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Determinants of conservation agriculture-based sustainable intensification technology adoption in smallholder farming systems: Empirical evidence from Nepal

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Abstract: A series of on-station and on-farm CASI-based zero tillage (ZT) trials with wheat, maize and kidney bean farming systems have proven to be beneficial in the Eastern Gangetic Plains (EGP) of South Asia economically and environmentally, yet the adoption of this technology among the Nepalese farmers remains low. A two-stage double hurdle model was used to identify and analyze the factors influencing the initial adoption and subsequent intensity of adoption decisions of CASI-based ZT technology in the Sunsari and Dhanusha districts in Nepal. Results showed that gender, education of farmers, farming experience, number of dependent members in households, migration, annual income, credit obtained for crop production, training attended, and exposure visits and field days were significant positive variables in both adoption and intensity of adoption decisions. It is recommended that efforts be made for improving farmers' knowledge through farmers' groups and cooperatives, and organizing training and exposure visits and field days for farmers to increase awareness and improve access to the adoption and spread the CASI technologies. The findings have large implications for the adoption and spread of CASI-based technologies and the sustainability of cereal-based farming systems not only in Nepal but in the entire EGP of South Asia.

Keywords: CASI technologies; double hurdle model; mechanization; smallholder farming systems; sustainable intensification; zero tillage

Introduction

The Eastern Gangetic Plain (EGP), located within the South Asian Indo-Gangetic Plains (IGP), is heavily populated with a strong dependence on agriculture for food security and livelihoods (CIMMYT, 2015; Timsina et al., 2018). Average crop yields and total cropping system productivity in this region are low due to several biophysical (e.g., poor soils and fragmented land, occurrences of extreme weather events, inadequate utilization of ground and surface water resources, insect and disease pressures) and socio-economic factors (e.g. small farm sizes, poorly developed markets, fragmented and sparse agricultural knowledge and service networks, farmers' lack of knowledge in the use of improved technologies) (Dixon et al., 2020; Islam et al., 2019; Krupnik et al., 2021). The majority of the farming systems of this region consist of water, capital and energy-intensive rice-based farming systems such as rice-rice, rice-wheat and rice-maize (Gathala et al., 2020b; Islam et al., 2019). These farming systems are less profitable than the non-rice based systems because of the costly labour and high use of costly and scarce water, capital and energy. In addition to low productivity and profitability, the resource-intensive practices used in these systems also produce large quantities of greenhouse gases (GHGs) and create serious threats to the environmental sustainability of the cereal-based farming systems of the region (Bhatt, et al., 2021; Gathala et al., 2020a, 2020b, 2021; Dixon et al., 2020; Timsina et al., 1995).

Nepal, located in the EGP, is an agrarian country but is challenged by agricultural labour scarcity due to out-migration, high dependence on rainfed farming, practicing agriculture with low or inadequate use of modern inputs such as irrigation water and fertilizers, thus resulting in high production costs and low crop productivity. In between 2009 to 2022, more than 4.7 million Nepalese issued new labour approval for work abroad (MoLESS, 2022), and this status is increasing. This data shows labour outmigration in Nepal in the last decade has created a chronic shortage of young and skilled human resources in agricultural production and agribusiness posing a critical threat to ensuring the country's food security (Maharjan et al., 2013; Gauchan, 2018). This situation has also contributed to a higher wage rate in rural areas (Wiggins and Ketas, 2014; Wang et al., 2016). Nevertheless, due to the poor growth of farm mechanization, Nepalese agriculture is still labour-intensive which in turn results in higher production costs and lower farm profit (Paudel et al., 2019). Furthermore, cultivation practices like intensive tillage, removal of crop residues, and low or inappropriate use of chemical fertilizers have also contributed to declining soil fertility and crop productivity (Krupnik et al., 2021). In addition to that, out of total land, only 39.6% land have year round irrigation facilities (CBS, 2023). The supply of chemical fertilizer is more than 50% low as compared to demand (Timsina et al., 2022). The fertilizer consumption per unit of land in Nepal is 97.8 kg/ha (World Data Atlas, 2021), which is far below as compared to neighbouring countries. The reason for low consumption is due to the low supply of fertilizer. Nepal In this context, production systems guided by the key concerns of agricultural sustainability are required to increase food production without compromising environmental integrity (Sapkota et al., 2018).

