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ORIGINAL PAPER

Effects of conservation farming practices on agro-ecosystem services for sustainable food security in Bangladesh

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Abstract
In South Asia, the long-term provision of agro-ecosystem services is threatened by accelerating climate change and undesirable farming practices. Conservation farming could help ensure sustainable ecosystem services and food security. This study was conducted in nine purposively selected districts in west and northwest Bangladesh. Data on conservation farming practices were collected from 540 farmers and 63 professionals, directly or indirectly involved with conservation farming, using two interview schedules and face-to-face interviews between July and November 2019. Multiple regression modeling (OLS) and path analyses were performed to identify the contribution of selected predictors of the direct and indirect effects of using conservation farming practices. Each conservation farming practice, including the system of rice intensification under permanent raised-beds, crop residue incorporation, and cover crops, affected components of farmers' food security. These conservation practices had moderately positive effects on agro-ecosystem services and food security for 82.2% of farmers studied. The effects of using conservation farming practices were significantly impacted by farmers' educational qualifications, training experience, and their knowledge about the conservation farming practices. The food security status of farmers was significantly impacted by their annual family income and knowledge about conservation farming practices. Regulation of soil fertility and water, soil structure, soil retention, nutrient cycling, and zero-tillage were important components of agro-ecosystems that improved food security by increasing crop yield. This study showed that conservation practices have a positive influence on agro-ecosystem services and food security in Bangladesh, individually and in combination. We suggest that further support to conservation farming is an important policy option for decision-makers given the vulnerability of ecosystem services and a need to ensure food security in South Asia.

Keywords Conservation farming · Agro-ecosystem · South Asia · Food security · Ordinary Least Squares (OLS) · Path analysis

Jel Classification Q5 · O1 · O3 · H51

1 Introduction

Conservation agriculture is an approach to managing agro-ecosystems to improve and sustain productivity and increase profits and food security while preserving and enhancing the resource base and the environment (AGRA, 2022). It is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (Meena, 2013). Agricultural production can be raised by optimizing the use of farming resources and reducing land degradation through the integrated management of available soil, water and biological resources, combined with external inputs. For example, mechanical tillage can be replaced by biological mixing of the soil, in which soil micro-organisms, roots, and soil fauna provide tillage and balance soil nutrients, while soil fertility can be managed through soil cover management, crop rotation, and weed management (Aziz et al., 2016; Nyanga et al., 2020; Peter et al., 2008). Conservation farming enhances

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soil health by improving soil aggregation (Blanco-Canqui & Lal, 2004) and increasing surface organic matter (SOM) and soil carbon (SOC) content (Franzluebbers, 2010). It also saves time and energy, enhances yields through timely seeding/planting, reduces pests and diseases through stimulation of biological diversity, and reduces greenhouse gas (GHG) emissions (Abdalla et al., 2016). Given its recognized benefits, there is an urgent need to implement conservation farming practices more widely to reduce the negative consequences of more intensive methods (Mishra, 2013). Where used, there are data showing that alternative agriculture management practices such as conservation farming have led to more positive than negative effects on ecosystem services (Lee & Lautenbach, 2016).

Like other South Asian countries, the sustainability of conservation farming practices and food security in Bangladesh is under threat from the continuous degradation of land and water resources. The Department of Agricultural Extension (DAE) is a government organization that promotes conservation farming practices throughout the country. The Department updated the New Agricultural Extension Policy (1996) as the National Agricultural Extension Policy (NAEP) (2012), which addressed the key constraints, emerging issues, and strategic shifts in the agriculture sector in the context of maintaining food security for a rapidly growing population. Several conservation farming practices are used in Bangladesh, including the system of rice intensification (SRI) in permanent raised soil beds; unflooded rice transplantation systems using the strip and raised bed method; permanent raised bed technology for wheat, maize, pulses, oil seeds, and vegetable and cotton crops; strip tillage technology; rain water harvesting; crop residue incorporation; drip irrigation; and mulching (Roth et al., 2005). However, a lack of technical knowledge, agricultural inputs, and resources have hindered the uptake of conservation farming (Kamwi & Siyambango, 2018; Mkomwa & Kassam, 2022; Silici, 2010). Therefore, understanding farmer perceptions of conservation farming is important for promoting the widespread adoption of these environmentally sustainable practices (Halbrendt et al., 2012).

An agroecosystem can be defined as a spatially and functionally coherent unit of agricultural activity and includes the living and non-living components involved in that unit, as well as their interactions (Schiera & Grasman, 1996). Agricultural ecosystems provide food, forage, bioenergy, and pharmaceuticals essential to human wellbeing and rely on ecosystem services provided by natural ecosystems (Power, 2010). Traditionally, agroecosystems have primarily been considered as sources of provisioning services, but, more recently, their contributions to other types of ecosystem services have been recognized (Djihouessi et al., 2022). Influenced by human management, ecosystem processes within agricultural systems can provide services that support provisioning services including pollination, pest control, genetic diversity for future agricultural use, soil retention, regulation of soil fertility, and nutrient cycling (MEA, 2005). Quantifying and appropriately managing agroecosystems can provide understanding of how conservation farming practices influence a wide range of ecosystem functions and services and summarize these effects in a meaningful way (Lindenmayer & Likens, 2011).

In Bangladesh, over half of the population faces some form of food insecurity, and food insecurity varies according to region (USAID, 2022). Households with the highest risk of food insecurity depend on low value, unsustainable, and unpredictable incomes from activities such as unskilled daily labor, marginal farming, or traditional/subsistence fishing (ARSS, 2018) and live in areas with a high recurrence of natural shocks (principally cyclones, flash and monsoon floods, riverbank erosion, and drought). These households are likely to possess the lowest levels of human capital (ARSS, 2018), physical capital (HIES, 2016), and financial capital (BBS, 2018). Uddin and Dhar (2016) reported a remarkable improvement in the livelihood status of farmers (including their food security) after adopting conservation agriculture practices in Bangladesh. Despite these associations, there is little information confirming the impact of conservation farming and ecosystem services on the livelihoods and food security of smallholder farmers in Bangladesh, and elsewhere.

Thus, the first objective of this study was to quantify the effects of selected conservation farming practices on agroecosystem services across a range of social, environmental, technical, economic, and psychological dimensions in Bangladesh. We then quantified conservation farming effects on food security status. We further assessed how a range of explanatory variables influenced these effects to help ensure sustainable agricultural and food security development in the country. It was hypothesized that there is a significant relationship between farmers' predictor variables and the effects of using conservation farming practices, and on food security status.

The remainder of the manuscript is structured as follows. Section 2 presents the methodology, with the results of our study given in Sect. 3. Section 4 contains a discussion of the research findings, and we draw overall conclusions with policy implications in Sect. 5.

2 Methodology

2.1 Data collection and sampling design

This research was carried out in nine Bangladesh *upazilas* (strata are sub-districts) from nine purposively selected *zilas* (strata are districts or provinces) where conservation farming practices are widely practiced: *Palashbari* from *Gaibandha*, *Khetlal* from *Joypurhat*, *Ghatail* from *Tangail*, *Nageshwari* from *Kurigram*, *Alamdanga* from *Chuadanga*, *Tetulia* from *Panchagar*, *Birganj* from *Dinajpur*, *Dimla* from *Nilphamari*, and *Jhikargachha* from *Jessor*. Two *union councils* (strata are municipalities) were selected randomly from each *upazila*, and three *mohollas* (strata are villages) were selected randomly from each *union council* (Fig. 1).

