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A R T I C L E I N F O

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A B S T R A C T

Soil degradation is a pressing issue in Nepal. The interrelation between soil degradation and nitrogen deficiency often creates feedback loops that exacerbate both problems. Further, there are debates as to whether sharecropping poses challenges to sustainable soil management. This study examines the comparative likelihood of sharecroppers and non-sharecroppers to adopt minimum or no-till, use of crop residues, incorporate fertiliser in the soil or deep placement of fertiliser, use compost and organic fertiliser, and adopt good water management practices. This study also investigates whether there are differences between adoption drivers/barriers of sharecropper and non-sharecroppers Seemingly Unrelated Regression (SUR) models are estimated. The results show that being a sharecropper is associated with a decrease in the likelihood of adopting no-tillage/minimum tillage and incorporating fertiliser rather than broadcasting. However, being a sharecropper is associated with a greater likelihood of adopting organic fertiliser, compost and crop residues. The main differences between the determinants of adoption among sharecroppers and non-sharecroppers are that older farmers were more likely to adopt certain practices for sharecroppers but not for non-sharecroppers. There are also differences in the adoption of no-tillage/minimum tillage and incorporation of fertiliser for non-sharecroppers between male and female farmers. However, for sharecroppers, male-headed farms were less likely to adopt most practices. Labour size, subsidy for synthetic fertiliser, and awareness of the soil/environment linkages also influenced adoption differently across sharecroppers and non-sharecroppers. Contrary to assertions that sharecropping acts as a barrier universally, the findings suggest that Nepalese sharecroppers' adoption of soil management practices is more context-dependent than uniformly hindered.

1. Introduction

Nepal's agriculture faces the challenge of declining soil fertility and increasing soil degradation (Kharal et al., 2018; Chalise et al., 2019). The different agroecological zones, ranging from the Terai plains to the hilly and mountainous regions present varied soil management challenges (Bhattarai et al., 2021; Krupnik et al., 2021). In the Terai, where most agriculture takes place, the issues are primarily related to soil degradation due partly to management practices employed by farmers. This has resulted in the depletion of organic matter, soil acidification, soil compaction, water logging and chemical degradation (Krupnik et al., 2021; Tripathi et al., 2022). This decline in soil structure and quality impacts the soil nitrogen cycle and limits the soil's ability to retain nitrogen, thereby exacerbating nitrogen deficiency. The interrelation between soil degradation and nitrogen deficiency often creates feedback loops that exacerbate both problems. Soil erosion, particularly in areas with steep topography in Nepal, leads to the loss of the topsoil layer which is rich in organic matter and nitrogen. When topsoil erodes, it takes with it the nitrogen bound within the organic matter (Shi and Schulin, 2018; Wang et al., 2023). Poor soil structure limits the ability of plants to uptake nitrogen efficiently, leading to the need for increased fertiliser application. However, as Li et al. (2009) and Singh (2018) noted, the excessive use of nitrogen fertilisers in degraded soils can lead to nitrogen leaching and volatilization, further degrading soil quality and polluting the environment. This creates a vicious cycle where degraded soils require more nitrogen and the increased nitrogen, in turn,

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contributes to further soil degradation with poor management practices. The lack of nitrogen in soils has been identified as a limiting factor in the production of crops (Shrestha et al., 2013).

Given these concerns, adopting practices beneficial to soil structure and soil nitrogen loss mitigation is crucial (Ndayisaba et al., 2023; Thapa and Dhakal, 2024). There are numerous practices that when effectively implemented can significantly improve soil structure and enhance nitrogen retention in agricultural soils. Efficient use of fertilisers, including the adoption of integrated nutrient management (INM) practices is critical for nitrogen retention. Islam et al. (2024) found that INM which combines organic and inorganic fertilisers, optimises nitrogen availability to crops and minimises losses. Organic fertilisers are known to release nutrients more slowly, hence maintaining long-term N supply (Iqbal et al., 2019; Shaji et al., 2021). Previous studies have also shown that fertiliser best management practices such as incorporating fertiliser in soil or deep placement by placing fertiliser below the soil surface and closer to plant roots is more efficient than surface application as it reduces nitrogen losses due to volatilization and runoff. This practice is also reported to increase nutrient acquisition and retention (Ma et al., 2009). Similarly, the use of compost results in positive changes in chemical, physical and biological soil quality. Specifically, it has been highlighted that compost improves soil aeration, water retention, nutrient availability and can also reduce the need for chemical fertilisers (D'Hose et al., 2014; Willekens et al., 2014; Scotti et al., 2016).

Reduced or conservation tillage or no-till practices are known to positively impact the physical properties of the soil, including nitrogen retention, reducing erosion, and increasing water infiltration and retention in the soil (Blanco-Canqui and Ruis, 2018; Li et al., 2019). Crawford et al. (2015) reported that conservation tillage practices improve soil health and productivity. Mallory et al. (2011) observed that no-tillage results in a greater proportion of micropores that are beneficial for water storage across the soil profile, leading to enhanced water infiltration and improved root development. Adopting zero tillage along with various conservation tillage methods has also been reported to improve soil health in farming systems that depend on synthetic agricultural chemicals for fertilisation and weed management (Carr et al., 2013).