Conservation Agriculture (CA) aims to make better use of agricultural resources through the simultaneous implementation of minimum soil disturbance, permanent soil cover and crop diversification (FAO, 2014; Friedrich and Kassam, 2009; Thiombiano and Meshack, 2009., Dixon et al., 2020). It is an approach to managing in agroecosystems for improved and sustained productivity and increased profits and food security while preserving and enhancing the resource base and the environment (Jat et. al., 2021, Fisher et.al., 2018., FAO, 2014). CA, however, is a knowledge-intensive system, involving a complex set of technologies, to learn and apply by the farmers as they face several problems during its implementation (Giller et al., 2009; Stevention et al., 2014). These problems are diverse, encompassing intellectual, social, biophysical, technical, financial, infrastructure and policy-related issues. Farmer adoption of CA involves many components and decision steps and hence its outscaling is not necessarily straightforward (Brown et al., 2017; 2021b; Giller et al., 2009; Knowler and Bradshaw, 2007; Stevention et al., 2014). It is therefore very important to identify problems which are hindering the adoption decisions (Dixon et al., 2019; Friedrich and Kassam, 2009). Despite years of effort to enhance the adoption and scaling of CA practices and technologies, South Asian countries are facing difficulties in achieving their targeted adoption (Akter et al., 2021; D'Souza and Ashok, 2018; Dixon et al., 2019). In the EGP of Nepal, the spread of CA technologies also remains limited (Brown et al., 2021b). Concerted efforts are required from all stakeholders for scaling the CA technologies and practices across the EGP including Nepal (Dixon et al., 2019; Karki and Shrestha, 2015).

Most adoption-related studies in the past, including the adoption of CA, only considered factors affecting the adoption (Anderson and D'Souza, 2014; D'Emden et al., 2008; Kassie et al., 2013; Uddin et al., 2017). Very little emphasis or priority was given to factors that influence the intensity of adoption. It has been accepted that the adoption of CA is not only a binary outcome but also involves a non-binary process and tends to be partial and incremental (Baudron et al., 2007; Umar et al., 2011). Thus, factors affecting adoption and intensity of adoption would be different. First, farmers make decisions to adopt CA practices in a part of their land and after that, they increase their area under CA (Akter et al., 2021). Arslan et al. (2014) and Brown et al. (2017) considered both adoption and the intensity of adoption of CA in their studies. A study conducted by Kunzekweguta et al. (2017) in Zimbabwe determined both decision and intensity of factors influencing CA using a double hurdle model. They found that farm size and experience with CA technology influenced adoption decisions while the distance from town and ownership of an ox-drawn plough reduced the intensity of uptake. Similarly, Yigezu et al. (2018) reported that education, field day visits, demonstration, extension contact, membership in cooperatives and credit takers significantly affected either decision to adopt or the intensity of CA technology adoption. Ngwira et al. (2014) in Malawi used a two-step Heckman model to find factors affecting the decision and intensity of CA technologies. They mentioned that hired labour, land size, and membership in farmers' groups influenced farmers' decision to adopt CA, while total cultivated land and CA farming experiences influenced the decision to extend their land to CA.

Conservation Agriculture-based Sustainable Intensification (CASI) practices have been widely promoted in the EGP including Nepal by various national and international organizations to improve the productivity, profitability and sustainability of smallholder farming systems (Dixon et al., 2020; Gathala et al., 2020a, 2020b, 2021; Islam et al., 2019; Thapa Magar et al., 2022). CASI practices decrease farm input costs (labour, fertilizers, irrigation, seed, etc.) and improve soil organic matter by retaining the crop residues on the soil surface or seeding crops into crop residues (Gathala et al., 2020a; 2020b; Islam et al., 2019; Sinha et al., 2019; Thapa Magar et al., 2022). The socioeconomic impacts of CASI have improved household food security and income, decreased input costs, improved returns to labour, benefits to women farmers, expanded social capital and strengthened system resilience (Dixon et al., 2019, 2020). In Nepal, CASI practices have increased productivity, lowered production costs, increased gross margins, increased energy-use efficiency and reduced GHG emissions at the farm level (Thapa Magar et al., 2022). However, factors affecting the adoption of agricultural technologies and practices differ across countries or regions due to diverse socioeconomic, cultural, and agroecological environments (Duong et al., 2019; Feder et al., 1985). Moreover, determinants of CA adoption are site-specific and hence a blanket approach to promote the adoption and scaling of CA or CASI would be unsuccessful (Chichongue et al., 2019). In Nepal and largely in the entire EGP, although CASI technologies and practices are beneficial to farmers, they have very limited spread. Due to different behaviours of adoption decisions across regions, factors influencing adoption decisions as well as the intensity of adoption decisions of CASI are important for better scaling of CASI technologies and practices in Nepal. Hence, there needs to be an improved understanding of the different components and processes of adoption. One of the approaches to improve such understanding is through the use of a double hurdle model which ascertains initial adoption decisions followed by the intensity of adoption decisions.

Most of the past studies on CA or CASI in the EGP focused on farmers' perceptions and economics of zero tillage (ZT) technology but none have considered the understanding of the adoption and intensity of adoption decisions of the farmers (Keil et al., 2016, 2017). Hence, in this study, we analyzed drivers influencing both the adoption as well as the intensity of adoption of ZT through a two-step process using a double-hurdle model in two eastern districts of Nepal. The key CASI intervention considered was ZT technology in wheat, maize and kidney bean grew after rice in two districts of the EGP in Nepal. An improved understanding of such adoption behaviour by farmers would help understand the sustainability or unsustainability of the CASI technologies and practices, which would be vital for their scaling not only in Nepal but in the entire EGP.

