



Modeling of Farmers' Preferences towards Climate-Smart Agriculture Using Conjoint Analysis

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HIGHLIGHTS

- Farmers preferred CSA practices with high adaptation potential.
- Adoption of expert-recommended CSA practices remains low.
- The conjoint model showed high reliability with Pearson's R and Tau of 0.934 and 0.856, respectively.

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ABSTRACT

Climate change poses a significant threat to agricultural productivity, particularly for smallholder farmers in India. The study utilized a mixed-method approach, which involved 150 farmers and expert consultations from Punjab and Uttar Pradesh states related to the domain in the year 2024-25. Farmers' preferences were studied using CSA attributes: productivity, adaptation, and mitigation, deploying the conjoint analysis. It was found that the farmers are continuously affected by the dynamic weather conditions, causing irregular rainfall to impact crop health and eventually crop yield. Although awareness related to CSA was present but its adoption was very low due to the absence of infrastructure and technology. A gap was found between the recommendation of the experts related to integrated and efficient nutrient management and the farmers' adoption level. As a result of the conjoint analysis, it was found that the adaptation attribute was highly favoured by the farmers, followed by the other two, i.e., mitigation and productivity. The reliability of the model was supported by Pearson's R (0.934) and Kendall's tau (0.856), which revealed a strong connection between the prediction and the actual preferences.

INTRODUCTION

Indian agriculture contributes significantly to rural households. The sector still faces continuous challenges due to unpredictability in the climatic occurrences (Raghuvashi & Ansari, 2020). Unpredictable weather dynamics have threatened the stability in the income of millions of farmers (Shanabhoga et al., 2023; Meena et al., 2023). These continuously growing vulnerabilities highlight

the immediate need for the adoption of more resilient and sustainable farming methodologies (Rampa et al., 2020; Ashoka et al., 2022). Climate-Smart Agriculture (CSA) has emerged as an efficient answer focused on reshaping and redirecting agricultural growth in the context of the current challenges brought by climate change (Ravindera & Singh, 2019; Mosso et al., 2022; Shitu & Nain, 2024). CSA can fulfill several major objectives, such as boosting agricultural productivity, improving adaptive resilience (Sodhi et

al., 2023), and decreasing greenhouse gas emissions (Das & Paul, 2021). It holds practices like crop diversification, agroforestry, conservation agriculture, efficient irrigation, and the utilization of enhanced seed varieties, which are the prominent ones (Bhatnagar et al., 2024). Despite its enhancing global significance and favourable policies in India, the understanding and adoption of CSA practices at the root level remain inconsistent and poor (Djufry et al., 2022). It is sought that there is a significant gap between the recommendations of experts and the practices adopted by farmers (Ndue & Pal, 2022). Although the agricultural bodies defend for technologically sound and environmentally sustainable walkovers (Sharma et al., 2021), farmers confront financial, infrastructural, and informational hurdles that retard their ability to incorporate innovations (Mo et al., 2023). Similarly, it is very important to understand farmers' thoughts, patterns of preferences, and awareness of CSA to design acceptable and feasible interventions for them (Mahto et al., 2021).

This document puts a thrust towards the existing gap by exploring the level of preferences and awareness among the farmers concerning different CSA practices in the selected Indian states, viz., Punjab and Uttar Pradesh. These areas were chosen to illustrate a range of CSA practice levels and awareness, from those with advanced adoption to those that are less informed. Simultaneously, this study collects deep insights from expert faculty and researchers from prominent agricultural universities selected from the two states, Punjab and Uttar Pradesh, to establish a framework for scientific recommendations.

