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Improving women's purchasing power through land-enhancing technologies: The case of bio-reclamation of degraded lands in Niger

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In Niger, about 50% of the land surface is composed of degraded lateritic soils, and rural women farmers have limited access to productive land. Targeting largely marginalized rural women with bio-reclamation of degraded land (BDL) technologies restores their rights to earn a livelihood through agriculture. This study examines the determinants and impacts of land-enhancing technology on women farmers in Niger. Data were collected from 1,205 randomly selected women farmers in the Maradi and Zinder regions. The sample included 69% of participants into BDL program and 31% of non-participants. To account for selection bias from observable and unobservable factors, an endogenous switching regression (ESR) model was used to estimate the impact of BDL technology on women's household income. A simple probit model was used to analyze the determinants of participation. The results show that key determinants of participation in BDL include income level before participation in BDL, household size, age of participants, number of women in the household, number of children under 5 years old, sex of household head, age of household head, and institutional support. Participation in BDL positively influences participants' income (+14%); non-participants may not benefit from participating as they would probably lose 31% of their income, and the impact of participation in BDL varies widely across regions. Before the advent of BDL, the income of non-participants was higher than that of participants by 25%. It can be inferred that BDL is a pro-poor technology that is not beneficial to all women farmers. This study makes a critical contribution to the literature on land-enhancing technologies. It suggests that the impact of land-enhancing technologies, such as BDL, is closely linked to spatial, economic, environmental, temporal, and cultural contexts. Accordingly, land-enhancing technologies should target locations with large percentages of degraded farmlands and the poorest farmers. These results contribute to food security and poverty alleviation policies in rural dryland areas.

KEYWORDS

bio-reclamation of degraded lands, impact assessment (IA), welfare, endogenous switching regression model (ESRM), Niger

1. Introduction

Land degradation is a persistent deterioration of land productivity (Adeel et al., 2005). It is characterized by three types of soil degradation, namely, chemical, physical, and erosional (Orchard et al., 2017). It has been a major global issue since the 20th century (Hamdy and Aly, 2014), affecting an estimated 1.5 billion people and a quarter of the land area in all agroecological zones worldwide (Lal et al., 2012, 2014). Annually, an area of ∼5–8 million hectares of formerly productive land goes out of cultivation globally due to degradation (TerrAfrica, 2006). The African continent is particularly vulnerable to land degradation (Obalum et al., 2012; Reed and Stringer, 2016). More than 75% of arable land in the continent is degraded (Khan et al., 2014), while agricultural production is predominantly rainfed and highly sensitive to climate variability (Nyakudya and Stroosnijder, 2015). This implies difficult living conditions for rural people who depend on agro-pastoralism for their livelihoods (Pricope et al., 2013).

In Niger, the Sahara Desert covers ∼77% of the land area, with average annual rainfall ranging from 100 to 200 mm in the north and 500–600 mm in the south (World Bank, 2020). The other 23% of the land area in the southern part of the country is inhabited by people, 87% of whom depend on rainfed agriculture (Moussa et al., 2016). Degraded lateritic soils occupy more than 50% of the land surface and are prevalent in and around most of the villages in the 400–800 mm/year rain belt, and cost approximately 11% of the 2007 GDP of US$6.773 (Moussa et al., 2016). Niger's Human Development Index is 0.39 in 2019 (UNDP, 2020)[1], and land degradation is one of the main causes of poverty in the country (Orchard et al., 2017). It contributes to decreasing land productivity, the provision of terrestrial ecosystem services, and the benefits they provide for human wellbeing (Gerber et al., 2014). Most of the Niger's population depend heavily on the land for food and income and are thus vulnerable to land degradation. Women are more vulnerable to poverty as they are predominantly in the social groups of the ultra-poor (Ahmed et al., 2007), and land is normally bequeathed to sons (Doss et al., 2015). Given the importance of land for food security and cash income generation for Niger's rural households, one possible solution to overcoming poverty is the introduction of farming techniques without compromising the sustainability of crop production (Baidu-Forson, 1999). Therefore, instead of abandoning severely degraded lands, they might be rehabilitated (Moussa et al., 2016) and made available to rural women farmers, as it has been demonstrated in the literature that agricultural policies targeted at women are more likely to perform better in terms of household welfare outcomes (Doss, 2005; Quisumbing and McClafferty, 2006).

