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A farming system typology for the adoption of new technology in Bangladesh

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Abstract

Over the last three decades, few studies have been conducted to tackle the complexity and heterogeneity of Bangladesh farming systems. We address these research gaps with a new survey. Accordingly, a survey was conducted in North-Western Bangladesh to understand how socio-economic traits influence technology adoption and to identify and characterize key farm types. The survey was based on farm household characteristics, farm structure, farming practices and livestock as well as the economic performance of the farm. Principal component analysis (PCA) and cluster analysis (CA) were used to establish the different farm typologies, and the data set based on 27 variables was carefully analysed. The findings confirmed that the key variables that significantly affect the adoption of new agricultural technologies relate to age, farming experience, level of education of the household head, income, access to markets, land ownership, the proportion of hired labour, savings, food self-sufficiency and income from off-farm activities. Four main farm types were identified in the study area based on resource endowment and livelihood orientation. These are (1) well-resourced farmers entirely dependent on agriculture and less reliant on off-farm activities; (2) moderately resourced households, which are headed by an older male with greater farming experience and which are engaged in both on-farm and off-farm activities; (3) resource-constrained households with cattle as the main livestock and with income generated by the sale of livestock products; and (4) severely resource-constrained households which are headed by young farmers/men and where income is generated by off-farm activities. These four farm categories represent the heterogeneity of farms in North-West Bangladesh, and it is hoped that the development of this farm household typology will help particularly the extension service, to set up appropriate extension advice that will benefit the farming community.

KEYWORDS
cluster analysis, farm typology, North-West Bangladesh, technology adoption

1 | INTRODUCTION

Bangladesh has a primarily agrarian economy and, with a population of over 165 million, is one of the most densely populated countries in the world. The population is still rising by 1.4% every year (BBS, 2017), and agricultural land is rapidly shrinking at a rate of 1% per year due to unplanned and uncontrolled urbanization and industrial development (Ahmed, 2013). The land/person ratio of the country is less than 0.05 ha capita-1 (Huq et al., 2013), and this continues to decline due to rapid population growth that could lead to food insecurity for the growing population in Bangladesh (Roy et al., 2019). In order to achieve food self-sufficiency, a wide variety of technological and policy solutions have been developed such as introducing drought and saline tolerant crop varieties, increasing irrigation facilities, promoting farm mechanization, ensuring the supply of good quality and high yielding seed varieties, optimizing the use of fertilizer and adopting integrated pest management (Bangladesh Economic Review, 2017). Unfortunately, the use of these modern technologies has not increased sufficiently due to the slow rate of adoption (Faruque et al., 2018; Karim et al., 2017; NAP, 1999). Lack of interest on the part of farmers is often cited as a reason for this. For example, most Bangladeshi farms do not follow the recommended guidelines on soil testing and the use of fertilizer (Daily Star, 2016). They rely mostly on traditional farming practices tacitly acquired through experience and knowledge passed down from one generation to the next (Mondol, 2010; Rahman & Zhang, 2018).

Research into the development of farming systems is hampered by global scale evaluations that under-perceive and undervalue local complexities and diversity, and this results in deterministic policy frameworks. Such inflexible policies for the development of the agricultural sector have proved to be ineffective (Chang, 2012). It is, therefore, crucial to design technological and policy interventions that target the diverse and spatially heterogeneous smallholder farming systems in order to address the pervasive constraints of that region. The foregoing literature suggests that few studies have been conducted to tackle the complexity and heterogeneity of Bangladesh farming systems and to formulate effective strategies and policies (Jabbar, 2011).

Farming systems in Bangladesh are highly complex and varied in their characteristics related to landholding, soil fertility, cropping systems, livestock assets, off-farm activities, labour, the availability of cash and access to credit, sociocultural traits and livelihood strategies. Therefore, it is not possible to develop specific recommendations for individual farm households, but the farming sector can be grouped into different categories with similar socio-economic characteristics so that appropriate recommendations can be made (Tittonell et al., 2010). Identifying variability within and among farms and across localities is the first step in developing interventions and policies that might be helpful for the adoption of advanced technologies in a farming community (Mutoko et al., 2014; Ruben & Pender, 2004).

Farming system typology (FST) is a useful tool to describe the diversity of households (Daloglu et al., 2014) and summarize the variability and diversity among different farming systems (Alvarez et al., 2018; Kuivanen, Michalscheck, et al., 2016) and has been used to understand the factors affecting the adoption of new technologies (Bidogeza et al., 2009; Daloglu et al., 2014). In addition, farm typologies have been used to study the adoption of agricultural greenhouses (Kuswardhani et al., 2014) and climate-smart technologies (Lopez-Ridaura et al., 2018), food security (Lopez-Ridaura et al., 2018) and resource use efficiency (Tittonell et al., 2007; Zingore et al., 2007) and to identify the potential adopters of alternative farming methods (Daskalopoulou & Petrou, 2002) or the overall classification of farm categories (Rahman et al., 2019). It is also very important to gather evidence of how a context-specific understanding of the constraints faced by farming households in the adoption of new agricultural technologies could shape future strategies for the introduction of innovations. A deeper knowledge of such local scale constraints is needed to guide context-specific technological and policy interventions directed at sustainable development that increase resilience and improve farm incomes (Mwongera et al., 2017). Therefore, farm typologies must be studied at the level of each household in a village to develop specific interventions for introducing new agricultural technologies (Rahman & Das, 2019). Where there are clear research aims and reliable data exist, multivariate statistical tools can underpin such typologies. Typology development should be guided by the aims of the research, the questions which these raise and the characteristics of the research area (Duvernoy, 2000; Kobrich et al., 2003).

Earlier research has been undertaken into the classification of farm households in Bangladesh. For example, Rahman and Das (2019) categorized farming families based on the homestead and owned land: i) having no homestead or cultivable land; ii) having only a homestead but no cultivated area and iii) having a homestead and limited cultivable land. Chowdhury (1978) classified farmers into three broad categories of class, status and power, based on the ownership of land. Alam and Swapan (2011) classified farms into four-landholding sized classes: marginal (<0.4 ha), small (0.41–1.01 ha), medium (1.02–3.03 ha) and large (3.03 ha). Furthermore, the most commonly used classification of farm households was carried out by the Bangladesh Bureau of Statistics (2017) based on landholdings; farms are classified as small (<1 ha), medium (1–3 ha) and large (3 ha). Recognizing this farm households' heterogeneity is an essential first step in the analysis of potential technological interventions and policy support (Kobrich et al., 2003).

There are many studies in the literature which assess the factors affecting the adoption of new agricultural technologies (e.g. Melesse, 2018; Mwangi & Kariuki, 2015; Bidogeza et al., 2009; Pilarova, 2018; Priegnitz et al., 2019, Mafimisebi, 2006; Dhraief et al., 2018; Obayelu et al., 2017; Kuswardhani et al., 2014), but all of these were conducted in regions where the farming system, climate and agroecology are very different from the north-western region of Bangladesh. For example, Islam et al., (2020) studied farmers' perceptions and adoption strategies in southern Bangladesh where the cropping system is different, the soil is saline and the climate is relatively humid. Similarly, Haqe et al. (2014) explored the adoption of mung bean (Vigna radiata L.) technologies in south-western Bangladesh, where new cultivation techniques were not practiced properly by most farmers. The reasons for this are unclear, since in-depth research on socio-economic factors from the northern and north-western regions is lacking (Farid et al., 2015). To develop a betterunderstanding of this requires a classification of farm households, since the adoption of new agricultural technologies may differ among farm households due to differences in socio-economic characteristics (Asfaw & Admassie, 2004; Mahapatra & Mitchell, 2001; Milan et al., 2006; Somda et al., 2004).

Existing research suggests that while many studies have been carried out on the process of adoption and the impact on farming households of adopting new agricultural technologies, few studies have been conducted to analyse the factors common to farm households in relation to the adoption of new technology, especially in Bangladesh. Therefore, we propose a categorization of farm household diversity based on the homogeneity of socio-economic circumstances to identify and define farm systems, improving the targeting of new technological interventions.

Finally, the present study aims to determine the underlying socio-economic factors that influence the decision of farmers to adopt modern technologies. The objectives of this study are twofold: (i) to identify and characterize farm types and (ii) to determine the major factors relating to the adoption of new agricultural technologies. This study offers important insights for policymakers that could stimulate and sustain the adoption of new technology in the study region. To achieve our objectives, this study sought to answer the following two research questions: (i) which types of smallholder farms can be identified and which factors drive their variability; (ii) which key factors are significantly related to the adoption of new agricultural technologies. To answer the research questions, we applied multivariate statistical techniques, using principal component analysis (PCA) and cluster analysis (CA), an approach used in similar studies (Bidogeza et al., 2009; Kuivanen, Alvarez, et al., 2016; Kuivanen, Michalscheck, et al., 2016; Mutoko et al., 2014; Sakané et al., 2013; Tittonell et al., 2010).

2 | MATERIALS AND METHODS

2.1 | Study area

The study area is located in the sub-district of Birganj, part of the Dinajpur district in North-Western Bangladesh (25°44´N and 88°40′E) (Figure 1). The district is located in the Old Himalayan Piedmont plan agro-ecological zone (AEZ-1), and the land types are highland (HL; 5%), medium highlands (MHL; 37%) and medium lowlands (MLL; 5%), respectively. Under the Köppen climate classification, the climatic condition of the North-Western part of Bangladesh including Dinajpur district is 'Cfa'. (Humid Subtropical Climate). These areas also experience high temperatures and limited soil moisture as well as low and erratic rainfall.