Retaining crop residues can enhance the physical, chemical, and biological properties of soil (Turmel et al., 2015). Utilizing crop residues for mulching or as organic amendments improves soil organic matter, enhances soil structure, conserves moisture and significantly improves soil physical and biological properties (Fu et al., 2021; Mirzaei et al., 2021). Incorporating crop residues has benefits for the accessibility of nitrogen for crops (Turmel et al., 2015). Retaining crop residues also increases soil stability (Klopp and Blanco-Canqui, 2022).

Previous research found that implementing controlled irrigation techniques significantly diminished the amount of nitrogen lost through leaching, enhanced soil quality, and improved soil nutrient cycling and the functioning of soil microorganisms (Bhaduri and Purakayastha, 2014; Cao et al., 2022). For example, Ippolito et al. (2017) found that sprinkler irrigation enhanced the soil quality of fields that were historically degraded due to furrow irrigation. Haque et al. (2021) observed that organic amendment with alternate wetting and drying irrigation improves the nutrient uptake and physicochemical properties of soil. The benefits of these practices are summarised in Table 1.

The adoption of sustainable soil management practices is influenced by a range of factors. Among these, socio-economic factors such as age, education level, and economic status of the farmers are prominent. Studies often find that younger, more educated farmers are more likely to adopt new practices, while better economic status influences the ability to invest in new technologies or practices (Tiwari et al., 2008; Dahal et al., 2023; Adhikari and Thapa, 2023). Also, the availability and access to agricultural extension services play a significant role. Farmers who are more informed about the benefits and techniques of soil management are more likely to adopt them. This includes participation in training programs and exposure to successful examples (Paudel and Thapa, 2004; Chaudhary et al., 2022).

Table 1
Synopsis of practices beneficial to soil structure and nitrogen retention.

Practices	Benefits
Reduced or conservation tillage or no-till	Reduce damage to soil structure, help to keep water in the soil, reduce soil runoff and improve soil health
Use of crop residues	Increase the content of organic carbon, nitrogen, available phosphorus, and potassium in soils, aids soil stability
Incorporating fertiliser in soil or deep placement	Better nutrient utilization efficiency
Using compost	Increases soil nutrient, SOM content, soil moisture and stability
Use any organic fertiliser	Increase soil nutrient, SOM content
Water management	Strengthens air exchange and accelerates soil organic matter mineralization

Other studies have found access to labour and secure land tenure is a crucial factor in the adoption of soil management practices (Khanal and Maharjan, 2014). It is reported that farmers who own their land are more likely to invest in long-term soil management practices than those who lease land. Government policies, subsidies, and incentives can encourage the adoption of soil management practices. For instance, policies subsidising the cost of soil-enhancing inputs or offering technical support can be either a driver or barrier to adoption (Kumar et al., 2020; Dahal et al., 2023). Other studies have found that awareness of environmental issues and sustainable farming practices can influence adoption (Begho et al., 2022). Farmers aware of the long-term benefits of sustainable soil management practices for their land and the environment may be more inclined to adopt them (Baumgart-Getz et al., 2012).

Sharecropping, "bataiya" or "bhagchash" is a common land tenure system in Nepal which involves landowners leasing out their land to tenants, who in return share a portion of the produce with the landowner (Lahiri-Dutt and Adhikari, 2016; Ranjitkar and Haukanes, 2022). The tenant farmer is usually responsible for providing labour and sometimes even farming inputs like seeds and tools. In some cases, the landowner might provide some input. The produce from the land is shared between the landowner and the tenant farmer according to a pre-agreed ratio. Common ratios might include a 50/50 split, though the specific terms can vary depending on the agreement and the nature of the crop (Chaudhari, 2017).

Globally, there are debates as to whether sharecropping poses unique challenges to sustainable soil management. On the one hand, sharecropping can provide opportunities for those without land to engage in farming and allow landowners and tenant farmers to share the risks associated with agricultural production. This can lead to more collaborative efforts in managing the land, with postulations that landlords might resort to sharecropping to limit land exploitation (Ray, 2005). However, on the other hand, the transient nature of sharecropping agreements often discourages long-term investments in soil health (Abdulai and Goetz, 2014; Lawin and Tamini, 2019). Sharecroppers may be hesitant to implement sustainable soil management practices, which typically yield benefits over an extended period (Tefera and Sterk, 2010; Deininger et al., 2013). This reluctance stems from the uncertainty of their tenure - as they might not farm the same land long enough to reap the benefits of their investments in soil improvement. Consequently, this can lead to short-term exploitation of the soil with practices that maximize immediate yields at the expense of long-term soil fertility. Further, sharecropping has been associated with increased intensity of fertiliser use (Kalkuhl et al., 2020).

Based on these premises this paper tested two hypotheses i.e., first, Sharecroppers and non-sharecroppers differ in their adoption of agricultural practices. Second, the drivers and barriers influencing the adoption of agricultural practices are different between sharecroppers and non-sharecroppers.

