



Exploring the Constraints and Factors in the Potential Adoption of Conservation Agriculture in Bangladesh

Riffat Ara Zannat Tama ^a and Md Mahmudul Hoque ^{b*}

^a Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh.

^b Centre for Peace and Security, Coventry University, Priory Street, Coventry, UK.

Authors' contributions

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ABSTRACT

Conservation agriculture (CA) is an alternative technique to conventional resource-intensive farming. It is advocated as a sustainable agricultural production approach for achieving improved land and labor productivity with minimal soil disturbance. Despite its proven benefits and widespread promotion from national and international agencies, the adoption rate of CA is substantially low among the farmers in many developing countries, including Bangladesh. This study explores perceived barriers for CA adoption in relation to farmers' socioeconomic and demographic characteristics using data collected from 220 farmers who have not adopted CA in Bangladesh. Statistical data analysis reveals the lack of specialized machines required for CA

*Corresponding author: E-mail: moni.hoque@coventry.ac.uk, mhmoni24@gmail.com;

farming as the most critical constraint perceived by the farmers. A lack of knowledge and information is also perceived as a crucial constraint. The results of multiple regression analysis show that formal education, training experience, timely availability of machines, and farm size are significant determinants of these constraints. Making critical machines, knowledge, input subsidies, and local-level extension services widely available for farmers can stimulate CA adoption.

Keywords: Conservation agriculture; potential adoption; availability of machines; socioeconomic factors.

1. INTRODUCTION

The world population is estimated to reach 9.6 billion by 2050, and the demand for food is expected to increase by 35% to 56% (Gerland et al., 2014; van Dijk et al., 2021). An analysis estimates that the current global crop production must be increased by 25% to 70% to meet the 2050 projected demand (Hunter et al., 2017). This is a big challenge for today's agricultural scientists and practitioners. The situation can be even more challenging as the productivity of the earth has been seriously exploited by the overuse of fertilizer, irrigation, and other technological and product innovations. Finding novel ways to increase the productivity of land is critical. The quest for exploring innovative ways of preserving or reviving soil fertility with minimum interventions is ever-growing. Farmers' overdependence on monoculture requires a change. Moreover, long-term conventional tillage-based farming reduces organic matter and the quality of the soil, which can cause a wide range of problems, including soil erosion and environmental degradation (Blevins & Frye, 1993; Pimentel, 2006; Robinson et al., 2017; Sinha et al., 2019; Tian et al., 2021). In this context, conservation agriculture (CA) has emerged as an advanced type of farming that can play a vital role in increasing the organic matter of soil (Dhar et al., 2018; Kafiluddin & Islam, 2008). CA is generally understood as a farming practice that aims to attain an adequate profit while preserving the essential environmental resources of soil and water.

The Food and Agriculture Organization (FAO) of the United Nations introduced the concept of conservation agriculture (CA) worldwide as "a response to sustainable land management, environmental protection, and climate change adaptation and mitigation" (FAO, 2019, p. 1). Intending to improve food security and increase agricultural profits by minimizing environmental damages caused by conventional farming, the CA system stands on three basic principles: (i)

minimum soil disturbance; (ii) permanent soil coverage (at least 30% of the land) in the form of crop residue or live mulches; and (iii) intercropping at least three different crop species via crop rotation (Banjarnahor, 2014; FAO, 2019). Bhan and Behera (2014) note that CA assumes that the social and economic benefits obtained by combining production and protecting the environment (including reduced cost of labor and other inputs) are more significant than production output alone. Apart from providing farmers with social and economic benefits, CA protects the environment by efficiently using natural resources through integrated management of available soil, water, and biological resources combined with external inputs. Keeping these aspects in mind, CA is advocated as a win-win approach that reduces operational costs (including machines, labor, and fuel costs) while increasing yields and utilizing natural resources more effectively (K. C. Roy et al., 2009). In this context, it was expected that CA would be widely adopted and practiced by farmers across the world. Emerging evidence suggests that CA uptake in developing countries remains substantially low. In the case of Bangladesh, studies illustrate that despite the intensive promotion, farmers remain surprisingly hesitant to adopt CA (Hossain et al., 2015; Tama et al., 2023; Uddin et al., 2016). This research aimed to explore and analyze the determining factors and constraints reported by farmers not adopting CA in Bangladesh.

2. JUSTIFICATION OF THE STUDY

Several studies have explored a wide range of benefits of CA (Abdulai & Abdulai, 2017; Ghaley et al., 2018; Hossain, 2017; Islam et al., 2019; Kaweesa et al., 2020; Pannell et al., 2014; Pradhan et al., 2018). A few recent studies have studied agricultural conservation practices in the Eastern Gangetic Plains (i.e., Bangladesh, India, and Nepal) of South Asia. Islam et al. (2019) found that CA-based sustainable intensification practices can substantially improve irrigation

