International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM May 2026, 17(5): 01-12 Article AR6940

Research Article Social Science

DOI: HTTPS://DOI.ORG/10.23910/1.2026.6940

Incentive Mechanisms and Institutional Frameworks for Scaling Climate-smart Agriculture Across Different Agro-ecological Regions in India

B. Malathi[1], B. Devojee[2], T. R. Sahoo[3], A. R. Reddy[1], J. V. Prasad[4], A. Bhaskaran[5] and Shaik N. Meera[6]

[1]Dept. of Agricultural Economics, [2]Dept. of Agricultural Engineering, [3]Dept. of Horticulture, [4]Dept. of Agricultural Entomology, [5]Dept. of Soil Science and Agricultural Chemistry, [6]Dept. of Agricultural Extension, ICAR-ATARI, Hyderabad (500 059), India

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Corresponding devojibhookya@gmail.com

0000-0002-9630-8071

ABSTRACT

The experiment was conducted during the period from 2022 to 2025 at ICAR-ATARI, Hyderabad, to study the impact of climate-resilient technology interventions implemented under the National Innovations in Climate Resilient Agriculture (NICRA) across different agro-ecological regions of India. An ex post facto research design was employed, covering 540 stakeholders, including 300 farmers, 90 Krishi Vigyan Kendra (KVK) personnel, and 150-line department officials from NICRA-implemented regions. Data were collected using a structured questionnaire administered on a five-point Likert scale (0–5). A Composite CSA Implementation Feasibility Index was developed by incorporating technical feasibility, cost–benefit ratio, gender inclusivity, and convergence with government schemes. The findings revealed moderate to high feasibility of CSA interventions, with overall index scores ranging from 2.98 to 3.33. Crop production interventions recorded the highest feasibility score (3.33), followed by soil quality and fertility management (3.26) and ex-situ water harvesting and efficient water use (3.19). Institutional interventions showed comparatively lower feasibility (2.98). Adoption barriers ranged from 2.52 to 3.26, with technology acceptability, limited awareness, and labour availability emerging as major constraints. Among incentive mechanisms, capacity building and market linkages ranked higher, whereas subsidies and affordable credit remained relatively weak. Custom Hiring Centres, youth farmer groups, and women self-help groups were identified as key institutional mechanisms supporting the scaling of CSA interventions.

KEYWORDS: Climate-smart agriculture, incentive mechanisms, institutional frameworks, adoption barriers

Citation* (VANCOUVER)*: Malathi et al., Incentive Mechanisms and Institutional Frameworks for Scaling Climate-smart Agriculture Across Different Agro-ecological Regions in India. *International Journal of Bio-resource and Stress Management,* 2026; 17(5), 01-12. HTTPS://DOI.ORG/10.23910/1.2026.6940.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, author have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The author has declared that no conflict of interest exists.

RECEIVED on 20th January 2026 RECEIVED in revised form on 08th April 2026 ACCEPTED in final form on 25th April 2026 PUBLISHED on 04th May 2026

1. INTRODUCTION

Indian agriculture is increasingly exposed to the adverse impacts of climate change, manifested through rising temperatures, erratic rainfall patterns, frequent droughts and floods, and increased incidence of pests and diseases (Ma and Rahut, 2024). These climatic stresses pose serious threats to agricultural productivity, livelihood security, and food systems, particularly for small and marginal farmers who depend largely on rainfed agriculture (Aggarwal et al., 2018). With more than half of the cultivated area in India being rainfed, enhancing climate resilience has become a critical priority for sustaining agricultural growth and rural livelihoods (Aggarwal et al., 2018). Climate-Smart Agriculture (CSA) has emerged as an integrated approach to address these challenges by simultaneously enhancing agricultural productivity, strengthening resilience to climate variability, and reducing greenhouse gas emissions wherever feasible (McNunn et al., 2020; Ma and Rahut, 2024). CSA promotes context-specific technological, institutional, and policy interventions that enable farmers to adapt to changing climatic conditions while maintaining environmental sustainability. In India, the adoption of CSA practices such as water-saving technologies, soil and nutrient management, climate-resilient crop varieties, and improved livestock and fisheries management has gained momentum through national and state-level initiatives (Khatri-Chhetri et al., 2017; Aggarwal et al., 2018; Singh et al., 2022). Recognizing the urgency to build climate resilience in agriculture, the Indian Council of Agricultural Research (ICAR) launched the National Innovations in Climate Resilient Agriculture (NICRA) project in 2011. NICRA aims to enhance the adaptive capacity of Indian agriculture through participatory on-farm demonstrations, technology refinement, capacity building, and institutional convergence across diverse agro-ecological regions (Rao et al., 2016; Thottadi and Singh, 2024). The project has played a pivotal role in generating evidence on the technical feasibility and field-level performance of climate-resilient technologies, while also strengthening extension mechanisms through Krishi Vigyan Kendras (KVKs) and line departments. Despite demonstrated benefits, scaling climate-smart agriculture beyond pilot locations remains a major challenge. Adoption of CSA technologies is influenced not only by technical performance but also by farmers' perceptions, availability of incentives, access to finance and markets, institutional support, and socio-economic factors including gender inclusivity (Aryal et al., 2020; Kangogo et al., 2021; Zhou et al., 2023; Belay et al., 2023).Constraints such as limited awareness, low acceptability of technologies, labour shortages, inadequate credit access, and weak institutional coordination often restrict wider adoption, particularly for resource-intensive and water-related interventions (Udmale et al., 2014; Nandini et al., 2024; Akter et al., 2022). Incentive mechanisms and institutional frameworks therefore play a crucial role in accelerating CSA adoption and scaling. Financial incentives such as subsidies and credit, non-financial incentives including capacity building and market linkages, and enabling institutions like Custom Hiring Centres, Farmer Producer Organizations, youth groups, and women self-help groups are essential for reducing adoption risks and transaction costs (Groot et al., 2019; Meena et al., 2020; Bahinipati et al., 2024; Olabanji and Chitakira, 2025). However, the relative effectiveness of these mechanisms varies across agro-ecological regions and CSA intervention domains, necessitating systematic assessment (Makate et al., 2019). In this context, the present study was undertaken under the NICRA framework to evaluate the implementation feasibility of major climate-smart agriculture interventions across different agro-ecological regions of India. The study assesses key adoption barriers, examines the role of incentive mechanisms, and identifies critical institutional actors involved in scaling CSA. By capturing perceptions of multiple stakeholders, including farmers, KVK personnel, and line department officials, the study provides empirical insights to inform policy, strengthen institutional convergence, and design targeted strategies for equitable and large-scale adoption of climate-smart agriculture in India. Therefore, the study aims to assess the implementation feasibility of major climate-smart agriculture (CSA) interventions across different agro-ecological regions of India under the NICRA project.