Research Methodology

Description of the study area and sampling techniques

In Nepal, different government and projects initiatives for the CASI based technologies promotion in various parts of the country. First, in 1980 Nepal Agricultural Research Council (NARC) initiated zero tillage wheat and direct-seeded rice in Rupandehi, Kapilbastu and Nawalparasi districts of Nepal. In 2014, NARC and CIMMYT took initiatives for the adoption of zero tillage and residue management in maize in Chitwan and Parsa districts. Likewise, Cereal Systems Initiatives for South Asia (CSISA) also promoted CASI based technologies in Rupandehi, Chitwan and Nawalparasi districts from 2009 to 2021. The Sustainable and Resilient Farming System Intensification (SRFSI) project, which was implemented in Sunsari and Dhanusha districts of the eastern Gangetic region of Nepal from 2014 to 2018 focusing on promoting CASI technologies. In our study, we purposively selected these two districts because farmers in some of the villages in these districts were exposed to CASI technologies.

The farming system of these two districts is rice-based mixed farming characterized by rice followed by maize, wheat, mustard and kidneybean. The dominant soil types are clay loam to silty clay loam in Sunsari and sandy loam to silty clay loam in Dhanusha (Sinha et al., 2019). A household survey was conducted from April to August 2018 with 337 households that comprised 116 CASI practitioners (adopters) and 221 non CASI-practitioners (non-adopters) from ten villages (five in each district) from these districts. Adopter farmers were identified with the help of key informants and 60% of the target population was selected using the proportion to the size sampling technique. Non-adopter farmers were selected from the same locality from which adopter farmers were selected. A structured interview schedule was used to collect data. The questionnaire covers all the details of socioeconomic and demographic information, land related information, household income, technology adoption status, training received, risk factors and major problems of CASI practices. The details of the respondents are presented in Table 1.

Table 1 - Sample household selection and distribution of surveyed farmers in the study districts in Nepal in the EGP

District	Village	Total	Adopters	Non adopters
Sunsari	Kaptangunj	52	22	30
	Bhaluwa	50	10	40
	Simariya	35	6	29
	Bhokraha	45	19	26
	Saalbani	58	18	40
Dhanusha	Giddha	26	9	17
	Lalgadh	8	3	5
	Phulgama	25	11	14
	Raghunathpur	15	7	8
	Sinurjora	23	11	12
Total		337	116	221

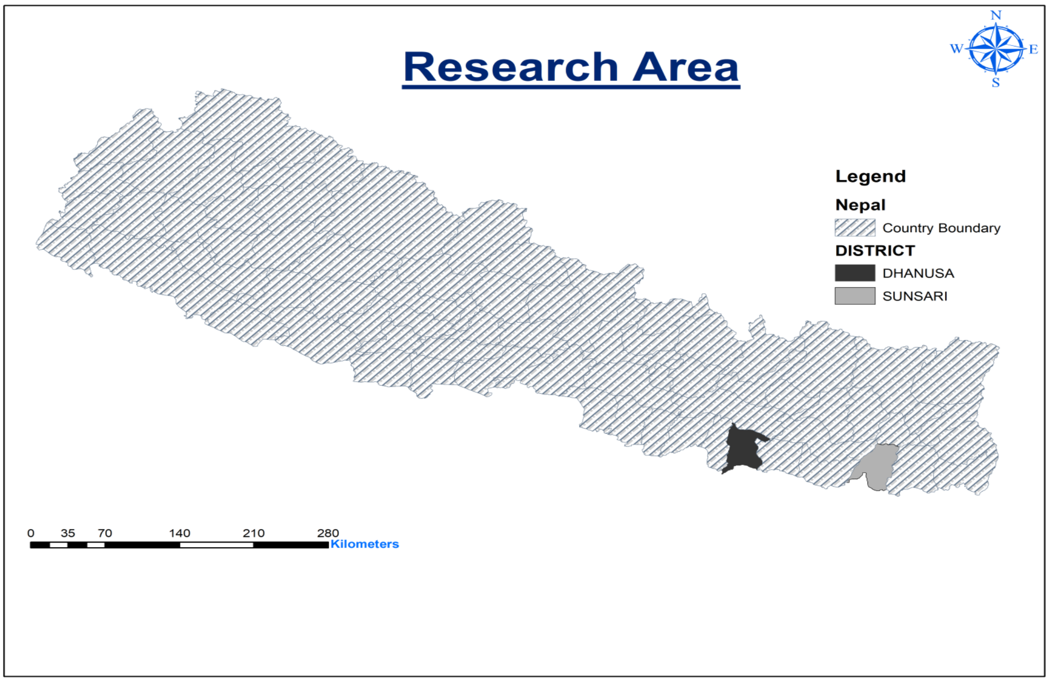

Figure 1 - Study districts

Econometric models used

Probit and logit models, which generally give similar results, are commonly used in the analysis of factors affecting the adoption of improved agricultural technologies. Though it is generally appropriate to analyze only determinants of the decision-making part of adoption it does not capture the intensity of adoption. Hence, for improved agricultural technology adoption, it is important to realize that the farmers' decision-making process involves two decision stages (Akter et al., 2021; Bellemare and Barrett, 2006; Noltze et al., 2012; Xu et al., 2009). The analysis of the decision-making process of adoption involves either to adopt or not to adopt followed by the extent of its adoption (Awotide et al., 2014). In this process, first, the farmer decides whether to adopt a new technology (a dichotomous choice) and then decides on the extent of adoption or the proportion of land adopted for a particular technology (a continuous variable), which is the intensity of adoption.

