RESPONSE OF DRYLAND CROPS TO CLIMATE CHANGE: UNDERSTANDING THE NEXUS BETWEEN WATER AND NUTRIENT USE EFFICIENCY, NUTRITIONAL SECURITY, AND FOOD SAFETY

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Overview

The alleviation of hunger and food insecurity is one of the most significant global challenges. This challenge is further compounded by the impact of climate change (CC) on agricultural yields in various world regions, particularly in dryland regions where water scarcity and temperature extremes impact crop production. These alterations affect the efficiency of water and nutrient use, subsequently compromising the nutritional quality of food produced. Moreover, studies have demonstrated that shifting climate conditions create environments conducive to mycotoxin-producing fungi and increased uptake of heavy metals by crops.

Literature review on the nexus

Systematic review (Fig. 1) with inclusion criteria:

- Projected climate change scenarios
- Target in dryland crops (Fig. 2)
- Resource use efficiency
- Nutritional quality
- Food safety
- Studies which conducted field or greenhouse experiments
- Quantitative data and detailed research methodology
- Studies published over the last 10 years

Search: Web of Science and Scopus (1271 papers)
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Duplicates removal: Zotero (1022)
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Screening: ASReview
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Data base formation: Zotero
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Data extraction

Fig 1. Systematic review process.

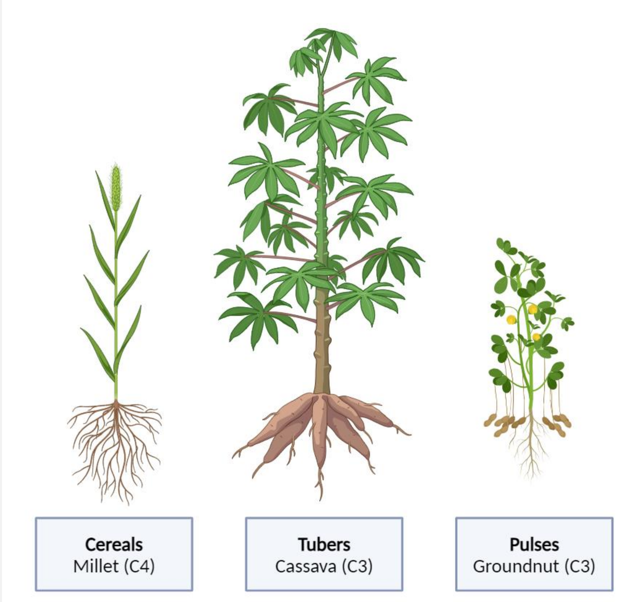

Fig 2. Exemplary dryland crops considered in the literature review.

Preliminary results

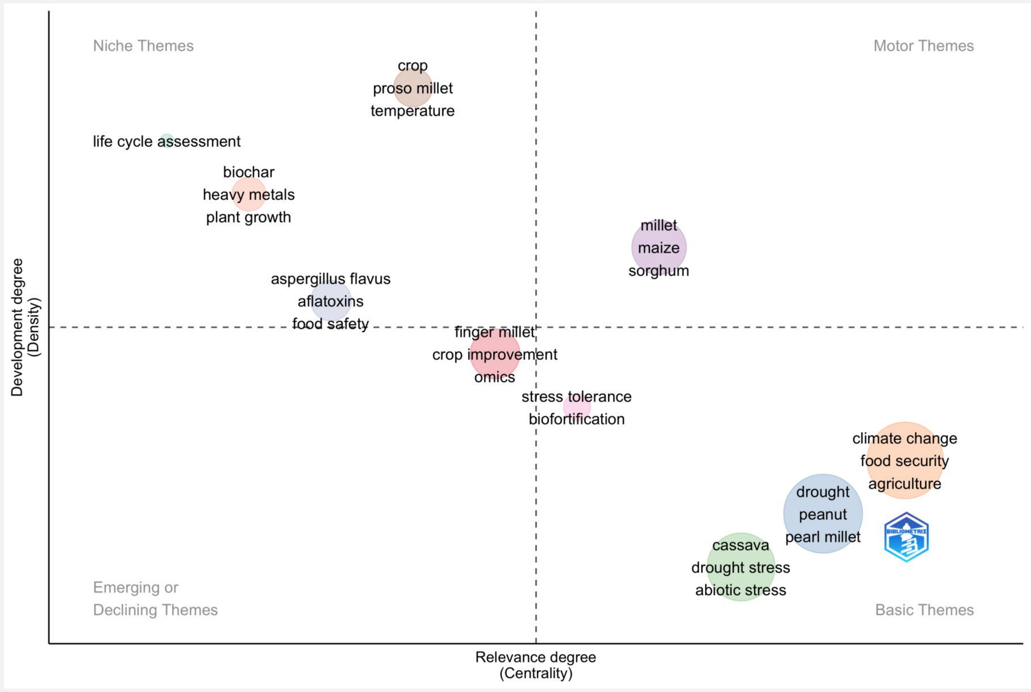

Fig 3. Classification of themes based on co-word cluster analysis related to climate change effects on dryland crops.