2. MATERIALS AND METHODS

2.1. Location of the field experiment

The experiment was conducted during the period from 2022 to 2025 at ICAR-ATARI, Hyderabad, to study the impact of climate-resilient technology interventions implemented under the National Innovations in Climate Resilient Agriculture (NICRA) across different agro-ecological regions of India. The study adopted an ex post facto research design, which was considered appropriate for assessing implementation feasibility, adoption barriers, incentive mechanisms, and institutional frameworks associated with technologies that had already been implemented under real-world conditions (Joshi et al., 2015; Ma and Rahut, 2024).

The investigation was carried out in NICRA-adopted villages representing diverse agro-ecological regions of India, where climate-resilient technologies had been implemented since 2011 (Rao et al., 2016). These villages covered rainfed, irrigated, and semi-arid production systems, ensuring representation of heterogeneous climatic and institutional contexts relevant for the assessment of climate-smart agriculture (CSA) interventions (Aggarwal et al., 2018).

2.2. Sampling design and respondents

A purposive sampling approach was employed to select respondents who were directly involved in the implementation, dissemination, and adoption of CSA interventions. The sample comprised farmers, Krishi Vigyan Kendra (KVK) personnel, and line department officials, as these stakeholders played complementary roles in technology adoption and institutional facilitation (Meena et al., 2020; Kangogo et al., 2021). Such stakeholder-based sampling had been widely recommended for institutional and adoption studies related to CSA (Aryal et al., 2020; Zhou et al., 2023).

2.3. Data collection and measurement

Primary data were collected using structured and pre-tested questionnaires administered through personal interviews. Responses were recorded on a five-point Likert scale (0–5) to capture stakeholder perceptions on implementation feasibility, adoption barriers, incentive mechanisms, and institutional support, following established approaches in CSA and climate adaptation research (Udmale et al., 2014; Zakaria et al., 2020; Belay et al., 2023). Pre-testing of the instrument helped ensure clarity, reliability, and contextual relevance of the indicators used.

2.4. Implementation feasibility assessment

Implementation feasibility of CSA interventions was assessed across four dimensions: technical feasibility, cost–benefit ratio, gender inclusivity, and synergy with government schemes. These dimensions were selected based on earlier empirical studies highlighting their importance in determining the adoption and scalability of CSA practices (Khatri-Chhetri et al., 2017; Aryal et al., 2020; Bahinipati et al., 2024). Gender inclusivity was explicitly incorporated to capture differential access to resources and institutional support, which had been shown to influence CSA adoption outcomes (Singh et al., 2022).

2.5. Construction of composite CSA implementation feasibility index

A Composite CSA Implementation Feasibility Index (CSA-IF) was developed using a weighted linear additive model to enable comparison of feasibility across different CSA intervention domains. Index construction followed standard procedures used in technology adoption, vulnerability assessment, and policy evaluation studies (Joshi et al., 2015; Makate et al., 2019; Aryal et al., 2020). Weights were assigned based on the relative importance of each dimension, and normalized scores were aggregated to derive intervention-wise feasibility values.

2.6. Data analysis

The collected data were analyzed using descriptive statistical techniques, including mean scores, standard deviation, composite indices, and ranking methods, to identify variations across CSA interventions, incentive mechanisms, and institutional actors. Such descriptive and index-based analyses had been commonly employed in CSA adoption and institutional assessment studies to generate policy-relevant insights (Groot et al., 2019; Olabanji and Chitakira, 2025).