Many studies have analyzed the determinants of the intensity of adoption of improved technologies using the Tobit model. However, a major drawback of this model is making an assumption that the determinants of the adoption of improved technology and the extent of adoption can be jointly determined and hence factors affecting both stages of the adoption are the same (Abegunde et.al., 2018). In the current study, a two-step model was used; first to identify the decision to adopt CASI technologies or not, and second, the decision for the area of land allocated to those technologies (adoption intensity). Normally, in the decision process, not all farmers adopted CASI technologies. Therefore, some observations have zero values for their adoption status. To overcome the drawbacks of the probit, logit and Tobit models, Cragg (1971) proposed a model called double-hurdle, which separates the variables that determine the adoption decision from those of the intensity of adoption in two steps. In this model, an individual's decision on the intensity of participation in an activity involves two processes; the first hurdle determines whether the individual is a zero type, and the second hurdle determines the intensity of participation given that the individual is not a zero type (Burke, 2009; Engel and Moffatt, 2014). In the current study, in the first hurdle, we estimated the probit model to determine the probability of adopting CASI technologies and in the second hurdle, we used a Tobit model to determine the extent or intensity of CASI adoption.

The double hurdle model contains two equations of combined probit and Tobit estimators. The model specification is:

$$d_i^* = Zi'\alpha + \varepsilon_{1,i}$$

$$y_i^{**} = X_i\,\beta + \varepsilon_{2,i}$$

Where, d_i^* is a latent variable that takes the value 1 if the household adopts CASI technologies and 0, if otherwise. Z_i' is a vector of household characteristics and α is a vector of parameters. The variance of $\varepsilon_{1,i}$ is normalized to 1, as required for identification, because the outcome of the first hurdle is dichotomous. Likewise, y_i^{**} is the intensity of land used for CASI technologies, while$X_i'$is a vector of household characteristics and β is a vector of parameters, $\varepsilon_{1,i}$ and $\varepsilon_{2,i}$ are independent error terms.

The first hurdle is represented by:

$$d_i = 1 \text{ if } d_i^* > 0$$

$$d_i = 0 \text{ if } d_i^* \leq 0$$

The first hurdle is thus assumed to be defined by the latent variable d_i^*.

The second hurdle is represented as:

$$y_i^* = \max(y_i^{**}, 0)$$

The observed variable, y_i, is determined as:

$$y_i = d_i y_i^*$$

The log-likelihood function for the double-hurdle model is:

$$\text{Log}L = \Sigma \ln \{1- \phi(Z_i'\alpha)\phi (Xi'\beta /\sigma)\} + \Sigma \ln \{\phi (Z_i'\alpha)\ 1/\sigma Ø\ (y_i- Xi'\beta/\sigma)\}$$

Where Ø and ϕ are the probability density and cumulative density functions of the standard normal variable. This model assumes that the two error terms are normally distributed and uncorrelated.

Description of variables used in the model

A total of 18 explanatory variables were included in both the first-hurdle and second-hurdle models, and are described in Table 2. The dependent variables are the adoption of CASI technology and the intensity of its adoption, respectively. The intensity of the adoption of CASI is the proportion of the total area cultivated with CASI technologies to the total cultivable area. The CASI technology adopted by the farmers was ZT wheat, ZT maize and ZT kidney bean.

Table 2 - Variables used in the double hurdle model for analysis of the process of the adoption of CASI technology

Variables	Description
Decision to adopt CASI	1-Adopt CASI technologies; 0-otherwise
Intensity of land use for CASI	Proportion of land area under CASI to total cultivated land
Gender	1-Male; 0-Otherwise
Age	Age of farmer in years
Education	Education of farmers in years
Membership to organization	1-Member; 0-otherwise
Farming experience	Years of farming experience
Total dependent members	Number of dependent (below 18 & above 65 years old) members in a household
Agriculture labour	Number of members who undertook local agricultural labour
Total irrigated land	Size of irrigated land in hectare
Primary occupation	1-Crop production; 0-Otherwise
Migration	1-Households members who have migrants; 0-Otherwise
Annual income	Log transformed income in Nepalese rupee
Borrowed money for crop production	1-Yes; 0-Otherwise
Machinery	Total number of owned farm machines
Training attended	1-CASI technology-related training attended; 0-Otherwise
Source of information	1-Farmers who got crop production and marketing information through TV, radio and newspaper; 0-Otherwise
Exposure visit & field day	1-Farmers who participated in exposure visits and field days; 0-Otherwise
Risk behavior	1-Farmers who are risk-takers; 0-Otherwise
CASI machinery availability	1-Access to CASI machineries; 0-Otherwise

