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Review Article

Climate-Smart Agriculture for Smallholder Resilience: Productivity, Adaptation and Mitigation Pathways in Sub-Saharan Africa with Evidence from Nigeria

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Abstract

Climate change is now the defining constraint on smallholder agriculture in Sub-Saharan Africa, where rain-fed production, degraded soils, limited finance and fragmented extension systems interact to depress yields and deepen food insecurity. This review article synthesises peer-reviewed evidence, institutional reports and recent field studies, with particular attention to Nigeria, to assess how climate-smart agriculture (CSA) can simultaneously advance productivity, adaptation and mitigation without imposing a single blueprint on heterogeneous farming systems. Drawing on the Food and Agriculture Organization of the United Nations framework, the article organises CSA into genetic, agronomic, soil and water, agroforestry, livestock, digital and institutional practices, and evaluates each against productivity, resilience, greenhouse gas, cost, labour and gender outcomes. Evidence shows that no practice is universally superior: improved drought-tolerant varieties, integrated soil fertility management, conservation agriculture, agroforestry, water harvesting and climate information services raise yields and stability in many contexts, but gains are conditional on rainfall regime, soil type, tenure security, input access, extension quality and market integration. Meta-analyses report modest average yield gains from conservation agriculture in Sub-Saharan Africa, larger gains where practices are combined, and substantial soil carbon and erosion benefits from cover crops, mulching and trees. Adoption remains uneven because upfront costs, labour peaks, insecure tenure, limited credit, weak seed systems and gendered access to land and information blunt incentives, especially for women and youth. The article argues for a bundled, site-specific and equity-sensitive approach: combine tolerant varieties with soil health and water management, pair climate information with input and insurance access, strengthen farmer organisations and pluralistic extension, and align public investment with landscape restoration. It proposes a practical decision framework for researchers, extension officers and policymakers and identifies priorities for long-term trials, disaggregated adoption data, mitigation measurement and inclusive scaling. CSA, properly contextualised, is not a fixed technology package but a portfolio for building productive, resilient and lower-emission food systems.

Keywords: climate-smart agriculture; smallholder farmers; food security; adaptation; mitigation; soil health; Nigeria; Sub-Saharan Africa

1. Introduction

Smallholder farmers produce a large share of food in Sub-Saharan Africa, yet they farm under conditions that climate change is making more variable and less forgiving (FAO, 2013; Lipper et al., 2014). In Nigeria, agriculture remains central to livelihoods, employment and gross domestic product, but production is overwhelmingly rain-fed, with small plots, low mechanisation, declining soil fertility and

limited irrigation (Adeagbo et al., 2021; Ojo et al., 2023). Erratic onset of rains, longer dry spells, floods, heat stress and new pest pressures now interact with older constraints such as poor roads, limited credit and weak extension to create compound risk (IPCC, 2022; FAO, 2021). A farmer who plants with the first rains may lose seedlings to a false start; a farmer who waits may lose the season to early cessation. These are not abstract climate statistics; they are planting-date gambles, lost harvests and depleted household food stocks.

The concept of climate-smart agriculture emerged to respond to this triple challenge: how to produce more food, adapt to a changing climate and, where possible, reduce greenhouse gas emissions (FAO, 2010; FAO, 2013). The Food and Agriculture Organization of the United Nations (FAO) defines CSA as agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces or removes greenhouse gases (mitigation) where possible, and enhances achievement of national food security and development goals (FAO, 2013). This definition is deliberately broad. It does not prescribe a single technology. Instead, it provides criteria for judging whether a practice, portfolio or policy is climate-smart in a particular place, for particular people, over a relevant time horizon (Lipper et al., 2014; Steenwerth et al., 2014). That breadth is both the strength and the vulnerability of CSA: it allows local adaptation, but it also allows almost any practice to be labelled climate-smart without evidence.