3. RESULTS AND DISCUSSION

3.1. Overall feasibility

The feasibility assessment of climate-smart agriculture (CSA) interventions indicated moderate to high feasibility, with scores ranging from 2.98 to 3.33. Crop production interventions recorded the highest feasibility score (3.33), followed by soil quality and fertility management (3.26) and ex-situ water harvesting and efficient water use (3.19). These higher scores were attributed to the technical maturity of the interventions, greater farmer familiarity, and strong extension support. Similar findings were reported by Ma and Rahut (2024), who observed that well-established, extension-led CSA practices exhibited higher adoption potential due to lower perceived risk and better institutional backing. McNunn et al. (2020) further demonstrated that technically proven CSA practices were more readily accepted by farmers because of their observable productivity and resilience benefits.

Livestock and fisheries (3.10), water-saving technologies (3.07), and in-situ moisture conservation practices (3.02) also exhibited reasonable feasibility, indicating good potential for adoption when supported by appropriate local customization and institutional facilitation. Recent studies by Akter et al. (2022) and Belay et al. (2023) similarly reported that these interventions required context-specific adaptation and targeted capacity building to overcome management complexity and labour constraints. Bahinipati et al. (2024) further emphasized that institutional convergence played a critical role in enhancing the feasibility of such resource-intensive CSA practices.

In contrast, institutional interventions recorded the lowest feasibility score (2.98), highlighting persistent challenges related to coordination, policy convergence, and institutional capacity. Comparable constraints were documented by Meena et al. (2020), who found that weak inter-agency coordination limited the effectiveness of institutional innovations in CSA scaling. More recently, Bahinipati et al. (2024) reported that inadequate financial integration and fragmented governance structures constrained the scalability of institutional CSA interventions in India. Overall, while technology-based CSA interventions were relatively easier to scale, the findings underscored that strengthening institutional mechanisms and incentive structures was critical for achieving sustained and widespread adoption across diverse agro-ecological regions (Groot et al., 2019; Ma and Rahut, 2024).

3.2. Implementation feasibility

The implementation feasibility assessment revealed generally high technical feasibility across climate-smart agriculture (CSA) interventions, with scores ranging from 3.43 to 4.12 (Figure 1). Crop production, soil quality and fertility management, and ex-situ water harvesting and efficient water use recorded higher technical feasibility, indicating that these interventions were well established, location tested, and operationally simple to implement. Similar evidence was reported by Aryal et al. (2020), who found that CSA practices with proven field performance and demonstrable economic benefits were more readily implemented by farmers. More recently, Ma and Rahut (2024) also observed that technically mature CSA interventions exhibited higher feasibility due to lower operational risk and stronger institutional support mechanisms.

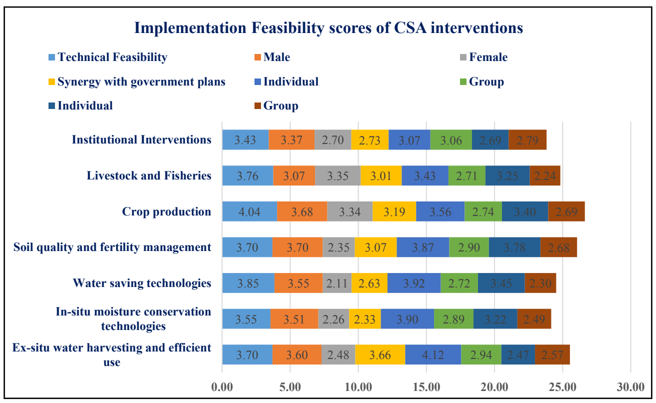

Figure 1: Implementation feasibility scores of climate smart agriculture interventions

Higher feasibility was observed under individual adoption modes compared to group-based adoption, suggesting that decision-making autonomy and flexibility played an important role in implementation success. This finding aligned with Kangogo et al. (2021), who reported that individual adoption often reduced coordination challenges and transaction costs associated with collective implementation of CSA practices.

Gender-wise analysis indicated that male respondents reported slightly higher feasibility scores than female respondents across most CSA interventions. This disparity reflected persistent gender-based differences in access to productive resources, information, and institutional support. Belay et al. (2023) demonstrated that women farmers often faced constraints related to land ownership, credit access, and extension outreach, which reduced their effective participation in CSA programmes. Singh et al. (2022) further highlighted that gendered decision-making structures significantly influenced technology uptake and implementation outcomes in climate adaptation initiatives.

Synergy with government plans contributed positively to implementation feasibility, particularly for water-related and crop production interventions. This finding underscored the importance of policy convergence and alignment of CSA technologies with existing agricultural and rural development programmes. Thottadi and Singh (2024) reported that integration of CSA interventions with government schemes enhanced institutional legitimacy, resource availability, and adoption outcomes. However, relatively lower feasibility scores for group-based and female-led implementation highlighted the need for targeted capacity building, inclusive institutional mechanisms, and gender-sensitive extension strategies. Recent studies by Zhou et al. (2023) and Bahinipati et al. (2024) similarly emphasized that inclusive governance structures and tailored support systems were essential for ensuring equitable and large-scale adoption of CSA interventions across diverse agro-ecological regions.

3.3. Assessment of adoption barriers

The assessment of adoption barriers (Figure 2) for climate-smart agriculture (CSA) interventions revealed moderate constraints, with average scores ranging from 2.52 to 3.26. Acceptability of technology emerged as the most significant barrier (3.26), followed by awareness about technology (2.98) and availability of labour (2.95). These results indicated that behavioural factors and human resource limitations strongly influenced farmers' adoption decisions. Similar findings were reported by Martey et al. (2021), who demonstrated that farmers' perceptions of risk and uncertainty significantly affected the uptake of CSA practices. More recently, Belay et al. (2023) showed that limited understanding of CSA benefits and labour-intensive management requirements constrained adoption, particularly among smallholder farmers.