Results

Relative contributions of model variables for the adoption of CASI technology

Table 3 shows the summary of the descriptive statistics of CASI technology adopting and non-adopting surveyed farmers. For both adopters and non-adopters, the majority of the farmers were males (86%), with the average age slightly higher for adopters (50 years) than non-adopters (49 years). Although farmers' average formal education was seven years, adopters had longer experience in education (8.3 years) than non-adopters (6.3 years). Overall, about 62% of the farmers had contacts with agriculture-related organizations such as agricultural cooperatives/groups for obtaining knowledge and farm inputs, such involvement was nearly two times higher for adopters than non-adopters. The farming experience was, however, similar for both adopters and non-adopters (29 years). Adopter farmers had more dependent members (2.84) than non-adopters (2.28), however, the number of agriculture labourers was higher with non-adopters (0.86) than adopters (0.55).

Table 3 - Statistical analysis of the explanatory variables included in the model among CASI-adopters and non-adopters.

Variables	All (N=337)		Adopters (N=116)		Non-adopters (N=221)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Gender (1-Male; 0-Female)	0.86	0.34	0.86	0.34	0.86	0.35
Age (years)	49.47	12.53	50.02	12.10	49.19	12.76
Education (years)	6.99	4.56	8.31	4.11	6.29	4.63
Membership in organization (1-Member; 0-Otherwise)	0.62	0.49	0.91	0.28	0.46	0.50
Farming experience (years)	29.00	13.60	29.22	12.58	28.89	14.13
Total dependent members (number)	2.47	2.11	2.84	2.82	2.28	2.03
Agriculture labour (number)	0.75	1.45	0.55	1.28	0.86	1.51
Total irrigated land (hectare)	1.27	1.46	1.73	2.10	1.03	0.87
Primary occupation (1-Crop production; 0-Otherwise)	0.96	0.20	0.97	0.18	0.95	0.20
Migration (1- Migrated; 0-Otherwise)	0.24	0.43	0.17	0.38	0.28	0.45
Annual income (USD)	3086	3021	3634	3956	2798	2347
Borrowed money for crop production (1-Yes; 0-Otherwise)	0.28	0.45	0.39	0.49	0.23	0.42
Machinery (number)	0.98	1.76	1.46	2.43	0.73	1.21
Training attended (1-Yes; 0-Otherwise)	0.44	0.50	0.78	0.42	0.26	0.44
Source of information (1-Yes; 0-Otherwise)	0.54	0.50	0.68	0.46	0.47	0.50
Exposure visit & field day (1-Yes; 0-Otherwise)	0.16	0.37	0.34	0.48	0.07	0.25
Risk takers (1-Yes; 0-Otherwise)	0.68	0.46	0.87	0.34	0.59	0.49
CASI machinery availability (1-Yes; 0-Otherwise)	0.24	0.43	0.36	0.48	0.18	0.38

Although the average irrigated land was 1.27 hectares, it was smaller in the case of non-adopters (1.03 ha) than adopters (1.73 ha). In the study area, the majority (96%) of the farmers had crop production as their main occupation. Overall, the out-migration of a family member for employment was observed in about 24% of the total farmers, but in comparison, it was greater in non-adopters (28%) than adopters (17%). Similarly, annual income was greater in adopters (USD 3,634) than in non-adopters (USD 2,798). On average, about 28% of the farmers borrowed funds for crop production but borrowing was higher among adopters (39%) than non-adopters (23%). Likewise, adopters had more farm machines than non-adopters. The main farm machinery types were: four-wheel tractor, two-wheel tractor, trailer, pump set, cultivator, rotavator, ZT machine, rice transplanter, multi-crop seed drill, flat flan nozzle sprayer, combine harvester, rice/mill huller, and corn sheller. The number of CASI-adopter farmers (78%) receiving training on various aspects of CASI technologies, agronomic management and marketing was three times higher than non-adopters (26%). About 54% of farmers used TVs, radios and newspapers as sources of information related to crop production and marketing. Furthermore, a small fraction of the farmers (16%) also participated in exposure visits and field day activities, but such opportunity was more highly sought by the adopters (48%) than non-adopters (7%). Another important variable was risk behaviour. Overall, about 68% of farmers were willing to take risks in practicing the CA technology, though such risk-taking ability was higher (87%) for adopters than non-adopters (59%). Finally, access to CASI machinery was another important variable, which was essential for CASI adoption. Overall, only a quarter (24%) of the farmers (36% of adopters and 15% of non-adopters) were satisfied with the availability of CASI machineries in their locality.

