



Review Article

Climate-Smart Agriculture in a Drying Region: A Scoping Review of Practices, Barriers, and Resilience Pathways in Arizona, USA

Sufyan Suleman^{1,*}  and Khadija Siita² 

¹ More-Than-Human-Ecologies Lab, Department of Anthropology, Northern Arizona University, Flagstaff, USA

² School of Education and Life-Long Learning, University of Business and Integrated Development Studies, Wa, Ghana

* Corresponding author: ss4826@nau.edu

Abstract

This study synthesizes evidence on climate-smart agriculture (CSA) in Arizona and closely related Southwestern dryland contexts to identify reported practices, associated resilience outcomes, adoption barriers and enabling factors, and evidence gaps. Following scoping review design, the study conducted searches in Scopus, Web of Science, CAB Abstracts, AGRICOLA, Academic Search Complete, and Google Scholar, as well as targeted grey literature. The search was conducted between February 2 and March 5, 2026, and retrieved on March 8, 2026. Eligible sources were English-language, full-text studies or credible institutional reports that focused on Arizona agriculture, or on closely related Southwestern dryland agricultural systems with direct relevance to Arizona. A total of 22 studies met the inclusion criteria. The findings show that CSA in Arizona is shaped primarily by chronic water scarcity, rising heat, and broader socioecological stress. The most frequently reported practices include water-saving irrigation, crop switching, fallowing, groundwater substitution, cover cropping, compost use, reduced tillage, biological pest control, nature-based solutions, and emerging low-water systems such as agrivoltaics and desert agroforestry. The evidence suggests that resilience outcomes are strongest in the domains of water management, production adjustment under scarcity, and adaptive capacity, while evidence for long-term productivity and environmental gains remains limited. The results further show that adoption is constrained by high transition costs, infrastructure limitations, weak market support for alternative low-water systems, and gaps in training, advisory capacity, and institutional coordination. Overall, the study argues that CSA in Arizona is not a fixed package of practices but an evolving, context-specific response to aridity.

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Statement of Sustainability: This study is novel in showing that climate-smart agriculture in Arizona is not only a farm-management issue, but a dryland sustainability challenge shaped by water allocation, advisory systems, and the fit between practices and arid ecologies. By synthesizing evidence on irrigation shifts, soil-building strategies, nature-based solutions, and low-water transitions, it offers a sharper pathway for linking agricultural adaptation to SDG 2 through resilient food production, SDG 6 through improved water stewardship, SDG 13 through climate adaptation, and SDG 15 through soil and ecosystem conservation in arid landscapes.

1. Introduction

Climate change is placing growing pressure on agriculture in dryland regions, where production already depends on scarce water, high climate sensitivity, and narrow ecological margins (Lipper et al., 2014; U.S. Global Change Research Program (USGCRP), 2023). In the Southwestern United States, the ongoing drought has been identified as the most severe at the 21-year timescale since at least 600 CE, and recent warming has intensified regional moisture deficits and reduced the likelihood of near-term recovery (Wahl et al., 2022). The Fifth National Climate Assessment likewise shows that the Southwest is experiencing rising temperatures, increasing aridity, higher evaporative demand, and mounting stress on water resources, with direct implications for agricultural productivity and rural livelihoods (U.S. Global Change Research Program (USGCRP), 2023).



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Arizona is a particularly important case within this broader regional pattern because its agricultural systems operate under arid conditions and depend heavily on increasingly vulnerable irrigation water supplies. In their Arizona-focused assessment, Nabhan et al. (2023) argue that long-term climate change has reduced, and will continue to reduce, the quantity and reliability of surface water available for irrigation. The same report further notes that declining aquifers, rising temperatures, increasing evapotranspiration, and soil salinity pressures are compounding the risks facing Arizona agriculture, especially in areas dependent on Colorado River allocations and groundwater pumping (Nabhan et al., 2023). This makes Arizona a strategically important setting for examining how agricultural systems respond to intensifying climate and water stress in a hot and drying environment.

Additionally, Arizona requires a dedicated scoping review because its adaptation challenges cannot be fully captured by broader Southwest evidence alone. Existing Arizona-focused studies show that climate-responsive agricultural practices vary across production contexts, including small-scale regenerative farms, irrigated field-crop systems, dairy-forage production, local food enterprises, and emerging low-water systems (Diaz, 2023; Eakin et al., 2016; Mpanga et al., 2021; Varyvoda et al., 2024). At the same time, this evidence remains dispersed across journal articles, theses, extension publications, policy reports, and scenario-based analyses. A focused review is therefore needed to clarify which climate-smart practices are being studied or proposed in Arizona, how they relate to resilience under state-specific water and governance constraints, and where the evidence base remains thin or fragmented.

