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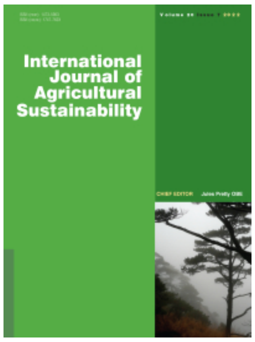

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RESEARCH ARTICLE

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Determinants of adoption of organic conservation agriculture in rainfed Nimar region of Central India

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ABSTRACT

In India, Conservation Agriculture (CA) is predominantly practiced in the irrigated Indo-Gangetic Plains and typically involves the use of agrochemicals. This study explores the unique context of the Nimar region in Central India, comprising rainfed, diverse, and organic farms. Utilizing primary data and a PROBIT model, we identify factors that influence the adoption of CA. Variables including farmers' age, household size (a proxy for labour), extension frequency, farmer's initiative-taking ability, farming experience, and market accessibility, were found to be significant. The study finds widespread recognition of the ecological and economic benefits and challenges as perceived by the sampled farmers. Over 90% of adopter farmers perceive improvements in soil health, reduction in water consumption, and increase in yield quality and quantity. More than 80% express that CA practices lead to cost savings and higher incomes. Despite its benefits, the biomass shortage hinders mulching a fundamental principle of CA. Farmers reported that biomass scarcity stems from declining cattle feed resources, which has heightened competition for available feed. To scale CA and produce food sustainably in rainfed areas, it is necessary to initiate supporting policy and institutional interventions that would improve extension, biomass production, and availability within the farming system.

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KEYWORDS
Biomass; extension frequency; mulching; no-till; rainfed

HIGHLIGHTS

- The adoption of CA in rainfed organic farming systems in Nimar region is determined by farmers' age, their experience, and initiative-taking ability, along with extension frequency, labour availability, and market access.
- Maintaining the required level of soil mulch is difficult due to biomass scarcity.
- Promoting in-situ biomass production within CA systems can help address mulch shortages.
- Extension efforts should target risk-taking farmers who are willing to adopt biomass management practices.

1. Introduction

India's rainfed areas play a crucial role in the nation's agricultural productivity, significantly contributing to the country's food security. These regions account for 44% of rice production, 87% of coarse cereals (such as sorghum, pearl millet, and maize), 72% of cotton, and 85% of food legumes, representing 40% of India's total food grain production (Rao et al., 2015). Given the challenges posed by climate variability, Conservation Agriculture (CA) offers potential solutions for improving the resilience and sustainability of rainfed systems. CA is a farming system that includes three principles – minimal soil disturbance, permanent soil cover, and crop diversification. It is a sustainable agricultural management system aiming to enhance crop production while providing multiple economic, environmental, and social benefits for farmers and their communities (Brown et al., 2018; Kassam & Kassam, 2020). By improving soil properties such as water infiltration, retention, and drainage, CA reduces runoff & evaporation, and supports groundwater recharge (Karbin et al., 2022; Magar et al., 2022; Thierfelder & Wall, 2012). CA helps mitigate climate change by

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lowering greenhouse gas emissions and increasing soil organic carbon content through reduced tillage, which also reduces energy consumption and machinery costs (Alam et al., 2019; Bhattacharyya et al., 2015; Carbonell-Bojollo et al., 2019; Corsi et al., 2012; Mangalassery et al., 2014). These factors collectively enhance the resilience of farming systems and contribute to climate adaptation and mitigation (Alam et al., 2019; Freitag et al., 2024; Jat et al., 2015; Sapkota et al., 2015).

Globally, CA was practiced on over 205 million hectares of cropland in 2018–19, representing approximately 15% of the world's cropland, with widespread adoption across more than 100 countries (Kassam et al., 2021). Smallholder farmers in many of these regions, especially in the Global South, are implementing uncertified organic CA practices. Notable examples of successful CA systems include large-scale initiatives in several African countries, including Tanzania, Mozambique, Zambia, Malawi, and Burkina Faso, where CA agroforestry systems have been adopted by tens of thousands of households (Lalani et al., 2018; Owenya et al., 2011). In India, around 3.5 million hectares, or 2.5% of the total cropland, are under the CA system, with the practice concentrated mainly in the Indo-Gangetic Plains (IGP) (Saharawat et al., 2022). This region is predominantly an irrigated monoculture system reliant on agrochemicals. However, outside the IGP, the adoption of CA remains limited, though it is more commonly practiced in organic forms, particularly in states like Maharashtra and Madhya Pradesh (Karbin et al., 2022). Despite the extensive benefits of CA, research on its adoption challenges in India's rainfed areas is limited, presenting an important research gap.

The adoption of CA faces several challenges, many of which have been well documented in the literature. According to Brown et al. (2017), successful adoption of CA requires financial resources, suitable land, skilled labour, and access to technical knowledge and training. The barriers to adoption are complex and include financial constraints, inadequate information and extension, inability to predict market trends, limited access to critical inputs such as fertilizers, seeds, herbicides, and machinery, as well as competition for crop residues (Araya et al., 2024; Bhadu et al., 2018; Chatterjee et al., 2021; Lemke et al., 2024; Mishra et al., 2022; Palash et al., 2024). These factors make it essential to understand what influences CA adoption, especially in organic systems where barriers can be more complex.

While much of the existing literature on the adoption of CA in India has focused on the Indo-Gangetic Plains (IGP), little research has been conducted on the factors influencing the adoption of organic CA systems in India's rainfed regions which are backbone of India's food security. This study aims to fill this gap by investigating the key drivers for the adoption of organic CA systems in rainfed Central India, where adoption rates remain low despite the potential benefits. Rainfed agriculture in India faces unique challenges, such as limited water resources and vulnerability to climate change, which makes sustainable practices like organic CA systems particularly relevant. While 'conventional' organic agriculture systems are designed to protect agrobiodiversity and reduce chemical intake by human, their reliance on tillage often results in diminished ecosystem services and reduced agricultural yields (Kassam & Kassam, 2020; Kassam et al., 2021; Lindwall & Sonntag, 2010). By exploring the determinants of organic CA adoption in rainfed regions, this research seeks to advance the CA system beyond organic agriculture as it strikes a balance between productivity, ecosystem health, and biodiversity conservation, ultimately contributing to the long-term sustainability of one of India's most ecologically and economically important agricultural areas.

The paper is structured into five sections. The introduction provides context for the study and highlights the research gap it addresses. The second section details the methodology and materials used. The third section presents the analysis of PROBIT model results and the perceived barriers and benefits of CA adoption. The fourth section discusses the study's relevance and policy implications. Finally, the conclusion summarizes key insights.

2. Materials and methods

2.1. Sampling strategy

The study was conducted in three districts of Nimar region – West Nimar, East Nimar, and Burhanpur in Madhya Pradesh of Central India (Figure 1). These districts are part of the Western Plateau and Hills region (IX) agro-climatic zone and the Central Plateau sub-agroclimatic zone, which has a semi-arid climate. The region receives approximately 900 mm of annual precipitation and is primarily rainfed. The mean temperature in the sampled districts ranges from 17 to 33°C (MPCCKP, 2025). The majority of the rural population

