











ARTICLE

The Impact of Government Subsidies on the Adoption of Sustainable Farming Practices and Their Long-Term Effects on Rural-Agricultural Economic Development Practices

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ABSTRACT

The study proves the importance of smart farming (SF) practices in addressing environmental changes (EC) and helping sustainable agriculture (SA). It investigates the effects of government subsidies (GS), farmer awareness (FA), and market access (MA) on SF adoption in Bihar, India, utilizing data from 582 farmers in five distinct regions. The research employs structural equation modeling (SEM) to analyze relationships among GS factors like farm size (FS), water resource management (WRM), soil quality (SQ), SF adoption, and the impact of FA and MA on financial outcomes. Results highlight that GS provides direct and indirect benefits for SF practices, particularly when FA is increased. GS impacts SF through an indirect pathway (GS → FA → SF) and proves a direct effect on SF adoption, with MA acting as a mediator. The findings indicate that SF adoption critically supports rural GDP growth and emphasize the importance of research and development for economic advantages. Also, SQ and WRM are very important to the adoption method. Farmers who practice SA are predicted to make more cash flow by having better market access, which is good for the sustainable environment. The model's validity is validated by fit measures, indicating robust results.

Keywords: Smart Farming; Organic Farming; Structural Equation Modelling; Machine Learning; Environmental Factors; Farmer Awareness

1. Introduction

A significant revolutionary tool in the conflict against environmental changes (EC), food insecurity is a problem, and smart farming (SF) is now coming into focus^[1]. Because traditional farming methods increased the demand on renewable resources and caused sustainability issues, an increasing number of farmers migrated to SF methods such as organic farming (OF), water resource management (WRM), crop diversification (CD), and sustainable supply chains (SSC)^[2]. Future generations of farmers may benefit from higher crop yields (CY), and agricultural regions may experience superior stability if these methods are profitable for boosting SF^[3, 4].

With over 50% of the population dependent on agricultural products, the industry is a key driver of rural GDP growth in India. Challenges such as declining SQ and WRM, and reliance on chemical resources, affect the natural environment and SF's income. Unsustainable agricultural practices harm the natural environment and the incomes of SF^[5], so an evolution towards SF that integrates yield with environmental protection is required to address these problems.

Due to its adaptability to ecological conditions, the eastern Indian state of Bihar serves as a model for pro-

moting the adoption of SF methods. To support farmers in their evolution to SF, the state has initiated several government training programs, including PKVY and the National Mission on Sustainable Agriculture (NMSA), with an emphasis on efficient resource use, OF, and sustainable quality (SQ). GS and technical assistance for SF deployment are the stated objectives of these policies^[6, 7].

Several factors contribute to SF adoption, particularly funding, farmer awareness (FA), farm size (FS), SQ, WRM, and market access (MA). An FA's expertise in the positive impacts of SF is an essential factor in applying SF. Environmental factors that can help SF implementation include SQ and WRM. The regulatory effect of MA is that farmers with higher MA are more likely to receive the money value of SF, particularly through higher-value sales of organic crops^[8].

Many factors influence SF adoption in Bihar, including government subsidy (GS), but the indirect pathways through FA and knowledge dissemination, which are equally important, have received less attention. Furthermore, there has been little investigation into how MA moderates the impact of SF practices on economic results^[9]. With a focus on the mediating function of FA and the moderating function of MA, this study seeks to fill these gaps by investigating the effect of GS on the adop-

tion of SF in Bihar^[10]. This study intends to measure the direct and indirect effects of GS on the environment and individual farms, using a mix of survey data and structural equation modelling (SEM). The study sheds light on the reasons behind farmers' SF adoption in Bihar and proposes policy-relevant recommendations for expanding SF across rural India by dissecting these connections^[11].

To identify direct, indirect, and moderated correlations and account for sampling error, the methodology uses a covariance-based SEM, with confirmatory factor analysis (CFA) as the statistical model. Because it finds hidden features and provides global-fit indices, such as the comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA), which provide empirical support^[12], SEM has been selected over regression-based mediation and PLS-SEM methods.

In the case of factor analysis, the Kaiser-Meyer-Olkin (KMO) test can be used to verify that the sample sizes are accurate, but it is not always evidence of symmetry or "proper sampling" in the broader context of statistical techniques for selecting samples. Univariate distributional hypotheses have been verified with skewness and kurtosis diagnostics. All statistical analyses were conducted in the statistical software SPSS AMOS v.26, with confidence intervals for all predicted methods generated via bootstrapping with 5000 samples^[13].

The reservoir of Lake Eğirdir is a significant groundwater source for the Lakes Region of the Turkish Republic, primarily the Isparta province. It is the second-largest lake in Turkey by area and the fourth-largest storage lake in the nation. Fruit plantations that use lake water for groundwater recharge have placed themselves and the close ecosystem at risk of pollution from chemicals and unsustainable SA practices. Using a Likert-scale survey with responses to 29 hypotheses and factor regression, one study examined the opinions and actions of 135 farmers in the region regarding the use and restoration of Lake Eğirdir. With a Cronbach's alpha of 0.749, the data were considered reliable, and factor analysis demonstrated that the 9 hypotheses predicted 69.6% of the heterogeneity^[14, 15].

Among those factors were the following topics: the

impact of chemical use in farming, the historical and financial significance of Lake Eğirdir, the causes of agricultural water pollution, and potential methods to prevent agricultural pollution. Guidelines that should help in securing the lake's natural environment are in support of SF. Today, SF affects vital resources—including the environment—in various ways, underscoring the need to address it^[16]. Severe water scarcity, driven by human-driven EC and population development, has significantly impacted agricultural output in Kenya^[17].