water productivity. Conventional farming in these areas is traditionally resource-intensive, requiring large inputs of water, energy, and labor (Gathala, Laing, Tiwari, Timsina, Islam, Bhattacharya, et al., 2020). In on-farm experiments (in over 400 farms) conducted in the same region, Gathala et al. (2020) concluded that CA benefits can potentially include a 10% yield increase, a 19% increase in water productivity, and a 50% reduction in human labor. These trials also revealed that improved sustainable management could reduce CO₂-equivalent emissions by around 10% compared to their baseline (Gathala et al., 2020). Sinha et al. (2019) also analyzed the critical soil properties for CA-based intensification practices in the Eastern Ganga Alluvial Plains region from 2014 to 2017 and found that zero-tillage practices reduce soil pH compared to conventional tillage, providing an opportunity to preserve soil organic carbon. Similarly, Alam et al. (2020) demonstrate that soil nutrients and the availability of crops increase in the region under CA practices. Hossain (2017) studied the best practices of CA in Bangladesh to identify some additional benefits for farmers, including its ability to save time and control weeds, and further revealed that in comparison to conventional farming, the conservation tillage-based method could significantly increase yield in several crops (e.g., 8% for boro rice, 8% for mungbean, 6% for wheat, 36% for jute, and 38% for lentil) in Bangladesh. However, Jayaraman et al. (2021) critically note that although CA's role in improving soil water conservation is well supported by adequate verification, the evidence regarding its effect on crop productivity is inconclusive. Critics of CA further point out that CA is a complex set of imposed technologies, and its adaptation needs integrated efforts from all actors across the value chain (Brown et al., 2017; Giller et al., 2009, 2015; Reij et al., 2013). In addition to advanced farm management skills, the practice requires investments in new farming equipment (Dhar, 2017).

Despite its revolutionary environmental benefits, the expansion of CA has slowed in several regions of the world. Even though intensive promotion of CA has been carried out through various dissemination schemes or projects, its adoption rate (with all three principles) is considered to be relatively low in most parts of the world (Chiputwa et al., 2010; Kassam et al., 2019; Michler et al., 2019; Tittonell et al., 2012; Ward et al., 2018). The rate is even lower in low-income countries and among small and medium farmers (Chalak et al., 2017). FAO estimates that

in 2015/16, about 180 million hectares (M ha) of cropland were used globally to practice CA, and the Asian continent represents only 7.7% (13.93 M ha) of this land area (Kassam et al., 2019). Only a few countries (i.e., the USA, Argentina, Brazil, Australia, and Canada) share 90% of CA land area, whereas South Asian countries have only around five million hectares under this farming system (Biswas et al., 2017). Brown et al. (2018) note that although CA was widely promoted in Sub-Saharan Africa as part of the sustainable agriculture campaign, the uptake among farmers has been low. The study argues that the region needs to adopt substantive institutional changes and collaborative measures with farmer organizations to accelerate the adoption rate. Kassam et al. (2019) reveal that the East, Middle, and West Asian nations (e.g., Uzbekistan, Azerbaijan, Kazakhstan, Laos, Vietnam, and Iran) have made a committed start to promoting rain-fed and irrigated CA cropping systems. However, such a commitment requires reconciliation and adequate policy support. For instance, Kvartiuk and Petrick (2021) reveal that Kazakhstan must adopt modest reforms and bolder steps to realize its sustainable agricultural vision. China started CA during the late 1990s (with a land area of 1.3 Mha) and since then has expanded further, mainly in the rice production system, with an area of 3.1 Mha in 2011 (Wani et al., 2016). However, the adoption, growth, and spread of CA practices are widely varied in different regions. Modest and skewed adoption of zero-tillage cultivation with full CA practice has been reported in South Asian countries, including India, Pakistan, Nepal, and Bangladesh (Basnet & Hoque, 2022; Farooq & Siddique, 2015; Jayaraman et al., 2021; Kassam et al., 2019). In Bangladesh, several international organizations (e.g., the International Maize and Wheat Improvement Center, the Cereal System Initiative in South Asia, and Cornell University) are working in collaboration with the Department of Agricultural Extension (DAE) and local non-government organizations (NGOs) to promote CA technologies among farmers in the north-west, south, and central parts of the country (Hossain et al., 2015). These projects increased the awareness of the farmers in this region and supported some farmers by providing quality seeds, the required information and training, and essential equipment and machines.

A normative assumption regarding research, trials, and promotional activities of a new agricultural technology is that it will be widely adopted by farmers (Alexander et al., 2020).

Ruzzante et al. (2021) note that empirical studies of such adoption attempt to identify and examine the motivational or demotivational factors for adoption associated with the characteristics of adopters and non-adopters. As Brown et al. (2017) argue, this binary classification to study agricultural technology adoption is a narrow and confined framework that does not dive deep into other adoption issues, including intensity, modification, and incentive-driven interim practices. Like the adoption of many other new technologies, CA is subject to a variety of variables and can be influenced by many factors, including costs, risks, perceived and received benefits, resources (human, land, and financial), and farmers' preferences (Hoque & Tama, 2021; Pannell et al., 2014). Morris and Potter (1995) argue that an individual's decision to adopt new technology depends on their characteristics, the context, and the properties of the technology. The interest of this research work lies in the adoption of CA in Bangladesh – its progress, challenges, and sustainability at large. Several research projects have been initiated and carried out over the last 15 years to spread CA across the country (Hossain, 2017). Hossain (2017) explored several factors that limit CA from occurring in Bangladesh, including farmers' beliefs, peer pressure, a lack of private sector investment, perceived difficulties, and environmental and health concerns. Islam et al. (2020) collected data from randomly selected 100 farmers from one district (Brahmanbaria, located in the eastern part of Bangladesh) and revealed that the majority of the farmers in the area had a medium extent of adoption, while 80% had a highly favorable attitude towards the practice. The study recommends further studies to explore various factors limiting CA adoption in the country. Recent technology adoption studies have highlighted the relations between factors and constraints (Onuche et al., 2020; Singas & Manus, 2014; Uddin et al., 2021). In the case of CA in Bangladesh, the existing studies have neither categorically focused solely on farmers who have prior knowledge but have not adopted CA practice nor explored the linkages and relations between socioeconomic factors and constraints perceived by the farmers. This study contributes to this knowledge gap.

