

# Mediating Effect of Technology Adoption: How Agricultural Extension Services Enhances Sustainability of Smallholder Tea Farmers in Sri Lanka

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Article

## Mediating Effect of Technology Adoption: How Agricultural Extension Services Enhances Sustainability of Smallholder Tea Farmers in Sri Lanka

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**Abstract:** This study examined the role of agricultural extension services in promoting the sustainability of smallholder tea farms in Sri Lanka through technology adoption. The study employed the Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB) to explore how extension services influenced farmers' decisions to adopt new technologies, which impacted their sustainability practices. Data were collected from 452 smallholder tea farmers in the Kandy and Badulla districts through the use of a structured questionnaire. The analysis employed PLS-SEM method, and the findings indicated that agricultural extension services significantly enhanced technology adoption and, subsequently, farm sustainability. The study confirmed that technology adoption mediated the relationship between extension services and farmers' sustainability, demonstrating that technology use enhanced productivity, environmental practices, and social outcomes for farmers. The results underscored the need for a comprehensive approach to sustainability that integrated extension services, social factors, and economic support. Recommendations included increasing investments in extension services and developing targeted policies to address financial constraints, training needs, and access to resources. The study offered valuable insights for policymakers and practitioners who aimed to enhance the sustainability of the smallholder tea sector in Sri Lanka by strategically supporting technology adoption initiatives.

**Keywords:** Technology adoption; sustainability; agricultural extension services; smallholder tea farmers; Sri Lanka

### Introduction

Sri Lanka is famous for its tea, grown in small holdings interspersed nationwide. Primarily due to their contribution to national rural development and tea production, these farms have assisted in enhancing the status of Sri Lanka as a global tea producer. However, although it has been around for 150 years, the industry has enduring problems. The story has traditionally centred on big estates, but the tea smallholder sector is a booming quiet achiever. These small to medium-sized family farms, located mainly in the mid and low-country regions, account for 60% of the tea growing land yet contribute to 75% of the tea produced in the country (Tea Small Holding Authority, 2022). This valuable addition underlines the significance of smallholders to the country's position in its ability to remain the largest tea producer globally.

However, several challenges affect this smallholder tea land and threaten its sustainability in the future. The lack of productivity is evident; the International Tea Committee (2022) indicates that the production per

unit area of Sri Lanka is still below that of comparable countries such as Kenya, Malawi, and India. The Tea Research Institute of Sri Lanka (TRISL) advises using Good Agricultural Practices (GAPs) to cultivate tea to help maintain the productivity of the crop, but smallholder farmers who suffer from low yields also have low-income levels (Mahaliyanarachchi, 1996). The sector's sustainability is under pressure due to land fragmentation, high production costs and over-dependence on chemical fertilisers (Jeewanthi & Shantha, 2021).

Sustainable Development Goals (SDGs) specifically target smallholder farmers to enhance their agricultural yields and productivity while also eradicating poverty, showing how important it is to address these problems. To this end, it is essential to understand why smallholder tea farmers do not heavily embrace the recommended technologies. Previous studies note that farmers' knowledge and awareness of these technologies are low (Mahaliyanarachchi, 1996). On the other hand, technology adoption has been associated with better income and economic outcomes (Chandio & Jiang, 2018). Among the challenges that hinder productivity improvement, the slow level of technology adoption by small farmers, the geographical remoteness of these farmers, and their limited access to extension services are critical (Ntume et al., 2015). In addition, research has also seen that the tea smallholders of Sri Lanka can enhance production without increasing inputs (Jeewanthi & Shantha, 2021), evidence of technology-led development. However, technology adoption still has excellent potential to improve tea production and farmers' income.

### Theoretical Underpinning

To that end, this study employs two theories to analyse the complex nature of the conceptual framework. The IDT and TPB are reviewed regarding the research project.

According to the Innovation Diffusion Theory (IDT), extension agents are the critical influential agents in farmers' adoption of technologies. They facilitate the provision of new eco-friendly technologies and farming methods and help ignite farmers' interest in the latest techniques. When implementing extension services, agents identify issues affecting farmers in agriculture and offer solutions to meet the client's needs and issues (Rogers, 2003). Extension agents act as the go-between, connecting farmers to such resources as research information, educational materials, funding, and expert advice to guarantee farmers whatever they need for a smooth adoption. They help farmers with the adoption process as process aids to guide farmers on what to do, when, how to do it, and who to involve in the process (Rogers, 2003).

Extension agents play an essential role in transferring innovations because they act as brokers between the researchers and implementers of the innovation. They align with the IDT precepts, emphasising the importance of social learning, communication, and fluid strategies to prepare farmers to embrace change and new technologies. The sustainability of agriculture practices needs a gradual and backed approach towards change (Rogers, 2003; Ugochukwu & Phillips, 2018). Knowledge of adopter categories, innovation attributes and the innovation-decision process can support the dissemination of better and sustainable practices in tea farming. To establish research to application, they may facilitate farmers' exchange of information on positive results to improve their communication, guide how to deal with complexity and promote awareness of new technologies to reduce the gap between research and practice. This focused strategy based on IDT may eventually lead to the expansion of sustainable practices by more farmers and or the enhancement of sustainability among such farmers.

