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REVIEW ARTICLE

Climate change and crop adaptation in the Sahelian savanna of Nigeria: a critical review of soil, crop and adaptation evidence

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ABSTRACT

Climate change threatens agricultural sustainability in Nigeria's Sahelian savanna, where rain-fed smallholder production depends on variable seasonal rainfall and on sandy soils with low organic matter and limited nutrient retention. This critical narrative review synthesises published evidence on climate effects on soil health, crop development, yield and nutritional quality, and appraises adaptation and mitigation options, distinguishing evidence from West Africa and the Sahel from evidence transferred from other regions. West African syntheses indicate predominantly negative yield effects, with a median change of about −11% and a larger median loss (−18%) in Sudano-Sahelian countries, driven mainly by warming; simulations for sorghum and millet suggest that warming above 2 °C cannot be offset by any rainfall change. Mechanistic evidence, largely from other regions, indicates that warming and rainfall variability alter soil moisture, organic-carbon dynamics, erosion and nutrient cycling, and that heat and water stress can impair crop development and grain filling. Elevated atmospheric CO_2 may improve some aspects of plant water-use efficiency but does not remove heat, drought or nutrient limitations, and may reduce protein and micronutrient concentrations in some cereals. Adaptation options (adjusted planting dates, locally adapted and stress-tolerant varieties, soil-cover and organic-matter management, fertiliser microdosing combined with water conservation, and improved climate information, extension and credit) are supported mainly by modelling and survey evidence rather than by controlled local trials. Few field studies in Nigeria's Sahelian savanna jointly measure climate, soil, yield, quality and cost outcomes. We identify priority research needs and propose an evidence-tiered framework for adaptation planning.

Keywords: Climate change; Crop adaptation; Sahelian savanna; Nigeria; West Africa; Soil health; Smallholder agriculture

HIGHLIGHTS

- Evidence on climate impacts is tiered by geographic relevance to Nigeria's Sahelian savanna.
- West African syntheses show mainly negative yield effects, largest in Sudano-Sahelian zones.
- Soil organic matter, water and nutrient dynamics mediate climate effects on crops.
- Adaptation options rest mainly on modelling and surveys rather than local field trials.
- Priority needs are integrated field-trial networks that include quality and cost outcomes.

Introduction

Climate change is increasingly a constraint on agricultural production, because crops and agricultural systems are sensitive to changes in temperature, rainfall, timing and extreme events. These pressures are compounded by rising food demand and the need to sustain agricultural livelihoods. Climate variability and extremes can interfere with planting, emergence, flowering, grain filling and harvesting, with implications for productivity and food security (Dell et al., 2014; FAO, 2016; Basso et al., 2015; Yuan et al., 2024a). Climate change may be caused by natural or anthropogenic factors, as illustrated in Figure 1.

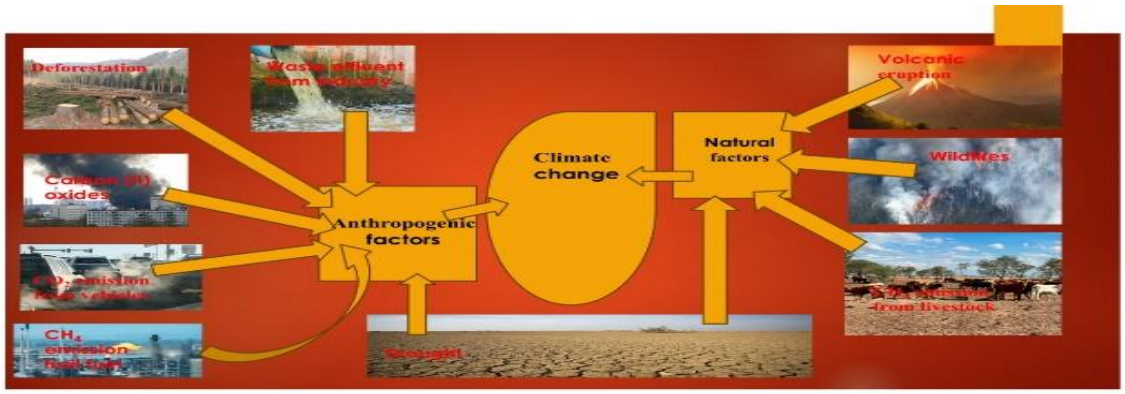


Figure 1. Natural and anthropogenic drivers of climate change.

West Africa is considered particularly vulnerable to climate change because of high climate variability, heavy reliance on rain-fed agriculture, and limited economic and institutional capacity to respond (Sultan and Gaetani, 2016). A synthesis of future crop-yield studies for the region points to predominantly negative effects, driven mainly by projected warming, with larger median losses in the Sudano-Sahelian countries than in the Guinean zone (Roudier et al., 2011). The extent and direction of impacts nevertheless depend on crop, growth stage, soil characteristics, local climate and management, and climate change is expected to alter the distribution and intensity of rainfall and to increase the risk of heat, drought and floods (IPCC, 2013; Tan et al., 2021). Because climate, soil and management interact, process-based crop models are widely used to explore productivity outcomes, although their projections depend on how the models are initialised and evaluated (Basso et al., 2015).

In the Sahel, rainfall trends and their causes have been widely examined (Biasutti, 2019). West Africa is currently experiencing widespread warming, a recovery of monsoonal precipitation and more frequent climate extremes, but projections of summer rainfall remain highly uncertain even where the evidence for yield loss is robust (Sultan and Gaetani, 2016). Surveys in the Nigerian savanna show that smallholders have noticed changes in climate and adjusted their farming practices, but that limited information on climate change and suitable adaptation measures, and lack of credit, constrain adaptation (Tambo and Abdoulaye, 2013).