The annual average rainfall in the Dinajpur district is 1710 mm which mainly occurs during the monsoon and varies widely both by season and year. For example, rainfall recorded in 1982 was 1,342 mm, while in 2015 it was 1,965 mm. The average annual maximum and minimum temperature in the region is 35.11°C and 20.28°C, respectively. These conditions make the region drought-prone, leading to poor crop productivity. Thus, the livelihood of people in the area is threatened by climate extremes, particularly drought, in the late winter season. This region is also geographically vulnerable to natural hazards such as flash floods, heat waves and cold spells, which have resulted in increased food shortage (Barma et al., 2019; Hossain & Teixeira da Silva, 2013; Paul et al., 2013). Historically, the regional economy has depended on the agricultural sector, with predominance of cereal crops, especially rice, as well as other major crops like maize, wheat, potato and pulses (Mainuddin et al., 2020). In addition to this, aquaculture, the rearing of livestock, poultry and off-farm activities provide additional income to the farm households in this area.

2.2 | Data collection

A sampling framework was constructed in consultation with the relevant local extension personnel, in particular, agricultural officers, before the final sampling. A multi-stage sampling procedure was used for this study to select a research area and sample farmers. A total of 92 farms were randomly selected to address the research objective as well as to identify the different farm household types (Figure 1). Afterwards, a draft semi-structured interview schedule was used on 10 non-sampled respondents for necessary modification. Finally, data were collected from the selected households from February to March 2019 by face-to-face interviews. This month was selected to minimize the possible recall bias relating to the quantities of inputs used and output (grain and residues) obtained. The primary

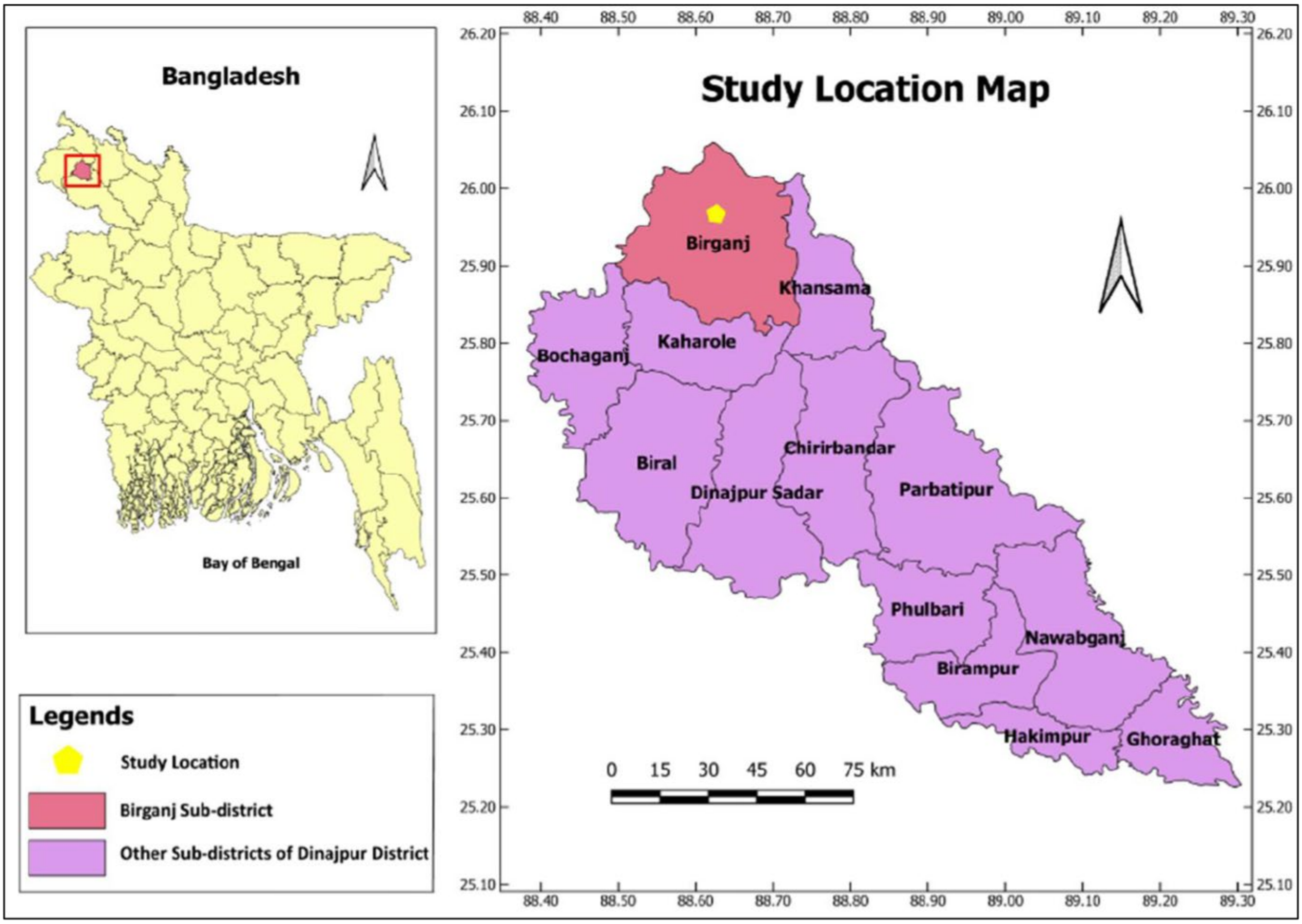

FIGURE 1 The study area is located in the Birganj sub-district, part of Dinajpur district in North-Western Bangladesh

data collection was carried out with the support of three agricultural graduates, and the interviews were conducted either at the respondent's house or in one of the farmer service centres where farmers regularly meet.

Seven sections were included in the interview schedule, the first focussing on information about household characteristics and the second including questions on access to food and other major assets. In the third section, questions were targeted at farm activities including herd size, land use, cropping patterns and field management practices etc. The fourth section focussed on crop residue management. The fifth section concentrated on livestock, such as breed type, herd structure, dynamics and feeding strategies. The sixth section was aimed at collecting information regarding the adoption of new technology, ease of access to a market and key constraints to farming. Finally, the last section recorded information about household income and expenditure.

The factors affecting the adoption of new technology were considered for selecting variables to construct a farm typology in the study area. The age of the household head, family size, level of education of the household head, farm size, household income, access to extension services, the distance of the farm to the market, access to information etc., all play a vital role in the adoption of new technology; especially important is the issue of producing enough food for the family. In this study, the education of the head of the household was considered as two variables: =1 if they had finished at least primary education, 0= otherwise corresponds to not capable of writing.

2.3 | Typology construction

Farm household data were analysed by using a multivariate statistical approach comprising principal component analysis (PCA) and cluster analysis (CA). PCA was used to reduce the data set and create a smaller set of independent components. The new set of independent components was used as an input for cluster analysis and, later on, identifying the farm household in the research area. The technique has been widely used in many studies to classify farm households (e.g. Bidogeza et al., 2009; Goswami et al., 2014; Kuswardhani et al., 2014). All analyses were done using the ade4 package (available online http://pbil.univ-lyon1.fr/ade-4 from R 3.6.0. software R Core Team (2019)

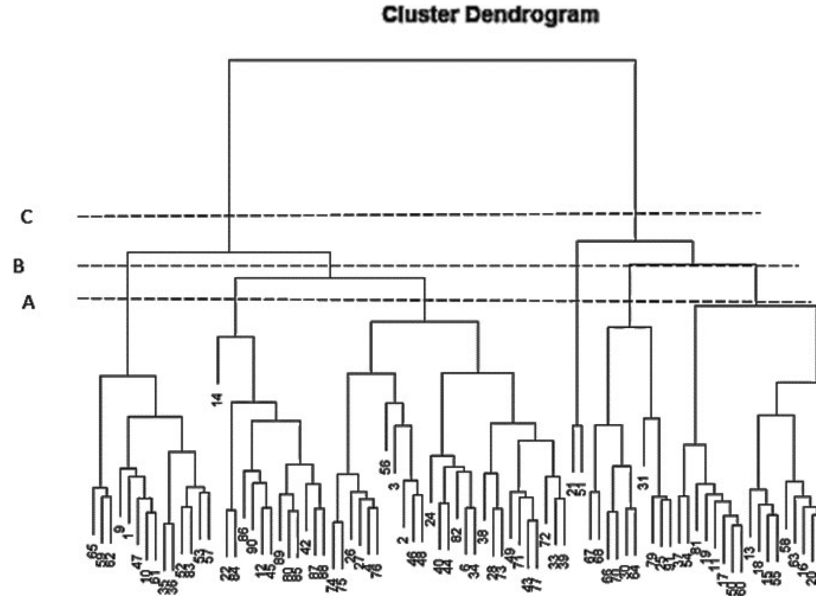

FIGURE 2 Dendrogram with three possible cutting lines for the study area

2.3.1 | Principal component analysis

The first steps for the PCA was data quality control, including identifying missing values and variables with strong correlations. The data set based on the 27 variables was carefully examined and missing data identified. Based on Kaiser's criterion, all PC having an eigenvalue of one was retained for further analysis (Field, 2005; Herve, 2001). If the number of variables is less than 30, Kaiser's criterion is considered to be accurate (Field, 2005). In our study, there were 27 variables, thus making it appropriate for this research. The number of the axis for principal component analysis can be determined based on the minimum cumulative percentage of variance, 60% or higher is usually best for PCA (Hair et al., 2010). In our case, it was about 69% which was suitable for our research. In addition, a loading of less than 0.40 was not considered for interpretation of our objectives.