3. MATERIALS AND METHODS

3.1 Conceptual Framework

Fig. 1 illustrates the framework and the relational dynamics among various components,

approaches, and rationales of the approaches to the objectives of this study.

Based on the review of existing literature and the pilot survey, this research identifies a set of socioeconomic and demographic factors influencing the farmers' decisions in Bangladesh, who decide not to adopt the technology. The factors are divided into three categories: (i) individual and household characteristics (age, formal education, and household size); (ii) institutional characteristics (training experience, access to extension services, access to CA training, and access to equipment and machines); and (iii) farming characteristics (farm size and farming experience). The factors serve as building blocks for conceptualizing this study. These factors influence farmers' perceptions about the constraints for CA adoption. Some of these factors are crucial to the perceived constraints. The SWOT analysis was conducted with the farmers through the questionnaire, which identifies the strengths, weaknesses, opportunities, and threats of CA. The relational dynamics among crucial factors, perceived constraints, strengths, weaknesses, opportunities, and threats show directions toward the required policy and research interventions to stimulate CA adoption among the farmers in the study area. The interventions can be designed based on the identified socioeconomic and demographic characteristics to influence crucial factors and mitigate perceived constraints.

3.2 Study Area

This study was done in three northern districts (Rajshahi, Dinajpur, and Rangpur) of Bangladesh. The Rajshahi district lies between 24°22'26" N and 88°36'04" E, and the Dinajpur district is located between 25°10' and 26°04' north latitudes and between 88°23' and 89°18' east longitudes. Rangpur is located between 15°03' and 26°00' north latitudes and 88°57' and 89°32' east longitudes (GOB, 2019). Agriculture is the main source of livelihood for the farmworkers in these selected districts (Alamgir et al., 2018; Haque et al., 2017; Hoque, 2024; Hoque & Tama, 2020; Roy et al., 2015; Tama et al., 2018). This plains-land region experiences low and erratic rainfall with relatively high temperatures and limited soil moisture storage (Rashid et al., 2017). The early impacts of climate change in this area include lack of fresh and irrigation water, frequent floods, and natural disasters (Salam et al., 2021). The major crops are rice, wheat, maize, potato, and mustard

(BAMIS, 2022). These highly drought-prone areas have drawn various interventions in their agricultural and irrigation practices (Farid et al., 2015). These national and international

interventions deal with a wide range from climate change issues related to agriculture, and CA remains an integral part of these interventions (GOB, 2019; Haque et al., 2016; Lee & Hoque, 2024).



Fig. 1. Conceptual framework

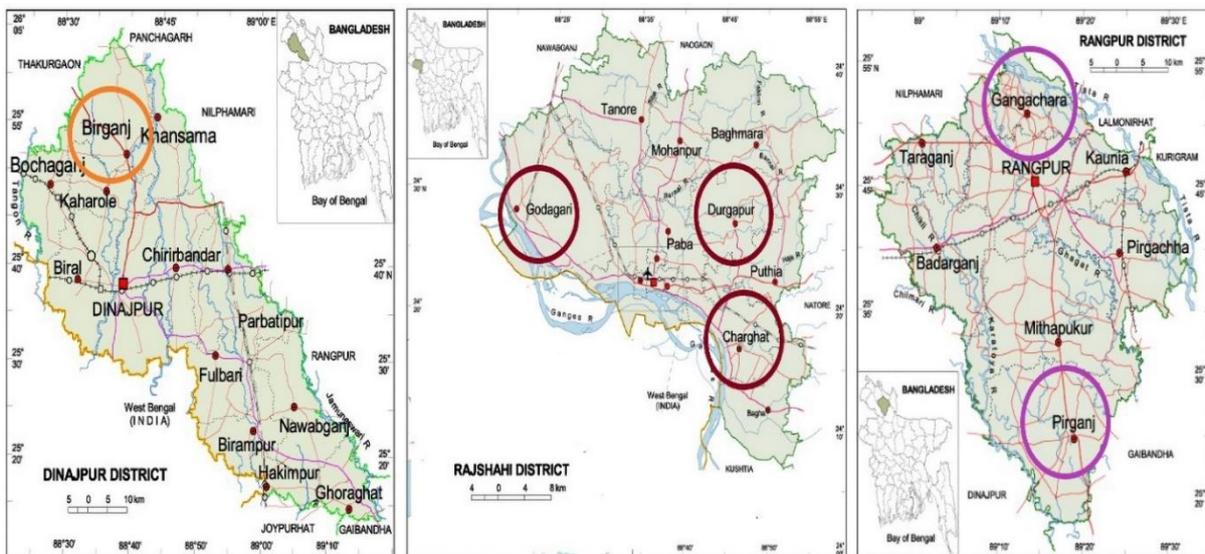


Fig. 2. Map of the study areas



Fig. 3. Sampling technique

Even though CA is less known in Bangladesh as an agricultural technological innovation, farmers from the selected areas are more aware of it due to the demonstrations made by the interventions mentioned above. This is a major reason why these areas were chosen for this study. The number of farmers engaged in CA is also relatively high in the country's northern parts (Alam & Hoque, 2022; Tama et al., 2021). Therefore, it was assumed that the participant farmers' knowledge and views could be easily accessible for this study.