Within this context, climate-smart agriculture (CSA) provides a useful framework for examining agricultural adaptation under climate change. Lipper et al. (2014) describe CSA as an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change. More broadly, CSA is understood to pursue three interrelated goals: improving agricultural productivity, strengthening adaptation and resilience, and reducing or removing greenhouse gas emissions where feasible (FAO, 2026; Lipper et al., 2014). Crucially, CSA is not a uniform technological package. Its relevance and performance are context-specific and depend on local agroecological conditions, institutional arrangements, and socio-economic constraints (Lipper et al., 2014). That place-based character is especially important in Arizona, where the feasibility of climate-responsive practices is shaped by aridity, irrigation dependence, farm scale, technical capacity, and uneven access to capital and markets (Mpanga et al., 2020; Nabhan et al., 2023; Varyvoda et al., 2024).

Although CSA has attracted substantial scholarly and policy attention, the evidence base remains uneven, particularly with regard to how productivity, resilience, and environmental sustainability interact in practice (Lipper et al., 2020). This concern is especially relevant in Arizona, where emerging studies point to several promising climate-responsive practices but do not yet provide a consolidated account of the literature. For example, Mpanga et al. (2021) report that small-scale growers in north-central Arizona are using regenerative practices such as cover cropping, compost application, crop rotation, animal and green manure, no-till, and reduced tillage. At the same time, Varyvoda et al. (2024) show that nature-based solutions among Arizona's local food entrepreneurs are often constrained by economic and technological limitations, even where their adaptation value is recognized. These studies suggest that Arizona contains a growing but still dispersed body of evidence on climate-responsive agriculture.

What remains unclear is the overall structure of that evidence base. The literature has not yet been synthesized in a way that clearly shows which CSA practices have been most frequently examined in Arizona, which dimensions of agricultural resilience have received the greatest attention, which farming systems and producer groups are most visible, and where the major evidence gaps remain. Against this background, this study undertakes a scoping review of climate-smart agriculture practices relevant to agricultural resilience in Arizona. Its contribution is to provide a more coherent map of the available evidence, identify the resilience-related outcomes associated with reported practices, and clarify the principal constraints, opportunities, and research gaps shaping CSA in the state. In doing so, the study aims to strengthen the basis for future research, policy design, and practice-oriented interventions in Arizona and in other arid and water-stressed agricultural regions.

The main objective of this study is to map and synthesize the available literature on CSA practices and their relevance to agricultural resilience in Arizona. The specific objectives are to:

1. Identify the types of climate-smart agriculture practices adopted in Arizona
2. Examine the agricultural resilience outcomes associated with these practices.
3. Assess the major challenges and enabling factors influencing the adoption and implementation of CSA practices; and
4. Identify key evidence gaps to inform future research, policy, and practice on climate-resilient agriculture in arid regions.

2. Theoretical Framework: Social-Ecological Systems and Resilience Theory

This study is guided by Social-Ecological Systems and Resilience Theory, which views agriculture as a coupled system in which ecological processes and human action interact in complex, dynamic ways. From this perspective, farming outcomes are shaped not only by biophysical conditions but also by interactions among water, soils, climate stress, institutions, knowledge systems, and human responses to change. In resilience thinking, the central concern is how such systems absorb disturbance, adapt, and continue functioning without crossing critical thresholds that undermine their viability (Folke et al., 2010; Ostrom, 2009; Walker et al., 2004).



This lens is especially appropriate for a review of CSA because the evidence shows that adaptation is shaped not only by farm practices but also by broader interactions among drought, water scarcity, soil constraints, governance arrangements, and producer decision-making (Burchfield & Gilligan, 2016; Hawes, 2019; Knutson et al., 2011). Social-Ecological Systems and Resilience Theory, therefore, makes it possible to interpret CSA as more than a set of isolated technologies. It frames resilience as the capacity of agricultural systems to persist, adapt, or transform under climatic and hydrological stress, while recognizing that this capacity depends on both ecological conditions and social institutions (Biggs et al., 2015; Folke et al., 2010). For agriculture more specifically, resilience scholarship has also emphasized the need to assess how farming systems respond to shocks, long-term stresses, uncertainty, and surprise, which aligns closely with the concerns of this study, with water stress, adaptive capacity, and long-term agricultural viability in arid regions (Meuwissen et al., 2019).

Building on this understanding of resilience, the framework is used not only as a conceptual background but also as a guide for data synthesis and interpretation. It helped organize CSA as a set of interconnected social, ecological, and institutional processes rather than as isolated farm technologies. Accordingly, practices such as irrigation efficiency, crop switching, cover cropping, reduced tillage, groundwater substitution, nature-based solutions, and agrivoltaics were interpreted in relation to the wider water, soil, climate, market, and governance systems in which they operate. The framework also guided the interpretation of resilience outcomes by distinguishing between short-term coping responses, adaptive adjustments, and more transformative pathways for dryland agriculture. For example, fallowing or groundwater substitution may help producers respond to immediate water scarcity, but their long-term resilience implications depend on their effects on farm income, aquifer sustainability, production stability, and water-governance arrangements. Similarly, adoption barriers and enabling factors were interpreted as system-level conditions, including infrastructure, finance, markets, extension capacity, policy incentives, local knowledge, and producer networks, rather than as individual farmer decisions alone. Using this lens, the review interprets CSA in Arizona as a place-specific social-ecological response to persistent aridity, while also allowing for a more cautious assessment of trade-offs and uncertainties where a practice may generate benefits in one domain but create risks in another.

