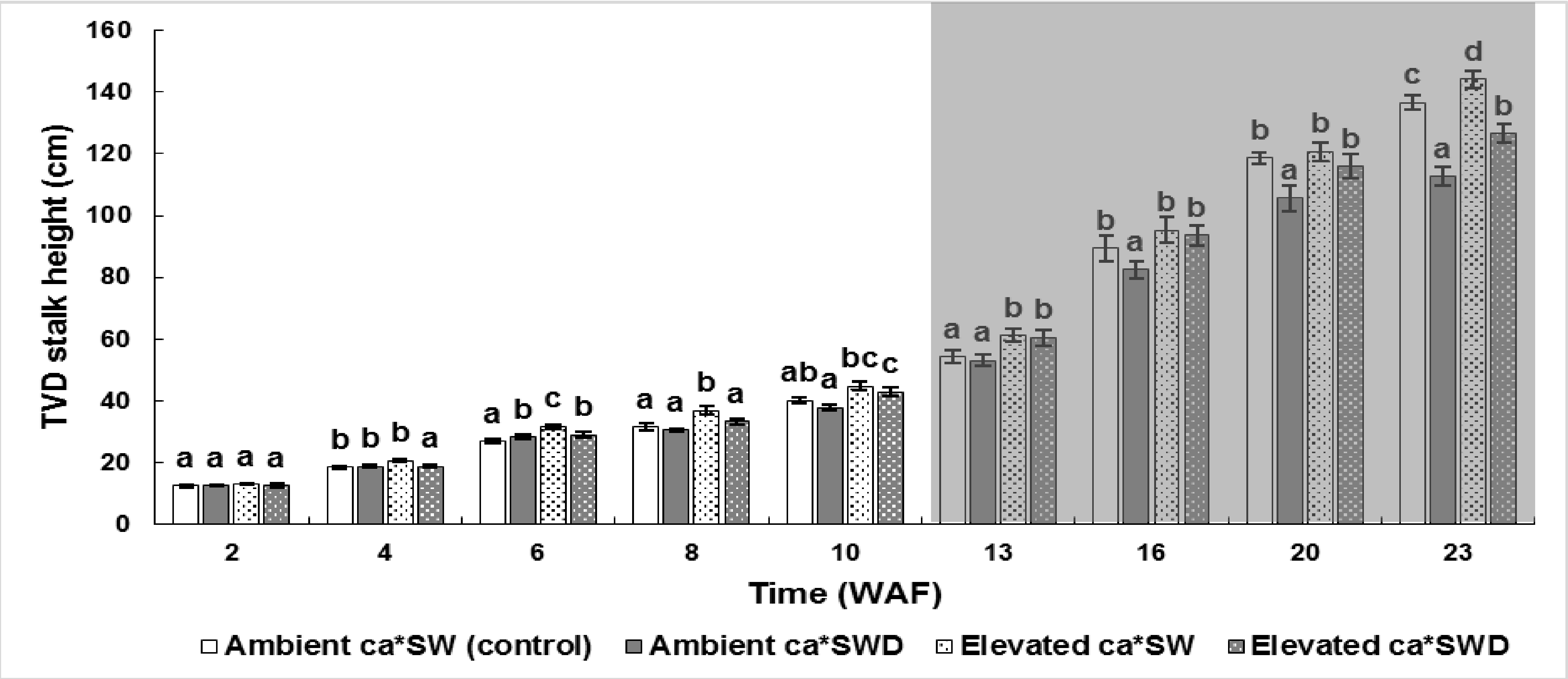


FIGURE: Effect of CO_2 concentration and soil water interaction on TVD stalk height. Different letters represent statistical differences (P<0.05) between treatment means at each sampling point. Bars are standard deviation (n=6). The unshaded area represent time before introduction of SWD conditions and the grey shaded area represent time after the introduction of the SWD treatment.

Results

Table 1: Interactive effect of CO_2 and soil water on stalks dry biomass, total aboveground dry biomass, ERC%, cane yield (g) stalk^{-1} and sucrose yield (g) stalk^{-1} of NCo376 sugarcane variety (23WAF). The lowercase letters (superscript) represent statistical differences between treatments at P<0.05.