3.3 Sample Selection

The study adopted a multi-stage sampling technique to select sample households and farmers. This technique is widely used in household-based surveys to collect data from a targeted group of people and render it sequentially across two or more ordered stages (Chauvet, 2015; "Multi-Stage Sample," 2008). Fig. 3 portrays the several stages followed as part of this sampling technique. Firstly, three districts (i.e., Dinajpur, Rajshahi, and Rangpur) from the northern parts of Bangladesh were selected as study areas. As mentioned earlier, projects have been in operation to spread CA in this region, and many farmers were already aware of the features and principles of this technology. Given that irrigation is often a very costly solution for drylands and not easily accessible at times, CA in this region is preferred as a practice to make efficient use of scarce water resources and make the best use of the minimum wetness of land (Hossain et al., 2015; Sunny et al., 2022).

In the second stage, upazilas (smaller geographic units under a district) were chosen from each of the districts based on the coverage of CA promotion and the availability of CA

adopters. Thirdly, with the help of the Regional Wheat Research Centre (RWRC) and Regional Agricultural Research Station (RARS), a list of CA farmers from the selected nine villages was obtained. These CA farmers provided a directory of their peer farmers who previously received awareness support (training and in-kind) from the local NGOs and extension services but did not adopt CA. This is how a register of 300 farmers, who had prior basic awareness about CA but never adopted it, was created as a primary sample. A working questionnaire led to a pilot survey with 30 farmers to test the reliability and adequacy of the research data and method. Later, with an updated questionnaire, a survey was conducted with 220 farmers (male: 217; female: 3) from July to September in 2019.

All respondents were heads of the households and were responsible for more than 70% of their household's agricultural activities. The farmers were interested in participating in the survey as it was off-season and their workload was light. Simultaneously, with the rest of the selected farmers, nine village-based Focus Group Discussions (FGDs) were conducted to further examine the survey data (e.g., extreme observations) and obtain crucial insights. Each discussion lasted about an hour and was joined by five participant farmers. Five local service providers (LSPs) who rent specialized machines to the CA farmers and often operate these machines themselves also participated in some of these discussions.

3.4 Designing the Questionnaire

Data collection for this research work demanded a solid and structured questionnaire that could collect pertinent information. Hence, the questionnaire used in this study was divided into two broad sections. The first section was

designed to accumulate the socioeconomic characteristics of respondents, including age, sex, formal education level, household size, farm size, and farming experience. The second section gathered information in relation to the practices of conservation agriculture, issues and concerns explored by practicing CA farmers, and perceived barriers mentioned by farmers to adopting CA. One part of the interview collected information regarding the strengths, weaknesses, opportunities, and threats of CA farming from the farmers. The questionnaire was informed mainly by the literature review (refer to Section 2), prior studies and observations of the researcher, and consultations with several experts in the field. The pilot study examined whether the initial questionnaire needed further corrections. Eventually, the final version of the questionnaire was prepared for data collection. Several students from the Bangladesh Agricultural University were hired and trained to collect data. During the data collection period, data enumerators collected most of the data in local units, which were later converted to the global standards with careful scrutiny.

3.5 Analytical Technique

The study applied descriptive statistics (i.e., percentages, averages, ranks, maximum value, minimum value, and so forth) to create an analytical foundation, while a mathematical technique (i.e., PCI-Problem Confrontation Index) was used to achieve the objective of the study. Studies have previously adopted PCI as a model to analyze the depth of a set of previously identified issues (e.g., Dhar et al., 2018; Uddin & Dhar, 2018). PCI scores of the perceived barriers were calculated for farmers in the areas where a large number of farmers practice CA. The selected farmers were asked to give their opinion on 12 selected problems that had been identified during the pilot study and data collection. After computing the PCI score, the problems were ranked according to their respective scores. Each farmer was asked to indicate the extent of difficulty caused by each of the problems by checking any of the four responses: "high," "medium," "low," and "not at all," and weights were assigned to these responses: 3, 2, 1, and 0. Thus, the possible range of the problem confrontation score for each problem could be 0 to 3, and the possible range of the overall problem confrontation score for 12 constraints for each farmer could range from 0 to 36. In this case, a score of 0 indicates that they do not perceive it as a problem at all, while a score of

36 indicates that the problem is perceived as a 'very high level' concern. The PCI scores of each selected problem were calculated using the following equation (1):

$$PCI = (P_{high} \times 3) + (P_{medium} \times 2) + (P_{low} \times 1) + (P_{not\ at\ all} \times 0) \text{ -----(1)}$$

where, P_{high} represents the number of responses indicating that the problem occurred frequently; P_{medium} is the number of responses indicating that the problem occurred occasionally; P_{low} denotes the number of responses indicating that the problem occurred rarely; and $P_{not\ at\ all}$ is the number of responses indicating no problem at all.

The cumulative PCI score of any given problem for 220 participating farmers could range from 0 to 660 (minimum score: 0, maximum: 3), where 0 indicates that the problem was perceived as an insignificant constraint and 660 indicates that the problem was regarded as a very high constraint with high frequency in the region. Pearson's product-moment correlation coefficient was conducted to explore the relation or association between socioeconomic and demographic characteristics of farmers and possible constraints to adopting CA farming.

$$r_{xy} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \text{ -----(2)}$$

where, r_{xy} denotes Pearson's product-moment correlation coefficient; and \bar{x} and \bar{y} are the averages of the variables, respectively.

Multiple regression analysis is an established technique in agricultural studies. For instance, in a farm-level analysis focused on tilapia fish culture in Bangladesh, Uddin et al. (2021) used this analysis to recognize the constraints and their related factors. This study also performed multiple regression analyses to determine the factors influencing the constraints. The equation of multiple regression is:

$$y_i = \beta_0 + \beta_i \sum_{i=1}^{11} X_i + \varepsilon_i \text{ -----(3)}$$

where, Y_i is the constraint to adopt CA farming, and $X_1, X_2, \dots,$ and X_{11} represent age, formal education, training experience, access to machines, household size, access to extension service age, access to CA training, farming experience (<10 years), farming experience (11-20 years), farming experience (>20 years), and farm size, respectively. β_i are the coefficients of the independent variables.

