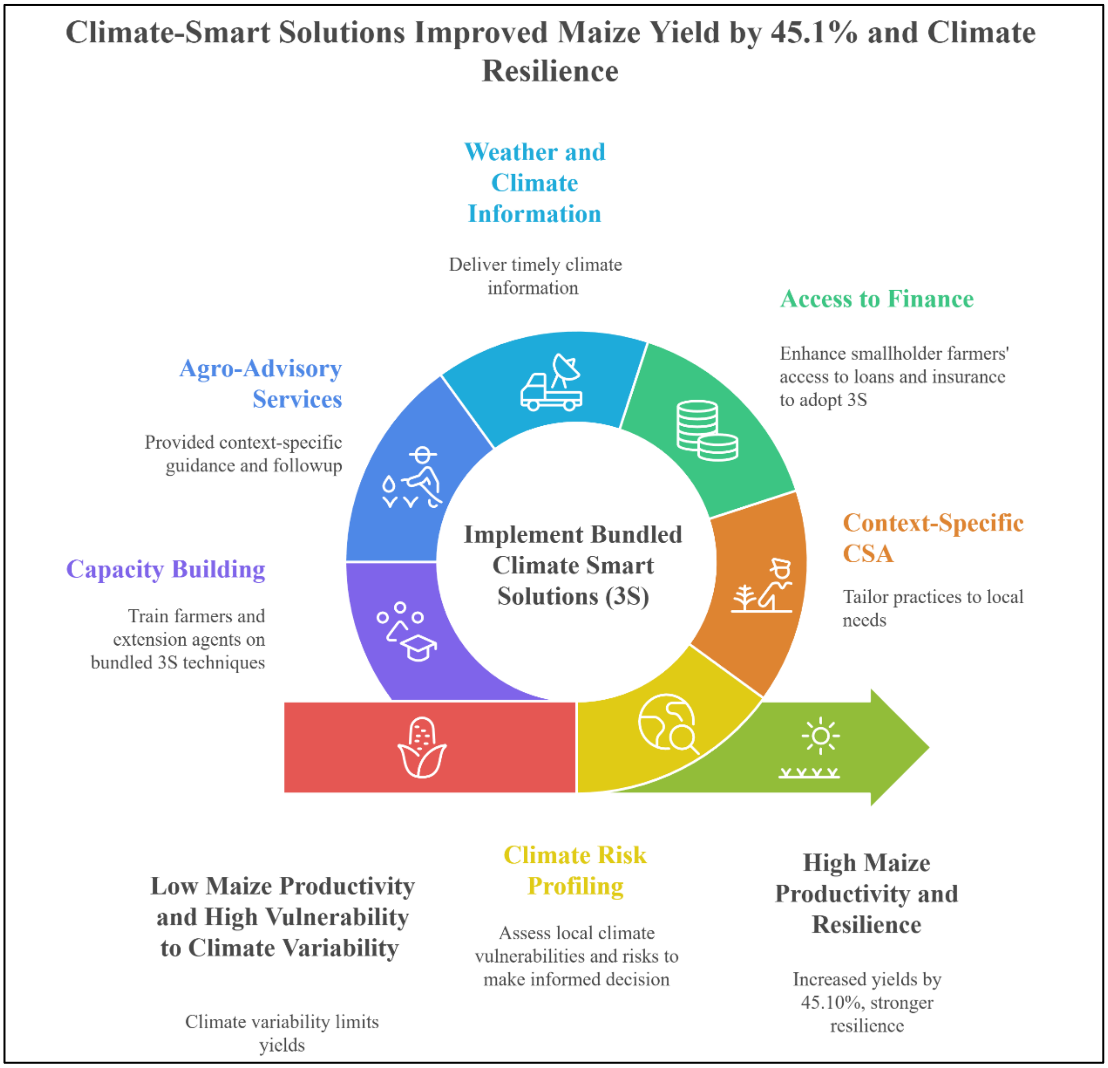
Impact of Bundled Climate-Smart Solutions (3S) on Maize Productivity and Resilience across Agricultural Commercialization Clusters (ACCs) in Southern Ethiopia



Sintayehu W. Dejene, Sintayehu Alemayehu, Tadesse Terefe, Lidiya Tesfaye, Pedro Chilambe and Evan Girvetz