The Theory of Planned Behaviour (Ajzen, 1991) is applied in the sense that various constructs connected with farmers' decision-making are assessed. Beliefs and evaluations of technology with farmers' attitudes towards technology adoption are asked. Subjective norms are measured with questions regarding the perceived pressure to use or not to use technology. Perceived behavioural control is assessed by asking about farmers' belief in their capability to use specific technology. Behavioural intention is not measured directly but can be deduced from the adoption-related questions and thus provides a good indication of the motivation behind adopting the technology.

## Literature Review

The tea smallholding sub-sector is vital to the Sri Lankan rural economy and the country's tea production. As stated by the Tea Control Act, these farms, which have less than 10-acre holdings, play a significant part in the tea industry of Sri Lanka and its economy (Tea Small Holding Authority, 2022). Smallholdings, although they have large land area and production, suffer from low productivity, declining yield, poor technology use, high production costs, low household income, declining soil fertility, limited labour, low green leaf prices, and inadequate infrastructure, among other challenges. Many of the problems are related (Mahindapala, 2020). In addition, farm sizes may be reduced due to the division of the family farms between generations, which leads to problems of effective management. According to the Tea Small Holding Authority, (2022), the smallholding sector's average productivity in 2022 was 1,200 kg of manufactured tea per hectare, 8% lower than in 2021.

Using technology has been seen as a crucial issue in the development of agriculture (Chandio & Jiang, 2018). The effectiveness of climate-smart agriculture practices in farm production is elaborated by Martey et al. (2020) by explaining how better crop varieties and water use result in better yields and improved resource use. Further, the use of chemical pesticides in IPM techniques can be minimised, promoting better soil health and biodiversity (Pretty, 2003).

Studies have revealed that technology and economic sustainability are related and favourable for smallholder farmers (Aker & Gathala, 2014). New technologies can enhance the farmers' income and production output by increasing productivity (Chandio & Jiang, 2018). However, there are also some constraints in adopting technology for smallholder farmers, such as poor information, lack of capital, and social-cultural factors.

Agricultural extension services are an essential link between research institutions and smallholder farmers. Extension agents may help farmers acquire ideas on new technologies, offer training on how to use those technologies and assist farmers who face difficulties in adopting the technologies (Wulandari, 2015). Nonetheless, several factors can determine the efficiency of the extension services, such as farmers' participation level, the quality of training offered, and the availability of extension agents (Maffioli et al., 2013). However, there is a link between growth and opportunity, or in other words – power. The Tea Small Holding Development Authority (TSHDA) is another important institution that assists small farmers with training and facilitating loan access (Tea Small Holding Authority, 2022).

While the literature on technology adoption and extension services for sustainable agriculture has received much attention, there is still limited understanding of how technology adoption mediates the relationship between extension services and tea farm sustainability in Sri Lanka's tea smallholders. This study aims to address this gap by examining four key areas: The first research question is on the role of extension services in the sustainability of small tea farmers in Sri Lanka; the second research question is on the link between extension services and technology; the third research question is on the role of technology in the sustainability of smallholder tea farms in Sri Lanka; and the fourth research question is on the mediating role of technology adoption in the relationship between extension services and farmer sustainability.

This study seeks to fill these gaps by exploring the relationship between agricultural extension services, technology adoption, and smallholder tea farmers' sustainability, as well as whether technology adoption mediates the relationship between extension services and farmer sustainability.

## Methodology

This study examined the smallholder tea sub-sector in the mid-country region of Sri Lanka, where smallholder tea growers experience peculiar problems. Tea Small Holding Development Authority (TSHDA) and Tea Board records show that mid-country tea growers are relatively less productive and consistently earn lower green leaf prices than their counterparts in the low and up-country regions. The survey was carried out in the Kandy and Badulla districts, which account for about 95% of the mid-country tea growers. One of this research's main objectives was to explore the mediating role of technology adoption between agricultural extension services and the sustainability of smallholder tea farmers. Four hypotheses were tested in this paper.

- H1: Agriculture extension services positively correlate with sustainability among smallholder tea farmers in Sri Lanka.
- H2: Technology adoption and sustainability is positively correlated among smallholder tea farmers in Sri Lanka.
- H3: Agricultural extension service is positively related to the adoption of technology by smallholder tea farmers in Sri Lanka.
- H4: Technology adoption mediates the effect of the role of agricultural extension services on the sustainability of smallholder tea farmers in Sri Lanka.