These variable agro-environmental problems affect all regions of the globe, including West Africa, where farming accounts for over 40% of land and water use^[18]. To overcome these drawbacks, knowledge is recommended to implement new policies, modernise technology, and remodel traditional organisations. Turkey demonstrated that SF solutions provide both environmental and economic benefits by reducing pesticide use and enhancing WRM through redesigned SF practices. To reduce the risk of negative results, FA measures should be implemented to support ecological pest control and crop cycles.

In a similar quantitative method, this complex SEM incorporates financial, environmentally friendly, and cognitive factors that impact SF. An SA's financial return can be improved with the support of GS, a policy-oriented financial administrator; FA, a cognitive intermediary between GS access and adaptive use; and MA, an administrative moderator. The model is firmly high and dry in terms of agroecological validity, as evidenced by the implementation of SQ, FS, and WRM metrics. Explicitly defined hidden ideas and test validation enhance the theoretical accuracy, validity, and accessibility of analytical results for evaluation^[19, 20].

Major problems at the boundaries of sustainability, rural GDP growth, and agricultural demand further research. In addition to improper SF methods, the efficient use of renewable resources in agriculture-dependent regions like Turkey's Lake Eğirdir can also generate pollution. Causes of the problem and their impact on the SF and OF contexts include ecological controls, such as the use of fertilisers with high chemical levels, as well as awareness and improper policy interventions^[21]. This is clear on a global scale; for instance, the WRM in Kenya

and the severe impact on West African agriculture show that training, technology, and government policies must be in total balance. But researchers currently have no idea how GS and other targeted interventions affect SF adoption, or how SF contributes to its financial benefits.

The level of FA and the actual human capacity to attain MA serve as regulatory factors that must be addressed in this research to measure these links accurately. The research endeavour will apply modern statistical methods, such as SEM, to provide an exhaustive survey of the first- and second-order adverse impacts of GS on the renewable resources and on GDP growth in rural regions^[22]. To advance SF and food security in the Third World and to fill current knowledge gaps on how to increase agricultural results while accounting for sustainability tests and financial risks, this research is essential.

Achieving SA and climate adaptation^[23] mainly depends on SF practices like crop diversification, conservation agriculture, WRM, and OF. When considering factors like OF, pH, and nutrient availability, the authors employ the acronym SQ in the current paper. When addressing the Pradhan Kisan Vikas Yojana (PKVY) or the National Mission for Sustainable Agriculture (NMSA), use the full titles at first, then abbreviate them. Differential adoption persists under GS schemes aimed at reducing the financial challenges faced by small farmers, highlighting the importance of these schemes for assessing both financial and non-financial factors.

The current research specifically addresses the following three gaps:

1. Quantification of direct versus knowledge-mediated effects of GS on SF adoption;
2. The moderating role of MA in converting adoption into economic results.
3. The disaggregation of environmental SQ, WRM, and FS effects within a unified SEM.

This study aims to predict direct and indirect GS effects, test FA as a mediator, and evaluate MA as a moderator of SF → rural GDP growth. The novelty of the research effort, in contrast with earlier motivational analyses, is rendered evident by this method.

The three core research questions of this study—(1) the direct effect of government subsidy (GS) on adoption

of smart-farming (SF) practices, (2) the mediating role of farmer awareness (FA) in the GS→SF pathway, and (3) the moderating influence of market access (MA) on the translation of SF adoption into rural economic outcomes—map directly onto the tripartite dimensions of sustainable development. Operationalized here as environmental integrity (soil quality, WRM), economic viability (rural GDP, crop yields), and institutional capacity (FA, MA), these constructs allow the empirical model to quantify how a policy instrument (GS) affects both resource-conserving practices (OF, WRM, crop diversification) and their downstream economic returns. Framing the hypotheses in these sustainability terms makes the normative stakes explicit: GS is not only a short-term income transfer but a mechanism that can alter the joint distribution of environmental and economic indicators; the SEM estimates (GS→SF $\beta = 0.35$, indirect GS→FA→SF = 0.24, SF→rural GDP $\beta = 0.49$) provide a basis for assessing whether subsidy policies generate durable progress on sustainability objectives rather than transient uptake alone.

In their efforts to promote SF, policymakers and development practitioners may derive significant implications from the results of this study. To develop measures that encourage SF adoption and ensure these practices deliver substantial economic benefits for the agricultural sector, it is necessary to understand the links among financial benefits, data sharing, environmental factors, and MA. An integrated method that addresses the financial and non-monetary challenges faced by farmers in Bihar and elsewhere is needed to facilitate the widespread adoption of SF.

This article is organised as follows: Sections 2 and 3 present the theory; Section 4 details the methodology; Section 5 analyses the results; and Section 6 concludes.

2. Overview of the Adoption of SF in India

As a result of EC and WRM, and their impact on CY, SF has been seen as more significant in India as an approach to addressing all of these problems^[24]. The frequent consumption of pesticides, chemical fertilisers, and frequent irrigation causes an unprecedented problem in the country's agricultural financial system, which

provides food for more than half of the nation's population. For optimal long-term CY and SF, along with OF, crop diversification, conservation agriculture, tree planting, and rainwater harvesting have been recommended as solutions that minimise environmental impact while improving SQ and WRM^[25].

GS in India is an essential tool helping people interested in using these approaches. There are several schemes set up designed to motivate farmers to employ more SF at the state and federal levels. To encourage resource optimisation and SF, important GS schemes such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), the National Mission for Social Assistance (NMSA), and the Pradhan Mantri Kisan Vikas Yojana (PKVY) provide financial and technical support, as well as infrastructure development^[26]. These methods provide organic inputs, SQ for irrigation setup, GS for agroecological practices, and more. The government's intention to advance environmentally friendly SF and boost farmers' incomes by 100% is more proof of its rising demand for SF.