This article has three objectives. First, it clarifies what CSA is and is not, and how its three pillars should be assessed together rather than in isolation. Second, it synthesises evidence on the major CSA practice families for crops, soils, water, trees, livestock and information systems, with emphasis on Sub-Saharan Africa and Nigeria. Third, it explains why adoption lags behind agronomic promise, and what bundled, inclusive scaling pathways can close that gap. The article is a narrative review informed by systematic search principles: peer-reviewed articles, meta-analyses, FAO and CGIAR reports, and recent Nigerian field studies were prioritised, and findings were cross-checked across sources rather than relying on a single trial or location. Throughout, the article treats farmers not as passive recipients of technology but as experimenters who weigh yield, risk, labour, cash, taste, marketability and social obligations when they decide what to adopt, adapt or abandon.

Section 2 sets out the conceptual framework and assessment principles. Section 3 reviews CSA practice families. Section 4 examines adoption determinants, gender and equity. Section 5 examines trade-offs, measurement and scaling. Section 6 proposes a decision framework. Section 7 concludes with research and policy priorities.

2. Conceptual Framework: Productivity, Adaptation and Mitigation Together

Figure 1 summarises the FAO framework. Productivity means sustainably increasing agricultural output and incomes from crops, livestock and fish without degrading the resource base on which future production depends (FAO, 2013). Adaptation means reducing vulnerability to climate variability and extremes, building capacity to recover from shocks, and maintaining production under new conditions (IPCC, 2022). Mitigation means reducing emissions per unit of output, avoiding emissions from land-use change and input inefficiency, and sequestering carbon in soils and biomass where feasible (Smith et al., 2014). The three pillars are interlinked. A practice that raises yields in a good year but collapses in a dry year fails adaptation. A practice that sequesters carbon but impoverishes farmers fails food security. Assessment must therefore be multi-criteria and time-sensitive (Rosenstock et al., 2016; Steenwerth et al., 2014).

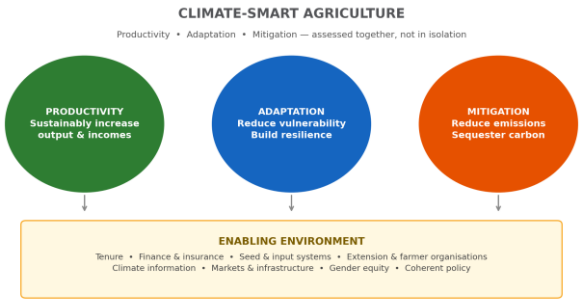


Figure 1. The three pillars of climate-smart agriculture and the enabling environment that determines whether practices can be adopted and sustained.

Three assessment principles follow. First, context matters more than labels. The same practice can be climate-smart in one agro-ecology and harmful in another. Minimum tillage, for example, conserves moisture in semi-arid soils but can increase waterlogging or weed pressure on poorly drained soils without complementary drainage and weed control (Giller et al., 2009; Pittelkow et al., 2015). Second, scale matters. Farm-level gains may disappear at landscape scale if, for instance, expanded irrigation depletes a shared aquifer, or if tree planting displaces food crops (Harvey et al., 2014). Third, distribution matters. Who gains, who bears labour costs, and who controls income determine whether CSA reduces vulnerability or reinforces inequality (Jost et al., 2016; Farnworth et al., 2017). A framework that ignores gender, tenure and age will misread adoption and impact.

CSA also overlaps with, but is not identical to, agroecology, conservation agriculture, sustainable intensification and regenerative agriculture (FAO, 2018; Pretty et al., 2018). These approaches share concerns for soil health, biodiversity and reduced chemical dependence, but they differ in emphasis. Agroecology stresses ecological processes, farmer knowledge and food sovereignty. Sustainable intensification stresses producing more from the same land with lower environmental cost. CSA stresses explicit climate

objectives and the integration of productivity, adaptation and mitigation. In practice, farmers combine elements from all of them. The useful question is not which label is correct, but which combination of practices improves outcomes on a given farm in a given climate, at acceptable cost and risk.

