CO_2 fertilization of C_4 grasses across experiments, field observations, and models

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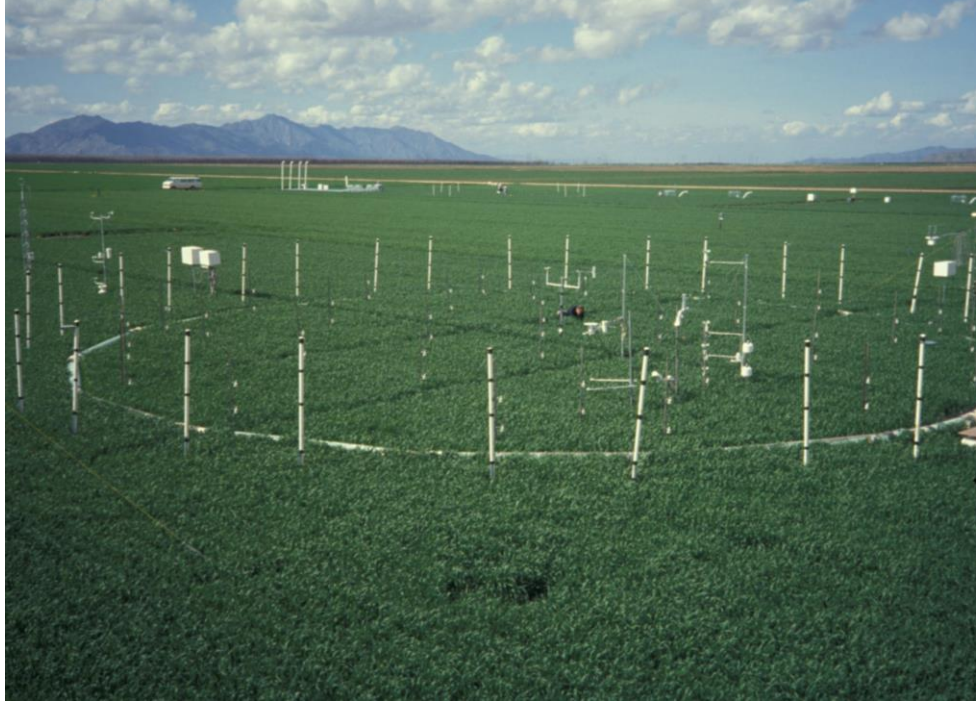
30 years of FACE experiments..

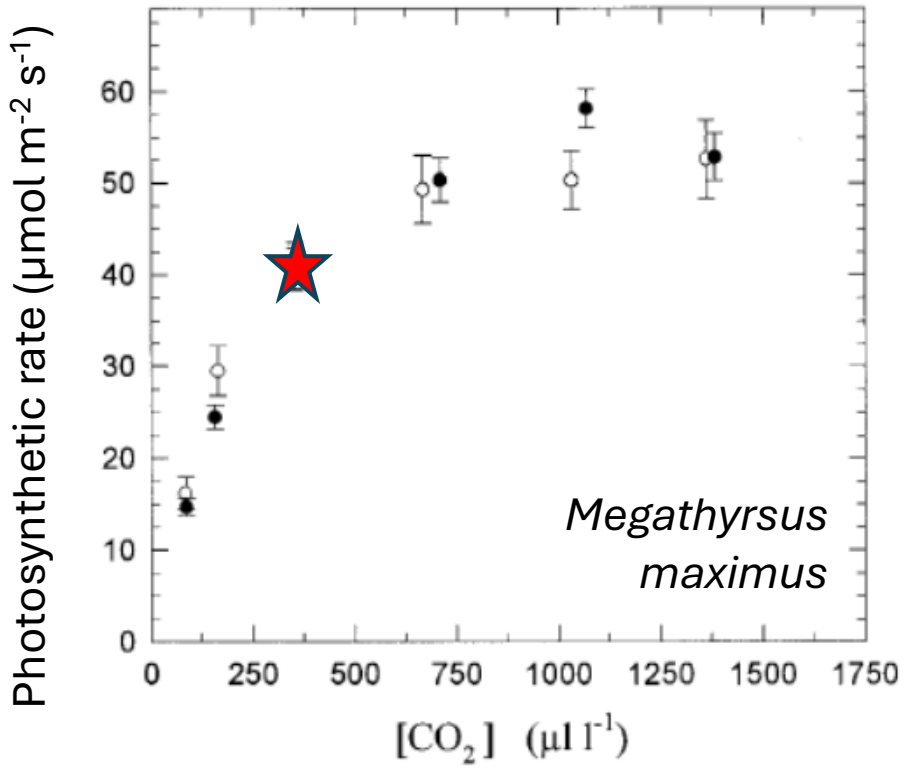
.. but none in savannas



How do C_4 savanna grasses respond to rising CO_2?

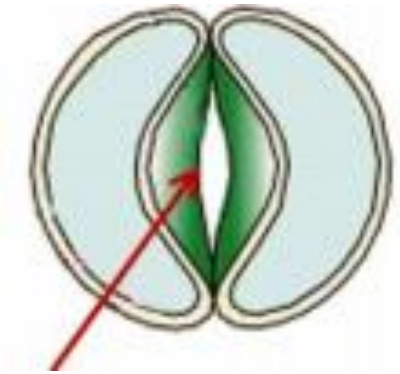
How do C_4 savanna grasses respond to rising CO_2?

1. Photosynthesis is not carbon-saturated under ambient conditions



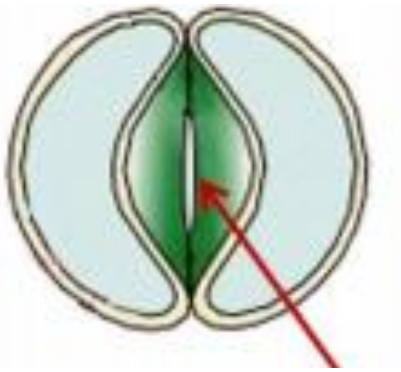
2. Reduced transpiration improves plant water relations & stimulates growth

Ambient CO_2



↑ stomatal conductance
↑ transpiration

Elevated CO_2



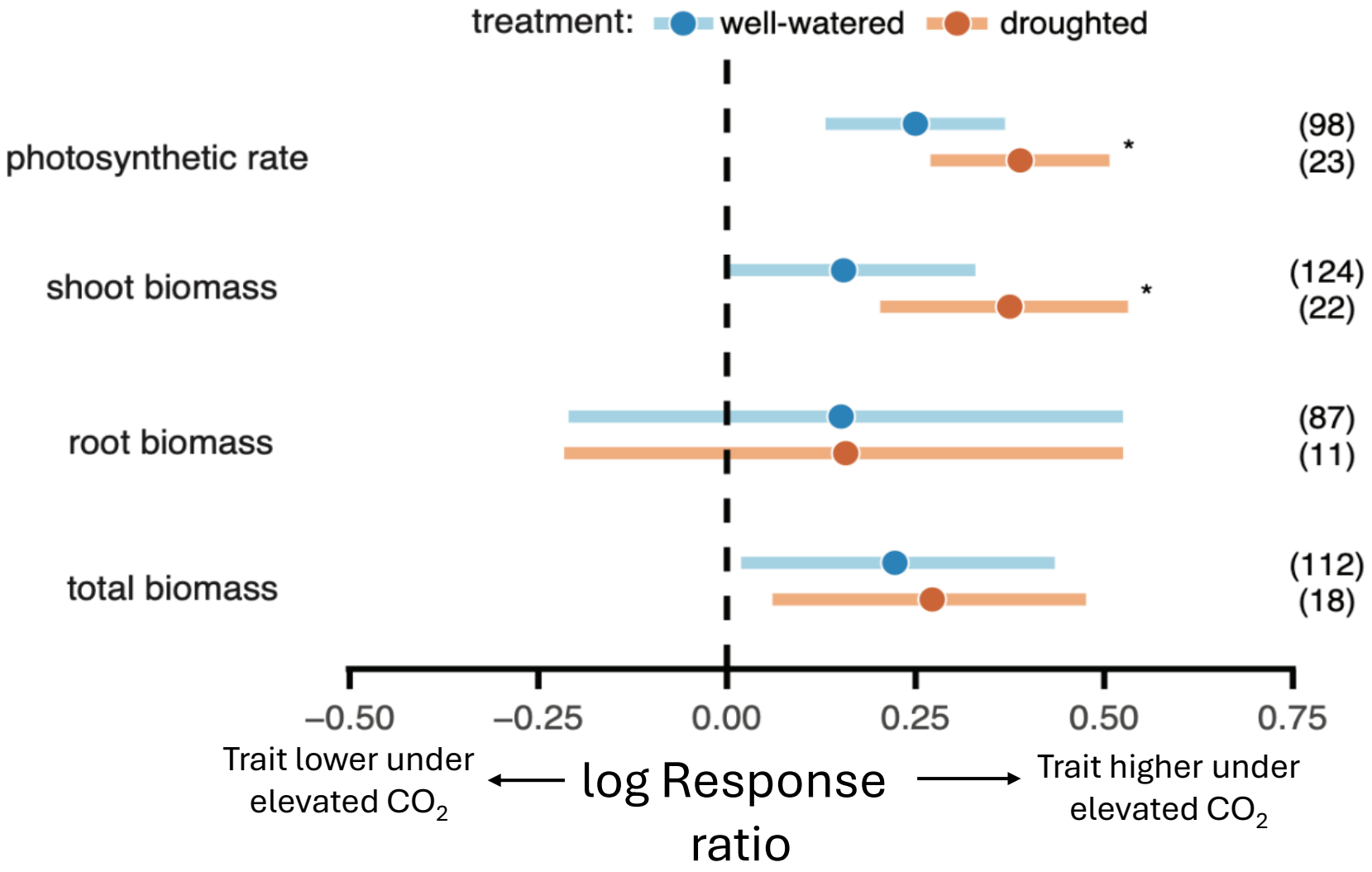
↓ stomatal conductance
↓ transpiration
= ↑ water use efficiency