*Corresponding authors; Email: s.workeneh@cgiar.org and/or s.alemayehu@cgiar.org

Alliance Bioversity International and CIAT, P.O. Box 5689, Addis Ababa, Ethiopia

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Summary

Maize production in Southern Ethiopia faces significant challenges from climate variability, including erratic rainfall, heat stress, and pest outbreaks, which constrain yields and threaten smallholder livelihoods. To address these challenges, the CGIAR Program on Scaling for Impact (SfI) piloted a bundled Climate-Smart Solutions (3S) package integrating climate risk profiling, context-specific CSA practices, access to finance, weather and climate information (WCIS) and agro-advisory services, and capacity-building interventions. This study assessed the impact of these bundled 3S on maize productivity and resilience among smallholder farmers across Agricultural Commercialization Clusters (ACCs) in south Ethiopia. A mixed-methods approach was applied, including a household survey of 600 farmers (150 CSA adopters and 150 non-adopters in 2025, plus 300 CSA farmers in 2024 as a baseline), focus group discussions, and systematic maize growth performance observations. Results indicated that CSA adopters in 2025 achieved an average yield of 36.33 quintal per hectare, representing a 45.65% increase from the 2024 (baseline) and 45.10% higher than non-adopters, who recorded 25.04 quintal per hectare. Field observations confirmed that bundled 3S enhanced germination, seedling vigor, vegetative growth, cob formation, and pest management, collectively strengthening resilience to climate variability. The study demonstrates that bundled 3S substantially improve maize productivity and strengthen smallholder farmers' resilience to climate variability in Southern Ethiopia. By integrating climate risk profiling, context-specific CSA practices, access to finance, climate information and advisory services, and targeted capacity-building, the bundled 3S approach boosts maize yields, stabilizes production under climate variability, and strengthens adaptive capacity across farm systems. This approach has the potential to transform smallholder systems, enhance food security, safeguard livelihoods, and drive sustainable, climate-resilient agricultural development across ACCs. Importantly, the study also demonstrated evidence for scaling, showing that a fully integrated, locally tailored CSA package can be replicated across regions to achieve similar productivity gains and resilience benefits. Overall, the findings highlight that bundled 3S can serve as a scalable model for climate-resilient maize production, supporting sustainable agricultural intensification, improved food security, safeguarded livelihoods, and strengthened adaptive capacity among smallholder farmers.

Keywords: Bundled Climate-Smart Agriculture (CSA); Local-Led Adaptation; Resilience; Smallholder Farmers;

1. Introduction

Maize is a cornerstone of food security and income generation in Southern Ethiopia, supporting millions of smallholder farmers and their households. Despite its importance, maize production in the region faces increasing threats from climate variability, including erratic rainfall, prolonged dry spells, heat stress, and recurrent pest and disease outbreaks such as fall armyworm. These challenges, combined with limited access to improved seeds, fertilizers, and timely climate information, constrain yield potential, reduce farmers' income, and threaten regional food security.

In response to these challenges, the CGIAR Program on Scaling for Impact (SfI) implemented a pilot project across ATI's Agricultural Commercialization Clusters (ACCs) in Ethiopia, aimed at enhancing smallholder maize farmers' productivity and resilience to climate variability through bundled Climate-Smart Solutions (3S). The bundled approach integrates five key interventions: (i) climate risk profiling to assess location-specific hazards and inform farm- and policy-level decision-making; (ii) co-identification and promotion of context-specific CSA practices tailored to local agro-ecologies; (iii) facilitation of access to finance to enable timely procurement of improved inputs; (iv) provision of climate information services (CIS) and agro-advisory support to optimize planting, input use, and pest management; and (v) targeted capacity-building activities to strengthen farmers' technical skills and adaptive capacity. By combining these complementary interventions, the CSA package is designed to increase productivity, stabilize yields under variable climatic conditions, and enhance farmers' resilience and adaptive capacity, providing a scalable model across Ethiopia's maize-producing ACCs.