3. Climate-Smart Practice Families: What the Evidence Shows

3.1 Improved varieties and crop diversification

Improved varieties are often the most accessible entry point to CSA. Drought-tolerant, early-maturing, flood-tolerant and heat-tolerant maize, rice, cassava, cowpea and millet varieties allow farmers to escape terminal drought, fit crops into shortened seasons, and stabilise yields (Cairns et al., 2013; Atlin et al., 2017). In Nigeria, studies of climate-smart maize varieties in Kaduna State and drought-tolerant maize in the South-West report significant yield and food-security gains among adopters, with adoption higher where extension and seed access are stronger (Ojo et al., 2023; Adeagbo et al., 2021). Diversification, including intercropping, rotation and varietal mixtures, spreads risk: if one crop fails, another may survive, and legume intercrops add nitrogen and improve diet diversity (Lin, 2011; Martin-Guay et al., 2018). Evidence from intercropping trials in Sub-Saharan Africa shows that cereal-legume systems often outperform monocrops in land-equivalent ratio, stability and soil nitrogen, though they demand more labour and management (Martin-Guay et al., 2018).

Variety adoption is not purely agronomic. Seed systems, taste, storability, market demand and cooking quality matter. A high-yielding variety that consumers reject or that shatters in storage will be abandoned, however well it performs on-station (Alene et al., 2018). Participatory variety selection, community seed banks, and last-mile agro-dealer networks therefore matter as much as breeding (Atlin et al., 2017). Climate information also raises the value of improved varieties: when farmers receive a credible seasonal forecast, they can choose a variety whose duration matches the expected season length, rather than planting the same variety every year regardless of forecast (Vaughan et al., 2019).

3.2 Conservation agriculture and soil health

Conservation agriculture rests on three principles: minimum soil disturbance, permanent soil cover, and crop rotation or association (FAO, 2013; Giller et al., 2009). Its logic is to protect soil structure, increase infiltration, reduce erosion, build soil organic carbon and suppress weeds through cover. A meta-analysis of 933 observations across 16 Sub-Saharan African countries found that average yields under conservation agriculture were only slightly higher than under conventional tillage, about 3.7 percent across six major crops and 4.0 percent for maize, with larger benefits under low rainfall and where herbicides were available (Corbeels et al., 2020). Other syntheses report larger gains when conservation agriculture is combined with fertility and water management, and greater benefits on coarse-textured soils and in tropical climates (Pittelkow et al., 2015; Corbeels et al., 2020). The lesson is not that conservation agriculture fails, but that it is not a silver bullet: its benefits accrue over years, depend on residue retention, and are undermined where residues are needed for livestock feed or fuel, or where weed pressure rises without control (Giller et al., 2009).

Integrated soil fertility management, combining organic inputs such as compost, manure and legume residues with judicious mineral fertiliser, micro-dosing and soil testing, addresses the central constraint of nutrient depletion in African soils (Vanlauwe et al., 2010; Agegnehu et al., 2017). Meta-analyses of climate-smart practices in Africa report that green manuring, crop residue retention and conservation tillage increased crop yield by about 9.2 percent and soil organic carbon by about 14.7 percent on average across studies, with variation by practice and context (Adeyemi et al., 2024). Biochar and compost can improve water retention and nutrient availability, but their cost, feedstock and application rates must be locally validated (Agegnehu et al., 2017). Soil health is a slow variable: organic matter builds over seasons, not weeks, so farmers need incentives and tenure security to invest in a resource they may not control next season.

Table 1. Summary of major CSA practice families, mechanisms, evidence signals and constraints. Signals are qualitative syntheses of the literature cited in Section 3; magnitudes vary by context.

Practice	Main mechanism	Productivity signal	Adaptation / mitigation signal	Key constraint
Drought-tolerant varieties	Escape / tolerate drought	Higher, more stable yield	Lower crop failure risk	Seed access, taste, market
Conservation agriculture	Soil cover, minimum tillage	Modest mean gain; larger in dry areas	More soil carbon, less erosion	Residue competition, weeds
Integrated soil fertility	Organic + mineral nutrients	Higher yield, better nutrient use	Soil carbon, lower N loss	Cost, labour, input access
Agroforestry	Trees in farms / boundaries	Yield stability, diversified income	Carbon in biomass, shade	Land tenure, tree tenure
Water harvesting / small irrigation	Capture, store, apply water	Dry-season production	Buffer against dry spells	Water source, energy cost
Climate information services	Forecasts, advisories	Better planting / variety choice	Earlier response to shocks	Trust, language, timing