Meta-analysis | Field Data | Vegetation models

(Simpson, Staver *et al* in review)

Meta-analysis | Field Data | Vegetation models

CO_2-fertilization of C_4 grass shoot biomass



- 70 studies
- >800 trait measurements
- 92 C_4 grass species
- Watered / droughted treatments

Under elevated CO_2:

Photosynthesis:

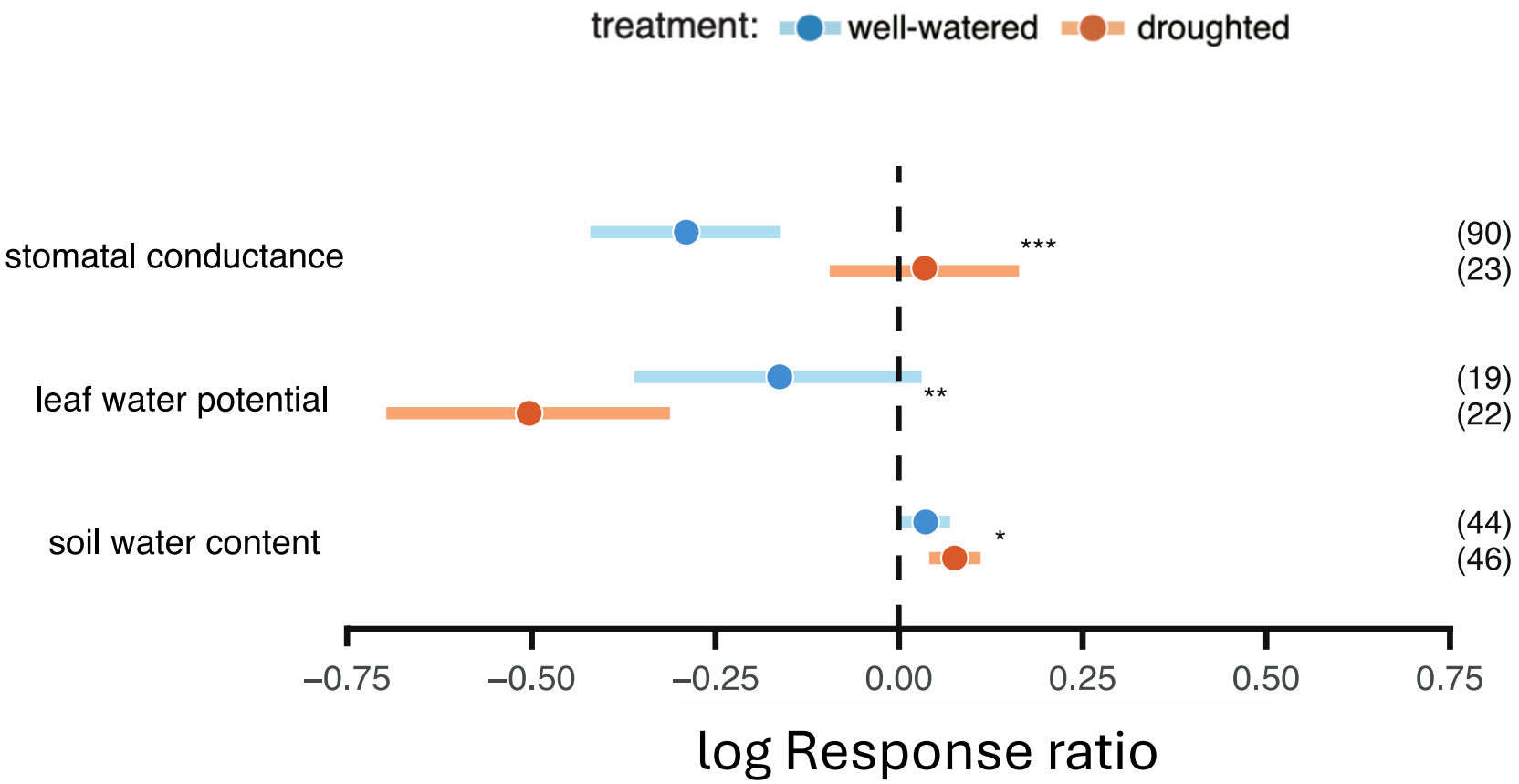
- well-watered +28%
- droughted +48%

Shoot biomass:

- well-watered +16%
- droughted +44%

Root biomass effects highly variable

Improved water relations under elevated CO_2



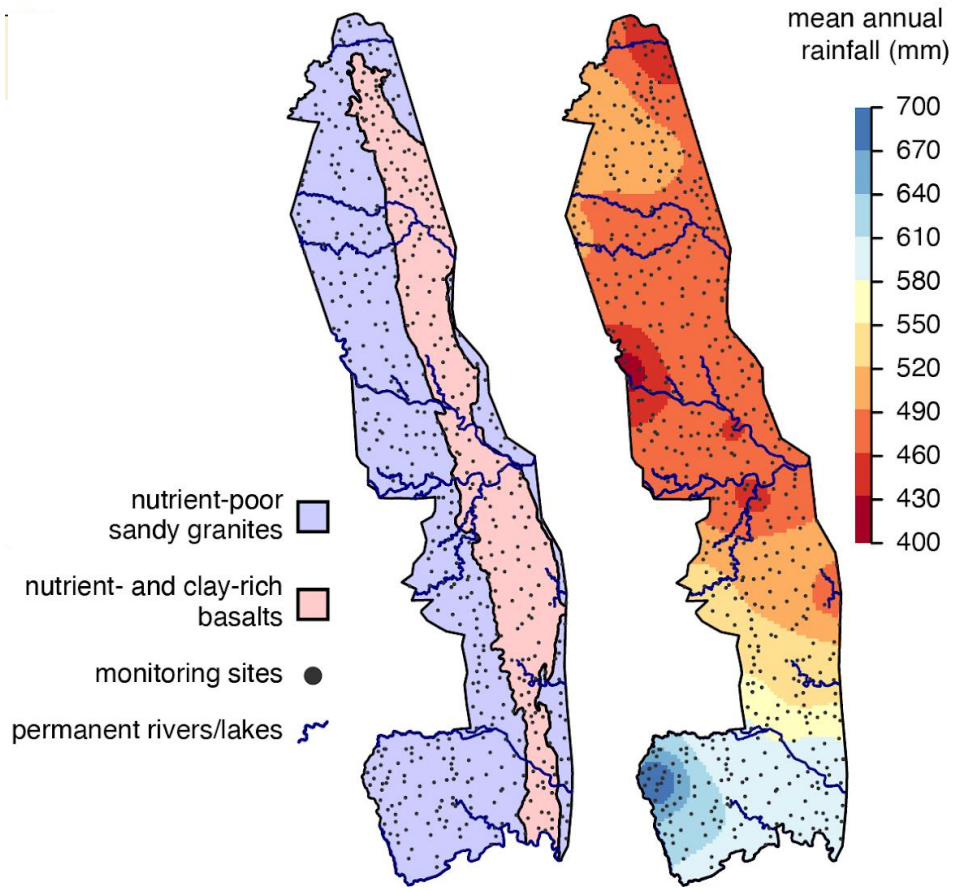
Under elevated CO_2:

