PLANT SCIENCE TODAY
Vol 12(sp4): 1-9
https://doi.org/10.14719/pst.11119

eISSN 2348-1900

RESEARCH ARTICLE

Climate-smart agricultural technologies and farmers attitude in Tamil Nadu

Dhivya C[1], Murugan P P[2*], Senthilkumar M[2], Asokhan M[1], Dheebakaran Ga[3] & Gangai Selvi R[4]

[1]Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[2]Directorate of Extension Education, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[3]Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[4]Department of Physical Sciences and IT, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - ppmurugan2008@gmail.com

Received: 05 August 2025; Accepted: 02 September 2025; Available online: Version 1.0: 01 December 2025

Cite this article: Dhivya C, Murugan PP, Senthilkumar M, Asokhan M, Dheebakaran Ga, Gangai SR. Climate-smart agricultural technologies and farmers attitude in Tamil Nadu. Plant Science Today. 2025; 12(sp4): 1-9. https://doi.org/10.14719/pst.11119

Abstract

Climate Smart Agriculture (CSA) is increasingly recognized as a vital approach for enhancing the sustainability, productivity and resilience of farming systems under changing climatic conditions. CSA encompasses a wide range of climate-smart agricultural technologies such as use of precise farming tools water-saving irrigation methods, cultivation of drought-tolerant crop varieties, integrated nutrient management, conservation tillage, agroforestry practices and renewable energy-based farm operations. These technologies are specifically designed to mitigate the adverse impacts of climate change while ensuring improved resource efficiency and long-term food security. This study investigates the attitudes of farmers toward CSA technologies in Tamil Nadu, a region where agricultural livelihoods are highly vulnerable to erratic rainfall patterns, prolonged droughts and rising temperatures. The research was carried out in five purposively selected districts representing diverse agro-climatic zones and technology adoption environments. A structured attitude scale comprising 32 statements related to the perceived benefits, applicability, risks and constraints of CSA technologies was developed and validated using Edward's criteria. The final scale was administered to a sample of 300 farmers using a five-point Likert format. The results revealed that 28 % of respondents expressed a highly favourable attitude toward CSA Technologies, 57 % respondents showed a favourable attitude and 14 % showed an unfavourable attitude. The favourable responses of the majority of farmers for CSA Technologies demonstrated its role in enhancing crop productivity, improving soil health, increasing water-use efficiency, reducing input costs in the long term and minimizing vulnerability to climate-induced risks. Conversely, unfavourable attitudes were largely influenced by challenges such as high initial investment requirements, technical complexity, inadequate access to credit, limited availability of technologies and insufficient institutional support. These findings underline the critical importance of strengthening awareness programs, providing need-based farmer training, developing cost-effective CSA Technologies packages and improving extension services for effective dissemination of climate-resilient technologies. Understanding farmer's attitudes toward CSA technologies is essential for formulating targeted outreach strategies, policy interventions and capacity-building initiatives aimed at scaling up the adoption of climate-smart agricultural technologies in Tamil Nadu.

Keywords: adoption; attitude scale; CSA; Tamil Nadu; technology dissemination; vulnerability

Introduction

Agriculture is increasingly vulnerable to the adverse impacts of climate change including rising temperatures (1,2), erratic rainfall patterns (3) and extreme weather events (4–6). According to the Intergovernmental Panel on Climate Change, global temperatures have already risen by approximately 1.1 °C since pre-industrial levels, leading to climatic changes such as increased frequency of droughts, floods and heatwaves (7). In India, agriculture employs nearly 46 % of the workforce and contributes around 18 % to the national GDP, making it highly sensitive to climatic shifts (8). Climate change is projected to lower farm incomes in India by approximately 15–25 %. Rain-fed areas are expected to be the most adversely affected (9).

CSA is a holistic approach that aims to sustainably enhance agricultural productivity and incomes from farms, strengthen resilience and adaptive capacity to climate-related risks and mitigate climate change by reducing or removing greenhouse gas emissions (10–12). This type of agriculture is not a single set of practices or technologies but represents a dynamic, context-specific approach developed for local agro-ecological and socio-economic conditions (13,14). It integrates diverse strategies such as conservation agriculture, integrated pest and nutrient management, agroforestry, crop diversification, stress-tolerant seed varieties and water-saving technologies like drip and sprinkler irrigation (15–22). Through technological and policy frameworks for CSA are gaining momentum, the attitude of farmers toward these practices remains a critical determinant of their successful adoption and implementation.

CSA encourages institutional innovation through multi-stakeholder platforms, climate information services, risk insurance and inclusive policy frameworks that facilitate access to resources and knowledge (23). One of the strengths of the CSA paradigm is its flexibility it promotes context-specific solutions rather than one-size-fits-all interventions, allowing farmers to tailor practices to their unique agro-ecological, economic and cultural contexts (24,25). These technologies are also creating enabling environments that build farmers' trust, confidence and capacity to transition towards climate-resilient agriculture (26).