** , ns = P<0.05 and No significance respectively.*

Source of variation	Stalk dry biomass (g)	Total biomass (g)	Cane yield (g) stalk^{-1}	ERC % cane	Sucrose yield (g) stalk^{-1}
CO_2 concentration	*	*	*	ns	*
Soil water deficit	*	*	*	*	*
CO_2 concentration*Soil water deficit	ns	ns	ns	ns	ns
Treatments					
Ambient c_a*SW	1041^{bc}	2017^{bc}	437^{b}	3.04^{a}	24.20^{ab}
Ambient c_a*SWD	517^{a}	1269^{a}	220^{a}	3.53^{a}	13.00^{a}
Elevated c_a*SW	1182^{c}	2239^{c}	517^{b}	3.61^{a}	30.80^{c}
Elevated c_a*SWD	864^{b}	1731^{b}	363^{b}	4.66^{b}	24.80^{bc}
$LSD_{0.05}$	205.8	305.1	86.5	0.805	6.44
CV%	27	19.9	26.6	25.6	32.8

Ambient (SW:SWD)	*50*	*37*	*50*	*14*	*46*
Elevated (SW:SWD)	*27*	*23*	*30*	*23*	*19*
Elevated (SWD): Ambient (SWD)	*40*	*27*	*39*	*24*	*48*