The data collection method involved using a semi-structured questionnaire on each of the constructs of the study. Multiple-item scales were used to collect data on the variables of interest, such as sustainability (economic, social, and environmental), technology adoption, and extension services. For all constructs, data was collected using a 5-point Likert scale.

**Data Collection:** A multi-stage stratified random sampling procedure was used to capture a proportional sample from the population. The study used a cross-sectional survey of farmers identified from the Tea Small Holding Authority (TSHDA) records, stratified by the Divisional Secretariat (DS) divisions until the 452 subject sample was achieved. The questionnaires were provided in the participants' local language, Sinhala. The data was collected through structured and unstructured questions (Bryman, 2016). The questionnaire was adopted following previous studies with a reliability coefficient of more than 0.7 (Pallant, 2001). A 16-item questionnaire used by Rogers (2003), Shah et al. (2013) and Al-Zahrani et al. (2016) was used to assess the agricultural extension services. A self-administered questionnaire of 11 items developed based on the most utilised measurement instrument by (Ajzen (1991) was used to establish the level of technology adoption. A 24-item survey was conducted based on Haq and Boz (2018), Ibrahim and Alola (2025), Palihakkara et al. (2015), and Waarts et al. (2012) to come up with the composite sustainability score. The data collection took place from September 2023 up to April 2024.

**Data Analysis:** The Partial Least Square Structural Equation Modelling (PLS-SEM) technique was used for hypothesis testing and employed SmartPLS 4 software. This approach is especially relevant for this study because it aims to capture the maximum amount of variance ( $R^2$ ) between the exogenous variable (agricultural extension services), mediating variable (technology adoption), and endogenous variable (sustainability) constructs (Hair et al., 2022).

**Assessment of Measurement Model:** The construct and measurement models for factor loadings, validity, reliability, and multicollinearity were assessed. The current study evaluated the multicollinearity using variance inflation factor (VIF); results of less than 5 indicated no severe multicollinearity problem (Hair et al., 2022). The ideal values with factor loadings above 0.70; any value higher than 0.4 can be acceptable if the composite reliability is greater than 0.7 (Hair et al., 2022). The current study established internal consistency using composite reliability (CR), superior to Cronbach's alpha in SEM analysis (Hair et al., 2022). Convergent validity was tested using average variance extracted (AVE), and AVE values greater than 0.5 are favoured (Hair et al., 2022). However, Lam (2012) suggested that an AVE value of 0.31 or higher can be acceptable if CR is above 0.6. Discriminant validity was evaluated by Heterotrait-Monotrait (HTMT) analysis to ensure that the constructs were not too closely related (Henseler et al., 2015) and that all constructs were distinct.

**Structural Model Assessment:** Path coefficients were estimated to determine the degree of strength and significance of agricultural extension services, technology adoption, and farmer sustainability. The bootstrap analysis was used to evaluate the proportion of the variance in technology adoption that mediates the relationship between the exogenous latent variable agricultural extension service and the endogenous latent variable sustainability.

## Results and Discussion

This section discusses the respondents' profile, descriptive analysis, measurement model, and hypothesis testing.

### 1. Respondent Profile

The data set was collected from 452 smallholder tea farmers in the Mid Country of Sri Lanka. Participants included 65.7% males, and the mean age of the farmers was 56.6 years old. Out of them, 66.7% of farmers are over 50 years old. All the respondents were married, and their average family size was 3.92. The average defenders in a family were 2.62. Many respondents were members of the Tea Smallholding Development Society (TSHDS).

Many farmers had more than 20 years of farming experience and an education level of GCE O/L based on their status. Most of them, with an average monthly tea yield of 241.39 kg per acre, had no more than one acre of tea land extent. Most farmers had less income & savings and limited credit possibilities. Most farmers engaged in full-time farming and monocropping.

### 2. Descriptive Statistics of Measurement Items

The findings of the descriptive statistics study are presented in three dimensions: agricultural extension services, technology adoption, and sustainability.

#### Agricultural Extension Service (AES)

Four significant dimensions were used in this study to evaluate how small tea growers perceived extension services: Change Catalyst, Problem Solver, Resource Linker, and Process Helper. This study also provides descriptive data for the measuring items in Table 1 (Rogers, 2003; Shah et al., 2013).

Table 1. Descriptive statistics of extension service measurement items

No.	Statement	Mean	Standard Deviation
Change of Catalyst			
1	Technical knowledge is empowering the tea smallholder community.	4.038	0.985
2	Your extension agent has a positive attitude toward the work and organisation of development agencies.	3.810	1.043
3	Your extension agent encourages you to adopt new technologies.	3.613	1.144
4	Your extension agent points out the advantages of using new technologies.	3.597	1.135
Problem Solver			
5	Your extension agent has extensive knowledge and experience related to work and social life matters.	3.770	1.109
6	Your extension agents will always be a reference source for the tea smallholder community.	3.562	1.199
7	Your extension agent encourages you to try agricultural innovation despite facing high risks.	3.336	1.291
8	Your extension worker discusses your problem and helps with solutions whenever you request	3.699	1.144