Farmers were selected from a list of farmers provided by the Department of Agriculture Extension (DAE), and the listed farmers were treated as the study population. As the Bangladesh government is actively and widely promoting conservation farming practices, this was a simple sample of all farmers in the nine sub-districts rather than those with certain characteristics. Then, ten farmers were selected randomly from each *mohalla*/village for face-to-face interviews. Thus, the sample size of the farmers in the study was 540. A structured interview schedule was used for data collection from the selected respondent farmers (see the questionnaire in Supplementary Material (SM) Appendix B). The draft schedule was pre-tested in the study areas to make necessary alterations prior to data collection. The validity and reliability of psychological variable scales, such as extent of accessibility, extent of use, and extent of effects, were determined by pre-testing the data and following expert opinions from several disciplines and institutions.

Additionally, sixty-three Deputy Directors (DD) from agricultural discipline/Agricultural Officer (AO)/Agricultural Extension Officer (AEO)/agroecologist and/or subject matter specialists were selected using purposive and stratified random sampling. We considered district/sub-district level government and non-governmental organizational officials directly or indirectly working with agro-ecosystem services in the selected nine districts (Table 1). All these professionals (who had at least five years of service experience with at least two professional training sessions) were interviewed face-to-face using another interview schedule to understand their attitudes toward each conservation farming practice, a range of agro-ecosystem services, and food security status (see the questionnaire in Supplementary Material (SM) Appendix C). Data were aggregated and mean values calculated. Data from both the farmers and professionals were collected simultaneously between July and November 2019.

2.2 Minimizing farmer response bias

Both open questions (for example: how old are you? …… years old) and closed-ended questions (for example: do you have primary education? Yes/no) were asked at interview based on the research hypothesis. Before the interviews, it was confirmed that (i) the questions were relevant, short, direct, clear, and unambiguous; (ii) there were no leading questions; (iii) difficult questions were broken down and included interval questions; (iv) the language was precise with a simple set of answer options; and (v) the questionnaire had an appropriate structure (number of questions per page, was logical, and of appropriate length) through validity and reliability testing. Interviewers completed the questionnaire and noted responses during the interview period. To avoid any misunderstanding/misleading information between the interviewer(s) and interviewees, an experienced DAE representative (Sub-Assistant Agricultural Officer, SAAO) was present during the interview period by prior schedule. Uncertain answers were mainly solved through help from the SAAO. The SAAO kept each farmer's data record as their regular official task. Their presence helped to minimize uncertain responses. If they felt that a farmer provided an uncertain response, they helped to correct it by crosschecking with an official data record sheet. Sometimes uncertainty was resolved by spending time with the interviewees, establishing a rapport and then repeating the questions. The interviewers (researchers) also applied their professional expertise while conducting face-to-face interviews and took further support from local society leaders to minimize unexpected environmental and social effects.

2.3 Measurement of variables

Data on the following variables were obtained. Age of a farmer referred to the period from his/her date of birth to the time of the interview. Farmer's level of education was measured based on classes attended in the formal education system expressed as years of schooling. Family size was measured by counting the total number of family members based on his/her response. Effective farm size and area coverage under conservation farming practices were measured in hectares (ha). Types of farming and conservation farming practices were measured considering farmer's level of use of different conservation farming practices for crop production (see Table 2). Conservation farming practices considered included the degree of use of conservation agriculture, such as direct seeded no till rice–wheat; double no till in rice wheat and relay cropping of pulses; and cover crops (green manuring and pulse crops), where no chemical fertilizer or chemical pesticide was used. This was according to a previous study by the author (Ali, 2008), and see Table 2.

Annual household income referred to the income that a farmer earns from different sources (crops, livestock, poultry, daily labor, job). Assets were directly converted to present market value, finally counted as a total value and converted into a score. Farming experience refers to the experience of a farmer in agriculture in her/his field or others, expressed in year(s). Training exposure was measured by the total number of days of agricultural training received by the target farmer in her/his life. Knowledge of conservation

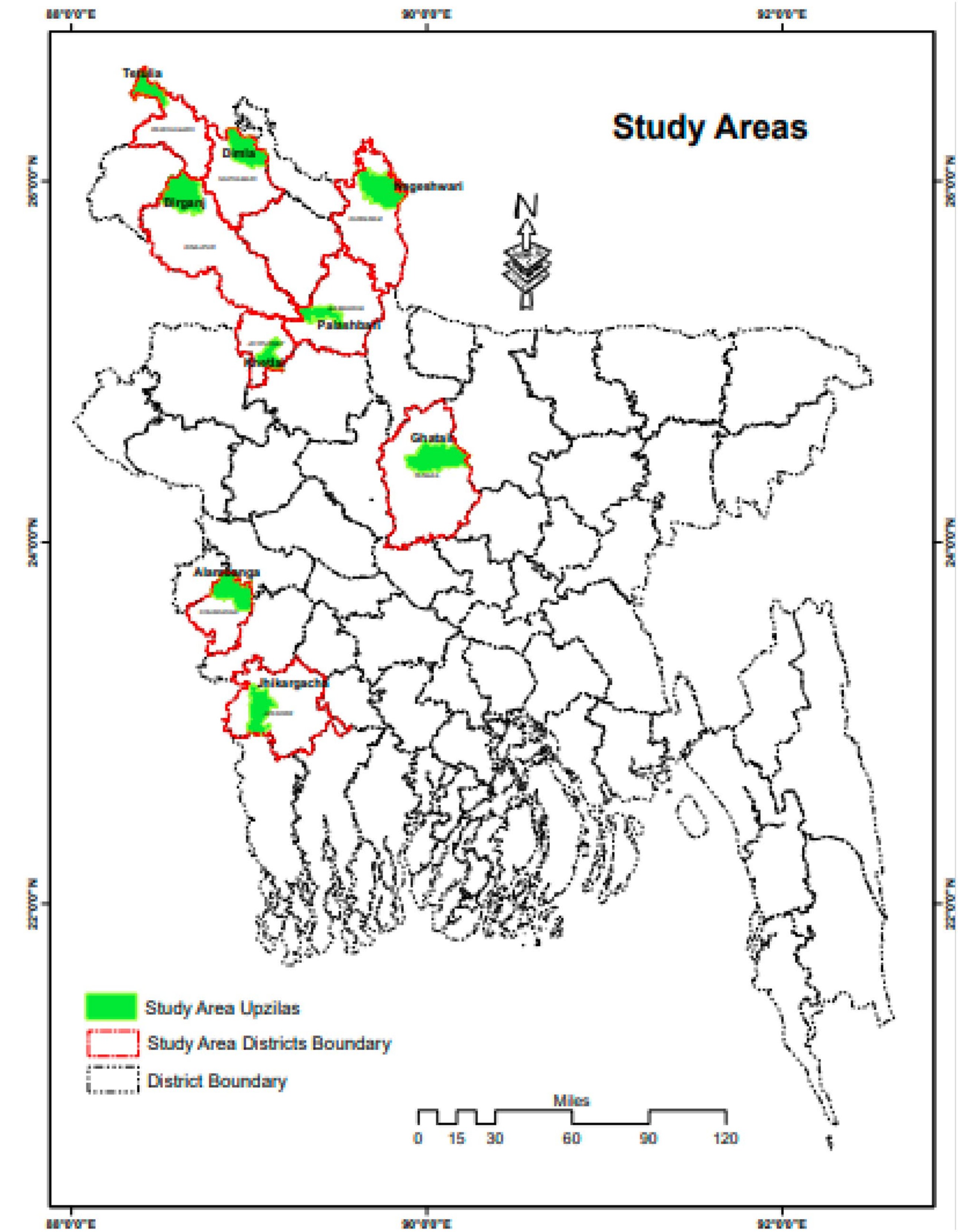

Fig. 1 Map of Bangladesh indicating study upazilas (sub-districts)