3. Methodology and Methods

3.1. Review Design

This study adopted a scoping review design because the purpose of the review was to map the extent, range, and nature of the available literature on CSA and agricultural resilience in Arizona, rather than to estimate pooled intervention effects. Scoping reviews are particularly appropriate when a body of evidence is conceptually broad, methodologically heterogeneous, and dispersed across different source types, including peer-reviewed research and grey literature (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020; Tricco et al., 2018). The study was informed by the original scoping review framework proposed by Arksey and O'Malley (2005), subsequent methodological refinements by Levac et al. (2010), and updated Joanna Briggs Institute guidance for scoping reviews (Peters et al., 2020). Reporting was structured in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) to enhance transparency and reproducibility (Tricco et al., 2018).

3.2. Review Question and Eligibility Framework

The review questions were developed using the Population–Concept–Context (PCC) framework recommended for scoping reviews by the Joanna Briggs Institute (Peters et al., 2020). In this review, the population comprised farming systems, producers, and agricultural enterprises; the concept was CSA practices and related resilience-oriented agricultural strategies; and the context was Arizona, with limited inclusion of closely related studies from the U.S. Southwest, where they directly informed the Arizona case (Peters et al., 2020). The PCC framework was used because scoping reviews typically address broader exploratory questions than effectiveness reviews and therefore require an organizing structure that can accommodate conceptual and contextual diversity in the evidence base (Peters et al., 2020).

3.3. Information Sources and Search Strategy

The search strategy was designed to identify both scholarly and practice-oriented evidence relevant to CSA and agricultural resilience in Arizona. Consistent with scoping review guidance, the search was conducted across multiple information sources in order to capture literature from different publication streams and reduce the risk of overlooking relevant evidence in an emerging field (Arksey & O'Malley, 2005; Peters et al., 2020). The search was conducted between February 2 and March 5, 2026, and the final database retrieval was completed on March 8, 2026. The review covered literature published from database inception to March 8, 2026. Search was conducted in Scopus, Web of Science Core Collection, CAB Abstracts, AGRICOLA, Academic Search Complete, and Google Scholar. Because Arizona-focused CSA evidence is not confined to journal articles, targeted grey literature searches were also undertaken to identify reports and applied documents from reputable institutions working on water, agriculture, and climate resilience in the region, including university and policy sources. The inclusion of grey literature is consistent with scoping review methodology, which recognizes that useful evidence may extend beyond conventional peer-reviewed databases, particularly where policy and applied practice are central to the topic under study (Levac et al., 2010; Peters et al., 2020).



The search strategy combined terms related to climate-smart agriculture, sustainable and regenerative agricultural practices, resilience, Arizona, and the U.S. Southwest. Core search string included the following: ("climate-smart agriculture" OR "climate smart agriculture" OR CSA OR "sustainable agriculture" OR "regenerative agriculture" OR agroecology OR "agroecological practices" OR "dryland farming" OR "dryland agriculture" OR "water conservation" OR "water-efficient" OR "water-use efficiency" OR "irrigation efficiency" OR "soil health" OR "soil conservation" OR "cover cropping" OR "reduced tillage" OR "nature-based solutions") AND ("agricultural resilience" OR "resilience") AND (Arizona OR "Southwest US" OR "Southwestern United States"). Search terms were iteratively refined during the review process to improve relevance and sensitivity, which is consistent with the flexible and iterative character of scoping review searching described in methodological guidance (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020).

3.4. Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria: first, they focused on Arizona agriculture or on the U.S. Southwest in ways that were directly relevant to agricultural systems in Arizona; second, they examined CSA practices or closely related resilience-oriented agricultural practices, including but not limited to irrigation efficiency, soil conservation, crop diversification, regenerative agriculture, renewable-energy applications, and nature-based solutions; third, they reported empirical findings, practice-based evidence, policy analysis, or synthesis relevant to adaptation, resilience, sustainability, or implementation; and fourth, they were available in full text and published in English. Both peer-reviewed and grey literature sources were eligible because scoping reviews are intended to map the breadth of available evidence and are not limited to one study design or one publication type (Arksey & O'Malley, 2005; Peters et al., 2020).

Studies were excluded if they focused on agricultural systems outside Arizona or the broader Southwest without clear relevance to the Arizona context, discussed climate change or agriculture only in general terms without addressing practices or resilience-related outcomes, or lacked sufficient methodological or substantive detail for data extraction. Commentaries and opinion pieces without analyzable evidence were also excluded. These criteria were intended to preserve conceptual focus while still allowing the breadth expected in a scoping review (Levac et al., 2010; Peters et al., 2020).

Because grey literature was included, sources were screened for credibility before final inclusion. Grey literature was retained only when it came from identifiable authors or credible institutions, such as universities, extension services, public agencies, research organizations, or policy bodies working on agriculture, water, climate, or sustainability in Arizona or the wider Southwest. Sources also had to provide sufficient methodological or substantive detail for data extraction and had to be directly relevant to the review's Population–Concept–Context framework. Opinion pieces, advocacy documents, or sources lacking identifiable authorship, institutional credibility, or analyzable evidence were excluded. This screening was not a formal risk-of-bias appraisal, but it helped ensure that non-peer-reviewed sources were credible, traceable, and relevant to the synthesis.