Despite its strong theoretical foundations and demonstrated benefits, the widespread adoption of CSA remains limited, especially among smallholder farmers in developing countries. This gap between availability and adoption is often attributed to behavioural, informational and perceptual barriers that influence farmers' decision-making processes (27). Positive attitudes rooted in perceived economic gain, risk reduction and compatibility with existing practices tend to foster greater openness to innovation and long-term behavioural change (28). Conversely, features such as complex, costly or uncertain make farmers, farmers may resist their uptake despite the potential benefits. These negative perceptions are often reinforced by lack of technical support, poor access to finance and weak extension systems (29). Adoption is further constrained by specific limiting factors such as water scarcity, land quality and temperature stress that shape farmers' responses to climate change (30).

The primary objective of this study is to measure and analyse the attitudes of farmers toward CSA practices in Tamil Nadu by employing a scientifically validated attitude scale. Based on this objective, the research hypothesizes that farmers with favourable attitudes toward CSA practices are more likely to adopt climate-smart agricultural technologies compared to those with unfavourable attitudes.

Materials and Methods

Study area

The present study was undertaken in the state of Tamil Nadu, India, focusing on districts identified as highly vulnerable to climate change impacts. Based on the classification provided by the National Innovations on Climate Resilient Agriculture (NICRA), five districts namely Perambalur, Ramanathapuram, Villupuram, Coimbatore and Dharmapuri were purposively selected for the investigation (Fig. 1). These districts represent diverse agro-climatic zones and varying levels of exposure to climate-resilient farming interventions, thus providing a broad spectrum for assessing farmers' attitudes and impact toward adoption of climate-smart agricultural technologies.

Research design

The study was based on an ex post facto research design, which is suitable for investigating existing phenomena where variables are fixed and cannot be manipulated by the researcher (31). This design was considered to be appropriate as the primary objective was to assess the attitude of farmers toward CSA technologies based on their prior exposure, experience and adoption levels. No direct control was evaluated.

Sampling method and procedure

A purposive-cum-random sampling technique was employed to select the respondents. This hybrid approach was adopted to ensure meaningful representation of both NICRA-intervened and non-NICRA districts while also allowing for the inclusion of farmers who have adopted CSA Technologies either through organized intervention or independent initiative.

Out of the 310 climate-vulnerable districts identified under the NICRA initiative, five districts namely Coimbatore, Perambalur, Dharmapuri, Ramanathapuram and Villupuram were purposively selected for this study (32). With the five selected districts, Perambalur, Ramanathapuram and Villupuram were identified as NICRA districts, wherein NICRA projects have been implemented to promote CSA. Within these districts, beneficiary farmers who had been directly exposed to CSA interventions were purposively selected. Coimbatore and Dharmapuri were categorized as non-NICRA districts, chosen to represent farmers who adopted CSA technologies independently or through other extension mechanisms. In these districts, farmers were randomly selected from villages sharing similar agro-ecological and socio-economic characteristics with the NICRA-implemented areas.