The co-word cluster analysis (Fig. 3) shows research themes on climate change effects on dryland crops over the last decade. These themes can be classified into two main categories: *(i)* basic themes focusing on drought effects, and *(ii)* niche themes examining food safety impacts such as heavy metal contamination and mycotoxins. Crop improvement and omics were identified as emerging themes.

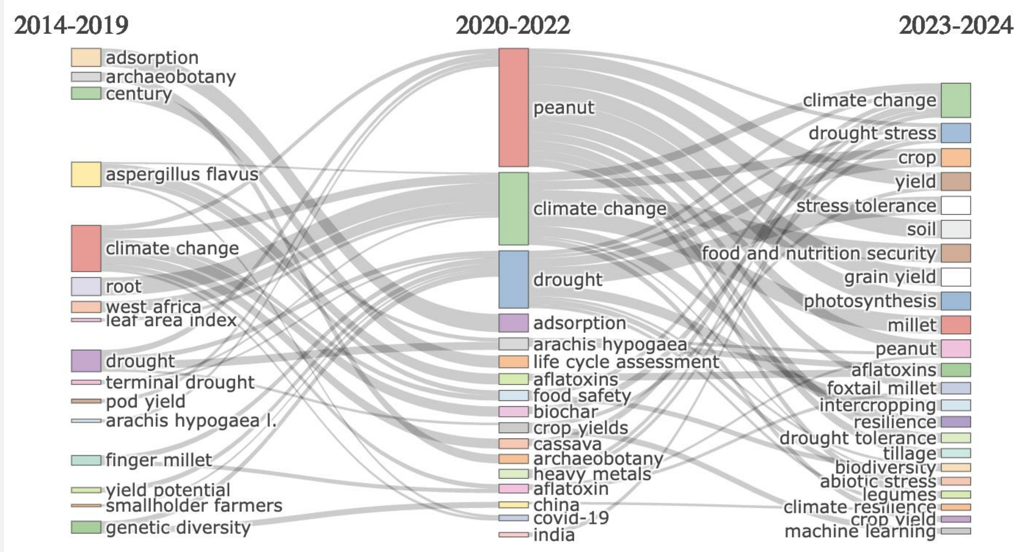

Fig 4. Thematic evolution on climate change research on dryland crops over the past decade.

Recent research on climate change effects on dryland crops has shifted towards adaptation strategies. Keywords such as climate resilience, drought tolerance and intercropping have become increasingly prevalent (Fig. 4). The use of machine learning in these kind of climate change research is also on the rise.

What do we know about the nexus?

Direct effects of climate change

- **Direct effects on crops:** The physiological mechanisms of plants are affected by elevated CO_2 levels, elevated temperatures, and water availability, with differences observed between C3 and C4 crops (Fig. 5).
- **Combined factors:** Elevated CO_2 mitigates some drought damage to yield and results in improved water use efficiency by modulating stomatal conductance without disrupting photosynthesis. Heat and drought combined have more adverse effects than individual stresses.
- **Direct effects on the resource base:** CC can alter water availability, pH, mineralisation, nutrient leaching (affecting availability), soil organic carbon (inputs and stability), increase metal bioavailability, and alter microbial communities.