Previous studies have shown that individual CSA practices, such as improved seed varieties, mulching, intercropping, and integrated pest management, can improve crop performance and mitigate climate risks. However, evidence on the effectiveness of fully integrated, bundled 3S under smallholder conditions is limited. Evaluating how these bundled interventions impact maize productivity and resilience is essential for guiding policy, scaling strategies, and investment decisions, while supporting Ethiopia's broader climate adaptation and food security objectives. The objective of this study is to assess the comparative impact of bundled CSA solutions on maize productivity and resilience in Southern Ethiopia. Specifically, the study aims to (i) quantify yield improvements among CSA adopters compared to non-adopters, (ii) examine crop growth performance across key stages, (iii) evaluate resilience outcomes under variable climatic conditions, and (iv) provide actionable recommendations for scaling and policy support.

2. Methods

2.1. Study area and intervention context

The study was conducted in maize-producing areas of Sidama Region, and Gamo, Omo and Wolayita Zone of South Ethiopia (Figure 1). These zones were selected because the areas are identified as a maize cluster area of ATI's Agricultural Commercialization Clusters (ACCs) in

Ethiopia and represent diverse agro-ecological conditions while sharing common climate-related constraints, including erratic rainfall, prolonged dry spells, heat stress, and recurrent pest outbreaks such as fall armyworm. The intervention focused on implementing a bundled 3S including climate risk profiling, co-identification and promotion of context-specific climate-smart agriculture (CSA) practices, facilitation of access to finance, provision of climate information services (CIS) and agro-advisory support, and targeted capacity building. This integrated approach aimed to enhance both maize productivity and resilience to climate variability.

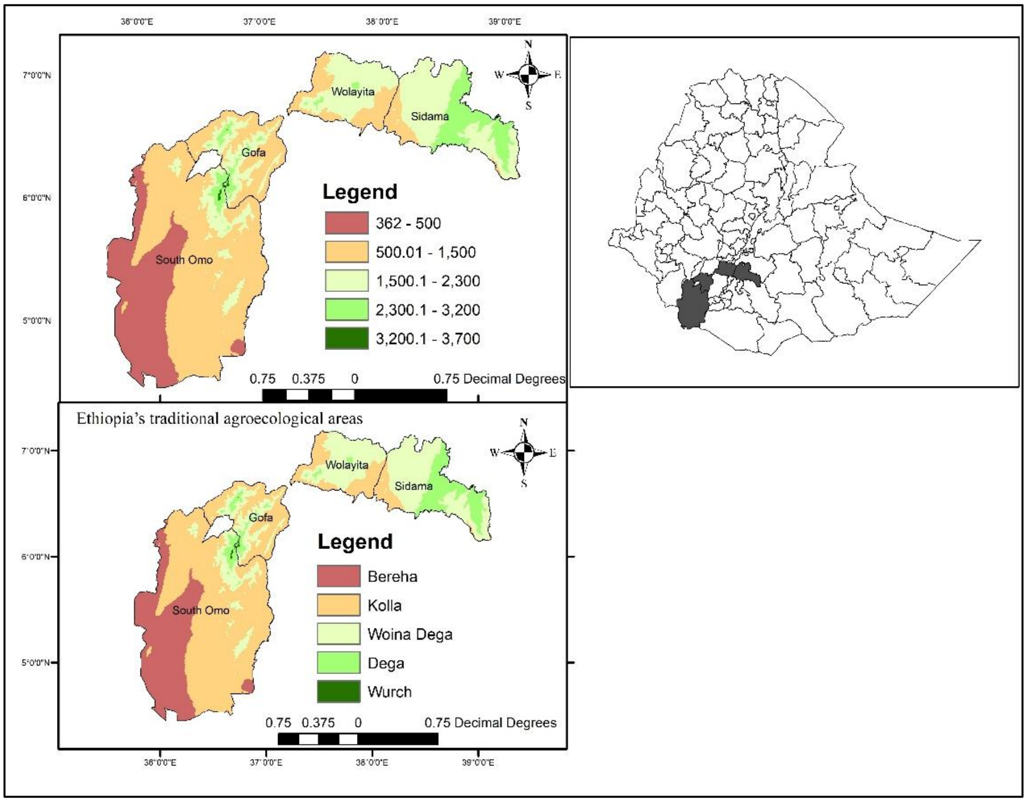

Figure 1. Map of the study area

2.2.Study design and sampling

The study employed a mixed-methods design to comprehensively evaluate the impact of bundled 3S on maize productivity and resilience. This design integrated quantitative household surveys with qualitative Focus Group Discussions (FGDs) to capture both measurable outcomes and contextual insights from farmers and extension agents. The mixed-methods approach allowed triangulation of data, ensuring that observed productivity and resilience gains could be linked to CSA adoption and crop-level performance.