A SWOT analysis identifies the positives and negatives inside an organizational setting (S-W) and outside of it in the external environment (O-T). A SWOT analysis was also conducted to identify the challenges and opportunities of CA practice. Identified SWOT components (strengths, weaknesses, opportunities, and threats) were compared against the constraints to achieve the matrix of required interventions. Finally, these recommended interventions were divided into three categories: policy intervention required, research required, and extension service required.

4. RESULTS AND DISCUSSION

The study investigates farmers' perceived barriers regarding the adoption of conservation agriculture practices and explores farmers' socioeconomic and demographic factors influencing those perceived barriers. It further evaluates the strengths, weaknesses, opportunities, and threats of CA practice. This section outlines the findings of the study and discusses their implications.

4.1 Socioeconomic and Demographic Characteristics of Farmers

Table 1's descriptive statistics show the farmer's socioeconomic and demographic characteristics. The data indicates that the average age of the 220 respondents is 44.3. More than two-thirds of the farmers left school before completing secondary education, while only three farmers reportedly received tertiary-level education. 65.45% of the farmers received some sort of training related to agricultural farming, including the technical know-how of new technologies and innovative farming skills and methods. Usually, NGOs and local extension service departments offer these training programs.

About half of these farmers shared that they could get access to heavy equipment and machines required for CA farming. The average number of individuals belonging to the respective households was 5.7. More than half of the farmers (56.36%) had access to government agricultural extension services. 34.64% of the respondents could receive or have access to training related to CA farming. All these farmers had considerable experience in farming. 44.09% of them had more than 21 years of farming experience, while 31.36% had experience spanning fewer than 10 years. The majority of the farmers were small-scale farmers, and the average cultivable farm size owned by the

farmers was about 83 decimals (i.e., 0.34 hectares). According to the Bangladesh Bureau of Statistics, farm sizes (in decimals) are divided into three categories: small (5–249; i.e., below 1 hectare); medium (250–749; i.e., 1–3 hectares); and large (750 and above; i.e., above 3 hectares) (BBS, 2018).

4.2 Extent of Constraints to Adopting CA

Table 2 shows the PCI of 220 farmers, and the computed PCI score of the 12 problems ranged from 398 to 618. When a problem statement receives a high PCI score, it indicates that farmers view it as a high-level constraint. 192 farmers identified the unavailability of machines (Problem 1) as their major worry about practicing CA. The farmers were found to be not too worried about the reduced yield in the short run of adopting CA since it received the lowest PCI score (398).

As mentioned above, the machines needed for CA farming were the most significant barrier for the farmers. Specialized machines are needed for minimizing soil disturbance when planting in strip mode. Although farmers reported that they had access to the required machines (Table 2), they perceived that they would not be able to use those machines when needed. Only a small number of machines (e.g., power tiller-operated seeders, power tiller-operated bed planters, power tiller-operated strip-tillage seeders, and power tiller-operated zero-tillage seeders) were available for several villages. Therefore, in the critical times of land preparation and seeding, this limited number of machines could not meet farmers' high demand. Farmers were also worried about the timely availability of trained operators for these specialized machines. In addition, LSPs, while participating in the group discussions, brought up the issue of spare parts scarcity. They often had to travel far to purchase spare parts for their machines, which cost them extra time and money. This remains a major obstacle for CA adoption in the study area. Based on their findings, Bell et al. (2018) similarly argued that increasing the adoption rate and continuation of CA practices in agriculture requires easy access for farmers to specialized machines and an increased supply of machines. Moreover, the performance analysis of newly developed CA machines is required, and the field-level economic evaluation of CA technology is also essential for farmers (Tabriz et al., 2021). Institutional credit can play a vital role in purchasing machines and spare parts for the machines.

Table 1. Socioeconomic and demographic profile of the farmers

	Variables	Type and description	No.	Avg	Percentage (%)
Individual or household characteristics	(1) Age	Continuous		44.31	
		(2) Formal education	Categorical		
		Illiterate (No formal education)	48		21.82
		Primary level (class 1-5)	65		29.54
		Secondary level (class 6-10)	82		37.27
		Higher Secondary (class 11-12)	22		10.00
		Graduate (bachelor and above)	3		1.36
	(3) Household size	Continuous		5.69	
Institutional characteristics	(1) Training experience	Dummy			
		Yes (1)	144		65.45
		No (0)	76		34.55
	(2) Access to machines	Dummy			
		Yes (1)	116		52.73
		No (0)	104		47.27
	(3) Access to extension service	Dummy			
		Yes (1)	124		56.36
	No (0)	96		43.64	
(4) Access to CA training	Dummy				
	Yes (1)	85		38.64	
	No (0)	135		61.36	
Farming characteristics	(1) Farming experience	Categorical			
		<10 years	69		31.36
		11-20 years	54		24.55
		>21 years	97		44.09
	(2) Farm size	Continuous		83.49	

The second-highest PCI score was recorded for the issue of farmers having little knowledge (understanding) of the new farming practice. Lack of adequate knowledge on this farming practice is a big concern, and farmers are worried about whether they would be able to execute this new technology and cope with the associated risks. Liniger et al. (2011) also identified knowledge deficiency and associated risk as key constraints to adopting CA farming in sub-Saharan Africa.