Access to extension services (2.87) and availability of water

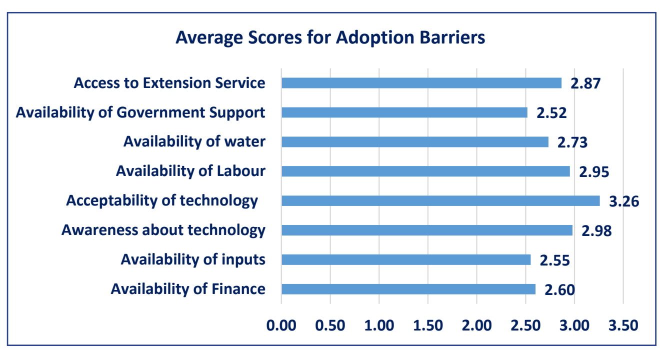

Figure 2: Adoption barriers scores of climates smart agriculture

(2.73) were also identified as notable constraints, reflecting gaps in outreach, climate information delivery, and natural resource availability across regions. Radeny et al. (2022) highlighted that inadequate access to climate and advisory services reduced farmers' capacity to respond effectively to climate risks. Aryal et al. (2020) further emphasized that limited water availability and weak institutional support exacerbated adoption challenges for water-dependent CSA interventions. Recent policy assessments by Nandini et al. (2024) similarly reported that extension system weaknesses remained a critical bottleneck in scaling CSA technologies in semi-arid regions of India.

Relatively lower barrier scores were observed for availability of finance (2.60), availability of inputs (2.55), and availability of government support (2.52), suggesting that although financial and input-related constraints persisted, they were comparatively less limiting than informational and labour-related barriers. Zakaria et al. (2020) found that improved access to inputs and partial subsidy support reduced financial constraints but did not fully address adoption gaps. Kangogo et al. (2021) further demonstrated that even when financial support was available, adoption remained limited in the absence of adequate knowledge and extension guidance.

Overall, the findings highlighted the need to strengthen extension systems, capacity-building initiatives, and awareness generation, along with improving technology suitability and labour efficiency, to enhance the adoption of CSA interventions across diverse agro-ecological regions. Recent studies by Zhou et al. (2023) and Bahinipati et al. (2024) similarly emphasized that integrated approaches combining institutional strengthening, behavioural change communication, and targeted support mechanisms were essential for overcoming adoption barriers and achieving sustainable scaling of CSA practices.

In contrast, crop production interventions exhibited comparatively lower barrier scores across most dimensions, reflecting greater farmer familiarity, higher extension penetration, and easier integration into existing farming systems. Similar patterns were reported by Aryal et al. (2020), who found that CSA practices aligned with existing crop management routines faced fewer behavioural and operational constraints. Makate et al. (2019) further demonstrated that long-term exposure to crop-based CSA interventions enhanced farmers' confidence and reduced perceived adoption barriers, while Aggarwal et al. (2018) highlighted the role of sustained extension support in lowering resistance to climate-resilient crop technologies.

Livestock and fisheries interventions showed moderate constraints, particularly related to input availability and awareness levels. These findings were consistent with those of Kangogo et al. (2021), who reported that higher capital requirements, specialised inputs, and management complexity limited the uptake of livestock-based CSA practices. More recently, Belay et al. (2023) emphasized that insufficient technical knowledge and limited extension coverage constrained the adoption of climate-resilient livestock and fisheries interventions, especially among smallholders.

Institutional interventions consistently recorded the lowest barrier scores, indicating relatively fewer perceived constraints. However, this trend also reflected limitations in visibility, field-level implementation, and direct farmer engagement. Meena et al. (2020) observed that institutional CSA mechanisms often faced fewer resistance barriers because they did not require immediate behavioural change by farmers. Zhou et al. (2023) further noted that weak on-ground presence and limited participatory engagement reduced farmers' awareness of institutional interventions, thereby lowering perceived barriers but also constraining their effective impact (Table 1).

3.4. *Overall score of adoption barriers for climate smart agriculture*

The intervention-wise assessment of adoption barriers for climate-smart agriculture (CSA) technologies revealed moderate constraints, with average scores ranging from 2.34 to 3.15. *Ex-situ* water harvesting and efficient water use recorded the highest barrier score (3.15), followed by water-saving technologies (3.09) and in-situ moisture conservation technologies (3.04). These results indicated that water-related interventions faced relatively greater adoption challenges due to higher initial investment requirements, technical complexity, and site-specific suitability. Similar constraints were reported by Aryal et al. (2020), who found that capital-intensive CSA technologies were less readily adopted in the absence of strong institutional and financial support. More recently, Akter et al. (2022) demonstrated that technical complexity and maintenance requirements significantly reduced farmers' willingness to adopt water-related CSA practices, while Radeny et al. (2022) highlighted the role of local hydro-climatic variability in shaping adoption outcomes.