3.5. Study Selection

Study selection was undertaken in two stages. In the first stage, titles and abstracts or executive summaries were screened to assess potential relevance to the review questions and eligibility criteria. In the second stage, full texts of potentially relevant records were reviewed to determine final inclusion. This staged screening approach follows established scoping review procedures and helps ensure that decisions about inclusion are made systematically and transparently (Arksey & O'Malley, 2005; Levac et al., 2010; Tricco et al., 2018). The study selection process was documented using a PRISMA-ScR-style flow structure showing the numbers of records identified, screened, excluded, and included in the final review, as shown in Figure 1 (Tricco et al., 2018).

3.6. Data Charting and Extraction

Data were extracted using a structured charting form developed for the review. In keeping with scoping review guidance, the charting process was used not only to record descriptive study information but also to capture how the evidence addressed the review questions (Levac et al., 2010; Peters et al., 2020). For each included source, the following information was charted where available: author(s), year of publication, study objectives, methods, key findings, relevance to the review, and limitations as presented in Table 1. The charting form was refined iteratively during the extraction process to ensure that it remained aligned with the range of evidence encountered, consistent with recommended scoping review practice (Levac et al., 2010; Peters et al., 2020).

3.7. Synthesis of Results

The extracted evidence was synthesized using descriptive numerical summary and thematic analysis. Scoping reviews commonly combine basic descriptive mapping of the literature with narrative or thematic synthesis in order to show both the distribution of the evidence and the substantive patterns emerging across studies (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020). In this review, descriptive synthesis was used to summarize the volume and characteristics of the included sources, while thematic synthesis was used to group practices and findings into major domains relevant to agricultural resilience in Arizona. These domains, as presented in Table 1, included water scarcity, water-use efficiency, and irrigation adaptation; oil health, conservation,



and regenerative production; sustainable crop, livestock, and low-water production systems; energy, technology, and mitigation-oriented innovations; and institutional, economic, market, and advisory-system conditions. Themes were developed inductively from the included literature but were also informed by the resilience and CSA concerns that recur in the Arizona evidence base.

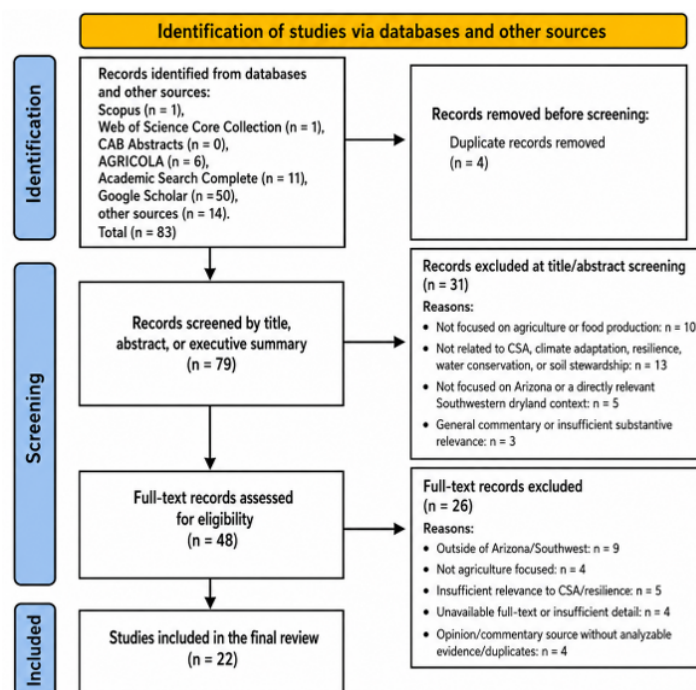


Figure 1. Study selection flow chart.

3.8. Methodological Limitations

This review has several limitations inherent to its design. First, because scoping reviews aim to map evidence broadly, they do not provide the same level of causal inference or comparative effectiveness assessment as a narrowly defined systematic review with formal quality appraisal (Peters et al., 2020; Tricco et al., 2018). Second, the Arizona-focused literature on CSA is still relatively limited and heterogeneous, which means that some thematic conclusions are based on a small number of studies or practice-oriented reports. Third, although grey literature was included to strengthen contextual coverage, such sources vary in methodological detail and may not always be directly comparable to peer-reviewed studies. These limitations were considered in interpreting the findings and in framing the review as a scoping exercise intended to map evidence and identify gaps rather than provide definitive effectiveness judgments.