Adoption and intensity of adoption decisions of CASI technology

Table 4 presents the maximum likelihood estimates of the independent double hurdle model. The first hurdle shows the factors that influence the decision to use CASI technology, and the second hurdle shows factors influencing the intensity of its use. Prior to the estimation of the double hurdle model, explanatory variables selected for both models were checked for multicollinearity using the Variance Inflation Factor (VIF). The average value of VIF in our test was 1.52 with none of the variables' VIF value exceeding 3.35, which confirmed that there was no multicollinearity between explanatory variables. The value of the Likelihood Ratio (LR) test is highly significant at a 1% level of significance suggesting a good model fit. Among the explanatory variables, ten variables were significant in the first hurdle whereas seven were significant in the second hurdle. The marginal effect (dy/dx) in the probit model represents the percentage change in CASI technology adoption per percentage change in other independent variables.

Cragg's double hurdle model shows that although gender had no significant effect on adoption decisions, it had a positive and significant effect on the adoption intensity of CASI practices (Table 4). This suggests that male headed-households are less likely to initially adopt the technology (although not significantly different to females), but once they decide to adopt, male-headed households are more likely to expand the area of land under CASI technology. The years of formal education was positively related to the adoption decision (P>0.01). The marginal effect of the probit model showed that for every year increase in farmer's education, there would be an increase in the probability of CA adoption by 2.3%. Another variable, the membership of farmers in agricultural organizations, was found to have a positive impact on both adoption and intensity of adoption. Holding other factors constant, farmers involved in an agricultural organization were likely to increase adoption by 17.6%.

The farming experience was positively related to the adoption decision in the first stage, while it was not significant in the second stage of the model. The marginal effect result indicates that with each year's increase in experience in farming, the probability of adoption increases by 0.8%. Likewise, the number of dependent members in a household had a significant positive impact on adoption decisions, while it was not significant in the intensity of adoption. The result showed that with an increase of one dependent member in a household, the probability of adoption increased by 3.3%. Similarly, a household that depended on crop production as a primary occupation had a significant positive effect on the adoption decision; however, it had a significant negative effect on the intensity of adoption. Farmers who have crop production as their main occupation were likely to increase adoption by 31.6% more than others. Another significant variable is outmigration, which had a negative effect on CASI technology adoption decisions. The result indicates that households with members migrating outside had 18.2% less probability of adoption than non-migrant households.

Table 4 - Maximum likelihood estimates of the double-hurdle model used in the study in Nepal in the EGP

Variables	1st Hurdle (probit)		Marginal effects in probit model		2nd Hurdle (Tobit)	
	CA adoption				Land under CA intensification (Intensity of adoption)	
	Coef	SE	Coef	SE	Coef	SE
Gender	-0.406	0.499	-0.076	0.092	0.210**	0.094
Age	-0.001	0.019	-0.000	0.004	-0.000	0.004
Education	0.120*	0.051	0.023	0.008	-0.014	0.010
Membership in organization	0.937**	0.363	0.176	0.071	0.403*	0.187
Farming experience	0.0429*	0.023	0.008	0.0039	-0.004	0.004
Total dependent members	0.174*	0.079	0.033	0.015	0.023	0.019
Agriculture labour	0.169	0.153	0.032	0.027	-0.038	0.025
Total irrigated land	0.0758	0.191	0.014	0.036	-0.023	0.019
Primary occupation	1.685*	0.742	0.316	0.121	-0.429**	0.171
Migration	-0.971*	0.465	-0.182	0.071	0.029	0.091
Annual income (log transformed)	0.441*	0.239	0.083	0.039	-0.048	0.040
Borrowed money for crop production	-0.127	0.385	-0.024	0.071	0.227***	0.067
Farm machinery	0.005	0.128	0.000	0.024	0.013	0.014
Training attended	1.261**	0.439	0.236	0.071	0.202	0.139
Source of information	0.151	0.314	0.028	0.059	0.005	0.065
Exposure visit & field day	0.413	0.557	0.077	0.103	0.127*	0.065
Risk behavior	1.012**	0.348	0.190	0.056	0.174*	0.104
CASI machinery availability	0.638*	0.339	0.119	0.061	0.193**	0.069
Constant	-11.403	3.507			0.226	0.877
Mills ratio	0.449**	0.179				
Pseudo R^2	0.3354					
LR chi^2 (19)	135.28*** (prob> chi^2 = 0.000)					
Log likelihood value	-134.012					

**10% level of significance; **5% level of significance; ***1% level of significance*

The annual income of households was positively related to adoption decisions, but it did not have a significant effect on the intensity of adoption. Likewise, farmers who borrowed money for crop production were more likely to intensify the CASI technology but borrowing money did not affect adoption decisions. In terms of participation in training, the chances of adoption were increased by 23.6% for those farmers attending training, while it did not significantly affect the intensity of adoption. Participation in exposure visits and field days was another significant factor in adoption intensity, while it did not affect adoption decisions. Moreover, risk-taking behaviour was positively related to both the adoption decision and the intensity of adoption. Risk-taking farmers had 19% higher chance of adoption than risk-averse farmers. Lastly, farmers' perception of the availability of CASI machinery in their location had a significantly positive impact on both adoption decisions as well as the intensity of adoption. Farmers who perceived accessibility of CASI technologies were more likely to adopt the technology by 11.9%.