No.	Statement	Mean	Standard Deviation
Resource Linker			
9	Your extension agent has a vast network of contacts with agricultural agencies.	3.608	1.080
10	Your extension agent exhibits friendly behaviour during the development and technology transfer process.	3.701	1.098
11	Your extension agents help you get agricultural loans.	3.004	1.365
12	Connecting tea farmers for resource sharing	3.577	1.194
Process Helper			
13	Your extension agent has the qualities of a diligent and dedicated mentor.	3.723	1.162
14	Your extension agent is confident in the capabilities demonstrated by the tea smallholder community.	3.770	1.022
15	Your extension agent always encourages the tea smallholder community to achieve the highest innovation progress.	3.876	1.030
16	Your extension agent has a high level of patience when developing agriculture.	3.996	0.938

Note: Mean scores are based on the Likert scale 1 to 5 (low to high).

The extent to which extension agents persuade farmers to adopt new technologies and practices is called the "Change of Catalyst" role. According to the farmers, AES is quite effective in promoting changes that lead to innovation, with a mean score of 3.76. Even though many farmers view AES as a vehicle for change, there is no universal agreement on its utility, as evidenced by a standard deviation of 0.84.

The "Problem Solver" sub-construct captures how AES enables farmers to solve problems. Farmers have assessed AES as relatively efficient, giving it a mean score of 3.59. The 0.85 standard deviation shows some variation in the answers, which means that not all the farmers face AES's problem-solving aspect simultaneously.

The "Resource Linker" position shows how well AES connects farmers to resources they need to produce crops, such as capital, implements and other farm inputs. Farmers consider the AES as a resource linker less beneficial than other methods when considering the mean score of 3.47. These results could lead to service delivery gaps because of the higher standard deviation of 0.87, which shows higher variability, meaning that some farmers have more access to the resources than others.

The "Process Helper" factor measures the degree to which AES supports farmers in understanding new processes or improvements in processes that lead to higher yields or quality improvements, such as the adoption of beneficial practices. This role is considered the best of the AES functions, with the highest mean score of 3.84. The moderate variability, as depicted by the standard deviation of 0.86, shows that while many farmers may have wanted AES to assist in the implementation processes, much can still be done.

Farmers view AES favourably, reflected in the overall mean score of 3.67 for all the dimensions. The overall impressions seem less dispersed than the individual dimensions, with a standard deviation 0.74. Results indicated that tea growers have a more stable experience with AES's general support of technology adoption and sustainability.

### Technology Adoption

Based on the Theory of Planned Behaviour (TPB), the research highlights three dimensions: attitude, subjective norms, and perceived behavioural control (Beedell & Rehman, 2000). A self-structured questionnaire containing eleven statements determined the farmers' perceptions of technology adoption.

Table 2. Descriptive statistics of farmer technology adoption measurement items

No.	Statement	Mean	Standard Deviation
<b>Attitude</b>			
1	I believe following the recommended technology in tea cultivation will produce high-quality tea.	4.473	0.65
2	Adopting new technology in my tea farming will improve yields and productivity."	3.823	0.764
3	Using technology in tea farming feels more advantageous than sticking to traditional methods.	4.184	0.778
4	I feel optimistic about the potential benefits of technological advances in tea cultivation.	4.035	0.838
<b>Subjective Norms</b>			
5	The opinions of tea cultivation experts and experienced farmers significantly influenced my decision to adopt the tea technologies.	3.885	0.938
6	I often seek advice and recommendations from other farmers who have successfully implemented recommended technologies in their tea cultivation practices.	3.92	0.986
7	My peers and family would support and appreciate my decision to incorporate technology in my tea farming."	3.735	1.127
<b>Perceived Behavioural Control</b>			
8	I have the necessary resources, skills, and knowledge to adopt and implement recommended technologies in my tea cultivation effectively.	3.715	1.018
9	I believe that I have control over the process of integrating recommended technologies into my tea cultivation practices.	3.819	0.949
10	With the proper training, I can overcome challenges in using new technology for tea farming.	4.179	0.896
11	My previous experiences with technology make me confident in adopting new technological advancements in tea farming.	3.927	0.896

Note: Mean scores are based on the Likert scale 1 to 5 (low to high).

The "Attitude" component of farmers' perception of new technologies is either positive or negative. In this case, the mean scores of the respondents averaged 4.13, which is pretty high, indicating that farmers have a good perception of the use of technology and consider it as enhancing their farming strategies. The degree of agreement within the responses, as indicated by the standard deviations, is depicted in Table 2, with a relatively low standard deviation of 0.61.

The theory has identified subjective norms as the perception of social pressure that may influence the farmer's decision to adopt technology. Farmers also felt moderate social influence or persuasion to use new technologies, having a mean score of 3.85. Thus, using the standard deviation of 0.76, it can be noted that there is some dispersion of the social norms concerning technology among farmers. Some farmers may be more sensitive to outside forces.