A structured household survey was conducted with a total of 600 maize farmers across the three pilot zones. In 2025, the survey covered 150 adopters of bundled 3S and 150 non-adopters, enabling a direct comparison of maize productivity and resilience outcomes under the same agro-ecological and seasonal conditions. This comparative design provided a clear understanding of the incremental benefits of bundled 3S adoption relative to conventional or partially adopted practices. In 2024, prior to full implementation of the bundled 3S pathway, the same 150 farmers who later adopted bundled 3S solutions were surveyed to establish a baseline reference point. This baseline allowed for the measurement of productivity changes and the attribution of improvements to the adoption of the full bundled 3S package.

Farmers were selected using purposive and stratified sampling techniques to ensure representation across the different agro-ecological zones and farming systems. Stratification considered factors such as maize commercialization intensity, exposure to climate risks, and prior participation in CSA-related programs. Within each stratum, households were randomly selected to reduce selection bias and improve the generalizability of results. Data collected included maize yields, crop management practices, adoption of CSA technologies, access to climate information services, extension support, and financial products, enabling a comprehensive assessment of both agronomic outcomes and the enabling environment for CSA adoption.

2.3.Focus group discussions (FGDs)

To complement quantitative data, FGDs were conducted with farmer groups and extension agents across the study area. The discussions provided contextual insights into maize management practices, experiences with bundled 3S adoption, and responses to climate variability. FGDs also served to validate maize growth performance observations, verify self-reported yields, and capture qualitative evidence on resilience outcomes. This qualitative component strengthened the overall assessment by providing explanations for observed differences between adopters and non-adopters and highlighting the practical challenges and benefits experienced by farmers in implementing CSA practices.

2.4.Maize growth performance recording

Systematic maize growth performance observations were conducted throughout the cropping season to link agronomic practices with yield and resilience outcomes. Trained extension staff and LERSHA field agents monitored key growth stages, including:

- **Germination and emergence:** Uniformity of seedling emergence, germination percentage, and seedling vigor.
- **Seedling stage:** Leaf development, root branching, and early biomass accumulation.
- **Vegetative stage:** Plant height, leaf greenness, biomass growth, uniformity, and signs of nutrient stress or stunting.
- **Reproductive stage:** Tasseling, silking, cob formation, and ear uniformity.
- **Grain-filling stage:** Kernel development, cob weight, and pest or disease damage.
- **Post-harvest stage:** Adoption of improved storage practices and incidence of post-harvest losses.

These growth performance records provided tangible evidence of bundled 3S impacts on crop establishment, growth, and yield stability, demonstrating how agronomic interventions translated into enhanced resilience under variable climatic conditions.

2.5.Data analysis

Quantitative data from household surveys were analyzed to calculate average maize yields, productivity differences between bundled 3S adopters and non-adopters, and percentage changes across years. Qualitative data from FGDs and maize growth performance observations were synthesized to assess resilience outcomes, including anticipatory, absorptive, and adaptive capacities. Integrating these data sources enabled a robust mixed-methods assessment linking productivity gains to specific CSA practices, crop-level performance, and resilience improvements across the maize value chain.

3. Results

3.1.Maize productivity

The adoption of bundled 3S in 2025 led to substantial increases in maize productivity across the pilot areas of Southern Ethiopia. Farmers who implemented the bundled 3S package achieved an average maize yield of 36.33 quintal per hectare, the highest productivity recorded during the assessment period (Figure 2). This result reflects the synergistic effects of improved maize varieties, timely and climate-informed agronomic practices, soil and water conservation measures, and access to inputs and advisory services.