Quantitative evidence on how climate change affects soil health, crop development, yield and nutritional quality specifically in Nigeria's Sahelian savanna nevertheless remains fragmented. Much of the mechanistic evidence originates in temperate or other regions, and modelling projections cannot be equated with direct measurements of local conditions. This review therefore (i) synthesises evidence on climate-related effects on soils, crop

development, yield and quality, and on adaptation and mitigation options; (ii) distinguishes evidence from the Sahel and West Africa from evidence transferred from elsewhere; and (iii) identifies the evidence gaps that most constrain agricultural planning in Nigeria. The conceptual framework that organises the review is shown in Figure 2.

Review methodology

Review design and scope

This paper is a critical narrative review. It addresses three questions: (1) what evidence links climate change to soil health, crop development, yield and quality in the Sahelian savanna; (2) how directly this evidence applies to Nigeria's Sahelian savanna; and (3) which adaptation and mitigation options are supported, and under what constraints. The literature was organised into five themes: (i) environmental and agricultural characteristics of the Sahelian region; (ii) climate-related changes in soil physical, chemical and biological properties; (iii) effects on crop development and productivity; (iv) effects on crop quality; and (v) adaptation and mitigation options. Findings were compared thematically to identify recurring mechanisms, areas of agreement and disagreement, and implications for farming systems in Nigeria's Sahelian savanna.

Literature identification

Sources were identified through searches of Scopus, Web of Science and Google Scholar using combinations of terms related to climate change, the Sahel, West Africa and Nigeria, soil health, crop development, yield, nutritional quality, adaptation and mitigation. The cited sources were published between 2001 and 2025. The searches were complemented by backward citation tracking and by targeted searches for studies from Nigeria, the Sahel and West Africa. Peer-reviewed journal articles, book chapters and institutional reports published in English were considered, and a source was retained when it addressed climate effects on soils or crops, or farming-system adaptation and mitigation, within one of the five themes above. The evidence base comprises 59 sources. Because no systematic protocol was applied, the review does not claim exhaustive coverage, and the possibility of selection bias is acknowledged in Section 5.

Evidence classification and reporting conventions

Each source was classified by geographic relevance and by study type (Table 1). Tier A comprises studies conducted in Nigeria, the Sahel or West Africa; Tier B comprises global or multi-regional syntheses and model ensembles that include low-latitude regions; and Tier C comprises studies from other regions that are used mainly to illustrate mechanisms. Study types were recorded as field or household surveys, field experiments, meta-analyses, process-based or statistical modelling, and reviews. Quantitative results are reported as stated in the original sources, together with the region, scenario and method; modelled projections are not presented as observed losses.

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Table 1. Evidence tiers, study types and representative sources used in this review.

Source	Region and crop(s)	Study type	Tier	Used for
Sultan et al. (2013)	Sudanian–Sahelian West Africa; sorghum, millet	Process-based crop-model simulations at 35 stations	A	Yield sensitivity to temperature and rainfall; cultivar resilience
Roudier et al. (2011)	West Africa; multiple crops	Meta-analysis of 16 studies	A	Overall yield change; north–south contrast
Sultan and Gaetani (2016)	West Africa	Review	A	Climate trends; adaptation through crop-model studies
Biasutti (2019)	African Sahel	Review of rainfall trends	A	Rainfall variability and causes
Pierre et al. (2017)	Sahelian croplands	Wind-erosion and management study	A	Erosion pathway in Sahelian soils
Tambo and Abdoulaye (2013)	Nigerian savanna	Household survey (200 households)	A	Farmer perceptions, adaptation and constraints
Sissoko and Lebailly (2019)	Sahelian and Sudano-Sahelian Mali; millet, sorghum	Producer survey (108 producers)	A	Microdosing and yield determinants
Rezaei et al. (2023); Zhu et al. (2022); Jägermeyr et al. (2021); Lesk et al. (2022)	Global, multiple crops	Global syntheses and model-based analyses	B	Yield risks at low latitudes; compound extremes
Ma et al. (2024)	Wheat field, China	Long-term warming experiment	C	Soil organic carbon and structure
Shen et al. (2022); Aguilera et al. (2013)	China croplands; Mediterranean cropping systems	Meta-analyses	C	Soil nutrients; soil-carbon management
Zhu et al. (2018); Asseng et al. (2019); Zhang et al. (2023)	Rice; wheat	Elevated-CO_2 analysis; process-based simulation	C	Grain protein and micronutrients
Han et al. (2023); Xu et al. (2024)	China; wheat and other crops	Regional impact analyses	C	Regional variability of yield impacts