2.3.2 | Cluster analysis

The nine components from the PCA were used to develop hierarchical clustering following Ward's method (Reynolds et al., 2006). Although there is no single procedure to determine the appropriate number of clusters, a two-step approach (i.e. the hierarchical method and the partitioning method) was used (Hair et al., 2006). The k-cluster solution was created by connecting with two clusters from the k+1 cluster solution, whereas the partitioning method was employed to isolate the farm household into a given number of clusters (Lattin et al., 2005). Ward's hierarchical method was used to define the number of groups as it was widely used to minimize the variation within the cluster and successively join with equal clusters (Kuivanen et al., 2016). A key point in this procedure is where to cut the tree to identify an appropriate number of clusters that is realistic for the study area.

Figure 2 presents the dendrogram with possible cutting lines from Ward's method of cluster analysis. Shifting the cutting line from A to B reduces the number of clusters to four; hence, line C denotes only two farm types. The number of clusters should reflect the real situation in the study area. By using the cutting line C, two clusters based on the partitioning method were appropriate, but it did not represent the real situation in the area. Finally, using information from the dendrogram and taking into account expert knowledge in the study area, the number of clusters was chosen which was meaningful and realistic. To identify the variance between clusters, one-way analysis of variance was carried out and this was largely used to analyse the clusters (Field, 2005).

3 | RESULTS

3.1 | Principal component analysis (PCA)

In total, 27 variables were used in the PCA (Table 1) and nine components with eigenvalues greater than one (Table 2) have been extracted for further analysis in the study area. The PCA results explain 69% of the variability of the data set. From Table 2, it was found that the first PC1, which is the highest variation, was about 17% of the variability in the data set. It was closely related to the variables describing land size, the number of crops grown per year, the amount of income from crops and food self-sufficiency, savings and off-farm income. This component shows a positive relationship between farm size, the number of crops per year, food self-sufficiency and

TABLE 1 The descriptive statistics of the selected variables used in principal component analysis

Variable	Description and units	Mean	Standard deviation
Household			
Size of household	Number of members	5.0	1.43
Age of household	Number of years	48	10.19
Farm experience	Years	27	9.81
Education			
Literacy of the head of the household	=1 if literature, 0=otherwise	0.65	0.47
Labour			
Total labour input	Hours per year	2864	312.93
Hired labour ratio		0.15	0.08
Infrastructure			
Distance house to the main road	Km	0.75	0.62
Distance to the nearest market	Km	0.50	0.26
Land use	Hectares		
Cropped land area		0.65	0.51
Rice ratio		0.63	0.20
Maize ratio		0.28	0.17
Number of crops grown		2.56	0.56
Livestock	TLU (Tropical livestock unit)		
Herd size		2.32	1.51
Small ruminant ratio		0.11	0.16
Poultry ratio		0.04	0.06
Food security			
Food self-sufficiency	Months per year	10	2.0
Saving	1=Yes, 0=otherwise	0.60	0.49
Land ownership	1= ownership, 0=otherwise	0.83	0.37
Income			
Crop sales	percentages	51	21.55
Livestock sales	percentages	15	12.14
Off/Non-farm income	percentages	33	25.28
Technological attributes			
Organic manure use	=1 if applying 0=otherwise	0.94	0.22
Improved livestock	=1 if applying 0=otherwise	0.20	0.40
Crop residue retention	=1 if 10 cm applying 0=otherwise	0.71	0.45
Marketing			
Crop product sale in near market	=1 if market, 0=otherwise	0.52	0.49
Extension			
Get extension service	=1 if receive, 0=otherwise	0.41	0.49
Family members joining FFS	=1 if join, 0=otherwise	0.76	0.42

savings and a negative relationship with off-farm activities. This implies that large farms rely on their farming activities rather than off-farm activities. PC2 correlated with animal resources (total TLU) as well as the majority of income coming from livestock and represents livestock enterprises. PC3 represents age and experience which are positively linked. PC4 is related to the marketing components and shows that farmers who are close to the market may have more opportunity to sell their products with lower transportation costs. The fifth, PC5, comprises access to information about technology, which is strongly correlated with a family member joining a farmer's field school. The sixth principal component (PC6) shows a negative relationship between landownership and herd size. PC7 represents CA practices, and PC8 correlated with the educational level of the household. The last PC only represents the breed of the livestock enterprise.

3.2 | Cluster analysis

The characteristics of the four different types of farm household clusters and p-value of one-way analysis of variance for the study area are reported in Table 3. Variables such as age, income from crop sector, farm experience, incorporation of crop residues in soil, savings, distance to the nearest market, income from livestock, tropical livestock unit, literacy of the head of household, hired labour ratio, landholding, off-farm income and food self-sufficiency could significantly differentiate the farm types in the study area (Table 3). All these variables were used to construct the typology.

3.3 | Farm types

Farm types (clusters) were identified based on the farmer's resource use efficiencies and capital endowment. Figure 3 shows the distribution of four different farmer types along with innovations taken up by farmers. Figure 4a and b further show the resulting four different clusters described as farm types (FT) with their specific characteristics. The following sub-sections (i.e. 3.3.1–3.3.4) describe the characteristics of four farm types in detail within the study area:

3.3.1 | Type 1 farm

This cluster comprised households having a large farm with a high ratio of hired labour and accounts for 32% of the farm households. They were households that adhered to many agricultural technology practices such as crop residue retention or incorporated on the soil (86% farm households), use of own organic manure (96% farmers) and animal rearing using improved breeds. Being a large farm, they were able to produce

TABLE 2 Eigenvalues and cumulative variances (%) explained by nine components (PCs)

	Components and their Eigen values								
Name of variables	**PC_1**	**PC_2**	**PC_3**	**PC_4**	**PC_5**	**PC_6**	**PC_7**	**PC_8**	**PC_9**
Age	0.10	**0.41**	**0.81**	−0.20	0.01	−0.04	−0.05	−0.09	−0.20
Land ownership	0.35	−0.34	0.04	0.07	−0.04	**−0.44**	**−0.45**	−0.08	0.06
Maize ratio	**0.44**	0.07	−0.07	−0.21	**0.47**	0.30	−0.19	0.15	0.28
Small ruminant ratio	−0.26	−0.23	0.11	−0.38	−0.03	**−0.62**	0.02	0.11	0.11
Income from crop (%)	**0.72**	0.03	−0.26	−0.01	−0.03	−0.06	0.10	0.17	−0.34
Extension service	0.14	**0.46**	−0.11	−0.34	0.05	0.20	−0.35	0.02	0.03
Farm experience	0.11	**0.40**	**0.83**	−0.17	0.07	−0.06	−0.04	−0.11	−0.15
Family members Joining FFS	0.04	−0.26	−0.18	0.03	**0.42**	−0.15	−0.20	**−0.47**	−0.26
incorporate crop residue	0.39	−0.01	−0.21	−0.14	−0.09	−0.17	**0.62**	−0.10	0.16
Number of crops grown	**0.40**	−0.28	0.23	0.20	0.33	−0.26	0.02	0.15	0.04
Saving	**0.67**	−0.34	0.04	0.06	−0.11	0.03	−0.19	−0.27	0.07
Distance house to main road (km)	−0.09	**−0.56**	0.26	**0.40**	0.24	0.13	−0.08	0.20	−0.26
Distance to nearest market (km)	−0.05	**−0.40**	0.21	**0.50**	0.13	0.11	0.17	0.17	0.24
Own manure use	0.19	**0.46**	0.01	0.39	−0.17	−0.01	−0.13	−0.30	0.25
Crop product sale	0.16	−0.08	0.36	**0.43**	−0.35	−0.05	−0.06	0.26	0.24
Income from Livestock (%)	0.20	**0.60**	−0.12	0.25	0.19	−0.38	0.16	0.08	0.01
Tropical livestock unit	0.38	**0.45**	−0.05	0.38	0.16	0.37	−0.04	0.06	−0.21
Improved livestock	0.17	0.16	−0.14	0.06	0.31	−0.01	−0.01	−0.26	**0.40**
Literacy of the head household	−0.07	−0.11	−0.02	0.11	**−0.47**	0.26	0.23	**−0.58**	−0.12
Hired labour ratio	**0.72**	−0.29	0.06	−0.17	−0.24	0.05	−0.04	0.13	−0.05
Size of household	0.20	0.16	**0.42**	0.09	0.27	−0.02	**0.41**	0.02	0.09
Poultry ratio	−0.16	**−0.47**	0.15	−0.21	0.38	0.20	0.29	−0.17	−0.17
Land holding (ha)	**0.72**	−0.29	0.03	−0.21	−0.24	0.15	0.04	0.10	−0.08
Off-income (%)	**−0.69**	−0.32	0.28	−0.09	−0.09	0.25	−0.16	−0.15	0.31
Rice ratio	**−0.56**	0.12	−0.15	0.38	−0.09	−0.25	−0.13	−0.01	−0.35
Food self-sufficiency (consume by own food month/year)	**0.78**	−0.12	0.07	0.06	−0.12	−0.07	−0.04	−0.12	0.09
Eigenvalues	4.56	2.86	2.22	1.73	1.54	1.45	1.30	1.19	1.14
Cumulative variance (%)	17%	28%	37%	43%	49%	55%	60%	65%	69%

Note: Bold numbers refer to loading equal to or higher than 0.4.

more crop residue from their own fields which allows them to incorporate the residue in the fields (Figure 3). This cluster was also characterized by farm households with family members working mainly full-time on the farm (with the lowest level of off-farm work) and household heads with an average level of education and literacy. However, they also had a high level of income from the crop sector which means that the farmer depends mostly on crop production. These clusters have a higher level of food self-sufficiency than the others. In addition, the households have a high average level of education and a high proportion of income (75.43%) from the crop sector and are also characterized by having a high level of savings (Figure 3).