Problems such as FA, costs, and resource access underlie geographic differences in SF adoption in India, despite attempts to address them. While some states have made significant advances in SF, such as Andhra Pradesh, Sikkim, and Kerala, others, such as Bihar, continue to rely on traditional approaches. In many instances, the success rate of GS in developing SF is determined by local economic factors, the practicality of the environment, and the cost of agricultural services^[27].

The positive and negative experiences of implementing SF practices across different agricultural regions are addressed in the present article, which also examines how GS has impacted this method in Bihar, India. Furthermore, research examines the detrimental impacts and economic benefits of these GSs on rural GDP growth and SF for future generations.

3. Conceptual Model and Hypothesis

Investigating how GIS and SF practices affect rural gross domestic product (GDP) growth, this research demonstrates a link between GIS and SF practices in the Indian state of Bihar. The result is an issue of facilities

for modern SF, low agricultural productivity, and severe flooding in Bihar. Because of its unstable financial situation and significant reliance on traditional farming practices, SF is unable to advance without direct government intervention, particularly given its current GIS. To help farmers adapt SF practices, the prototype emphasises GS's function in minimising technical and financial difficulties. Integrated pest management and WC are examples of environmentally conscious methods that schemes like NMSA and PKVY aim to diffuse by providing financial rewards to minimise initial costs and boost adoption rates^[28]. The adoption of SF is expected to boost rural incomes, climate adaptation, and agricultural productivity. Resources from the environment and rural income can be improved in regions like Bihar, where SF are the foremost, by GS's development of SF^[29, 30].

Following several hypotheses that have been made on this conceptual framework:

H1. *Farmers in Bihar are far more likely to adopt SF methods as a result of GS.*

H2. *Adoption of SF, which benefits GS, contributes to long-term rural GDP growth. This phenomenon can be explained by the fact that adopting SF increases CY and income stability.*

H3. *There are several socioeconomic and geographic variations in the deployment of GS, with more successful and resource-poor regions implementing SF earlier than less developed regions within the state of Bihar.*

By measuring the immediate impact of GS on implementation rates and its long-term implications for rural Bihar's GDP growth, the above model attempts to identify the complicated network of links between policy changes and SF practices.

The central hypothesis of this study is that SF in Bihar will be more likely to adopt SF practices if they are provided with a source of GS. This focuses on the idea that environmental inputs, training, and technology are lower in cost when funded directly by government agencies, thereby making SF practices more accessible to more people. Logically, farmers may find it financially challenging to evolve to SF if such GS is unavailable, as WRM measures and other SF practices are significantly more expensive (**Figure 1**).

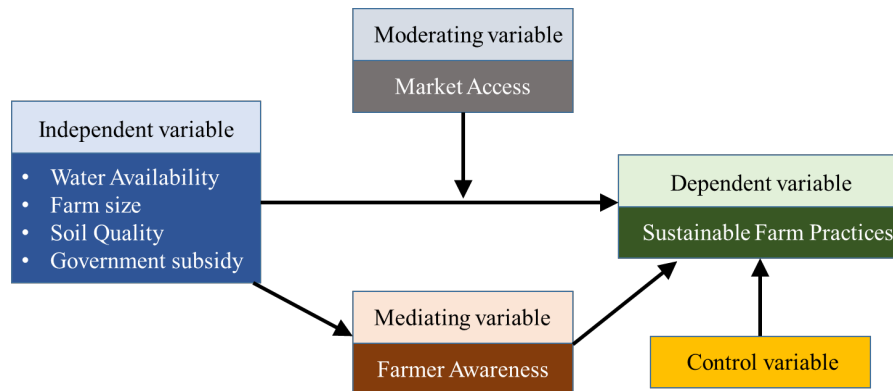


Figure 1. Conceptual model.

Hypothesis H2 evaluates how GS has an impact on the long-term development of the rural GDP growth. The design posits that CY will increase with the help of GS after introducing SF, thereby refining SQ, WRM, and input-use profitability. As a result, agricultural businesses in rural regions may experience increased GDP growth, higher revenue, and improved financial conditions. If Bihar intends to mitigate poverty and improve food security, this strategy is a must. Differences in the detrimental impact of GS across multiple geographical regions and socioeconomic contexts are the primary objective of Hypothesis H3.

This conclusion supports the theory that more advanced regions of Bihar will implement SF practices more rapidly than smaller regions, due to their more advanced physical infrastructure. Because farmers in regions like this have problems getting involved in GS and require access to technological resources to apply SF properly, these factors have probably increased the SF diffusion failure rate.

4. Materials and Methods: Analytical Methods

The research study employed three key analytical methods to measure the links among GS, SF adoption, and GDP growth in rural regions. To find the accuracy and scale of connections between the collected variables, those techniques have been selected.

SEM: The conceptual model, including both direct and indirect connections among GS, SQ, FS, FA, and rural GDP growth, was primarily used as an analytical tool. Because it may simulate relationships and those achieved

through regular methods concurrently, SEM is appropriate for complex frameworks with multiple dependent and independent variables.

The SEM can be expressed as Equation (1).

$$\eta_1 = \beta_{11}\xi_1 + \beta_{12}\xi_2 + \zeta_1 \quad (1)$$

where:

- η_1 is the adoption of SF (Endogenous),
- ξ_1 is GS (Exogenous),
- ξ_2 is FA,
- β_{11} and β_{12} are the path coefficients representing the relationships between the variables,
- ζ_1 is the error term.