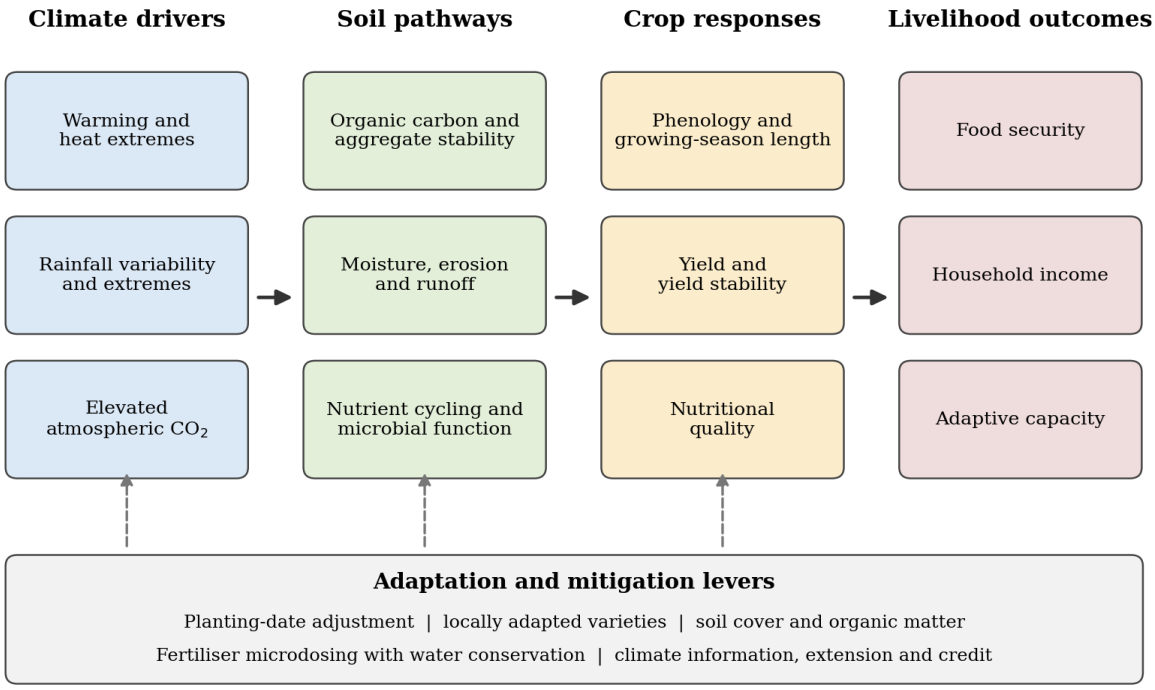


Figure 2. Conceptual framework linking climate drivers, soil pathways, crop responses and livelihood outcomes, with adaptation and mitigation levers.

Environmental and agricultural characteristics of the Sahelian region

The Sahel is a semi-arid transition zone along the southern margin of the Sahara that spans several countries. Its agricultural environment is characterised by high temperatures, limited and variable rainfall, and substantial seasonal water stress (Biasutti, 2019; Pierre et al., 2017). These conditions constrain crop establishment and make production sensitive to the timing of rainfall, not simply its seasonal total. Agriculture in West Africa is predominantly rain-fed, and fertiliser and other inputs remain limited in much of the region (Sultan and Gaetani, 2016). Crop production and livestock keeping are both important livelihood activities, although their relative importance varies among communities.

Many Sahelian soils are sandy and contain relatively little organic matter, which can limit water retention, nutrient storage and soil structural stability (Pierre et al., 2017). Loss of organic matter through land clearing and continuous cultivation can further reduce soil productivity, particularly where nutrient replenishment is inadequate (Radulov and Berbecea, 2023). These constraints interact with rainfall variability: low water-holding capacity can intensify drought stress, while intense rainfall may increase runoff and erosion. Sorghum and millet, two staple crops of the Sudanian and Sahelian savannas (Sultan et al., 2013), are important cereals because of their relative adaptation to dry conditions; cowpea contributes food and, through biological nitrogen fixation, can support nutrient cycling. Maize is also cultivated, but its performance depends strongly on local water availability and management.

The crops grown in the Sahel are not equally tolerant of heat, drought or poor soil fertility. Consequently, adaptation should not rely on a single crop or variety across all locations.

Results and discussion

Climate change and soil health

The reviewed literature indicates that climate change can affect soil health through interacting physical, chemical and biological pathways. Warming may accelerate organic-matter decomposition where moisture and substrate conditions permit (Rustad et al., 2001; Wan et al., 2005), while drought can suppress plant growth and reduce the return of crop residues to the soil. A long-term warming experiment in wheat fields in China reported a 10.6% reduction in soil organic carbon (SOC) together with changes in soil physical structure (Ma et al., 2024), and soil compaction can further impair soil health and crop productivity (Shah et al., 2017). Reduced SOC can weaken aggregate stability, water retention and nutrient supply, increasing the vulnerability of crops to dry spells (Mehra et al., 2018).

Rainfall changes can also influence soil physical condition and erosion. Intense rainfall may increase runoff and remove nutrient-rich topsoil, whereas prolonged dry periods reduce soil moisture and constrain microbial activity and nutrient transport; the resulting changes affect soil structure, plant-available water and nutrient cycling (Furtak and Wolińska, 2023; Mandal and Roy, 2024; Yuan et al., 2024b). In Sahelian croplands, wind erosion is an additional

pathway and is influenced by agropastoral management (Pierre et al., 2017). Leaving soil bare or repeatedly disturbing it can intensify these losses; maintaining soil cover and reducing unnecessary disturbance are therefore relevant management responses. The balance of risks varies with slope, soil texture, vegetation cover and rainfall intensity, so recommendations should be tailored to local conditions.

Climate-related changes in soil chemistry may include shifts in nutrient availability, pH and salinity, but the direction and magnitude depend on the soil and on the interaction between climate and management (Radulov and Berbecea, 2023; Oishy et al., 2025; Shokri et al., 2024). Higher temperatures and altered soil moisture can change decomposition and mineralisation, while heavy rainfall may leach mobile nutrients such as nitrate, potassium, calcium and magnesium (Pareek, 2017; Yao et al., 2021). Drought, in contrast, can restrict nutrient movement to roots and reduce uptake even when nutrients remain present in the soil. Where soils become acidic, for example through nitrogen-fertiliser use, aluminium phytotoxicity can further limit crop performance (Molin et al., 2020; Rahman et al., 2023). Soil fertility problems therefore cannot be attributed to climate alone; fertiliser practices, residue removal, cultivation intensity and initial soil properties are also important.

Elevated atmospheric CO_2 can stimulate photosynthesis and plant growth in some crops (Kimball et al., 2002), potentially increasing biomass inputs and changing soil carbon and nutrient cycling (Dijkstra et al., 2010). However, these responses are conditional on water, nutrient availability and crop type (Reddy et al., 2004). A meta-analysis of croplands across China reported increases in available potassium and total nitrogen under some global-change factors, alongside decreases in some soil nutrient pools associated with greater plant uptake (Shen et al., 2022).