The implication for extension is practical: promote conservation agriculture as a system, not as minimum

tillage alone. Where residues are scarce, prioritise cover crops, mulching with locally available materials, and rotation with legumes rather than insisting on full residue retention. Where herbicides are unavailable or undesirable, invest in labour-saving weed management and cover-crop timing. Long-term trials on farmers' fields, with soil carbon and yield measured over five to ten years, are more informative than one-season demonstrations (Corbeels et al., 2020; Pittelkow et al., 2015).

3.3 Water management: harvesting, irrigation and drainage

Water is the most binding constraint in rain-fed systems. In situ water harvesting, including tied ridges, contour bunds, zaï pits, half-moons and stone lines, increases infiltration, reduces runoff and concentrates moisture where crops need it (Zougmore et al., 2014; Amede et al., 2023). Meta-analyses of in situ water harvesting in Sub-Saharan Africa report improvements in soil moisture, yield and reductions in runoff and soil loss, with effects strongest in low-rainfall zones (Amede et al., 2023). Small-scale irrigation, including treadle pumps, solar pumps, drip kits and small reservoirs, enables dry-season production, higher-value crops and more reliable income, but requires water governance, energy and maintenance (Xie et al., 2014; Burney et al., 2010). Solar irrigation can lower fuel costs and emissions, but without regulation it can accelerate groundwater depletion (Xie et al., 2014). Drainage and flood management are the counterpart in humid and lowland zones: raised beds, improved drainage and flood-tolerant rice protect against waterlogging and flood losses that are becoming more frequent (FAO, 2021; IPCC, 2022).

Water management is most climate-smart when it is demand-managed and landscape-aware. Scheduling irrigation by soil moisture, using mulch to reduce evaporation, and choosing crops whose water demand matches available water raise water productivity more than simply expanding irrigated area (Burney et al., 2010). Community water user associations, clear rules for sharing dry-season water, and maintenance funds for pumps and canals determine whether infrastructure survives beyond the project cycle. In Nigeria, smallholder irrigation remains underdeveloped relative to potential, and expansion must be paired with agronomy, markets and energy planning if it is to raise incomes without depleting aquifers (Adeagbo et al., 2021; FAO, 2021).

3.4 Agroforestry and landscape restoration

Agroforestry integrates trees with crops and livestock on the same land, providing shade, windbreaks, fodder, fruit, timber, fuel and habitat, while sequestering carbon and protecting soils (Mbow et al., 2014; Kuyah et al., 2019). A meta-analysis of agroforestry in Sub-Saharan Africa, based on 1,106 observations from 126 publications, found that agroforestry improved crop yield, soil fertility, erosion control and water regulation on average, with benefits varying by tree species, arrangement and management (Kuyah et al., 2019). Farmer-managed natural regeneration, in which farmers protect and prune trees that regenerate naturally on their farms, has restored millions of hectares in the Sahel at low cost, improving soil cover, fodder and microclimate (Reij et al., 2009; Mbow et al., 2014).

Trees also create trade-offs. Some species compete with crops for water, light and nutrients; others fix nitrogen or provide deep-rooted nutrient capture that benefits crops (Mbow et al., 2014). Tree tenure is decisive: if farmers do not have rights to plant, protect or harvest trees, they will not invest in them. In many Nigerian contexts, tree planting is associated with land claims, so clarifying rights for women, tenants and migrants is a precondition for scaling agroforestry (Farnworth et al., 2017). Extension should promote species that farmers value for food, fodder or income, not only for carbon, and should support nurseries, grafting and pruning skills so that trees become assets rather than obstacles.