Stomatal conductance:
- well-watered -25%
- droughted 0%

Leaf water potential:
- well-watered 0%
- droughted +20%

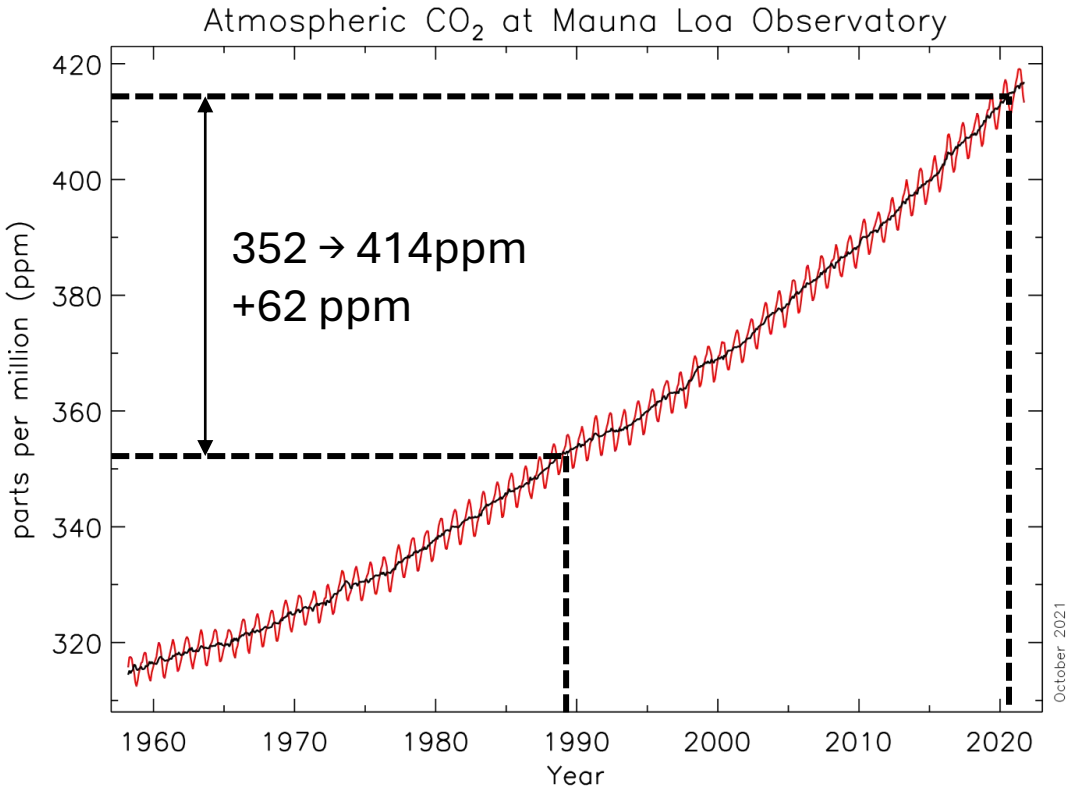
Soil water content
- well-watered 0%
- droughted +8%

Meta-analysis | Field Data | Vegetation models



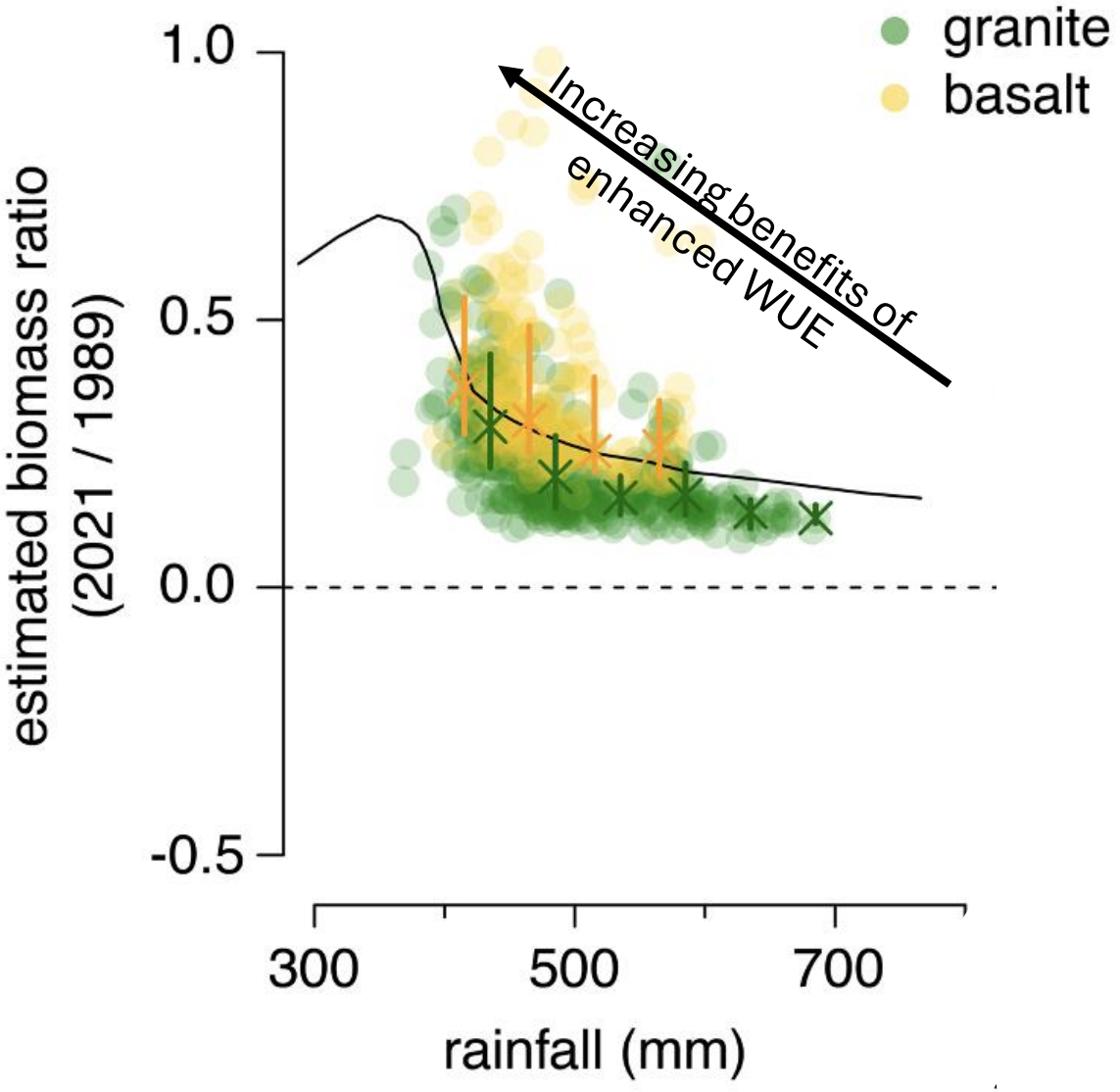
32 annual measurements of grass biomass (1989-2021) across 533 permanent plots in KNP

Rainfall gradient and two soil types



Do we observe increases in grass biomass over this timeframe?

Can we attribute this to the increase in CO_2?