Soil moisture is central to nutrient availability. Dry conditions can reduce the movement of soluble nutrients toward roots and limit diffusion of less mobile nutrients such as phosphorus and zinc, while excessive rainfall can promote leaching of mobile nutrients (Mehra et al., 2018; Pareek, 2017; Yao et al., 2021; Djodjic et al., 2023). Nutrient uptake can therefore decline during drought even when soil tests indicate that some nutrients are present. Climate and management can also affect nitrogen transformations, including nitrification and denitrification, which influence nitrogen availability and nitrous oxide emissions (Hui et al., 2024; Plett et al., 2020). Efficient nutrient management should consequently match fertiliser type, rate and timing to crop demand and rainfall conditions.

Flooding and drought can alter soil microbial communities and soil functioning, while warming and dry conditions may reduce soil multifunctionality (Furtak and Wolińska, 2023; Sünnemann et al., 2023); even in dryland ecosystems, the timing and amount of precipitation influence soil microbial communities (Xiao et al., 2023). These effects are not uniform: soil texture, vegetation, organic-matter content and land management can modify the response.

Overall, soil health provides an important link between climate stress and crop performance (Bonfante et al., 2019). Practices that maintain organic matter, reduce erosion and improve infiltration can help buffer rainfall variability, but they cannot fully offset severe heat or prolonged drought. Most of the mechanistic evidence in this subsection derives from temperate, Mediterranean or Asian settings (Table 1); direct measurements of these soil processes under Nigerian Sahelian conditions are scarce in the sources reviewed. Future

assessments should examine multiple soil functions together, including organic carbon, aggregate stability, infiltration, nutrient availability and biological activity.

Effects on crop development and agricultural productivity

Crop development in the Sahel is governed by the interplay of temperature, photoperiod and the timing of rainfall. Process-based simulations for West Africa indicate that the response is cultivar-specific: photoperiod-sensitive traditional sorghum and millet cultivars were simulated to be more resilient to future climate than modern high-yielding cultivars (yield changes of −28% versus −40% under a +4 °C and −20% rainfall scenario), although modern cultivars would still yield more under optimal fertility conditions (Sultan et al., 2013). Compound heat and moisture extremes during sensitive stages such as flowering and grain filling can intensify losses beyond those caused by either stress alone (Lesk et al., 2022), and global analyses indicate that warming can reduce cropping frequency as well as yield (Zhu et al., 2022).

The response is crop- and location-specific: a shorter season may sometimes allow earlier maturity, but it can also expose sensitive stages such as flowering to heat or water stress. Planting-date adjustment and variety selection should therefore be based on local seasonal patterns and crop duration, an approach that has been evaluated mainly through crop-model studies for West Africa (Sultan and Gaetani, 2016).

Effects on crop yield

A synthesis of 16 studies of future crop yields in West Africa reported a median yield change of about −11%, with very wide dispersion (−50% to +90%), a larger median loss in Sudano-Sahelian countries (−18%) than in Guinean countries (−13%), and a negative signal driven mainly by warming rather than rainfall change; the carbon-fertilisation effect was identified as pivotal to the sign and amplitude of change (Roudier et al., 2011). Simulations of sorghum and millet at 35 West African stations found negative impacts in 31 of 35 climate scenarios, up to −41% for +6 °C and −20% rainfall; when warming exceeded 2 °C, no rainfall change could offset the temperature effect, and Sahelian yields were more sensitive to rainfall change whereas Sudanian yields were more sensitive to temperature (Sultan et al., 2013). Despite diverging rainfall projections, robust evidence of yield loss emerges for West Africa (Sultan and Gaetani, 2016).

The wider literature identifies heat stress, water limitation and changes in rainfall distribution as major pathways through which climate change can reduce crop yield (Lobell and Field, 2007). Higher temperatures can increase evaporative demand, accelerate crop development and intensify soil-water deficits. When heat and drought occur together, their combined effects may be greater than either stress alone (Lesk et al., 2022; Jägermeyr et al., 2021). Estimates of temperature effects on yield can also be sensitive to which co-occurring stressors, such as ozone, are included in the analysis (Liu et al., 2025). Global modelling studies indicate that low-latitude regions may face greater yield risks than some cooler regions, although outcomes vary by crop, climate scenario and management (Zhu et al., 2022; Rezaei et al., 2023; Han et al., 2023; Xu et al., 2024). The 7–23% yield-loss range cited by Rezaei et al. (2023) is a modelled range under severe scenarios without adaptation; it should not be presented as an observed yield loss for Nigeria.

These findings suggest that crop productivity is determined by the interaction of climatic exposure, crop sensitivity and farmers' capacity to adapt (Nelson et al., 2014). Irrigation and improved nutrient management can reduce some production risks, but irrigation is constrained by water availability, infrastructure and cost (Ahmad et al., 2023). For predominantly rain-fed smallholders, measures such as timely planting, short-duration or stress-tolerant varieties, diversified cropping, soil-moisture conservation and locally appropriate fertiliser use may be more accessible. For the Nigerian Sahel, local yield records linked to rainfall, temperature, soil and management are still needed to move from modelled projections to observed impacts.

Effects on crop quality and nutritional value

Climate change may affect not only the quantity of harvested crops but also their nutritional composition and processing quality. Elevated CO_2 and higher temperatures have been associated in some studies with changes in protein and micronutrient concentrations, although the magnitude varies among crops, varieties and growing conditions (Asseng et al., 2019; Zhu et al., 2018). Experiments on rice indicate potential reductions in protein, iron, zinc and some B vitamins under elevated CO_2 (Zhu et al., 2018), and cotton studies show that CO_2 effects on fibre quality interact with nitrogen nutrition (Reddy et al., 2004). These results warn of possible nutritional consequences, but wheat, rice and cotton are not the principal Sahelian crops, and the sources reviewed contain little direct evidence for millet, sorghum or cowpea. Crop-quality assessments in the Sahel should therefore measure both yield and relevant nutritional traits under realistic combinations of heat, water stress and soil fertility.