This method enabled the analysis of how GS (ξ_1) and FA (ξ_2) directly impact the use of SF (η_1) and how these factors indirectly affect rural GDP growth.

Confirmatory Factor Analysis (CFA) was used within the SEM to verify that the collected variables, such as review responses on FA, MA, and SQ, accurately echoed the basic hypotheses. CFA helped validate the hypothetical model and check the scales' reliability in assessing these theories.

The CFA can be stated as Equation (2)

$$y_i = \lambda_i\eta_i + \epsilon_i \quad (2)$$

where:

- y_i is the trial indicators (e.g., responses on FA),
- λ_i is the factor loadings, which indicate the strength of the link between the latent variable η_i (e.g., FA) and its trial indicators,
- ϵ_i is the measurement error.

CFA allowed us to assess whether the model fits the data adequately by examining factor loadings and applying fit indices such as the CFI and RMSEA.

Goodness-of-Fit Tests: Goodness-of-fit tests were conducted to assess the overall adequacy of the SEM. These tests evaluated how well the hypothesized model fit the experimental data using several commonly accepted indices.

The key fit indices employed were:

- **The Chi-Square Test** measured the difference between the expected covariance matrix and the experimental data. A non-significant chi-square value indicates a good model fit.
- **CFI:** CFI compares the fit of the target model to a baseline model in which all variables are assumed to be uncorrelated. A CFI value close to 1 indicates a good fit, and values above 0.90 generally indicate an acceptable fit.
- **RMSEA:** RMSEA evaluates the error of estimate in the model. Lower values of RMSEA (below 0.08) indicate a better fit.

The results of these goodness-of-fit tests supported the validity of the SEM, indicating that the relationships among GS, SF, and rural GDP growth were well represented in the data.

4.1. Variables

In this study, variables were considered into dependent, independent, mediating, and moderating roles to comprehensively assess the impact of GS on the adoption of SF and their subsequent effects on rural GDP growth in Bihar, India. SF deployment was used as a dependent factor in this study. To measure this, researchers evaluated the frequency with which SF practices like OF,

WRM, crop diversification, and environmentally friendly inputs were used by agriculturalists. The level of adoption was measured on a Likert scale, with low adoption representing full integration of multiple SF, and data on adoption of those methods were collected through surveys and experience.

Four factors—GS, SQ, FS, and WRM—served as independent variables in the study. GS programs, including the NMSA, which provides financial support to farmers, were used to determine GS, the primary independent factor. The research examined the reasons farmers used SF, including the monetary value and availability of GS, SQ, FS, and WRM. The results demonstrated that adoption rates may be biased by factors such as high SQ and larger farms with greater human resources. WRM, which assesses seasonal rainfall levels and access to agricultural irrigation systems, played a crucial role in evaluating the practicality of adopting

To enable authors to evaluate the impact of SF expertise on the GS-adoption relationship, FA was added as a mediating variable in the research project. A Likert-scale survey evaluates SF FA, which includes OF, WRM, and integrated pest control. By optimising for the link between GS (in the form of funding) and increased awareness that leads to SF adoption, that factor was a significant mediator. Because MA could mitigate the link between SF adoption and rural GDP growth, this has been incorporated into the model. Farmers who can access buyers in the closest vicinity are at an advantage in capturing the financial rewards of SF practices, such as charging higher prices for OF. Location, market accessibility, and ease of access for prospective buyers were used to calculate this metric. The transportation system and MA are examples of other factors that can increase or decrease the financial benefits of SF, as shown by MA's balancing role (**Table 1**).

Table 1. Variable List.

Type	Variable	Description
Dependent	Adoption of SF	Measured by the extent to which farmers implement SF, like OF and WRM.
Independent	GS	The availability and ease of access to GS schemes, such as NMSA, provide farmers with financial help.
Independent	SQ	Measured using field tests assessing organic stock content, pH levels, and nutrient availability.

Table 1. Cont.

Type	Variable	Description
Independent	FS	Measured in terms of hectares cultivated, larger farms are expected to have more resources for SF.
Independent	WRM	It is measured by farmer reports and regional water data, capturing access to irrigation and the requirement for rainfall.
Mediating	FA	Measured by a Likert-scale survey measuring FA of SF.
Moderating	MA	It is measured by setup, closeness to markets, and ease of access, reflecting how MA impacts financial benefits.

4.2. Study Region and Data Description

Figure 2 shows the research was conducted in the fertile and SF state of Bihar, India. Additionally, there has been an increase in buyer demand for SF due to numerous problems in Bihar’s agricultural sector, including declining SQ, frequent rainfall, and flooding. To address these problems, GS programs such as the NMSA and the PKVY encourage FA to implement SF practices. The primary objective of this research was to determine

the impact of these GS on SF adoption and, by implication, rural GDP growth. Muzaffarpur (23.7%), Patna (19.4%), Purnea (18.9%), Gaya (21.3%), and Bhagalpur (16.7%) were the five districts in Bihar examined, each with distinct demographic and agroclimatic characteristics. These districts were chosen because they have varying levels of SQ, WRM, MA, and CY, making them appropriate for studying the factors that determine SF adoption. To ensure a balanced selection, the method also considered the availability of GS in these regions.



Figure 2. Bihar state map.

The original targeted group for the research effort was 817 farmers in the mentioned regions. The total number of participants was 582 farmers after data quality tests and partial response corrections were performed. This sample included all aspects of farm sizes, from micro to macro. The data collection was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Department of Computer Science and Engineering, PSN College of Engineering and Technology, Tirunelveli, India (2025-CSE-01). Informed consent was obtained from all subjects involved in the study.