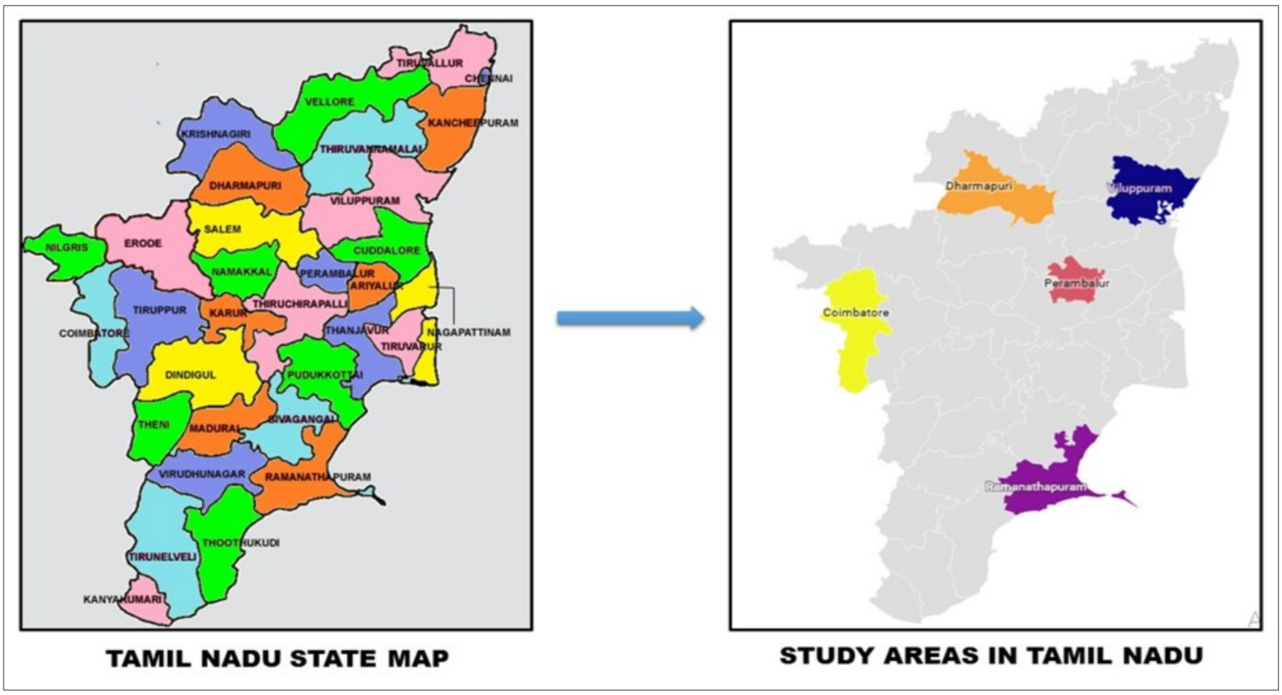

Fig. 1. Map depicting areas selected for the present study in the state of Tamil Nadu.

In total, 300 farmers were selected for the study, comprising 60 farmers from each district. This ensured balanced representation across both NICRA and non-NICRA regions, allowing for comparative analysis of attitudes toward CSA Technologies.

Data collection

Data was collected from 300 farmers across five selected districts in Tamil Nadu using a structured interview schedule. The schedule was specifically developed to assess the attitude of farmers toward CSA technologies. Responses were recorded on a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Prior to the main survey, the instrument was pre-tested in a non-sample area to ensure clarity, content validity and reliability.

Scale construction and statistical analysis

Collection of statements

A total of 72 attitude statements were initially developed to assess farmers' attitudes toward CSA interventions. These statements were framed to reflect multiple dimensions, including economic viability, environmental sustainability, social acceptance, institutional support and technological applicability. The scale comprised a balanced mix of positively and negatively worded statements to avoid response bias and to capture a comprehensive attitudinal profile.

The guidelines of Edward's criteria for scale construction were followed and each statement was critically examined for clarity, relevance and uniqueness (33). Redundant, ambiguous and overlapping items were eliminated or revised and a refined list of 55 well-structured statements were used in the main study. These 55 attitude statements were administered to a group of respondents holding degrees from diverse academic backgrounds. Respondents were asked to indicate their level of agreement on a five-point Likert scale, ranging from strongly agree to strongly disagree.

Item analysis

The finalized attitude statements were administered to a group of respondents holding academic degrees across various disciplines to ensure a well-informed evaluation. Participants were asked to indicate their level of agreement with each statement using a five-point Likert scale, ranging from 'strongly agree' to 'strongly disagree'. For positively worded statements, scores of 5, 4, 3, 2 and 1 were assigned respectively, whereas the scoring was reversed for negatively worded items to maintain consistency in the direction of attitude measurement.

Each respondent's cumulative score was derived by summing the scores across all items. The scores ranged from a minimum of 55 to a maximum of 275. Based on these total scores, respondents were ranked in descending order to identify the most and least favourable attitudes toward CSA Technologies. To assess the discriminatory power of each statement, the t-value (critical ratio) was calculated following the method proposed by Edwards (33). Two criterion groups were formed: the top 25 % of respondents with the highest total scores (high group) and the bottom 25 % with the lowest scores (low group). The t-test was then applied to determine the extent to which each statement effectively differentiated between these two groups, thereby identifying the most valid items for inclusion in the final attitude scale. The formula for t value is given below

$$t = \frac{\bar{X}_H - \bar{X}_L}{\sqrt{\frac{\sum(X_H-\bar{X}_H)^2+\sum(X_L-\bar{X}_L)^2}{n(n-1)}}} \quad \text{(Eqn. 1)}$$

Where,

$$\sum (X_H - \bar{X}_H)^2 = \sum X_H{}^2 \frac{-(\sum X_H)^2}{n} \quad \text{(Eqn. 2)}$$

$$\sum (X_L - \bar{X}_L)^2 = \sum X_L{}^2 \frac{-(\sum X_L)^2}{n} \quad \text{(Eqn. 3)}$$

$\bar{X}_H$ = represent the mean score for the high group on a specific statement

$\bar{X}_L$ = denotes the mean score for the low group on that same statement

$\overline{\sum X_H} 2$ = sum of the squared individual scores for the high group on the given statement

$\overline{\sum X_L} 2$ = sum of the squared individual scores for the low group

$\sum X_H$ = signifies the total score of the given statement for high group

$\sum X_L$ = signifies the total score of the given statement for low group

n = number of judges in both the high and low groups

t = the degree to which a specific statement differentiates between high and low groups

$\sum$ = summation

The resulting "t" value served as an index of how well each attitude statement discriminated between the high and low scoring groups. A t-value of 1.96 or greater was considered statistically significant at the 5 % level, indicating a meaningful difference in the average response between the two groups. Statements meeting or exceeding this threshold were deemed to have strong discriminatory power and were therefore retained for the final attitude scale.

Results and Discussion

Attitude scale construction

A total of 55 attitude statements related to CSA Technologies were initially developed and subsequently subjected to item analysis based on Edward's method of scale construction with the primary objective of evaluating their discriminatory power (33). This method involved dividing the respondents into two extreme groups: the upper 25 % (high scorers) and the lower 25 % (low scorers) based on their total attitude scores. For each statement, the mean score differences between these two groups were computed and t-tests were conducted to determine whether the observed differences were statistically significant.