The ability of farmers to adopt new technology and their resource and knowledge endowment is assessed through a scale known as Perceived Behavioural Control. Farmers have a relatively high perception of their capacity to adopt new technology since the average score is 3.91. These results and the 0.68 standard deviations mean some dispersion, which means that some believe they can adopt technology as a farmer's skill and resources. These results suggest that farmers acknowledge potential difficulties but believe training can address them.

The mean score for the dimension "Technology Adoption" is 3.96, implying that farmers' attitudes towards adopting new technologies are favourable but can still be enhanced. The standard deviation of 0.56 shows that most farmers had similar experiences concerning new technology adoption; therefore, they had positive perceptions of using innovation in running their tea farming businesses.

#### Farmer Sustainability

A 24-item survey construct was used in the research to assess various aspects of sustainability: social, economic, and environmental. The standard deviations and the means of the two groups are shown in Table 3.

Table 3. Descriptive statistics of farmer livelihood sustainability measurement items

No.	Statement	Mean	Standard Deviation
Social			
1	I can access essential social services such as healthcare, education, and clean water.	4.069	0.918
2	I engaged in community activities and have a strong sense of social cohesion.	4.177	0.839
3	I have opportunities for skills development and training to enhance my knowledge and capabilities.	3.934	0.962
4	I am satisfied with the balance between tea cultivation work and social life.	4.058	0.834
5	I wish to make decisions with community members on sustainable tea farming activities.	4.241	0.813
6	The community promotes gender equality and provides equal opportunities and support for women in tea farming.	4.173	0.847
7	I have been recognised as a successful farmer in the tea farming community.	4.06	0.841
8	I feel that cultivating tea will save our future.	4.144	0.97
Economic			
9	My tea factories or leaf collectors are given mostly reasonable prices for green leaves.	3.591	0.956
10	I am willing to increase my yield further by adopting sustainable agricultural practices.	4.374	0.755
11	I can access financial services and credit facilities to invest in my farms and businesses.	2.861	1.424

No.	Statement	Mean	Standard Deviation
12	I can access affordable, high-quality inputs, such as fertilisers and new tea varieties.	3.117	1.287
13	I receive training and support to improve my farming practices and increase productivity.	3.071	1.3
14	I am willing to spend money on all the agricultural practices required to increase the yield.	3.67	1.093
15	My yield has been improving over the years.	2.785	1.083
16	I am actively involved in decision-making processes related to my economic activities and have a say in market development initiatives.	4.018	0.982
Environmental			
17	My tea farming community actively conserves and protects biodiversity in and around tea farms.	3.695	1.024
18	I adopt and promote soil conservation practices, such as terracing or cover cropping, to prevent soil erosion on tea farms.	4.004	0.833
19	I adopt climate-smart agriculture techniques (e.g. proper shade management, light plucking in the dry season, and using drought-resistant or disease-resistant varieties).	3.863	0.822
20	I practice organic or agroecological farming methods to minimise the use of synthetic pesticides and fertilisers.	3.179	0.944
21	I ensure that I am not contributing to adding chemicals to typical water streams or water sources.	3.212	0.769
22	I have implemented sustainable waste management practices such as composting and recycling in my tea land.	3.741	0.739
23	I use pesticides as recommended and carefully to maintain pesticide residues.	4.412	0.716
24	I wish to get environmental certification for my tea land and proceed accordingly. (e.g. Rainforest Alliance (RA) certificate)	4.325	0.766

Note: Mean scores are based on the Likert scale 1 to 5 (low to high).

The social, economic, and environmental aspects of the smallholder tea growers' sustainability are presented in Table 3 of this study. The tea farmers feel that they are sustainable and that some improvement can be made, especially in the economic aspects of sustainability, with a total mean score of 3.782 for farmer sustainability.

### 3. Social Sustainability

The social aspect of sustainability is the most developed among the farmers since they have an average of 4.107. This high ranking indicates that farmers have good accessibility to social services and social cohesiveness.

Some of the significant social factors that have influenced this are social integration and community participation (mean = 4.177), which shows that tea growers enjoy high levels of social capital. As for the sense of farmers' power in their communities, they seem to have adequate access to opportunities for skill enhancement and a relatively good work-life balance (mean = 3.934 and 4.058, respectively). The interest in using cooperative decision-making in sustainable farming is the highest (4.241), which shows that farmers are keen to involve everyone. Farmers' social well-being is also associated with gender equality (mean = 4.173) and status as wealthy farmers (mean = 4.06). Some of these measures have rather significant coefficients of variation (0.918) for social service access, for example, which implies that the experiences of different farmers with social sustainability may differ.