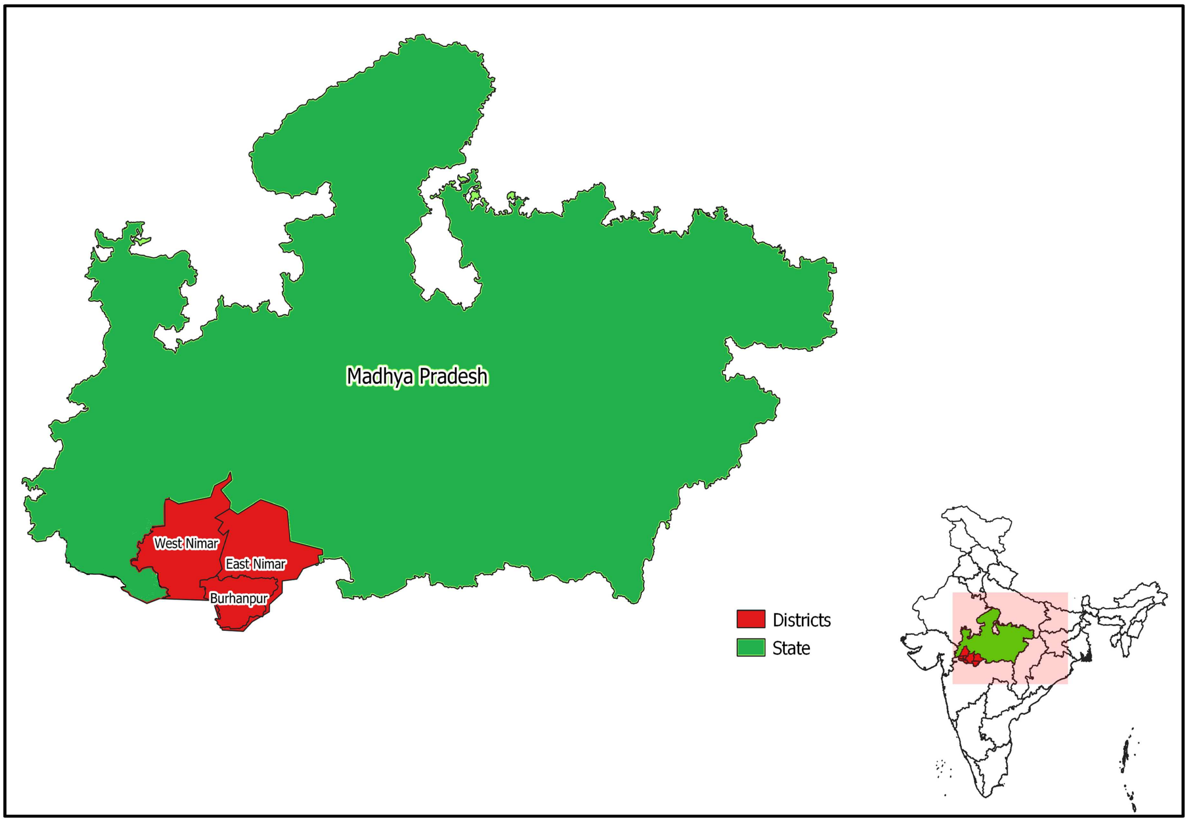

Figure 1. Sample study districts in Madhya Pradesh of Central India.

in the region is tribal, with the major tribes being Bhil, Bhilala, and Warli. 44% of the rural population in East Nimar, 45% in West Nimar, and 46% in Burhanpur are multidimensionally poor (NITI Aayog, 2023). Since the region is primarily rainfed, most farmers can only harvest one crop per year during the Kharif season (June to October), with some farmers harvesting another crop during the Rabi season (November to March) if they have irrigation or residual soil moisture in their field. Soybean and cotton are the major Kharif crops grown in the region, while wheat and chickpea are the major Rabi crops. We chose the study area for three reasons: one, it had about 1000 farmers adopting organic CA systems; two, the facilitating organization, Aga Khan Rural Support Programme-India (AKRSP-I), was open to help us to get this study conducted with the randomly selected farmers; and lastly, the villages mainly were rainfed with subsistence farming.

AKRSP-I has been promoting organic Conservation Agriculture (CA) systems in the region for nearly seven years. To accomplish this, AKRSP-I has established several farmer field schools (FFS), village-level extension, and training platforms to raise awareness among farmers and encourage them to adopt the organic CA system. Several demonstration plots/models farm of organic CA systems were established near each FFS, where farmers received extensive hands-on training on the three principles of a CA system. In each FFS, lead farmers were chosen to train other farmers. Farmers were also taken on exposure visits at model farms to learn about the benefits of CA practices. Following these training and exposure visits, farmers voluntarily agreed to adopt the CA system in either their entire agricultural land, at first, or a portion of their land. All three principles of the CA system were introduced to farmers simultaneously in the first season of the first year of adoption, and this practice was continued in subsequent seasons. Since most farmers do not plant summer crops, the Kharif (July–October) and Rabi (October–March) seasons are considered one agricultural year. Farmers practised direct seeding using manual tools, ensuring minimal mechanical soil disturbance during the Kharif season, and continued to do so during the Rabi season. Similarly, they implemented permanent soil organic cover with crop residues and/or cover crops, and crop diversification through various crop rotations, sequences, and associations, such as intercropping, mixed-cropping, border cropping, and trap cropping. Farmers have switched to bio-fertilizers, bio-pesticides, and pest control methods like integrated pest management (IPM) and non-pesticidal management (NPM) measures creating an 'organic' CA system.

2.2. Data

The study is based on primary data collected from 237 randomly selected farmers from a sampling frame of about 1000 farmers practising organic CA systems. Our sample had 83 adopter farmers practicing no-tillage, mulching, crop diversification, and other organic system practice for four years ('adopters') and 80 farmers discontinuing these principles within a year or after two cropping seasons and returning to conventional tillage-based farming ('dis-adopters'). In addition, the sample size includes 74 farmers who practiced conventional tillage-based farming and have never adopted any of the CA principles ('non-adopters'). While the data of 'adopters' and 'non-adopters' ($n = 157$) was used for PROBIT regression, the data of 'dis-adopters' ($n = 80$) was used to analyse the perceived challenges to adoption or discontinuation of the practice.

A structured survey schedule was used to collect data on the farmers' socio-economic profile, including age, education, household size, farming experience, total asset value, household income, off-farm access, market access time, extension frequency, credit availability, risk-taking behaviour, asset value of animals, number of animals owned, land fragmentation, and total operated area, along with their perception of institutional accessibility for adoption The survey schedule also had Likert scale questions to measure the perception of farmers on a scale of one to five, about the ease of adoption and benefits of CA. On the scale, 1 = Strongly Disagree, 2 = Disagree, 3 = Neither or Neutral, 4 = Agree, 5 = Strongly Agree. The data collection utilized a computer-assisted personal interview (CAPI) software called Survey Solutions, developed by the World Bank. This Android-based application, compatible with mobile devices and tablets, minimizes errors during surveys and post-processing of data. The software automatically converts data into STATA-compatible files, streamlining analysis and ensuring accuracy. A pilot test of the survey schedule and the app-based data collection was conducted alongside training for the field team. The schedule was then revised based on the feedback from pilot survey. We collected the final data during September and October 2021. In the next section we discuss the method of data analysis.

2.3. Method of analysis

2.3.1. PROBIT regression

Adoption behaviour is widely accepted as the farmer's process of utility maximization (Carrer et al., 2017; Jara-Rojas et al., 2012; Varma, 2018). We used the utility maximization framework and ran a PROBIT regression on the data to identify the key factors determining the adoption of organic CA system. We ran a PROBIT regression to find the determinants of adoption from the data collected from participating farmers. The analysis was carried out using STATA software. A farmer maximizes her utility by 'adopting' or 'not-adopting' the practice. For the practice to be adopted by a farmer, the estimated utility $U*$ of 'adoption' must be greater than the utility observed due to 'non-adoption' of any technology. Different attributes of the farmer, institutions, and environment influence the adoption (Adesina & Zinnah, 1993; Varma, 2019). The utility estimation $U*$ is a factor of independent variables (X), with β as an estimate of the variables X and some error term epsilon (ε), as shown in Equation (1).

$$U* = X\beta + \varepsilon \tag{1}$$

Equation (2) shows the value of the dependent variable Y_i. If a farmer's expected utility is greater than 'zero', Y_i is 'one'; otherwise, it is 'zero'. If the i^{th} farmer's expected utility is greater than 'zero', the farmer will adopt the technology. If the expected utility is less than 'zero', the farmer will not adopt.

$$Y_i = \begin{cases} 1 & if\ U* > 0 \\ 0 & otherwise \end{cases} \tag{2}$$

PROBIT regression is an appropriate strategy for fitting utility maximization models with a binary dependent variable, which in our case is the choice of 'adoption' or 'non-adoption' measured as 'one' or 'zero', respectively. It takes the probability of the independent variable *Y,* as shown in Equation (3).

$$E\,(Y|X_i) = \Pr(Y = 1|X_i) \tag{3}$$

$$\Pr(Y = 1|X_i) = \Phi f\,(X) = \Phi\,(\beta_0 + \beta_i X_i + \varepsilon) \tag{4}$$

Alternately,

$$\begin{aligned}\Pr(\mathrm{Y} = 1|\mathrm{X}) = \phi\,(\beta_0 &+ \beta_1\,\mathrm{Age_i} + \beta_2\,\mathrm{Market\_access\_time_i} + \beta_3\,\mathrm{HH\ Size_i} + \beta_4\,\mathrm{HH\ Income_i}\\ &+ \beta_5\,\mathrm{Total\ Asset\ Value_i} + \beta_6\,\mathrm{Operated\ Area_i} + \beta_7\,\mathrm{Education\ Years_i} + \beta_8\,\mathrm{Land\_Fragmentation_i}\\ &+ \beta_9\,\mathrm{Extension\ Frequency_i} + \beta_{10}\,\mathrm{Rainfall\ Status_i} + \beta_{11}\,\mathrm{Water\ Availability_i} + \beta_{12}\,\mathrm{Risk\ Trait_i}\\ &+ \beta_{13}\,\mathrm{Farming\ Experience_i} + \beta_{14}\,\mathrm{Access\ to\ off-Farm_i} + \beta_{15}\,\mathrm{Member\ Farmer\ Group_i}) + \epsilon\end{aligned} \tag{5}$$

where $\Phi f(x)$ represents the cumulative standard normal distribution function of ε. X_i is the vector of explanatory variables associated with the i^{th} farmer, and β (beta) is the coefficient vector. Maximum Likelihood Estimation (MLE) is an appropriate method for estimating the betas of independent variables X_i (Greene, 2003). In the PROBIT model, the beta coefficients indicate how much the Z-score changes with a one-unit change in an independent variable, while keeping other variables constant. For instance, a beta value of 0.3 means a one-unit increase in the variable, increases the Z-score by 0.3. To simplify comprehension of the analysis, we ran a marginal effect analysis after PROBIT regression.

$$\frac{\partial \Pr_i}{\partial X_i} = \Phi(X_i\beta)\beta_n \tag{6}$$

Marginal effects, derived from the estimated probabilities, show how a unit change in an explanatory/independent variable affects the probability of adoption while keeping other variables constant. Equation (6) represents this relationship, with the marginal effect of each variable calculated at mean sample values to account for joint effects (Pampel, 2020).