According to Edward's criteria, a t-value greater than 1.96 is considered statistically significant at the 5 % level of significance ($p < 0.05$), indicating that the item meaningfully distinguishes between respondents with favourable and unfavourable attitudes towards CSA Technologies. The results indicated that 32 out of the 55 statements met this criterion and were therefore considered statistically valid and reliable indicators of attitude (Table 1). These items demonstrated sufficient discriminatory capacity and were consequently retained for inclusion in the final attitude scale.

The remaining 23 statements, which yielded t-values less than 1.96, were found to be statistically non-significant. These items lacked the ability to effectively differentiate between the high and low attitude groups and, as such, were excluded from the final scale. The exclusion of these items ensures that the finalized attitude scale comprises only those statements that robustly capture the variance

Table 1. Final attitude statements towards climate smart agricultural technologies

S. No.	Statements	Nature of the statement	't' value	Significance
1	Climate-smart agriculture is essential for coping with climate change	Positive	2.6207	Significant
2	Implementing CSA technologies improves agricultural productivity	Positive	2.3778	Significant
3	CSA interventions help reduce greenhouse gas emissions from farming	Positive	1.9708	Significant
4	CSA technologies are too complex for small-scale farmers to implement	Negative	3.6042	Significant
5	Long-term farm sustainability is supported by CSA interventions	Positive	2.6109	Significant
6	The benefits of CSA outweigh its implementation costs	Positive	2.2552	Significant
7	CSA enhances food security in rural communities	Positive	1.8765	Not significant
8	Diversification of farm enterprise ensures income security	Positive	2.097	Significant
9	The cost of CSA adoption is unaffordable for many small farmers	Negative	-1.213	Not significant
10	High initial investment discourages CSA adoption	Negative	1.9753	Significant
11	CSA helps lower input costs like fertilizers and pesticides	Positive	1.4576	Not significant
12	Financial returns from CSA take too long to realize	Negative	0.8853	Not significant
13	Risk of crop failure due to erratic weather is reduced through CSA	Positive	3.5101	Significant
14	Effectiveness of CSA technologies is uncertain for my farm	Negative	2.8642	Significant
15	CSA improves resilience to climate shocks such as droughts	Positive	3.1151	Significant
16	Peer pressure negatively influences decisions about CSA adoption	Negative	0.4832	Not significant
17	CSA aligns with traditional and local farming technologies	Positive	4.2180	Significant
18	Lack of community support creates a barrier to CSA adoption	Negative	2.0484	significant
19	Social acceptance encourages farmers to adopt CSA technologies	Positive	0.2150	Not significant
20	CSA technologies improve environmental and social well-being in villages	Positive	2.3218	Significant
21	Women's involvement in CSA decision-making strengthens adoption	Positive	3.5673	Significant
22	Some CSA technologies conflict with community norms	Negative	0.9871	Not significant
23	Knowledge of CSA benefits influences adoption behaviour	Positive	2.7560	Significant
24	Farmer training increases understanding of CSA technologies	Positive	1.5672	Not significant
25	Local extension agents play a key role in CSA awareness	Positive	3.6541	Significant
26	Many farmers lack adequate understanding of CSA technologies	Negative	1.9653	Significant
27	CSA enhances effective land use planning and improves pest management technologies	Positive	2.1653	Significant
28	Weather knowledge helps farmers choose suitable crops	Positive	3.1234	Significant
29	CSA helps reduce soil degradation and erosion	Positive	2.6402	Significant
30	CSA contributes to on-farm biodiversity conservation	Positive	1.1763	Not significant
31	CSA tools like drones and sensors are difficult to use regularly	Negative	2.1275	Significant
32	Technology-based CSA solutions improve decision-making	Positive	3.4218	Significant
33	Farming becomes more efficient with CSA adoption	Positive	0.7658	Not significant
34	CSA adoption requires infrastructure that is not widely available	Negative	1.3981	Not significant
35	Government policies are vital to scaling CSA technologies	Positive	1.4063	Not significant
36	Poor policy support limits CSA adoption	Negative	-1.145	Not significant
37	Trust in institutions promoting CSA supports farmer confidence	Positive	3.3432	Significant
38	CSA methods help ensure efficient and optimal irrigation levels	Positive	2.5981	Significant
39	Key CSA technologies are designed to provide solutions tailored to specific local conditions	Positive	4.8965	Significant
40	Extension services provide necessary support for CSA implementation	Positive	0.7865	Not significant
41	CSA techniques lead to higher labour expenses	Negative	1.9821	Significant
42	CSA improves yields even under adverse weather conditions	Positive	2.4706	Significant
43	Profitability increases with consistent CSA adoption	Positive	0.2441	Not significant
44	CSA recommendations often fail to reflect local needs	Negative	1.2426	Not significant
45	Farmer organizations encourage wider CSA adoption	Positive	0.6423	Not significant
46	Adoption of CSA forces drastic changes in farming routines	Negative	1.2453	Not significant
47	CSA technologies reduce dependency on chemical inputs	Positive	0.7321	Not significant
48	Crop and varietal diversification serves as an effective adaptation strategy under CSA technologies	Positive	3.6541	Significant
49	Effective communication and region-specific extension services facilitate the wider adoption of smart agricultural technologies	Positive	2.0975	Significant
50	CSA promotes environmentally sustainable agricultural technologies	Positive	1.2167	Not significant
51	Traditional farming knowledge is often ignored in CSA promotion	Negative	-0.567	Not significant
52	Labour and time demands of CSA discourage adoption	Negative	0.5631	Not significant
53	Traditional crop varieties are low-cost and readily accessible	Positive	2.7595	Significant
54	Adoption is hindered by fear of unpredictable outcomes	Negative	1.4562	Not significant
55	CSA fosters long-term ecological and economic resilience	Positive	4.3128	Significant