3.5 Livestock, fisheries and integrated systems

Livestock are both vulnerable to climate change and a source of emissions, but they are also central to nutrition, income, draught power and risk management for millions of households (Thornton, 2010; FAO, 2018). Heat stress reduces milk yield, fertility and growth; drought reduces fodder and water; floods spread disease. Climate-smart livestock practices include improved breeds adapted to heat and disease, fodder conservation and silage, rotational grazing, destocking and restocking strategies, animal health services, and manure management for biogas and compost (Thornton, 2010; FAO, 2018). Integrated crop-livestock systems, where manure fertilises crops and crop residues feed livestock, close nutrient loops and diversify income, but require labour and coordination. Fisheries and aquaculture, including integrated rice-fish systems, offer protein and income diversification, yet face warming waters, flooding and feed constraints (FAO, 2021). The mitigation potential of livestock interventions is real, through better feed efficiency and manure management, but it must be pursued without undermining the food security and cultural roles of livestock for poor households (Smith et al., 2014).

3.6 Climate information, digital tools and index insurance

Climate information services translate forecasts into decisions: when to plant, which variety to sow, when to apply fertiliser, and when to harvest or store (Vaughan et al., 2019; Tall et al., 2018). Participatory approaches, such as Participatory Integrated Climate Services for Agriculture, combine historical climate data, local knowledge and farmer discussion to co-produce advisories that farmers trust and can act on (Tall et al., 2018). Mobile phones, radio, extension messaging and digital platforms now deliver forecasts, market prices and agronomic advice at scale, but digital divides by gender, age, language and literacy limit reach (Vaughan et al., 2019). Index insurance, which pays out when rainfall or satellite indices cross a threshold, can protect farmers against catastrophic loss and encourage investment in improved inputs, but uptake remains low where premiums

are high, payouts are slow, or farmers do not understand the product (Greatrex et al., 2015). Bundling insurance with credit, inputs and advisories, and designing contracts that farmers help to define, improves uptake and trust (Greatrex et al., 2015).

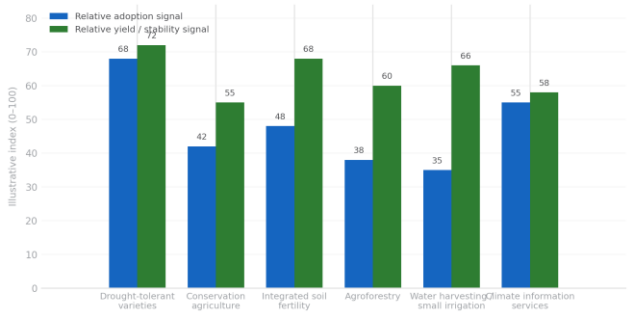


Figure 2. Illustrative synthesis of adoption and yield signals for selected CSA practices. The figure is an author synthesis for teaching and planning; it should not be read as a single survey estimate.

4. Adoption: Why Good Agronomy Does Not Automatically Scale

Adoption studies in Nigeria and across Africa consistently find that education, extension contact, credit access, farm size, household labour, membership in farmer organisations, and access to climate information increase the likelihood of adopting CSA practices, while age, risk aversion, insecure tenure and distance to markets reduce it (Adeagbo et al., 2021; Ojo et al., 2023; Asfaw et al., 2016). A study of 1,534 farmers across six agro-ecological zones in Nigeria found that early-maturing and drought-tolerant varieties were most adopted, while more complex or costly practices lagged, and that socio-economic, institutional and environmental factors jointly shaped adoption (Edewor et al., 2026). In North-West Nigeria, adoption of CSA practices increased technical efficiency, crop income and household food expenditure among adopters, but non-adopters faced barriers that were not simply lack of knowledge (Abdul-Rahaman et al., 2024). These findings converge on a central point: adoption is a system outcome, not a knowledge deficit alone.

Costs and labour are often decisive. Practices that demand extra labour at planting or weeding, or cash for seed, fertiliser or equipment, compete with school fees, health costs and other livelihood needs. Women farmers, who provide much of agricultural labour in Nigeria and Sub-Saharan Africa, face additional constraints: less secure land rights, less access to credit, extension and inputs, and greater time burdens from domestic work (Jost et al., 2016; Farnworth et al., 2017). CSA that increases women's labour without increasing their control over income can worsen their welfare, even if yields rise. Gender-responsive CSA therefore requires labour-saving tools, joint decision-making, and targeting of information and finance to women as farmers in their own right, not only as household members (Jost et al., 2016).