TABLE 3 Characteristics of four clusters of farm households

Name of variables	Cluster 1 well resource endowed with entirely depended on agriculture $N = 30$	Cluster 2 resource-constrained with herd dominated by cattle $N = 9$	Cluster 3 medium resource-endowed, households are headed by an elder man with greater farm experience $N = 34$	Cluster 4 severely resource-constrained, households are headed by young, income generated from off-farm $N = 18$	Cluster means	Cluster standard deviation	*p*-value
Age	44	50	54	42	47.94	5.46	0.00
Land ownership	0.93	0.66	0.82	0.77	0.80	0.11	0.22
Maize ratio	0.32	0.31	0.28	0.22	0.28	0.04	0.22
Small ruminant ratio	−0.76	−0.65	−0.56	−0.60	−0.64	0.08	0.45
Income from crop (%)	75.43	42.22	46.02	23.33	46.75	21.54	0.00
Extension service	0.46	0.66	0.32	0.33	0.45	0.15	0.30
Farm experience	24.10	28.55	33.94	21.88	27.12	5.32	0.00
Family members joining FFS	0.83	0.77	0.36	0.88	0.78	0.10	0.17
Incorporate crop residue	0.86	0.77	0.70	0.44	0.69	0.18	0.01
Number of crops grown	2.63	2.66	2.64	2.27	2.55	0.18	0.10
Saving	0.80	0.44	0.55	0.44	0.56	0.16	0.04
Distance house to main road (km)	0.69	0.46	0.77	0.96	0.72	0.20	0.22
Distance to nearest market (km)	0.43	0.40	0.61	0.49	0.48	0.09	0.02
Own manure use	0.96	1.00	0.97	0.83	0.94	0.07	0.13
Crop product sale	0.43	0.55	0.64	0.44	0.52	0.10	0.32
Income from livestock (%)	17.06	41.66	10.44	7.88	19.26	15.42	0.00
Tropical livestock unit	3.01	3.07	1.92	1.60	2.40	0.75	0.001
Improved livestock	0.26	0.33	0.14	0.16	0.22	0.08	0.49
Literacy of the head household	0.66	0.22	0.73	0.72	0.58	0.24	0.02
Hired labour ratio	0.18	0.13	0.15	0.11	0.14	0.02	0.02
Size of household	4.80	5.33	5.41	4.50	5.01	0.43	0.10
Poultry ratio	0.03	0.01	0.03	0.06	0.03	0.02	0.17
Land holding (ha)	0.88	0.42	0.59	0.35	0.56	0.23	0.001
Off-income (%)	7.50	16.11	43.82	68.22	33.91	27.62	0.00
Rice ratio	0.58	0.65	0.62	0.68	0.63	0.04	0.38
Food self-sufficiency (consume by own food month/year)	11.60	10.66	10.91	8.94	10.53	1.12	0.00

3.3.2 | Type 2 farm

The Type 2 cluster represented small livestock-based farms with middle-aged farmers who have moderate farm experience (9% of the assessed farms). This cluster comprised quite small farms relying on agricultural level incomes, especially from livestock, with lower levels of ownership of cultivated land and a medium dependency on off-farm work (Table 3). The Type 2 cluster farms were also characterized by medium adherence to adopted agricultural technologies such as recycling crop residue (42% farm households) and the use of organic manures in the fields (Figure 3). These farm households were larger in comparison with the other clusters and had middle-aged household heads with a poorer level of education. They had excellent links to extension agents with access to information on crop and livestock production (Figure 4a). In addition, they had moderate food self-sufficiency (they consumed their own food at least 10 months of the year) and the lowest levels of family savings and the highest level of access to information regarding livestock products, especially milk, as their house is close to the market.

3.3.3 | Type 3 farm

This farm type consists of medium resource farms with an older farmer who has a high level of farm experience (Figure 4a and b). They are market-oriented farm households, with the best-educated and most literate household heads, and a greater off-farm income (37% of the assessed farms). Type 3 farm households represented farms where, on average, the household heads were relatively old (54 years), had a high level of farm experience and where the levels of both agricultural and non-agricultural income were moderate. Although owning livestock, the number of livestock was lower compared to other farm households. This cluster also consisted of households with five family members, mainly involved in off-farm activities (with least full-time work on the farm) and with the best-educated and most literate household heads. They also demonstrated the lowest use of recycled crop residue (only 7%) in the field (Figure 3) and also have poor access to the market as they live far away from the market. Furthermore, these households had a low level of regular contact with extension workers which resulted in a lower level of adoption of improved breeds (Figure 4b).

3.3.4 | Type 4 farm

This farm type includes low resource endowment, with the youngest household heads and reliance on off-farm activities which is greater on rented land (19% of the assessed farms). The most distinguishing factor in this type of farm is that households are headed by relatively younger farmers (42 years old on average) with a good level of education. These households are also characterized by smaller landholdings and lower food self-sufficiency (Figure 4a and b) and relied mainly on off-farm activities (68% income from

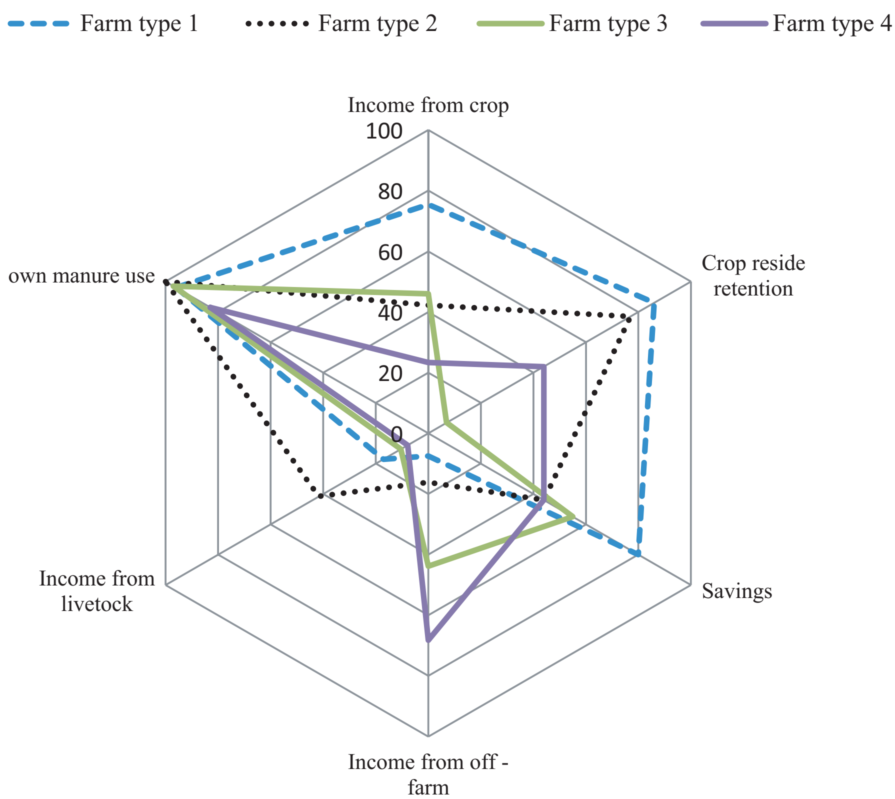

FIGURE 3 Spider diagram displays percentage distribution of different key variables across four farm types

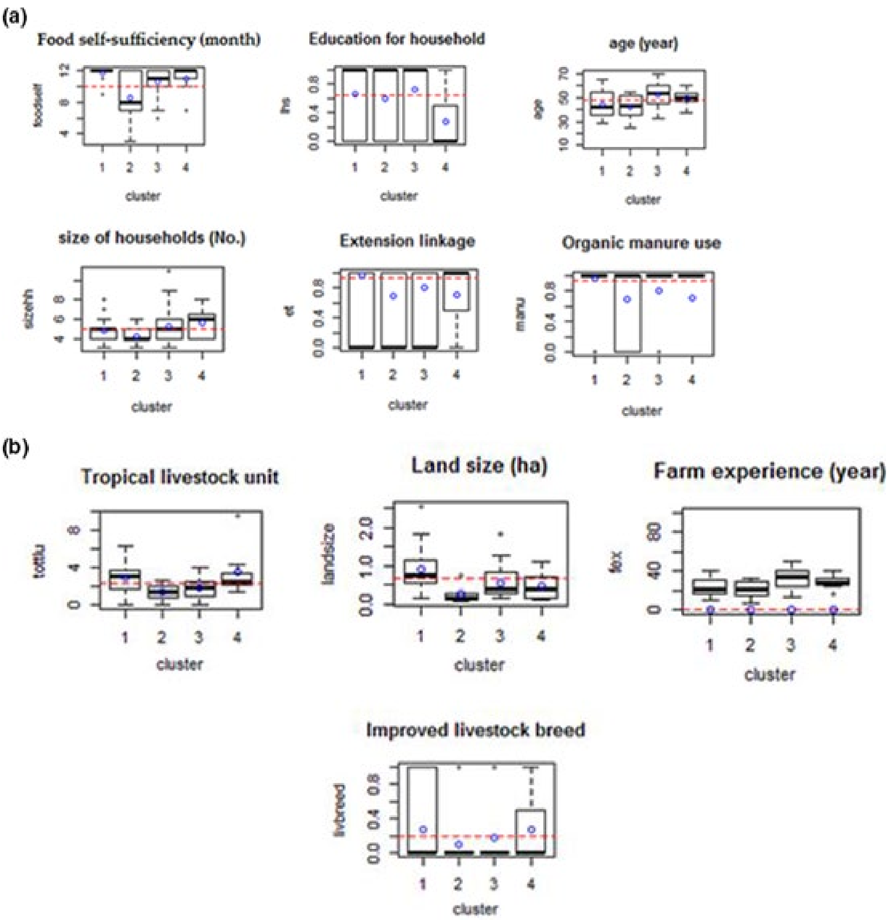

FIGURE 4 (a) Variables for the four farm types based on farmers food self-sufficiency, farmers level of education, age, size of household, extension linkage and organic manure use. Box plots show cluster means (coloured squares), median values (solid horizontal lines) and outlier values (closed circles). The dashed line represents the survey means for each variable. (b) Variables for the four farm types based on farmers tropical livestock unit, land size, livestock breed and farm experience. Box plots show cluster means (coloured squares), median values (solid horizontal lines) and outlier values (closed circles). The dashed line represents the survey means for each variable

off-farm). They also had the lowest levels of income from crops and livestock (Figure 3) and were the least likely to adopt new technologies with little use of organic manure and recycled crop residue in their fields. Moreover, these households had a low level of access to information on new technologies and had weak links with extension agents (Figure 4a). Type 4 farmers were also found to have the smallest landholdings and livestock was concentrated on poultry.