Table 1 The sample size of the eight survey districts in Bangladesh

Unit	Sampling method used	Sample size
District/province	Purposive	9
Upazila/sub-district	Stratified random sampling	9 × 1 = 9
Union councils/municipalities	Stratified random sampling	9 × 1 × 2 = 18
Moholla/village	Stratified random sampling	9 × 1 × 2 × 3 = 54
Household head	Simple random	9 × 1 × 2 × 3 × 10 = 540
Total farmers		**540**
DD/AO/AEO/agro-ecologist/subject matter specialist	District-based purposive sampling with stratified random sampling	**63**

farming practices was measured through a set of 15 questions in the interview schedule, such as How do you preserve soil fertility? Which kinds of fertilizers are applied by you? How do you control pests and diseases? How do you control weeds? etc. A score of two was assigned to each question. If the respondent could answer the question fully, she/he scored two; if she/he could answer the question partially, she/he scored one; and if she/he could not answer the question, she/he scored zero. The conservation agriculture knowledge score was measured as the sum of the scores for the 15 questions, so ranged from 0 to 30, where 0 indicated no conservation agriculture knowledge and 30 indicated very high knowledge. A farmer's agricultural extension contact was measured as the farmer's extent of contact with different channels used by extension services. Communication skill referred to the response of targeted farmers about their extent of use of ten agro-based communication media.

We employed four subcomponents of the effects of using conservation farming practices: i.e., social effects, environmental effects, technical and economic effects, and psychological effects measured with six, five, eleven, and three related statements, respectively (Ali, 2008). Statements related to social effects were: i. development of knowledge and skills; ii. development of organizational participation and extension contacts; iii. development of employment opportunities; iv. development of participation in meetings and training; v. development of counseling ability; and vi. development of decision-making ability. Statements related to environmental effects were: i. decrease in air and water pollution; ii. development of human health environment; iii. development of environment for animal and bird health; iv. decrease in crop pests; and v. increase in beneficial insects, earth worms, frogs, etc. Statements related to technical and economic effects were: i. increase in integrated crop management; ii. increase in cropping intensity; iii. increase in the use of local resources; iv. increase in soil microbial activity and fertility; v. increase in production of vegetables, fruits, and trees; vi. increase in poultry rearing; vii. increase in cow and goat rearing; viii. increase in fish culture; ix. decrease in production costs; x. increase in product quality; and xi. decrease in human diseases. Statements related to psychological effects were: i. positive development of human conduct; ii. development of social norms and values; and iii. positive development of human food habit.

The farmers' responses to each of the above statements were evaluated using a four-point Likert scale (high effect, moderate effect, low effect and no effect, and assigned scores of 3, 2, 1, and 0, respectively) while collecting the data. Therefore, the subcomponents scored 0–18 for social effects; 0–15 for environmental effects; 0–33 for technical and economic effects, and 0–9 for psychological effects. Finally, the observed aggregated mean score for each statement was

Table 2 Types of general farming and conservation farming practices employed in Bangladesh, according to (Ali, 2008)

Farming practice type	Level of use of general farming and conservation farming, chemical fertilizer, and chemical pesticide	% area in Bangladesh covered
Type-I	No use of conservation farming like "zero tillage technology", i.e., complete use (100%) of chemical fertilizers and chemical pesticides (i.e., general farming)	20–30%
Type-II	Less use of conservation farming practices like "rain water harvesting", with high use of chemical fertilizers and chemical pesticides (i. e., farmers use ± 25% conservation farming practices and ± 75% chemical fertilizer/chemical pesticides)	> 50%
Type-III	High use of conservation farming practices like "Mulching—crop residues, paddy straw, green leaves", with less use of chemical fertilizers and chemical pesticides (i. e., farmers use ± 75% conservation farming practices and ± 25% chemical fertilizer/chemical pesticides)	< 50%
Type-IV	Complete use (100%) of conservation farming practices like "strip tillage technology by the same crops", i.e., use of conservation farming practices without any chemical fertilizers and chemical pesticides	< 10%

treated as the effect of using conservation farming practices by the farmers in an ordinary least squares (OLS) model (Carifio & Perla, 2007). The overall observed score (0 to 75) was used to classify farmers into those with low-level effects (0 to 25), medium-level effects (26 to 50), and high-level effects (51 to 75) by considering the mean ± 1SD.

Food security was based on the four pillars described by FAO (2014): i.e., (i) food availability: focuses on the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (Wheeler & von Braun, 2013); (ii) food access: a variable condition of human consumers that affects all consumers every day (NSF, 2018); (iii) food utilization: the ability to exercise cultural food preferences and the effective use of food within households and communities to guarantee equitable nutrition (NSF, 2018); and (iv) food stability: when a population, household, or individual has access to food at all times (McMillan, 2018)**.** Food availability was measured by considering four related statements: i. conservation farming increases field crop, vegetable and fruit production that helps increase the availability of sufficient quantities of food of appropriate quality; ii. conservation farming helps to increase cow, goat, and poultry rearing to improve protein availability; iii. conservation farming controls water pollution and increases fish production and availability; and iv. conservation farming increases product quality that helps the intake of quality food. Food access was measured with three related statements: i. saving on production costs helps to increase farmers' food purchasing ability; ii. organic fruit and vegetables will attract higher prices that will help food access; and iii. organic produce increases farm income that increases food access. Food utilization was measured with four related statements: i. having access to information about conservation farming would make it easier for farmers to produce quality fruit and vegetables that allows better utilization of food; ii. conservation farming develops positive human food habits that helps positive food utilization; iii. increases farmer decision-making that helps food utilization; and iv. increases farmer knowledge and skills that helps food utilization. Food stability was measured with four related statements: i. conservation farming improves soil fertility and soil structure that helps to increase cropping intensity that maintains food stability; ii. conservation farming protects the environment and decreases water and air pollution to ensure food stability; iii. it decreases health hazards that increase food stability; and iv. conservation farming provides opportunities to reach better markets to increase food stability (Ali, 2008). Each item was evaluated using a four-point Likert scale (high, medium, low, and no, assigned scores of 3, 2, 1, and 0, respectively). Therefore, the subcomponents scored 0–12 for food availability; 0–9 for food access; 0–12 for food utilization; and 0–12 for food stability. Finally, the observed aggregated mean score for each statement was treated as a measure of food security status in the OLS model (Carifio & Perla, 2007). The variable measurements are shown in Table 3.

2.4 Professional opinion on effects of conservation farming practices on agro-ecosystem services and pillars of food security

We considered numerous combinations of conservation farming practices and agro-ecosystems services in this study in Bangladesh (see Table 4). Lists were constructed through validity and reliability testing. Expert opinion was considered by asking experts what percentage effect each conservation farming practice had on each agro-ecosystem component/service and on each food security pillar. Then the percentages of opinions were aggregated and calculated as a mean score.