Youth and tenure shape long horizons. Young farmers, often more open to digital tools and new varieties, may lack land and capital, while older farmers may lack labour or risk appetite for long-term investments such as trees or soil conservation (Asfaw et al., 2016). Tenants who may lose land next season rationally avoid investments whose benefits accrue over years, such as terracing or tree planting. Secure, documented tenure, including customary rights, is therefore a climate adaptation policy, not only a land policy (FAO, 2013). Social learning also matters: farmers adopt what they see working on a neighbour's field, what a trusted extension officer demonstrates, and what a cooperative can supply and buy. Farmer field schools, demonstration plots, lead-farmer models and community radio remain powerful, especially when they are sustained beyond a single project (Pretty et al., 2018).

Table 2. Common adoption barriers and practical responses. Adapted from synthesis of adoption literature cited in Section 4.

Barrier	How it blocks adoption	What helps
Upfront cost / no credit	Cannot buy seed, fertiliser, equipment	Savings groups, input credit, insurance bundling
Labour peaks	Weeding, mulching, planting coincide	Labour-saving tools, cover crops, group labour
Insecure tenure	No incentive for soil / tree investment	Documented customary rights, tree tenure clarity
Weak seed / input supply	Improved varieties unavailable locally	Community seed, agro-dealer networks
No climate information	Planting decisions are guesses	Co-produced forecasts, local language advisories
Gendered access	Women lack land, credit, extension	Targeted finance, women extension, joint decisions
Poor market access	Surplus cannot be sold profitably	Cooperatives, storage, roads, market info

5. Trade-offs, Measurement and Scaling

Every CSA portfolio involves trade-offs. Residues can mulch soil or feed livestock; land can grow food or trees; labour can weed, fetch water or earn off-farm income; fertiliser can raise yields or, if over-applied, pollute water and emit nitrous oxide (Smith et al., 2014; Steenwerth et al., 2014). Intensification can spare land for restoration, but it can also drive expansion if markets reward higher output without land-use controls. Mitigation benefits are often small per farm and hard to measure: soil carbon changes slowly, requires baseline sampling, and varies with rainfall and management (Rosenstock et al., 2016). Emissions from fertiliser, livestock and land-use change must be counted honestly, not assumed to fall because a practice is labelled climate-smart. Credible measurement, reporting and verification, using low-cost soil sampling, remote sensing and farmer records, is essential if carbon

finance is to reach smallholders rather than only intermediaries (Rosenstock et al., 2016).

Scaling requires moving from pilots to systems. The literature distinguishes scaling out (more farmers, more places), scaling up (policy, finance and institutional change) and scaling deep (changing norms, knowledge and values) (Pretty et al., 2018). All three are needed. Scaling out without scaling up leaves farmers without inputs, credit or markets. Scaling up without scaling deep leaves technologies that farmers do not trust or cannot sustain. Successful scaling in Africa has often combined farmer organisations, pluralistic extension, public investment in roads and storage, private-sector seed and input supply, and local government support for landscape restoration (Pretty et al., 2018; FAO, 2018). It has also respected farmer autonomy: farmers adapt, combine and sometimes reject practices, and that adaptation is evidence of learning, not failure.

Policy coherence is the missing link. Agricultural, climate, land, water, energy and trade policies often pull in different directions. Fertiliser subsidies that ignore soil health, irrigation expansion that ignores aquifers, or tree-planting targets that ignore food crops can undermine CSA (FAO, 2013; Harvey et al., 2014). National adaptation plans, nationally determined contributions and agricultural investment plans should be aligned, with budgets, targets and accountability for smallholder outcomes, not only for hectares covered. In Nigeria, aligning the National Agricultural Technology and Innovation Policy, climate adaptation plans and state-level extension reforms with CSA principles would help to focus investment on bundles that work, rather than on isolated demonstrations (FAO, 2021).