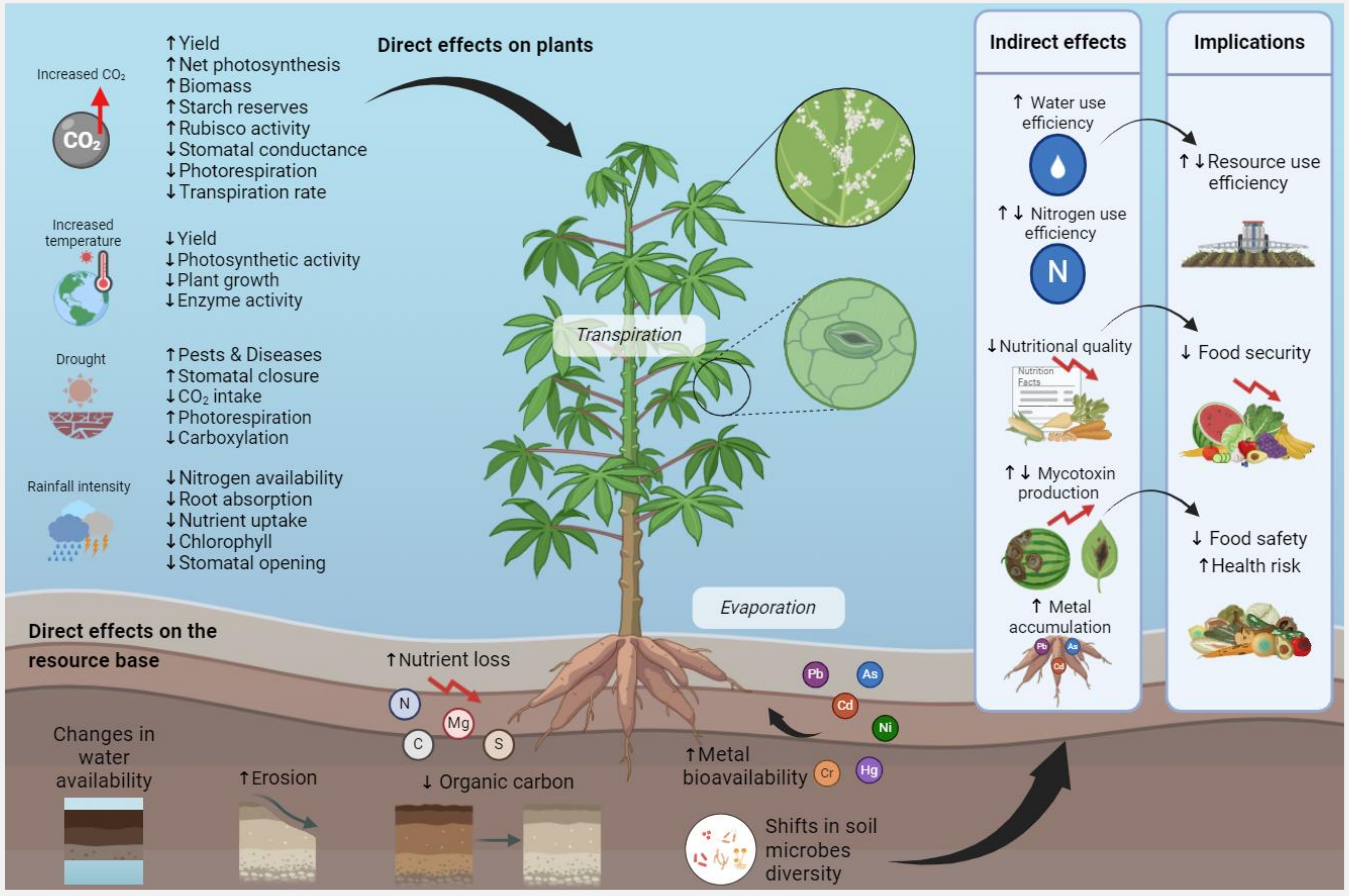

Fig 5. Schematic representation of the direct and indirect effects of climate change on crops, and the associated implications.

Indirect effects & Implications

- **Indirect effects on crops:** Alterations in soil functioning and water availability, in conjunction with their impact on plant mechanisms, can result in enhanced water use efficiency, diminished nutrient uptake by plant roots, and augmented accumulation of metals.
- **Implications**: CC affects resource availability, crop nutrition and contamination risk. These effects are mutually reinforcing, creating a complex nexus where changes in resources also affect plant mechanisms, growth and nutritional quality. This, in turn, influences soil inputs, nutrient cycles and microorganisms. This dynamic may exacerbate micronutrient deficiencies and elevate the risk of mycotoxins and metal toxicity, particularly among vulnerable populations.

Which experimental platforms do we use?

Platform	Controlled factors
Field-based heat units	T
Rainout shelters	W
Open-top chambers	T, CO_2, W
Free-air CO_2 enrichment (FACE)	CO_2
Temperature free-air controlled enhancement (T-FACE)	T
Closed growth chambers	T, CO_2, W

Fig 6. Platforms and controlled factors (temperature (T), water (W) and CO_2) to study CC impacts on crops.

What do we not know about the nexus?

- Sequential stressors (more than two) and their combined effects on the nexus.
- How new methods and technologies can be used for in-depth in situ research.
- How we can further improve collaboration across disciplines for integrated strategies and systematic research.

Which nuclear and stable isotopic techniques can be used?

- **$\delta^{13}C$** – Plant response to drought and heatwaves.
- **$\delta^{15}N$** – Nitrogen use efficiency.
- **$\delta^{18}O$** and **$\delta^{2}H$** – Water use efficiency and water source use.
- **$\delta^{13}C$ & $\delta^{18}O$** - Stomatal sensitivity to drought and heat stress.
- **^{13}C Pulse-labelling** – Carbon allocation.
- Compound specific isotope ratio – Analysis of biomarkers.
- **$^{13}C_2$-retinol isotope dilution** - Provitamin A bioefficacy.
- **X-Ray Fluorescence (XRF)** - Rapid metal profiling.
- **Metal stable isotopes** – Sources and metal migration processes.
- **Stable isotope dilution assays (SIDAs)** - Mycotoxin analysis.
- **Surface-enhanced Raman Spectroscopy (SERS)** - Rapid mycotoxin screening.
- **Stable isotope probing** – Identification of active microorganisms ^{13}C-labeled DNA, RNA, proteins, or PLFA.
- **Seed irradiation with gamma rays, X rays, ion or electron beams** – Induce genetic changes to develop improved varieties.

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