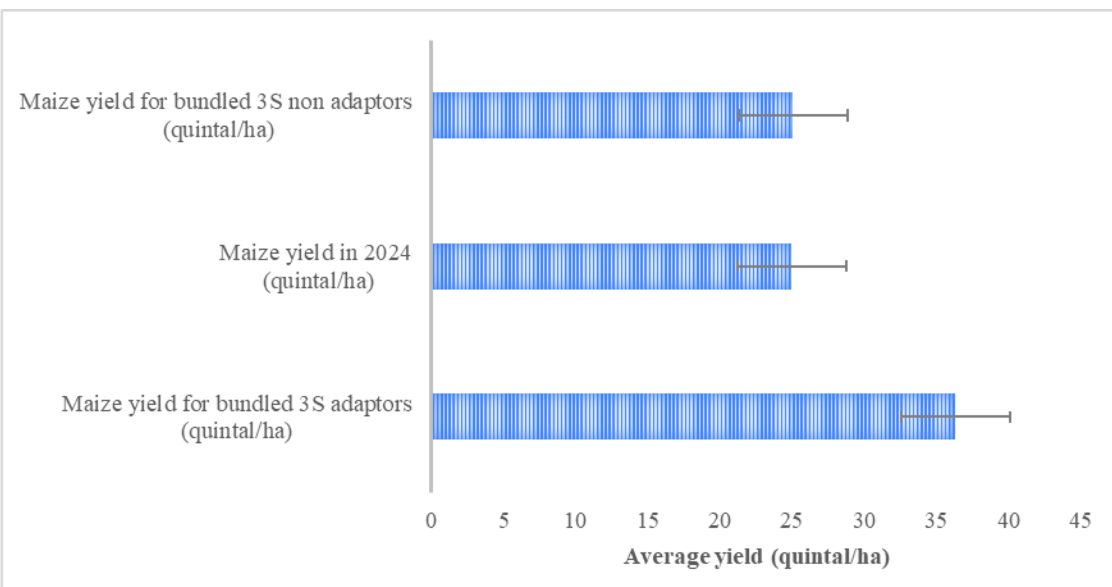

Figure 2. Average maize productivity by year and bundled 3S adoption status (quintal/ha)

In comparison, non-adopters of bundled 3S recorded an average maize yield of 25.04 quintal per hectare in the same season, highlighting a significant yield gap of approximately 11.29 quintal per hectare (Figure 2). In 2024, prior to full bundled 3S implementation, the same group of farmers recorded an average yield of 24.94 quintal per hectare, closely matching the yields of non-adopters in 2025. This similarity indicates that baseline productivity levels were largely comparable across farmer groups before bundled 3S adoption, confirming that observed improvements in 2025 can be attributed to the bundled 3S interventions rather than pre-existing differences.

3.2.Changes in maize productivity

Comparative analysis of maize yields between 2024 and 2025 demonstrates the effectiveness of bundled 3S adoption. Bundled 3S adopters experienced an increase from 24.94 to 36.33 quintal per hectare, representing a 45.65% increase within a single cropping cycle. By contrast, non-adopters saw only a marginal increase from 24.94 to 25.04 quintal per hectare, equivalent to a 0.4% change (Table 1).

Table 1. Changes in maize productivity associated with CSA adoption

Comparison	Yield Change (qt/ha)	% Change
Bundled CSA adaptors (2024–2025)	11.39	45.65
Bundled CSA non adaptors (2024–2025)	0.1	0.4
Bundled CSA adaptors and non-adaptors (2025)	11.29	45.1

Furthermore, in 2025, farmers adopting the bundled 3S solution achieved maize yields that were 45.10% higher than those of non-adopters, clearly demonstrating the substantial productivity advantage of the integrated bundled 3S package. This pronounced yield gap highlights that transitioning from conventional or partially implemented practices to a fully bundled 3S approach is critical for unlocking maize yield potential. Scaling these best practices to other maize-producing areas has strong potential to transform smallholder farming systems and significantly strengthen the effectiveness and impact of interventions across Agricultural Commercialization Clusters (ACCs).