Among the farmers in the sample, the majority (41.8%) irrigated rice, 27.4% wheat, and 22.6% maize, all of which are considered primary crops. Only 8.2% of farmers harvested profitable crops, which included vegetables and sugarcane. Formal surveys, field investigations, and secondary information collected from government information systems were used to collect the data. The survey collected data on several important factors, including farm features, crop types, irrigation accessibility, FA of SF, and GS application ratios. The SQ data were collected through field experiments on several farms to determine nutrient accessibility, pH levels, and biological substance content. We used farmer reports and government data on irrigation systems and seasonal rainfall at the district level to collect WRM.

The questionnaire also collected data on SF, which was adopted. Drip irrigation, crop rotation, soil con-

servation, and OF were all components of these approaches. Both farmer declarations and SF investigations were used to record these methods. Additional context on the scale of GS distributed across districts and overall, as well as on CY and rural GDP growth measures, was provided by secondary data from government surveys, such as those from the Ministry of Agriculture and Farmer Welfare. The details from these supplementary sources complemented and validated the primary data from the questionnaire. The data were collected over the course of one agricultural cycle in 2023, spanning the period before and after the monsoon season concluded.

5. Result

The statistical data on the primary variables used in the study to determine the features of farmers and business SF. **Table 2** presents an in-depth analysis of the dataset by reporting the mean, standard deviation, minimum, and maximum values for each variable. The sample size is N = 582. The farmers' ages ranged from 25 to 78, with a mean of 45 (SD = 12.7). This data indicates that the farming community has been established for some time and has likely studied traditional methods. The distinct age range of the farmers is symptomatic of a mix of younger and older generations, which may have distinct impacts on their embrace of new SF, depending on the group under consideration.

Table 2. Descriptive statistics.

Variable	Mean	Std Dev	Min	Max	N
Age of Farmers (Years)	45.30	12.70	25.0	78.0	582
FS (Hectares)	1.92	0.98	0.5	5.2	582
GS Received (INR)	18,735	8325	5000	35,000	582
Soil OF (%)	3.60	1.20	1.2	6.5	582
FA (Likert Scale)	3.40	1.10	1.0	5.0	582
WRM (binary: 1 = yes, 0 = no)	0.68	0.47	0.0	1.0	582
MA (Distance to nearest Market, km)	15.4	7.6	1.5	35.0	582
Adoption of SF (Likert Scale)	3.2	1.1	1.0	5.0	582

The survey revealed a range of FS from 0.5 to 5.5 acres, with a mean of 1.92 hectares (SD = 0.98). A wide range of farms fall into the small- to medium-size range, but there are a few instances with vast areas of land, demonstrated by the standard deviation. It is essential

because the capacity to adopt SF, which requires a significant amount of resources, is frequently tied to FS. The GS that farmers received encompassed 5000 to 35,000 INR, with an average of 18,735 INR (SD = 8325). Differences in MA subsidy levels, which affect farmers' ca-

capacity to invest in SF, are shown in the range of subsidy amounts. Different methods or distinct geographic areas may cause disparities in subsidy provision.

The soil quality index (soil OF) ranged from 1.2% to 6.5% and had a mean of 3.60% (SD = 1.20). The variance in SQ highlights the sustainability challenges farmers face across multiple regions worldwide. Regions with better SQ may have higher adoption rates of SF because SQ is more supportive of it. On a Likert scale ranging from 1 to 5, the average FA score was 3.4 (SD = 1.1), indicating that nearly all farmers experience considerable FA of SF. The range of 1.0 to 5.0, however, indicates that a few farmers have an infinite level of experience, and others lack it. To fully appreciate the impact of experience on SF, this FA difference is essential. 68% of participants had access to WRM, while 32% relied heavily on seasonal rainfall. WRM was measured as a binary variable (1 = Yes, 0 = No)—standard SF practices, such as drip irrigation, require WRM to be implemented accurately. Collecting WRM in water-scarce regions can be challenging due to unreliable water supplies.

The distance to the nearest market, which represents MA, ranged from 1.5 to 35.0 km, with a mean of 15.4 km (SD = 7.6). Because of this diversity, some farm-

ers have easy access to MA, while others face significant challenges when selling their agricultural products. Access to markets mitigates the economic benefits of SF; however, farmers with better access to these regions tend to profit more. Last but not least, a mean score of 3.2 (SD = 1.1) on a Likert scale from 1 to 5 for SF adoption indicates moderate adoption in the data set. The range of 1.0 to 5.0 indicates that a few farmers have fully incorporated SF into their operations, while others are in the early stages of adoption or have completely discarded it. The knowledge that FS, GS, FA, WRM, and MA are among the variables that impact adoption rates is the basic idea of this range.

Important factors, such as GS, farm features, environmental factors, FA, MA, and SF adoption, are shown in **Table 3** with their coefficients. A positive value indicates a clear connection, and a moderately positive correlation suggests that the probability of adopting SF increases with GS. It has been predictable that GS improves FA and promotes SF adoption, which might further drive adoption, given the strong connection between the two. Analysing the data can help us understand the relationship between GS, farm features, and SF adoption.

Table 3. Correlation Analysis.

