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Evaluating the impact of awareness and adoption of soil health cards on sustainable farming practices in Punjab and Haryana: A quantitative study

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ABSTRACT

This study aims to explore how farmers in Punjab and Haryana perceive the soil health card (SHC) programs and their role in promoting sustainable agriculture practices. It examines the effectiveness of SHCs in providing farmers with critical information on soil nutrition status, which helps improve soil quality and reduce environmental pollution. A standardized questionnaire using Likert scale statements was developed to assess the farmer's perception of the SHC program. Data were collected from farmers across Punjab and Haryana, and the collected data was analysed using Smart PLS software. The analysis identified a significant positive correlation between the use of SHCs and adopting eco-friendly farming practices. Farmers who utilize SHCs were found to improve their long-term productivity, lower input costs, and reduce environmental pollution. However, the study is limited to the farmers in Punjab and Haryana, and the findings may not be fully generalizable to other regions with different farming practices or levels of SHC program awareness. The findings suggest that for SHCs to reach their full potential, they need continuous education and support for farmers. Policymakers and agricultural extension services need to ensure that farmers are aware of SHCs and provided with the necessary resources and training to implement the recommended practices effectively. This study contributes to the growing body of literature on sustainable agriculture by providing insights into farmers' perceptions and adoption behaviour regarding the SHCs program.

1 | INTRODUCTION

In recent years, soil degradation caused by the overuse of chemical fertilizers has become a critical concern, particularly in regions that heavily rely on traditional farming practices. To address these challenges, a SHC program was introduced, offering farmers a detailed analysis of their soil nutrition content. SHC service is vital for promoting more efficient and sustainable use of fertilizers, reducing reliance on chemical inputs and fastening better soil management practices. It contributes to environmental sustainability by encouraging practices that lower the risk of soil erosion, nutrition depletion and water contamination (Niranjan *et al.,* 2018; Reddy, 2019). The SHC initiative aims to promote more balanced and environmentally friendly farming practices by encouraging the efficient use of inputs and reducing dependence on chemical fertilizer, which maintains long-term soil productivity (Islam *et al.,* 2017; Patel *et al.,* 2017; Sonune *et al.,* 2021). Previous researchers have highlighted the benefits and challenges of SHC programs in various agriculture settings. Studies have shown that SHCs improve soil management practices and increase crop yield. Gupta *et al.* (2019) found out that SHC led to 10 to 15% improvement in crop productivity when farmers follow the fertilizers recommendations provided. Further, the reduced use of chemical inputs, as guided by SHCs, helps lower production costs and minimise the environmental impact on farming, mainly by reducing soil degradation and water pollution (Purakayastha *et al.,* 2019; Paul *et al.,* 2019; Singh *et al.,* 2023).

However, some researchers have also revealed some shortcomings in the implementation of SHC. One significant challenge is the low rate of adoption and comprehension of SHC among farmers, particularly those with limited education or technical knowledge (Rani *et al.,* 2022; Reddy, 2019). A significant percentage of farmers from Punjab and Haryana, according to Reshmi (2019), had a positive perception of SHCs and accepted that this could increase the output of Agriculture. However, the survey highlighted problems such as the inability of small and marginal farmers to understand and grasp the concept behind the SHC. Another study that Chowdary and Theodore (2016) conducted in Andra Pradesh also found that although most farmers were familiar with the SHC system, there was a big gap in the actual use of the cards. Similarly, in a study by Bordoloi and Das (2017), it was shown that while farmers from Assam believed in the benefits they expected to derive from using SHCs, a lack of adequate training and extension support made it challenging for them to implement recommendations. A detailed study by Chouhan *et al.* (2017) found that the indiscriminate use of chemical fertilizers dropped drastically in Madhya Pradesh due to the use of SHCs. Rani *et al.* (2022) assessed yet another study on the benefits of SHCs to the environment in Rangareddy district. The results showed that SHCs allowed for optimal fertilization, improving the soil's health and reducing the potential for contaminating and degrading the soil. This trend could be similar to what Kaur *et al.* (2020) observed; it was noted that resource-friendly operation practices resulted from the adoption of SHC principles, such as optimal resource use, and underpin sustainable agricultural practices.