4. Results and Discussion

4.1. Overview of the Selected Studies

The 22 studies reviewed show that the literature on climate-smart agriculture in Arizona and the wider American Southwest is diverse in topic and method, but uneven in evidentiary depth. Taken together, the corpus includes studies on cover crops and desert soils, statewide Arizona adaptation planning, regional water governance, drought and aridification, resilience-oriented adaptation, nature-based solutions, regenerative practice adoption, forage water efficiency, Pinal County adaptation, central Arizona drought impacts, arid-adapted crop futures, adaptive capacity, advisory systems, scenario planning for water-resilient agriculture, innovation-oriented policy responses, urban and regional water governance, acequia resilience, and local food entrepreneurship (Arp et al., 2024; Bechok, 2014; Condon et al., 2023; Diaz, 2023; Dignam, 2024; Eakin et al., 2016; Gleick, 2010; Idhirij & Ward, 2025; Lisonbee et al., 2022; MacDonald, 2010; McCarthy, 2012; McCarthy, 2024; McCarthy & Rushforth, 2025; Mpanga et al., 2021; Nabhan et al., 2020, 2023; Pierce, 2011; Rosenberg et al., 2020; Samar, 2019; Sharma, 2025; Varyvoda et al., 2024; Witinok-Huber et al., 2026). Overall, the reviewed evidence is strongest for identifying the kinds of practices, pressures, barriers, and adaptation pathways being discussed or used in arid agriculture, and weaker for estimating long-term causal effects across Arizona production systems.

Methodologically, the corpus is dominated by descriptive surveys, qualitative case studies, theses, professional papers, research reports, extension documents, and scenario-based analyses. Only a smaller share of the reviewed studies provides stronger causal



or longitudinal evidence. This means the literature is more useful for mapping what CSA looks like in Arizona and comparable dryland settings than for making precise claims about the size or durability of outcomes. That pattern also helps explain why themes such as practice diversity, water stress, institutional constraints, and future pathways emerge more clearly than quantified state-wide effect estimates.

Table 1. Thematic evidence map of selected studies.

CSA/resilience theme	Studies contributing to the theme	Contribution to the review	Evidence limitation
Water scarcity, water-use efficiency, and irrigation adaptation	Gleick (2010); MacDonald (2010); Samar (2019); Diaz (2023); Sharma (2025); Bechok (2014); Mpanga et al. (2021); Nabhan et al. (2023); Pierce (2011); Idhirij and Ward (2025); Dignam (2024); Lisonbee et al. (2022)	Shows that CSA in Arizona and comparable Southwestern contexts is organized primarily around water stress, irrigation dependence, water-use efficiency, crop-water demand, fallowing, crop switching, ground-water substitution, rainwater harvesting, water pricing, and water-allocation institutions.	Evidence is uneven across sectors and locations. Some studies are regional, modeled, thesis-based, or policy-oriented rather than direct comparative evaluations of farm-level CSA outcomes in Arizona.
Soil health, conservation, and regenerative production	Arp et al. (2024); Mpanga et al. (2021); Condon et al. (2023); Rosenberg et al. (2020); McCarthy, S. (2024); McCarthy and Rushforth (2025); Nabhan et al. (2023); Dignam (2024)	Identifies cover crops, compost, manure, crop rotation, reduced tillage/no-till, organic amendments, soil improvement, erosion reduction, moisture retention, and soil-health monitoring as important conservation and resilience pathways.	Much of the evidence is descriptive, extension-oriented, exploratory, or based on stakeholder perspectives. Long-term Arizona field evidence on soil carbon, yield effects, and water-use trade-offs remains limited.
Sustainable crop, livestock, and low-water production systems	Diaz (2023); Samar (2019); Sharma (2025); Nabhan et al. (2020); Nabhan et al. (2023); Bechok (2014); McCarthy, S. (2024); McCarthy and Rushforth (2025); Varyvoda et al. (2024); Rosenberg et al. (2020); Mpanga et al. (2021)	Captures crop switching, forage-water efficiency, arid-adapted crops, perennial desert polycultures, agroforestry, rotational grazing, local food systems, water harvesting, and other low-water production models.	Many findings are small-sample, conceptual, place-specific, or forward-looking. Evidence on long-term productivity, adoption equity, and environmental performance remains limited.
Energy, technology, and mitigation-oriented innovations	Nabhan et al. (2023); Dignam (2024); Varyvoda et al. (2024); Nabhan et al. (2020); Diaz (2023)	Highlights agrivoltaics, indoor/vertical farming, AI-based irrigation and soil monitoring, precision irrigation, drought-resistant crops, and other innovation pathways that may connect water adaptation with energy use, resource efficiency, and mitigation-oriented CSA.	Evidence is mostly emerging, technology-focused, scenario-based, or illustrative. Trade-offs around cost, land use, market viability, energy demand, and displacement of food production require further study.
Institutional, economic, market, and advisory-system conditions	Eakin et al. (2016); Witinok-Huber et al. (2026); Condon et al. (2023); Nabhan et al. (2023); Varyvoda et al. (2024); McCarthy and Rushforth (2025); Mpanga et al. (2021); Samar (2019); Dignam (2024); Rosenberg et al. (2020); Idhirij and Ward (2025); Pierce (2011); Gleick (2010)	Shows that CSA adoption depends on producer learning, linking capacity, extension support, climate literacy, financing, equipment access, markets, policy incentives, water institutions, community trust, and collaborative governance.	Institutional evidence is strong for identifying barriers and enabling conditions, but weaker for measuring how specific policy, advisory, or market interventions affect resilience outcomes over time.

Note: Studies are grouped by thematic relevance; therefore, some studies appear in more than one domain. The table is intended as a cross-domain evidence map rather than a mutually exclusive classification of the 22 included sources.