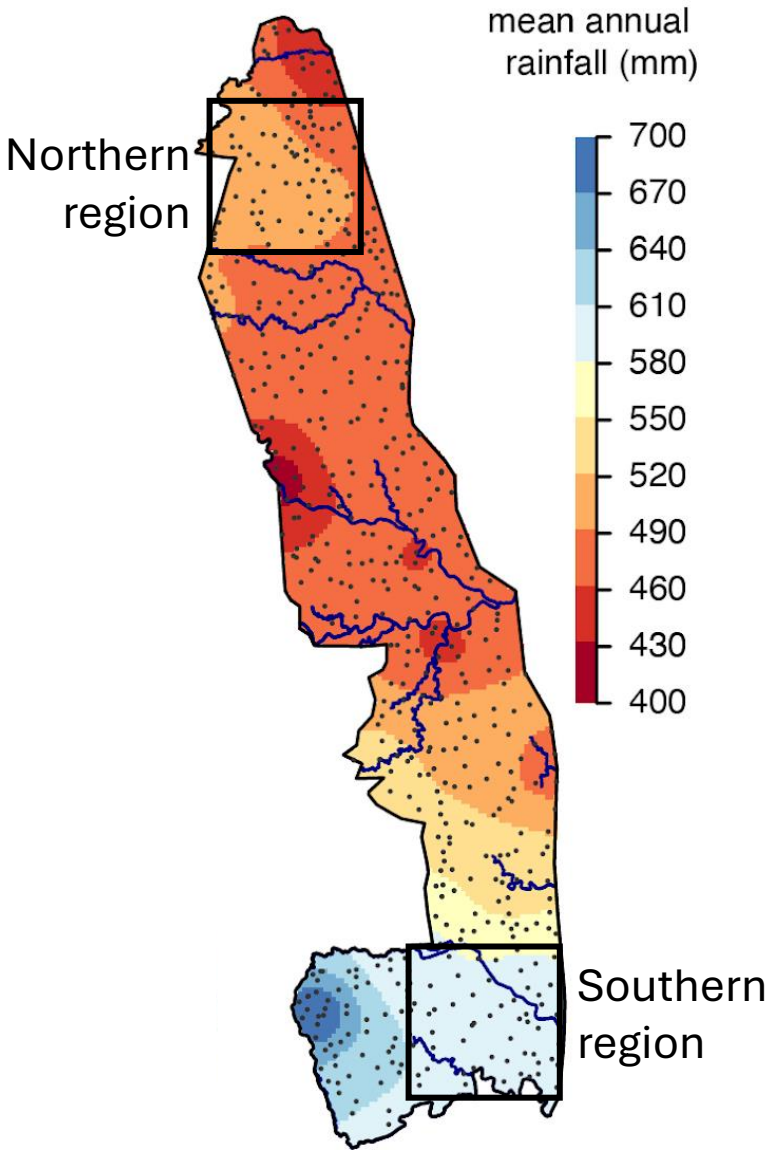


After accounting for climatic and ecological factors..

Long-term increases are greater at drier than wetter sites, and on the more nutrient-rich soil type

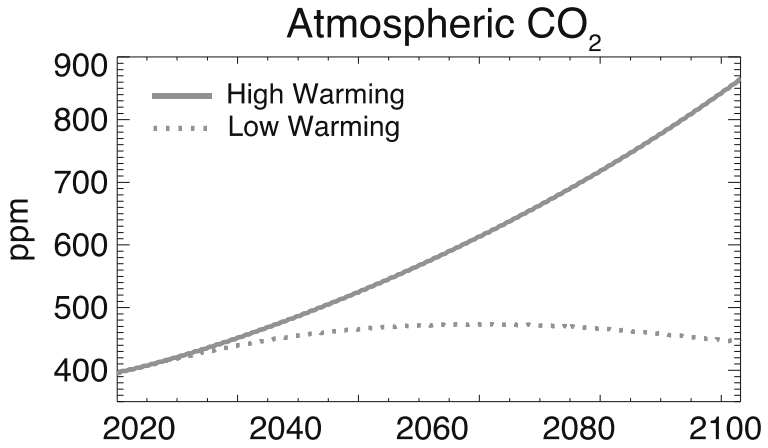
Magnitude similar to meta-analysis of experiments

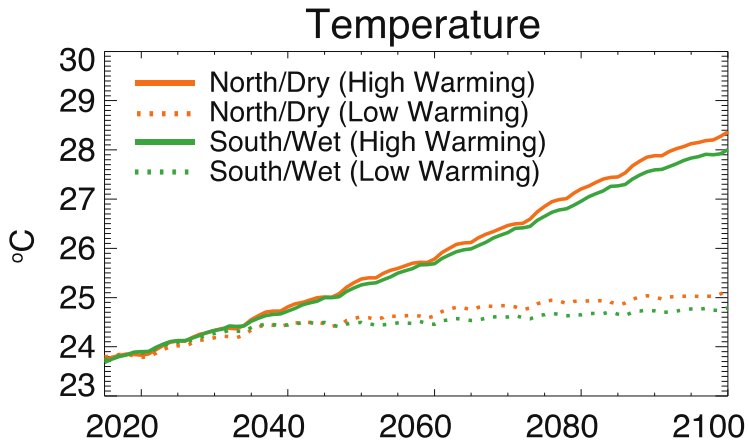
Meta-analysis | Field Data | Vegetation models

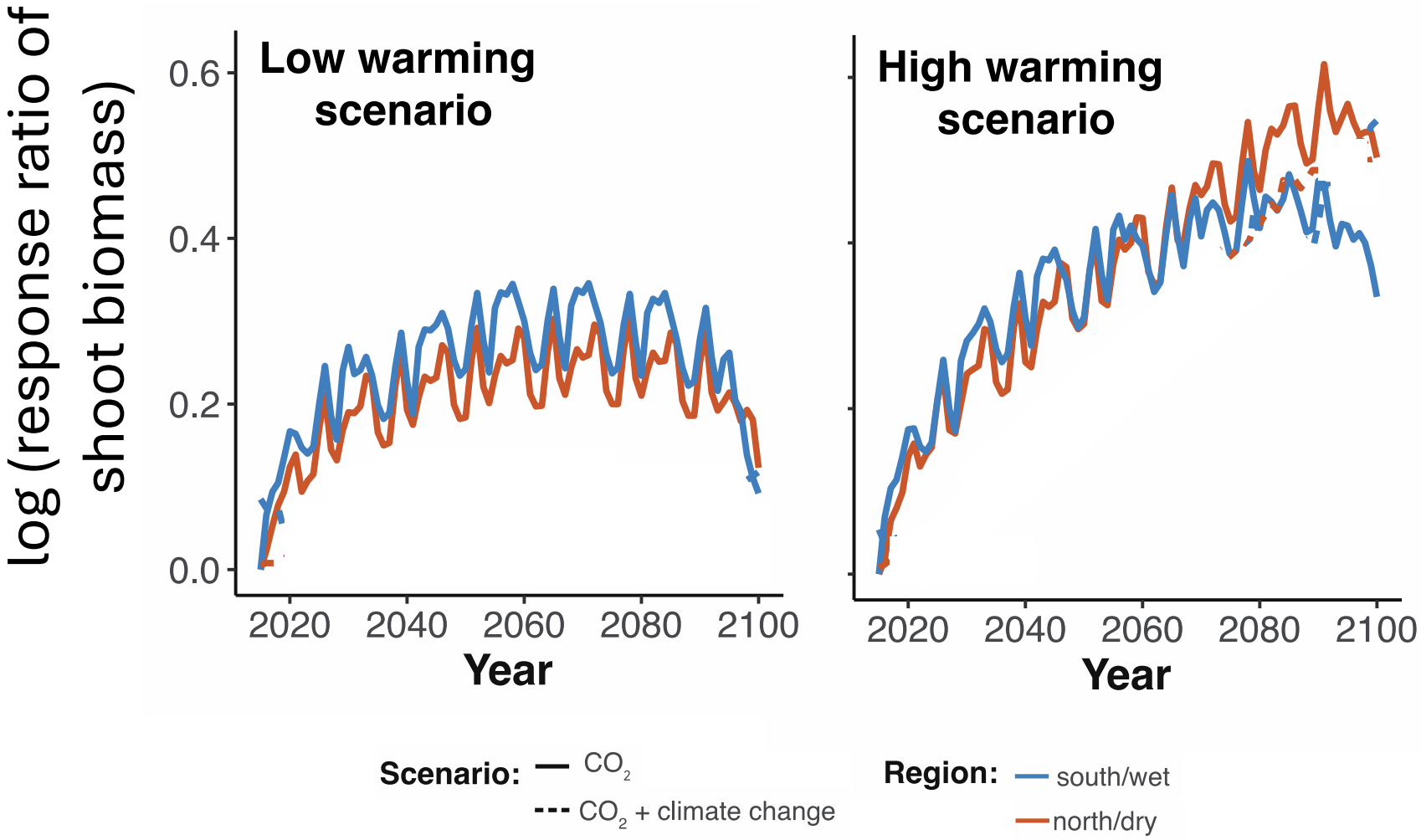


Modelling C_4 grass responses to rising atmospheric CO_2 and climate change at the two C_4-grass dominated regions using the Community Land Model v5

Two warming scenarios (based on Shared Socioeconomic Pathways 1 and 3)







Climate change reduced the modelled CO_2-fertilisation of C_4 grass biomass into the future but **did not eliminate it**.