This study is justified on several grounds. First, it addresses a significant gap in the literature regarding the impact of land tenure or contract systems on the adoption of sustainable soil management practices in Nepal. While there is a considerable number of research on the factors influencing the adoption of sustainable agricultural practices more generally, there is a lack of study focusing on how different land tenure systems, particularly sharecropping, impact adoption. Given the prevalence of sharecropping in Nepal, there is a need for detailed studies investigating whether this land contract system determines the soil management practices farmers adopt. Second, there is a lack of studies which provides a more differentiated and context-specific understanding of how various factors influence the adoption of different agricultural practices. Third, there are research gaps in examining existing management practices with a direct impact on the interrelated issue of soil degradation and nitrogen losses from soils in Nepal. Understanding this interrelationship is vital for promoting soil management practices that optimize nitrogen use, minimize environmental impact and enhance agricultural productivity. Lastly, previous studies in Nepal often examine the adoption of a single agricultural practices at a time.

2. Materials and methods

2.1. Survey approach

Data was collected through a multistage sampling process in three provinces: Koshi Province (in Morang district), Madhesh Province (in Mahottari district), and Far Western Province (in Kailali district) using a well-structured household survey. From each district, four villages were selected at random. Within each village, 25 farming households were also chosen randomly. This resulted in a sample of 100 farmers from each district, cumulatively totalling 300 farmers. Only farmers who are involved in decision-making in relation to farming activities and are above 18 years old were included in the study.

To determine the inclusion of sharecropping in this study, participants were asked a series of targeted questions. Initially, participants were asked, "Do you engage in sharecropping?" If the farmer responded affirmatively, follow-up questions to understand the specifics of their sharecropping arrangement were asked. These questions included: "What percentage of the inputs do you provide?" and "What percentage of the harvest do you retain?". Further, the study assessed agricultural practices by asking questions on the methods of soil cultivation, crop residue management, fertiliser application techniques, use of compost and organic fertilisers, and water management practices.

2.2. Analytical method

Following previous studies, this study postulates that there may be correlation in the error terms across the adoption of different agricultural practices, i.e., no-till practices, crop residue use, method of fertiliser application, production and use of compost, organic fertiliser use, and water management. Thus, this study estimates a seemingly unrelated regression (SUR) (Zellner, 1962). SUR models are particularly useful when dealing with a system of equations where the error terms are correlated across different equations. However, each equation has its own set of explanatory variables. This model is appropriate for analysing multiple outcomes that may be influenced by different factors but are related through unobserved components. The SUR is specified by:

$$Y_1 = X_1\beta_1 + u_1, Y_1 = \begin{cases} 1 \text{ } if \text{ } Y_1 > 0 \\ 0, otherwise \end{cases} \quad (1)$$

$$Y_2 = X_2\beta_2 + u_2, Y_2 = \begin{cases} 1 \text{ } if \text{ } Y_2 > 0 \\ 0, otherwise \end{cases} \quad (2)$$

$\vdots$

$$Y_k = X_k\beta_k + u_k, Y_k = \begin{cases} 1 \text{ } if \text{ } Y_k > 0 \\ 0, otherwise \end{cases}$$

where Y_i is the dependent variable (representing the adoption of no-till practices, crop residue use, method of fertiliser application, production and use of compost, organic fertiliser use, and water management). X_i is a matrix of explanatory variables. β_i is a vector of coefficients for the *i-th* equation. u_i is the error term for the *i-th* equation, with the assumption that $u_1, u_2, \ldots, u_k$ are possibly correlated. The analytical steps are summarised in Fig. 1.

2.3. Study area

The study area is the Terai region which covers an area of 33,998.8

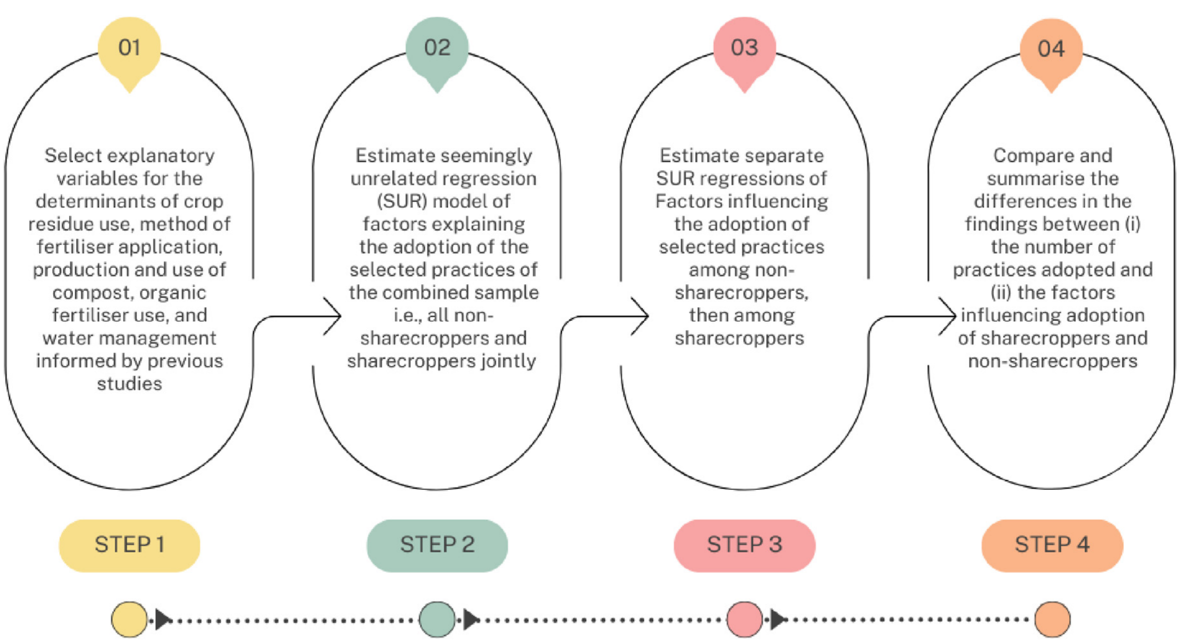

Fig. 1. Summary of the research flow of the study.