This pattern is broadly consistent with CSA scholarship, which frames CSA around productivity, adaptation, resilience, and mitigation, while also recognizing that institutional, financial, and governance conditions shape adoption and outcomes (Lipper et al., 2014, 2020; Totin et al., 2018). However, the Arizona evidence gives this broader argument a more specific dryland expression: water scarcity and water governance are not simply one dimension of CSA, but the central conditions through which many practices become feasible, constrained, or contested (Gleick, 2010; MacDonald, 2010; Nabhan et al., 2023). This means that CSA in Arizona must be assessed not only by technical promise, but also by hydrological limits, water rights, infrastructure, markets, and institutional capacity (Eakin et al., 2016; Samar, 2019; Sharma, 2025).



4.2. Types of Climate-Smart Agriculture Practices

Across the reviewed studies, climate-smart agriculture in Arizona is best described as a portfolio of practices centered on water management, soil stewardship, regenerative farming, and, in some cases, broader agroecosystem redesign. At the farm level, the most frequently reported practices include cover cropping, compost use, manure application, crop rotation, reduced tillage or no-till, biological pest control, and water-saving irrigation. The clearest direct Arizona evidence comes from small-scale growers in Yavapai and Coconino Counties, where regenerative practices were reported as part of practical, low-input farming systems shaped by local markets, community-supported agriculture, and climate pressures (Mpanga et al., 2021). Similar emphasis on soil-building and water-sensitive strategies appears in comparative Southwest studies, though often through different institutional and cultural forms (Rosenberg et al., 2020; McCarthy, 2024).

Water-centered adaptation is the most prominent practice domain in the Arizona literature. In Pinal County and central Arizona, the reviewed studies identify groundwater development, fallowing, land-use change, crop switching, drip irrigation, reclaimed water exploration, and changes in water sourcing as important adaptation responses to shrinking Colorado River supplies and CAP-related cuts (Samar, 2019; Sharma, 2025). In Arizona dairy-forage systems, the evidence also shows that water demand varies substantially across major forage crops, which makes crop choice itself an important water-management decision under scarcity (Diaz, 2023). At the wider regional level, policy and systems analyses similarly frame agricultural adaptation in the Southwest as inseparable from water conservation, reallocation, and planning under tightening hydrological constraints (Gleick, 2010; MacDonald, 2010). Compared with broader CSA literature, which often treats water-use efficiency as one practice domain among several, the Arizona evidence positions water as the organizing constraint around which many other CSA decisions are made. This is strongly supported by Frimpong et al. (2023), who show that under climate stress, irrigation practices, water harvesting, cropping choices, and water-use efficiency become the organizing core of agricultural adaptation rather than one dimension among many. However, the findings also caution that water-saving practices do not automatically produce resilience if they increase groundwater dependence, reduce cultivated area, or require investments that smaller producers cannot absorb (Bechok, 2014; Diaz, 2023; Samar, 2019; Sharma, 2025; Nabhan et al., 2023).

A second major set of practices centers on soil health. In the reviewed literature, cover crops, compost, manure, reduced tillage, and related soil-building strategies are presented as potentially important for reducing erosion, increasing soil organic matter, improving moisture-use efficiency, and supporting soil function in arid systems (Arp et al., 2024; Mpanga et al., 2021). In acequia-related research from the wider Southwest, producers also identified soil improvement to reduce evaporation as an important drought-adaptation response (Rosenberg et al., 2020). These findings are consistent with CSA literature, which treats soil and land management as central to adaptation because improved soil condition can support water retention, reduce degradation, and strengthen resilience under climate stress (FAO, 2013; IPCC, 2019).

The literature also points to more transformative pathways, though mostly through conceptual, exploratory, or scenario-based work rather than broad empirical evaluation. Arizona and Southwest studies identify water harvesting, agroforestry, rotational grazing, agrivoltaics, desert agroforestry, arid-adapted crops, perennial polycultures, watershed stewardship, and biocultural restoration as possible future directions (Bechok, 2014; McCarthy, 2024; McCarthy & Rushforth, 2025; Nabhan et al., 2020; Nabhan et al., 2023; Dignam, 2024; Varyvoda et al., 2024). Wider CSA literature supports taking such possibilities seriously but also cautions against treating them as universal solutions. For example, agrivoltaics in drylands can reduce plant drought stress and produce food–energy–water benefits, yet newer evidence from agrisolar co-location also shows trade-offs, including displacement of food production even where water sustainability and economic security improve (Barron-Gafford et al., 2019; Stid et al., 2025). The critical implication is that transformative adaptation options should be discussed as promising but conditional, not as unqualified win-wins.