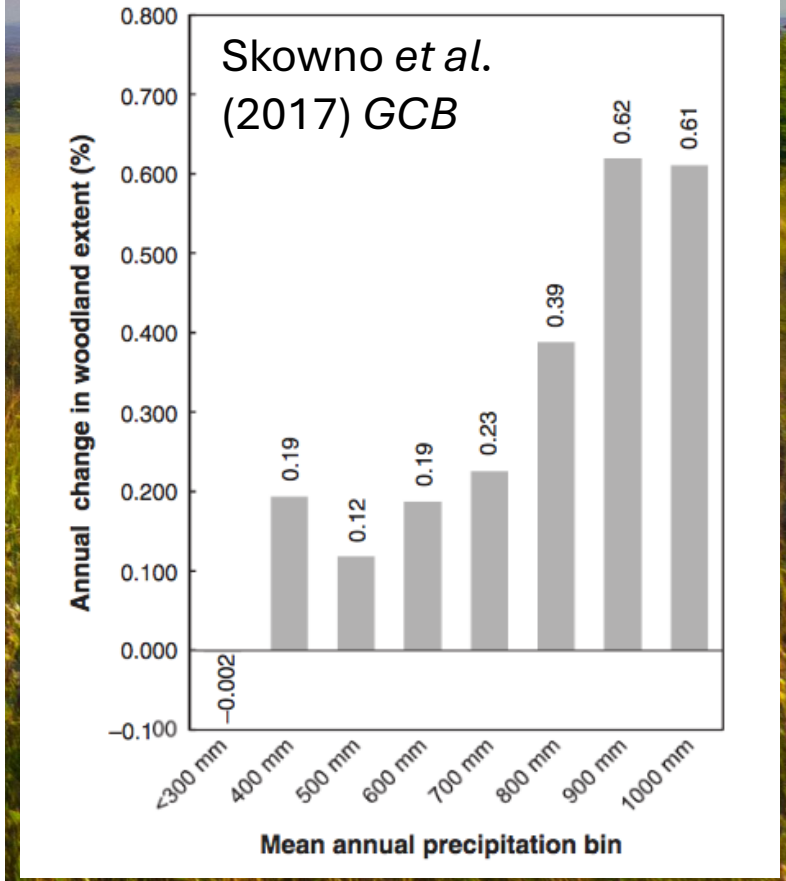
Declines in photosynthesis and productivity linked to lower stomatal conductance and higher leaf temperatures

Conclusions

Overlooked C_4 grass CO_2-fertilization has major implications for savanna ecosystem function.

<u>Carbon storage:</u> Experimental gains in productivity were **concentrated aboveground**, such that any **increase in production could be lost** and not stored in soil organic carbon.

<u>Savanna vegetation dynamics:</u> CO_2 fertilization of both savanna C_4 grasses and C_3 trees could also change the dynamics of savanna tree-grass interactions. **Slower rates of woody plant encroachment in** drier savannas - due to stronger CO_2 fertilization of C_4 grasses?



Meta-analysis	Field Data	Vegetation models

Colin Osborne (Sheffield)

Carla Staver (Yale)

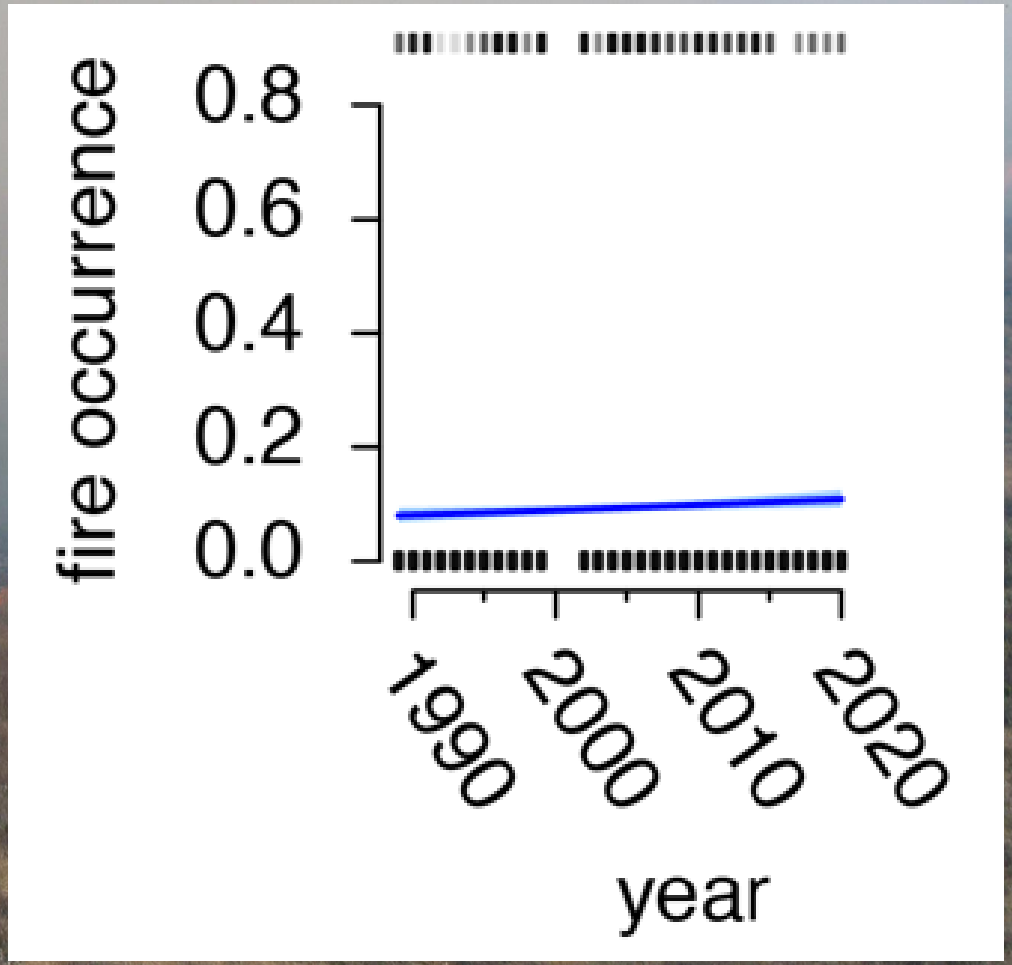
James King & Maria Val Martin (Sheffield)

And: William Bond (Cape Town), Corli Coetsee (South Africa National Parks), Nita Pallett (Rhodes), Adam Pellegrini (Cambridge), Sarah Raubenheimer (Michigan) and Brad Ripley (Rhodes)

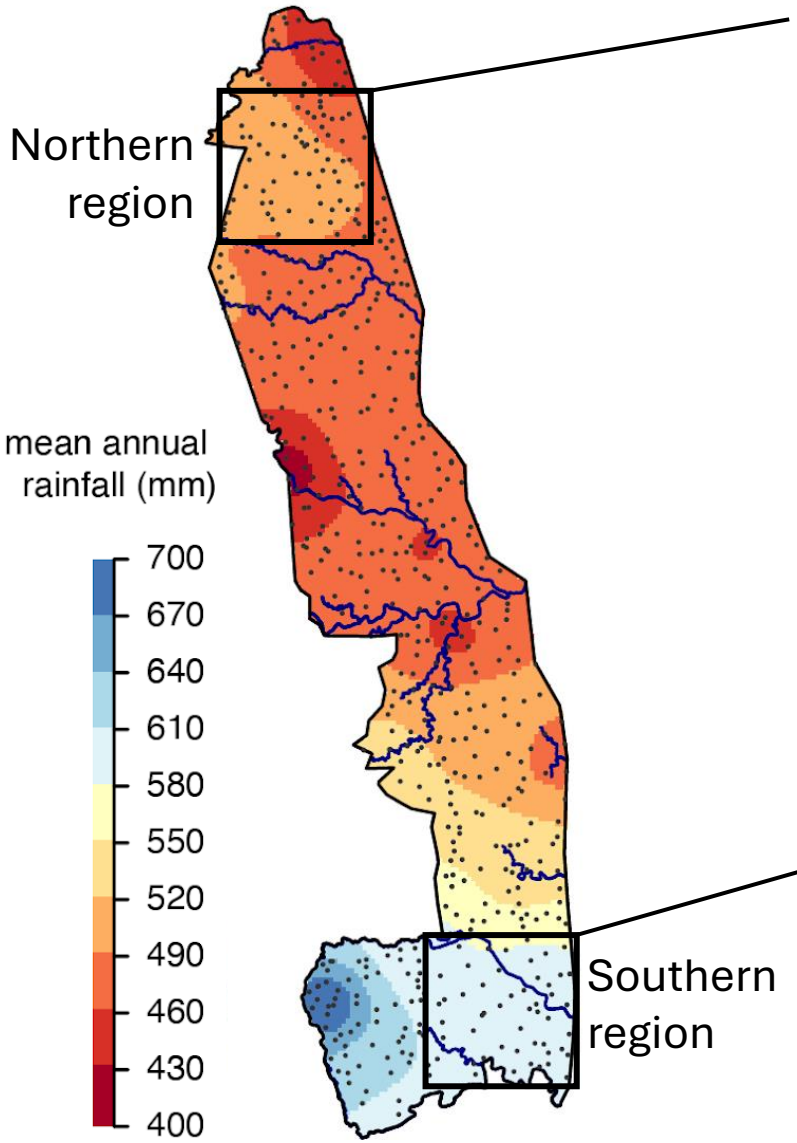
UKRI Natural Environment Research Council

What about fire?