in farmers' perceptions and attitudes towards CSA technologies, thereby enhancing the scale's overall validity, reliability and discriminatory strength.

Statement-wise distribution of farmer's responses towards attitude on CSA technologies

The statement-wise analysis of farmer's attitude towards CSA Technologies was carried out using a five-point continuum scale comprising strongly agree, agree, undecided, disagree and strongly disagree (Table 2). This section presents the frequency and percentage distribution of responses for each of the 32 selected statements. The data provide a detailed understanding of farmer's perceptions regarding the relevance, benefits, challenges and applicability of CSA technologies. Such insights are crucial for identifying the strengths and gaps in awareness and acceptance which can guide the design of targeted extension and policy interventions to promote CSA adoption more effectively.

The distribution of responses across the 32 attitude statements indicates a positive disposition among farmers towards CSA Technologies. A significant proportion of respondents either strongly agreed or agreed with key statements affirming the relevance, effectiveness and sustainability of CSA practices (Table 2).

The findings indicate that a significant majority of farmers which account to nearly three-fifths (57.3 %) strongly agreeing and about one-third (32.3 %) agree and considered CSA as essential for coping with climate change. This reflects a broad awareness of the potential of CSA to address climate-related risks. The results are consistent with the findings of Campbell which emphasized CSA as a critical strategy for achieving agricultural sustainability under climate uncertainty (10,34). Over half (55.0 %) of the respondents strongly believed that CSA improves agricultural productivity including more than a quarter (26.3 %) who agreed. CSA interventions can enhance yield stability and farm productivity through improved resource use efficiency, climate-resilient practices and adaptive technologies (35,36).

Table 2. Statement wise distribution of farmers on attitude towards climate smart agricultural technologies