km^2 and has elevations ranging from 60m to 300m above sea level (Sharma, 2018). The Terai is the main agricultural region of Nepal. The Terai has a hot and humid climate (Manandhar et al., 2011). The cropping system is mostly multiple cropping with rice wheat, maize dominating (Krupnik et al., 2021). In this region, soil degradation primarily manifests in the loss of the topsoil layer, nutrient depletion compaction, reduced soil porosity and other forms of physical degradation. Additionally, there are chemical degradation concerns, including soil contamination by pesticides (Karki and Ojha, 2021). Although there are reports of a decrease in sharecropping, unregistered and informal forms of the practice is prevalent in the region (Bhandari, 2007).

3. Results

3.1. Description of respondents

The data indicates that 51.65% of the individuals in the sample are non-sharecroppers, while 48.35% are sharecroppers. The mean age of farmers is 49 years. The gender distribution shows that 86% are male and 14% female. The majority (92%) are household heads. The average formal education duration among the respondents is 5.2 years. The respondents have an average farming experience of 29.1 years. The farms are generally small, with an average size of 0.9 ha for each household. The primary source of income for 81.5% of the households is crop farming. 84.3% of the respondents own at least one plot where they cultivate their crops.

The results in Table 2 show that no-tillage/minimum tillage is adopted by 25.16% of non-sharecroppers compared to 11.31% of sharecroppers. The use of crop residues is highly adopted by both groups, with 92.31% of non-sharecroppers and 99.39% of sharecroppers utilizing crop residues in the soil. Only 14.29% of non-sharecroppers and 5.56% of sharecroppers incorporated fertiliser or used deep placement methods suggesting a low adoption rate of efficient fertiliser application techniques. A higher percentage of sharecroppers (30.95%) produce and use compost compared to non-sharecroppers (13.29%). A higher percentage of sharecroppers (90.48%) use organic fertilisers than non-sharecroppers (66.04%), while there was a high adoption of water management for both non-sharecroppers (93.06%) and sharecroppers (90.97%).

3.2. Factors explaining the adoption of the selected practices of all farmers combined

Non-sharecroppers and sharecroppers are compared in Table 3. The dummy variable for sharecropper (with a reference category non-sharecropper) is significant for 4 of the 5 practices. Specifically, compared to non-sharecroppers, being a sharecropper is associated with a decrease in the likelihood of adopting no-tillage/minimum tillage and incorporating fertiliser/deep placement. In contrast, being a sharecropper is associated with an increase in the likelihood of adopting organic fertiliser, compost and crop.

Being an older farmer increases no-tillage/minimum tillage adoption. Male-headed households have a higher likelihood of adopting no-tillage but not fertiliser use and composting. More years of farming experience reduces crop residue use, while larger farm sizes have a higher likelihood of incorporating fertiliser use, but it is a barrier to adopting no-tillage. Larger labour size decreases no-tillage and water management adoption, but drives the adoption of composting. Farmers' with recent agricultural training have a higher likelihood of using compost, but the opposite is the case for no-tillage. Subsidies for synthetic fertilisers resulted in lower likelihood of adopting no-tillage, crop residue use, and fertiliser incorporation but increased compost use. Negative attitudes towards soil nutrition and awareness of soil-environmental linkages reduce the likelihood of adopting water management and no-tillage respectively.

As shown in Table 4, the model presented in Table 3 shows statistical significance. This suggests that, in each case, one or more significant predictors influence the dependent variable. The Breusch-Pagan test result ($\chi^2\,(15) = 46.612, p < 0.001$) suggests that the residuals across the equations are not independent. This validates using SUR over separate Probit regressions for each equation, as it accounts for potential correlations in the error terms across different agricultural practices.

3.3. Correlation matrix of residuals of the combined model

The correlations among the residuals are generally weak, with no values indicating a very strong relationship. This suggests that while some level of shared unexplained variation across these models may exist, it is not particularly pronounced (Table 5). However, the SUR model remains advantageous in this scenario, as it accounts for these correlations in the estimation process and potentially leads to a more efficient and accurate estimates than separate probit regressions for each equation.

3.4. Factors influencing the adoption of practices among non-sharecroppers

The results of a separate regression of the determinants of the adoption of no-tillage/minimum tillage, use of crop residues, incorporating/deep placement of fertiliser, producing and using compost, use of organic fertiliser and water management methods among non-sharecroppers are presented in Table 6. Male non-sharecroppers are more likely to adopt no-tillage/minimum but less likely to adopt methods that incorporate fertiliser into the soil. Higher farm income levels are associated with a

Table 2
Proportions of households practicing various agronomic practices which have benefits for soil quality and nitrogen loss mitigation.