Conjoint analysis as a statistical tool is utilized to quantitatively evaluate farmers' preferences for specific selected CSA properties: productivity, adaptability, and mitigation impacts (Andati et al., 2023). This proposition facilitates the calculation of part-worth utilities and relative importance scores, providing deep insights into what farmers keep into priority when selecting among various CSA alternatives (Malarkodi et al., 2023). By orienting these empirical insights perceived from the farmer respondents along with the expert's advice, the present study seeks to guide towards policy development and extension initiatives that could encourage the widespread adoption of climate-resilient agricultural methodologies in Indian agriculture (Sarker et al., 2025). The results are directly coinciding with the significance towards India's obligations under Sustainable Development Goals (SDGs) 2 and 13, which concentrate on Zero Hunger and Climate Action, respectively (Vatsa et al., 2023).

METHODOLOGY

This research was conducted in three selected districts within the states of Punjab and Uttar Pradesh (U.P.), India. The three selected districts were Kapurthala in Punjab (under the jurisdiction of PAU), Sant Kabir Nagar in Uttar Pradesh (under ANDUA&T), and Kanpur in Uttar Pradesh (under CSAUA&T). The districts were purposefully chosen based on their differing levels of Climate-Smart Agriculture (CSA) adoption. Kapurthala, Kanpur, and Sant Kabir Nagar, all three districts, were identified as being advanced, moderate, and relatively low in awareness and adopting CSA practices, respectively, illustrating a gamut from least to significant practice levels. The layout enabled a comparative study of CSA

awareness and preference inclination across various agro-climatic and institutional borders. The chosen agricultural experts were identified and selected on the basis of their professional experience in climate-resilient agriculture, active participation in CSA extension and research initiatives. Total 15 experts were consulted, five from each university, to get professional insights on important CSA attributes and their relevance in farmer's decision processes. A population sample of 150 farmers was selected for study, with 50 respondents from each selected district using Slovin formula (Asenahabi & Ikoha, 2023). The selection criteria were such that they must be actively involved in farming for a minimum time period of five years, have experienced climate-related happening at least in the past five years, and must be intended to take part in a structured interview. A well-structured questionnaire was developed to collect information on awareness of CSA practices, adoption level, and preferences related to CSA attributes. The preference evaluation employed a conjoint analysis statistical tool, pointing up three primary CSA attributes; Productivity, Adaptation, and Mitigation in three scales i.e., Low, Medium, and High. An orthogonal exhibition was used to develop CSA practice profiles, which were then ranked by the selected respondents. The experts were contacted additionally using a Delphi-approach to validate and allocate weights to the CSA attributes. Data collection with the respondents involved direct interviews and online consultations (calls, emails, and structured Google forms) with experts. The data collection process was performed within six months, from July to June in 2024-25. The data was analysed using descriptive statistics to assess awareness variables. Conjoint analysis was engaged for the estimation of part-worth utility magnitudes and relative relevance scores. The model validation used Pearson's correlation coefficient and Kendall's Tau towards observed and predicted preferences. Additionally, a comparative examination was done between expert preferences and farmer practices to highlight the adoption gaps.

RESULTS

Effects of dynamic climatic conditions on agriculture

The farmers surveyed across the three selected districts, Kapurthala of Punjab and U.P., reported a wide range of challenges imputable to unpredictable dynamic climatic conditions. As shown in Table 1, the most common effect was an increase in pest infestation and disease incidence, cited by 93 per cent of farmers. This is particularly significant, as it not only reduce yields but also

Table 1. Impact of fluctuating and unpredictable climate on Farming Methods

Effects of dynamic climatic conditions	Observations Recorded (%)
Yield decline	89
Erratic Rainfall/ Droughts	90
Temperatures rise	88
Growing Diseases & Pests	93
Post-harvest losses	68
Boosted Input costs	64
Impact on Livestock's	61