In contrast, soil quality and fertility management exhibited a moderate barrier score (2.88), while crop production (2.57) and livestock and fisheries (2.58) interventions showed comparatively lower constraints. These lower barrier levels reflected greater farmer familiarity, lower capital requirements, and easier integration into existing farming systems. Makate et al. (2019) reported that soil fertility and crop-based CSA interventions benefited from incremental adoption pathways that reduced perceived risk. Kangogo et al. (2021) further emphasized that livestock-related CSA practices were more readily adopted when they aligned

Table 1: Interventions-wise scores of adoption barriers

Sl. No.	CSA Interventions	Avail-ability of finance	Avail-ability of inputs	Awareness about technology	Accept-ability of technology	Avail-ability of labour	Avail-ability of water	Availability of govern-ment sup-port	Access to extension service
1.1	*Ex-situ* water harvesting and efficient use	2.53	2.70	3.53	4.09	3.14	2.89	3.00	3.35
1.2	*In-situ* moisture conservation technologies	2.93	2.67	3.40	3.71	3.30	2.81	2.36	3.16
1.3	Water saving technologies	2.97	2.61	3.37	3.61	3.21	3.37	2.47	3.10
1.4	Soil quality and fer-tility management	2.60	2.86	2.98	3.26	3.21	2.91	2.06	3.12
2	Crop production	2.38	2.39	2.45	2.94	3.18	2.25	2.63	2.36
3	Livestock and fisheries	2.67	2.46	2.73	2.63	2.28	2.61	2.69	2.61
4	Institutional interventions	2.12	2.17	2.39	2.58	2.36	2.29	2.42	2.37

with existing livelihood strategies and resource availability.

Institutional interventions recorded the lowest barrier score (2.34), suggesting fewer direct adoption constraints. However, this outcome also indicated limitations related to visibility, coordination, and field-level implementation. Meena et al. (2020) observed that institutional CSA mechanisms often encountered fewer behavioural barriers because they did not require immediate changes in farm practices. More recently, Zhou et al. (2023) noted that inadequate stakeholder engagement and weak local presence constrained the effectiveness of institutional interventions, despite their lower perceived adoption barriers.

Overall, the findings emphasized that water-centric CSA interventions required targeted financial, technical, and extension support to overcome adoption barriers and enhance scaling across diverse agro-ecological regions. Recent assessments by Bahinipati et al. (2024) and Olabanji and Chitakira (2025) similarly underscored that integrated support mechanisms combining credit access, capacity building, and institutional convergence were essential for the widespread adoption of resource-intensive CSA technologies.

3.5. Incentive mechanisms to promote CSA interventions

3.5.1. Average scores for incentives

The analysis of institutional support mechanisms for promoting climate-smart agriculture (CSA) interventions (Figure 3) indicated varying levels of access among stakeholders, with scores ranging from 1.54 to 3.23.

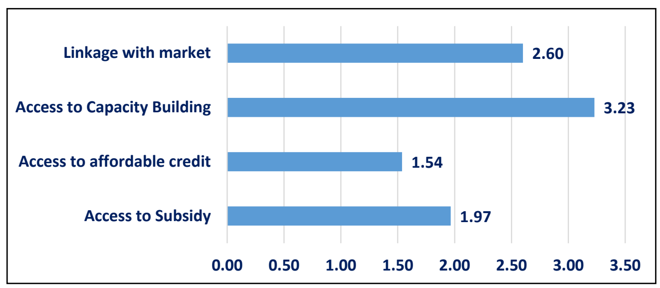

Figure 3: Incentive mechanism scores of climate smart agricultures

Access to capacity building recorded the highest score (3.23), suggesting relatively better availability of training programmes, demonstrations, and skill development initiatives. This trend was largely driven by public extension systems and project-based interventions. Similar observations were reported by Ma and Rahut (2024), who found that extension-led capacity-building initiatives played a central role in improving farmers' awareness and technical competence for CSA adoption. Groot et al. (2019) further demonstrated that continuous training and participatory learning approaches significantly enhanced the effectiveness of climate adaptation interventions.

Linkage with markets exhibited a moderate score (2.60), indicating partial integration of CSA adopters with output markets and value chains. Kangogo et al. (2021) reported that limited aggregation mechanisms and weak value-chain coordination constrained market participation of CSA adopters, particularly smallholders. Recent global assessments by the Anonymous (2019) similarly emphasized that inadequate market connectivity reduced incentives for sustained adoption of climate-resilient technologies.

In contrast, access to subsidies (1.97) and access to affordable credit (1.54) recorded substantially lower scores, highlighting significant financial constraints in scaling CSA interventions, especially for capital-intensive and water-related technologies. Zakaria et al. (2020) showed that high upfront costs and delayed subsidy disbursement reduced farmers' willingness to invest in CSA practices. More recently, Bahinipati et al. (2024) documented that limited access to institutional credit remained a major bottleneck in the adoption of resource-intensive CSA interventions in India.

Overall, these findings suggested that while capacity-building efforts were relatively strong, financial and market-related institutional support mechanisms remained weak. Strengthening access to affordable credit, streamlining subsidy delivery, and improving market linkages were therefore identified as critical for enhancing adoption and large-scale dissemination of CSA technologies across diverse agro-ecological regions. Recent evidence from Olabanji and Chitakira (2025) similarly underscored that integrated institutional support systems were essential for achieving sustainable scaling of CSA interventions.