2.3.2. Perception analysis

We conducted a qualitative assessment of farmers' perception regarding ease and benefits of CA system adoption, drawing on questions adapted from previous studies, including Khandker and Gandhi (2018), Abid et al. (2015), and Ntshangase et al. (2018). Additional questions were developed based on insights from the pilot survey. To measure farmers' perceptions, we employed a Likert scale, assessing their views on the ease of adopting CA principles, and the benefits of adoption. Farmers responded to perception-based questions on a five-point scale, where 1 = Strongly Disagree, 2 = Disagree, 3 = Neither or Neutral, 4 = Agree, and 5 = Strongly Agree. Sample questions included: 'Is no-tillage easy to adopt?' and 'Does CA increase yield?' We used R software, and its 'Likert' package, to analyse the data and generate bar graphs. The bar graphs illustrate the percentage distribution of responses from strongly disagree to strongly agree. The analysis was disaggregated by type of farmers–'adopters' and 'dis-adopters' and three sampled districts.

2.4. Descriptive statistics of the variables

The PROBIT analysis is factored on independent variables to estimate the determinants of adoption, their coefficients, and their marginal effect on the probability of 'adoption' (see Table 1). Adoption studies in the past have considered independent variables – such as age (Pivoto et al., 2019; Shang et al., 2021), market accessibility (Aggarwal, 2018; Shamdasani, 2021; Suri, 2011; Zeller et al., 1998), household size as a proxy for labour (Adeoti, 2008; Grabowski et al., 2016; Noltze et al., 2012; Pender & Gebremedhin, 2008; Ruzzante et al., 2021), household income, and value of asset (Ruzzante et al., 2021; Varma, 2018), operated area

Table 1. Descriptive statistics of the 'adopters', 'non-adopters', and 'dis-adopters' farmers.

		Adopters ($n = 83$)		Dis-adopters ($n = 80$)		Non-Adopters ($n = 74$)	
Variable	Description	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	Age of the farmer	43.90	8.68	42.98	8.58	40.20	8.58
Education years	Years of education	3.53	3.97	2.85	3.74	3.29	4.15
Household size	No of household members	6.14	1.95	6.33	2.78	5.74	2.20
Farming experience	In years	47.94	219.17	25.55	18.18	21.54	10.05
Total asset value	In INR for all the assets	93184	142270	150676	394136	75803	78338
HH income	Annual income in INR	88669	70827	91875	71420	80608	61982
Access to off farm	Dummy 0 = No, 1 = Yes	0.17	0.38	0.24	0.43	0.30	0.46
Market access time	Time taken to reach market in minutes	57.51	38.17	65.44	39.48	67.09	50.20
Extension frequency	1 to 4 Likert, 4 for highest frequency	3.29	1.05	3.13	1.04	3.00	1.02
Credit dummy	Access = 1, Otherwise = 0	0.51	0.50	0.48	0.50	0.53	0.50
Risk taker	Yes = 1, No = 0	0.90	0.30	0.83	0.38	0.76	0.43
Asset value animals	In INR	80127	111983	123533	377527	70346	61072
Animal owned	Number of animals	7.48	4.75	6.49	3.88	6.39	4.73
Land fragmentation	Number fragments of total land	2.16	1.48	2.14	1.26	1.86	1.16
Operated area	In acres	5.32	2.95	4.86	3.76	4.52	3.30

Source: Primary Survey Data, 2021.

(Madramootoo & Morrison, 2013; Tesfaye et al., 2021), education level (Abdulai & Huffman, 2014; Mittal & Kumar, 2000), land fragmentation (Deininger et al., 2017; Orea et al., 2015; Rahman & Rahman, 2009) access to extension captured as the frequency of extension (Barrett et al., 2004; Khonje et al., 2015), status of rainfall and water availability (Schulz & Ioris, 2017), ability to take risks, percent share of agriculture and access to off-farm incomes (Winters et al., 2009), and membership in a farmer organization or social network (Abdulai & Huffman, 2014; Pino et al., 2017; Ward & Pede, 2015).

These variables can influence adoption positively or negatively, indicated by the sign of their corresponding beta coefficients in a PROBIT analysis. For example, a farmer's age may reflect experience and a significant amount of physical and social capital, influencing the 'adoption' of CA systems positively. Age may also reflect the farmer's lower willingness to change to adopt new technology or practice (Teklewold et al., 2013), thus discouraging the adoption. Table 1 shows the descriptive statistics for all variables for each category: 'adopters', 'non-adopters', and 'dis-adopters'. Adopters are farmers who have practiced CA principles for the past four years, while dis-adopters are those who abandoned them within two cropping seasons. Non-adopters are those who have never adopted CA principles. The table presents descriptive statistics, and we will examine the relationship between adoption and these variables using PROBIT regression. The study used two categories – 'adopter' and 'non-adopter' in the PROBIT regression, to understand which determinants significantly influence farmer's adoption. We have used the 'adopters' and 'dis-adopters' data to analyse perceptions of the benefits and challenges of adopting organic CA systems.

An analysis of the demographic and socio-economic characteristics of farmers across 'adopters', 'dis-adopters', and 'non-adopters' reveals distinct patterns. 'Adopters' tend to be slightly older (mean = 43.90) and possess slightly higher educational levels (mean = 3.53 years) than the other two groups, indicating a potential relationship between experience, knowledge, and adoption behaviour. Farmers across all categories take about an hour to reach the market, a key factor influencing decisions on inputs, sales, and technology adoption. Adopters generally have larger families, providing more labour for farming. A larger family may signify more assisting hands in agricultural tasks, particularly in labour-intensive practices.

Economically, 'adopters' exhibit higher asset ownership (₹93,184) and annual household income (₹88,669) than 'non-adopters', enabling them to assume the risks of adopting new practices. They also show greater market access (mean travel time of 57.51 minutes), benefit from more frequent visits by extension workers (mean 3.29), and display a stronger inclination toward risk-taking, with 90% identifying as risk-takers compared to 76% of 'non-adopters'. Among the three categories, 'adopters' exhibit the highest mean frequency of visits by agricultural experts or extension workers. 'Adopters' operate on average, 5.32 acres of land, which is slightly larger than the non-adopters (4.52 acres) and dis-adopters (4.86 acres). The size of the land owned and operated by a farmer can significantly affect the adoption process. It reflects their societal position, ability to access credit, and willingness to invest in novel agricultural practices on a portion of their land. 'Adopters', on average, have more fragmented land (mean = 2.16 parcels) than 'non-adopters' (mean = 1.86 parcels), highlighting its potential impact on adopting new practices. We will establish any significant relationship between adoption and these variables using PROBIT regression, the results of which is presented in the next section.

3. Analysis

3.1. Determinants of organic CA adoption: a PROBIT analysis

In a PROBIT regression analysing farmers' technology adoption, the null hypothesis for each independent variable asserts that the variable has no significant effect on the probability of adoption. If the *p*-value is less than the chosen significance level, the null hypothesis is rejected. Table 2 presents the results of the maximum likelihood estimates (MLE), marginal effects of each independent variable on adoption and its statistical significance. *** = ($p < 0.01$), ** = ($p < 0.05$), and * = ($p < 0.1$) indicate high, moderate, and weak statistical significance, respectively. Lower *p*-values suggest stronger evidence against the null hypothesis that the variable does not matter. The MLE results indicate that a one-unit increase in age significantly increases the Z-score for the probability of a farmer being an adopter by 0.035, holding all other variables at their mean values. In the fourth column of Table 2, we present the marginal effects, which indicate the change in the probability of adoption associated with a one-unit increase in each independent variable.