S. No.	Attitude statement	SA	A	UD	DA	SDA
1.	Climate-smart agriculture is essential for coping with climate change	172 (57.3)	97 (32.3)	21 (7.0)	8 (2.7)	2 (0.7)
2.	Implementing CSA technologies improves agricultural productivity	165 (55.0)	79 (26.3)	43 (14.3)	8 (2.7)	5 (1.7)
3.	CSA interventions help reduce greenhouse gas emissions from farming	158 (52.7)	62 (20.7)	38 (12.7)	23 (7.7)	19 (6.3)
4.	CSA technologies are too complex for small-scale farmers to implement	20 (6.7)	32 (10.7)	48 (16.0)	96 (32.0)	104 (34.7)
5.	Long-term farm sustainability is supported by CSA interventions	134 (44.7)	72 (24.0)	54 (18.0)	25 (8.3)	15 (5.0)
6.	The benefits of CSA outweigh its implementation costs	101 (33.7)	94 (31.3)	39 (13.0)	39 (13.0)	27 (9.0)
7.	Diversification of farm enterprise ensures income security	115 (38.3)	98 (32.7)	26 (8.7)	38 (12.7)	23 (7.7)
8.	High initial investment discourages CSA adoption	18 (6.0)	35 (11.7)	51 (17.0)	96 (32.0)	100 (33.3)
9.	Risk of crop failure due to erratic weather is reduced through CSA	119 (39.7)	92 (30.7)	37 (12.3)	32 (10.7)	20 (6.7)
10.	Effectiveness of CSA technologies is uncertain for my farm	24 (8.0)	37 (12.3)	44 (14.7)	98 (32.7)	97 (32.3)
11.	CSA improves resilience to climate shocks such as droughts	102 (34.0)	97 (32.3)	45 (15.0)	38 (12.7)	18 (6.0)
12..	CSA aligns with traditional and local farming technologies	186 (62.0)	37 (12.3)	32 (10.7)	28 (9.3)	17 (5.7)
13.	Lack of community support creates a barrier to CSA adoption	23 (7.7)	37 (12.3)	55 (18.3)	87 (29.0)	98 (32.7)
14.	CSA technologies improve environmental and social well-being in villages	103 (34.3)	86 (28.7)	51 (17.0)	35 (11.7)	25 (8.3)
15.	Women's involvement in CSA decision-making strengthens adoption	113 (37.7)	85 (28.3)	43 (14.3)	42 (14.0)	17 (5.7)
16.	Knowledge of CSA benefits influences adoption behaviour	115 (38.3)	76 (25.3)	43 (14.3)	39 (13.0)	27 (9.0)
17.	Many farmers lack adequate understanding of CSA technologies	28 (9.3)	51 (17.0)	59 (19.7)	89 (29.7)	73 (24.3)
18.	CSA enhances effective land use planning and improves pest management technologies	105 (35.0)	70 (23.3)	53 (17.7)	46 (15.3)	26 (8.7)
19.	Weather knowledge helps farmers choose suitable crops	111 (37.0)	99 (33.0)	39 (13.0)	28 (9.3)	23 (7.7)
20.	CSA helps reduce soil degradation and erosion	127 (42.3)	93 (31.0)	43 (14.3)	22 (7.3)	15 (5.0)
21.	CSA tools like drones and sensors are difficult to use regularly	34 (11.3)	38 (12.7)	35 (11.7)	91 (30.3)	102 (34.0)
22.	Technology-based CSA solutions improve decision-making	117 (39.0)	89 (29.7)	43 (14.3)	31 (10.3)	20 (6.7)
23.	CSA improves yields even under adverse weather conditions	94 (31.3)	102 (34.0)	50 (16.7)	35 (11.7)	19 (6.3)
24.	Crop and varietal diversification serve as an effective adaptation strategy under CSA technologies	121 (40.3)	67 (22.3)	54 (18.0)	43 (14.3)	15 (5.0)
25.	Effective communication and region-specific extension services facilitate the wider adoption of smart agricultural technologies	107 (35.7)	81 (27.0)	55 (18.3)	24 (8.0)	33 (11.0)
26.	Traditional crop varieties are low-cost and readily accessible	116 (38.7)	77 (25.7)	43 (14.3)	32 (10.7)	32 (10.7)
27.	CSA fosters long-term ecological and economic resilience	32 (10.7)	41 (13.7)	54 (18.0)	81 (27.0)	92 (30.7)
28.	Financial returns from CSA take too long to realize	108 (36.0)	90 (30.0)	56 (18.7)	25 (8.3)	21 (7.0)
29.	Local extension agents play a key role in CSA awareness	122 (40.7)	78 (26.0)	50 (16.7)	32 (10.7)	18 (6.0)
30.	CSA enhances food security in rural communities	110 (36.7)	85 (28.3)	46 (15.3)	38 (12.7)	21 (7.0)
31.	CSA helps lower input costs like fertilizers and pesticides	124 (41.3)	89 (29.7)	34 (11.3)	37 (12.3)	16 (5.3)
32.	Farmer training increases understanding of CSA technologies	158 (52.7)	67 (22.3)	32 (10.7)	24 (8.0)	19 (6.3)

Perceived complexity does not appear to be a major barrier to the adoption of CSA technologies among the respondents (37). In this study, perceived complexity refers to the extent to which farmers view CSA technologies as difficult to understand, implement or integrate into their existing farming systems. Only a small proportion, 6.7 %, strongly agreed that CSA Technologies are too complex for small-scale farmers. In contrast, approximately two-thirds accounting for 66.7 % either disagreed or strongly disagreed with this statement. This suggests that most farmers did not find CSA practices difficult to understand or implement, indicating a positive perception toward their usability and accessibility. These findings challenge commonly held assumptions in earlier studies which highlighted technological complexity as a deterrent to adoption in resource-limited settings (38,39). In terms of sustainability, approximately three-fourths of farmers either strongly agreed (44.7 %) or agreed (24.0 %) that CSA supports long-term farm sustainability (40). Perceptions on economic feasibility varied. Around one-third (33.7 %) strongly agreed and about 31.3 % agreed that the benefits of CSA outweigh its costs while approximately one-fifth showed disagreement.

The role of diversification in income security was positively perceived by nearly two-thirds of respondents, with 38.3 % strongly agreeing and 32.7 % agreeing (41). A significant proportion of farmers (65.3 %) did not support the idea that high initial investments encourage the adoption of CSA Technologies, indicating persistent financial apprehensions (42). CSA's role in mitigating weather-related crop failure was affirmed by 39.7 % of the respondents who strongly agreed and 30.7 % who agreed, indicating that a large majority recognized its risk-reducing potential. This shows that farmers are aware of CSA's capacity to buffer against erratic climatic events and safeguard crop yields (43). On the other hand, uncertainty about CSA effectiveness was rejected by a majority (65.0 %) disagreed or strongly disagreed.

A notable three-fifths (62.0 %) of the farmers strongly agreed that CSA aligns with traditional and local farming practices, suggesting a strong cultural compatibility. This alignment is crucial, as farmers are more likely to adopt innovations that resonate with their indigenous knowledge and established practices (44). The perception that CSA does not conflict with, but rather complements, traditional methods may reduce resistance to change and foster smoother integration of new technologies. Its role in improving environmental and social well-being was also positively viewed, with 34.3 % strongly agreeing and 28.7 % agreeing to highlight a growing awareness among farmers about the broader community-level benefits of CSA. This reflects the perception that CSA practices not only support individual farm outcomes but also contribute to sustainable rural development and ecological balance (45). Additionally, women's involvement in CSA decision-making was acknowledged as beneficial by two-thirds of respondents showing a positive response with 37.7 % strongly agreeing and 28.3 % agreeing. This underscores the importance of inclusive decision-making processes and suggests that empowering women in agricultural innovations can enhance the effectiveness and reach of CSA interventions at the household and community levels (46). Similarly, 38.3 % strongly agreed and 25.3 % agreed that awareness of CSA benefits directly influences adoption behaviour.