Practice	Code	Category	Non-sharecropper (%)	Sharecropper (%)
Method of soil cultivation	1 =	No tillage/Minimum tillage	25.16	11.31
	0 =	Deep tillage	74.84	88.69
Use of crop residues	1 =	Returned to soil (incorporated into the soil, left on the field and used as mulch, used in composting)	92.31	99.39
	0 =	Taken out of the field	7.69	0.61
Method of fertiliser application	1 =	Incorporated after broadcasting, deep placement	14.29	5.56
	0 =	Broadcasting surface	85.71	94.44
Use compost	1 =	Yes	13.29	30.95
	0 =	No	86.71	69.05
Use any organic fertiliser	1 =	Yes	66.04	90.48
	0 =	No	33.96	9.52
Water management	1 =	Manage water (alternate wetting and drying, mid-season drainage)	93.06	90.97
	0 =	No water management including all year flooding	6.94	9.03

Table 3
SUR model estimates of factors explaining the adoption of the selected practices of combined sample.

	No-tillage/minimum tillage	Use of crop residues	Incorporating fertiliser in soil or deep placement	Using compost	Use any organic fertiliser	Water management
	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)
Sharecropper	−0.122***	0.096***	−0.086**	0.074*	0.296***	−0.038
	(0.041)	(0.027)	(0.038)	(0.043)	(0.053)	(0.035)
Age	0.036***	0.003	−0.021	0.018	0.007	−0.002
	(0.017)	(0.011)	(0.016)	(0.018)	(0.022)	(0.014)
Gender (1 = male)	0.192***	−0.014	−0.183***	−0.11*	−0.036	0.007
	(0.055)	(0.036)	(0.051)	(0.058)	(0.07)	(0.047)
Farming experience	0.001	−0.002**	0.00	−0.002	0.001	0.00
	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
Farm income	−0.026	0.01	0.034	−0.01	0.017	−0.034
	(0.052)	(0.034)	(0.048)	(0.055)	(0.067)	(0.044)
Farm size	−0.004**	0.00	0.006***	−0.001	−0.002	0.00
	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Labour size	−0.015***	−0.001	0.001	0.005*	0.001	−0.007***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Training	−0.133**	0.022	0.042	0.179***	0.051	0.059
	(0.054)	(0.035)	(0.05)	(0.057)	(0.07)	(0.046)
Subsidy for Synthetic fertiliser	−0.234***	−0.113***	−0.135***	0.478***	0.003	0.039
	(0.053)	(0.034)	(0.049)	(0.056)	(0.068)	(0.045)
Attitude to soil nutrition	0.014	−0.003	0.008	−0.016	−0.043	−0.084***
	(0.028)	(0.018)	(0.026)	(0.029)	(0.035)	(0.023)
Awareness of soil/environ linkage	−0.117***	−0.027	−0.02	0.04	0.047	−0.041
	(0.025)	(0.016)	(0.023)	(0.027)	(0.032)	(0.021)
_cons	0.566***	1.065***	0.289***	−0.075	0.507***	1.277***
	(0.12)	(0.078)	(0.111)	(0.126)	(0.154)	(0.102)

*** indicates significance at 1%.
** indicates significance at 5%.
* indicates significance at 10%, Note: Standard error are in parenthesis.

Table 4
Levels of model fit and significance across different regression equations in the combined (sharecropper and non-sharecroppers) model.

Items	χ^2	p
Soil cultivation	146.5	0.000
Use of crop residues	32.64	0.001
Method of fertiliser application	53.83	0.000
Produce and use compost	208.71	0.000
Use organic fertiliser	43.67	0.000
Water management method	53.83	0.000

Breusch-Pagan test of independence: χ^2 (15) = 46.612, $p < 0.001$.

lower likelihood of producing and using compost. Larger farms are more likely to adopt deep placement of fertiliser. Labour availability increases the likelihood for farms to produce and utilize compost. However, these farms are less likely to engage in no-tillage/minimum tillage and water management practices. Training is associated with a lower likelihood of adopting no-tillage/minimum tillage. Subsidies for fertilisers tend to be a barrier to adopting no-till practices and incorporating crop residues, but it increases the likelihood of producing and using compost. Negative attitudes towards soil nutrition and awareness of soil-environmental linkages decrease the likelihood of adopting no-tillage/minimum tillage and good water management techniques.

The model depicted in Table 6 indicates statistical significance, i.e., for each scenario at least one significant predictor affects the outcome variable. Further, the outcome of the Breusch-Pagan test ($\chi^2(15)$ = 45.563, $p < 0.001$) implies that the residuals are interrelated across the equations (Table A1 of the Appendix). This supports the decision to employ SUR instead of individual Probit regressions for each equation.