The results show that a one-year increase in the farmer's age raises the probability of adoption by 1.2%, holding all other variables constant. Age signifies the farmer's experience in agriculture, leading to better decision-making and greater command over agronomic practices. As a result, 'adopters' are more likely to be older farmers. Farmers with limited market access (measured by access time) are less likely to adopt new technologies (Aggarwal, 2018; Shamdasani, 2021). Our findings align with this, showing that the longer it takes to reach the market, the lower the likelihood of technology adoption. However, the marginal effect is minimal, at −0.2%. Household size, serving as a proxy for labour availability, is significant. Our results indicate that with each additional household member, the probability of adopting CA systems increases by four percentage points, holding all other variables constant. Discussions with farmers further revealed that managing bio-mulch – searching for, collecting, and applying it – is a time-consuming and labour-intensive. Conservation Agriculture systems that do not generate biomass within the system may exacerbate the challenge of limited labour availability for this task.

The frequency of contact with agricultural extension services positively influences adoption, with each additional extension visit increasing the likelihood of adoption by 6.6%. Since farmers have traditionally relied on tillage-based practices for many years, transitioning from generational knowledge of tillage to no-tillage methods require substantial support. Extension services play a crucial role in this transition, particularly for lead farmers who, after adopting the technology, can serve as promoters and facilitators for wider adoption within their communities. Farmers' traits as innovators or initiative takers had the highest impact on adoption behaviour. This variable was self-reported, where farmers were asked whether they consider themselves initiative-takers or open to trying new ideas. Farmers who identified as initiative-takers were 25.8% more likely to adopt the practice. According to Rogers (2003), these individuals are classified as innovators, constituting 2.5% of the population who are willing to take the lead in innovation. These innovator farmers should be the initial target in any extension programme as they have high risk-bearing capacity and may also help increase adoption. The strategy may be referred to as the 'lead farmer promoter-adopter strategy', which involves selecting promoter farmers with adequate exposure to the technology, a genuine interest in adopting it without excessive incentives, and are representative of the target smallholder population. Interestingly, farming experience has a very small but positive impact, suggesting that while experience may influence adoption, its effect is minimal in this context. The association of farmer with social network was not significant in our analysis. The reason could be that the current adopting population is fragmented, as the lead farmers have been the extension strategy's initial target. Over time, social networks may start playing a role during coverage expansion of CA system, from innovators to early adopters and the early majority. Other variables like household income, total asset value, and operated area show no significant effect on adoption, indicating that these factors may not play a crucial role in the adoption decision in this sample.

Table 2. Maximum likelihood estimates and marginal effects of variables on CA system adoption.

	Maximum likelihood estimates			Marginal effect
Independent variable	Coefficients	Robust Std. Err.	dy/dx	Delta method Std. Err.
Age	0.035**	0.013	0.012***	0.004
Market_access_time	−0.005***	−0.003	−0.002*	−0.001
HH_Size	0.119**	−0.061	0.040**	−0.02
HH_Income	0	0	0	0
Total_Asset_Value	0	0	0	0
Operated_Area	−0.014	−0.046	−0.005	−0.015
Education_years	0.023	−0.028	0.008	−0.009
Land_Fragmentation	0.061	−0.086	0.021	−0.029
Extension_frequency	0.196**	−0.108	0.066**	−0.036
Rain_status	0.34	−0.281	0.114	−0.093
Water_availability	0.185	−0.199	0.062	−0.066
Risk_trait	0.767**	−0.322	0.258**	−0.103
Farming_Experience	0.001**	−0.001	0.000**	0
Access_off_Farm	−0.333	−0.295	−0.112	−0.098
Member_farmer_group	0.303	−0.488	0.102	−0.163
Constant	−5.110*	−1.518		
Observations	157			
Log-likelihood	−91.96			

*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

3.2. A perception analysis of ease of adoption and benefits of CA

In this section we analyse farmers' perception about the ease of adoption of the CA principles and the benefits of the CA system. We examined how farmers perceive the ease of adopting the three CA principles and the benefits of doing so. The survey received 163 responses, including 83 from 'adopters' and 80 from 'dis-adopters.' Participants responded using a five-point Likert scale, where 1 indicated 'strongly disagree' and 5 indicated 'strongly agree'.

Figure 2 presents a bar graph which provides insights into the perceived ease of adopting various CA principles. Crop diversification appears to be the easiest principle to implement, with 78% of respondents agreeing that it is manageable, while only 7% disagree. Similarly, the overall perception of adopting CA is positive, with 71% agreeing that it is easy, though 19% disagree, indicating some barriers still exist. No-tillage is also considered relatively feasible, with 63% agreeing, but a notable 26% disagreeing, suggesting that mechanization or soil conditions might be constraints for some farmers. Mulching and cover cropping, however, show greater adoption challenges, with only 51% agreeing that it is easy, while 36% disagree. The biggest hurdle appears to be mulch availability, where 60% disagree that it is easily accessible, and only 34% agree. This highlights a critical barrier to the adoption of CA system, as mulch plays a key role in soil health and moisture retention. Addressing these challenges, particularly by improving access to mulch resources, could significantly enhance the adoption of CA practices.

Figure 3 presents a bar graph categorized by 'adopters' ($n = 74$) and 'dis-adopters' ($n = 80$). 71% of 'dis-adopters' and 48% of adopters disagree that bio-mulch was easily available, citing it as the primary reason they abandoned the practice after one year. 55% of 'dis-adopters' believe that mulching is a difficult practice to implement. Crop diversification is easy to implement for a larger proportion of farmers, with 92% of 'adopters' and 64% of 'dis-adopters' believing so. Similarly, 78% of 'adopters' and 48% of 'dis-adopters' believe no-tillage is easy to implement, while 40% of 'dis-adopters' believe it is not. The majority of farmers in both categories believe the CA system is easy to adopt given 87% of 'adopters' and 55% of 'dis-adopters' believe so.

Figure 4 presents the perceived ease of adopting of Conservation Agriculture (CA) principles, which varies significantly across the districts. Burhanpur leads with the highest agreement rate (82%) regarding the ease of adoption of CA practices, followed by East Nimar (74%) and West Nimar (58%). However, these regional variations may be influenced by differences in infrastructure, extension services, or levels of farmer awareness. Diversification is considered easy, with agreement rates of 87% in East Nimar and 79% in West Nimar. The availability of mulch emerges as a critical challenge impacting CA adoption across all regions. In West Nimar, an overwhelming 86% disagree that mulch is easily available, highlighting significant obstacles. East Nimar also faces difficulties with 60% disagreeing on mulch availability. In contrast, Burhanpur shows

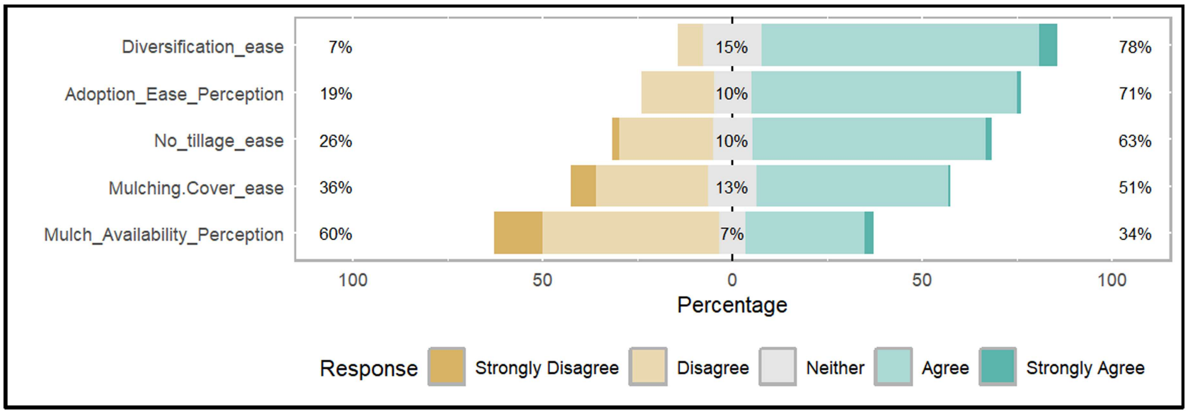

Figure 2. Bar graph presenting the perceived ease of adopting Conservation Agriculture principles by sampled farmers.