Despite this growing corpus of research on the impact of the SHC programme and farmer perceptions, there are still quite substantive gaps in the literature. There is very limited research into the long-term effects of SHC recommendations and their regional integration; most studies now only cover short-term benefits such as increased crop yields and reduced fertilizer consumption. Socio-economic factors such as education level, resource availability, and services for agricultural extension are commonly neglected influences on SHC adoption. Therefore, this study tests the farmers' awareness and willingness to adopt SHCs and the effects associated with SHC adoption on agricultural productivity. The study aimed to review theories relating to the effects of SHC use on farmers' knowledge, condition of the soil, savings on expenses, agricultural pollution reduction, and long-term crop yield gains. The study examines the following five hypotheses on SHCs adoption and associated perceived benefits.

Hypothesis 1: Farmers who are aware of SHCs demonstrate a higher adoption and understanding of soil health concepts than farmers who have not received SHCs. Farmers accustomed to using SHCs are more likely to hold a positive view towards soil health and believe in their ability to engage in soil management practices. Soil health indicators such as nutrient balance, organic matter content, and soil structure, when maintained diligently, can be observed to derive benefits as long as prescribed procedures are adhered to and soil conditions kept under regular monitoring (Ajzen, 1991).

HIGHLIGHTS

- Awareness is pivotal in driving the adoption of SHCs.
- Farmers perceive the benefits of SHC as reducing agricultural pollution, fostering cost savings and long-term productivity, and improving soil health.
- The adoption of SHC can potentially promote sustainable farming practices in Punjab and Haryana.

Hypothesis 2: Farmers who consistently use SHCs report a greater perceived improvement in soil health indicators over time than farmers who do not use SHCs. Using SHCs, farmers can apply fertilizers, ideally depending on the chemical need of the soil, and as such avoid over application of fertilizers that end up being wasted. This application minimizes the cost of the inputs and, at the same time, makes the soil healthier.

Hypothesis 3: Farmers who effectively utilize SHCs to optimize fertilizer application experience cost savings compared to farmers who do not use SHCs. In conventional farming systems, the misuse of fertilizer has often led to nutrient runoff in the freshwater systems, causing eutrophication. SHC-guided methods promote balanced fertilizer application on need and hence reduce excess nitrogen runoff and all its associated environmental damage (Srivastav *et al.,* 2024).

Hypothesis 4: Widespread adoption of SHC-guided practices contributes to decreased agricultural pollution from excess nutrients compared to conventional practices. The practice of SHCs consistently will keep soil conditions optimal and thus ensure the provision of crop nutrients for healthy growth. Unlike the traditional methods, this sustainable technique resists diminishing yields (Meena *et al.,* 2024). According to Agricultural Intensification, raising the yield of a crop without increasing the area of cultivation could be achieved if efficiency in the use of inputs could be increased.

Hypothesis 5: Farms that consistently utilize SHCs and implement recommended soil health practices experience higher average crop yields in the long term than farms that do not use SHCs.

Fig.1 represents the hypothesized model illustrating the proposed relationships and variables examined in this study.

2 | MATERIALS AND METHODS

2.1 | Research Design

The study adopted a quantitative descriptive research design to assess how farmers perceive and use the SHC program for sustainable farming practices. A descriptive design was appropriate for this study as it provided a comprehensive overview of the current state of the SHC programs and their impact on farmers' knowledge and agricultural practices in Punjab and Haryana.

2.2 | Data Collection

Data was collected using a structured questionnaire distributed to farmers in the Haryana and Punjab states. The questionnaire included statements measured on a 7-point Likert scale, with 1 indicating "strong disagreement" and 7 indicating "strong agreement". The Likert scale was selected to capture farmers' perceptions of the SHC program and its impact on their farming practices. It enabled the assessment of both positive and negative attitudes of farmers towards SHC as well as the degree of influence their perceptions had on sustainable farming techniques.