3.5. Factors influencing the adoption of practices among sharecroppers

The results of the determinants of the adoption of farm practices among sharecroppers are presented in Table 7. Older sharecroppers were more likely to adopt no-tillage/minimum tillage. Households headed by male farmer shows varied effects on different agricultural practices, highlighting possible gender-based differences. Specifically, male farmers are more likely to adopt no-tillage/minimum tillage but less likely to incorporate fertiliser and use compost and organic fertilisers. Higher farming income is associated with a lower likelihood of adopting no-tillage/minimum tillage, suggesting that relatively wealthier farmers may opt out of this practice. Larger farm sizes are more likely to incorporate fertiliser rather than broadcasting and leaving it on the surface.

More available labour decreases the likelihood of adopting no-tillage/minimum tillage, but increases the likelihood of incorporating crop residues into the soil. Recent agricultural training reduces the likelihood of adopting no-tillage/minimum tillage but results in higher tendency to use compost. Fertiliser subsidies are less likely to encourage the adoption of no-tillage/minimum tillage but are more likely to encourage the

Table 5
Correlation of residuals from the SUR model estimation obtained from the combined model.

	Soil cultivation	Use of crop residues	Method of fertiliser application	Use compost	Use organic fertiliser	Water management method
Soil cultivation						
Use of crop residues	0.0985					
Method of fertiliser application	−0.229	0.0093				
Produce and use compost	0.000	0.0914	0.0136			
Use organic fertiliser	0.0688	−0.0519	−0.0549	0.189		
Water management method	0.1121	−0.0556	0.2243	0.022	0.0116	

Table 6
Factors influencing the adoption of selected practices among non-sharecroppers.

	No-tillage/minimum tillage	Use of crop residues	Incorporating fertiliser in soil or deep placement	Using compost	Use organic fertiliser	Water management
	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)
Age	0.007	0.013	−0.028	0.016	−0.02	−0.02
	(-0.024)	(-0.021)	(-0.026)	(-0.021)	(-0.037)	(-0.017)
Gender (1 = male)	0.163**	−0.026	−0.266***	−0.037	0.04	−0.022
	(0.084)	(0.072)	(0.092)	(0.075)	(0.129)	(0.061)
Farming experience	0.00	−0.002	0.00	−0.002	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Farm income	0.004	−0.009	0.088	−0.140*	−0.025	−0.036
	(0.082)	(0.07)	(0.089)	(0.072)	(0.125)	(0.059)
Farm size	−0.001	0.001	0.006**	−0.002	−0.004	0.00
	(0.002)	(0.002)	(0.003)	(0.002)	(0.004)	(0.002)
Labour size	−0.017***	−0.002	0.002	0.006**	0.002	−0.008***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)	(0.002)
Training	−0.313***	−0.021	0.123	0.087	0.111	−0.021
	(0.104)	(0.089)	(0.114)	(0.092)	(0.16)	(0.075)
Subsidy for Synthetic fertiliser	−0.287***	−0.241***	−0.142	0.353***	0.046	0.058
	(0.086)	(0.073)	(0.093)	(0.076)	(0.131)	(0.062)
Attitude to soil nutrition	−0.071*	0.001	0.036	−0.003	−0.03	−0.092***
	(0.04)	(0.034)	(0.043)	(0.035)	(0.061)	(0.029)
Awareness of soil/environ linkage	−0.223***	−0.062*	−0.023	0.01	0.065	−0.082***
	(0.042)	(0.036)	(0.046)	(0.037)	(0.065)	(0.03)
_cons	1.173***	1.160***	0.20	0.113	0.563	1.485***
	(0.179)	(0.153)	(0.195)	(0.158)	(0.274**)	(0.129)

*** indicates significance at 1%.
** indicates significance at 5%.
* indicates significance at 10%, Note: Standard error are in parenthesis.

Table 7
Factors influencing the adoption of practices among sharecropper.

	No-tillage/minimum tillage	Use of crop residues	Incorporating fertiliser in soil or deep placement	Using compost	Use organic fertiliser	Water management
	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)	Coeff. (std. err)
Age	0.065***	−0.009	−0.013	0.017	0.039*	0.017
	(-0.02)	(0.006)	(0.017)	(0.027)	(0.023)	(0.022)
Gender (1 = male)	0.213***	0.025	−0.118**	−0.168*	−0.123*	0.047
	(0.066)	(0.02)	(0.056)	(0.089)	(0.074)	(0.073)
Farming experience	0.002	0.00	−0.001	0.00	0.002	0.00
	(0.002)	(0.001)	(0.002)	(0.003)	(0.002)	(0.002)
Farm income	−0.102*	−0.01	−0.012	0.052	0.047	−0.055
	(0.059)	(0.018)	(0.051)	(0.08)	(0.067)	(0.065)
Farm size	−0.005	−0.002	0.007**	−0.001	0.003	0.003
	(0.003)	(0.001)	(0.003)	(0.005)	(0.004)	(0.004)
Labour size	−0.011***	0.003**	0.00	0.003	−0.004	−0.003
	(0.003)	(0.001)	(0.003)	(0.005)	(0.004)	(0.004)
Training	−0.095**	0.008	0.003	0.17**	0.008	0.084
	(0.055)	(0.017)	(0.047)	(0.074)	(0.062)	(0.06)
Subsidy for Synthetic fertiliser	−0.086	0.011	−0.109*	0.551***	−0.028	0.083
	(0.065)	(0.02)	(0.056)	(0.088)	(0.074)	(0.072)
Attitude to soil nutrition	0.092***	−0.011	−0.018	−0.029	−0.057	−0.079**
	(0.032)	(0.01)	(0.028)	(0.044)	(0.037)	(0.036)
Awareness of soil/environ linkage	−0.024	0.028***	−0.013	0.079**	0.032	−0.007
	(0.029)	(0.009)	(0.025)	(0.039)	(0.033)	(0.032)
_cons	−0.202	0.99***	0.242*	−0.185	0.723***	1.004***
	(0.149)	(0.046)	(0.128)	(0.202)	(0.169)	(0.165)