Variation among crop varieties also matters: different genotypes can respond differently to heat, drought and elevated CO_2, including in grain protein and starch-related traits (Zhang et al., 2023; Shamim et al., 2024). Breeding and selection programmes should therefore consider yield stability and nutritional quality together. This is especially important where households depend on locally produced cereals and legumes for both food and income.

Adaptation and mitigation options for the Nigerian Sahel

Adaptation aims to reduce harm from current and expected climate impacts, whereas mitigation aims to reduce greenhouse-gas emissions or increase carbon storage (Denton et al., 2014); adaptation planning in other sectors illustrates the value of explicit risk assessment and monitoring (Rosenzweig et al., 2007). Table 2 summarises the options discussed in the literature, the evidence supporting them and the constraints on their use by smallholders in the Sahelian savanna.

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Table 2. Adaptation and mitigation options, supporting evidence and constraints for smallholders in the Sahelian savanna.

Option	Main mechanism	Evidence in sources reviewed	Key constraints	Evidence strength
Planting dates matched to rainfall onset	Aligns sensitive stages with water availability	Crop-model adaptation studies for West Africa (Sultan and Gaetani, 2016)	Needs reliable onset information; within-season variability	Moderate (modelling)
Locally adapted and stress-tolerant varieties	Phenology matched to season; tolerance of heat and drought	Simulations: traditional photoperiod-sensitive cultivars more resilient, but modern cultivars higher-yielding under optimal fertility (Sultan et al., 2013)	Seed availability; trade-off between yield potential and resilience	Moderate (modelling)
Fertiliser microdosing with soil and water conservation	Targets nutrients at the root zone; conserves water	Positive, significant association with millet and sorghum yield in Mali (Sissoko and Lebailly, 2019)	Fertiliser access and cost; labour; associative evidence	Moderate (survey, Mali)
Soil cover, residue retention, reduced disturbance, cover crops	Reduces evaporation and erosion; supports organic carbon	Reviews of soil health and carbon storage (Lal, 2019; Radulov and Berbecea, 2023; Ţopa et al., 2025)	Competing livestock-feed use of residues; labour	Low–moderate (reviews, mostly non-Sahel)
Legume rotations, intercropping and green manure	Biological nitrogen fixation; diversification	General soil-health reviews (Radulov and Berbecea, 2023; Ţopa et al., 2025)	Land and labour; market access for legumes	Low–moderate (reviews)
Biochar and organic amendments	Repair of soil–plant system after extreme weather	Perspective article (Kumar et al., 2022)	Feedstock, cost and logistics	Low (perspective)
Irrigation and water harvesting	Buffers water deficit in sensitive growth phases	Shifts in irrigation demand and supply in South Asia (Ahmad et al., 2023)	Water availability, infrastructure and cost	Low for the Sahel
Climate information, extension and credit	Enables adoption and timely decisions	Farmer surveys (Tambo and Abdoulaye, 2013; Waibel et al., 2018)	Information gaps; credit access; institutional capacity	Moderate (surveys)

Options should be combined according to local conditions (Xu et al., 2024). For example, mulching and residue retention can reduce evaporation and protect the soil surface, while rotations that include legumes can diversify production and support nitrogen cycling; their feasibility depends on residue availability, competing livestock-feed needs, labour and input costs. Fertiliser microdosing is a notable example of a practice developed for Sahelian conditions: a survey of 108 producers in the Sahelian and Sudano-Sahelian regions of Mali found that microdosing, improved varieties, organic manure and soil and water conservation techniques were positively and significantly associated with millet and sorghum yields (Sissoko and Lebailly, 2019). The evidence is associative, however, and comparable replicated trials in Nigeria's Sahelian savanna were not identified in the sources reviewed.

Conservation-oriented practices, including reduced soil disturbance, maintaining ground cover, using cover crops where feasible, incorporating green manures or legumes, and preventing deforestation, can contribute to soil protection and carbon storage (Lal, 2019; Radulov and Berbecea, 2023; Ţopa et al., 2025). Soil-carbon management has been shown to offer both mitigation and adaptation benefits in Mediterranean cropping systems (Aguilera et al., 2013), although transferability to Sahelian soils is uncertain. Biochar has also been proposed as a way to repair damage to the soil–plant system caused by climate-driven extreme weather (Kumar et al., 2022). Mitigation benefits should not be assumed to occur automatically: they depend on implementation, duration, and local soil and climate conditions. Likewise, irrigation can help where sustainable water supplies and suitable infrastructure exist, but it is not a universal solution in water-limited environments.

Enabling conditions are as important as the technologies themselves. Extension services, access to climate information, seed availability, credit and farmer participation influence adoption (Tambo and Abdoulaye, 2013; Waibel et al., 2018). Integrated pest management is often proposed as part of adaptation packages, but the sources reviewed here provide no Sahel-specific evidence on it, and it is therefore not assessed. Overall, the strategies identified in the literature are not yet supported by comparative local measurements of effectiveness or cost; these remain priorities for applied research.

Research gaps and implications

Priority evidence needs

A central limitation of the literature synthesised here is the uneven availability of evidence specific to Nigeria's Sahelian savanna. Several quantitative findings come from experiments, models or regions outside West Africa and therefore establish plausible mechanisms rather than direct local estimates. Six priorities emerge:

1. Long-term observational datasets that combine weather records with farm-level crop yields, soil measurements and documented management practices.
2. Participatory, multi-location trials comparing planting dates, varieties, residue management, legume rotations and nutrient strategies (including microdosing) across soil types and rainfall gradients.
3. Measurements of soil-health indicators under Sahelian conditions, including organic carbon, aggregate stability, infiltration, nutrient availability and biological activity.
4. Assessment of the nutritional quality of millet, sorghum and cowpea under heat, water stress and elevated CO_2, rather than reliance on evidence from wheat, rice or cotton.
5. Evaluations that report yield stability, labour requirements, costs and farmer acceptability alongside agronomic performance.
6. Integration of local climate projections and farmer knowledge into adaptation planning, so that modelled impacts are tested against observed conditions.