3.3.Maize growth performance and resilience to climate variability

Field-level observations clearly demonstrated that adoption of the bundled 3S approach significantly enhanced maize crop establishment, vegetative growth, and reproductive performance, thereby directly contributing to higher and more stable yields. During the germination and emergence stages, fields managed by bundled 3S adopters exhibited uniform and vigorous seedling emergence, reflecting timely planting decisions informed by climate information services and improved soil moisture management. At the seedling stage, maize plants showed welldeveloped leaves and extensive root branching, indicating the combined benefits of improved maize varieties, intercropping with legumes, integrated soil fertility management (ISFM), and the use of crop cover to conserve soil moisture and nutrients (Table 2; Figure 3). As crops progressed into the vegetative stage, bundled 3S adopters' fields displayed rapid and uniform green leaf development, minimal yellowing, and strong biomass accumulation, demonstrating effective nutrient uptake and enhanced water-use efficiency. During the reproductive and grain-filling stages, maize plants exhibited uniform ear and cob formation with minimal pest and disease incidence, highlighting the effectiveness of integrated pest management (IPM), timely agronomic interventions, crop cover, intercropping and agroforestry-based microclimate regulation. Collectively, these improvements in crop growth and development translated into enhanced yield stability and resilience, even under conditions of climatic variability.

CSA adopters demonstrated enhanced resilience across crop and farm-system levels. Access to climate information allowed farmers to anticipate weather variability, adjust planting schedules, and optimize agronomic management. Crop-level absorptive capacity improved through robust germination, seedling vigor, and vegetative growth, while adaptive capacity was strengthened by integrated pest management and post-harvest handling practices. Access to climate-smart finance and digital advisory services further increased farmers' ability to respond to shocks, manage input use, and maintain stable production under adverse conditions.

Beyond crop performance, bundled 3S adopters demonstrated strengthened resilience across both crop and farm-system levels. Access to climate information services enabled farmers to anticipate weather variability, adjust planting calendars, and optimize agronomic management, thereby enhancing anticipatory capacity. Crop-level absorptive capacity improved through robust germination, seedling vigor, and sustained vegetative growth, while adaptive capacity was reinforced through integrated pest management and improved post-harvest handling practices that reduced losses and income variability. In addition, access to finance, insurance, and agro-advisory services increased farmers' ability to manage input use, respond to climate shocks, and maintain stable production under adverse conditions. Together, these outcomes demonstrate that the bundled 3S approach not only boosts maize productivity but also strengthens systemic resilience, providing a robust pathway for locally led climate adaptation and scalable climate-smart agricultural transformation.

Table 2. Resilience to climate variability indicators among bundled CSA Adopters (2025)

Growth Stage	Indicator	Measurement / Observation
Germination & Emergence	Seedling establishment	Uniformity of emergence, percent germination, seedling vigor
Seedling	Leaf development and root branching	Number of leaves, leaf length/width, root depth and branching intensity

Vegetative	Biomass accumulation	Leaf greenness, plant height, uniformity, yellowing or stunting
Reproductive	Tasseling, silking, and cob formation	Number of ears per plant, uniformity of cob development
Grain-Filling	Kernel filling, ear uniformity	Grain size, cob weight, presence of pest/disease damage

Figure 3. Field performance of maize at different stages

3.4.Adoption of CSA practices

Differences in maize productivity and resilience are closely linked to the scope and integration of the bundled 3S interventions. In 2025, farmers adopting the bundled 3S solution implemented a comprehensive set of practices, including improved maize varieties (Damot P3506W), mulching, intercropping with legumes, early planting guided by climate information and agro-advisory services, access to finance to support full implementation, improved post-harvest storage, and integrated pest management (IPM). In contrast, non-adopters in 2025 and farmers in 2024 relied primarily on a limited set of improved varieties such as Shone, Kurtu, BH-540, BH-520, BH-661, and BH-140, with fewer complementary CSA practices. While all farmers applied integrated fertilizer management, the absence of additional practices such as mulching, intercropping, cover crops, early planting, and climate-informed advisory support likely constrained yield potential and reduced resilience among non-adopters. These findings underscore the importance of adopting a fully integrated, bundled 3S approach to maximize productivity gains and strengthen adaptive capacity under climate variability.