3.4 | Drivers of technology adoption by farm category

3.4.1 | Household-related variables

Farm types significantly differed with the age of the household heads and their farming experience (Table 2). The findings reveal a positive correlation between the age and farming experience of the household heads (Figure 4a). In particular, the heads of Type 3 farm households were the oldest and had the greatest farming experience. Type 2 farmers, on the other hand, were middle-aged, and their farming experience was greater in comparison with the other types (Table 2). However, the age of the household head did not have a significant positive influence on the practice of new technologies. This indicates that the adoption of new technologies was not dependent on the age of the households but rather on the size of cultivated land as well as ownership and use of legally owned land. In particular, the heads of Type 1 households had the largest landholdings and legally owned land because they have practised more innovative technologies in comparison with other farms.

There is a positive correlation between land size and the household's food self-sufficiency (Table 2). In particular, farmers from Type 1 households had the greatest amount of land and the highest crop production with greater food self-sufficiency, while farmers of Type 4 were the youngest, had the smallest amount of land and lower crop production with poor food security. The results indicated that those households that had a good level of education were more involved in a farmers' field school. In particular, the heads of Type 1 households had higher levels of education and literacy.

3.4.2 | Resource endowment variables

The size and ownership of land, livestock, off-farm income and labour were distinguishing factors for the different farm types (Table 2). Variables in on-farm income and land ownership, as well as the use of legally owned land, correlated with each other. Also, the practice of recycling crop residues and the use of organic manure was positively correlated with land size and ownership and how it is used, while it was negatively correlated with non-agricultural employment income (Table 2). Type 1 and 2 farms, which had adopted new technologies, owned larger farms. Type 4 farms can be classified as smaller farms with greater reliance on rented land. Having savings was strongly correlated with income from crops, livestock and other sources. This indicates that ownership of productive assets was highly correlated with income. For example, Type 1 farms have a higher level of asset ownership than other farm households (Table 2). In addition, the economic factor was strongly linked to the practice of new agricultural technologies (Table 2).

The key variables, such as full-time on-farm and off-farm labour, did not differ significantly among the different farm types. While Type 2 farms were mainly focussed on full-time, off-farm family labour, implying reliance on hired labour, Type 1 and 4 farms relied on full-time on-farm family labour (Table 3). As noted earlier, ownership of livestock was a significant distinguishing factor between the farm types (Table 2). Nonetheless, it differentiated Type 1 (3.01 TLU) and 2 (3.07 TLU) farm households which owned the greatest number of livestock compared to the other farm types (Table 2).

3.4.3 | Cropping practices concerning the adoption of new technologies

The way in which farm households managed their farms differed significantly between farm types and the availability of resources (Table 3). A positive correlation was observed between the adherence to conservation agriculture (CA), that is the practice of crop residue retention or incorporation on the soil, and the use of organic manure and the ownership of existing assets (i.e. land and number of livestock). Farms of Type 1 had similar characteristics but differed from Types 3 and 4. However, farms of Type 4 showed low adherence to CA principles (Table 3), which could be explained by their low ownership of land and wealth. The adoption of the new cropping system was also strongly and positively correlated with a higher income from agricultural sources.

3.4.4 | Access to information

It was expected that there would be a positive correlation between extension agents and access to information on crop and livestock production and input use. Type 2 farm households had excellent links with extension agents, and this may result in adopting improved livestock breeds in comparison with other households who had no links (Figure 4a and b). Moreover, our results also demonstrate that those farm types with a low level of adoption of agricultural technologies (e.g. recycling crop residue) had limited access to information compared to other farm households. These results indicated the importance of access to information for the adoption of agricultural technologies. Overall, results largely indicate a connection between the level of resource endowment of a farm household and good links with a farmer's field school and access to information and the adoption of agricultural technologies.

4 | DISCUSSION

Farm household typologies were developed based on study objectives that determine the rate of adoption of new agricultural technologies. The results of this research show key differences between the four identified farm types. The factors influencing the diversity of farm households, how they evolve to each other and the implications of this are discussed regarding the adoption of new agricultural technologies.

4.1 | Household characteristics

The farm household typology describes the importance of the age and level of literacy of the household head as well as the size of the household. It also helps us to explain the diversity of farm households in the study area. Other studies reported similar findings, although with variations. Kamau et al., (2018) revealed that farm types significantly differed regarding the age of the household heads, their education and literacy levels, as well as the number of members in the farm household. In Kenya and Tanzania, van de Steeg et al., (2010) found that family size and the number of years of education explained heterogeneity in the five farm types. In Rwanda, the significant household discriminants were family size and the age and level of education and literacy of the household head (Bidogeza et al., 2009). The results of our study showed that the significant household discriminants were the age and amount of farming experience of the household head but that the level of literacy was not. Similar findings were reported by Pilarova et al., (2018) who found that the age of the household head was a significant distinguishing factor between different farm types in Moldova but that the level of education of the household head was not. Kuswardhai et al., (2014) found that age and farming experience explained heterogeneity in the four farm types they found in the West-Java province, Indonesia. A study conducted in Ethiopia by Jena et al., (2012) reported that certified smallholder farms were headed by relatively older household heads with a mean age of 48 years, who had a low level of education. The results of this study show this is true for farm Type 2, but not for Types

3 & 4. An inverse link between age and education as well as the literacy level of the household head was also reported by Bidogeza et al., (2009) in Rwanda, where young household heads were more educated. Similar findings were reported by Signorelli (2016) who found that wealthier households were more often headed by young household heads with a high level of education.

The results of the current study suggest that among the sampled households, farming is mainly practiced by the older generation. This finding is in line with that of Mutoko et al., (2014) in western Kenya. In Bangladesh, young people who are engaged in the agricultural sector tend to migrate to urban areas due to poor employment opportunities in rural areas (Hossain, 2001). In addition, as stated by Zaman et al., (2010), the agricultural sector is not capable of absorbing the surplus labour force entering the economy every year, thereby encouraging people to migrate to urban areas. In these circumstances, it is necessary to emphasize the important role played by household characteristics in the adoption of new technologies. Firstly, support for youth education with an emphasis on vocational training, to help them to improve their technical skills as, among other benefits, being able to absorb new ideas and innovations would enable farmers to create market opportunities (Radwan, 1995). Secondly, the older and more experienced generation of farmers who are engaged in farming cannot be ignored. For Type 3 farm household heads who were relatively older and had extensive farming experience but a moderate level of education, the support of special extension services is required to help them adopt new technologies. In general, educated farmers are very flexible about adopting new technologies (Ahimbisibwe et al., 2020; Mignouna et al., 2011).

4.2 | Resource endowment and farming practices

Thirty-two per cent of the farms sampled belonged to Type 1 and were well endowed. These farms were heavily reliant on farm income mainly from crops and with low levels of off/non-farm activities and income. They relied on hired labour, had high financial capital (savings) and high food security. In contrast, resource-constrained Type 4 farms, which depended on on-farm labour or off-farm employment as casual labourers, had a subsistence level of living. These two types correspond to other typologies for smallholder farmers (Kuivanen, Alvarez, et al., 2016; Mutoko et al., 2014; Signorelli, 2016; Tittonell et al., 2005a). Type 3 farms differed from the other types because despite being relatively moderately resource endowed, they were heavily reliant on farm income mainly from crops and had average access to external financing, which could explain their limited ownership of productive assets as well as livestock. This farm type was similar to a type found in Ghana by Kuivanen, Alvarez, et al., (2016). Type 2 farms differed from the other types as farmers already own or have access to small farms. They were heavily reliant on income from livestock. The literature suggests that their poverty and level of risk can be reduced by the adoption of recommended technologies (Kuivanen, Alvarez, et al., 2016; Melesse, 2018). However, for Type 4 farm households, diversification into off/non-farm activities would also generate income (Barrett et al., 2001a; Kuivanen, Alvarez, et al., 2016) which could be invested in the purchase of more productive assets, including land and improved livestock to boost productivity. In well resource endowed Type 1 farm households with more labour intensive technologies, interventions could include the primary focus being on farm mechanization. Type 4, that is severely resource-constrained farm households, needs to focus attention on improved breeds as their livestock entirely depended on poultry and small ruminants. Keeping small ruminants and poultry is financially economical for resource-constrained farm households because little input (land, labour, cash etc.) is required for their maintenance (Kuivanen, Michalscheck, et al., 2016).