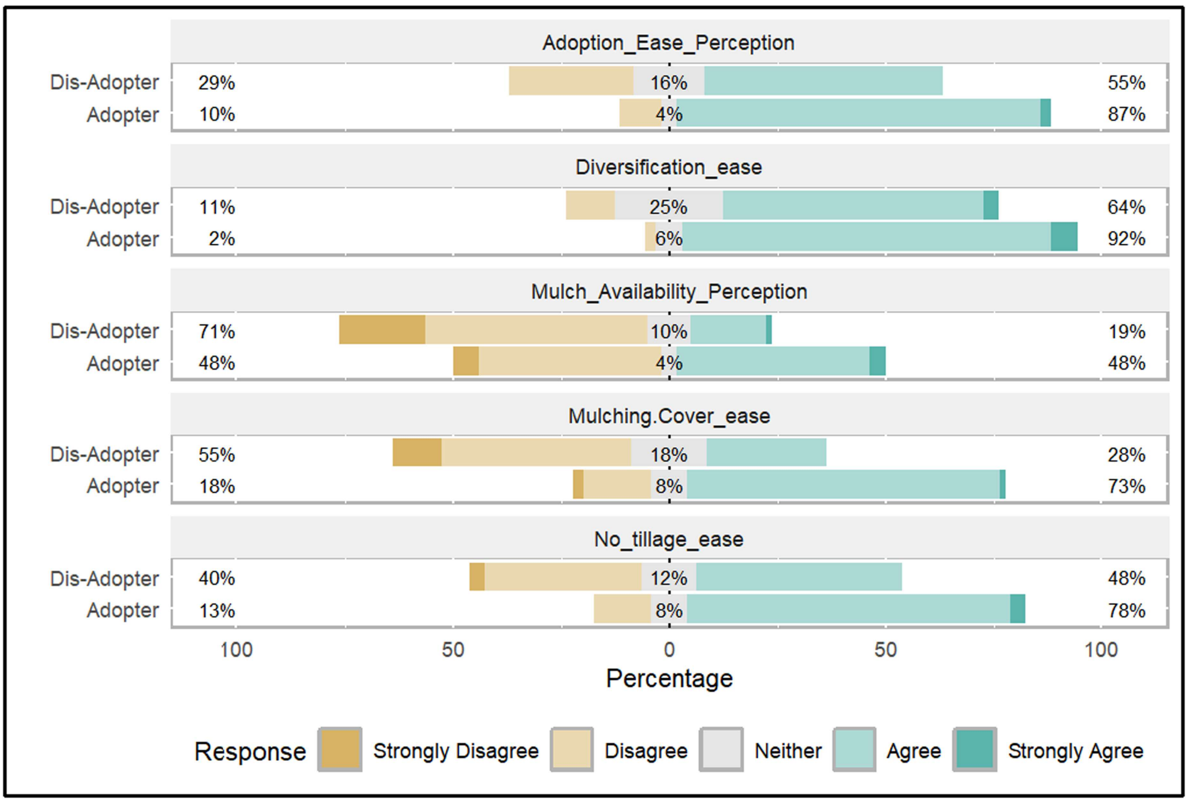

Figure 3. Bar graph presenting the perceived ease of adopting Conservation Agriculture principles by sampled farmers: Categorized by 'adopters' and 'dis-adopters'.

relatively better conditions with only 24% disagreement. The scarcity of mulch could be attributed to competition for crop residues, inadequate biomass production, or logistical issues in distribution. In West Nimar, 58% of farmers disagree on the ease of adopting mulching, compared to 36% in East Nimar and 9% in Burhanpur. 64% of respondents in Burhanpur agree that mulching is easy–could be a testament to their better access to mulch resources. No-tillage practices also exhibit regional disparities–high agreement rates in Burhanpur (79%), followed by East Nimar (60%) and West Nimar (58%). Despite this overall acceptance, both West and East Nimar report significant levels of disagreement (~33%), indicating persistent challenges potentially related to soil type compatibility, farmer familiarity with no-tillage techniques, and access to suitable machinery.

Figure 5 illustrates the distribution of responses from all farmers, regardless of the adoption category, about the benefits of adoption. A staggering 91% of farmers ($n = 163$) agreed that their farm's water usage

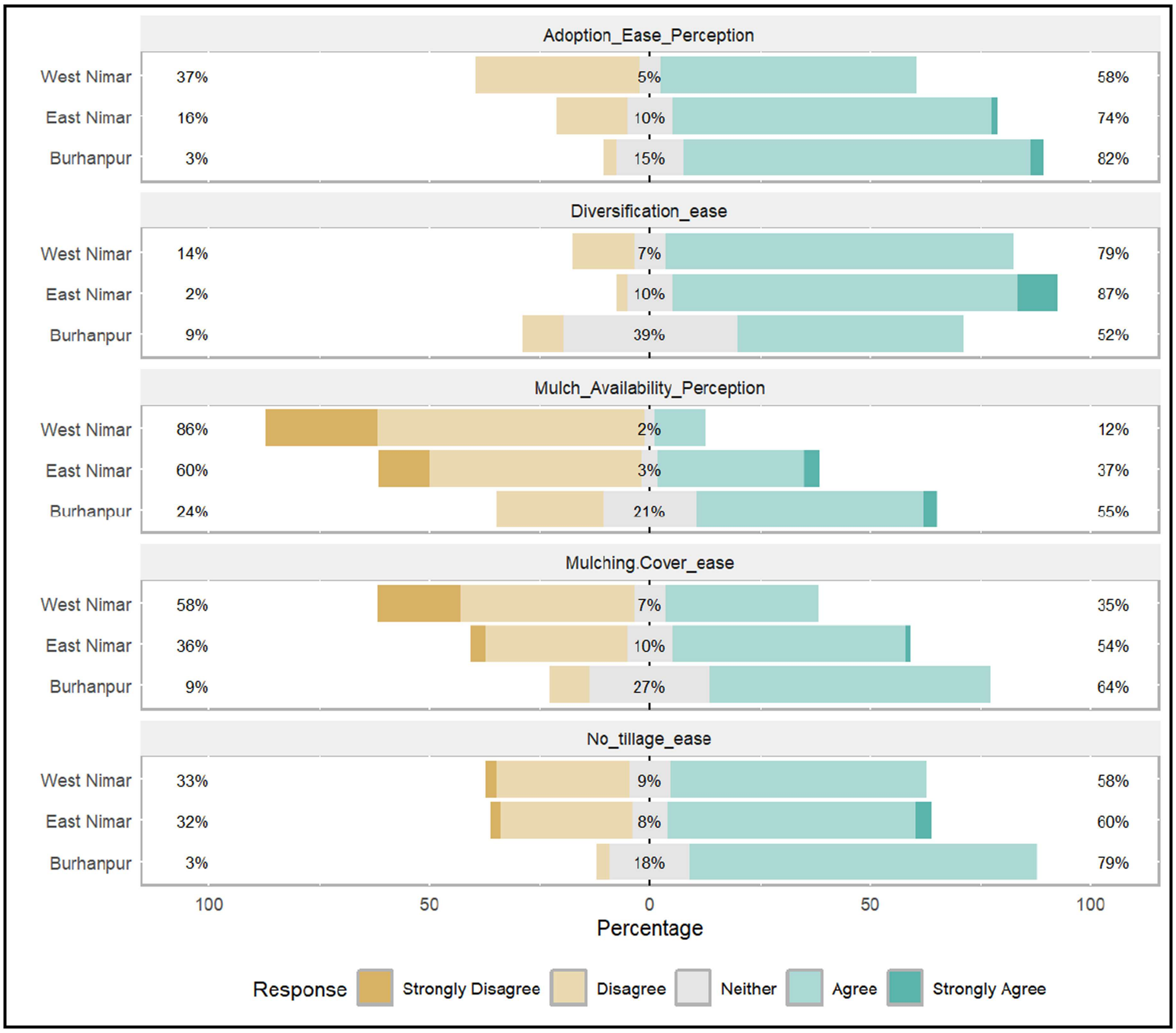

Figure 4. Bar graph presenting the perceived ease of adopting Conservation Agriculture principles by sampled farmers: Categorized by sample districts.