2.3 | Sampling Techniques

This study used a purposive sampling technique, targeting farmers from Punjab and Haryana who were actively engaged in agriculture practices and familiar with SHC programs. A structured design using Likert scale statements was developed to capture the farmer's perception of the SHC program and its impact on sustainable farming practices. The questionnaire was administered using a scheduled method, where farmers were assisted in completing the survey. This method ensured that respondents fully understood the questions, especially those with limited literacy skills, thereby enhancing the reliability of responses. This technique was crucial in obtaining detailed insights directly from the farmers in a face-to-face setting, which allowed for better clarity and accurate data collection.

A total of 210 responses were collected through this process. After a thorough data screening, 37 responses were excluded due to incomplete or inconsistent data, ensuring that only high-quality, reliable responses were used in the analysis. Consequently, 173 responses were retained for the final analysis, providing a robust sample size for examining the relationship between SHC awareness and adopting sustainable agriculture practices. The exclusion of incomplete responses maintained the integrity and reliability of the findings, minimising the risk of bias from missing or inaccurate information (Basir *et al.,* 2024).

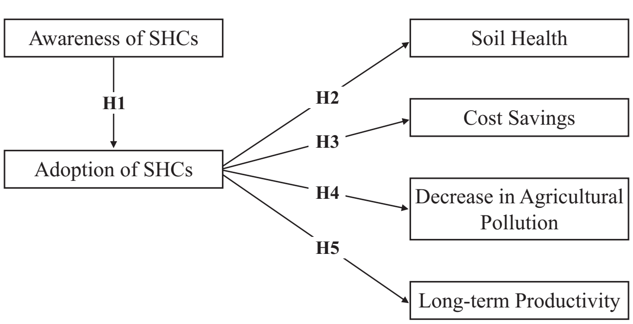

FIGURE 1 Proposed model

2.4 | Tool Used

The collected data were analysed using smart PLS software, chosen for its capability to handle complex models and provide accurate results. This software is particularly useful for structural equation modelling (SEM), allowing the assessment of both direct and indirect relationships between variables, which is essential for understanding the farmer's perception and impact of SHC on sustainable farming practices. The reliability of the questionnaire was checked using Cronbach's alpha with an acceptable threshold indicating internal consistency among the items. Factor analysis was conducted to ensure the validity of the constructs used in the study, followed by path analysis to examine the relationship between the key constructs, such as the perception of SHCs and their influence on sustainable farming, and the significance of this relationship.

3 | RESULTS AND DISCUSSION

3.1 | Demographic Profile

Findings, as shown in Table 1, indicate that 30% (52) were aged 35-44, 25% (43) were aged 45-54, and 20% (35) were aged 25-34. The main group consisted of males (75%) (130 respondents), whereas females constituted 25% (43). 30% (52) had an education level of primary and secondary, while 20% (35) had no formal education. Farm sizes were medium 40% (69), large-scale 26% (45), and semi-medium 22% (38). In terms of experience, 35% (61) and 30% (52) had 10-20 and over 20 yrs, respectively. Half the respondents (50%, 87) earned less than 10,00,000 every year. Access to the markets was largely local, 60% (104), while 30% (52) accessed regional markets, and only 10% (17) tapped the international markets.

The demographic characteristics of the farmers play a crucial role in their comprehension and utilisation of SHCs. For instance, the relatively older age group (35 to 54 yrs) that dominates the sample may have varying levels of adaptability to new agriculture technology like SHCs, potentially influencing the acceptance and use. The education level, with 30% having primary or secondary education and 20% lacking formal education, is particularly relevant as lower education could hinder farmers' ability to understand and apply the technical information provided by SHCs. Furthermore, the predominance of medium and large-scale farmers (66%) and those with significant pharming experience (65% having over 10 years) suggest that these respondents are more familiar with soil management practices, which could enhance their readiness to adopt SHCs for improving productivity. Additionally, income levels and market access can influence the extent to which