2.5 Descriptive statistics and multivariate analysis

Data were coded, tabulated, compiled, and analyzed as needed. SPSS software was used for data analysis. Descriptive statistical measures including frequency, percentage distribution, range, rank order, average, and standard deviation (SD) were used. Multiple regression analysis was performed to explore the contributions of each farmer's selected factor/predictor/variable to the extent of the effects of using chosen conservation farming practices. To select and use more appropriate explanatory variables, variance inflation factor (VIF) analysis was conducted before OLS to minimize the variance of the regression coefficients by identifying multicollinearity (Sharoon, 2020) (see details in the Supplementary Material, Appendix A and Table A1).

The multiple regression models were:

$$Y_i = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + e; (i = 1 \& 2)$$

where Y_i is the effect of using conservation farming practices by the farmers (where $i = 1$) and Y_i is the food security status (where $i = 2$); α is the intercept; x_1 is their age; x_2 is level of education; x_3 is family size; x_4 is effective farm size; x_5 is area coverage under conservation farming practices; x_6 is annual family income; x_7 is farming experience; x_8 is training exposure; x_9 is knowledge on conservation farming practices; x_{10} is agricultural extension media contact; x_{11} is agricultural communication skill. β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8, β_9, β_{10}, β_{11} are regression coefficients of the corresponding independent variables, and "e" is a random error (the error in predicting the value of Y).

It is not possible to know the status of a direct effect of an independent variable through the combined effects

Table 3 Variable measurement technique, including variable name, measuring unit and fitted score

Variable name	Score
Age	1 for each complete year of age of the respondent
Level of education	Years of schooling
Family size	1 for each family member
Effective farm size	1 for each hectare (ha) of land
Area coverage under conservation farming practices	1 for each hectare (ha) of land under conservation farming practices
Types of farming/conservation farming practices	1 for Type-I, 2 for Type-II, 3 for Type-III, and 4 for Type IV
Annual household income	1 for each 1000 'taka' income in a year
Farming experience	1 for each year of farming experience
Training exposure	1 for each day of relevant training received by the respondent
Knowledge of conservation farming practices	2 for a correct answer, 1 for partial answer and 0 for no answer
Agricultural extension media contact	4 for regular contact, 3 for frequent contact, 2 for occasional contact, 1 for rare contact, and 0 for no contact
Agricultural communication skill	4 for regular communication, 3 for frequent communication, 2 for occasional communication, 1 for rare communication, and 0 for no communication
Effects of using conservation farming practices: social effects, environmental effects, technical and economic effects, and psychological effects	The effects were measured using a 4-point Likert scale: 0 for no effect, 1 for low effect, 2 for medium effect, and 3 for high effect. Mean scores for each statement were considered with respect to the dependent variable (effects of conservation farming practices) in the OLS model (Carifio & Perla, 2007) Categorical effects were measured by considering 3 categories as low-, medium-, and high-level effects from the observed positive scores (0 to 75) (mean ± 1SD)
Food security status:	Consists of the four pillars (FAO, 2014) and measured using a 4-point Likert uniform measuring scale. Mean scores were calculated for each statement (under each pillar) with respect to the dependent variable (food security status) in the OLS model (Carifio & Perla, 2007)
Food availability	0 for no, 1 for low, 2 for medium and 3 for high availability
Food access	0 for no, 1 for low, 2 for medium and 3 for high access
Food utilization	0 for no, 1 for low, 2 for medium and 3 for high utilization
Food stability	0 for no, 1 for low, 2 for medium and 3 for high stability

of other variables on the dependent variable. Path analysis was therefore conducted to investigate the direct and indirect effects of significant independent variables obtained through multiple regression analysis (Sasmal & Chakrabarty, 1978). The direct effect of an independent variable on the dependent variable is the standardized beta co-efficient ('b' value of regression analysis) of the respective independent variable. The indirect effect of an independent variable is measured by the following formula:

$$e = \sum bxr$$

where, e = total indirect effect of an independent variable; b = direct effect of the variable through which indirect effect is channeled; and r = correlation co-efficient between respective independent variables through which indirect effect is channeled.

2.6 Limitations of study

Our study used cross-sectional data from a household survey and there were no repeat observations for the same households, i.e., the study did not use panel data. With cross-sectional data we cannot control for time invariant unobserved heterogeneity. Given the data available and econometric estimations, the conclusions were subject to the caveats of cross-sectional data. Moreover, opinions by professionals about selected conservation farming practices had different degrees of usefulness, which could have influenced the study outcomes. Additionally, the farmers' limited knowledge about conservation farming practices, on which many of the assessments were made, was also a shortcoming of the study. Finally, overall, the food security assessment was relatively simple and indirect.

Table 4 List of conservation farming practices used in Bangladesh, agro-ecosystem components, and food security pillars

Selected conservation farming practices used by Bangladeshi farmers	Argo-ecosystem component/service considered	Food security pillars
System of rice intensification (SRI) with permanent raised soil bed	Pollination including wild pollinators	Food availability
Unflooded rice transplantation system using strip and raised beds	Biological pest control	Food access
Permanent raised soil bed technology for wheat, maize, pulses, oil seed, and vegetable and cotton crops	Regulation of soil fertility	Food utilization
Strip tillage technology for wheat, maize, pulses, oil seed, and vegetable and cotton crops	soil structure	Food stability
Dry seeded rice (DSR) under strip tillage and zero tillage	Water regulation	
Zero tillage technology, especially for chickpea, wheat and maize crops	Biodiversity	
Unflooded zero-till rice transplanting system in *boro* rice season	Genetic diversity for future agricultural use	
Rain water harvesting	Soil retention	
Crop residue incorporation	Soil nutrient cycling	
Drip/sprinkle/gated irrigation	Crop diversity	
Mulching-crop residues, paddy straw, green leaves	Crop rotation with mass/huge-flowering crops to sustain vital pollination services	
Cover crops, using green manuring and pulse crops	No-till systems	
Strip/hedgerow cropping system	Offset agricultural greenhouse gas emissions	
Double no-till in rice–wheat system and relay cropping of pulses	Planting cover crop	
Direct seeded no-till rice–wheat system Integrated farming with livestock	Soil organic carbon	
	Grow bioenergy (oilseed) crops at lower costs for biofuel production	

3 Results

Our findings are presented in six sections: (i) the predictive variables of the farmers; (ii) the effects of using conservation farming practices; (iii) opinions of professionals about the effects of conservation farming practices on components of their agro-ecosystem; (iv) professional opinions about the effects of conservational farming practices on components of their food security; (v) the level of contribution of each predictor to the effects of using conservation farming practices and effects on food security status; and (vi) the comparison of means of the effects of using conservation farming practices and food security status between selected districts.

3.1 Socio-economic profiles of farmers

Numerous factors could have influenced the effects of using conservation farming practices. Eleven predictor factors were selected through validity testing (based on advice from a panel of experts who reviewed the survey tool) and reliability testing (pre-testing in the survey areas through using the survey tool) as influencing the predictors. The predictors were age of farmer, level of education, family size, effective farm size, types of conservation farming practices, annual household income, farming experience, training exposure, knowledge of conservation farming practices, agricultural extension media contact, and agricultural communication skills. The values of these factors for the farmers and farms surveyed are in Table 5.