*** indicates significance at 1%.
** indicates significance at 5%.
* indicates significance at 10%, Note: Standard error are in parenthesis.

production and use of compost. A positive attitude towards soil nutrition significantly increases the likelihood of adopting no-tillage/minimum tillage, whereas it decreases the likelihood of adopting water management practices. Greater awareness of soil-environment linkages increases the likelihood of incorporating crop residues and using compost.

Similar to Table A1, the chi-squared values testing the null hypothesis that all the coefficients (except the intercept) in the regression model for sharecroppers are equal to zero imply that the models have explanatory power. The Breusch-Pagan test of independence for the model in Table 7 is presented in Table A2. The statistics ($\chi^2(15) = 26.009$, $p = 0.037$) indicate that the residuals across these models are not independent.

3.6. Correlation matrix of residuals of each separate model

The relationships among the residuals are mostly weak, as indicated by the lack of values showing a very strong correlation. This implies that although there might be a minor degree of shared unexplained variation across these models, it is not particularly strong (Table A3).

3.7. Summary of the differences in the findings between factors influencing adoption between sharecroppers and non-sharecroppers

The main difference is that age i.e., being older influenced adoption for sharecroppers but not for non-sharecroppers. Male-headed farms determined adoption of more practices for sharecroppers. For non-sharecroppers, labour size influences the adoption of water management, using compost and no-tillage/minimum tillage. In contrast, for sharecroppers, it impacts the adoption of no-tillage/minimum tillage. Subsidy for synthetic fertiliser has a significant impact on the adoption of no-tillage/minimum tillage, using compost and crop residues for non-sharecroppers, whereas for sharecroppers, it influences the incorporation of fertiliser and the use of compost only. There is an association between awareness of the soil/environment linkages, no-tillage/minimum tillage and water management for non-sharecroppers and for sharecroppers.

4. Discussion

The study shows the comparative likelihood of sharecroppers and non-sharecroppers to adopt agricultural practices. Sharecroppers are less likely to adopt reduced tillage/no-till and fertiliser incorporation, possibly due to their limited tenure security and lack of incentives for long-term land improvement. This finding aligns with literature suggesting that sharecroppers might prioritize short-term over long-term land productivity (Tefera and Sterk, 2010; Deininger et al., 2013). On the other hand, the positive association with the use of crop residues, compost and organic fertilisers may be due to the preference for low-cost and accessible inputs as sharecroppers often operate under financial and resource constraints (Matoussi and Saidi, 2014).

The positive effect of age on reduced tillage/no-till suggests older farmers might be more inclined towards sustainable practices. This could be attributed to their accumulated experience and greater awareness of the long-term benefits of good soil health (Devkota and Phuyal, 2018). However, the limited influence of age on other practices indicates that experience does not uniformly translate into the adoption of all sustainable practices. Male farmers are more likely to adopt reduced tillage/no-till but less inclined towards fertiliser incorporation and compost use. This finding might reflect gender differences in access to resources, information, and labour in favour of men. Also, previous studies have reported that the labour of hand-weeding which is often undertaken by women, may become more burdensome with the implementation of no-till farming methods (Gattinger et al., 2011). Further, composting which is often considered a female-associated activity in many cultures, might be less adopted by male farmers (Nepal et al., 2022; Seager et al., 2020).

Interestingly, farming experience shows limited effects and differ from past findings e.g., Begho et al. (2022) that experience correlates with innovative practice adoption. This might be due to entrenched farming habits or a lack of exposure to new information and techniques. The varied effects of farm income and size on practice adoption can be understood through the perspective of resource availability. While higher income farmers or larger farms might afford more inputs, they may not always align with sustainable practices like composting or reduced tillage. This could possibly be due to their focus on mechanization and scalability. Further, the economic rationale for reduced tillage and no-till methods is partly based on reducing labour and machinery costs (Townsend et al., 2016). Larger labour sizes negatively impacting reduced tillage/no-till and water management implies that, with a large labour force the cost-saving benefits of these methods might be less pronounced, potentially affecting the overall economic viability of these practices on the farm. Besides, the transitioning to such practices often requires a change in traditional farming techniques which can be challenging in a setting with a large labour force. Training and adapting a larger number of workers to new methods can be more complicated and time-consuming and lead to resistance or slow adoption of these practices.

The negative effect of subsidies for synthetic fertiliser on reduced tillage/no-till and the positive effect on compost use suggest that subsidies might encourage reliance on synthetic inputs. Subsidies for synthetic fertiliser can make fertiliser more affordable and accessible to farmers. This incentive may encourage farmers to rely less on the natural fertility of the soil (enhanced through sustainable methods) and rely more on chemical inputs. Further, farmers may indirectly use more organic fertiliser as they perceive it to be complementary to synthetic fertiliser (Joshi et al., 2023). Also, the negative impact of a focus on improving soil nutrition and less on water management might lead to the neglect of important water conservation practices.