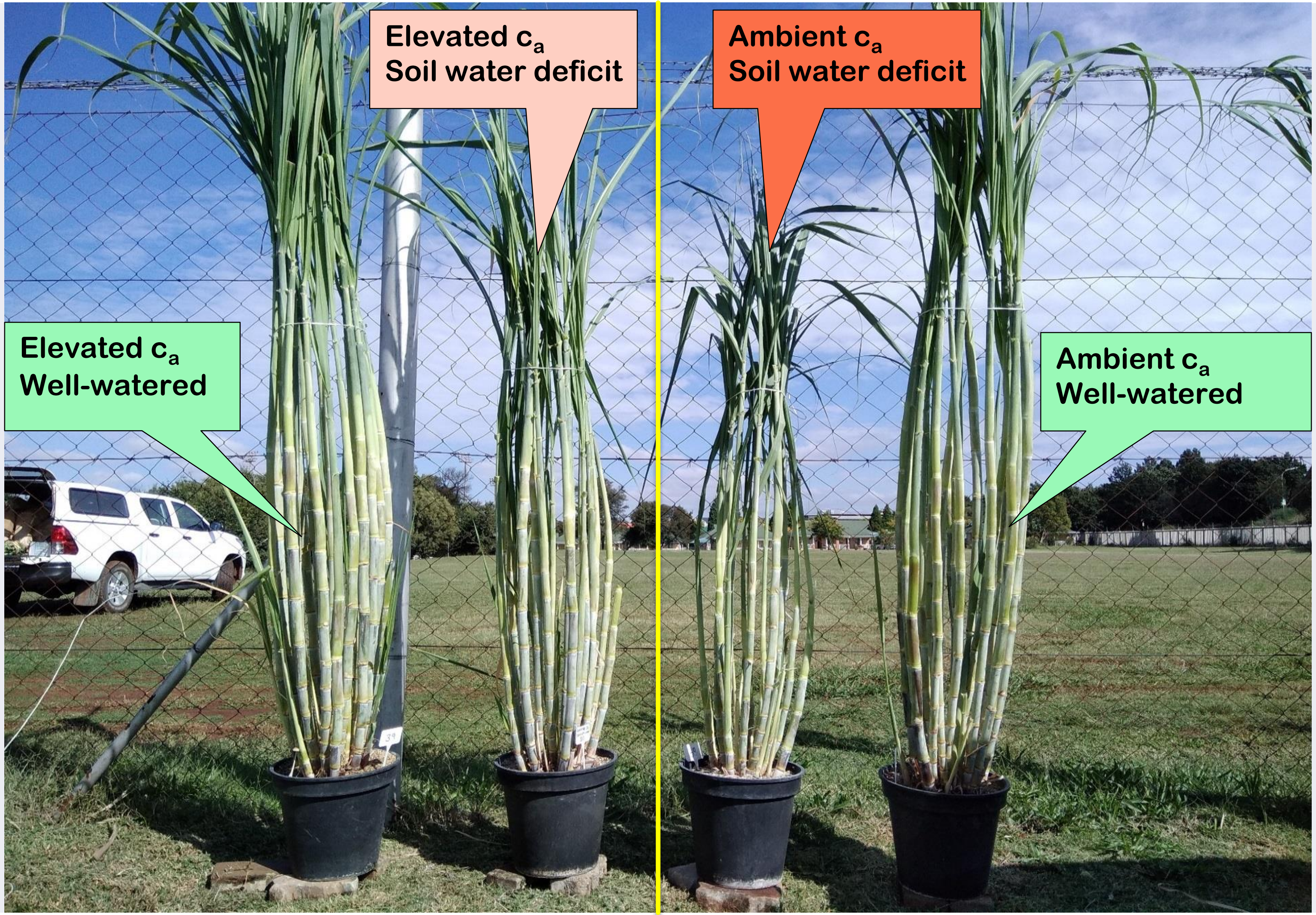
NWU®

Results

Table 2: Normalised actual and simulated (Canesim® model) results of NCo367 sugarcane cultivar grown under ambient ca*SW, ambient ca*SWD, elevated ca*SW and elevated ca*SW conditions. Total simulated irrigation volume (mm) and normalised ET values are presented. Normalised treatment values less than one show low treatment performance while those greater than one show high treatment performance relative to the ambient ca*SW treatment.

	Water Balance		Simulated		Actual	
Treatments	**Irrigation (mm)**	**ET**	**Dry Cane yield**	**Sucrose yield**	**Dry Cane yield**	**Sucrose yield**
Ambient c_a*SW (control)	1248.00	1.00	1.00	1.00	1.00	1.00
Ambient c_a*SWD	1064.00	0.86	0.80	0.86	0.50	0.54
Elevated c_a*SW	1248.00	0.93	1.08	1.01	1.18	1.27
Elevated c_a*SWD	1064.00	0.82	0.90	0.92	0.83	1.02

Results


Elevated c_a
Soil water deficit
Ambient c_a
Soil water deficit
Elevated c_a
Well-watered
Ambient c_a
Well-watered

Conclusion

The current study hypothesised that the negative consequences of mild SWD on plant productivity in sugarcane would be partially mitigated under elevated CO_2. This could be attributed to the indirect effects of elevated c_a, which may buffer transient periods of drought stress:

- Elevated c_a increases sugarcane plant biomass, cane and sucrose yield under SWD conditions through the indirect effect of reduced g_s, E and increased WUE.

- Elevated c_a promotes stomatal downregulation which increased WUE, buffering the detrimental effects of mild soil water deficit on sugarcane crops. Hence the increased WUE, result in a significant increase in biomass partitioning for sugarcane crop grown under elevated c_a*SWD conditions.

Conclusion

- The Canesim® sugarcane model underestimated the magnitude of yield response of elevated c_a and SWD relative to empirical results.
- The study demonstrated the difficulties of representing pot (limited soil layers in pots compared to field conditions) and open-top chamber conditions in the model. This is attributed to the parameterisation of the Canesim® model, as it is designed to mimic field conditions.

Recommendation

- Further studies are needed to explore the refinement of the model to account for pot and open-top chamber environments.
- This will enable more precise exploration of sugarcane plant response to predicted future climate change scenarios.