### 4. Economic Sustainability

The economic sustainability is the least rated, with a mean score of 3.436. Farmers complained about the difficulties of accessing credit facilities and financial services (mean = 2.861) and affordable, quality inputs (mean = 3.117). The finding on significant adoption of sustainable practices (mean = 4.374) reveals farmers' willingness to move forward despite the challenges. The mean price of tea leaves is 3.591, which is reasonable, while more evidence is required to confirm an improved outcome of a mean of 2.785

Farmers viewed themselves as purchasers of appropriate goods and services (mean = 4.018). These findings showed that farmers are involved in their economy's economic development but require better funding to sustain their farming activities. The relatively high standard deviation (1.424) for financial services indicates the variance in the economic status of the farmers, which is a clear indication of the inequality in access to services and financial needs.

### 5. Environmental Sustainability

The agricultural practices related to resource conservation and environmental management are relatively well recognised in the present study, as evidenced by the above-average score of 3.804 for the environment.

Pesticide management methods (mean = 4.412) are well entrenched, with farmers ensuring that they use the right measure of pesticides as recommended; climate-smart agriculture (mean = 3.863) and soil conservation (mean = 4.004) indicate a good understanding of sustainable farming practices. The desire for environmental certification (mean = 4.325) shows that farmers would like to improve their ecological status and get the certification of eco-friendly measures.

Nevertheless, there are problems, for instance, in organic farming (mean = 3.179) and preventing water pollution from their activities (mean = 3.212). These areas have relatively poor performance and suggest the need for increased effort and knowledge in pursuing enhanced environmental standards.

Finally, the social aspect of sustainability of smallholder tea producers in Sri Lanka is the most robust due to gender balance, community engagement, and participatory decision-making. However, there are constraints to sustainable economic growth, which include low crop yields and limited access to improved inputs and finances. Even though environmental sustainability standards are quite high, there is still some scope for growth, particularly in water management and ecological development. Agricultural extension services and adopting technology could be vital to reduce those gaps and enhance the economy and environment for better sustainability.

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### 6. Measurement Model Results: Reliability and Validity

The quality of the measurement model was assessed using internal consistency and convergent validity tests, factor loading assessment, and collinearity diagnostics. The average VIFs of all constructs were less than five (Hair et al., 2022), meaning that multicollinearity is not likely to be a problem in the proceed to analysis data.

Following Hair et al. (2022), only the items with factor loadings of less than 0.4 were excluded from analysis (n=3). However, those with factor loadings of 0.4 – 0.7 were kept if they had a Cronbach's Alpha of > 0.70 and Average Variance Extracted (AVE) of > 0.33. All constructs were reliable, with Cronbach's Alpha coefficients greater than 0.728 and convergent validity with AVE higher than 0.333 (Lam, 2012). For this reason, due to the Composite Reliability (CR) and Cronbach's Alpha coefficients, the convergent validity of the constructs can be considered appropriate (Table 5). HTMT ratio analysis was used to assess discriminant validity, and all the values were below the cutoff level of 0.85 (Henseler et al., 2015) (see Table 6).

Table 4. Collinearity results

Model Variables	Collinearity Statistics VIF
Extension service	2.092
Technology Adoption	2.599
Farmer sustainability	

Table 5. Reliability and convergent validity of constructs

	Cronbach Alpha	Composite Reliability	Average Variance Extraction (AVE)
Extension service	0.915	0.926	0.446
Technology Adoption	0.835	0.867	0.333
Sustainability	0.848	0.879	0.403

Table 6. HTMT discriminant validity result

	Extension Service	Sustainability	Technology Adoption
Extension Service		0.750	0.718
Sustainability	0.750		0.848
Technology Adoption	0.718	0.848	

## 7. Structural Model Results: Hypothesis Testing

This study explored the proposition of agriculture extension services, technology adoption and the sustainability of smallholder tea farmers in Sri Lanka using the Partial Least Squares Modeling (PLS-SEM) to test the hypothesised links within the model, four hypotheses (H1, H2, H3, H4) were suggested in the present research. Consequently, H1 proposes that agricultural extension services have a positive effect on sustainability, H2 examines the relationship between technology adoption and sustainability, H3 examines the relationship between agricultural extension services and technology adoption, and H4 seeks to establish the mediating role of technology adoption on the relationship between agricultural extension services and sustainability among smallholder tea farmers in Sri Lanka.

Figure 1 shows the path analysis model and confirms a significant positive influence between agricultural extension services and farmer sustainability ( $\beta = 0.382$ ,  $p < 0.01$ ). Agricultural Extension Service on Technology adoption has a positive and significant correlation and was the most influential determinant ( $\beta = 0.664$ ,  $p < 0.01$ ) followed by technology adoption on the sustainability of the farmers ( $\beta = 0.514$ ,  $p < 0.01$ ). Furthermore, AES and TA explained 67% of the variance of tea farmer sustainability, and AES accounted for 44.1% of the variance. These results were computed using Smart PLS Algorithm analysis. The following presents the structural model of the study of mediating effect.