In Kruger, fire occurrences slightly increased through time (from a probability of 0.12 in 1989 to 0.17 in 2021)

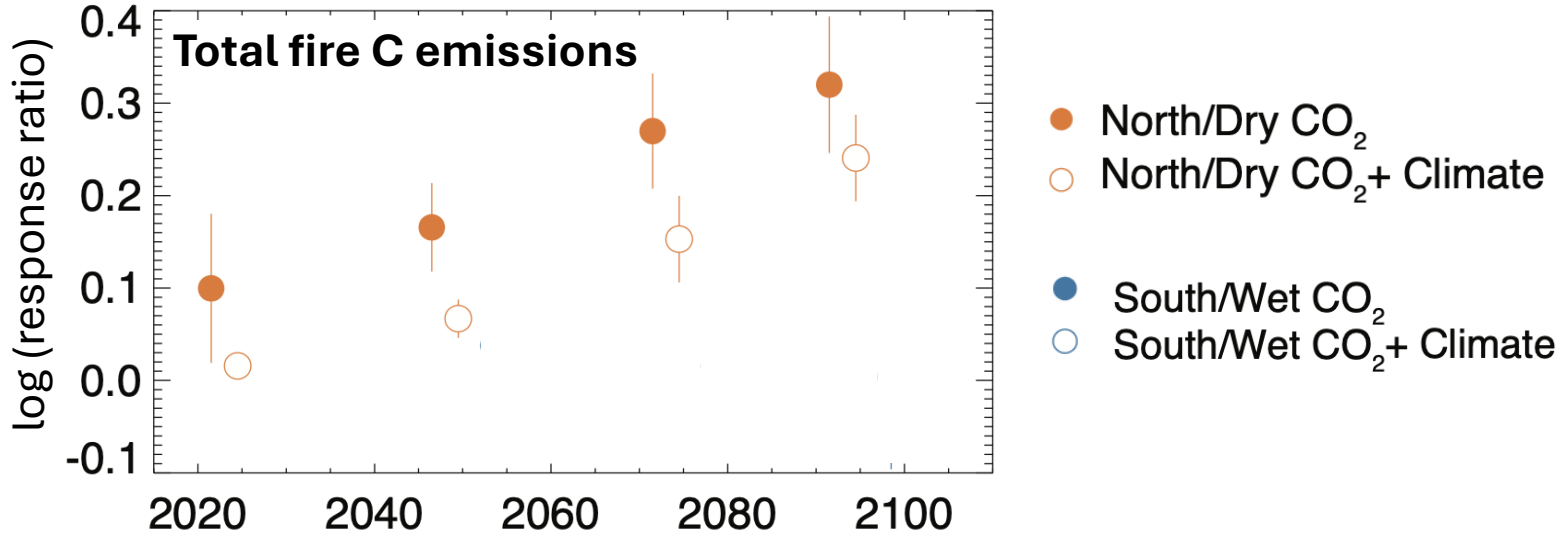


Modelled future fire depends upon the limiting factor



Fuel-load limited fire regime (drier region)

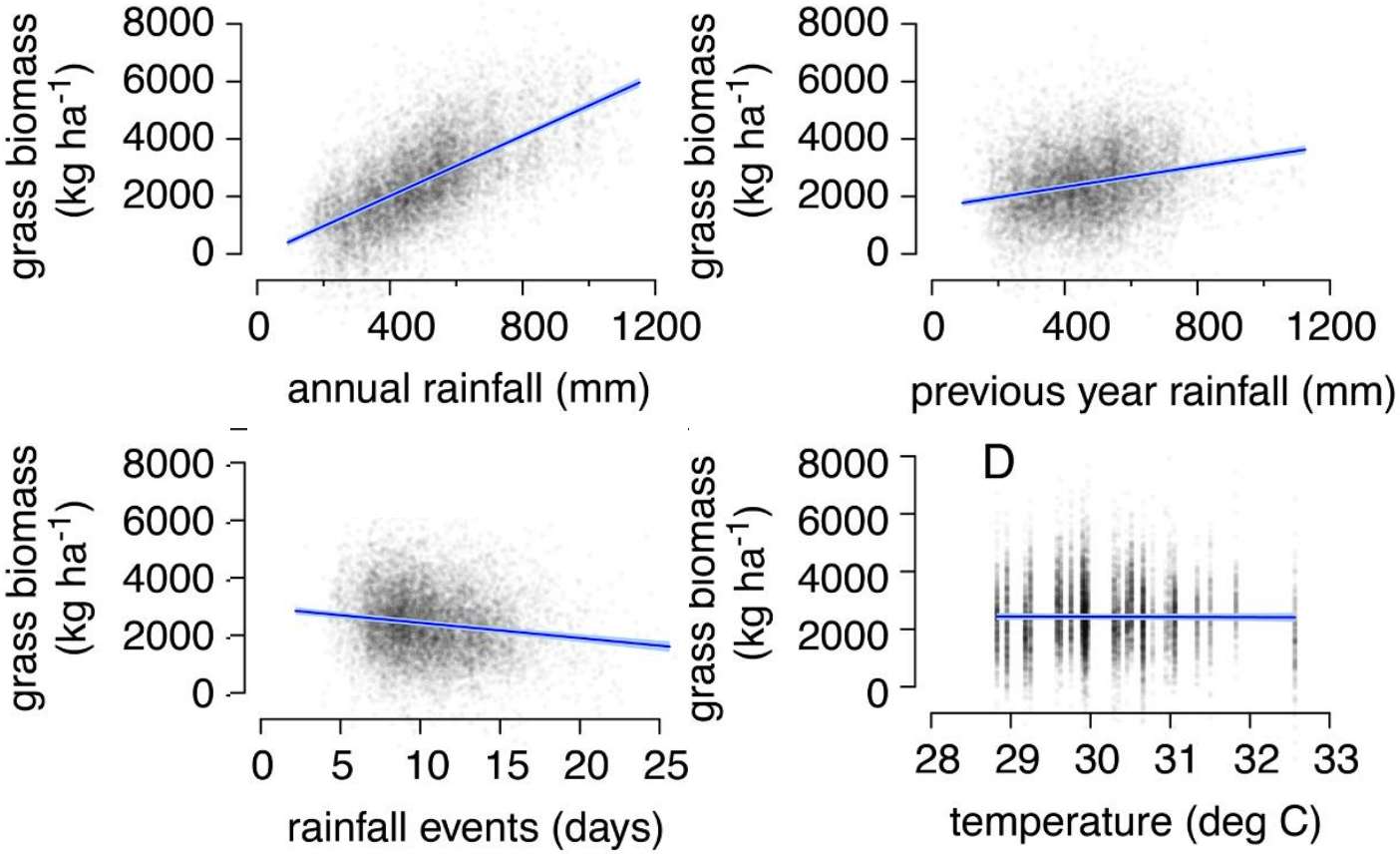
CO_2-driven increases in fire activity (higher grass biomass) are damped by climate change (lower grass biomass)