Discussion

This study used a double hurdle model to identify and analyze the drivers influencing the adoption and intensity of the adoption of zero tillage (ZT), a widely recommended and promoted CASI technology in the EGP of South Asia, including Nepal. In the double hurdle model, we found different drivers that affect the adoption decision and intensity of adoption of the CASI technology in the Terai region in the EGP of Nepal. We found ten variables significantly affecting the adoption decision, while seven variables influenced adoption intensity and four variables influenced both the adoption and intensity of adoption of the technology.

There was no significant difference between the likelihood of CASI adoption by male and female farmers; however, male-headed farmers who adopted CASI were more likely to intensify their adoption. This is because since CASI technology needs significant inputs for crop maintenance, male farmers have better access to these resources, which will result in higher intensity of adoption of these technologies (Esabu and Ngwenya, 2019). This result is consistent with previous findings that male farmers are resource endowed by their cultural environment and have more chances to the adoption of new technology (Baffoe et. al., 2013). As expected, the study has shown a higher propensity to adopt the technology among farmers with more years of schooling, supporting the issue that CASI technology adoption may require more knowledge and skills in crop management and machinery use/handling. Educated farmers also have better knowledge of herbicide application and soil management practices which is crucial for CASI practices; education helps in gaining more ideas and confidence to adopt new technology compared to less-educated farmers. This result is similar to Yigzeu et al. (2018), in which education was positively and significantly related to adoption in the first hurdle model, while it was not significant in the second hurdle model. The involvement of farmers in an agriculture-related group/cooperative has positive effects on both the adoption and intensity of adoption decisions. This finding is consistent with Bola et al. (2012), Duong et al. (2019), Mignouna et al. (2011), Sharma and Kumar (2000) and Ghimire and Huang (2018); they all mentioned that involvement in an agriculture-related group/cooperative helps expose to different types of agricultural information and extension services, which will motivate farmers to adopt new technology. Farmers' experience in farming is crucial in technology adoption decisions as experience helps them understand what works and what does not, compared to those farmers who are new or have less experience. Moreover, experienced farmers have better management skills as they can use the knowledge accumulated over time and practice more confidently with the new technology. Ntshangase et al. (2018) also reported that experienced farmers have a higher probability of adopting conservation agriculture as compared to less experienced farmers. Households with a higher number of dependent members have a higher likelihood of adopting the technology because CASI helps in saving time, energy, labour and cost compared to conventional tillage-based farming; therefore, farmers can spend more time, energy and invest more money in taking care of children.

The occupation of farmers has both positive and negative impacts on CASI technology adoption. In the first stage, farmers who have crop production as their main occupation are likely to adopt, whereas in the second stage, farmers are unlikely to intensify the technology. Firstly, as a farmer, the increased exposure to ZT might have raised their interest in such new technology, but once they adopt it, they might have become reluctant to expand it due to the excessive weed growth on the fields, lack of timely access to machinery and other inputs, lack of appropriate knowledge and skills on crop management and machinery use/handling (Brown et al., 2021a,b; Giller et al., 2009). The study also showed there was a negative effect of migration on technology adoption. As migrant households have regular income sources such as remittances, they are more likely to have less focus on agricultural production and also abandon farming land, which can affect the adoption of any technology. Moreover, it is mostly the educated and male members that migrate to cities within the country or overseas and taking decisions to adopt a new technology might be risky for the households in the absence of their educated members, therefore, they have less interest in adopting the technology. Land abandonment due to labor shortage due to outmigration is a big issue for the sustainability of farming in the EGP and particularly in Nepal (Gauchan, 2018; Krupnik et al., 2021; Maharjan et al., 2013). Most literature on CA or CASI has consistently shown that CA or CASI practices are more labor efficient compared to conventional practices (Gathala et al., 2021) so it would be expected that the technology would be attractive to migrant households. However, our findings suggest that though CASI practices are labor-efficient and cost-effective, they would not necessarily be adopted by farmers due to the unavailability of male members of the households. More research is required on this aspect to gain a better understanding of the farmers' adoption process of CA or CASI practices under the prevailing labor shortage conditions due to outmigration.

The study also showed a positive effect of higher annual income on the adoption of the technology, which might be due to the greater capacity of these households to bear the input and machinery costs as well as the risks even if the crop fails. Beltran et al. (2011) also found that annual household income had a significantly positive impact on herbicide use in both stages of the double hurdle model. Likewise, a positive impact on the intensity of CASI adoption is observed in the case of farmers seeking credit for crop production. In general, farmers taking credit for agricultural production are risk-takers (Duong et al., 2019) and this behaviour might have encouraged them to take the risk of choosing a technology like CASI even if it is new to them. Yigezu et al. (2019) also found out that credit is positive and statistically significant for the second hurdle and not for the first hurdle model.