Figure 4. CSA practices

4. Discussion

The findings of this study clearly demonstrate that adoption of the bundled 3S approach substantially improved maize productivity and resilience in Southern Ethiopia. Farmers who adopted the full package in 2025 achieved an average yield of 36.33 quintal per hectare, representing a 45.65% increase relative to their 2024 baseline, whereas non-adopters recorded only a marginal increase of 0.4% over the same period. This pronounced difference underscores the critical advantage of fully integrated CSA interventions compared to conventional or partially implemented practices. The results indicate that combining improved maize varieties, intercropping, mulching, cover crops, soil and water conservation, agroforestry, integrated pest management, weather and climate information and agro-advisory services, post-harvest management, and access to finance support produces synergistic effects that surpass the benefits of individual practices applied in isolation.

Field observations of maize growth provided clear evidence of the mechanisms through which the bundled 3S approach enhances resilience. Fields managed by 3S adopters exhibited uniform germination, vigorous seedling growth, rapid and consistent vegetative development, well-formed ears and cobs, and minimal pest or disease incidence. These crop-level improvements illustrate that adoption of the bundled 3S package strengthens farmers' capacity to manage risks associated with climate variability, enabling them to better anticipate, absorb, and adapt to climatic shocks. In addition, access to timely weather and climate information, targeted agro-advisory services, and extension support further reinforced farmers' ability to make informed management decisions, strategically invest in improved inputs and CSA practices, and maintain stable maize production even under adverse climatic conditions. Collectively, these outcomes demonstrate that the bundled 3S approach not only boosts productivity but also builds systemic resilience at both crop and farm levels.

The study highlights that productivity and resilience improvements are interlinked, with enhanced crop performance serving as both an outcome of bundled 3S adoption and a driver of adaptive capacity. By promoting locally tailored, integrated interventions, the bundled 3S approach not only raises yields but also builds farm-system resilience, supporting sustained maize production in climate-sensitive environments. These findings provide strong evidence for scaling CSA packages across Agricultural Commercialization Clusters (ACCs), where combining farmer knowledge with targeted technical, financial, and advisory support can transform smallholder maize systems and contribute to climate-resilient agricultural development in Ethiopia.

5. Conclusion

The adoption of the bundled 3S approach in Southern Ethiopia demonstrates an innovative, evidence-based strategy for enhancing maize productivity and resilience among smallholder farmers. By integrating climate risk profiling, context-specific CSA practices, access to finance, climate information and advisory services, and targeted capacity-building, the bundled 3S approach increases maize yields, stabilizes production under climate variability, and strengthens adaptive capacity. Empirical evidence from field observations and surveys confirm that the fully integrated package delivers consistent, reproducible outcomes, establishing it as a best-practice model for smallholder maize production. Importantly, the bundled 3S approach provides a scalable framework for locally led, evidence-driven interventions, offering a pathway to responsibly expand climate-smart solutions across Ethiopia's Agricultural Commercialization Clusters. This approach has the potential to transform smallholder systems, enhance food security, safeguard livelihoods, and drive sustainable, climate-resilient agricultural development.

6. Practice and policy influence

The bundled 3S intervention has significantly influenced both on-farm practices and policy/program frameworks. At the farm level, it accelerated the adoption of CSA practices such as intercropping and cover crops to reduce moisture stress, supported by weather and climate information services (WCIS), targeted agro-advisory guidance, and insurance mechanisms that encouraged investment in improved inputs. At the policy and program level, project outputs and best practices are being integrated into the Agricultural Transformation Institute's (ATI) ACC II initiative, while strengthened public–private partnerships are creating an enabling environment for scaling climate-smart solutions across ACC II.

7. Recommendations

Based on the study findings, several policy and scaling recommendations emerge. First, the delivery of climate information services and agro-advisory support should be strengthened to ensure farmers can make timely planting, pest management, and input application decisions.

Second, access to climate-smart finance and insurance should be expanded to reduce financial barriers and enable smallholder farmers to adopt improved seeds, fertilizers, and CSA practices. Third, promoting fully integrated bundled 3S rather than single practices is essential to maximize productivity and resilience gains. Fourth, the bundled 3S model should be scaled across maize commercialization clusters and adapted to other strategic crops and mixed crop–livestock systems, ensuring wide-reaching impacts. Finally, continuous monitoring of crop-level resilience indicators, such as germination, seedling vigor, vegetative growth, and reproductive success, is recommended to track bundled 3S effectiveness and guide adaptive management. Implementing these recommendations can help build climate-resilient maize production systems, improve food security, and enhance smallholder adaptive capacity in Ethiopia.