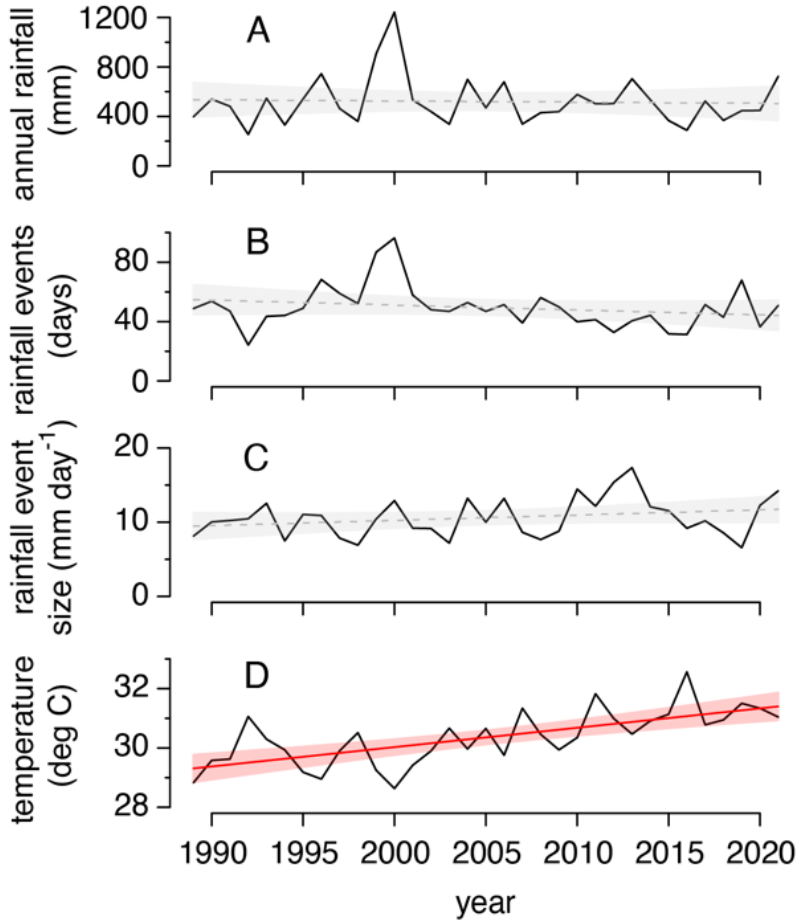
Fuel-moisture limited fire regime (wetter site)

Little impact of rising CO_2 alone (high biomass moisture) on fire activity, but climate change increases fire activity (declining biomass moisture)

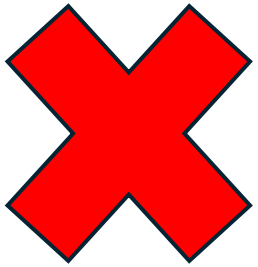
... but did not change in a directional way that would lead to the observed increase in grass biomass



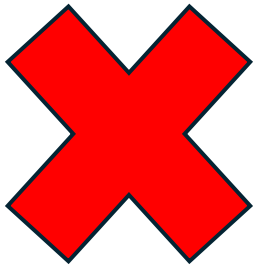
Rainfall and temperature cause year-to-year grass biomass variation...



Ecological factors cannot explain the increasing grass biomass trend

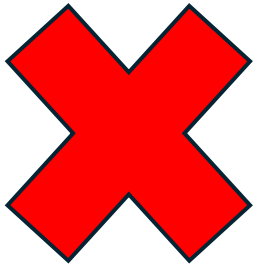


Total herbivore abundance

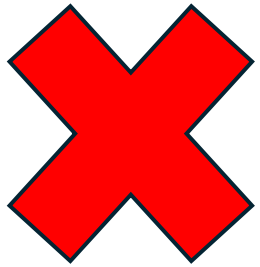


Anthropogenic N deposition

(del Toro et al 2024 New Phyt.)