Such evidence would help policymakers and extension agencies prioritise options that are both agronomically effective and feasible for smallholder farmers.

Limitations of this review

This review is narrative rather than systematic, and the selection of sources may therefore be incomplete or biased towards English-language, open-access and recent publications. Evidence from the Nigerian Sahel is thin, so conclusions about this specific region rely on evidence from West Africa and from other regions with different soils, crops and management systems. Quantitative values are model- or scenario-dependent and should not be interpreted as forecasts for individual farms.

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Conclusions

The literature reviewed indicates that climate change threatens the sustainability of crop production in the Sahelian savanna through interacting effects on soil moisture, organic matter, erosion, nutrient cycling, crop development, yield and nutritional quality. West African syntheses point to predominantly negative yield effects, largest in the Sudano-Sahelian zone, while mechanistic evidence on soils and crop quality comes mainly from other regions. Heat and rainfall variability can shorten effective crop-growth periods and intensify water stress, and soil degradation can reduce the capacity of farming systems to withstand climatic shocks. Elevated CO_2 may benefit some plant processes under particular conditions, but it does not remove the constraints imposed by heat, water scarcity and nutrient limitations.

A practical response for Nigeria should integrate locally appropriate planting dates and crop varieties with soil-cover and organic-matter management, balanced nutrient application (including microdosing where suitable) and water conservation, supported by climate information, extension services, credit and farmer participation. Because much of the quantitative evidence comes from outside the Nigerian Sahel, region-specific field studies are required. Transparent evaluations of the costs and outcomes of adaptation options are essential for turning general recommendations into reliable policy and farm-level guidance.

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Ethics approval and consent (where applicable): *Not applicable*

Data availability: *Not applicable*

Use of AI tools (where applicable): *Not applicable*

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References

Aguilera, E., Lassaletta, L., Gattinger, A., & Gimeno, B.S. (2013). Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agriculture, Ecosystems & Environment*, 168, 25–36.

Ahmad, Q.-A., Moors, E., Biemans, H., Shaheen, N., Masih, I., & Ur Rahman Hashmi, M.Z. (2023). Climate-induced shifts in irrigation water demand and supply during sensitive crop growth phases in South Asia. *Climatic Change*, 176(11), 1–22. https://doi.org/10.1007/s10584-023-03629-7

Asseng, S., Martre, P., Maiorano, A., Rötter, R.P., O'Leary, G.J., Fitzgerald, G.J., et al. (2019). Climate change impact and adaptation for wheat protein. *Global Change Biology*, 25(1), 155–173. https://doi.org/10.1111/gcb.14481

Basso, B., Hyndman, D.W., Kendall, A.D., Grace, P.R., & Robertson, G.P. (2015). Can impacts of climate change and agricultural adaptation strategies be accurately quantified if crop models are annually re-initialized? *PLOS ONE*, 10(6), e0127333. https://doi.org/10.1371/journal.pone.0127333

Biasutti, M. (2019). Rainfall trends in the African Sahel: Characteristics, processes, and causes. *WIREs Climate Change*, 10(4), e591. https://doi.org/10.1002/wcc.591

Bonfante, A., Terribile, F., & Bouma, J. (2019). Refining physical aspects of soil quality and soil health when exploring the effects of soil degradation and climate change on biomass production: an Italian case study. *SOIL*, 5, 1–14. https://doi.org/10.5194/soil-5-1-2019

Dell, M., Jones, B.F., & Olken, B.A. (2014). What do we learn from the weather? The new climate–economy literature. *Journal of Economic Literature*, 52(3), 740–798. https://doi.org/10.1257/jel.52.3.740

Denton, F., Wilbanks, T., Abeysinghe, A.C., Burton, I., Gao, Q., Lemos, M.C., et al. (2014). Climate-resilient pathways: Adaptation, mitigation, and sustainable development. In C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, et al. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1101–1131). Cambridge University Press.

Dijkstra, F.A., Blumenthal, D., Morgan, J.A., Pendall, E., Carrillo, Y., & Follett, R.F. (2010). Contrasting effects of elevated CO_2 and warming on nitrogen cycling in a semiarid grassland. *New Phytologist*, 187, 426–437. https://doi.org/10.1111/j.1469-8137.2010.03293.x

Djodjic, F., Bergström, L., Schmieder, F., Sandström, C., Agback, P., & Hu, Y. (2023). Soils potentially vulnerable to phosphorus losses: speciation of inorganic and organic phosphorus and estimation of leaching losses. *Nutrient Cycling in Agroecosystems*, 127(2), 225–245. https://doi.org/10.1007/s10705-023-10298-6

Food and Agriculture Organization of the United Nations (FAO). (2016). *The State of Food and Agriculture 2016: Climate Change, Agriculture and Food Security*. FAO, Rome.