A relatively small segment of the respondents (9.3 % strongly agreed and 17.0 % agreed) believed that there is a widespread lack of understanding about CSA among farmers. In contrast, over half (54.0 %) disagreed or strongly disagreed with this perception, indicating that the majority felt reasonably informed about CSA Technologies. Over two-thirds (70.0 %) of the respondents acknowledged that weather-related knowledge plays a critical role in guiding appropriate crop selection decisions. Similarly, the potential of CSA to mitigate soil degradation and erosion was strongly endorsed by the farming community, with nearly three-fourths expressing agreement with 42.3 % strongly agreeing and 31.0 % agreeing. These findings highlight the perceived ecological advantages of CSA in enhancing climate resilience and sustainable land use practices among rural farmers.

Regarding technology adoption, more than three-fifths (64.3 %) of respondents disagreed or strongly disagreed that CSA tools like drones and sensors are difficult to use regularly (47). In contrast, decision-making benefits from technology-based CSA solutions were acknowledged by over two-thirds (68.7 %). Furthermore, two-thirds of the farmers agreed that CSA ensures better yields even during adverse weather conditions. CSA's emphasis on crop and varietal diversification as a key adaptation strategy was positively received by more than three-fifths (62.6 %) of the farmers, with 40.3 % strongly agreeing and 22.3 % agreeing with the statement (48). This indicates a growing awareness among farmers about the benefits of diversification in enhancing resilience against climate-induced risks, such as droughts, pests and erratic rainfall. Traditional crop varieties were considered affordable and accessible by another two-thirds of farmers. However, long-term resilience under CSA was less favourably viewed, with a combined 57.7 % of farmers expressing disagreement.

Perceptions about delayed returns from CSA were also evident, as more than two-thirds (66.0 %) agreed or strongly agreed that financial gains are not immediate. The importance of local extension agents in promoting CSA was recognized by over two-thirds (66.7 %) of the respondents, indicating their significant influence in awareness creation and technology dissemination (49). Similarly, 65.0 % of farmers acknowledged CSA's role in enhancing food security, underscoring its contribution to stable and sustainable food systems in rural communities. Furthermore, about three-fourths (75.0 %) of the respondents agreed that farmer training plays a crucial role in improving understanding of CSA Technologies, thereby facilitating their effective adoption and implementation at the grassroots level.

Overall distribution of farmers based on their attitude toward CSA technologies

To gain a broader understanding of farmer's attitude levels, respondents were categorized into three groups as highly favourable, favourable and unfavourable based on their total attitude scores. The values were expressed as mean ± standard deviation.

A notable number about 28.0 % of farmers exhibited a highly favourable attitude toward CSA technologies (Fig. 2, Table 3). About one-fourth of the sample demonstrated strong agreement with the benefits, adaptability and long-term value of CSA interventions. Their positive perceptions were especially reflected in statements such as "CSA fosters long-term ecological and economic resilience" and "CSA improves yields even under adverse weather conditions," which aligns with findings of Adimassu and Noriega who emphasize the adaptive potential and sustainability of CSA practices in the face of climate change (38,48).

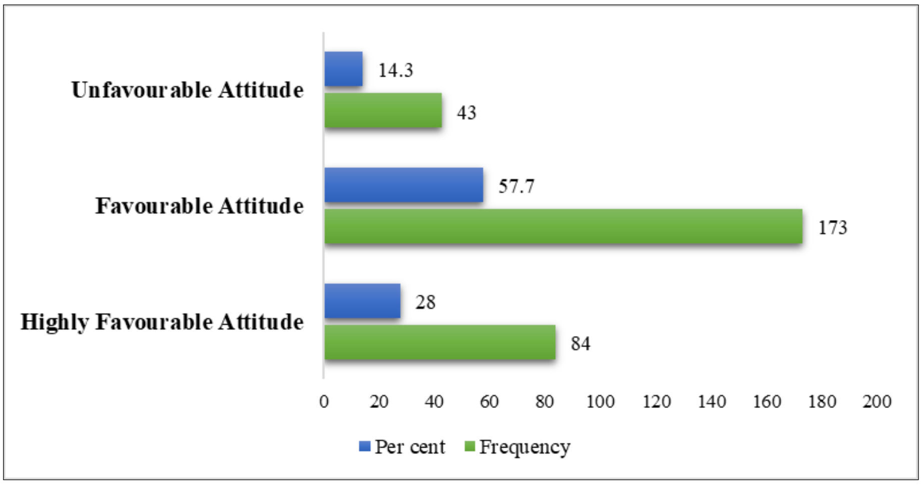

Fig. 2. Overall attitude of farmers on climate smart agricultural technologies.