4.3 | Access to information

It was expected that access to information through extension personnel and farmers' field schools (FFS) would positively influence the adoption of new agricultural technologies. This study reveals a robust positive link with extension service, FFS and the adoption of new technology practices such as conservation agriculture and improved livestock breeds. In this study, Type 2 farms consisted of households owning a greater number of livestock who had excellent links with extension agents and this may result in the greater adoption of improved livestock breeds in comparison with other households who had no links (Figure 3). This is in line with the findings of Ahimbisibwe et al., (2020), who found that access to extension services has a significant association with the adoption of new technologies. This finding also corresponds to previous studies regarding the importance of extension services; Kassie et al., (2015) found that access to extension services has a positive effect on the adoption of sustainable practices and new agricultural technologies. Abdulai (2016) found that the adoption of new technologies, such as conservation agriculture, relies on the awareness of farm households and access to comprehensive information about the new technology. In contrast, Tesfaye et al., (2014) demonstrated that extension services did not have any effect on the adoption of innovative practices. Other studies such as Shikuku et al., (2017) showed that extension services have a negative effect on the adoption of practices to deal with climate change as well as the introduction of new agricultural technologies, while Maumbe (2010) also found that the acquisition and utilization of information are influenced by the level of literacy of the household head, the cost of implementing new technologies and links with external support for farmers, such as extension agents and a FFS. Interestingly, this study found no link between the level of literacy of the household head and the acquisition and utilization of information regarding new technologies. Based on our findings, Type 3 farm households have a high education level, but these households frequently had little contact with extension workers which resulted in a lower level of adoption of improved breeds (Figure 4). However, membership of cooperatives or a similar community structure, such as FFS, can play an important role in acquiring and sharing valuable information regarding new agricultural technologies and sustainable adaptation practices in Bangladesh. Therefore, development projects in these areas need to emphasize increasing the access of farm households to farm cooperatives, farming groups and farmers' associations as a way to enhance their ability to adopt new agricultural technologies (Aryal et al., 2020).

4.4 | Adoption of new agricultural technologies are linked to farm types

The results indicated that farming practices associated with new agricultural technologies were higher among older and wealthier farm households heads. Jena et al., (2012) reported the ability of older farmers to earn more because they were more knowledgeable and better established than younger farmers. Our study indicates that the households which is a high average level of education may be more inclined to adopt technology, that is the retention of residue in the fields (Figure 3). Similar results were also observed in the studies of the adoption of improved maize seed in Tanzania (Nkonya et al., 1997). Abdulai (2016) suggested that the adoption of agricultural technologies were influenced by the education level of household heads. The results indicated that farmers for whom agriculture is the main source of income had significantly influenced the adoption of various farming practices and technology. In contrast, Van Hulst and Posthumus (2016) showed that the percentage of income from the agricultural sector did not significantly influence the adoption of new agricultural technologies. According to the survey data, Type 1 farmers were involved in on-farm activities as their income from the agricultural sector is higher than that of other farm types. The education level of the household head was average which could provide them with more opportunity to be involved in farm work and, consequently, they might be well informed about the various new farming technologies. In contrast, agriculture was a less important activity for Type 4 farm households. Greater reliance on off-farm income, especially for Type 4 farm households, could limit the number of resources they can allocate to crop production activities. However, in the future, off-farm income diversification may be viewed as a way to avoid risk and uncertainty and may later influence adoption decisions (Marra et al., 2003). Concerning the cropping-management practices, Type 1 farms comprised households with a large farm and a high proportion of hired labour. In terms of adopting new practices, these households recycle crop residue in the field as a large farm produces more residue which can be incorporated in the fields. According to the previous study by Melesse (2018), land size had a positive influence on the adoption of new agricultural technologies. In contrast, Ogada et al., (2014) reported the opposite effect of land size on the adoption of new agricultural technologies. But this study suggests that for most of the Bangladeshi farmers who have grown different types of crops of various varieties, this requires a larger farm. Fernandez (2017) suggested that the adoption of irrigation management practices is positively influenced by hiring permanent labour, but the present study did not confirm this finding. This study indicated that the practice of new agricultural technologies is positively influenced by land ownership, especially for Type 1 farms. This finding is in line with reports by Nsiah et al., (2006) who stated that tenant farmers are reluctant to adopt sustainable practices. The results suggested that highly and moderately resource endowed farms have their feed resources and are in a better financial position to keep a large number of livestock (Sarker, 2015). A large herd also encourages the use of a large amount of crop residue which is transported from the field to their farmhouse/homestead for stall feeding (Diressie, 2011). Farmers in this category also produced more manure on their farm, while a relatively high proportion of the manure was used in the field. This finding is in line with the reports by Diressie (2011) who stated that farmers applied more manure to their fields if they owned more livestock compared to those who had fewer or no cattle.

The study indicated that larger farms (Farm 1) have a higher level of savings compared with small farms. This is because large farms cultivated different types of high-value crops on their farms and make a good profit. The results suggest that economic factors, such as savings, significantly influenced the adoption of agricultural technologies. These findings correspond to Abdulai (2016) who demonstrated that financially constrained farmers are less likely to adopt new agricultural technologies compared with well-resourced farm households. Yigezu et al., (2018) also mentioned that a high initial investment is needed to cope with new agricultural technologies and Teshome et al., (2016) indicated the importance of adequate cash resources. Moreover, in terms of food security, larger farms (Farm 1) have greater food security compared with small farms because they produced a greater amount of food. This finding is in line with Signorelli (2016) who found that wealthy farm households had high rates of food security, while the opposite was true for the poorly endowed farm households.

The results suggest that the distance of farm households from the market had a negative influence on the adoption of new technologies. These findings correspond to a previous study by Tefera et al., (2016) which demonstrated that the adoption of maize and teff technology increase with proximity to markets. It was expected that the distance from markets would be very important for the farmers to get the optimum market price by reducing transportation costs. Type 2 farms had relatively high livestock numbers and are close to the market—this might allow them to get higher prices for livestock products, especially milk. Extension messages and decision makers should focus more on these groups, especially in the adoption of improved livestock breeds. The study indicates that the distance of residence from all-weather roads did not significantly influence the adoption of new technologies. In contrast, Melesse (2018) mentioned that the distance of a residence from all-weather roads had a negative relationship to the adoption of fertilizer. It was expected that access to information through extension agents would play an important role in the adoption of new agricultural technologies. The present findings are also in line with other studies conducted by Akudugu et al., (2012) and Tefera et al., (2016) which investigated the effect of extension agents on the promotion of new agricultural interventions. On the other hand, Tesfaye et al., (2014) investigated the effect of extension services on the implementation of agronomic practices, soil conservation measures, and pest and weed control in Ethiopia. Their research suggests that no significant relationship was found between access to extension services and the adoption of new technologies. Type 2 farms had excellent links with extension agents, and this may result in a greater willingness to adopt new technology, that is improved livestock breeds, and compared with other households which had no links (Figure 4a,b). Given the importance to farmers of links with external support (e.g. from extension officers), young farmers, even those not involved in full-time farming, could benefit from becoming involved in innovative farming.

4.5 | Limitations of the study

This research was subject to some limitations due to time and financial constraints. Recall-based farm data provided by the farm households were used to develop farm typology in the study area. Because of the memory bias of respondents, some of these values may be inaccurate. The findings of the research cannot be generalized for the whole country due to the small sample size as a result of time and funding constraints. Furthermore, it was expected that farm households would be dynamic; production systems could rapidly change as well as farm typologies, which would need to be constantly updated (Alvarez et al., 2014). However, this study can help inform policymakers, researchers and development practitioners, as it provides insights into how systems may evolve over-time.

5 | CONCLUSION AND POLICY IMPLICATIONS

Agricultural research and development projects provide a particular set of new technologies such as the use of recycled crop residue and improving crop and livestock systems by introducing new varieties and breeds in the farming community. The key objective of such projects is the differentiation of the projects' target population based on farm types which are often used for targeting the introduction of innovations. Constructing farm typologies can be especially helpful in describing the existing heterogeneity within a target farming community.

A multivariate statistical technique that combines PCA and CA enabled the identification of four typical farm types in the selected area with respect to adopting new agricultural interventions using socio-economic factors. Concerning the first research objective, a farm typology was found with significant differences among the four farm types. With reference to the second research objective, the key factors in the adoption of new agricultural technologies by farmers are their age, farming experience, education, income, access to market, land ownership, savings, food self-sufficiency, access to extension services and the proportion of hired labour and income from off-farm activities.

The wealthier and less literate farm households in Type 1 could be encouraged to increase their use of improved technologies, inputs and farming practices that are environmentally friendly, such as recycling crop reside and the use of organic manure, animal rearing with improved breeds and the reduction of post-harvest losses by improving storage facilities. Livestock-based Type 2 farms could benefit from interventions to increase knowledge about improved technologies, such as providing pure breeds and increasing AI facilities, through training and access to extension services. In addition, they could also benefit from efforts to improve access to capital, particularly land, low-input technologies and high yielding crop varieties. Type 3 households have an average level of literacy; they could also benefit from more knowledge-intensive technologies. Type 4 farms could benefit from efforts aimed at income diversification in non- and off-farm activities by increasing credit access and improving the level of education.

Finally, it can be concluded that a multivariate statistical technique that combines PCA and CA is suitable tools for identifying major socio-economic characteristics of typical farms. This research has also highlighted the heterogeneity of farm household concerning the present use of new agricultural technologies and identified the factors that determine their future use. As some types of farm household have a better ability to cope with new technologies than others, extension messages and decision makers should focus greater attention on specific groups, such as these four farm types.