Furtak, K., & Wolińska, A. (2023). The impact of extreme weather events as a consequence of climate change on the soil moisture and on the quality of the soil environment and agriculture – a review. *Catena*, 231, 107378. https://doi.org/10.1016/j.catena.2023.107378

Han, W., Wang, D., & Lin, X. (2023). Uncovering the primary drivers of regional variability in the impact of climate change on wheat yields in China. *Journal of Cleaner Production*, 421, 138479. https://doi.org/10.1016/j.jclepro.2023.138479

Hui, D., Ray, A., Kasrija, L., & Christian, J. (2024). Impacts of climate change and agricultural practices on nitrogen processes, genes, and soil nitrous oxide emissions: a quantitative review of meta-analyses. *Agriculture*, 14(2), 240. https://doi.org/10.3390/agriculture14020240

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P.M. Midgley, Eds.). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324

Jägermeyr, J., Müller, C., Ruane, A.C., Elliott, J., Balkovic, J., Castillo, O., et al. (2021). Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nature Food*, 2(11), 873–885. https://doi.org/10.1038/s43016-021-00400-y

Kimball, B.A., Kobayashi, K., & Bindi, M. (2002). Responses of agricultural crops to free-air CO_2 enrichment. *Advances in Agronomy*, 77, 293–368. https://doi.org/10.1016/S0065-2113(02)77017-X

Kumar, A., Bhattacharya, T., Mukherjee, S., & Sarkar, B. (2022). A perspective on biochar for repairing damages in the soil–plant system caused by climate change-driven extreme weather events. *Biochar*, 4(1). https://doi.org/10.1007/s42773-022-00148-z

Lal, R. (2019). Accelerated soil erosion as a source of atmospheric CO_2. *Soil and Tillage Research*, 188, 35–40. https://doi.org/10.1016/j.still.2018.02.001

Lesk, C., Anderson, W., Rigden, A., Coast, O., Jägermeyr, J., & McDermid, S. (2022). Compound heat and moisture extreme impacts on global crop yields under climate change. *Nature Reviews Earth & Environment*, 3(12), 872–889. https://doi.org/10.1038/s43017-022-00368-8

Liu, X., Sun, H.Z., & Wang, H. (2025). Inflated negative impacts of temperature on global agricultural yields due to ozone omission. *Earth's Future*, 13, e2024EF005072. https://doi.org/10.1029/2024EF005072

Lobell, D.B., & Field, C.B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters*, 2, 014002.

Ma, R., Kou, T., Cheng, X., & Yu, N. (2024). Long-term warming altered soil physical structure and soil organic carbon pools in wheatland field. *Experimental Agriculture*, 60. https://doi.org/10.1017/s0014479723000236

Mandal, D., & Roy, T. (2024). Climate change impact on soil erosion and land degradation. In *Advances in Global Change Research* (pp. 139–161). https://doi.org/10.1007/978-981-99-7935-6_5

Mehra, P., Singh, B.P., Kunhikrishnan, A., Cowie, A.L., & Bolan, N. (2018). Soil health and climate change: a critical nexus. In *Burleigh Dodds Series in Agricultural Science* (pp. 39–68). https://doi.org/10.19103/as.2017.0033.04

Molin, S.J.D., Ernani, P.R., & Gerber, J.M. (2020). Soil acidification and nitrogen release following application of nitrogen fertilizers. *Communications in Soil Science and Plant Analysis*, 51(20), 2551–2558. https://doi.org/10.1080/00103624.2020.1845347

Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., et al. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. *Proceedings of the National Academy of Sciences of the USA*, 111(9), 3274–3279. https://doi.org/10.1073/pnas.1222465110

Oishy, M.N., Shemonty, N.A., Fatema, S.I., Mahbub, S., Mim, E.L., Raisa, M.B.H., & Anik, A.H. (2025). Unravelling the effects of climate change on the soil–plant–atmosphere interactions: A critical review. *Soil & Environmental Health*, 3(1), 100130. https://doi.org/10.1016/j.seh.2025.100130

Pareek, N. (2017). Climate change impact on soils: adaptation and mitigation. *MOJ Ecology & Environmental Sciences*, 2(3). https://doi.org/10.15406/mojes.2017.02.00026

Pierre, C., Kergoat, L., Hiernaux, P., Baron, C., Bergametti, G., & Rajot, J.-L. (2017). Impact of agropastoral management on wind erosion in Sahelian croplands. *Land Degradation & Development*, 29, 800–811. https://doi.org/10.1002/ldr.2783

Plett, D.C., Ranathunge, K., Melino, V.J., Kuya, N., Uga, Y., & Kronzucker, H.J. (2020). The intersection of nitrogen nutrition and water use in plants: new paths toward improved crop productivity. *Journal of Experimental Botany*, 71(15), 4452–4468. https://doi.org/10.1093/jxb/eraa049

Radulov, I., & Berbecea, A. (2023). Role of soil health in mitigating climate change. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.1002402

Rahman, S.U., Han, J., Ahmad, M., Ashraf, M.N., Khaliq, M.A., Yousaf, M., et al. (2023). Aluminum phytotoxicity in acidic environments: a comprehensive review of plant tolerance and adaptation strategies. *Ecotoxicology and Environmental Safety*, 269, 115791. https://doi.org/10.1016/j.ecoenv.2023.115791

Reddy, K.R., Koti, S., Davidonis, G.H., & Reddy, V.R. (2004). Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield, and fiber quality. *Agronomy Journal*, 96, 1148–1157. https://doi.org/10.2134/agronj2004.1148

Rezaei, E.E., Webber, H., Asseng, S., Boote, K., Durand, J.L., Ewert, F., Martre, P., & MacCarthy, D.S. (2023). Climate change impacts on crop yields. *Nature Reviews Earth & Environment*, 4, 831–846.

Rosenzweig, C., Major, D.C., Demong, K., Stanton, C., Horton, R., & Stults, M. (2007). Managing climate change risks in New York City's water system: Assessment and adaptation planning. *Mitigation and Adaptation Strategies for Global Change*, 12, 1391–1409. https://doi.org/10.1007/s11027-006-9070-5

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, 21(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

Rustad, L.E., Campbell, J.L., Marion, G.M., Norby, R.J., Mitchell, M.J., Hartley, A.E., Cornelissen, J.H.C., Gurevitch, J., & GCTE-NEWS. (2001). A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. *Oecologia*, 126, 543–562.