Middle-aged and older farmers were almost equally involved (middle-aged 42.2% and older 43.9%; total 86.1%) in using conservation farming practices, while only 13.9% of younger farmers were involved, similar to findings by Chandrani (2008) in a neighboring part of India. Farmers with a secondary education were most common (36.7%), followed by those that could write their name only (21.1%) and those educated at primary level (18.9%). The lowest proportion of farmers (6.7%) were above secondary educated, and 16.7% of farmers were illiterate, which was less than the national average (Bangladesh Bureau of Statistics (BBS), 2017). Farmer's wealth was not associated with educational status, although farmer's average farm size and their annual household incomes were above with the national average. Table 5 also shows that 82.2% of the study population were medium-sized families followed by large families (13.3%). Only 4.5% of farmers had a small family. The average farm size in the study area (1.51 ha) was significantly higher than the national average of 0.6 ha (BBS, 2017). With respect to area coverage under conservation farming practices, the majority of farmers had small (47.8%) or medium (46.3%) areas of conservation farming practices. Depending on crop type, ecological environment, and finances, all farmers used combined practices rather than solely chemical fertilizers and chemical pesticides or only conservation farming practices. The majority of farmers (38.9%) used Type-I and II combined practices; i.e., they used mixed practices involving a combination of chemical fertilizer with chemical pesticide and a few conservation farming practices. 30.2% used Type-I and III combined. Types-I, II, and III combined were used by 21.1% of farmers, and the

Table 5 Characteristics of the farmers and farms in the study areas in Bangladesh

Predictors	Category	Measuring unit	Number (%)	Mean	SD
Age	Young (≤ 35)	Year	75(13.9)	49.63	9.82
	Medium (36–50)		228(42.2)		
	Old (≥ 50)		237(43.9)		
Level of education	Illiterate (0)	Level of Schooling	90(16.7)	4.85	4.35
	Can sign only (0.5)		114(21.1)		
	Primary (1–5)		102(18.9)		
	Secondary (6–10)		198(36.7)		
	Above secondary (≥ 10)		36(6.7)		
Family size	Small (≤ 3)	Score	24(4.5)	6.17	2.19
	Medium (4–6)		444(82.2)		
	Large (≥ 6)		72(13.3)		
Effective farm size	Landless (≤ 0.02)	Hectare	0(0)	1.51	0.93
	Marginal (0.021–0.20)		0(0)		
	Small (0.21–1.0)		183(33.9)		
	Medium (1.01–3.0)		282(52.2)		
	Large (≥ 3.0)		75(13.9)		
Area coverage under conservation farming practices	Small (0.21–1.0)	Hectare	258(47.77)	1.36	1.19
	Medium (1.01–3.0)		250(46.30)		
	Large (≥ 3.0)		32(5.93)		
Types of conservation farming agriculture practices	Type-I & II	Score	210(38.9)	1.43	1.17
	Type-I & III		163(30.2)		
	Type-I, II & III		114(21.1)		
	Type-II & III		53(9.8)		
Annual household income	Low (≤ 120)	'000'Tk.	99(18.3)	198.73	87.77
	Medium (121–250)		318(58.9)		
	High (≥ 250)		123(22.8)		
Farming experience	Low (≤ 5)	Score	122(22.5)	7.32	2.58
	Medium (6–16)		289(52.0)		
	High (≥ 16)		138(25.4)		
Training exposure	Low (≤ 2)	Score	75(13.9)	5.91	3.52
	Medium (3–9)		366(67.8)		
	High (≥ 9)		99(18.3)		
Knowledge of conservation farming practices	Low knowledge (≤ 10)	Score	60(11.1)	14.22	3.31
	Medium knowledge (11–18)		417(77.2)		
	High knowledge (≥ 18)		63(11.7)		
Agric. extension media contact	No contact (0)	Score	53(9.9)	11.70	1.95
	Low contact (1–3)		117(21.6)		
	Medium contact (4–6)		243(45.0)		
	High contact (≥ 6)		127(23.5)		
Agric. communication skill	Low skill (≤ 8)	Score	109(20.2)	16.02	2.17
	Medium skill (9–20)		342(63.3)		
	High skill (≥ 21)		89(16.5)		

remainder (9.8%) used Types-II and III conservation farming practices. With respect to annual household income, 58.9% had a medium annual family income, followed by 22.8% with a high annual family income and 18.3% with a low annual income. Over half of farmers (52.0%) had six to 16 years farming experience, while an almost equal number of farmers had either less than five years or more than 16 years of farming experience. Although about 44% of farmers were in the "old" age group, only 25% had high levels of experience with farming activities. Just 4% of households (those with 2 ha land and above) controlled about one-third of the land area (BRAC, 2015). Training exposure scored one for each day of professional training. The highest proportion of farmers (67.8%) had medium training exposure compared with 18.3% with high and 13.9% with low training experience. Over two-thirds (77.2%) of farmers had medium knowledge of conservation farming practices, while 11.7% had high knowledge and 11.1% had low knowledge. The majority of farmers had a medium level of agricultural extension contact (45%) and agricultural communication skills (63.3%), both of which influence using conservation farming practices since both are directly related to agricultural department activities (see Ofuoku, 2012).

3.2 Effects of conservation farming practices on agro-ecosystem services and food security as perceived by farmers

Based on the effects of conservation farming practices on components of agro-ecosystem services and on farmers' food security as derived from Likert scores from the farmers, the farmers were categorized into a low-level effects group (scores 0 to 25), medium-level effects group (scores 26 to 50), or high-level effects group (scores 51 to 75) with respect to agro-ecosystem and food security. For agro-ecosystem services, 69.5% of farmers reported medium-level effects, 9.4% high-level effects, and 4.3% low-level effects of using conservation farming practices. Conservation farming practices were also said to affect the environment, with 53.8% reporting medium-level environmental effects, followed by 12.9% with low-level effects and 7.7% with high-level effects. In the case of technical and economic effects of using conservation farming practices, 64.2% had medium-level technical and economic effects, followed by 8.8% with low-level effects and 6.9% high-level effects. About 71.3% claimed medium-level psychological effects of using conservation farming practices, while only 0.9% had low and 10.0% had high-level psychological effects of using using conservation farming practices. Thus, an overwhelming majority of farmers perceived medium-level effects (69.5%; 53.8%; 64.2% and 71.3%) on agro-ecosystem from using conservation farming practices. The effects of using conservation farming practices on farmers' food security were higher than the effects on agro-ecosystem services in all cases (see Table 6). Medium effects of conservation farming practices were reported more often for farmers' food security than the low and high effects.

3.3 Professional opinions about effects of conservation farming practices on components of agro-ecosystem

In Table 7 the experts we surveyed reported that conservation farming practices had no effects on pollination, including wild pollinators as a component of agro-ecosystems. The professionals reported positive effects of conservation farming practices on several other components of agro-ecosystems like growing bioenergy crops, genetic diversity, soil organic carbon, and planting cover crops, but only at a low level (Table 7).