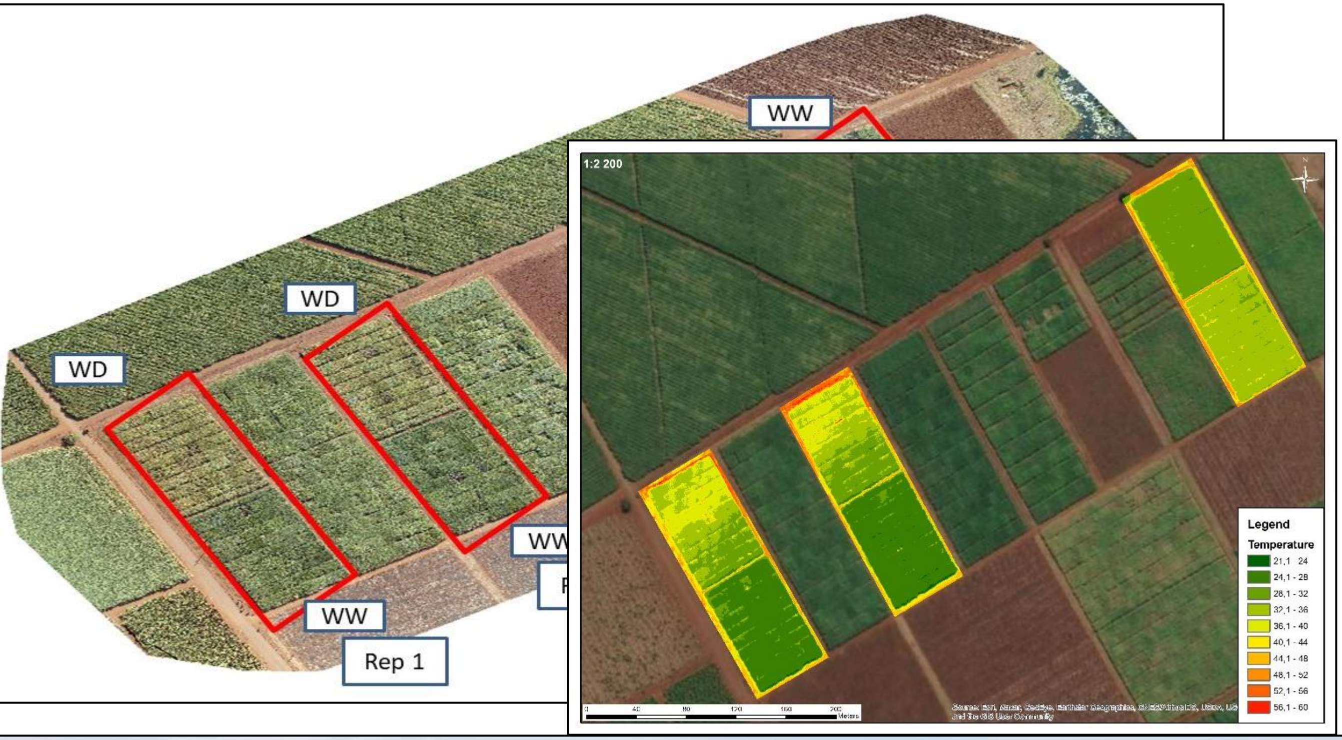
Remaining Knowledge Gaps

- At elevated CO_2 lower transpiration rates could reduce evaporative cooling of leaves.
- In a changing climate, where warmer temperatures are predicted with a high degree of certainty, this leaves us with questions about the effect of heat stress on sugarcane.
- Heat stress might offset some of the WUE benefits associated with elevated CO_2 in sugarcane production.
- Recent high-throughput phenotyping research at SASRI have demonstrated the relationship between canopy temperature and cane yield.

High-throughput phenotyping (HTP) to assist breeding for drought tolerant sugarcane

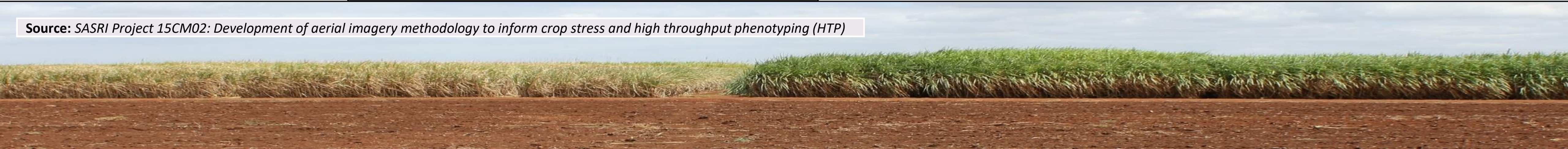
Overall aim:

Develop a HTP protocol for screening early-stage breeding populations for drought tolerance



- SASRI Komati Research Station, Mpumalanga (plant & ratoon crops)
- 53 genotypes (commercial & foreign varieties, unreleased breeding lines)
- Three replicate blocks (~1ha each), divided into well-watered (WW) & water deficit (WD) treatments
- Leaf physiological traits, canopy development & temperature under a range of moisture conditions, and stalk yield at harvest