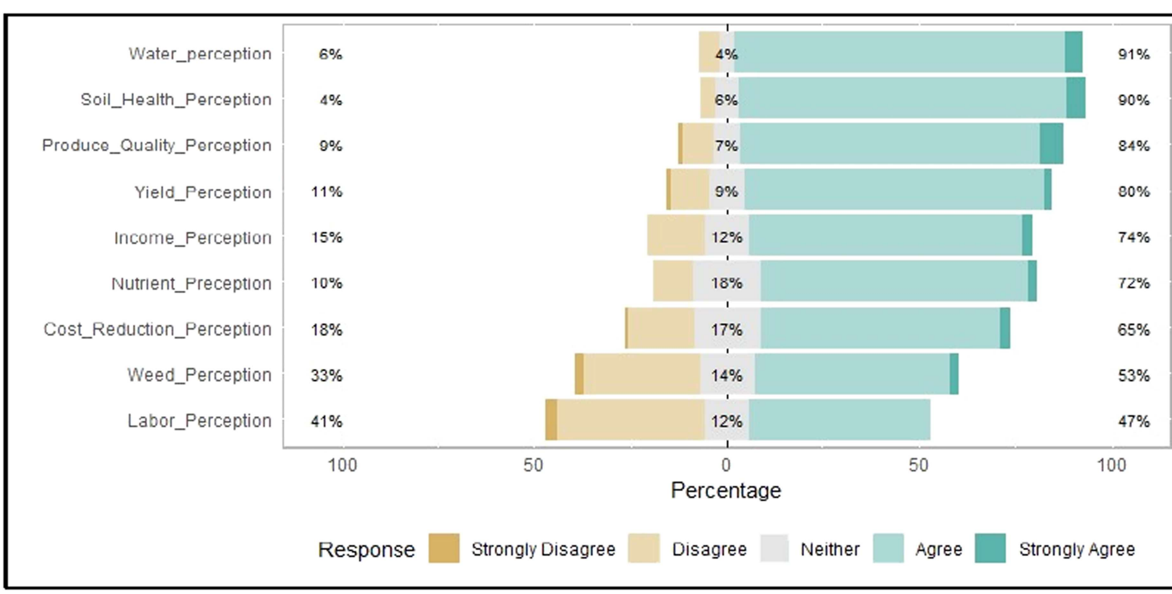

Figure 5. Bar graph presenting the perceptions of output impact for the adoption of CA practices.

has decreased since adopting the principles of no-tillage and mulching. They believe that mulching has led the soil to retain moisture for a longer period, reducing the soil demand for irrigation. 90% of farmers agreed that there was an improvement in soil health in their field and that more earthworms were observed on the farm. 84% of farmers agreed that the quality of crops also improved along with overall yield to which 80% farmers agreed. The farmers reported that the cob filling in maize and grain size in pulses were better after the adoption. Many farmers reported an increase in income after implementing the CA system, and 65% attributed this increase in income to lower cultivation costs in the CA system. The impact on labour saving was inconclusive, as 41% of farmers believed that adoption increases their labour costs. In comparison, 47% of farmers agreed that there are lower labour costs or labour days in the adoption of the CA practices. Discussions with farmers revealed that managing bio-mulch – sourcing, collecting, and applying, is a labour-intensive process that often requires family help. Therefore, larger households with more available members are better suited for this task. The quantitative analysis results in Table 2 corroborated this observation, indicating that households with more members exhibit a higher propensity to embrace CA principles, potentially due to the greater availability of labour resources for managing the intricate tasks associated with the adoption.

4. Discussion

4.1. Adoption of conservation agriculture: constraints, enablers, and food security implications

Labor availability, frequency of extension services, and farmer innovation traits are critical determinants in facilitating the adoption of CA systems. While age and farming experience contribute to the decision-making, their role is secondary to more immediate socioeconomic and institutional factors. A key constraint identified in our perception study is availability of mulch, thus adopting the principle of keeping soil surface covered. Previous research (Mishra et al., 2022; Thierfelder & Wall, 2012) has established that in mixed crop-livestock farming systems, the dual demand for crop residues presents a major barrier to CA adoption. Given that a significant proportion of Indian livestock depends on rainfed agriculture (Rao et al., 2015), this competition is particularly acute in regions where animal husbandry plays a crucial role in household livelihoods. Addressing this challenge requires strategies that balance crop residue retention for soil health with its use as fodder. Future interventions could explore the development of alternative mulching materials or the promotion of integrated crop residue management systems.

Despite market access being traditionally considered an important determinant of technology adoption (Aggarwal, 2018; Shamdasani, 2021), our study found its impact to be minimal in the CA context. Instead, household size plays a more direct role, as larger households with greater labour availability are more inclined to adopt CA practices. This aligns with the observation that bio-mulch management is labour-intensive, necessitating a household labour force for tasks such as collecting and applying mulch. The role of extension services in technology diffusion has been well-established (Rogers, 2003), and our findings confirm that frequent engagement with extension agents significantly enhances the likelihood of CA adoption. Farmers who receive consistent support are better positioned to transition away from conventional tillage-based practices. The lead farmer led peer-to-peer learning (Tran-Nam & Tiet, 2022) can be particularly effective, wherein early adopters act as community influencers, guiding their peers through the adoption process.

Another significant insight from our study is the strong association between farmer innovation traits and CA adoption. Farmers who self-identified as initiative takers were far more likely to embrace CA systems, a finding consistent with Rogers (2003) diffusion of innovations theory. These innovators, often willing to experiment with new practices, serve as crucial drivers of broader adoption within their communities. Extension efforts should prioritize engaging such individuals, as they can accelerate the scaling of CA through peer influence. Social networks did not show a significant immediate impact, their role may become more pronounced as CA adoption expands. In the early stages of diffusion, adoption tends to be driven by individual decisions and institutional support. However, as more farmers transition to CA, the role of farmer-to-farmer or peer-to-peer knowledge exchange and social learning mechanisms is likely to increase.

Farmers strongly acknowledged the perceived benefits of CA practices, particularly in terms of water use efficiency, soil health improvement, and enhanced yield and production quality. Studies in South Asia (Kumar et al., 2013; Mishra et al., 2022; Pradhan et al., 2018; Sapkota et al., 2014) have demonstrated similar economic and environmental benefits of CA. Our research enhances understanding of CA adoption by focusing on the small farm holders in rainfed areas and uncovers the unique factors and challenges that they face. Evidence suggests that, locally adapted CA can improve resource efficiency and boost smallholder farm productivity (Opoku-Acheampong et al., 2024; Pradhan et al., 2018), as farmers in our study also agreed. The ability of CA to enhance resilience against climate variability is particularly relevant for rainfed farming systems, where erratic rainfall and soil degradation often threaten production stability and eventually the food security of the region.

4.3. Policy insights

The adoption and scale of Conservation Agriculture (CA) requires targeted policy interventions that address the discovered barriers. Strengthening extension services is paramount, with a focus on identifying and supporting lead farmers who can act as community advocates for CA practices. These proactive farmers can serve as local extension agents, facilitating peer learning and accelerating technology diffusion. To overcome the challenge of mulch scarcity, policies should promote integrated crop residue management, encouraging farmers to cultivate high-biomass crops and multi-purpose cover crops. Policy strategy may also include the introduction of fast-growing tree species and perennial grasses to provide alternative biomass sources for mulching.

Policies must consider risk reduction mechanisms and financial incentives to farmers during the transition to CA. Financial support mechanisms, such as payments for ecosystem services (PES) or carbon credits (Bell et al., 2018; El Bakali et al., 2023), should be designed to compensate farmers for adopting sustainable practices that contribute to soil conservation, carbon sequestration, and water retention. Community-based institution, such as Farmer’s Producer Organisation, should play a central role in these efforts, fostering collective ownership of sustainable land management practices and ensuring long-term viability. Tailored or site-specific interventions, responsive to regional disparities as observed in research, will be necessary to create an enabling environment for CA adoption.

4.4. Limitation and extension of the study

This study primarily relies on farmers' perceived benefits of CA adoption, which may not quantitatively capture its long-term socio-economic and environmental impacts. Given this limitation of research in assessing these aspects in the rainfed Indian context, future studies can contribute to the scientific literature of impact in the rainfed region. While farmers acknowledge its advantages, a thorough scientific evaluation will strengthen the evidence base, inform policy decisions, and support the broader scaling of CA practices.

5. Conclusion

This study examined the adoption of organic CA among farmers in rainfed Central India, identifying key determinants and challenges. Farmer initiative, labour availability, and extension support emerged as critical factors. Farmers found crop diversification and no-tillage practices relatively manageable, but mulching remained a significant challenge due to limited biomass availability. Addressing these barriers through targeted interventions, such as integrated mulching or cover crop strategies, payment for ecosystem services and enhanced extension support, will be essential for scaling CA in the region.