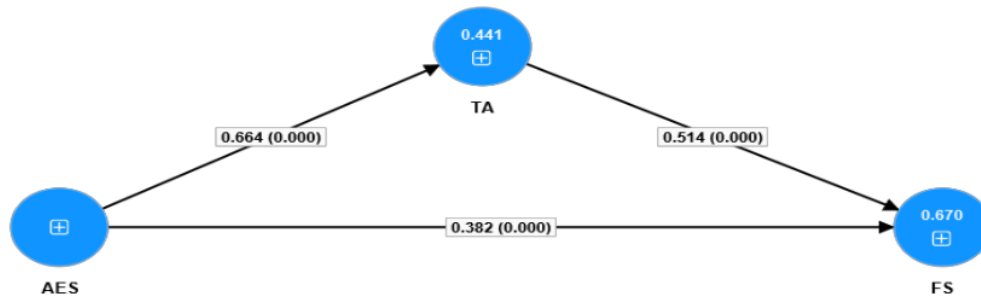


Figure 1. Structural model of Bootstrapping – Mediation effect of Technology Adoption (TA) between Agricultural Extension Service (AES) and Farmer Sustainability (FS)

The direct effects of agricultural extension services and technology adoption on farmer sustainability are indicated in Table 7, while the mediating effect of technology adoption is shown in Table 8.

Table 7. Path coefficients for technology adoption and sustainability

Relationship	Std. Beta	Std. Deviation	Std. Error	T Value	P Value	Results
AES -> FS	0.382	0.04	0.001	9.661	0.000	** significant
AES -> TA	0.664	0.028	0.001	23.504	0.000	** significant
TA -> FS	0.514	0.041	0.002	12.645	0.000	** significant

AES -Agricultural Extension Service, TA – Technology Adoption, FS- Farmer Sustainability

\*\* Significant 0.01 level

Table 8. The mediation effect of TA on the relationship between AES and FS

Relationship	Indirect Effect	Std. error	t- value	p-value	CI		Result
					LL (2.5%)	UL (97.5%)	
AES -> TA -> FS	0.341	0.001	11.258	0.000	0.304	0.458	Significant**

Note: AES – Agricultural Extension Service, TA- Technology Adoption, FS- Farmer Sustainability

H1: There is a significant relationship between agriculture extension services and sustainability among smallholder tea farmers in Sri Lanka.

According to the path coefficients, a positive relationship between agricultural extension services and sustainability is statistically significant (H1:  $\beta = 0.382$ ,  $p = 0.000$ ), thus supporting H1. The study's findings tend to substantiate the hypothesis suggesting that the extent of farmers' engagement in the use of agricultural extension services has a positive and significant effect on the sustainability of smallholder tea farmers in Sri Lanka. Agricultural extension services play the role of translating research findings into real-life practices for the benefit of farmers. Agricultural extension services contributed to tea farmer sustainability through knowledge dissemination, capacity building and technology adoption.

In addition, as postulated in the literature review by Hameed and Sawicka (2023), extension agents transfer research findings such as harvesting tea, soil conservation, and water conservation to enhance sustainable farming practices. Moreover, extension programs aim to transform farmers to adopt sustainable measures by educating them to become informed farmers on their farms (Pretty, 2003). In addition, extension

services help farmers adopt sustainable innovations, including precision agriculture technologies and efficient resource-use techniques (Westermann et al., 2018).

H2: <sup>4</sup> There is a significant relationship between technology adoption and sustainability among smallholder tea farmers in Sri Lanka.

The relationship between technology adoption and farmer sustainability was significant at 0.01 level (H2:  $\beta=0.514$ ,  $p=0.000$ ). These results support the hypothesis (H2) and indicate that technology adoption improves farmer sustainability in this study.

It is often known that farmer sustainability and technological adoption are linked. A recent systematic review conducted by Shariff et al. (2022) that analysed the literature on Asian farmers' intentions to use technology identified several critical factors influencing the use of technology and, consequently, sustainability results. These findings show that technology and sustainability are intertwined so that specific technologies and situations of adoption matter. In addition, technology adoption positively impacts agriculture's sustainability by increasing resource productivity and yield and quality outputs.

H3: <sup>4</sup> There is a significant relationship between agricultural extension services and technology adoption among smallholder tea farmers in Sri Lanka.

As shown in Table 7, the results confirm a significant positive relationship between agricultural extension services and technology adoption among tea farmers (H3:  $\beta= 0.664$ ,  $p=0.000$ ). These results agree with earlier works that have emphasised the importance of extension services in information dissemination, overcoming constraints to adoption, and thus encouraging new technology adoption (Feder et al., 2004). Extension agents can offer essential information resources, training, and other demonstrations to help farmers decide whether to change their farming practices.

H4: <sup>4</sup> Technology adoption mediates the relationship between the role of agricultural extension services and the sustainability of smallholder tea farmers in Sri Lanka.