Shah, A.N., Tanveer, M., Shahzad, B., Yang, G., Fahad, S., Ali, S., Bukhari, M.A., Tung, S.A., Hafeez, A., & Souliyanonh, B. (2017). Soil compaction effects on soil health and crop productivity: an overview. *Environmental Science and Pollution Research*, 24, 10056–10067.

Shamim, S., Abdullah, M., Shair, H., Ahmad, J., Farooq, M., & Ajmal, S. (2024). Evaluation for impact of climate change on wheat (*Triticum aestivum* L.) grain quality and yield traits. *Biological and Clinical Sciences Research Journal*, 1, 842.

Shen, X., Ma, J., Li, Y., Li, Y., & Xia, X. (2022). The effects of multiple global change factors on soil nutrients across China: a meta-analysis. *International Journal of Environmental Research and Public Health*, 19(22), 15230. https://doi.org/10.3390/ijerph192215230

Shokri, N., Hassani, A., & Sahimi, M. (2024). Multi-scale soil salinization dynamics from global to pore scale: A review. *Reviews of Geophysics*, 62, e2023RG000804. https://doi.org/10.1029/2023RG000804

Sissoko, P., & Lebailly, P. (2019). Determinants of millet and sorghum yield with fertilizer microdosing technique. *Revue Marocaine des Sciences Agronomiques et Vétérinaires*, 7(2), 213–222.

Sultan, B., & Gaetani, M. (2016). Agriculture in West Africa in the twenty-first century: climate change and impacts scenarios, and potential for adaptation. *Frontiers in Plant Science*, 7, 1262. https://doi.org/10.3389/fpls.2016.01262

Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., et al. (2013). Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environmental Research Letters*, 8, 014040. https://doi.org/10.1088/1748-9326/8/1/014040

Sünnemann, M., Beugnon, R., Breitkreuz, C., Buscot, F., Cesarz, S., Jones, A., et al. (2023). Climate change and cropland management compromise soil integrity and multifunctionality. *Communications Earth & Environment*, 4, 394.

Tambo, J.A., & Abdoulaye, T. (2013). Smallholder farmers' perceptions of and adaptations to climate change in the Nigerian savanna. *Regional Environmental Change*, 13(2), 375–388. https://doi.org/10.1007/s10113-012-0351-0

Tan, M.L., Liang, J., Samat, N., Chan, N.W., Haywood, J.M., & Hodges, K. (2021). Hydrological extremes and responses to climate change in the Kelantan River Basin, Malaysia, based on the CMIP6 HighResMIP experiments. *Water*, 13(11), 1472. https://doi.org/10.3390/w13111472

Țopa, D.-C., Căpșună, S., Calistru, A.-E., & Ailincăi, C. (2025). Sustainable practices for enhancing soil health and crop quality in modern agriculture: A review. *Agriculture*, 15(9), 998. https://doi.org/10.3390/agriculture15090998

Waibel, H., Pahlisch, T.H., & Völker, M. (2018). Farmers' perceptions of and adaptations to climate change in Southeast Asia: The case study from Thailand and Vietnam. In L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw, & G. Branca (Eds.), *Climate Smart Agriculture* (Natural Resource Management and Policy, vol. 52). Springer, Cham. https://doi.org/10.1007/978-3-319-61194-5_7

Wan, S., Hui, D., Wallace, L., & Luo, Y. (2005). Direct and indirect effects of experimental warming on ecosystem carbon processes in a tallgrass prairie. *Global Biogeochemical Cycles*, 19, GB2014. https://doi.org/10.1029/2004GB002315

Xiao, Y., Bao, F., Xu, X., Yu, K., Wu, B., Gao, Y., & Zhang, J. (2023). The influence of precipitation timing and amount on soil microbial community in a temperate desert ecosystem. *Frontiers in Microbiology*, 14. https://doi.org/10.3389/fmicb.2023.1249036

Xu, Q., Liang, H., Wei, Z., Zhang, Y., Lu, X., Li, F., et al. (2024). Assessing climate change impacts on crop yields and exploring adaptation strategies in Northeast China. *Earth's Future*, 12, e2023EF004063. https://doi.org/10.1029/2023EF004063

Yao, Y., Dai, Q., Gao, R., Gan, Y., & Yi, X. (2021). Effects of rainfall intensity on runoff and nutrient loss of gently sloping farmland in a karst area of SW China. *PLoS ONE*, 16(3), e0246505. https://doi.org/10.1371/journal.pone.0246505

Yuan, X., Li, S., Chen, J., Yu, H., Yang, T., Wang, C., Huang, S., Chen, H., & Ao, X. (2024a). Impacts of global climate change on agricultural production: A comprehensive review. *Agronomy*, 14(7), 1360. https://doi.org/10.3390/agronomy14071360

Yuan, Y., Zhu, X., Gao, X., & Zhao, X. (2024b). An evaluation of future climate change impacts on key elements of the water–carbon cycle using a physics-based ecohydrological model in Sanchuan River Basin, Loess Plateau. *Remote Sensing*, 16(19), 3581. https://doi.org/10.3390/rs16193581

Zhang, D., Liu, J., Li, D., Batchelor, W.D., Wu, D., Zhen, X., & Ju, H. (2023). Future climate change impacts on wheat grain yield and protein in the North China region. *Science of the Total Environment*, 902, 166147.

Zhu, C., Kobayashi, K., Loladze, I., Zhu, J., Jiang, Q., Xu, X., Liu, G., Seneweera, S., Ebi, K.L., & Drewnowski, A. (2018). Carbon dioxide (CO_2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. *Science Advances*, 4, eaaq1012.

Zhu, P., Burney, J., Chang, J., Jin, Z., Mueller, N.D., Xin, Q., Xu, J., Yu, L., Makowski, D., & Ciais, P. (2022). Warming reduces global agricultural production by decreasing cropping frequency and yields. *Nature Climate Change*, 12(11), 1016–1023. https://doi.org/10.1038/s41558-022-01492-5