6. A Practical Decision Framework for Researchers, Extension Officers and Farmers

The framework below translates the review into decisions that can be used in a village meeting, a demonstration plot or a programme design workshop. It is iterative: farmers try, observe, adjust and try again, and extension officers learn from that iteration.

Table 3. A seven-step CSA decision framework for farm and programme levels. Authors' synthesis based on FAO (2013), Lipper et al. (2014) and Pretty et al. (2018).

Step	Question to ask	Action
1. Diagnose	What climate risks, soils, water and markets define this farm?	Map risks, soils, tenure, labour, gender roles
2. Prioritise	Which 2-3 practices address the biggest risk at lowest cost?	Bundle variety + soil + water, not single practice
3. Test small	Can we trial on a small plot with a control?	Farmer-managed trial, record yield, labour, cost
4. Add information	What forecast / advisory would change the decision?	Link trial to seasonal forecast and market info
5. Secure inputs	Are seed, finance, labour and markets available?	Link to agro-dealer, savings group, cooperative
6. Measure	Did yield, income, soil and risk improve? Who gained?	Track disaggregated outcomes over 3+ seasons
7. Adapt / scale	What should be kept, changed or dropped?	Share learning, adapt bundle, scale with support

An example illustrates the framework. In a semi-arid Nigerian community facing late onset and dry spells, the priority bundle might be an early-maturing drought-tolerant maize variety, tied ridges or zaï pits for water harvesting, compost plus micro-dosed fertiliser, and a seasonal forecast delivered by radio and extension. The trial plot compares the bundle with the farmer's usual practice on yield, labour and cost. If the bundle wins in a dry year but not in a wet year, the lesson is to keep the variety and soil practices and adjust water harvesting. If women report that tied ridges increase their labour without increasing their income, the bundle must be redesigned with labour-saving tools or a different division of labour and income. This is CSA as learning, not as a fixed package.

7. Conclusion and Priorities

Climate-smart agriculture offers a useful, if imperfect, framework for navigating the triple challenge of productivity, adaptation and mitigation in smallholder systems. The evidence reviewed here shows that improved varieties, integrated soil fertility, conservation agriculture, agroforestry, water harvesting, livestock management and climate information can raise yields, stabilise production and build soil and ecosystem health, but that gains are conditional, variable and often modest in the short term. Adoption is constrained less by agronomic ignorance than by cost, labour, tenure, seed systems, finance, markets and gendered access to resources. Scaling therefore requires bundled, site-specific, equity-sensitive approaches, not single-technology campaigns.

Four priorities stand out. First, invest in long-term, farmer-managed trials that measure yield, income, labour, soil carbon, water and gender outcomes over multiple seasons, so that claims about CSA are evidence-based rather than promotional. Second, build the enabling system: secure tenure, pluralistic extension, community seed systems, affordable finance, index insurance and climate information that farmers co-produce and trust. Third, centre women and youth as farmers, entrepreneurs and decision-makers, with labour-saving tools and control over income. Fourth, align policy, budgets and measurement so that agricultural, climate and land policies reinforce rather than contradict each other. If these priorities are pursued, CSA can help smallholders in

Nigeria and across Sub-Saharan Africa to produce more, withstand shocks and contribute to lower-emission food systems, on terms that farmers themselves judge to be worthwhile.

Abbreviations

CA: Conservation agriculture; CGIAR: Consultative Group on International Agricultural Research; CSA: Climate-smart agriculture; FAO: Food and Agriculture Organization of the United Nations; ISFM: Integrated soil fertility management; SSA: Sub-Saharan Africa.

Declarations

Ethics approval and consent to participate

Not applicable. This article is a narrative review of published literature and reports and did not involve human participants, human data, animals, or field experiments requiring ethical approval.

Consent for publication

Not applicable. This article does not contain any individual person's data in any form.

Availability of data and materials

Not applicable. All evidence discussed in this review is drawn from the published literature and institutional reports cited in the References. No new datasets were generated.

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The authors declare that they have no competing interests.

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Authors' contributions

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