These findings also suggest that there is an urgent need for researchers, policymakers and disseminators to give serious consideration to these key socio-economic factors when deciding on ways to increase the rate of adoption of agricultural technologies by farmers. Future research should, therefore, be aimed at the development of support tools to assist farmers in making decisions appropriate for their farms based on these typical farms.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

MRS involved in conceptualization, methodology, analysis, data curation and writing–original draft. MG and AC involved in supervision, formal analysis and editing. AH involved in visualization, questionnaire preparation and editing.

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REFERENCES

Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. *Agricultural Economics*, *47*, 729–741.

Ahimbisibwe, B. P., Morton, J. F., & Feleke, S. (2020). Household welfare impacts of an agricultural innovation platform in Uganda. *Food and Energy Security*, *9*(3), e225. https://doi.org/10.1002/fes3.225

Ahmed, S. (2013). Food and agriculture in Bangladesh. *Encyclopedia of Food and Agricultural Ethics*, *1*, 1–8.

Akudugu, M., Guo, E., & Dadzie, S. (2012). Adoption of modern agricultural production technologies by farm households in Ghana: What factors influence their decisions? *Journal of Biology, Agriculture and Healthcare*, *2*, 1–13.

Alam, M. & Swapan, K. S. (2011). Homestead agroforestry in Bangladesh: Dynamics of stand structure and biodiversity. *Journal of Sustainable Forestry*, *30*, 584–599. https://doi.org/10.1080/10549811.2011.571606

Alvarez, S., Paas, W., Descheemaeker, K., Tittonell, P., & Groot, J. (2014). *Typology construction, a way of dealing with farm diversity: General guidelines for humidtropics*. CGIAR Research Program led by IITA.

Alvarez, S., Timler, C. J., Michalscheck, M., Paas, W., Descheemaeker, K., Tittonell, P., Andersson, J. A., & Groot, J. C. J. (2018). Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farming system typology development. *PLoS One*, *13*(5), e0194757. https://doi.org/10.1371/journal.pone.0194757

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Krupik, T. J., Shahrin, S., Jat, M. L., & Stirling, C. M. (2020). Major climate risks and adaptation strategies of smallholder farmers in coastal Bangladesh. *Environmental Management*, *66*, 105–120. https://doi.org/10.1007/s00267-020-01291-8

Asfaw, A. & Admassie, A. (2004). The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia. *Agricultural Economic*, *30*(3), 215–228.

Bangladesh Bureau of Statistics. (2017). *Statistical year book of Bangladesh, statistics division, ministry of planning*. Government of the People's Republic of Bangladesh.

Bangladesh Economic Review. (2017). *Finance division, ministry of finance*. Government of the People's Republic of Bangladesh.

Barma, N. C. D., Hossain, A., Hakim, M. A., Mottaleb, K. A., Alam, M. A., Reza, M. M. A., & Rohman, M. M. (2019). Progress and challenges of wheat production in the era of climate change: A Bangladesh perspective. In M. Hasanuzzaman, K. Nahar, M. Hossain (Eds.) *Wheat Production in Changing Environments* (pp. 615–679). Singapore: Springer. https://doi.org/10.1007/978-981-13-6883-7_24

Barrett, C. B., Reardon, T., & Webb, P. (2001a). Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy*, *26*, 315–331.

Bidogeza, J. C., Berentsen, P. B. M., De Graaff, J., & Oude, L. A. G. J. M. (2009). A typology of farm households for the Umatara province in Rwanda. *Food Security*, *1*(3), 321–335.

Chang, H. J. (2012). Rethinking public policy in agriculture – Lessons from history, distant and recent. *Public Policy and Agricultural Development*, *36*, 15–80. https://doi.org/10.1080/0306615090314274

Chowdhury, A. A. (1978). *A Bangladesh village : a study in social stratification*. Dacca: Centre for Social Studies.

Daloglu, I., Nassauer, J., Riolo, R., & Scavia, D. (2014). Development of a farmer typology of agricultural conservation behavior in the American Corn Belt. *Agricultural Systems*, *129*, 93–102.

Daskalopoulou, I. & Petrou, A. (2002). Utilising a farm typology to identify potential adopters of alternative farming activities in Greek agriculture. *Journal of Rural Studies*, *18*(1), 95–103. https://doi.org/10.1016/S0743-0167(01)00027-4

Dhraief, M. Z., Bedhiaf, R. S., Dhehibib, B., Oueslati, Z. M., Jebali, O., & Ben, Y. S. (2018). Factors affecting the adoption of innovative technologies by livestock farmers in arid area of Tunisia. *FARA Research Report*, *3*(5), 22.

Diressie, H. T. (2011). Crop residue management and farm productivity in smallholder crop-livestock system of dry land North Wollo, Ethiopia. MSc Thesis, Wageningen University, the Netherlands. https://edepot.wur.nl/171984

Duvernoy, I. (2000). Use of a land cover model to identify farm types in the Misiones agrarian frontier (Argentina). *Agricultural Systems*, *64*, 137–149.

Farid, K., Tanny, N., & Sarma, P. (2015). Factors affecting adoption of improved farm practices by the farmers of Northern Bangladesh. *Journal of the Bangladesh Agricultural University*, *13*(2), 291–298. https://doi.org/10.3329/jbau.v13i2.28801

Faruque, A. S., Huang, Z., & Karimanzira, T. T. P. (2018). Investigating key factors influencing farming decisions based on soil testing and fertilizer recommendation facilities (STFRF)—A case study on rural Bangladesh. *Sustainability*, *10*, 4331.

Fernandez, M. A. (2017). Adoption of erosion management practices in New Zealand. *Land Use Policy*, *63*, 236–245. https://doi.org/10.1016/j.landusepol.2017.01.040

Field, A. (2005). *Discovering statistics using SPSS* (2nd ed.). Sage.

Goswami, R., Chatterjee, S., & Prasad, B. (2014). Farm types and their economic characterization in complex agro-ecosystems for informed extension intervention: study from coastal West Bengal, India. *Agricultural and Food Economics*, *2*(1), 2–5.

Hair, J. F., Black, C. W., Babin, J. B., Anderson, E. R., & Tatham, L. R. (2006). *Multivariate data analysis* (p. 928). Pearson Prentice Hall, Upper Saddle River.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis: A global perspective* (7th edn). Pearson.

Hossain, A. & Teixeira da Silva, J. A. (2013). Wheat production in Bangladesh: It's future in the light of global warming. *AoB Plants*, *5*, pls042. https://doi.org/10.1093/aobpla/pls042

Hossain, M. Z. (2001). Rural-urban migration in Bangladesh: A micro-level study. For presentation in a poster session on internal migration at the Brazil IUSSP. Conference during August 20-24.

Islam, M. A., Warwick, N., Koech, M. N., & Bruyn, L. L. D. (2020). The importance of farmer's perceptions of salinity and adaption strategies for ensuring food security: Evidence from the coastal rice-growing areas of Bangladesh. *Science of the Total Environment*, *727*, 138674.

Jabbar, M. A. (2011). *Policy constraints for implementation of the proposed programs for investment in agriculture, food security and nutrition in Bangladesh*. The International Food Policy Research Institute.

Jena, P. R., Stellmacher, T., & Grote, U. (2012). The impact of coffee certification on small-scale producers' livelihoods: Evidence from Ethiopia. In: Presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz Do Iguaçu, Brazil, 18–24.

Kamau, J. W., Till, S., Lisa, B. F., & Christian, B. (2018). Organic and conventional agriculture in Kenya: A typology of smallholder farms in Kajiado and Murang'a counties. *Journal of Rural Studies*, *57*, 171–185.

Karim, M. A., Qauyyum, M. A., Samsuzzaman, S., Higuchi, H., & Nawata, E. (2017). Challenges and opportunities in crop production in different types of char lands of Bangladesh. *Tropical Agriculture and Development*, *61*(2), 77–93.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and Southern Africa. *Land Use Policy*, *42*, 400–411. https://doi.org/10.1111/1477-9552.12099

Kobrich, C., Rehman, T., & Khan, M. (2003). Typification of farming systems for constructing representative farm models: Two illustrations of the application of multi-variate analyses in Chile and Pakistan. *Agricultural Systems*, *76*(1), 141–157.

Kuhn, B. A. & Offutt, S. E. (1999). Farm policy in an era of farm diversity. *Choices*, *14*, 37–38.

Kuivanen, K. S., Alvarez, S., Michalscheck, M., Adjei-Nsiah, S., Descheemaeker, K., Mellon-Bedi, S., & Groot, J. C. J. (2016). Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: a case study from the Northern Region, Ghana. *NJAS - Wagening Journal of Life Sciences*, *78*, 153–166. https://doi.org/10.1016/j.njas.2016.04.003

Kuivanen, K. S., Michalscheck, M., Descheemaeker, K., Adjei-Nsiah, S., Mellon-Bedi, S., Groot, J. C. J., & Alvarez, S. A. (2016). A comparison of statistical and participatory clustering of smallholder farming systems – A case study in Northern Ghana. *Journal of Rural Studies*, *45*, 184–198.

Kuswardhani, N., Soni, P., & Shivakoti, G. P. (2014). Cluster analysis for classification of farm households based on socio-economic characteristics for technology adoption in agriculture: A case study of West Java province, Indonesia. *Journal of Food, Agriculture and Environment*, *12*(1), 238–247.

Lattin, J., Carroll, D., & Green, P. (2005). *Analyzing multivariate data* (2nd ed., p. 525). Duxbury.

Lopez-Ridaura, P. S., Frelat, R., Van Wijk, M. T., Valbuena, D., Krupnik, T. J., & Jat, M. L. (2018). Climate smart agriculture, farm household typologies and food security: An exante assessment–Eastern India. *Agricultural Systems*, *159*, 57–68.