Variables	GS	SQ	FS	WRM	FA	MA	Adoption of SF
GS	1.00	0.42	0.35	0.30	0.53	0.25	0.48
SQ	0.42	1.00	0.19	0.47	0.36	0.22	0.44
FS	0.35	0.19	1.00	0.28	0.31	0.41	0.38
WRM	0.30	0.47	0.28	1.00	0.39	0.24	0.43
FA	0.53	0.36	0.31	0.39	1.00	0.33	0.59
MA	0.25	0.22	0.41	0.24	0.33	1.00	0.29
Adoption of SF	0.48	0.44	0.38	0.43	0.59	0.29	1.00

A high correlation between SQ and WRM is vital when using SF, and the investigation found that farmers' probability of adopting SF increases as SQ improves. Because of superior resources, larger farming operations can implement SF more effectively, which suggests a discrete correlation between FS and SF adoption. Farmers with SF operations may have an advantage in implementing SF because of their more extensive MA. The research conducted here indicates an integral connection between WRM and SF adoption, signifying that farmers require access to sustainable water sources to im-

plement WRM. Also, data indicate that FA programs supporting SF may be increasingly common in areas with improved access to groundwater. Farmers with greater expertise are more likely to adopt SF practices, so training and learning results are key factors in promoting adoption. A low level of correlation exists between FA and the variables GS, SQ, and WRM, and financial and environmental factors can impact FA. However, the analysis finds that other factors, such as MA, may not be as vital as the financial support required to purchase higher-value SF or OF.

The results of the regression study on the implications of critical distinct variables on the adoption of SF are presented in **Table 4**. A significant correlation between the GS variable and adopting SF has been shown by a coefficient of 0.32 ($p = 0.00010$). A further unit of subsidy increases the probability of adopting SF practices. Financial support is required to support SF adoption, as evidenced by the t-statistic of 4.00 and the highly significant p -value.

According to this work, SQ has a significant impact on SF adoption, with a coefficient of 0.27. Larger farms are more likely to adopt SF simply because they have more resources and can more easily implement innovative techniques. This implies that boosts in SQ lead to higher adoption of SF practices, with an increase of 0.27 units for each unit increase in SQ. The FS variable also demonstrated an uptrend with SF adoption.

In regions highly susceptible to drought, WRM is

particularly significant for increasing SF. Deploying SF, such as drip irrigation or WRM-SF, relies heavily on water availability. With a coefficient of 0.41, experience with SF is the most reliable indicator of adoption. Adopting SF improves by 0.41 units for every 1 unit increase in FA. A t -statistic of 4.56 and a very low p -value indicate that education, training, and knowledge sharing play a key role in supporting SF.

Results from a mediation analysis using FA as the mediating variable are obtainable in **Table 5**, which evaluates both the direct and indirect effects of GS on SF adoption. Financial help increases FA and comprehension of SF, as indicated by the findings, which indicate a significant beneficial impact of GS on FA. Knowledge sharing plays a key role in promoting SF adoption, and FA has a significant impact on this method's adoption (coefficient of 0.46). This correlation is highly significant, as shown by the high t -statistic of 5.75.

Table 4. Regression analysis.

Variables	Coefficient (B)	Std. Error	t-Statistic	p-Value
GS	0.32	0.08	4.00	0.00010
SQ	0.27	0.07	3.86	0.00020
FS	0.19	0.05	3.80	0.00020
WRM	0.24	0.06	4.00	0.00010
FA	0.41	0.09	4.56	0.00001

Table 5. Mediation Analysis.

Pathways	Coefficient (B)	Std. Error	t-Statistic	p-Value
GSFA (Direct)	0.51	0.09	5.67	0.00001
FAAdoption of SF Practices (Direct)	0.46	0.08	5.75	0.00001
GSAdoption of SF (Direct)	0.35	0.07	5.00	0.00010
GSFAAdoption of SF (Indirect)	0.24	0.06	4.00	0.00006
Adoption of SFRural GDP Growth (Direct)	0.49	0.08	6.13	0.00001

With a coefficient of 0.35, this research indicates that GS beneficially impacts SF adoption, providing a direct pathway between the two. The relationship between GS and financial assistance reveals that GS impacts adoption indirectly, with a coefficient of 0.24. This implies that financial support directly influences adoption and improves FA, which in turn drives adoption. The direct effect of SF on rural GDP growth is highly beneficial.

Adopting SF significantly boosts rural GDP growth, according to a study on moderation. If a farmer has an

advantageous MA, they are more likely to earn higher returns because proximity to markets increases sales and profits. A t -statistic of 5.33 means that SF practices have a direct impact of 0.48 on rural GDP growth. With a t -statistic of 4.86, MA has a direct impact of 0.34 on rural GDP growth. Farmers with superior MA experience benefit more from SF adoption at higher levels (t -statistic = 3.50; interaction effect = 0.21). According to **Table 6**, the results imply that MA and setup are essential for optimising financial benefits from SF.

Table 6. Moderation Analysis.

Pathways	Coefficient (B)	Std. Error	t-Statistic	p-Value
Adoption of SF Rural GDP Growth (Direct)	0.48	0.09	5.33	0.00001
MA Rural GDP growth (Direct)	0.34	0.07	4.86	0.00002
Adoption of SF× MA (Interaction Effect)	0.21	0.06	3.50	0.00040

The analyses of the chi-square tests that were performed to examine the link between the dependent variable, adoption of SF practices, and a few independent variables (GS, SQ, WRM, MA, FA, and FS) are provided in **Table 7**. If these independent variables are related in any way, the chi-square test will reveal it. This four-degree-of-freedom chi-square test revealed a significant correlation between GS and SF practice adoption ($p =$

0.00004). The research results indicate a strong correlation between GS and SF adoption, highlighting the crucial role of financial support in SF implementation. The link between SQ and the adoption of SF is highly significant, with three levels of freedom, evidenced by the Chi-square value of 18.34 ($p = 0.00036$). Since SQ can ease the adoption of SF, the result implies that farmers with higher SQ are more motivated to act accordingly.

Table 7. Chi-square results.