increases the dependency on chemical approaches, hence raising input costs and affecting sustainability of the environment. Similarly, 90 per cent of respondents reported irregular rainfall and droughts, which is prevalent in Sant Kabir Nagar and parts of Kanpur, is particularly vulnerable. Respondents in these areas revealed their inability to forecast the sowing and harvesting periods, leading to mismatches in crop cycles. This has also contributed to 89 per cent of the yield decline, a statistic that match with national-level data linking reduced productivity to unexpected off time rainfall, extreme weather conditions, and delayed monsoons. Further another significant concern was raised by 88 per cent of respondents, was the rise in temperature. This has a direct impact on both physiology of the crop and health of the livestock. Shortened crop growth, and reduced grain fillings, especially in cereals like wheat and paddy, was reported due to increased temperature. Additionally, to these primary impacts, 68 per cent of farmers reported post-harvest losses, highlighting that a lack of storage facilities and infrastructural bottlenecks hiked the climatic effects. In the same pathway, 64 per cent of respondents faced increasing costs of inputs, which could be linked to the demanding need for fertilizers, irrigation, and pesticides to overcome climatic stress. Notably, the impact on livestock, including reduced milk yield, stress of heat, and fodder unavailability, especially in dry periods, was reported by about 61 per cent of farmers. There was a significant impact of climate change, requiring immediate steps for adaptation strategies and interventions related to infrastructure for the sustainability of agricultural livelihoods.

Awareness and adoption of CSA practices

Table 2 shows the levels of awareness and adoption of 18 CSA practices selected and identified among the surveyed farmers. The data shows a lacunae which is found significant between awareness and actual implementation, identifying the difference between behavioural adoption and propagation of knowledge. The most widely known CSA practice is CIS, which was found with awareness of 85 per cent and adoption of 60 per cent. This high level of apprehension can be attributed to large-scale government defends and increasing farmer exposure to climatic risks. However, concerns by respondents about transparency lacunae, delays in processing, and lesser compensation amounts, which insignificantly explains the 25 per cent decline between awareness and adoption. Governance of Soil Health is another practice with a relatively high adoption rate of 80 per cent awareness, 55 per cent of adoption, due to ongoing initiatives like the scheme of Soil Health Card and targeted awareness acts by KVKs and other organisations. Similarly, Crop Diversification holds a 75 per cent of awareness and 60 per cent of adoption, particularly in Kapurthala, where water-intensive crops are being substituted by lesser water-consuming crops. In contrary the awareness and adoption levels in Use of Solar Energy showed 25 per cent, 10 per cent, Agroforestry of 30 per cent and 10 per cent, and Protected Cultivation of 35 per cent and 12 per cent have significantly low levels of both awareness and acquisition. These practices, although having the potential for boosting resilience, suffer from poor outreach, limited demonstrations, and greater primary investment costs. The Digital and ICT-based tools, which have unlimited ability for real-time agro-advisory, show 50

Table 2. Farmers response frequencies towards CSA Awareness and Adopted Practices

CSA Practice	Awareness (%)	Practices (%)
Crop Diversification	75	60
Drought-Resistant and Climate-Resilient Varieties	60	35
Conservation Agriculture	40	20
Agroforestry	30	10
Organized and effective irrigation systems	65	30
Rainwater Harvesting	50	25
IFS	55	30
IPDM	45	20
Enhanced Animal Husbandry Practices	60	40
SHM	80	55
Agro-Advisories Based on Weather	70	40
No Tillage or Reduced Tillage	30	15
Utilization of Solar Power in Agriculture	25	10
Cultivation Under Protection	35	12
Infrastructure That Withstands Climate Challenges	40	20
CIS	85	60
Digital and ICT-Driven Instruments	50	25
Community-Driven Resource Management	30	15

(IFS = Integrated Farming System, IPDM = Integrated Pest & Disease Management, SHM = Soil Health Management, CIS = Crop Insurance Scheme)

per cent awareness but only 25 per cent adoption, showing a digital divide exaggerated by low accessibility to smartphones, poor network connectivity, and lack of training.

Surprisingly, Weather-Based Agro-advisories have a relatively good awareness level of 70 per cent but only 40 per cent of the adoption, as many farmers still depend on traditional knowledge or informal networks for weather knowledge.

The results show that awareness does not guarantee the adoption, and targeted interventions are required to alter knowledge into action. Factors such as access to resources, extension services, economic feasibility, and ascertain reliability play a significant role in moulding the behaviour of the farmer.