TABLE 1 Demographic profile

Category		Number	Frequency (%)
Age	Under 25	17	10%
	25-34	35	20%
	35-44	52	30%
	45-54	43	25%
	55 and above	26	15%
Gender	Male	130	75%
	Female	43	25%
Education level	No formal education	35	20%
	Primary education	52	30%
	Secondary education	52	30%
	Higher education	26	15%
	Vocational training in agriculture	9	5%
Farm size	Marginal farmers	9	5%
	Small farmers	12	7%
	Semi-medium farmers	38	22%
	Medium farmers	69	40%
	Large-scale	45	26%
Years of experience	Less than 5 yrs	17	10%
	5-10 yrs	43	25%
	10-20 yrs	61	35%
	More than 20 yrs	52	30%
Annual income	Less than 10,00,000	87	50%
	10,00,000 - 20,00,000	52	30%
	20,00,000 - 30,00,000	26	15%
	More than 30,00,000	9	5%
Access to market	Local markets	104	60%
	Regional markets	52	30%
	International markets	17	10%

Source: Author's calculation

farmers are willing and able to invest in sustainable practices, further affecting the usage of SHCs.

3.2 | Measurement Model

Factor loadings indicate the extent to which each item becomes a measure for each associated concept of the construct, demonstrating the relationship of observable variables to underlying latent structures. In simpler terms, they show how strongly each questionnaire item reflects the concept it's intended to measure. In this study (Table 2), factor loading ranges from between 0.636 and 0.919 across the constructs. Hair *et al.* (2012) suggest that the factor loading of 0.70 is ideal for confirming well-defined concepts. However, in exploratory research, loadings above 0.60 are acceptable. In this case, most of the items are over the minimum acceptable criterion of 0.60 in the study, which indicates that the observed variables are contributing to the evaluation of the associated constructs and match well with them.

Reliability measurements assess how consistently the items in a construct measure the same concept. In this study, the reliability of constructs was evaluated using cronbach's alpha, composite reliability (rho_a) and composite reliability (rho_c). Cronbach's alpha values range from 0.611 to 0.906, with 0.70 considered an acceptable threshold for internal consistency. Although the adoption construct has a slightly lower cronbach's alpha of 0.611, the values between 0.60 and 0.70 can be considered acceptable for exploratory research (Wong, 2013).

The rho_c values provide a more refined measure of internal consistency than cronbach's alpha by accounting for the variability in factor loadings of individual items. Composite reliability values in this study range from 0.792 to 0.934, which are above the threshold of 0.70, hereby confirming that the constructs show strong internal consistency (Hair *et al.,* 2012).

The average variance extracted (AVE) shows how much of the variance in observed variables is captured by the construct versus how much is due to the measurement error. A higher AVE indicates that the construct explains a greater proportion of the variance in its indicators. AVE value greater than 0.5 0 is considered acceptable as it suggests the constructs explain at least half of the variance in the items (Fornell and Larcker, 1981). In this study all constructs have AVE value exceeding the threshold of 5.0 further supporting their validity (Table 2).

Discriminant validity ensures that each construct is distinct from others and captures phenomena that are not being measured by any other constructs. Fornell and Larcker (1981) propose that discriminant validity is achieved when the square root of AVE for each construct is larger than its correlation with other constructs. In this study, the diagonal numbers in the correlation matrix (Table 3) range from 0.732 to 0.883, confirming discriminant validity. The highest correlation, 0.808 (between adoption and soil health), remains below the threshold limit of 0.85, confirming sufficient distinction between the constructs (Hair *et al.,* 2012).

The correlation matrix presented in Table 3 shows the relationship between the six constructs - adoption (ADP), agricultural pollution (AP), awareness (AWR), cost savings (CS), long-term productivity (LTP), and soil health (SH). This correlation ranges from 0.124 to 0.808, with the highest being adoption and soil health (0.808) and the lowest being cost savings and soil health (0.124).

The results of this measurement model demonstrate strong reliability and validity. Factor loading, internal consistency and AVE all meet or exceed the recommended threshold. Additionally, discriminant validity is confirmed, ensuring that the constructs are distinct and suitable for further analysis in the study.