The intervention-wise analysis of institutional support for climate-smart agriculture (CSA) adoption revealed moderate overall support, with average scores ranging from 2.05 to 2.60. *Ex-situ* water harvesting and efficient water use recorded the highest average institutional support score (2.60), primarily driven by better access to subsidies and capacity-building programmes. This pattern was consistent with earlier findings that water management interventions received relatively stronger policy and programme backing under CSA frameworks due to their strategic importance in climate adaptation. Bahinipati et al. (2024) reported that targeted public investments and scheme convergence significantly improved institutional support for water-related CSA technologies. Similarly, Aryal et al. (2020) emphasized that policy-aligned water interventions benefited from greater institutional facilitation and financial incentives.

Water-saving technologies and livestock and fisheries interventions also exhibited relatively higher institutional support, particularly in terms of training and skill development. Kangogo et al. (2021) demonstrated that capacity-building initiatives enhanced farmers' technical competence in managing livestock-based CSA practices, while Ma and Rahut (2024) reported that structured training programmes played a critical role in improving adoption outcomes for water-saving technologies.

In contrast, in-situ moisture conservation technologies recorded the lowest average institutional support score, indicating weaker facilitation despite reasonable access to capacity-building activities. Meena et al. (2020) observed that such low-visibility natural resource management practices often received limited institutional attention due to delayed and less tangible benefits. Zhou et al. (2023) further highlighted that insufficient field-level monitoring and stakeholder engagement reduced institutional emphasis on in-situ conservation practices.

Across all CSA interventions, access to capacity building emerged as the strongest institutional support mechanism, reflecting the active role of public extension agencies, training programmes, and project-based demonstrations in promoting CSA adoption. Belay et al. (2023) demonstrated that continuous extension engagement significantly improved farmers' awareness and confidence in adopting CSA practices. However, access to affordable credit consistently remained low, followed by limited access to subsidies, highlighting persistent financial constraints in scaling CSA technologies, particularly resource-intensive interventions. Zakaria et al. (2020) reported that high upfront costs and limited credit availability constrained farmers' investment capacity in CSA technologies, while Olabanji and Chitakira (2025) emphasized the need for integrated financial instruments to support climate-resilient agricultural transitions.

Market linkage support remained moderate across interventions, underscoring the need to strengthen value-chain integration alongside financial mechanisms. Overall, the results suggested that while institutional efforts in capacity building were relatively strong, strengthening financial mechanisms and improving market linkages were critical for enhancing the adoption and scaling of CSA interventions across diverse agro-ecological regions. Recent assessments by Ma and Rahut (2024) similarly emphasized that balanced institutional support combining capacity building, finance, and market access was essential for sustainable CSA implementation (Table 2).

3.5.2. *Overall score of incentives for climate smart agricultures*

The assessment of institutional support across climate-smart agriculture (CSA) interventions indicate**d** moderate levels of support, with average scores ranging from 2.05 to 2.60. Ex-situ water harvesting and efficient water use received the highest institutional support score (2.60), followed by water-saving technologies (2.41) and livestock and fisheries interventions (2.37). This pattern reflected relatively better access to subsidies, capacity-building programmes, and market linkages for these interventions. Similar trends were reported by Bahinipati et al. (2024), who found that water-related CSA interventions benefited from stronger policy backing and programme convergence. Aryal et al.

Table 2: Interventions-wise scores of various incentives

Sl. No.	CSA interventions	Access to subsidy	Access to affordable credit	Access to capacity building	Linkage with market	Average
1.1.	*Ex-situ* water harvesting and efficient use	3.02	1.37	3.16	2.86	2.60
1.2.	*In-situ* moisture conservation technologies	1.18	1.37	3.32	2.35	2.05
1.3.	Water saving technologies	1.64	1.59	3.63	2.78	2.41
1.4.	Soil quality and fertility management	1.63	1.12	3.54	2.57	2.21
2.	Crop production	1.92	1.54	2.98	3.01	2.36
3.	Livestock and fisheries	2.46	1.89	3.04	2.11	2.37
4.	Institutional interventions	1.90	1.90	2.94	2.53	2.32

(2020) also demonstrated that institutional alignment and financial incentives significantly enhanced support for water management technologies under CSA frameworks.

Crop production (2.36) and institutional interventions (2.32) also exhibited moderate levels of support, consistent with earlier evidence on extension-led CSA promotion in India. Aggarwal et al. (2018) highlighted that sustained public extension efforts improved outreach and institutional facilitation for crop-based CSA practices. Groot et al. (2019) further emphasized that participatory extension approaches strengthened institutional engagement and farmer access to advisory services.

In contrast, *in-situ* moisture conservation technologies recorded the lowest institutional support score (2.05), followed by soil quality and fertility management (2.21). These lower scores indicated gaps in financial incentives and access to affordable credit, despite reasonable availability of training support. Meena et al. (2020) reported that low-cost but low-visibility CSA practices often received limited institutional attention due to delayed and less tangible benefits. Kangogo et al. (2021) similarly observed that inadequate financial facilitation constrained scaling of natural resource management interventions, while Zhou et al. (2023) emphasized that weak policy prioritization reduced institutional support for such practices.

Overall, the findings suggested that although capacity-building mechanisms were relatively strong, the effectiveness of institutional support for scaling CSA interventions was constrained by limited access to affordable credit and subsidies. This underscored the need to strengthen financial and policy instruments, including improved credit facilitation and subsidy convergence, to enhance adoption across diverse agro-ecological regions. Recent assessments by Olabanji and Chitakira (2025) similarly highlighted that integrated financial and institutional support systems were critical for achieving large-scale implementation of CSA technologies.