The third-highest PCI scores reflect the lack of technical support and farmers' perceptions of CA being a more complex practice than conventional farming. Maintaining all three principles together seems like a complex and tedious task for the farmers. Tama et al. (2021) revealed that farmers with adequate knowledge about CA farming are more likely to develop behavioral intentions to adopt it in Bangladesh. Several participants in the FGDs point out that farmers are skeptical about getting regular extension services for CA farming. As per the PCI score, the issue ranked as the 5th-most critical constraint.

Farmers do not have easy access to updated information about CA. They could not mention any government-run awareness program in CA. In the case of Lebanon, Chalak et al. (2017) found that farmers who receive practical knowledge and information about farming systems from extension agents have a higher probability of adopting CA. Concern about the short-term economic benefits of adopting CA is the next issue that PCI highlights. Since CA farming gives a maximum return in the long run, farmers are unsure about the extra costs related to this practice. Regarding the adoption, farmers expect and wait to have easy access to formal or institutional credits, providing them with financial support. Dhar (2017) and Dhar et al. (2018) highlight the lack of credits as a major barrier to widespread CA adoption in Bangladesh. The second principle of CA is to leave 30% of crop residue, which will mix with the soil later and improve soil quality (FAO, 2019). Conventional farming allows farmers to reap crop residue for livestock feed and cooking fuel. Most of the selected farmers stated that leaving crop residues in the field is an additional burden.

Rufino et al. (2011) and Dhar (2017) also found that retaining residue of the crop on the field is hard for farmers, especially for those with low income and small areas of land. Farmers are also worried about bearing the cost of machines and the initial capital investment required for CA farming. Government incentives, subsidies, and support always play a significant role in stimulating adoption behavior for any new agricultural technology, including CA (Kassam et al., 2014). The PCI score regarding soil quality and water retention shows that many farmers are highly concerned. They are worried about the future scarcity of irrigation and groundwater. It means that CA is a potential solution to their concern.

Two-thirds of the farmers were found to have relatively low confidence in CA. However, they were seeking to gather more information and evidence from their peers who had been practicing CA. This finding indicates that farmers who are currently less confident about CA are likely to develop positive attitudes towards CA adoption, but that requires incentives to motivate their intention. It further reflects that experience is a significant driver in this issue, and sharing stories of best practices may also work as a stimulus. The lowest PCI score belongs to the problem that farmers are worried about minimum tillage reducing the regular yield. Corbeels et al. (2020) compared the yields of tillage-based and CA-based farming in sub-Saharan Africa and concluded that, despite having benefits regarding soil conservation, CA is not suited for smallholder farmers. In the case of crop yield productivity, their evidence showed mixed results. However, only a quarter (26%) of farmers (who are most smallholders) expressed their fear that adopting CA may lessen their crop yield. In contrast, half of the farmers do not perceive zero-tillage or minimum-tillage farming as a worrying factor for crop yield.

4.3 Linkages Between Farmers' Socioeconomic and Demographic Characteristics and the Perceived Barriers in Adopting CA

Our research demonstrates that a variety of socioeconomic factors make the adoption of CA farming methods challenging (Table 3).

Farmers' age, household size, and farming experience (more than 20 years) were found to have positive correlations with constraints, which means that the constraints are more strongly

perceived and valued by farmers with more experience and relatively large household sizes. This reflects the risk-avoiding tendency of elderly farmers. In contrast, negative associations were found between the rest of the socioeconomic variables (formal education, training experience, timely availability of machines, access to extension services and CA training, farming experience with less than 20 years, and farm size) and perceived constraints. The perceptions regarding these constraints are less strong among educated and trained farmers. Mitigating the perceived barriers requires more attention to the negatively associated explanatory variables. After studying a farm-level fish culture in Bangladesh, Uddin et al. (2021) revealed a similar negative correlation between socioeconomic variables (education, farming experience, training experience, extension media contact) and constraints.

4.4 Socioeconomic Factors Affecting the Decision to Adopt CA

Evidence suggests that the factors attached to the socioeconomic characteristics of a potential user are always crucial drivers of new technology adoption (Afza et al., 2015; Islam & Hoque, 2022; Khoza et al., 2019; Mittal & Mehar, 2016; Tambotoh et al., 2015). Table 4 represents the results of a multiple linear regression analysis that was performed to determine the factors that influence the constraints perceived by farmers when adopting CA farming. The findings demonstrate that out of all explanatory variables, farmers' level of formal education, training experience, availability of machines, and farm size are significantly related to the constraints perceived by farmers.

Table 4 shows that the coefficient of determination (R^2) is 0.580, which indicates that the exogenous variables (e.g., age, formal education, farm size) included in the model could explain 58% of the variance of the endogenous variable (i.e., perceived constraints). The results demonstrate that the level of formal education, training experience, availability of machines, and farm size of these farmers have a significant and negative influence on the constraints to adopting CA farming. Access to extension services and CA training has a negative but non-significant effect on constraints. The rest of the explanatory variables (i.e., age, household size, and farming experience) are non-significant but have a positive impact on the constraints faced by non-CA farmers.