Variables	Chi-Square Value	Degrees of Freedom	p-Value
GS and Adoption of SF	23.58	4	0.00004
SQ and Adoption of SF	18.34	3	0.00036
WRM and Adoption of SF	20.89	4	0.00012
MA and Adoption of SF	15.76	3	0.00150
FA and Adoption of SF	22.45	4	0.00007
FS and Adoption of SF	17.21	3	0.00045

Researchers use a chi-square test with 4 degrees of freedom to show a significant relationship between WRM and SF adoption ($\chi^2 = 20.89, p = 0.00012$). This data point underscores the importance of water availability in SF adoption, particularly in areas where WRM is a problem. With three degrees of freedom, the chi-square value for the link between MA and adoption of SF guidelines is 15.76 ($p = 0.00150$), implying that it is highly significant, however, less significant than other variables. This result implies that GS and environmental factors may have more impact on the adoption of SF practices than MA does. For FA and adoption of SF, the chi-square value is 22.45 ($p = 0.00007$) across all four types. This highly significant result emphasises the vital role of FA and knowledge of SF in increasing adoption. Their adoption is substantially more likely among FAs. The three-degrees-of-freedom Chi-square test for the link between FS and the adoption of SF practices yields a value of 17.21 ($p = 0.00045$). Since FS has more resources and capacity to implement novel techniques, this result supports a significant link, signalling that FS are more likely to adopt SF.

Implementing SF solutions is vital for India's agricultural adaptation to the EC plan, according to new policy and scientific research. Those measures improve water-use efficiency, soil health, and input level. The environmental impacts from high fertiliser and irrigation use are prevalent in India's agrarian sector, which employs the majority of the rural population. Considering these financial limitations, it is valid to analyse the integrated impact of GS, FA, and MA on SF adoption.

All redundant regional topics regarding Lake Egirdir, Kenya, and West Africa have been removed from the introduction to maintain the theoretical model's cohesiveness. Instead, the discussion consists of links to critical global examples to provide proper policy ideas. Using a measurement model that includes CFA, the methodological model predicts direct, indirect, and moderated relationships and accounts for measurement error through a covariance-based SEM.

SEM has been selected over PLS-SEM and regression-based mediation because it provides more accurate model fit indices (CFI, TLI, and RMSEA), thereby supporting theoretical validation. Data testing, such as

Bartlett’s test of sphericity and the Kaiser-Meyer-Olkin (KMO) test, confirmed that the datasets were sufficiently large, and skewness and kurtosis statistics confirmed that the data were approximately normal. A robust confidence interval method based on 5000-sample bootstrapping was used in the analyses done with IBM SPSS AMOS v.26. The enhanced SEM approach captures multiple endogenous constructs and performs MA filtering.

$$\eta_1 (SF \text{ Adoption}) = \beta_{11}\xi_1 (GS) + \beta_{12}\xi_2 (FA) + \beta_{13}\xi_3 (SQ) + \beta_{14}\xi_4 (FS) + \beta_{15}\xi_5 (WRM) + \zeta_1$$

$$\eta_2(RuralEconomicDevelopment) = \gamma_{21}\eta_1(SFAdoption) + \gamma_{22}\xi_6(MA) + \gamma_{23}(\eta_1 \times \xi_6) + \zeta_2$$

where ξ is exogenous latent constructs, η is endogenous constructs, and ζ is residual errors. This refined network provides a straightforward, statistically valid method for measuring how GS and associated mediating and controlling factors impact SA transformation and rural GDP growth in Bihar.

For each network that was SEM-analysed, **Table 8** presents the appropriate CFI and RMSEA values. These indicators measure the degree to which the proposed theories correlate with the experimental results. The CFI and RMSEA values for the GS (SF) model are 0.94 and 0.048. With a CFI value close to 1 and an RMSEA below 0.05, we conclude that the model fits well and displays little parameter error. The CFI and RMSEA values for the GS→FA→SF are 0.96 and 0.042. An improved model fit compared to the direct subsidy-to-practices approach is demonstrated by a higher CFI. Also, a lower RMSEA indicates that the FA-mediated system precisely describes the data, providing support for the theory that FA is a key component of SF. A CFI of 0.93 and an RMSEA of 0.053 were resolute for the FA→SF→Rural GDP growth. A reasonable fit with some approximation error is provided by the slightly increased RMSEA, even though the CFI remains above 0.90, signalling a good fit. This increase could be caused by the difficulty in predicting the economic impacts of SF implementation.

Table 8. CFI and RMSEA.

Model	CFI	RMSEA
GS→SF	0.94	0.048
GS→FA→SF	0.96	0.042
FA → SF→Rural GDP Growth	0.93	0.053
GS→MA→SF (Moderation)	0.91	0.060

Last but not least, the GS→MA→SF (Moderation) model’s CFI and RMSEA values are 0.91 and 0.060. Although the CFI remains within normal limits, the RMSEA is considerably higher, signifying that the controlling impact of MA increases the complexity and finally results in a significantly less accurate fit. However, the model’s fit remains acceptable.

6. Discussion

The key factors have been charted in **Table 2**, which provides an overall summary of the farmers and their SF based on fundamental statistical analysis. In **Table 2**, we can see the farmer statistics. Members of the FSS’ age group range from 25 to 78 years. With a standard deviation of 12.7, the group’s average age was 45.3 years. The farmers who participated in the investigation were

probably very old and used to doing tasks according to traditional methods.

Most of the farms were classified as small or medium in size, with an average of 1.92 hectares (SD = 0.98). The variation in SF adoption has been influenced by changes in tangible subsidies, as indicated by the estimated GS of ₹18,735 (SD = ₹8325). The organic fraction’s index was 3.60% (SD = 1.20), implying environmental problems.