4.3. Agricultural Resilience Outcomes

The resilience outcomes discussed in the reviewed studies cluster around improved water management, stronger soil function, production adjustment under scarcity, adaptive capacity, and wider socioecological resilience. Water-related outcomes are the most consistently supported. In Arizona forage systems, evidence shows substantial differences in irrigation demand across crop types (Diaz, 2023). In central Arizona irrigation districts, drought-related cuts were associated with reduced area under cultivation in the more vulnerable district, shifts away from water-intensive crops, and greater use of groundwater and other non-CAP sources (Sharma, 2025). In the wider Southwest, hydro-economic modeling suggests that more flexible water-sharing arrangements can reduce shortage costs more effectively than rigid proportional allocation (Idhirij & Ward, 2025). These studies support the conclusion that agricultural resilience in arid systems depends not only on irrigation technology, but also on crop choice, water governance, and the ability to reconfigure water use under scarcity.

Soil-related outcomes are also prominent, though the Arizona evidence is more suggestive than experimentally definitive. The reviewed studies indicate that cover crops and other soil-building practices may support reduced erosion, improved soil organic matter, stronger aggregate stability, and better moisture-use efficiency in desert or dryland systems (Arp et al., 2024; Mpanga et al., 2021). In acequia-related research, surveyed producers also emphasized soil improvement as part of drought preparedness



(Rosenberg et al., 2020). These findings align with wider assessments showing that sustainable soil and land management can support adaptation and resilience by improving soil condition and reducing land degradation under climate stress (FAO, 2013; IPCC, 2019). Thus, while Arizona evidence aligns with broader CSA literature in recognizing soil health as a resilience pathway, it also complicates universal claims about regenerative practices by showing that cover crops, compost, manure, and reduced tillage must be evaluated in relation to water availability, management capacity, time horizons, and long-term field evidence in desert systems (Arp et al., 2024; Mpanga et al., 2021; Rosenberg et al., 2020; FAO, 2013; IPCC, 2019).

The reviewed literature is more cautious on productivity outcomes. Arizona studies do not provide a strong statewide body of causal evidence showing consistent yield increases across systems from specific climate-smart practices. Instead, productivity is usually framed in terms of sustaining output, adjusting crop portfolios, or improving performance under water-constrained conditions (Diaz, 2023; Samar, 2019; Sharma, 2025). Nabhan et al. (2020) argued that arid-adapted perennial or desert-based food systems have potential for greater stability and lower dependence on groundwater and fossil-fuel-intensive systems, but this remains forward-looking rather than broadly demonstrated through current farm-level adoption studies (Nabhan et al., 2020).

Another important outcome domain is adaptive capacity. Evidence from central Arizona shows that producers often display interest in learning, experimentation, and adaptive management, but also uncertainty about their own efficacy under future climatic and hydrological change (Eakin et al., 2016). In statewide and scenario-based Arizona studies, future resilience is likewise framed as depending on combinations of soil health, innovation, collaboration, regenerative practices, crop shifting, and institutional coordination rather than field practices alone (Condon et al., 2023; Nabhan et al., 2023). In this sense, the reviewed studies supports a multidimensional understanding of resilience in which agronomic responses are intertwined with social, institutional, and hydrological conditions.

4.4. Major Challenges and Enabling Factors Influencing the Adoption and Implementation of CSA

Across the 22 studies, the most consistent challenge is the interaction between climate stress and structural water scarcity. The literature identifies reduced water supplies, hotter conditions, declining soil quality, drought-related uncertainty, and policy or governance rigidities as major threats to agricultural viability (Condon et al., 2023; Samar, 2019; Sharma, 2025). Regional studies reinforce this by showing that the Southwest faces long-term drought, rising heat, declining snowpack, reduced runoff, and increasing pressure on water planning and allocation systems (Gleick, 2010; MacDonald, 2010; Lisonbee et al., 2022). The evidence therefore, supports the conclusion that CSA in Arizona must be understood within a broader context of chronic water stress rather than as a purely field-level management issue.

A second recurring barrier is the cost and uncertainty of transition. Several studies identify financing constraints, infrastructure limitations, market uncertainty, limited support for low-water crops, and equipment access as important obstacles to adopting regenerative or water-resilient systems (Samar, 2019; McCarthy & Rushforth, 2025; Nabhan et al., 2023; Varyvoda et al., 2024). This is one of the clearest cross-study findings in the review: promising practices and pathways are often present, but implementation is constrained by whether producers have the resources, infrastructure, and risk tolerance needed to make changes under uncertain conditions. This reinforces wider institutional critiques of CSA, which show that finance, markets, policy coherence, knowledge systems, and governance strongly shape whether climate-smart practices are adopted and sustained (Lipper et al., 2014; Totin et al., 2018). The Arizona evidence sharpens this argument by showing that technical options may exist, but without financing, equipment access, market support, extension capacity, and water-governance alignment, they may remain isolated experiments rather than scalable resilience pathways (McCarthy & Rushforth, 2025; Nabhan et al., 2023; Samar, 2019; Varyvoda et al., 2024).

Knowledge systems and advisory capacity are another major theme. Adaptive capacity research in Arizona shows that producer response depends partly on cognitive and relational factors, including willingness to learn, flexibility, and access to “linking capacities” that connect producers to collective strategy formation (Eakin et al., 2016). Comparative research on technical service providers likewise shows that stronger climate literacy, communication capacity, locally relevant monitoring, data interpretation, and professional networks are important for supporting producer adaptation (Witinok-Huber et al., 2026). The study therefore supports a broader view in which advisory systems and trusted intermediaries are part of CSA’s enabling environment.