3.4 Professional opinions about effects of conservation farming practices on components of food security

Table 8 shows the professionals surveyed reported that conservational farming practices had less of an effect on food utilization than on the other three pillars of food security. The food utilization metric measures nutritional imbalance and malnutrition. Conservation farming practices also had

Table 6 Distribution of farmers according to their assessment of the percentage contribution of effects of conservation farming practices on components of agro-ecosystems and on their food security

Effects	Types of effects	% In low effects group (with observed scores 0 to 25)	% In medium effects group (observed scores 26 to 50)	% In high effects group (observed scores 51 to 75)
Effects on the agro-ecosystem	Social effects	4.3	69.5	9.4
	Environmental effects	12.9	53.8	7.7
	Technical and economic effects	8.8	64.2	6.9
	Psychological effects	0.9	71.3	10.0
	Overall effects	12.1	58.4	10.5
Effects on food security	Social effects	7.7	77.6	11.2
	Environmental effects	13.6	60.0	10.3
	Technical and economic effects	10.4	71.9	9.6
	Psychological effects	3.2	78.1	14.5
	Overall effects	14.8	65.4	12.3

Table 7 Percentages of professional opinion about effects of various conservation farming practices on components of agro-ecosystem

		Components of agro-ecosystem															
		Pollination including wild pollinators	Biological pest control	Regulation of soil fertility	Soil structure	Water regulation	Biodiversity	Genetic diversity for future agricultural use	Soil retention	Soil nutrient cycling	Crop diversity	Crop rotation with mass-flowering crops	No-tillage system	Offset agricultural greenhouse gas emissions	Planting cover crop	Soil organic carbon	Grow bioenergy crops
% Of opinion about effects of conservation farming practices on components of agro-ecosystem (mean value)	System of rice intensification (SRI) under permanent raised-bed conditions			24		31	26		19								
	Unflooded rice transplanting system by the strip and raised bed method				32	23			25					20			
	Permanent raised-bed technology for wheat, maize, pulse, oil seed, and vegetable and cotton crops				25	21			24				30				
	Strip tillage technology by the same crops			15	15	20			10	5	10	5			10		10
	DSR under the strip tillage and zero tillage methods				19	19			11	11			40				

Table 7 (continued)

	Components of agro-ecosystem															
	Pollination including wild pollinators	Biological pest control	Regulation of soil fertility	Soil structure	Water regulation	Biodiversity	Genetic diversity for future agricultural use	Soil retention	Soil nutrient cycling	Crop diversity	Crop rotation with mass-flowering crops	No-tillage system	Offset agricultural greenhouse gas emissions	Planting cover crop	Soil organic carbon	Grow bioenergy crops
Zero tillage technology, especially chick pea, wheat, and maize crops				13	7			6			6	48	20			
Unflooded zero till rice transplanting system in *boro* rice season				15				15				42	28			
Rain water harvesting					100											
Crop residue incorporation			20	10	5			11	39						15	
Drip/sprinkle/gated irrigation				23	50			27								
Mulching—crop residues, paddy straw, green leaves		10	15	14	11			26	11						13	
Cover crops—green manuring and pulse crops			10	10	5			10		10	15			30	10	
Strip/hedgerow cropping system				17	19			24		21	19					

Table 7 (continued)

	Components of agro-ecosystem															
	Pollination including wild pollinators	Biological pest control	Regulation of soil fertility	Soil structure	Water regulation	Biodiversity	Genetic diversity for future agricultural use	Soil retention	Soil nutrient cycling	Crop diversity	Crop rotation with mass-flowering crops	No-tillage system	Offset agricultural greenhouse gas emissions	Planting cover crop	Soil organic carbon	Grow bioenergy crops
Integrated farming with livestock			23			17	35		25							
Double no till in rice wheat and relay cropping of pulses			16		14					24		46				
Direct seeded no till rice – wheat				9	17			16	13			45				

no major impact on this pillar. Conservation farming had a comparatively greater positive impact on food availability and food access. Table 8 also suggests that the effects on food availability were higher than those on food access and that effects on food access were higher than on food stability.

3.5 Factors contributing to effects of using conservation farming practices and to food security status

About 61.1% (model-I; $R^2=0.611$) and 49.1% ($R^2=0.491$) of the variation of using conservation farming practices and farmers' food security status was attributed to farmer age, level of education, area coverage with conservation farming practices, annual family income, farming experience, training exposure, knowledge about conservation farming practices, and agricultural extension media contact. Additionally, 49.1% (model-II; $R^2=0.491$) of the variation in farmer's food security status was attributed to their age, level of education, effective farm size, area coverage with conservation farming practices, annual family income, farming experience, training exposure, and knowledge about conservation farming practices, making these suitable models. The F value indicated a significant model (model-I, $p=0.000$ and model-II, $p<0.0001$), and the adjusted R-square values of 0.584 (model-I) and 0.463 (model-II) showed that the variance was attributable to the predictor variables rather than chance, making it a suitable model (Table 9).

3.6 Path analysis: identifying direct and indirect effects of significant predictors

The path coefficient is a standardized partial regression coefficient which measures the direct influence of one variable upon another. In this way, it permits the separation of the correlation coefficient into components of direct and indirect effects, as in Table 10.

In model-I, the influencing predictors were: age (x_1); level of education (x_2); area coverage under conservation farming practices (x_5); annual family income (x_6); farming experience (x_7); training exposure (x_8); knowledge of conservation farming practices (x_9); and agricultural extension media contact (x_{10}). In model-II, influencing predictors were: age (x_1); level of education (x_2); effective farm size (x_4); area coverage under conservation farming practices (x_5); annual family income (x_6); farming experience (x_7); training exposure (x_8); and knowledge on conservation farming practices (x_9).

Model-I in Table 10 shows that, among the independent variables, conservation farming practices were affected by the farmer's level of education (x_2), and this had the greatest direct effect (0.178) in the positive direction followed by the other variables. In model-II, of the independent

Table 8 Professional opinion (percentage of respondents identifying an effect) about effects of conservation farming practices on components of farm food security

		Food availability	Food access	Food utilization	Food stability
% Of opinion about effects of conservation farming practices on components of food security (mean value)	System of Rice Intensification (SRI) under permanent raised-bed conditions	42	35	4	19
	Unflooded rice transplanting system by the strip and raised bed method	33	34	7	26
	Permanent raised-bed technology for wheat, maize, pulse, oil seed, and vegetable and cotton crops	53	15	15	17
	Strip tillage technology by the same crops	36	28	10	26
	DSR under the strip tillage and zero tillage methods	25	41	12	22
	Zero tillage technology, especially chick pea, wheat, and maize crops	20	34	16	30
	Unflooded zero till rice transplanting system in boro rice season	38	33	11	18
	Rain water harvesting	30	40	6	24
	Crop residue incorporation	43	31	5	21
	Drip/sprinkle/gated irrigation	33	30	13	24
	Mulching—crop residues, paddy straw, green leaves	34	23	8	35
	Cover crops—green manuring and pulse crops	28	36	15	21
	Strip/hedgerow cropping system	31	40	6	23
	Integrated farming with livestock	35	26	12	27
	Double no till in rice wheat and relay cropping of pulses	46	21	16	17
	Direct seeded no till rice – wheat	26	48	9	17

variables, farmer's food security by area coverage under conservation farming practices (x_5) had the greatest direct effect (0.167) in the positive direction followed by the other variables. Therefore, with the other variables remaining constant, farmer's level of education (x_2) and their area coverage under conservation farming practices (x_5) were the foremost determinants of the effects of conservation farming practices on farmer's agro-ecosystem services. Without path co-efficient analysis, it is impossible to know the direct effect of an independent variable through the combined effects of other variables on the dependent variable. Therefore, emphasis was given to the indirect effects obtained from path co-efficient analysis. Again, conservation farming practices and farmer's food security were affected by the farmer's age (x_1), and this variable had the highest (0.380 and 0.317) total indirect effect in both cases (model-I and model-II), followed by any other total indirect effects.