Expert preferences vs. farmer adoption of CSA practices

A significant component of the study included capturing the preferences of agricultural experts from the organisations viz., PAU, ANDUA&T, and CSAUA&T and comparing them with adoption behaviour of the farmer. Table 3 illustrates this comparison and highlights some critical lacunae that must be considered. Experts gave priority preference to efficient irrigation systems up to 95 per cent, drought-resilient varieties up to 90 per cent, soil health management up to 95 per cent, and integrated farming systems up to 90 per cent. These practices are considered complete resolutions that denotes both sustainability and productivity under climatic stress. Although, the level of adoption among farmers for the practices mentioned above is much lower i.e., between 30 per cent and 60 per cent. For instance, while experts strongly advocate for efficient methods of irrigation, only 30 percent of farmers revealed that they used systems such as sprinkler and drip irrigation. Factors which were identified for it included, high initial costs, lack of

Table 3. CSA Practices recommendations and their adoption by the farmers

CSA Practice	Expert Preference (%)	Farmer Adoption (%)
Structured Efficient Irrigation Systems	95	30
Drought-Resistant & Climate-Resilient Varieties	90	35
SHM	95	55
IFS	90	30
CIS	90	60
Agroforestry	70	10
Digital & ICT-Based Tools	85	25
Protected Cultivation	80	12

technical knowledge, and inadequate subsidy programs. In the same way, although 70 per cent of experts favour Agroforestry, only 10 per cent of farmers have adopted this practice. Despite its long-term advantages, like carbon sequestration and diversification of income, it faces challenges due to the lack of short-term incentives and tangled land tenure systems. ICT and Digital Tools were support by 85 per cent of experts, yet only 25 per cent of farmers reported employing them. This difference can be linked to issues with digital infrastructure, digital literacy levels, and a lack of trust in technological advices. This adversity highlights a mismatch between expert recommendations and the ground realities. Bridging these lacunae necessitates participatory methods that indulge farmers in both planning and technological choices, along with efforts to build their capacity and improved accessibility.

Utility estimates and model fitness

To measure farmer's preferences quantitatively for CSA characteristics, a conjoint analysis was utilised. The results, shown in Table 4, detailed the utility scores and relative importance for three primary CSA attributes: Adaptation, Productivity, and Mitigation, each at Low, Medium, and High levels.

Utility magnitudes

The highest positive utility score was recorded for High Adaptation which was found 1.030, followed by High Productivity of 0.360 and Medium Mitigation of 0.490 units. These preferences shows that farmers are more bended towards CSA practices that strengthen their resilience against variability in climate rather than those that prioritize only yield or environmental perks. Antagonistically, Low Adaptation of -0.620 and Low Mitigation of -0.520 units received the lowest utility scores, reflecting the farmer's strong disinclination to practices that lack climate risk protection.

Relative weights

Adaptation was observed as the most significant attribute, holding a relative importance of 49.76 per cent, which was followed by Mitigation at 33.39 per cent and Productivity at 16.84 per cent. This shows a clear view for prioritization of climate-resilient approaches towards production enhancement. Respondents preferences for adaptation align directly with their actual challenges,

like unpredictable rainfall and hiked pest pressure. Resolution strategies that can mitigate these risks are viewed as more precious than those that merely boost output.

Credibility of the model

The validation of the conjoint model revealed the fitness of the model through Pearson's R value of 0.934, Kendall's Tau of 0.856, and a p-value of less than 0.01. The results indicate that the model exhibits a high level of internal consistency and predictive validity, suggesting that respondents' stated preferences closely reflect their actual decision-making behavior. Overall, the conjoint analysis provides a rigorous, quantitative framework for understanding how farmer respondents perceive different features of CSA practices, providing actionable insights for policymakers and extension personnel.