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Disclosure statement

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References

Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics*, *90*(1), 26–43. https://doi.org/10.3368/le.90.1.26

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225–243. https://doi.org/10.5194/esd-6-225-2015

Adeoti, A. I. (2008). Factors influencing irrigation technology adoption and its impact on household poverty in Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *109*(1), 51–63. https://www.jarts.info/index.php/jarts/article/view/73

Adesina, A. A., & Zinnah, M. M. (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics*, *9*(4), 297–311. https://doi.org/10.1111/j.1574-0862.1993.tb00276.x

Aggarwal, S. (2018). Do rural roads create pathways out of poverty? Evidence from India. *Journal of Development Economics*, *133*, 375–395. https://doi.org/10.1016/j.jdeveco.2018.01.004

Alam, M. K., Bell, R. W., & Biswas, W. K. (2019). Increases in soil sequestered carbon under conservation agriculture cropping decrease the estimated greenhouse gas emissions of wetland rice using life cycle assessment. *Journal of Cleaner Production*, *224*, 72–87. https://doi.org/10.1016/J.JCLEPRO.2019.03.215

Araya, T., Ochsner, T. E., Mnkeni, P. N., Hounkpatin, K. O. L., & Amelung, W. (2024). Challenges and constraints of conservation agriculture adoption in smallholder farms in sub-Saharan Africa: A review. *International Soil and Water Conservation Research*, *12*, 828–843. https://doi.org/10.1016/j.iswcr.2024.03.001

Barrett, C. B., Moser, C. M., McHugh, O. V., & Barison, J. (2004). Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics*, *86*(4), 869–888. https://doi.org/10.1111/J.0002-9092.2004.00640.X

Bell, A. R., Benton, T. G., Droppelmann, K., Mapemba, L., Pierson, O., & Ward, P. S. (2018). Transformative change through Payments for Ecosystem Services (PES): A conceptual framework and application to conservation agriculture in Malawi. *Global Sustainability*, *1*, e4. https://doi.org/10.1017/sus.2018.4

Bhadu, K., Choudhary, R., Poonia, T., Patidar, P., Choudhary, K. M., & Kakraliya, S. K. (2018). A review paper on concept, benefits and constraints of conservation agriculture in India. *International Journal of Chemical Studies*, *6*(4), 36–40.

Bhattacharyya, R., Das, T. K., Sudhishri, S., Dudwal, B., Sharma, A. R., Bhatia, A., & Singh, G. (2015). Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains. *European Journal of Agronomy*, *70*, 11–21. https://doi.org/10.1016/J.EJA.2015.06.006

Brown, B., Llewellyn, R., & Nuberg, I. (2018). Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. *Global Food Security*, *17*, 213–220. https://doi.org/10.1016/J.GFS.2017.10.002

Brown, B., Nuberg, I., & Llewellyn, R. (2017). Negative evaluation of conservation agriculture: Perspectives from African smallholder farmers. *International Journal of Agricultural Sustainability*, *15*(4), 467–481. https://doi.org/10.1080/14735903.2017.1336051

Carbonell-Bojollo, R., Veroz-Gonzalez, O., Ordoñez-Fernandez, R., Moreno-Garcia, M., Basch, G., Kassam, A., de Torres, M. A. R. R., & Gonzalez-Sanchez, E. J. (2019). The effect of conservation agriculture and environmental factors on CO_2 emissions in a rainfed crop rotation. *Sustainability 2019*, *11*(14), 3955. https://doi.org/10.3390/SU11143955

Carrer, M. J., de Souza Filho, H. M., & Batalha, M. O. (2017). Factors influencing the adoption of Farm Management Information Systems (FMIS) by Brazilian citrus farmers. *Computers and Electronics in Agriculture*, *138*, 11–19. https://doi.org/10.1016/j.compag.2017.04.004

Chatterjee, R., Acharya, S. K., Biswas, A., Mandal, A., Biswas, T., Das, S., & Mandal, B. (2021). Conservation agriculture in new alluvial agro-ecology: Differential perception and adoption. *Journal of Rural Studies*, *88*, 14–27. https://doi.org/10.1016/J.JRURSTUD.2021.10.001

Corsi, S., Friedrich, T., Kassam, A., Pisante, M., & de Moraes Sà, J. (2012). *Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: A literature review. Food and Agriculture Organization of the United Nations*. FAO.

Deininger, K., Monchuk, D., Nagarajan, H. K., & Singh, S. K. (2017). Does land fragmentation increase the cost of cultivation? Evidence from India. *The Journal of Development Studies*, *53*(1), 82–98. https://doi.org/10.1080/00220388.2016.1166210

El Bakali, I., Ait El Mekki, A., Maatala, N., & Harbouze, R. (2023). A systematic review on the impact of incentives on the adoption of conservation agriculture: New guidelines for policymakers and researchers. *International Journal of Agricultural Sustainability*, *21*(1), 2290415. https://doi.org/10.1080/14735903.2023.2290415

Freitag, M., Friedrich, T., & Kassam, A. (2024). The carbon footprint of conservation agriculture. *International Journal of Agricultural Sustainability*, *22*, 2331949. https://doi.org/10.1080/14735903.2024.2331949

Grabowski, P. P., Kerr, J. M., Haggblade, S., & Kabwe, S. (2016). Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. *Agriculture, Ecosystems & Environment*, *231*, 54–67. https://doi.org/10.1016/j.agee.2016.06.027

Greene, W. H. (2003). *Econometric analysis*. Pearson Education India.

Jara-Rojas, R., Bravo-Ureta, B. E., & Diaz, J. (2012). Adoption of water conservation practices: A socioeconomic analysis of small-scale farmers in Central Chile. *Agricultural Systems*, *110*, 54–62. https://doi.org/10.1016/j.agsy.2012.03.008

Jat, R., Wani, S., Pathak, P., Singh, P., Sahrawat, K., Chander, G., & Sudi, R. (2015). Evaluating climate change mitigation and adaptation potential of conservation agriculture in semi-arid tropics of Southern India. *British Journal of Environment and Climate Change*, *5*(4), 324–338. https://doi.org/10.9734/BJECC/2015/18479

Karbin, S., Kassam, A., Oza, A., Sawhney, T., Sahu, P., Mogare, B., Mitra, B., Viswakarma, S., Singh, J., Mahajan, R. K., Malviya, S., Badole, P., & Patidar, N. (2022). Initiating conservation agriculture shows reduced soil CO2 emissions and improved soil aggregate stability in the first season in rainfed cropping in India. *International Journal of Environmental Studies*, *79*(6), 998–1014. https://doi.org/10.1080/00207233.2021.1987050

Kassam, A., Gonzalez-Sanchez, E., Carbonell-Bojollo, R. M., Friedrich, T., & Derpsch, R. (2021). Global spread of conservation agriculture for enhancing soil organic matter, soil health, productivity, and ecosystem services. In *Soil organic matter and feeding the future: Environmental and agronomic impacts* (pp. 91–126). https://doi.org/10.1201/9781003102762-4

Kassam, A., & Kassam, L. (2020). Paradigms of agriculture. In *Rethinking food and agriculture: new ways forward*. Woodhead Publishing. https://doi.org/10.1016/B978-0-12-816410-5.00010-4

Khandker, V., & Gandhi, V. P. (2018). Post-adoption experience of hybrid rice in India: Farmers' satisfaction and willingness to grow. *Agricultural Economics Research Review*, *31*(1), 95–104. https://doi.org/10.5958/0974-0279.2018.00009.5

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development*, *66*, 695–706. https://doi.org/10.1016/j.worlddev.2014.09.008

Kumar, V., Saharawat, Y. S., Gathala, M. K., Jat, A. S., Singh, S. K., Chaudhary, N., & Jat, M. L. (2013). Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. *Field Crops Research*, *142*, 1–8. https://doi.org/10.1016/J.FCR.2012.11.013

Lalani, B., Al-Eter, B., Kassam, S. N., Bapoo, A., & Kassam, A. (2018). Potential for conservation agriculture in the dry marginal zone of central Syria: A preliminary assessment. *Sustainability 2018*, *10*(2), 518. https://doi.org/10.3390/SU10020518

Lemke, S., Smith, N., Thiim, C., & Stump, K. (2024). Drivers and barriers to adoption of regenerative agriculture: Cases studies on lessons learned from organic. *International Journal of Agricultural Sustainability*, *22*(1), 2324216. https://doi.org/10.1080/14735903.2024.2324216

Lindwall, W., & Sonntag, B. H. (2010). *Landscapes transformed: The history of conservation tillage and direct seeding* (Vol. C). Saskatoon: University of Saskatchewan. S7N 5B8.