3.6. Key Institutions to scale out climate smart agricultures

The assessment of institutional actors involved in promoting climate-smart agriculture (CSA) interventions (Figure 4) revealed varying levels of engagement, with scores ranging from 0.66 to 2.26. Custom Hiring Centres (CHCs) recorded the highest engagement score (2.26), followed by Youth Farmers' Groups (2.06) and Women Self-Help Groups (2.02). This higher engagement indicated their stronger role in facilitating access to farm machinery, labour-saving services, and collective action, which were particularly important for small and marginal farmers adopting CSA practices. Similar findings were reported by Bahinipati et al. (2024), who showed that CHCs significantly reduced capital and labour constraints associated with climate-resilient technologies. Groot et al. (2019) further demonstrated that community-based institutions enhanced local ownership and accelerated diffusion of agricultural innovations.

In contrast, Farmer-Producer Organizations (1.20) and

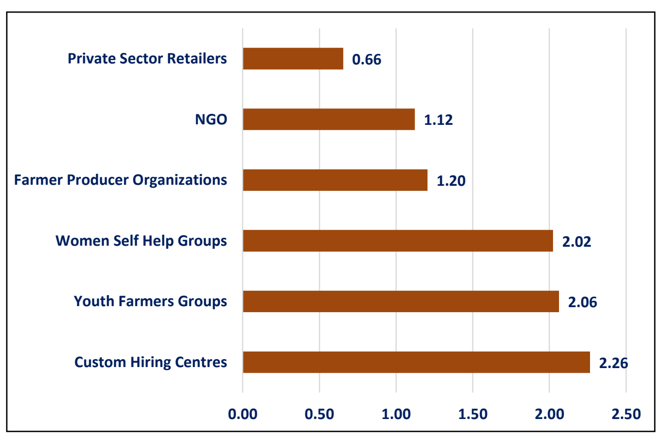

Figure 4: Average scores for key institutions of CSA interventions

non-governmental organizations (1.12) exhibited moderate levels of involvement. These lower engagement levels reflected constraints related to organisational capacity, financial sustainability, and limited CSA-specific mandates. Kangogo et al. (2021) reported that while FPOs had the potential to support CSA adoption through aggregation and market access, weak institutional capacity and limited technical focus constrained their effectiveness. Kumar et al. (2019) similarly noted that NGOs often faced funding and scale limitations that restricted their long-term engagement in technology-intensive CSA initiatives.

Private sector retailers recorded the lowest engagement score (0.66), indicating minimal participation in promoting CSA technologies. This limited involvement was attributed to weak incentive structures, market uncertainty, and poor alignment with public extension systems. Zhou et al. (2023) highlighted that inadequate policy incentives and fragmented institutional linkages discouraged private sector participation in climate adaptation programmes. Earlier assessments by the Anonymous (2019) also emphasized that risk aversion and limited profitability reduced private investment in CSA promotion, particularly in rainfed and resource-constrained regions.

Overall, the findings highlighted the need to strengthen private sector engagement and institutional partnerships, while further leveraging Custom Hiring Centres, youth groups, and women-led institutions to enhance outreach, service delivery, and scaling of CSA interventions across diverse agro-ecological regions. Recent evidence from Ma and Rahut (2024) and Olabanji and Chitakira (2025) similarly underscored that multi-actor collaboration and inclusive institutional frameworks were critical for achieving sustainable and large-scale adoption of climate-smart agriculture.

3.6.1. Interventions-wise scores for key institutions

The intervention-wise analysis of institutional actors involved in promoting climate-smart agriculture (CSA) technologies showed that Custom Hiring Centres (CHCs) played the most prominent role across all interventions, with scores ranging from 2.06 to 2.41, particularly for water-saving technologies and soil quality and fertility management. This pattern reflected the effectiveness of CHCs in improving access to farm machinery, reducing labour constraints, and facilitating the adoption of resource-efficient technologies. Meena et al. (2020) reported that CHCs significantly lowered entry barriers for smallholders by enabling shared access to costly equipment. More recently, Bahinipati et al. (2024) demonstrated that CHCs enhanced the scalability of mechanisation-based CSA interventions by reducing capital and labour bottlenecks, while Groot et al. (2019) emphasized their role in strengthening service delivery at the local level.

Youth Farmers' Groups and Women Self-Help Groups also demonstrated strong engagement across most CSA interventions, particularly in crop production, livestock and fisheries, and institutional interventions. Their involvement highlighted the importance of collective and community-based platforms in facilitating CSA adoption through peer learning, social capital formation, and collective action. Kangogo et al. (2021) found that group-based approaches improved information dissemination and risk-sharing among CSA adopters. Zhou et al. (2023) further emphasized that women- and youth-led institutions enhanced inclusivity and sustained participation in climate adaptation initiatives.

In contrast, Farmer-Producer Organizations (0.89–1.60) and non-governmental organizations (0.80–1.68) exhibited moderate levels of involvement, reflecting constraints related to organisational capacity, limited financial resources, and weak integration with CSA-specific extension and incentive frameworks. Kumar et al. (2019) reported that many FPOs lacked the technical focus and financial stability required to support CSA promotion effectively. More recently, Ma and Rahut (2024) observed that institutional fragmentation and limited convergence with public programmes reduced the effectiveness of NGOs and producer organizations in scaling CSA technologies.