3.3 | Structural Model

The path analysis results confirmed all the assumptions, illustrating a strong relationship among the constructs. The path coefficient between awareness and adoption of SHCs

TABLE 2 Factor loadings and reliability of constructs

Construct		Factor loadings*	Cronbach's alpha**	Composite reliability (rho_a)***	Composite reliability (rho_c)****	Average variance extracted (AVE)****
Adoption	ADP1	0.636	0.611	0.637	0.792	0.561
	ADP2	0.810				
	ADP3	0.789				
Agricultural pollution	AP1	0.919	0.906	0.916	0.934	0.781
	AP2	0.893				
	AP3	0.860				
	AP4	0.861				
Awareness	AWR1	0.750	0.714	0.719	0.822	0.536
	AWR2	0.718				
	AWR3	0.755				
	AWR4	0.705				
Cost savings	CS1	0.907	0.885	0.923	0.920	0.742
	CS2	0.894				
	CS3	0.892				
	CS4	0.740				
Long term productivity	LTP1	0.698	0.762	0.764	0.849	0.585
	LTP2	0.821				
	LTP3	0.747				
	LTP4	0.789				
Soil health	SH1	0.757	0.719	0.751	0.840	0.637
	SH2	0.775				
	SH3	0.858				

**Measure the strength of the relationship between an indicator and its construct; **Represents the internal consistency or reliability of the construct; ***Indicates the internal consistency of the construct; ****A similar measure to rho_a is used to assess the internal consistency of the construct; *****Reflects the proportion of variance captured by the construct from its indicators.*

Source: Author's calculation

TABLE 3 Discriminant validity using Fornell-Larcker criterion*

	ADP	AP	AWR	CS	LTP	SH
ADP	0.749					
AP	0.807	0.883				
AWR	0.583	0.495	0.732			
CS	0.238	0.143	0.217	0.861		
LTP	0.723	0.604	0.510	0.159	0.765	
SH	0.808	0.618	0.488	0.124	0.637	0.798

**Ensures that constructs in a model are distinct and measure different concepts.*

Source: Author's calculation

TABLE 4 Hypothesis testing

	Path coefficients	T-value	P-value	Hypothesis supported
H1: AWR - > ADP	0.583	6.734	0.000	Yes
H2: ADP - > AP	0.807	18.495	0.000	Yes
H3: ADP - > CS	0.238	3.042	0.002	Yes
H4: ADP - > LTP	0.723	11.463	0.000	Yes
H5: ADP - > SH	0.808	19.790	0.000	Yes

Source: Author's calculation

was 0.583, with a t-value of 6.734 and a p-value of 0.000, indicating a statistically significant and strong relationship (Table 4). This suggests that greater awareness about SHC significantly boosts their adoption among farmers.

The structural model results indicate significant relationships between the constructs in the study, with all hypotheses being supported. Awareness (AWR) has a strong positive impact on adoption (ADP) (H1: $\beta = 0.583$, T = 6.734, $p < 0.001$), supporting H1 and confirming that awareness plays a crucial role in driving the adoption of SHCs. Adoption (ADP) significantly influences agricultural pollution (AP) (H2: $\beta = 0.807$, T = 18.495, $p < 0.001$), validating H2 and highlighting that adoption contributes to reducing agricultural pollution. Additionally, adoption (ADP) positively affects cost savings (CS) (H3: $\beta = 0.238$, T = 3.042, p = 0.002), supporting H3 and demonstrating that adoption can lead to cost efficiencies. Adoption (ADP) also has a substantial impact on long-term productivity (LTP) (H4: $\beta = 0.723$, T = 11.463, $p<0.001$), confirming H4 and showcasing its role in enhancing agricultural productivity over time. Finally, ADP exhibits the strongest effect on SH (H5: $\beta = 0.808$, T = 19.790, $p < 0.001$), supporting H5 and emphasizing its critical role in improving soil health. These findings collectively reinforce the importance of awareness and adoption in promoting sustainable farming practices in Punjab and Haryana.

However, while the adoption of SHC is statistically significant, potential barriers such as literacy level and access to SHC resources could influence this relationship. Farmers with lower literacy may struggle to understand SHC data and recommendations, limiting the effectiveness of awareness campaigns. Moreover, accessibility to SHC-related services (soil testing labs, training programs) is often uneven, particularly in rural areas, which may hinder broader adoption despite awareness.