Madhya Pradesh Climate Change Knowledge Portal, MPCCKP (2025). Temperature dashboard, http://www.climatechange.mp.gov.in/en/temprature-dashboard

Magar, S. T., Timsina, J., Devkota, K. P., Weili, L., & Rajbhandari, N. (2022). Conservation agriculture for increasing productivity, profitability, and water productivity in rice-wheat system of the Eastern Gangetic Plain. *Environmental Challenges*, *7*. 100468. https://doi.org/10.1016/J.ENVC.2022.100468

Madramootoo, C. A., & Morrison, J. (2013). Advances and challenges with micro-irrigation. *Irrigation and Drainage*, *62*(3), 255–261. https://doi.org/10.1002/ird.1704

Mangalassery, S., Sjögersten, S., Sparkes, D. L., Sturrock, C. J., Craigon, J., & Mooney, S. J. (2014). To what extent can zero tillage lead to a reduction in greenhouse gas emissions from temperate soils? *Scientific Reports*, *4*(1), 4586. https://doi.org/10.1038/srep04586

Mishra, A. K., Shinjo, H., Jat, H. S., Jat, M. L., Jat, R. K., Funakawa, S., & Sutaliya, J. M. (2022). Farmers' perspectives as determinants for adoption of conservation agriculture practices in Indo-Gangetic Plains of India. *Resources, Conservation Recycling Advances*, *15*. 200105. https://doi.org/10.1016/J.RCRADV.2022.200105

Mittal, S., & Kumar, P. (2000). Literacy, technology adoption, factor demand and productivity: An econometric analysis. *Indian Journal of Agricultural Economics*, *55*(3), 490–499. https://doi.org/10.22004/ag.econ.297767

NITI Aayog. (2023). *India National Multidimensional Poverty Index: A Progress Review*, *2023*. https://niti.gov.in/sites/default/files/2023-08/India-National-Multidimentional-Poverty-Index-2023.pdf

Noltze, M., Schwarze, S., & Qaim, M. (2012). Understanding the adoption of system technologies in smallholder agriculture: The system of rice intensification (SRI) in Timor Leste. *Agricultural Systems*, *108*, 64–73. https://doi.org/10.1016/j.agsy.2012.01.003

Ntshangase, N. L., Muroyiwa, B., & Sibanda, M. (2018). Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal province. *Sustainability*, *10*(2), 555. https://doi.org/10.3390/su10020555

Opoku-Acheampong, K., Tham-Agyekum, E. K., Ankuyi, F., Okorley, E. L., Bakang, J. E. A., & Nimoh, F. (2024). Effect of adoption of conservation agriculture on household food security of smallholder maize farmers in Ghana. *Environmental and Sustainability Indicators*, *23*. 100436. https://doi.org/10.1016/j.indic.2024.100436

Orea, L., Perez, J. A., & Roibas, D. (2015). Evaluating the double effect of land fragmentation on technology choice and dairy farm productivity: A latent class model approach. *Land Use Policy*, *45*, 189–198. https://doi.org/10.1016/j.landusepol.2015.01.016

Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., & Kassam, A. (2011). Conservation agriculture (CA) in Tanzania: the case of the Mwangaza B CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha. *International Journal of Agricultural Sustainability*, *9*(1), 145–152. https://doi.org/10.3763/IJAS.2010.0557

Palash, M. S., Hasan, A. K., Hasan, M. M., Hossain, M. A., & Sultana, S. S. (2024). Unveiling drivers of conservation agriculture amidst climate challenges: A coastal Bangladeshi case study. *Heliyon*, *10*(19), e38001. https://doi.org/10.1016/j.heliyon.2024.e38001

Pampel, F. C. (2020). *Logistic Regression: A Primer* (Vol. 132). Sage Publications.

Pender, J., & Gebremedhin, B. (2008). Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. *Journal of African Economies*, *17*(3), 395–450. https://doi.org/10.1093/jae/ejm028

Pino, G., Toma, P., Rizzo, C., Miglietta, P. P., Peluso, A. M., & Guido, G. (2017). Determinants of farmers' intention to adopt water saving measures: Evidence from Italy. *Sustainability*, *9*(1), 77. https://doi.org/10.3390/su9010077

Pivoto, D., Barham, B., Dabdab, P., Zhang, D., & Talamin, E. (2019). Factors influencing the adoption of smart farming by Brazilian grain farmers. *International Food and Agribusiness Management Review*, 22(4), 571–588. https://doi.org/10.22434/IFAMR2018.0086

Pradhan, A., Chan, C., Roul, P. K., Halbrendt, J., & Sipes, B. (2018). Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: A transdisciplinary approach. *Agricultural Systems*, *163*, 27–35. https://doi.org/10.1016/j.agsy.2017.01.002

Rahman, S., & Rahman, M. (2009). Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. *Land Use Policy*, *26*(1), 95–103. https://doi.org/10.1016/j.landusepol.2008.01.003

Rao, C. S., Lal, R., Prasad, J. V. N. S., Gopinath, K. A., Singh, R., Jakkula, V. S., Sahrawat, K. L., Venkateswarlu, B., Sikka, A. K., & Virmani, S. M. (2015). Potential and challenges of rainfed farming in India. *Advances in Agronomy*, *133*, 113–181. https://doi.org/10.1016/bs.agron.2015.05.004

Rogers, E. M. (2003). *Diffusion of innovations* (Vol. 551). New York: Free Press. https://doi.org/10.4324/9780203887011-36/diffusion-innovations-everett-rogers-arvind-singhal-margaret-quinlan

Ruzzante, S., Labarta, R., & Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development*, *146*, 105599. https://doi.org/10.1016/j.worlddev.2021.105599

Saharawat , Y. S., Gill, M., Gathala, M., Karki, T. B., Wijeratne, D. B. T., Samiullah, S., Chaudhary, N., Haque, Md. E., Bell, R. W., Parihar, C. M., Nayak, H., Singh, R., Malik, R. K., Singh, U., Paroda, R., & Kassam, A. (2022). Conservation agriculture in South Asia. In A. Kassam (Ed.), *Advances in conservation agriculture: Adoption and spread,* (Vol. 3, pp. 491–532). Cambridge: Burleigh Dodds. https://doi.org/10.19103/AS.2021.0088.12

Sapkota, T. B., Jat, M. L., Aryal, J. P., Jat, R. K., & Khatri-Chhetri, A. (2015). Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: Some examples from cereal systems of Indo-Gangetic Plains. *Journal of Integrative Agriculture*, *14*(8), 1524–1533. https://doi.org/10.1016/S2095-3119(15)61093-0

Sapkota, T. B., Majumdar, K., Jat, M. L., Kumar, A., Bishnoi, D. K., McDonald, A. J., & Pampolino, M. (2014). Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research*, *155*, 233–244. https://doi.org/10.1016/J.FCR.2013.09.001

Schulz, C., & Ioris, A. A. R. (2017). The paradox of water abundance in Mato Grosso, Brazil. *Sustainability*, *9*(10), 1796. https://doi.org/10.3390/su9101796

Shamdasani, Y. (2021). Rural road infrastructure & agricultural production: Evidence from India. *Journal of Development Economics*, *152*, 102686. https://doi.org/10.1016/j.jdeveco.2021.102686

Shang, L., Heckelei, T., Gerullis, M. K., Börner, J., & Rasch, S. (2021). Adoption and diffusion of digital farming technologies-integrating farm-level evidence and system interaction. *Agricultural Systems*, *190*. 103074. https://doi.org/10.1016/j.agsy.2021.103074

Suri, T. (2011). Selection and comparative advantage in technology adoption. *Econometrica*, *79*(1), 159–209.

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597–623. https://doi.org/10.1111/1477-9552.12011

Temperature Dashboard. (2025). *Madhya Pradesh Climate Change Knowledge Portal (MPCCKP)*. Retrieved January 26, 2025, from https://www.climatechange.mp.gov.in/en/temprature-dashboard

Tesfaye, M. Z., Balana, B. B., & Bizimana, J.-C. (2021). Assessment of smallholder farmers' demand for and adoption constraints to small-scale irrigation technologies: Evidence from Ethiopia. *Agricultural Water Management*, *250*. 106855. https://doi.org/10.1016/j.agwat.2021.106855

Thierfelder, C., & Wall, P. C. (2012). Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. *Soil Use and Management*, *28*(2), 209–220. https://doi.org/10.1111/J.1475-2743.2012.00406.X

Tran-Nam, Q., & Tiet, T. (2022). The role of peer influence and norms in organic farming adoption: Accounting for farmers' heterogeneity. *Journal of Environmental Management*, *320*, 115909. https://doi.org/10.1016/j.jenvman.2022.115909

Varma, P. (2018). Adoption of system of rice intensification under information constraints: An analysis for India. *The Journal of Development Studies*, *54*(10), 1838–1857. https://doi.org/10.1080/00220388.2017.1336541

Varma, P. (2019). Adoption and the impact of system of rice intensification on rice yields and household income: An analysis for India. *Applied Economics*, *51*(45), 4956–4972. https://doi.org/10.1080/00036846.2019.1606408

Ward, P. S., & Pede, V. O. (2015). Capturing social network effects in technology adoption: The spatial diffusion of hybrid rice in Bangladesh. *Australian Journal of Agricultural and Resource Economics*, *59*(2), 225–241. https://doi.org/10.1111/1467-8489.12058

Winters, P., Davis, B., Carletto, G., Covarrubias, K., Quiñones, E. J., Zezza, A., Azzarri, C., & Stamoulis, K. (2009). Assets, activities and rural income generation: Evidence from a multicountry analysis. *World Development*, *37*(9), 1435–1452. https://doi.org/10.1016/J.WORLDDEV.2009.01.010

Zeller, M., Diagne, A., & Mataya, C. (1998). Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income. *Agricultural Economics*, *19*(1–2), 219–229. https://doi.org/10.1111/j.1574-0862.1998.tb00528.x