Private sector retailers recorded the lowest engagement levels (0.36–1.07) across interventions, indicating limited market-led promotion of CSA technologies. This limited participation was attributed to low commercial incentives, risk perceptions, and weak public–private coordination. Zhou et al. (2023) highlighted that uncertainty in demand and policy support discouraged private sector involvement in CSA dissemination. Olabanji and Chitakira (2025) similarly noted that inadequate incentive structures constrained private investment in climate-resilient agricultural technologies.

Overall, these results indicated that CSA promotion was driven predominantly by public and community-based institutions rather than market-led mechanisms. Strengthening the role of Farmer-Producer Organizations and private sector actors, alongside further leveraging CHCs, youth groups, and women-led institutions, was identified as critical for improving service delivery, market integration, and the scaling of CSA interventions across diverse agro-ecological regions. Recent evidence from Bahinipati et al. (2024) and Ma and Rahut (2024) similarly emphasized that multi-actor collaboration and stronger institutional convergence were essential for achieving sustainable and large-scale adoption of CSA technologies (Table 3).

3.6.2. Overall score of the key institutions for climate smart agriculture interventions

The average involvement of institutional actors in

Table 3: Interventions-wise scores for key institutions

Sl. No.	CSA Interventions	Custom hiring centres	Youth farmers groups	Women self help groups	Farmer -producer organizations	NGO	Private Sector Retailers
1.1	*Ex-situ* water harvesting and efficient use	2.32	2.02	2.32	1.02	1.68	0.51
1.2	*In-situ* moisture conservation technologies	2.06	1.84	1.77	0.92	0.88	0.40
1.3	Water saving technologies	2.41	2.11	1.44	1.19	1.14	0.66
1.4	Soil quality and fertility management	2.34	2.02	2.05	0.89	0.95	0.77
2	Crop production	2.34	2.12	2.13	1.49	0.80	0.36
3	Livestock and fisheries	2.06	2.05	2.18	1.33	1.20	0.81
4	Institutional Interventions	2.32	2.28	2.29	1.60	1.21	1.07

promoting climate-smart agriculture (CSA) interventions was moderate, with scores ranging from 1.31 to 1.80 (Figure 8). Institutional interventions recorded the highest average score (1.80), followed by ex-situ water harvesting and efficient water use (1.64) and livestock and fisheries (1.60). This pattern indicated relatively stronger institutional engagement in these domains, largely through programme-based implementation and extension support. Similar trends were reported by Bahinipati et al. (2024), who observed that CSA interventions aligned with government programmes and flagship projects received greater institutional attention and operational support. Aryal et al. (2020) further demonstrated that institutional backing enhanced coordination and resource mobilisation for water- and livestock-based CSA interventions, while Meena et al. (2020) highlighted the role of public agencies in facilitating programme-driven CSA implementation.

In contrast, in-situ moisture conservation technologies registered the lowest average institutional involvement score (1.31), suggesting limited institutional presence, weaker financial incentives, and reduced field-level facilitation. Groot et al. (2019) reported that such low-visibility natural resource management practices often received less institutional priority due to delayed and less tangible benefits. More recently, Zhou et al. (2023) emphasized that insufficient policy emphasis and weak extension outreach constrained institutional engagement in promoting in-situ conservation practices.

Crop production (1.54), soil quality and fertility management (1.50), and water-saving technologies (1.49) exhibited comparable levels of institutional involvement, reflecting moderate but uneven support across interventions and regions. This variability was largely influenced by project focus, funding allocation, and extension intensity. Kangogo et al. (2021) demonstrated that uneven institutional support resulted in inconsistent adoption outcomes across CSA domains, while Ma and Rahut (2024) highlighted that extension intensity significantly shaped institutional effectiveness in promoting CSA technologies.

Overall, the findings suggested that although institutional engagement existed across CSA domains, its intensity remained insufficient to achieve large-scale and sustained impact. Strengthening institutional convergence, enhancing private sector participation, and further leveraging community-based platforms were therefore identified as essential for improving coordination, service delivery, and scaling of CSA interventions across diverse agro-ecological regions. Recent assessments by Olabanji and Chitakira (2025) and Bahinipati et al. (2024) similarly emphasized that integrated, multi-actor institutional frameworks were critical for effective and sustainable CSA implementation.

4. CONCLUSION

The study demonstrated that climate-smart agriculture (CSA) interventions under the NICRA framework exhibited moderate to high implementation feasibility across diverse agro-ecological regions of India, with crop production and soil quality and fertility management emerging as the most feasible domains. Capacity building and market linkages were identified as key incentives, while Custom Hiring Centres, youth farmer groups, and women self-help groups facilitated the scaling of CSA interventions. However, adoption was constrained by limited acceptability, low awareness, labour shortages, and weak institutional coordination, indicating the need for strengthened financial and extension support.

5. ACKNOWLEDGEMENT

This research was funded by ICAR and the project was lead by ICAR-ATARI, Hyderabad and implemented by 30 KVKs under 11 ATARIs. The contribution of 30 KVKs and 11 ATARIs is duly acknowledged by the authors.

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