Table 2. Problem Confrontation Index (PCI) for non-CA farmers

Problems stated by respondents	High	Medium	Low	Not at all	PCI	Rank
1. I am worried about the timely availability of machines required for CA practice.	192	15	12	1	618	1
2. I don't know the details about CA and am worried about making a decision.	179	25	14	2	601	2
3. I need technical support to adopt CA.	172	34	12	2	596	3
4. I think CA is more complicated than my current practice.	161	33	21	5	570	4
5. I am worried about getting services from extension service providers when needed.	157	27	34	2	559	5
6. CA will increase the yield only in the long run, and I am not able to operate in the current situation.	152	31	36	1	554	6
7. I think that CA could be more expensive than conventional methods.	136	51	30	3	540	7
8. Currently, I use crop residues for livestock feeding and fuel, so I cannot leave them on the ground.	108	78	31	3	511	8
9. I cannot afford the machine's cost or the initial investment required for CA.	120	59	32	9	510	9
10. Soil quality and water are major concerns for me.	57	131	28	4	461	10
11. I shall adopt CA in the future, as I have less confidence now.	73	71	70	6	431	11
12. I worry that minimum or zero tillage would reduce the yields.	58	65	94	3	398	12

Table 3. Relationship between farmers’ socioeconomic characteristics and constraints

Explanatory variables	Correlation coefficient (r)
Age	0.380**
Formal education	- 0.541**
Training experience	- 0.492**
Access to machines	- 0.518**
Household size	0 .241**
Access to extension services	- 0.411**
Access to CA training	- 0.318**
Farming experience (<10 years)	- 0.278**
Farming experience (11-20 years)	- 0.168*
Farming experience (>20 years years)	0.400**
Farm size	- 0.584**

** Correlation is significant at the 0.01 level (2 tailed); * Correlation is significant at the 0.05 level (2 tailed)

Table 4. Summary of the Multiple Linear Regression Model

Explanatory variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	β_i	Std. Error	Beta		
β_0 (Constant)					0.000
β_1 (Age)	0.072	0.079	0.082	0.912	0.363
β_2 (Formal education)	-1.526	0.574	-0.165	-2.657	0.009
β_3 (Training experience)	-2.800	1.029	-0.147	-2.721	0.007
β_4 (Access to machines)	-3.508	0.993	-0.194	-3.533	0.001
β_5 (Household size)	0.119	0.311	0.019	0.382	0.703
β_6 (Access to extension services)	-1.189	1.003	-0.065	-1.185	0.237
β_7 (Access to CA training (β_7))	-1.604	0.944	-0.086	-1.700	0.091
β_8 (Farming experience: <10 years)	2.176	4.545	0.112	0.479	0.633
β_9 (Farming experience:11-20 years)	2.419	4.537	0.115	0.533	.0595
β_{10} (Farming experience: (>21 years)	2.250	4.339	0.124	0.518	0.605
β_{11} (Farm size)	-0.069	0.009	-0.391	-7.558	0.000
$R^2= 0.580$ Adjusted $R^2= 0.558$					

Findings demonstrate that years of formal education have a negative coefficient, meaning that the higher level of formal education received by the farmers is less likely to have future constraints on adopting CA farming. Singas and Manus (2014) note that the successful adoption of new technology or innovation depends on the level of knowledge and skills of the farmers. Making these farmers more educated through informal educational platforms such as social media, messaging, television, and door-to-door information dissemination can be helpful not only in increasing their knowledge but also in engaging them in the cognitive process of actively recognizing the value of CA. Training experience has negative coefficients, meaning that with more training experience on any farming-related issues, farmers are less likely to face problems related to the adoption of CA farming. Training is crucial for diffusing any technology among the target group. In this case, government departments and NGOs that provide agricultural extension services can also arrange

regular training programs for both CA and non-CA farmers. Ongoing projects can provide the trainee farmers with in-kind benefits to motivate them to adopt and practice CA. Amin et al. (2016) reveal that a higher level of experience, education, and training decreases the level of constraints faced by the farmers in Bangladesh.

Another factor that negatively influences the constraints of adopting this farming is the access to and timely availability of the machines required for CA farming. Access to modern machines for CA farming encourages farmers to adopt this farming method (Bell et al., 2018). Esabu and Ngwenya (2019) and Shetto et al. (2007) report that the inefficiency of CA machines and farm power impede its adoption. Farmers must be assured that machines will be available whenever they need or want them. Otherwise, their demotivation will further explode. And this is where the investments can be made by local and national public or private enterprises. A greater

Table 5. Summary of Strength, Weakness, Opportunities, Threats (SWOT) analysis matrix

	Positive Items	% of farmers	Negative Items	% of farmers
Internal	Strengths		Weakness	
	Lowering production costs	47.2	Lack of technical support and motivational program	78.2
	Beneficial to the environment	32.1	Crop residue management	51.5
	Improvement of soil quality	51.3	Scarcity of specialized machines	81.3
	Reducing attack by pests and insects	24.4	Low short-run economic return	45.1
	Sustainable production and economic return	51.6		
	Increasing farmers' income	71.2		
External	Opportunities		Threats	
	Saving irrigation water	68.9	Unpredictable nature of climate	52.3
	Labor opportunities	41.6	Effects of a fast-growing population	43.1
	Cooperative organization	37.8	Unstable market and price	44.2
	Subsidy on inputs	51.3		

Table 6. Required intervention matrix for future actions

Items	Policy intervention required	Research required	Extension service required
1. Properly introduce and explain the advantages and disadvantages of CA to the farmers who have not adopted this practice yet.		√	√
2. Enhance the farmers' knowledge about CA.		√	√
3. Arrange the training program for CA regularly.			√
4. Organize 'Field Days' frequently and regularly to discuss the benefits and limitations of CA.	√		√
5. Provide easy financing for the purchase of equipment or machines required for CA farming.	√		
6. Enhancing direct input subsidies.	√		
7. Arrange training programs to operate equipment or machines required for CA farming.	√		√
8. Providing farmers with easy access to agricultural technology, equipment, and machines	√		√

supply of these machines can meet the demand and reduce costs. The coefficient of farm size is negative in predicting the constraints to adopting CA farming. Large farmers with sufficient resources and capital are less likely to encounter barriers when adopting CA. Noack and Larsen (2019) report that larger farms provide farmers with a more stable income, and such farmers are more likely to benefit than the smaller farms in any farming. Muddassir et al. (2019) note that farm size is a vital factor that is significantly associated with awareness of adoption in fish farming, and in the case of tilapia culture, Uddin et al. (2021) found a positive association between farm size and constraints.