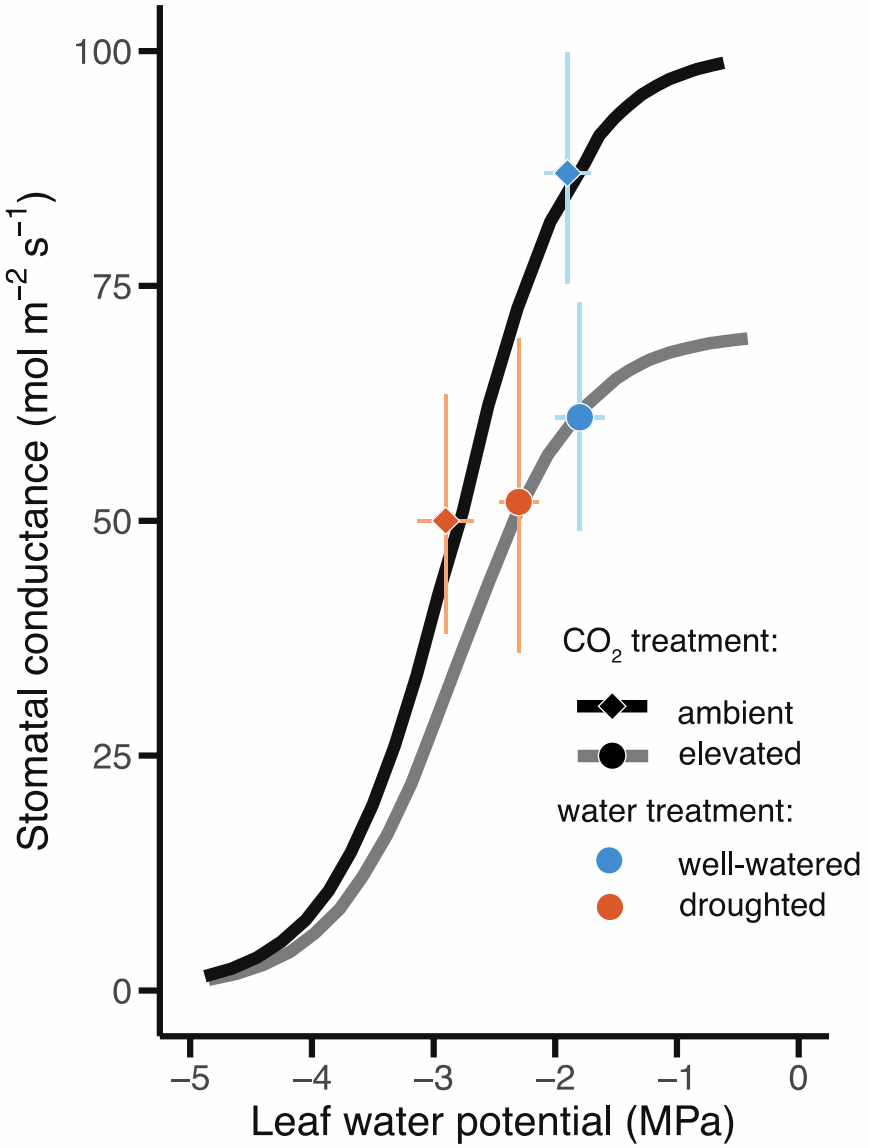


Dominant grass species abundance



Grass functional turnover

Elevated CO_2 reduces water stress in C4 grasses

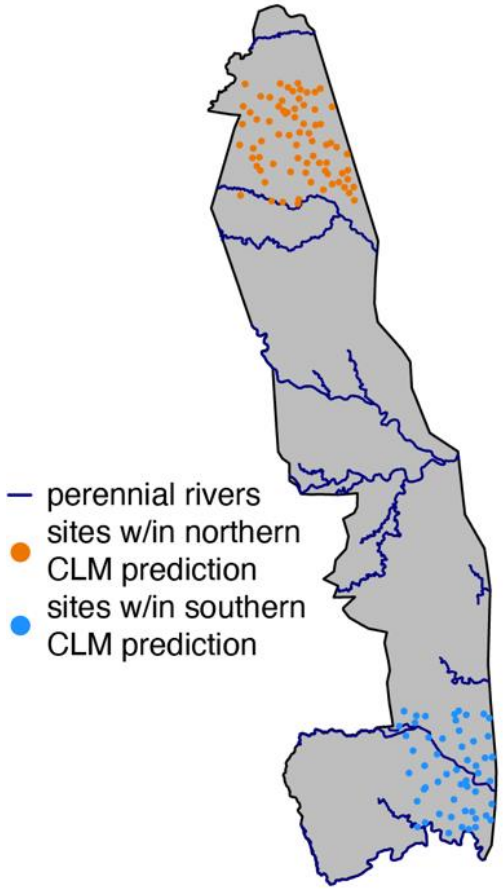


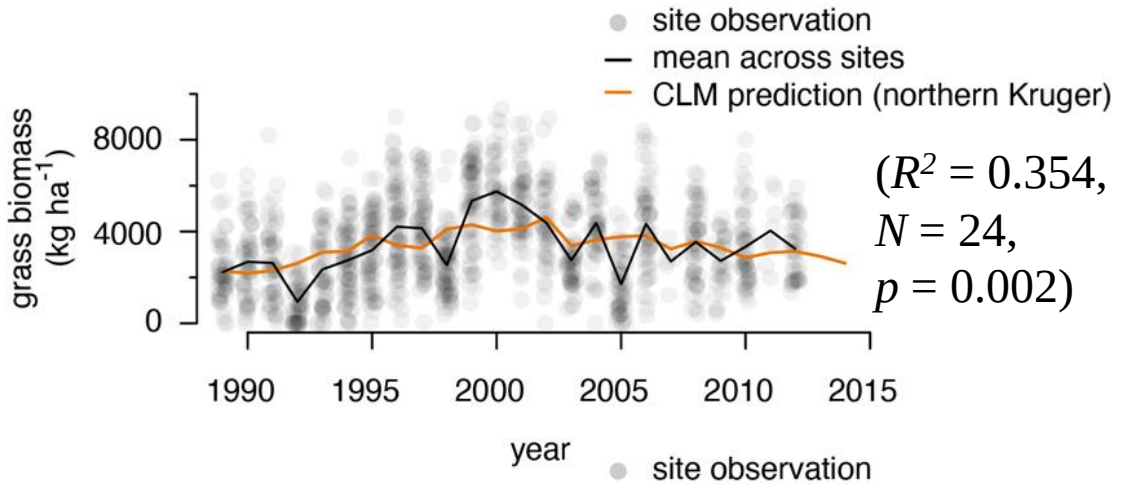
Stomatal conductance decreased significantly under water-limitation at ambient CO_2 but not at elevated CO_2

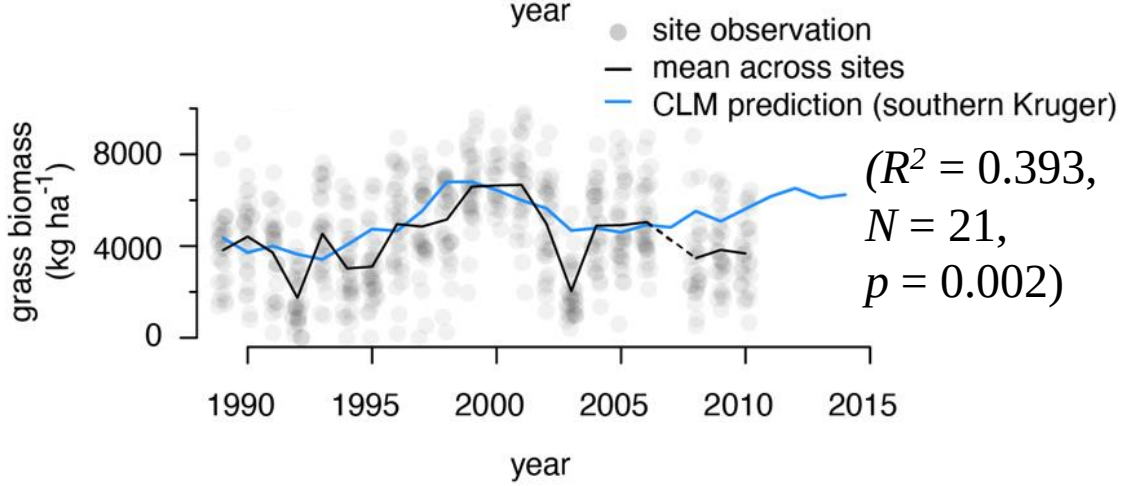
Under water limitation, leaf water deficits were alleviated under elevated CO_2 (*i.e.*, higher midday leaf water potential)

3. Vegetation simulations via the Community Land Model

First – how good is the match between historical observations of C_4 grass biomass variation in the Kruger field data and model predictions?







Model predictions of past grass biomass closely matched mean observed grass biomass in both north/dry and south/wet regions

3. Vegetation simulations via the Community Land Model

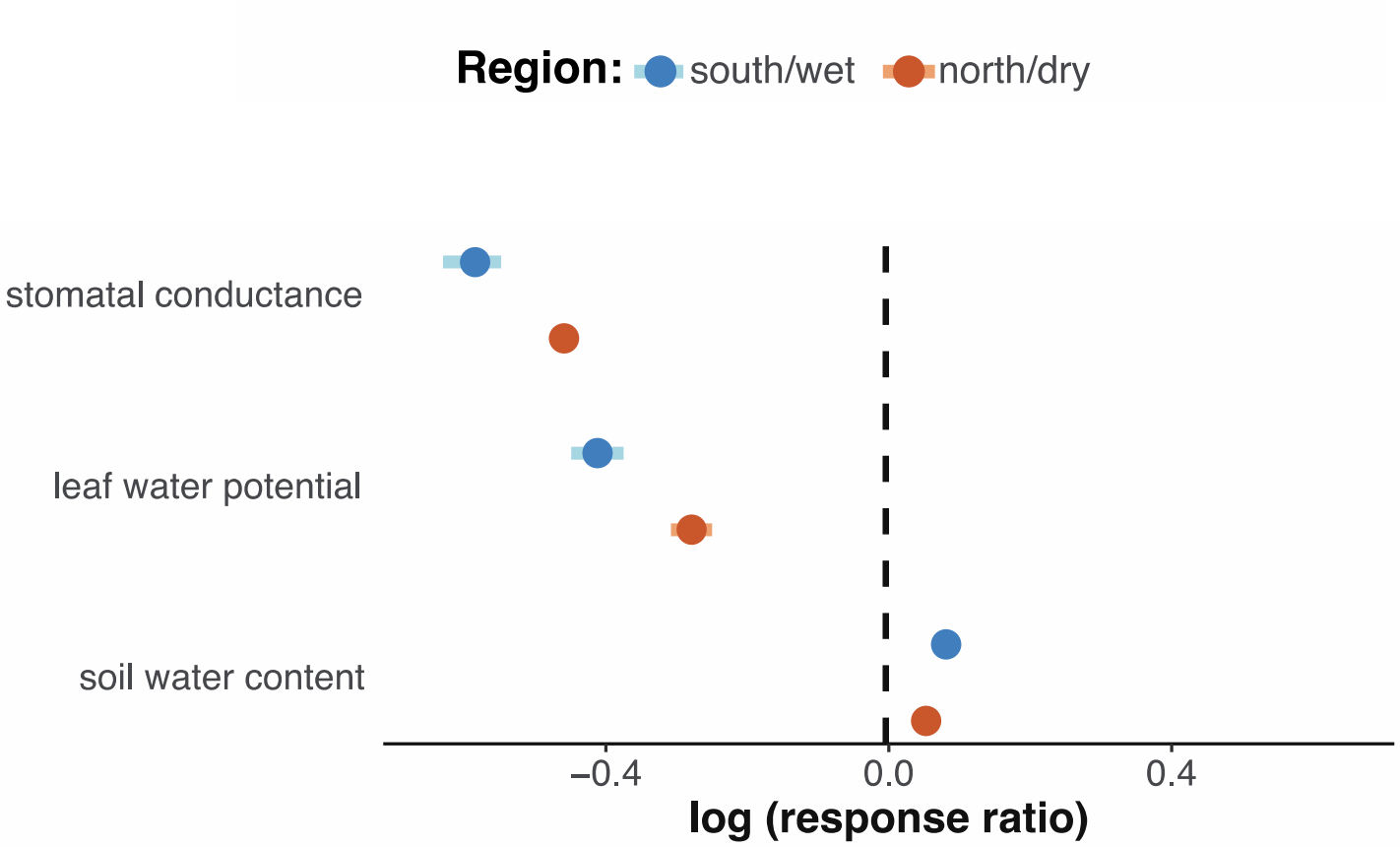


Figure. The response of grass water relation traits to CO_2 concentrations (high warming scenario) in the year 2075 relative to those today displayed as log-response ratios.

<u>CO_2 only</u>

Improvements in plant water status and soil water availability under elevated CO_2 concentrations

Stomatal conductance consistently reduced under elevated CO_2 (contrasts with meta-analysis and FACE experiments showing that C_4 grasses can maintain high stomatal conductance under drought with CO_2 enrichment)

Meta-analysis of C_4 grass CO_2-responses

770 studies/theses

(LitsearchR used to develop search terms)

Criteria:

- Wild C_4 species from grass-dominated systems
- Species-specific measurements of biomass, A or Gs under ambient & elevated CO2
- Well-watered or droughted conditions

800 trait measurements

92 species

96 studies/theses

MCMCglmm model:

Response_ratio ~ stress + eCO2_duration + pot_size + CO2_difference, random = species + study + SE_response_ratio