At the same time, literature identifies several enabling factors. Local market demand, peer learning, workshops and training, access to equipment, community-supported agriculture, and place-based ecological knowledge all appear as conditions that can improve the feasibility or attractiveness of adoption (Mpanga et al., 2021; McCarthy & Rushforth, 2025; Varyvoda et al., 2024). Some studies also suggest that adaptation pathways may be strengthened when they are aligned with local hydrology, traditional knowledge, and watershed stewardship rather than imposed as generic solutions for very different agroecological settings (Bechok, 2014; McCarthy, 2024; Rosenberg et al., 2020; Nabhan et al., 2020).

4.5. Evidence Gaps and Implications for Future Research, Policy, and Practice

The first major evidence gap concerns long-term effectiveness, trade-offs, and comparative performance under Arizona field conditions. The literature provides substantial insight into practices, barriers, and adaptation trajectories, but relatively limited evidence on causal effects, long-term outcomes, and the conditions under which specific CSA practices generate durable resilience benefits.



This is important because several practices identified in the review involve potential trade-offs. For example, cover crops and soil-building practices may improve soil structure, erosion control, and moisture retention, but their feasibility in desert systems depends on water availability and management capacity (Arp et al., 2024; Mpanga et al., 2021). Similarly, fallowing and crop switching may reduce water demand but can also affect farm income, production continuity, and rural livelihoods (Samar, 2019; Sharma, 2025). Groundwater substitution may buffer short-term irrigation shortages, yet it can deepen long-term aquifer stress where pumping is not carefully governed (Nabhan et al., 2023; Sharma, 2025). Emerging low-water systems such as agrivoltaics, desert agroforestry, vertical farming, and digital irrigation technologies are promising, but their long-term economic feasibility, land-use implications, equity effects, and scalability remain uncertain (Dignam, 2024; Nabhan et al., 2020; Nabhan et al., 2023; Varyvoda et al., 2024). Therefore, the review can say more confidently what is being tried, proposed, or constrained than exactly how much resilience benefit a given practice delivers over time across different Arizona production systems.

A second gap concerns geographical and sectoral coverage. Within Arizona, the reviewed studies are concentrated in a relatively limited set of contexts, especially north-central small-scale farms, Pinal County, central Arizona irrigation districts, dairy-forage systems, and local food entrepreneurship. These are important windows into climate-smart adaptation, but they do not capture the full diversity of Arizona agriculture. As a result, broad statewide generalization should be made cautiously, especially where evidence comes from a small number of districts, sectors, or grower groups (Diaz, 2023; Sharma, 2025; Varyvoda et al., 2024).

A third gap concerns integration across domains. The reviewed studies repeatedly show that water, soils, crop systems, markets, institutions, and advisory systems interact, yet these dimensions are still often studied separately. Wider CSA literature makes a similar point: CSA is conceptually framed around productivity, adaptation, and mitigation together, but these dimensions are not always jointly assessed in empirical work (Lipper et al., 2014; Totin et al., 2018). In Arizona's case, this matters because the viability of any practice depends not only on agronomic fit, but also on hydrology, infrastructure, markets, and governance.

The policy implication that follows from the reviewed evidence is that climate-smart agriculture in Arizona should not be treated simply as a list of recommended farm practices. The strongest Arizona-wide and scenario-based studies support a broader approach that links soil health, water planning, innovation, crop adaptation, training, collaboration, and institutional coordination (Condon et al., 2023; Nabhan et al., 2023). Broader CSA literature also supports the need for enabling systems, including policy coherence, institutional support, and sustainable land management frameworks, if climate adaptation is to be sustained in practice (Totin et al., 2018; IPCC, 2019).

5. Conclusion

This study shows that climate-smart agriculture in Arizona is emerging as a practical and uneven response to chronic water scarcity, rising temperatures, and wider socioecological stress. Across the 22 studies reviewed, the literature consistently highlights water-saving irrigation, crop switching, fallowing, groundwater substitution, soil-building practices, reduced tillage, cover cropping, nature-based solutions, and other low-water systems as the principal pathways through which adaptation is being pursued. However, the evidence also makes clear that resilience is not determined by farm practices alone. It is equally shaped by water governance, infrastructure, financing, market conditions, advisory support, and institutional capacity to respond to hydrological uncertainty. A major contribution of the study is that it establishes that Arizona's CSA literature is strongest in documenting adaptation through water management and production adjustment, while evidence on longer-term productivity, environmental performance, and comparative effectiveness remains limited. Much of the available research is descriptive, exploratory, or scenario-based. Overall, the findings suggest that climate resilience in Arizona depends less on promoting isolated "smart" practices than on building flexible, place-sensitive socioecological and institutional systems capable of supporting agriculture under persistent aridity. However, because many proposed CSA pathways remain supported by descriptive, exploratory, or scenario-based evidence, future research must more carefully assess their long-term effectiveness, trade-offs, distributional consequences, and scalability across Arizona's diverse agricultural systems.

Author Contributions

Sufyan Suleman: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; Khadija Siita: Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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