4 Discussion

Our interpretation and discussion is divided into five subsections (with sections i and ii developed from the farmers' survey data): (i) farmers' major socio-economic profiles; (ii) the effects of conservation farming practices on agro-ecosystems and food security; (iii) professional opinions about the effects of conservation farming practices on agro-ecosystems and on farmers' food security; (iv) factors that contribute to the effects of using conservation farming practices and food security status; and (v) path analysis: identifying direct and indirect effects of significant predictors.

4.1 Socio-economic profiles of farmers

Most middle-aged and older farmers studied and owners of small to large farms (0.21 to $\geq$ 3.0 ha of land) were involved with conservation farming practices. Their prior experience

Table 9 Multiple regression coefficients of contributing factors to using conservation farming practices and food security status

Focus variable	Predictor variables	Beta coefficient (B)	Probability value *(P)*	Coefficient of determination (R^2)	Adj. R^2	F statistic	Probability level *(P)*
Effects of using conservation farming practices (Model I)	Age	-0.077	0.031*	0.611	0.584	66.21	0.000**
	Level of education	0.192	0.002**				
	Family size	-0.032	0.88				
	Effective farm size	0.126	0.801				
	Area coverage under conservation farming practices	0.170	0.028*				
	Annual family income	-0.010	0.049*				
	Farming experience	0.126	0.015*				
	Training exposure	0.044	0.001**				
	knowledge on conservation farming practices	0.124	0.001**				
	Agricultural extension media contact	0.145	0.042*				
	Agricultural communication skill	0.107	0.236				
Food security status (Model II)	Age	-0.28	0.025*	0.491	0.463	63.98	0.000**
	Level of education	0.881	0.016*				
	Family size	0.453	0.241				
	Effective farm size	0.108	0.013*				
	Area coverage under conservation farming practices	0.202	0.017*				
	Annual family income	0.155	0.000**				
	Farming experience	0.082	0.028*				
	Training exposure	0.205	0.031*				
	Knowledge on conservation farming practices	0.099	0.000**				
	Agric extension media contact	0.166	0.128				
	Agric communication skill	0.127	0.203				

*Significant at $p < 0.05$; **Significant at $p < 0.01$

with conservation farming had an influence on adopting such innovative practices while considering risk. Their level of education had no influence. Farmers with medium and large families were comparatively more involved with conservation farming practices, perhaps partly due to the more ready availability of labor. Farmers considered farming small to medium land areas (not larger areas) with conservation practices to be best and innovative. We also found the majority of farmers used balanced/mixed farming, i.e., they combined conservation farming practices with use of chemical fertilizers and pesticides. The majority of the conservation farming practitioners (58.9%) were from middle class families and had moderate farming experience; that is, 6–16 years farming experience. Farmers with higher economic capacity and more experience were more likely to be involved with conservation farming, as they were more willing to take risks (Rogers, 2003). However, a high level of farming experience with training exposure had a comparatively lower impact, while medium knowledge about conservation farming practices with medium media contact and farmers with communication skills were more involved in conservation farming practices.

The adoption of new technology requires a time investment for learning, locating, and developing markets and for training hired labor; needs that could be supported by governmental and non-governmental organizations. There appears to be an opportunity to introduce conservation farming practices to more farmers. Conservation farming practices are innovative and technical, so the Government of Bangladesh should continue large-scale initiatives to provide training through projects like integrated crop management (ICM). Gradually, the Bangladesh Government is recognizing the importance of removing agrochemicals through eco-friendly agricultural practices.

4.2 Farmer inputs about effects of conservation farming practices on agro-ecosystem and food security

Conservation farming practices were said to have the greatest impacts on social (83.2%) and psychological (82.2%) components of the agro-ecosystem; more so than environmental effects (74.1%) and technical and economic effects (79.9%).

Table 10 Path coefficients showing the direct and indirect effects of significant predictors entered in ordinary least square (OLS) modeling of linear regression

Model	Independent Variables	Indirect effects through Channeled Variables	Total indirect effect	Direct Effect
Model-I	x_1	x_2=0.040; x_5=0.035.; x_6=0.044; x_7=0.049; x_8=0.043; x_9=0.026; x_{10}=0.033	**0.380**	-0.073
	x_2	x_1=0.052; x_5=0.024.; x_6=0.051; x_7=0.038; x_8=0.034; x_9=0.045; x_{10}=0.049	0.362	**0.178**
	x_5	x_1=0.024; x_2=0.030; x_6=0.042; x_7=0.044; x_8=0.043; x_9=0.035; x_{10}=0.037	0.321	0.160
	x_6	x_1=0.031; x_2=0.029; x_5=0.025.; x_6=0.044; x_7=0.022; x_8=0.036; x_9=0.028	0.315	0.148
	x_7	x_1=0.032; x_2=0.020; x_5=0.036; x_6=0.034; x_8=0.033; x_9=0.025; x_{10}=0.045	0.301	0.123
	x_8	x_1=0.028; x_2=0.023; x_5=0.027.; x_6=0.038; x_7=0.40; x_9=0.027; x_{10}=0.034	0.290	0.041
	x_9	x_1=0.032; x_2=0.030; x_5=0.026.; x_6=0.046; x_7=0.030; x_8=0.034; x_{10}=0.035	0.281	0.119
	x_{10}	x_1=0.033; x_2=0.031; x_5=0.026.; x_6=0.045; x_7=0.020; x_8=0.033; x_9=0.025	0.264	0.140
Model-II	x_1	x_2=0.040; x_4=0.037; x_5=0.026.; x_6=0.033; x_7=0.041; x_8=0.041; x_9=0.032	0.317	0.152
	x_2	x_1=0.042; x_4=0.030; x_5=0.033.; x_6=0.048; x_7=0.036; x_8=0.024; x_9=0.035	0.302	0.088
	x_4	x_1=0.029; x_2=0.043; x_5=0.025.; x_6=0.051; x_7=0.028; x_8=0.024; x_9=0.026	0.289	0.128
	x_5	x_1=0.022; x_2=0.038; x_4=0.044; x_6=0.032; x_7=0.038; x_8=0.031; x_9=0.047	0.265	**0.167**
	x_6	x_1=0.035; x_2=0.027; x_4=0.028; x_5=0.035.; x_7=0.045; x_8=0.037; x_9=0.030	0.241	0.118
	x_7	x_1=0.038; x_2=0.050; x_4=0.021; x_5=0.023.; x_6=0.042; x_8=0.020; x_9=0.029	0.227	0.098
	x_8	x_1=0.041; x_2=0.038; x_4=0.031; x_5=0.027.; x_6=0.030; x_7=0.039; x_9=0.042	0.211	0.125
	x_9	x_1=0.040; x_2=0.039; x_4=0.031; x_5=0.032.; x_6=0.033; x_7=0.044; x_8=0.047	0.203	0.039

It seems that developing farmers' social and psychological activities such as decision-making ability, scope of training, and development of social norms and values highly influenced components of farmers' agro-ecosystem. A study conducted by Dessart et al. (2019) and found that behavioral factors enrich farmer decision-making, and can lead to a more realistic and effective farmers' agro-ecosystem. Conservation farming practices can be expected to ensure sustainability of ecosystem services (Lee et al., 2019).

The effects of using conservation farming practices on components of food security were reported greatest for psychological effects (95.8%) followed by 91.9% technical and economic effects, 89.2% social effects, and 83.9% environmental effects. Here, psychological effects like the development of positive human food habits directly influenced components of human food security. There is little information from elsewhere about the impact of conservation farming practices on the livelihoods and food security of smallholder farmers.