A moderate level of FA was defined by an average of 3.4 on a Likert scale for SF, and 68% of farmers validated their WRM, emphasising their irrigation water reliability. Transport problems have been emphasised by the MA being maintained at 15.4 km (SD = 7.6) and by SF adoption averaging 3.2, indicating that variables such as FA, GS, and resource accessibility drive variability. **Table 3** shows a moderate correlation between GS and SF

adoption ($r = 0.48$), indicating that GS plays a significant role in supporting disaster response methods.

Training was emphasised by FA's strong and highly significant positive correlation with the education point ($r = 0.59$). Also, WRM ($r = 0.47$) and SQ ($r = 0.44$) were more significant, providing support to SF. **Table 4** depicts the results of the regression analysis, which concluded that the variables with the most significant positive impact on the use of genetically modified crops in the examined area were GS (correlation coefficient: 0.32), SQ (correlation coefficient: 0.27), and FA (correlation coefficient: 0.41). The findings from the mediation analysis indicate that FA mediated the relationship between GS use and SF adoption (**Table 5**). **Table 6** summarises the results of the moderation analysis, which shows that MA reduces the economic benefits of adopting SF. The chi-square tests presented in **Table 7** confirmed the critical connections among the adoption of SF, GS, SQ, WRM, and FA. To understand the effects of economic, environmental, and educational factors on SF and rural GDP growth, it is necessary to analyse the findings presented here.

Financial, environmental, and educational benefits drive SF adoption, as demonstrated by the significant impact of the findings. Based on the research, GS is crucial for SF because it enables farmers to increase FA and implement SF, thereby fast-tracking SF changes. After paying attention to these individuals, we found that SQ and WRM were two additional critical environmental facilitators of SF practices, and we recognised a need for ecological solutions. Although FS appeared to have greater financial resources, this did not translate into higher adoption rates; MA boosted SF's economic returns, indicating that additional setup costs were essential.

Assuming the relatively significant effect of MA on rural GDP growth, the research also provides evidence that adopting SF organisations leads to rural GDP growth. The overall socioeconomic impacts are motivated by increased productivity, which, in turn, improves the economic feasibility of SF methods.

As a result of their significant influence on integration levels, the analysis further demonstrates that FA and education impact the level of SF adoption. Therefore, it is essential to resolve those problems to enable

the implementation of successful educational programs, infrastructure development, and financial interventions to facilitate SF transitions. In conclusion, the research project provides practical advice to aid the development of sustainable rural communities in SF by pinpointing key challenges, including scarce resources, MA, and a lack of background data.

Both directly ($\beta = 0.35, p < 0.001$) and indirectly (indirect = 0.24, $p < 0.001$), GS dramatically increase the adoption of SF. A combination of financial benefits and organised knowledge extension programs can achieve the most significant impact.

Translating the empirical findings into sustainable-development language clarifies policy relevance. The covariance-SEM used here models latent sustainability constructs and decomposes total effects into direct, indirect and interaction components, which is essential for evaluating multifaceted policy outcomes. In our results, GS exerts a statistically significant direct effect on SF adoption ($\beta = 0.35, p < 0.001$) and a substantive knowledge-mediated effect through FA (indirect = 0.24, $p < 0.001$); SF adoption in turn predicts rural GDP growth ($\beta = 0.49, p < 0.001$), while MA amplifies economic returns (interaction $\beta = 0.21, p < 0.001$). Interpreting these coefficients in sustainability terms: (a) GS increases the probability of adopting resource-conserving practices (environmental dimension), (b) FA converts financial incentives into persistent behavioural change (institutional capacity), and (c) MA determines whether environmental improvements are monetized into higher rural incomes (economic dimension). Given the observed model fit (CFI ≥ 0.91 ; RMSEA ≤ 0.060), these decomposed estimates support targeted policy designs that combine fiscal transfers with extension services and market infrastructure to achieve integrated sustainability outcomes rather than isolated uptake.

The significance of investing in facilities and MA is verified by evidence that MA significantly boosts the financial return on SF ($\beta = 0.49$; interaction $\beta = 0.21, p < 0.001$). Because of their crucial role in SF uptake, SQ and WRM should be the primary targets of policies focused on minimising the use of natural resources. Periodic, global studies should assess the scalability and sustainability of GS-driven SF adoption across distinct agro-

climatic contexts.

7. Conclusion and Future Work

Findings from the present investigation provide data on the links between SF adoption in Bihar, India, forest fires, and other environmental factors. To determine what factors impact rural GDP growth and what promotes SF adoption, it utilises empirically verified regression SEM. The ongoing research highlights the crucial role of GS in bolstering sustainable practices by providing financial support and indirect benefits to farmers. To ensure farmers are informed about the benefits of SF, it is essential to combine GS with information-sharing programs. Adoption of SF demonstrates a positive correlation with SQ and WRM, as indicated by the research results. The probability of SF deployment increases with an improved MA-to-WRM ratio on farms. To guarantee that farmers in SA experience real improvements to the SA ecological system as a result of SF adoption, the study recommended investing in services to improve MA.

Initial research on novel SF should focus on evaluating their global applicability and SA, while future research should examine the socio-economic impact of GS across multiple agricultural and climate regions.

Author Contributions

Conceptualisation, methodology, formal analysis, writing—original draft, writing—review and editing, investigation: S.S. Software: H.M.A. and S.V. Validation: D.A.S.S.L. Resources: A.S. and K.G. Data Curation: M.E. Visualisation: Z.M. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the reported results in this study are available upon request from the corresponding author. The datasets analysed or generated during the study are not publicly available due to privacy and ethical restrictions. However, data can be made available for academic research purposes upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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