Table 4. Utility Coefficients Estimated Using Part-Worth Model and the fitness of the model

Attribute	Attribute Level	Utility Estimate	Std. Error	Relative Importance (%)
Productivity	Low	-0.285	0.395	16.842
	Medium	-0.075	0.395	
	High	0.360	0.395	
Adaptation	Low	-0.620	0.395	49.764
	Medium	0.410	0.395	
	High	1.030	0.395	
Mitigation	Low	-0.520	0.395	33.394
	Medium	0.490	0.395	
	High	0.030	0.395	
(Constant)		4.620	0.290	
Model estimation		Value (r or τ)	p-Value	-
Pearson's R		0.934	0.000**	
Kendall's tau (τ)		0.856	0.000**	

(**significant at 1 per cent level)

DISCUSSION

The results highlight insights into the awareness, preferences, and adoption of CSA practices of farmers in selected districts. The data reveal that the effects of climate change are widely seen across all districts, demonstrating an increased prevalence of pests and diseases, irregular rainfall, and decreasing crop yields. These show that small farmers are particularly vulnerable to climatic variability due to their limited capacity for adaptation. Despite a significant level of awareness about the CSA practices, a significant gap persists between the knowledge and implementation. Farmers revealed high awareness of exercises such as soil health management, crop insurance, and crop diversification. However, adoption was found moderate or low, particularly for technical or capital-intensive exercises such as protected cultivation, agroforestry, or solar energy use. This proposes that while awareness campaigns and extension services have created information flow, economic, institutional, and infrastructural problems continue to hinder the adoption.

The contrast between expert preference and farmer adoption is particularly noticeable. Experts from leading agricultural

universities unanimously emphasized practices such as integrated farming systems, efficient structured irrigation systems, and drought-resilient crop varieties as important for shaping resilience. However, these attempts are either partially adopted or significantly underutilized at the root level. This shows a mismatch between scientific recommendations and ground, possibly due to differences in technical understanding, risk perception, and access to assets among producers. Further, the conjoint analysis deepens this understanding by measuring the relative importance of CSA attributes. Respondents showed the strongest preference for attributes connected to adaptation, suggesting an immediate concern with surviving the impacts of climate rather than long-term mitigation or even productivity perks. This is reflected in the highest utility score for high adaptation and the negative utility associated with low adaptation. Mitigation and productivity features followed in significance, proposing that farmers prioritize resilience over environmental goals or yield perks, especially in erratic climatic conditions. The high reliability of the conjoint model with Pearson's R of 0.934, Kendall's Tau with a 0.856 value, and p-value of less than 0.01 adds statistical robustness to these results. It confirms that the preferences stated by farmers are linked with predicted choices, which makes the results valuable for policy design. Additionally, the findings highlight the need for a multi-pronged approach to gauge CSA adoption. Beyond awareness developments, there is an immediate requirement for financial perks, grass-root level training, infrastructure support, and participatory extension structures to amplify CSA knowledge into sustained practice. Filling the lacunae between expert opinions and farmer ascendancies will be important for amplifying the adoption of climate-resilient technologies in India's diverse farming landscapes.

CONCLUSION

Information perceived from this study reveals that awareness of CSA practices is increasing among farmers, but root level implementation is still low, particularly for technically complex or require significant resources. The findings from conjoint analysis reveal that farmers place a higher magnitude on CSA features that grow their ability to adapt to climate fluctuations rather than those that aid productivity or mitigation efforts. This show there is immediate need to protect their livelihoods from unpredictable rainfall, temperature hikes, and pest occurrences. A significant disparity is found between the CSA methods recommended by experts and those that farmers are found with. Experts advocate for integrated and resource-efficient approaches, such as enhanced livestock management, efficient irrigation systems, whereas farmers frequently encounter barriers to adopting these practices due to costs, insufficient institutional support, or limited knowledge. Filling this void is crucial for effective adaptation and resilience at the community level.

DECLARATIONS

Ethics approval and informed consent: Informed consent was sought from the respondents during the course of the research.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare that during the preparation of this work, thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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