4.3 Professional opinions about effects of conservation farming practices on agro-ecosystems

Professionals reported that all the 16 selected conservation farming practices in Bangladesh (strip tillage technology by the same crops, Dry Seeded Rice (DSR) under the strip tillage and zero tillage methods, zero tillage technology, especially chickpea, wheat and maize crops, unflooded zero till rice transplanting system in *boro* rice season, crop residual incorporation, mulching and cover crop, and double no till in rice–wheat and relay cropping of pulses), had effects on selected agro-ecosystem services. Conservation farming practices had effects largely by environmentally executable components of agro-ecosystems like the regulation of soil fertility and water, soil structure and soil retention. All of these components of agro-ecosystems enhance soil microbial activities and processes to improve food security by increasing agricultural productivity (Sharma et al., 2012).

4.4 Professional opinions about the effects of conservation farming practices on farmers' food security

The professionals reported that permanent raised-bed technology for wheat, maize, pulse, oil seed, vegetable and cotton crops, strip tillage technology by the same crops, DSR under the strip tillage and zero tillage methods, zero tillage technology, unflooded zero till rice transplanting system, drip irrigation, cover crops and double no-till in rice–wheat, and relay cropping of pulses had the greatest effects on farmers' food security. As would be expected, we also learned from the experts that the farmers' food availability had a direct influence on their access to food, and food access had a direct influence on food stability. Food availability depends on productive cultivated and natural land systems; thus, it is widely recognized that ecosystem-aware food security policies are necessary for sustaining food security into the long term (Caiafa & Wrabel, 2019).

4.5 Contribution of farmers´ predictors to the effects of using conservation farming practices and food security

Conservation farming practices are an innovative technical development for farmers. They must have at least a minimum level of education, enough knowledge to understand these practices, and training for proper implementation of the selected practices to overcome any risk associated with starting conservation farming. In our study, the farmer's level of education, knowledge about conservation farming practices, and professional training experience directly influenced the effects of using conservation farming practices along with their food security status. The education level of a farm operator is related to knowledge. Education, either specific or general, usually correlates positively with the adoption of conservation farming practices (Warriner & Moul, 1992). In Kenya, Mutisya et al. (2016) concluded that investment in the education of impoverished householders may, in the long term, contribute to a reduction in the prevalence of food insecurity. Elsewhere in Africa, Nyanga (2012) concluded that knowledge about conservation farming reduced the intensity of food shortages during peak hunger periods due to early green harvests, and also that adopters of conservation farming are relatively more food secure than non-conservation farmers.

Farmer age was another important predictor of conservation farming practices as well as food security. As young and middle-aged farmers are willing to engage with innovation by taking risks and receiving education, the Department of Agricultural Extension (DAE) could focus on these two age groups under the ICM project program, as young people have a higher level of environmental concern (Diamantopoulos et al., 2003) and risk tolerance. Moreover, food insecurity among smallholder farmers was correlated with sociodemographic factors (e.g., age, education, migration) and asset ownership (Alpízar et al., 2020), while older farmers with large farms had greater food security. As with food security status, area coverage under conservation farming practices was directly related to the effects of conservation farming practices. In the case of model II, farmer's income was highly significant (at the 1% level of significance) and positively contributed to food security status.

A farmer's experience in farming also had a positive influence on both conservation farming practices and food security status, since it meant that they are technically more competent. Training exposure also predicted both use of conservation farming practices and better food security status in our study. For Bangladesh, Mazumder and Lu (2015) found that training programs develop the technical skills of participants that directly influence their economic strength through increased income. Agricultural extension media contact organized by the DAE and related NGO representatives also significantly contributed to the effects of conservation farming practices. Extension programs have been the main conduit for disseminating information about farm technologies, supporting rural adult learning, and assisting farmers in developing their farm technical and managerial skills in the country (see Danso-Abbeam et al., 2018). These helps increase farm productivity, farm revenue, reduce poverty, and minimize food insecurity by practicing conservation farming, as also shown in Africa (see Danso-Abbeam et al., 2018).

4.6 Path analysis models

Both models used suggest that governmental and non-governmental authorities should consider farmer age, level of education, area coverage under conservation farming practices, farming and training exposure, knowledge about conservation farming practices, and agricultural extension media contact when offering conservation farming practices. Additionally, model-II suggests that a farmer's farm size, along with their annual income and knowledge about conservation farming practice, had a comparatively more significant and contributory role to improving their food security status. A farmer's economic strength and their knowledge about conservation practices strongly and directly influenced their ability to improve food security. Furthermore, agricultural extension programs have been the main conduit for disseminating information on farm technologies, supporting rural adult learning, and assisting farmers in developing their farm technical and managerial knowledge and skills. It is expected that extension programs will help increase farm productivity, farm revenue, reduce poverty, and minimize food insecurity. It is, therefore, recommended that agricultural extension service delivery should be enhanced through timely recruitment, periodic training of agents, and provision of adequate logistics (Gideon et al., 2019). For substantial and equitable progress towards food security, increased attention to and investment in agricultural development is required.

5 Conclusions, with policy implications

This study showed that using conservation farming practices were assessed by farmer and expert stakeholders to have a considerable positive influence on agro-ecosystem services and food security in Bangladesh. Conservation farming practices are therefore an important policy option for decision-makers given the vulnerability of ecosystem services in the country. Authorities should encourage farmers to use conservation farming practices to help achieve a safe and healthy environment with secure availability of food. The DAE can design policy that helps academics professionals, policymakers, and government and non-government officials develop sustainable agriculture.

Related NGOs could also design projects to motivate the targeted farmers. Regular extension contact should also be ensured by different relevant government organizations to motivate farmers to adopt conservation farming practices. An intact ecosystem could provide more benefits in terms of local or regional food production. There are opportunities to maximize the expected benefits, and policymakers and development practitioners should continue to be appraised of the potential of conservation farming to contribute to the Sustainable Development Goals in this area. To sustain productive agriculture, effects of conservation farming practices need to be managed. Much is now known about a widening array of good management practices to mitigate environmental degradation and ensure a healthy agro-ecosystem service and food security.

Policymakers and government education departments could start initiatives to offer adult education programs to improve farmers' awareness of and interest in improving their food security status and in using conservation farming practices. Offering both education and professional training programs will play a vital role in improving farmer knowledge about conservation farming practices and a healthy food security status. These can lead to higher productivity, greater knowledge, and the adoption of environmentally sustainable technologies (Fatima et al., 2018). More experienced farmers can be encouraged to lead community engagement with conservation farming practices and ensure food security through increasing farm productivity. Overall, farmers' level of education and their area coverage under conservation farming practices could be the most important factors influencing the conservation farming practices on agro-ecosystem services for sustainable food security in Bangladesh and other similar countries. It is difficult to recognize definite patterns of their effects across technologies given a shortage of empirical evidence. More research using standardized surveys and methods of analysis is needed to formulate better guidelines and recommendations for policymakers (Serebrennikov et al., 2020). In future research, longer-term studies with a greater area of coverage are needed to provide further evidence of links between conservation agriculture, agroecosystems and food security in Bangladesh and different regions of the world.

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Intellectual property We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Research ethics Any aspect of the work covered in this manuscript that involved humans was conducted with the ethical approval of all relevant bodies.

Conflict of interest There were no conflicts of interest.

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