The relationship between adoption and cost savings was also found to be positive, with a path coefficient of 0.2 38. Although the coefficient is moderate, it still suggests that the adoption of the SHC assumption can contribute to cost savings over time, as farmers can adjust their use of fertilizers according to SHC recommendations. However, cost savings might be influenced by factors such as initial investment in SHC-related technology and access to government subsidies. Path coefficient between 0.20 to 0.30 represents small to moderate effect sizes, and therefore, while adoption does have a significant impact on cost savings, it is not the sole determining factor. The broader economic factors and accessibility of SHC resources may also come into play (Cohen, 1988) .

Furthermore, as illustrated in Table 4, adoption was found to predict three key constructs: AP, LTP and SH. with path coefficients of 0.807, 0.723, and 0.808, respectively. These relationships with t-values ranging from 3.042 to 19.790 are both significant and strong. This indicates that SHC adoption plays an important role in reducing AP, increasing LTP and improving overall SH. Fig. 2 represents the structural model designed using Smart PLS, illustrating the relationships between the key constructs in our study.

The findings of this study confirm a strong relationship between the variables and validate all the hypotheses. There is a statistically significant correlation between awareness (AWR) and adoption (ADP), emphasizing the crucial role of knowledge in encouraging the adoption of innovative farming techniques such as SHCs. While the study found a moderate effect of adoption on cost savings (CS), this is in alliance with the findings of Meena *et al.* (2024) who reported that using innovative techniques like SHCs can lead to small-scale cost savings. This suggests that while SHC adoption does result in some cost reduction, the overall impact may depend on factors such as the extent of SHC utilisation and external support mechanisms like subsidies and government incentives.

Moreover, ADP strongly predicts LTP, SH and AP. This demonstrates the central role of adoption in driving improvements in soil health and productivity and reducing environmental harm. The significant relationships between adoption and these outcomes confirm the mediating role of adoption.

Despite these positive findings, it is important to consider the potential barriers that may hinder the widespread adoption of SHCs. The current study primarily focused on the benefits of SHC adoptions but did not