Source: *SASRI Project 15CM02: Development of aerial imagery methodology to inform crop stress and high throughput phenotyping (HTP)*



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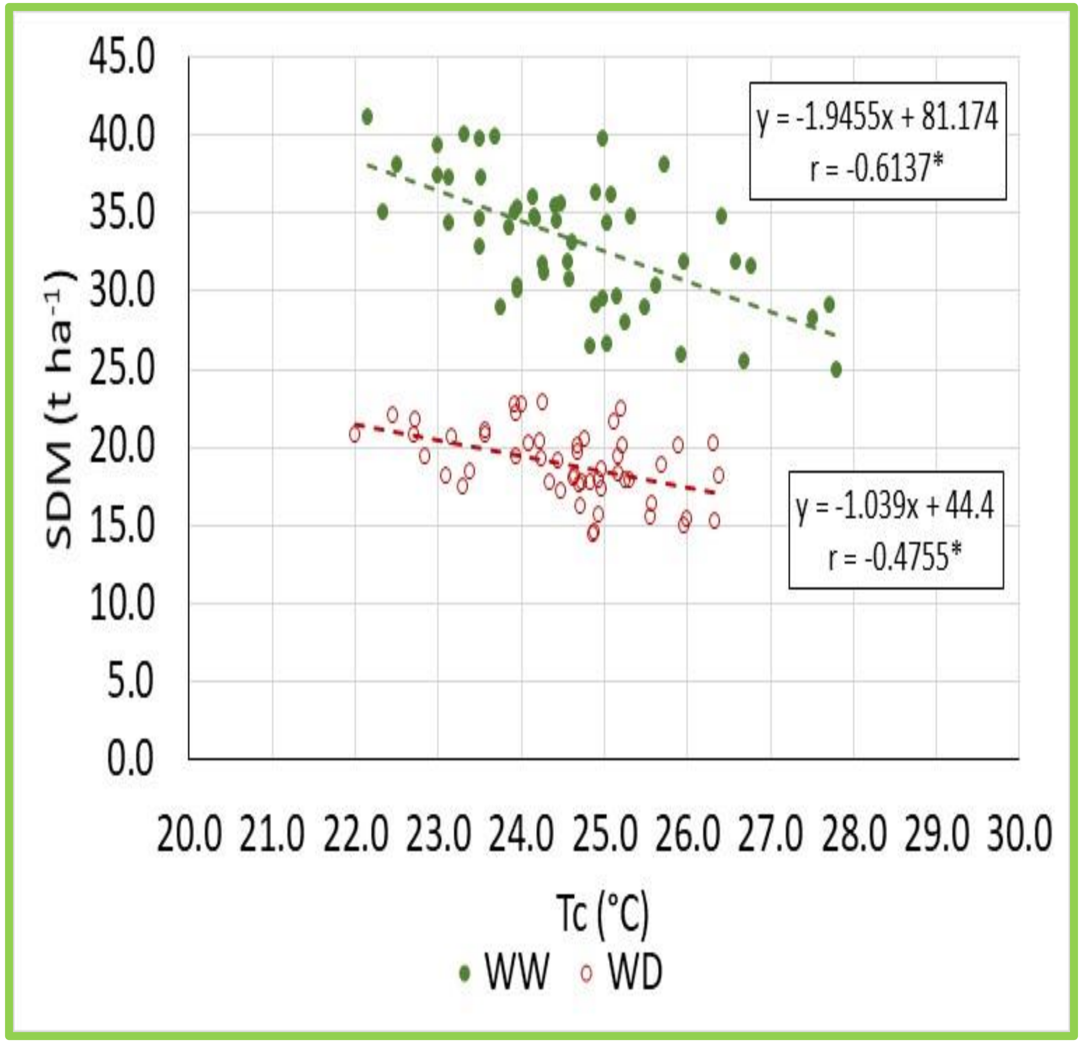

Stalk dry matter (SDM) yield vs. canopy temperature (Tc): Significant correlations for both water treatments.

Higher SDM yields are achieved at lower canopy temperatures.

Hence, higher canopy temperatures under elevated CO_2 conditions could offset some of the reported benefits.

Thank you

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