Mafimisebi, T. E. (2006). Analysis of farmer–specific socio-economic determinants of adoption of modern livestock management technologies by farmers in Southwest Nigeria. *Journal of Food, Agriculture & Environment*, *4*(1), 183–186.

Mahapatra, A. K. & Mitchell, C. P. (2001). Classifying tree planters and non-planters in a subsistence farming system using a discriminant analytical approach. *Agroforestry Systems*, *52*(1), 41–52.

Mainuddin, M., Maniruzzaman, M., Alam, M. M., Mojid, M. A., Schmidt, E. J., Islam, M. T., & Scobie, M. (2020). Water usage and productivity of Boro rice at the field level and their impacts on the sustainable groundwater irrigation in North-west Bangladesh. *Agricultural Water Management*, *240*, 106294. https://doi.org/10.1016/j.agwat.2020.106294

Marra, M., Pannell, D. J., & Ghandim, A. A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? *Agricultural Systems*, *75*(2–3), 215–234.

Maumbe, B. M. (2010). International Journal of ICT Research and Development in Africa: an Official Publication of the Information Resources Management Association. v. 1, no. 1, January-March.

Melesse, B. (2018). A review on factors affecting adoption of agricultural new technologies in Ethiopia. *Journal of Agricultural Science and Food Research*, *9*(226), 208–216.

Mignouna, B., Manyong, M., Rusike, J., Mutabazi, S., & Senkondo, M. (2011). Determinants of adopting imazapyr-resistant maize technology and its impact on household income in Western Kenya. *AgBioforum*, *14*(3), 158–163.

Milan, M. J., Bartolome, J., Quintanilla, R., Garcia, M. D., Espejo, M., Herraiz, P. L., Sánchez-Recio, J. M., & Piedrafita, J. (2006). Structural characterisation and typology of beef cattle farms of Spanish wooded rangelands (dehesas). *Livestock Science*, *99*(2–3), 197–209.

Mondal, M. H. (2010). Crop agriculture of Bangladesh: Challenges and opportunities. *Bangladesh Journal of Agricultural Research*, *35*, 235–245.

Mutoko, M. C., Hein, L., & Shisanya, C. A. (2014). Farm diversity, resource use efficiency and sustainable land management in the western highlands of Kenya. *Journal of Rural Studies*, *36*, 108–120. https://doi.org/10.1016/j.jrurstud.2014.07.006

Mwangi, M. & Kariuki, S. (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development*, *6*(5), 208–216.

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., Twomlow, S., & Winowiecki, L. A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural Systems*, *151*, 192–203. https://doi.org/10.1016/j.agsy.2016.05.009

National Agriculture Policy. (1999). *Ministry of agriculture*. Government of the People's Republic of Bangladesh.

Nkonya, E., Schroeder, T., & Norman, D. (1997). Factors affecting adoption of improved maize seed and fertiliser in Northern Tanzania. *Journal of Agricultural Economics*, *48*(1), 1–12.

Nsiah, S. A., Saïdou, A., Kossou, D., Dawson, O. S., & Kuyper, T. W. (2006). Tenure security and soil fertility management: Case studies in Ghana and Benin. Colloque international "Les frontières de la question foncière – At the frontier of land issues", Montpellier. Retrieved from www.mpl.ird.fr/colloque_foncier/Communications/PDF/Adjei%20Nsiah.pdf.

Obayelu, A., Ajayi, O., Oluwalana, E., & Ogunmola, O. (2017). What does literature say about the determinants of adoption of agricultural technologies by smallholders farmers? *Agricultural Research & Technology*, *6*(1), 555675. https://doi.org/10.19080/ARTOAJ.2017.06.555676

Ogada, M. J., Mwabu, G., & Muchai, D. (2014). Farm technology adoption in Kenya: A simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. *Agricultural and Food Economics*, *2*(1), 2–12.

Paul, S., Hossain, M. D., Shudarshan, K. R. (2013). Monga' in northern region of Bangladesh: A study on people's survival strategies and coping capacities. *Rajshahi University Journal of Life & Earth and Agricultural Sciences*, *41*, 41–56. https://doi.org/10.3329/rujleas.v41i0.21620

Pilarova, T., Bavorova, M., & Kandakov, I. (2018). Do farmer, household and farm characteristics influence the adoption of sustainable practices? The evidence from the Republic of Moldova. *International Journal of Agricultural Sustainability*, *16*(4-5), 367–384. https://doi.org/10.1080/14735903.2018.1499244

Priegnitz, U., Lommen, W. J. M., Onakuse, S., & Struik, P. C. (2019). A farm typology for adoption of innovations in potato production in Southwestern Uganda. *Frontiers in Sustainable Food Systems*, *3*, 68. https://doi.org/10.3389/fsufs.2019.00068

R Core Team. (2019). *A language and environment for statistical computing*. R Foundation for Statistical Computing. ISBN 3-900051-07-0.

Radwan, S. (1995). Challenges and scope for an employment-intensive growth strategy. In: *Employment for poverty reduction and food security* (pp. 21–45). International Food Policy Research Institute.

Rahman, K. M. A. & Zhang, D. (2018). Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability. *Sustainability*, *10*, 759. https://doi.org/10.3390/su1003059

Rahman, M. W. & Das, M. (2019). Unfolding household typology towards better extension advisory services in typical Southern villages of Bangladesh. *Bangladesh Journal of Extension Education*, *31*(1&2), 51–67.

Reynolds, A. P., Richards, G., Iglesia, B., & Smith, V. J. (2006). Clustering rules: A comparison of partitioning and hierarchical clustering algorithms. *Journal of Mathematical Modelling and Algorithms*, *5*(4), 475–504.

Roy, D., Dev, D. S., & Sheheli, S. (2019). Food security in Bangladesh: Insight from available literature. *Journal of Nutrition and Food Security*, *4*(1), 66–75.

Ruben, R. & Pender, J. (2004). Rural diversity and heterogeneity in less-favoured areas: The quest for policy targeting. *Food Policy*, *29*, 303–320. https://doi.org/10.1016/j.foodpol.2004.07.004

Sakané, N., Becker, M., Langensiepen, M., & van Wijk, M. T. (2013). Typology of smallholder production systems in small east-african wetlands. *Wetlands*, *33*, 101.

Sarker, M. M. R. (2015). Trade-off analysis of crop residues use in smallholder mixed crop –Livestock systems to support more effective use of conservation agriculture (CA) in 'South Western' Bangladesh. MSc Thesis, Wageningen University, the Netherlands.

Shikuku, K. M., Winowiecki, L., Twyman, J., Eitzinger, A., Perez, J. G., Mwongera, C., & Läderach, P. (2017). Smallholder farmers'attitudes and determinants of adaptation to climate risks in East Africa. *Climate Risk Management*, *16*, 234–245. https://doi.org/10.1016/j.crm.2017.03.001

Signorelli, S. (2016). Typology characterization of farmers in West Africa. Presented at the Africa RISING West Africa Review and Planning Meeting, Accra, Washington, D.C.: IFPRI.

Somda, J., Kamuanga, M., & Tollens, E. F. (2004). Characteristics and economic viability of milk production in the smallholder farming systems in The Gambia. *Agricultural Systems*, *85*(1), 42–58.

Tefera, T., Tesfay, G., Elias, E., Diro, M., & Koomen, I. (2016). *Drivers for adoption of agricultural technologies and practices in Ethiopia—A study report from 30 woredas in four regions*. CASCAPE project.

Tesfaye, A., Negatu, W., Brouwer, R., & Van der Zaag, P. (2014). Understanding soil conservation decision of farmers in the gedeb watershed, Ethiopia. *Land Degradation & Development*, *25*(1), 71–79. https://doi.org/10.1002/ldr.2187

Teshome, A., de Graaff, J., & Kassie, M. (2016). Household-level determinants of soil and water conservation adoption phases: Evidence from north-western Ethiopian highlands. *Environmental Management*, *57*, 620–636. https://doi.org/10.1007/s00267-015-0635-5

The Daily Star. (2016). Balanced fertilizer usage. The Daily Star, 25 September 2016. Retrieved from https://www.thedailystar.net/round-tables/balanced-fertiliser-usage-1289308.

Tittonell, P., Muriuki, A., Shepherd, K. D., Mugendi, D., Kaizzi, K. C., Okeyo, J., Verchot, L., Coe, R., & Vanlauwe, B. (2010). The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. *Agricultural Systems*, *103*, 83–97. https://doi.org/10.1016/j.agsy.2009.10.001

Tittonell, P. A., Vanlauwe, B., de Ridder, N., & Giller, K. E. (2007). Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients? *Agricultural Systems*, *94*(2), 376–390.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Rowe, E. C., & Giller, K. E. (2005a). Exploring diversity in soil fertility management of smallholder farms in western Kenya: Heterogeneity at region and farm scale. *Agriculture, Ecosystems and Environment*, *110*, 149–165. https://doi.org/10.1016/j.agee.2005.04.001

Van de Steeg, J. A., Verburg, P. H., Baltenweck, I., & Staal, S. J. (2010). Characterization of the spatial distribution of farming systems in the Kenyan Highlands. *Applied Geography*, *30*, 239–253. https://doi.org/10.1016/j.apgeog.2009.05.005

Yigezu, Y. A., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y., & Loss, S. (2018). Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. *Technological Forecasting and Social Change*, *134*(C), 199–206.

Zaman, A. K. M., Alam, K. T., & Islam, J. (2010). Urbanization in Bangladesh: Present status and policy implications. *ASA University Review*, *4*(2), 1–16.

Zingore, S., Murwira, H. K., Delve, R. J., & Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems & Environment*, *119*, 112–126.

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