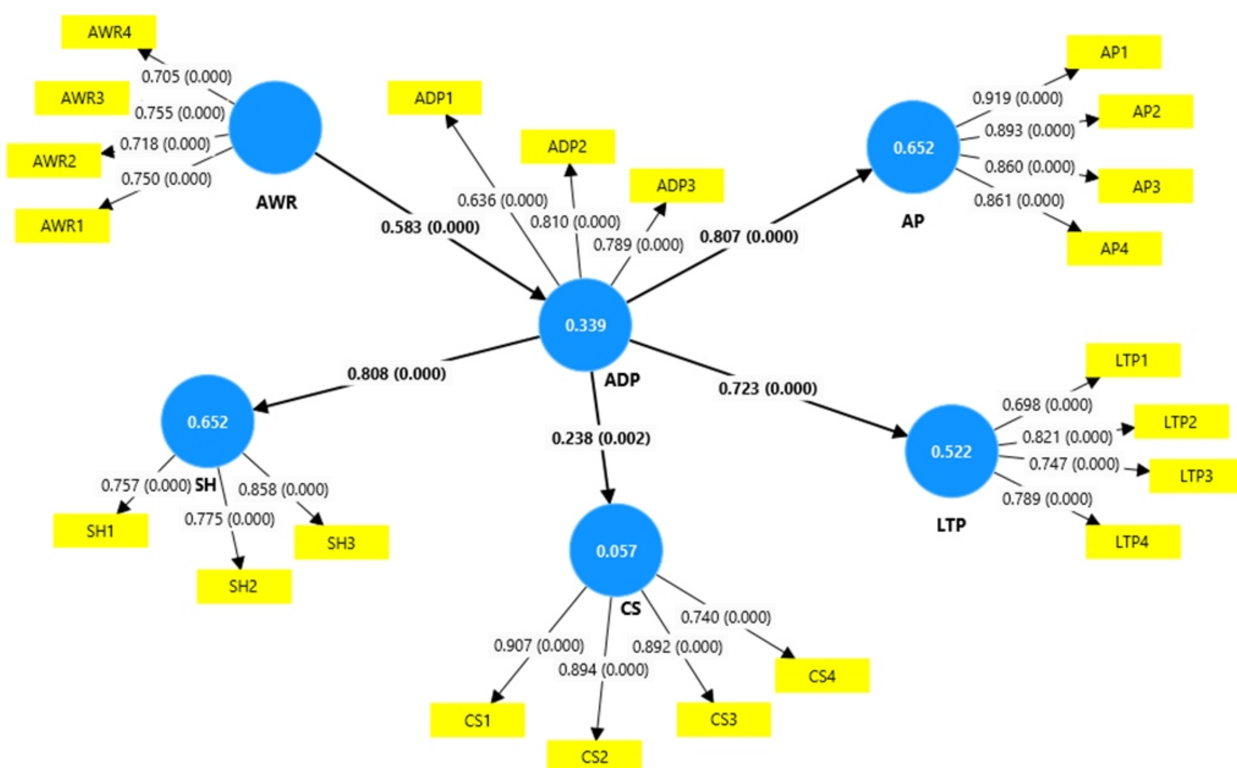

FIGURE 2 Structural research model

extensively discuss obstacles such as farmer literacy levels and budgetary constraints, which could influence these relationships.

Singh *et al.* (2023) highlighted that limited comprehension of SHC recommendations and inadequate financial resources are critical challenges that can hinder adoption. To address this gap, future research should explore the social-economic factors that affect adoption, such as access to training programs, government assistance and the role of an external support system. Studies like those by Patel *et al.* (2017) and Kaur *et al.* (2020) have already integrated the importance of such support mechanisms, offering a broader framework for understanding soil health adoption.

Additionally, the results of the study are consistent with other research on SHCs. Purakayastha *et al.,* 2019) found that SHC significantly increases the farmer's knowledge of soil characteristics and nutrition management, which in turn leads to improved soil health and crop yield. Similarly, Shah (2022) demonstrated that SHCs help farmers implement more precise and sustainable soil management techniques, leading to reduced input costs and enhanced soil fertility.

4 | CONCLUSIONS

The health of the environment is closely linked to soil fertility, which is essential for sustainable agriculture. SHC programs provide farmers with crucial information about soil nutrition, enabling them to make more informed decisions. This study emphasizes the importance of awareness and the adoption of practices that improve soil health, thereby boosting long-term productivity, achieving financial savings, and reducing agricultural pollution. However, knowledge alone is not sufficient; farmers need education on how to interpret and apply the recommendations from SHCs. Future research should explore the correlations identified in this study in different contexts and with larger sample sizes to validate and broaden these findings. Additionally, it would be valuable to investigate the long-term effects of adopting SHCs on economic, social, and environmental sustainability, as well as to assess the barriers that hinder adoption in various settings, such as farmer literacy, resource availability, and access to technology.

This study highlights key implications for policymakers and agricultural practitioners. It emphasizes the need for targeted interventions to promote SHCs through subsidies, especially in areas with significant soil degradation, while addressing barriers like farmer literacy. Additionally, it emphasizes the importance of educational programs to raise awareness about SHCs. Providing training and extension services will help farmers understand and utilize SHC recommendations, ultimately improving soil health, enhancing productivity, and achieving cost savings.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request. However, due to privacy and ethical concerns, some data may not be publicly available.

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.

AUTHOR'S CONTRIBUTION

AM was responsible for designing the study, drafting the protocol, conducting the statistical analysis, and writing the initial version of the manuscript. SA guided the writing (review and editing) and the final revision of the study.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used ChatGPT, a language model developed by OpenAI, to assist with drafting and refining the manuscript on the topic of SHC. The tool was utilized to enhance the content's clarity, coherence, and structure. After using this tool, the author(s) thoroughly reviewed and edited the content as needed and take(s) full responsibility for the accuracy and integrity of the published article.

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