The key differences between sharecroppers and non-sharecroppers in adopting various agricultural practices can be attributed to several factors. Sharecroppers, typically work on land they do not own and may face different economic constraints compared to non-sharecroppers (Tefera and Sterk, 2010; Deininger et al., 2013; Abdulai and Goetz, 2014). This difference might influence their adoption of practices, as sharecroppers might be more cautious taking up practices that affect long-term soil health or have upfront costs. Their focus could be more on immediate yield maximization, which aligns with practices like use of organic fertiliser and compost. Non-sharecroppers on the other hand often have more control and security over their land and may have a long-term interest in maintaining soil fertility and productivity. This could explain why they are more inclined towards practices like tillage/minimum tillage that benefit the soil in the long run. However, contrary to some assertions that sharecropping inherently acts as a barrier to agricultural practices universally, these empirical findings challenge the longstanding belief that sharecropping is holistically an inefficient practice and supports previous findings such as Garrett Jr and Xu (2003).

This study has limitations. First, it is important to acknowledge that various factors can drive the adoption of agricultural practices or technologies. Such factors include productivity, ease of use, associated costs, and perceived benefits. However, these were not included in this study. Future studies are encouraged to address these elements to provide more holistic findings of adoption drivers. Second, the adoption of no tillage or minimum tillage by sharecroppers may not solely be attributable to the nature of sharecropping itself. In some cases, a tenant is expected to continue using the tillage system already in place on the farm. Critical information such as whether the sharecroppers used a different tillage system from what was existing before the tenancy, the reasons behind any such changes, and whether they consulted with the landlord before implementing these changes, were not explored in this study. Lastly, the duration of the tenancy contract was not addressed but could influence the adoption of sustainable soil management practices by tenants. The likelihood of a tenant investing in, or adopting these practices may increase with the length of the contract. A longer duration could provide sufficient time to recover the initial investment. Future research should consider these factors.

5. Conclusions

The paper advances understanding of the association between land tenure systems, particularly sharecropping, and the adoption of beneficial soil management practices in Nepal. The objectives of this paper were to examine, first, the comparative likelihood of sharecroppers and non-sharecroppers to adopt agricultural practices. Second, whether there are differences between adoption drivers/barriers of sharecropper and non-sharecroppers. The results show that being a sharecropper is associated with a decrease in the likelihood of adopting no-tillage/minimum tillage and incorporating fertiliser rather than broadcasting. However, being a sharecropper is associated with a greater likelihood of adopting organic fertiliser, compost and crop residues. The main differences between the determinants of adoption among sharecroppers and non-sharecroppers are that older farmers were more likely to adopt some practices for sharecroppers but not for non-sharecroppers. There are also differences in the adoption of no-tillage/minimum tillage and incorporation of fertiliser for non-sharecroppers between male and female farmers. However, for sharecroppers, male-headed farms were less likely to adopt most practices. Labour size, subsidy for synthetic fertiliser and awareness of the soil/environment linkages also influenced adoption differently across sharecroppers and non-sharecroppers. These findings are crucial for comprehending the drivers behind the adoption of sustainable agricultural practice and offering targeted recommendations for policy and practice, for example, the distinct needs and limitations faced by Nepalese farmers under varying land tenure arrangements. In addition, strategies could include a rethink of incentives, training programs that are considerate to the characteristics of farmers, and extension services that are specifically designed to overcome the constraints faced by Nepalese farmers to encourage both sharecroppers and non-sharecroppers to adopt practices that improve soil health and minimize nitrogen depletion. Practically, this study holds significant implications for improving agricultural productivity and environmental sustainability in similar regions globally. For example, other regions can benefit from these findings to design tailored policy interventions, such as specific incentives and training programs to address the needs of sharecroppers and non-sharecroppers. Extension services should be adapted to support farmers to overcome the distinct barriers faced by different demographics, including gender-specific and age-related considerations. Promoting awareness about the environmental benefits of sustainable practices, strengthening land tenure security and supporting farmers in sharecropping agreements to ensure compliance with sustainability can encourage uptake of sustainable practices.

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Consent

The study was approved by the Social Science Ethics committee of Scotland's Rural College (Ethical Clearance Reference Number: 35218734) on March 05, 2021. Participants were informed of the anonymity and confidentiality of their data. Voluntary participation and use of the information obtained for non-commercial purposes only was sought. All participants whose data are analysed in this study gave informed consent prior to participating.

CRediT authorship contribution statement

Toritseju Begho: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rajendra Joshi:** Writing – review & editing, Supervision, Project administration, Investigation, Data curation, Conceptualization. **Bigyapti Nepal:** Writing – review & editing, Writing – original draft, Validation, Resources, Investigation, Data curation, Conceptualization. **Rakesh Shrestha:** Writing – review & editing, Resources, Project administration, Investigation, Data curation. **Subodh Sharma:** Writing – review & editing, Supervision, Resources, Project administration, Investigation. **Vera Eory:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.farsys.2024.100108.

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