Table 3. Overall attitude of farmers towards climate smart agricultural technologies

S. No	Attitude category	No. of farmers	Percentage (%)
1.	Highly favourable attitude	84	28.00
2.	Favourable attitude	173	57.70
3.	Unfavourable attitude	43	14.30
	Total	**300**	**100.00**

A majority of farmers (57.7 %) which constitutes approximately two-fifths of the respondents were categorized as showing favourable attitude. Their responses indicated appreciation for the role of CSA in improving farm productivity, reducing climate-related risks and aligning with traditional practices. Statements such as "CSA helps reduce soil degradation and erosion" and "Technology-based CSA solutions improve decision-making" received broad support from farmers. This supports earlier studies which highlighted that farmers are more likely to adopt CSA when the technologies are perceived as practical, locally adaptable and beneficial in both economic and environmental terms (24,50). In contrast, 14.3 % of respondents showed an unfavourable attitude toward CSA, expressing concerns over statements like "CSA is too complex for small-scale farmers" and "High initial investment discourages adoption." These views likely reflect worries about cost, complexity and inadequate support. Similar barriers were reported in earlier studies that highlighted risk perceptions and institutional shortcomings as key constraints to CSA adoption (29,42). Studies from other regions also reflect similar patterns in farmer's responses to CSA technologies. The research in Northern Nigeria revealed that farmers recognized the benefits of CSA for improving yields and combating climate-related challenges yet concerns about cost and institutional support limited adoption. In Kenya, smallholder farmers expressed favourable attitudes toward CSA practices such as agroforestry and water conservation, particularly when they were promoted through participatory extension and community-based initiatives. Within India, studies in Madhya Pradesh and Maharashtra reported that while farmers acknowledged CSA's role in improving soil fertility and reducing climate risk, adoption was constrained by limited awareness, inadequate credit facilities and lack of technical support. Similarly, research in Andhra Pradesh indicated that peer learning and institutional support strongly influenced positive attitudes toward CSA practices such as system of rice intensification and crop diversification.

The findings show that farmers in Tamil Nadu generally hold positive attitudes toward CSA technologies, with nearly 86 % of respondents expressing favourable or highly favourable views. This reflects strong recognition of CSA's role in coping with climate risks, improving productivity and ensuring sustainability. Similar results were reported by earlier studies (10,34–36), which emphasized the contribution of CSA to yield stability, soil health and resource efficiency.

Despite these positive perceptions, a minority (14.3 %) expressed unfavorable attitudes, mainly due to concerns over high investment costs, delayed returns and perceived risks. Such challenges are consistent with earlier reports (29,42) highlighting financial and institutional barriers as significant constraints to CSA adoption.

The low proportion of farmers perceiving CSA as complex suggests that usability is less of a barrier than previously assumed, contrasting with studies that emphasized technological complexity (38,39). Instead, cost-related concerns and delayed economic returns appear to be stronger deterrents. This underlines the importance of providing financial support mechanisms, affordable technology packages and timely institutional support to encourage adoption.

Positive responses toward the cultural compatibility of CSA and women's involvement highlight social strengths for scaling up adoption. Farmers are more inclined to adopt practices that align with traditional systems and empower household decision-making as also supported by prior research (44,46). Similarly, the strong recognition of CSA's role in soil conservation, risk mitigation and food security (40,43,49) points to its potential as both an ecological and economic adaptation strategy.

Overall, the results underscore the need for targeted extension efforts, participatory training programs and awareness campaigns to address cost-related apprehensions and strengthen institutional support. By leveraging farmer's generally favourable orientation while addressing barriers for the minority with unfavorable views CSA adoption in Tamil Nadu can be effectively accelerated.

Conclusion

The study assessed farmer's attitudes toward CSA technologies in five districts of Tamil Nadu using a statistically validated scale. Findings revealed that majority of farmers held favourable to highly favourable attitudes, recognizing CSA's role in enhancing productivity, sustainability and resilience to climate change. A smaller group expressed reservations, mainly due to cost and institutional barriers. The results highlight that positive farmer perceptions are pivotal for CSA diffusion and strengthening attitudinal support through awareness, training and enabling policies will be essential for wider adoption.

Acknowledgements

The authors would like to express their deepest gratitude to the Department of Agricultural Extension and Rural Sociology for their invaluable guidance and support throughout this study. Special thanks are extended to the Chairman and advisory members for their valuable feedback and constructive suggestions on the manuscript. The authors also extend their sincere thanks to the Directorate of Extension Education for the institutional support that significantly contributed to the successful completion of this research.

Authors' contributions

DC conceptualized the study, analyzed the data and prepared the original manuscript. MPP provided overall research supervision, contributed to the formulation of the research concept and approved the final version of the manuscript. SM supported the development of ideas and reviewed the manuscript. AM and DG contributed to summarizing the content and revising the manuscript. GSR provided support with statistical analysis and helped in summarizing key findings. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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