Capacity-building activities are vital for transferring knowledge and skills about the technologies to the farmers. Training had a significant positive effect on the adoption decision of the CASI technology in this study. Farmers who have received training might have gained knowledge, exposure and skills about the ZT technology, which raised their confidence and motivation to adopt it. This finding is consistent with Nyanga (2012), who reported that training in CA significantly increased the decision to adopt CA and its uptake. Another capacity development activity is exposure visits and field days for the farmers. Exposure to a new technology creates a low or risk-free environment to motivate farmers to try out new technologies increasing the speed and the propensity of adoption (Yigezu et al., 2018). Similar to training, the number of exposure visits and field day activities might have helped farmers to learn more about the CASI technology and implement it in the field, and thus, facilitated the intensity of adoption of the technology. Holden et al. (2018) and Duong et al. (2019) also reported that field days, training, and exposure visits were valuable factors for the dissemination of the CA technology.

The study also showed that risk behaviour is a major factor in both CASI technology adoption and intensification in the study area. Farmers are not always sure of the benefits that they could derive from adopting CASI practices. CASI is a new set of technology introduced to a locality where there is often limited knowledge, skills and support services available. So, it is their risk-taking behaviour that drives them to adopt and also intensify such technologies. Lastly, the availability of CASI machines (especially ZT seed drills) in the villages is the major limitation for both the adoption and intensification of CASI technology. Most of the non-adopter farmers perceived that the timely availability of ZT machines was a problem and is one of the major factors for their non-adoption. In the study area, there are only a few ZT machine service providers, so they are unable to provide their services to many of the farmers during the peak season of crop cultivation, which resulted in low adoption of the CASI technology. Similarly, there were also instances of poor repair and maintenance of ZT machines and out-migration of the skilled ZT machine operators, which also affected the availability of the ZT machinery and in turn the adoption of ZT technology in the study villages. These findings are consistent with several other studies in the EGP which have shown a lack of CA machines such as ZT seed drills and their spare parts and a lack of service providers to provide ZT services to interested farmers constrain the adoption of CA or CASI practices even though such practices were found to be consistently more productive and profitable and more energy-efficient than the conventional practices (Gathala et l., 2020a; Keil et al., 2016, 2017). Akter et. al. (2021) in Bangladesh also found that CA machinery is crucial for the adoption of any CA technology in both first and second hurdle models. Krishna et al. (2012) in West Bengal and Keil et al. (2016) in Bihar, India also noted that ZT machines availability with the private sector were crucial factors to catch critical mass adopters for a rapid adoption process. Our findings also suggest that sufficient numbers of ZT machines and machine service providers need to be ensured for the successful adoption of ZT, a CASI technology in Nepalese farming systems.

Conclusions and Policy Recommendations

This paper investigated both adoption decisions and the intensity of adoption of ZT, a CASI technology, in the Terai region of Nepal in the EGP. This study identified the key factors influencing the adoption and intensity of adoption decisions by the farmers which would be useful for making appropriate strategies for the spread/scaling of such technology. The results show that different socioeconomic, financial and institutional factors affect CASI technology adoption. The significant decision variables (first hurdle model) driving adoption include education, membership in a farmer's organization, years of farming experience, total dependent members in a household, occupation, outmigration, annual income, participation in training, risk behaviour, and availability of CASI machinery. Among them, only outmigration has a detrimental effect while others have a positive impact on adoption. Likewise, in the case of the intensity of adoption (second hurdle model), the influencing drivers found to have a significant positive impact on CASI intensification include gender, membership in farmers' organizations, loans for crop production, participation in exposure visits and field days, risk behaviour, and CASI machinery availability. The primary occupation was the only variable that had a negative effect on the intensity decision model.

Based on the findings of this study, the following policy recommendations are made to facilitate the adoption and intensification of CASI technology. Firstly, a focus on building capacities of the farmers in farm management, machinery and CASI technologies through training, exposure visits and field days, and organizing field demonstrations and interactions and other means of extension would be required so that farmers could be well-exposed to these technologies and gain sufficient knowledge and skills before taking the risk of adopting any technology. Secondly, a focus on building and strengthening mechanisms such as farmers' groups and cooperatives that help farmers access the required knowledge, skills and other inputs is critical, which could facilitate the adoption and spread of such technology. And lastly, ZT machines, their repair and maintenance services, including skilled operators along with other essential inputs such as herbicides should sufficiently be made available in a timely manner so that farmers could easily use them when they need them. Since the majority of the Nepalese farmers are smallholders and farming is undertaken from low-lying Terai to the mid and high hills, scale-appropriate ZT machinery that is appropriate for the smallholder farmers with diverse landscapes and farming systems should be developed and promoted for scaling out of any CASI technologies. Such efforts would help the adoption and outscaling of such technologies not only in Nepal but in the entire EGP with millions of smallholder farmers practicing similar farming systems and experiencing similar growing conditions in the region.

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Declaration of Competing Interest

We declare no conflict of interest for any of the authors associated with the publication of this manuscript.

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