Path coefficients, R-square values, T-values, confidence interval levels and significance levels offer an understanding of how technology adoption mediates between agricultural extension services and farmer sustainability—including technology adoption as a mediator significantly enhanced the model, with the indirect effect of AES towards FS was positive (H4:  $\beta= 0.341$ ,  $p=0.000$ ). The bootstrap confidence interval (LL = 0.304, UL = 0.458) was not inclusively zero, thus supporting the mediation role of TA. Therefore, hypothesis H4 received support, confirming that technology adoption is essential in the mediating relationship between agricultural extension services and farmer sustainability.

This result aligns with recent studies showing that extension services play an essential link between technology and farmers. According to Gao et al. (2020), it is crucial to illuminate the process of information sharing among farmers when introducing new technologies in agriculture, noting that "it is crucial to understand the information diffusion among the farmer who has already adopted <sup>12</sup> is mode and ensure that this information is passed to the elderly and the small-scale farmers." Likewise, the adoption of technology by farmers is high when extension service is provided because, through extension service, the farmers are informed on the benefits of the new technologies through extension agents, which are a bridge between researchers and farmers. Several authors have documented that extension services, agricultural technology adoption, productivity or income improvement, and farmer sustainability are related. Similarly, Walisinghe et al. (2017) established that public agricultural extension interventions influenced technology adoption among rice farmers in Sri Lanka. Likewise, Ali and Rahut (2013) found that farmers in Pakistan provided with extension services had higher yields and incomes. Furthermore, Pan et al. (2018) highlighted those women farmers in Uganda who engaged in extension programs received higher agricultural yields, more savings, and more earned wages than the non-participants. The results align with the innovation diffusion theory, which

postulates that exposure to information leads to adoption. From adopting technology comes increased production, which leads to better earnings for farmers. Hence, agricultural extension officers, especially those dealing in the tea sector, can significantly improve technology uptake and sustainability among the smallholder tea farmers in Sri Lanka.

### Conclusion

This study focused on the linkage between extension services, technology adoption and the sustainability of smallholder tea farmers in Sri Lanka. The study also supports the extension services in encouraging technology adoption to improve farmers' sustainability.

These change agents, problem solvers, resource linkers, and process helpers – extension agents – have played a critical role in the rollout of technology adoption among farmers. The study confirmed a positive relationship between extension services and technology adoption, underlining the role of quality extension services in closing the gap in information access and promoting improved practices.

In addition, as hypothesised, technology adoption mediated the relationship between extension services and farmer sustainability. The adoption of technology significantly affects the livelihoods of smallholder tea farmers by increasing production, supporting environmentally friendly practices, and boosting resource efficiency. However, the study also emphasises other factors impacting farmer sustainability, even though technology adoption is an important mechanism. These results emphasise the necessity of a comprehensive strategy that considers social, economic, and environmental aspects of sustainability.

Finally, it is possible to conclude that this research offers empirical evidence to support the interaction between extension services and technology adoption on smallholder tea farming sustainability. Additionally, the study confirmed that technology adoption mediates the relationship between agricultural extension services and farmer sustainability, supporting the proposed hypotheses. Therefore, this study recommends that by increasing the investments in proper extension services and encouraging the adoption of technologies, the tea sub-sector in Sri Lanka may be sustainably developed.

### Implications and Recommendations

The results suggest that further efforts should be made to enhance agricultural extension services to facilitate technology adoption and support farmers' businesses. Both policymakers and agricultural agencies should increase their efforts concerning extension agents, especially regarding financial resources and supporting the application of new technologies. These results could include further education for the extension agents, better communication tools and enhanced relationships with the financial sector. This paper also underlines the importance of developing specific extension programs for smallholder farmers to respond to problems like credit access and risk management.

More research should be conducted to determine the constraints limiting smallholder farmers' use of risky innovations. Specific attention should be given to identifying the level of financial literacy, the availability of credit to overcome these barriers. It is therefore suggested that longitudinal designs be used to evaluate the impacts of technology use and agricultural extension on farm management practices' viability. Further work should be conducted on comparisons with other regions and different crops so that effective practices can be distinguished, and effective extension strategies tailored for specific settings.

Using quantitative research tools such as interviews and focus group discussions to gather data would enable the researchers to understand the situation better as farmers perceive it. This approach could result in more improved and precise interventions by providing information that quantitative methods cannot obtain. In addition, understanding the factors that explain why farmers decide to innovate could help to design targeted extension programs. Thus, one of the crucial steps is an assessment of the effects of these technologies on farmers' well-being and the environment from a long-term perspective to estimate the overall positive or negative impact on sustainability.

Exploring these research gaps would provide the necessary information for policy makers and practitioners to formulate sound approaches. These strategies would raise the effectiveness of agricultural extension services in supporting the sustainability of smallholder farmers by using the right technologies.

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