4.5 Results of SWOT Analysis

The SWOT analysis identifies and analyzes the factors (internal and external) that can influence farmers' decisions to adopt CA. Results (Table 5) indicate that 47.2% of farmers believed CA farming could lower the cost of production. 51.3% of farmers believed that CA can enhance soil quality, and 32.1% thought it was helpful for the environment. 24.4% of farmers thought that CA farming reduces pests and insects (e.g., rats in wheat cultivation). 51.6% of them believed CA practice provides sustainable production and economic returns.

78.2% of farmers perceived a lack of technical support and motivational programs for promoting CA. 51.5% of the farmers were interested in retaining crop residue in the field, while 81.3% were worried about the scarcity of specialized machines required for CA practice, and 45.1% were concerned about low economic returns in the short run.

Almost two-thirds of them believed that CA farming could save irrigation water. 41.6% of respondents perceived that CA requires less labor in comparison to conventional farming. 37.8% agreed that there is an opportunity to form different cooperative organizations for CA. 51.3% opined that there is a demand for providing government input subsidies for CA farming practices.

Several pieces of research highlight the role of CA in buffering against climate change (Brown et al., 2018; Hoque, 2020, 2023; Michler et al., 2019). However, 52.3% of participating farmers reported that the unpredictable nature of the climate is a major threat. They could not anticipate when rainfall would come, due to

which their preparation of the land could hardly rely on the nature of the climate. According to 43.1% of farmers, the need for more food production for the growing population increased. 44.2% of farmers identified unstable market prices as a potential threat. Often the price of the goods they produce goes down during harvesting season, and they have no other option but to sell their products at a loss. Those who were mindful that CA can potentially reduce crop yield in the initial years of its application perceived this unstable market price as an additional threat. Reduced use of inputs (e.g., labor, irrigation, machine cost) is less valuable for the non-CA farmers. Farmers are primarily concerned with immediate output in the form of yields.

4.6 Required Intervention Matrix

Based on the findings, this study recommends eight actions and interventions that can expedite the adoption rate and accelerate the diffusion of this technology in Bangladesh. The following matrix presents these recommendations against three relevant categories: policy intervention required, research required, and extension service required (Table 6).

5. CONCLUSIONS

This study aimed to investigate the perceived barriers that prevent farmers from adopting CA by assessing the relations between those constraints and farmers' socioeconomic and demographic characteristics. The analysis identified the strengths, weaknesses, opportunities, and threats of CA farming to recommend interventions and actions at different levels, which may propel the adoption rate of CA by the farmers in the study area. Findings indicate that participating farmers perceive several issues as constraints; some of those are directly related to their socioeconomic background, while others concern external factors. Farmers vividly opine that the unavailability of machines in the study area is one of the major external issues that negatively influences their willingness to adopt CA. Providing farmers with easy-to-get loans for buying these machines through cooperative measures can be one way to address this issue. Financial and administrative incentives to stimulate large-scale private investments and active assistance from concerned government offices can also boost the adoption rate.

Farmers' formal education level, training experience, access to machines, and the size of

farms are all influential determinants of the perceived constraints. Targeted interventions to address constraints related to the socioeconomic background are an obvious but long-term investment. The analysis indicates that interventions may also target influencing the demographic characteristics of current and future farmers. Knowledge is found to be a crucial factor in adoption. Besides formal schooling, farming experience increases the knowledge of a farmer. However, knowledge about traditional farming is rooted in the culture, while the requirement of relevant knowledge in adopting a new technology remains equally important. Skills that can be achieved either by practicing or by participating in training courses have a significant impact on forming positive attitudes in farmers. Apart from conventional ways of providing information and training, some peer group activities among experienced and non-experienced farmers may provide good results since subjective norms can be used as a guiding influence in rural areas. The findings also indicate that smallholder farmers are less likely to take risks by adopting CA since they are either not sure about the change in yield in the future or they simply do not have enough courage to experiment with the little land they have.

In conclusion, the constraints identified in this study explain the reasons why the farmers have not adopted CA. Interventions may be designed to address these constraints. Based on the findings, some policy actions and further research have been recommended to boost the CA adoption rate among farmers and improve environmental sustainability.

However, the limitations of this research have implications for how the findings of this study can be used. First, this research focused only on those farmers who did not adopt CA. A comparison with the practicing farmers could generate some interesting results. This attempt to assess the extent of constraints in CA adoption and explore the determinants of constraints is a limited view toward assessing the willingness of the farmers, considering that their decisions may have been influenced by other determinants in the wider socio-political context. The perceived barriers set out in the questionnaire were an outcome of the prior pilot survey and literature review done by the authors. In this regard, future studies can consider exploring more variables through in-depth interviews or a qualitative study design. As CA is a widely disseminated technology in the northern parts of Bangladesh, this research purposefully

selected some districts from that region. Therefore, findings may not have the same implications or relevance to other geographical areas of the country where socioeconomic and demographic factors are different.

CONSENT

The authors obtained written informed consent from the participating farmers.

The participating farmers gave oral consent to publish the data in an article.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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