Since 2013, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), in collaboration with Catholic Relief Services (CRS), has introduced the bio-reclamation of degraded land (BDL) technologies in 170 villages in the regions of Maradi and Zinder in Niger. The rationale for developing BDL systems is to bring these degraded lands back into production and transform them into productive soil. In practice, recovered lands are restored to Niger's largely marginalized rural women to improve their livelihoods through crop production. These technologies are implemented by women farmers' groups and depend on the types that fit the village/region where the system is implemented. In each village, a group of women was trained to build their capacity for cooperative management and traditional vegetable and fruit tree production in the BDL fields. The village chief provided the degraded lands to them, which were used to produce indigenous vegetables using BDL technologies. In Niger, similar to most countries in dryland areas, women do not have access to productive assets, including land, because they are not allowed to inherit the land. Therefore, introducing BDL technologies is seen to help women in the agricultural sector who mostly produce a short-duration cultivar of okra (*Abelmoschus esculentus*) introduced jointly by the World Vegetable Center (AVRDC) and ICRISAT.

However, since the introduction of BDL agricultural farming practices, less is known about their effect on women's wellbeing. To fill this gap in the literature, this study analyzes the determinants and impact of women's participation in the BDL system on their incomes. It extends the existing literature by revealing a new limiting factor of land-enhancing technology adoption by women and by showing that BDL is a pro-poor technology that is not equally beneficial to all rural farmers

1 HDI ranges from 0 to 1, with HDI = 1 being the highest level of development and 0 the lowest level.

(refer to Baidu-Forson, 1999). The remainder of this article is organized as follows. The "bio-reclamation of degraded lands program and its impact pathway in Niger" section briefly describes the BDL systems. The sections 3, 4 present the analytical framework, research design, and data. The section 5 presents the results and discussion. The final section presents the conclusions and policy implications.

2. Bio-reclamation of degraded lands program and its impact pathway in Niger

The BDL is an integrated system aimed at increasing food production and income of poor farmers (chiefly women) through the utilization of degraded lands for the production of rain-fed fruit trees and vegetables. The BDL improves soil fertility and harvested rainwater and is a successful tree-crop system. BDL combines indigenous water-harvesting techniques, application of organic matter, and planting of high-value trees and vegetables. The idea is to restore the productivity of the barren lateritic soils by using traditional water-harvesting planting techniques, like half-moons or zai pits, for the cultivation of high-value vegetables and trees. The impact on incomes and family nutrition makes the intensive labor investment worthwhile.

Degraded lands are sacrificed to break the surface crust. Micro-catchments (called demi-lunes) are built to catch and store runoff rainwater. The demi-lune is usually 2 × 3 m in size, but size can vary if necessary. The harvested water is stored in the soil for long periods and is utilized by a tree planted in the 40 × 80 cm ridge left in the center of the open side of the demi-lune to avoid waterlogging. Demi-lunes are usually spaced at 5 × 10 m. The area between the demi-lunes is occupied by planting pits known as "zaï" holes, which are holes 20 × 20 × 20 cm deep dug in the laterite. About 300 g dry weight of compost or manure is placed in the bottom of the zaï hole and is covered with a 5 cm layer of soil. The zaï holes are usually spaced at 0.5 × 1.0 m and also collect runoff water. The deeply placed compost in the hole results in extensive root growth, allowing the plant to exploit both water and nutrients. In addition, trenches are dug every 20 m down the slope to further harvest runoff water.

Trees are a major component of the BDL. They are much more resilient to droughts and can cope better with dry spells than annual crops. In a 200 m^2 plot, there are two "Pomme du Sahel" (*Ziziphus mauritiana*) trees and two *Moringa stenopetala* trees intercropped with traditional vegetables.

The most suitable vegetable crops are okra (*A. esculentus*) and roselle (*Hibiscus sabdariffa*). Other traditional leafy vegetables such as *Cassia tora* (*Senna obtusifolia*) can also be planted in the BDL system in addition to okra and roselle. Okra is a very important component of the diet in Niger.

The implementation of BDL technology promotes women's economic empowerment, improves micronutrient availability and access to nutrition, mitigates climate change, enhances women's access to land, improves soil fertility, and promotes soil conservation techniques in targeted communities (Pasternak et al., 2009; Moussa et al., 2016). The BDL development process consists of negotiating agreements with the village development committees, land commissions, women's groups, and land owners; then developing documents and legalizing lease agreements with signatures of land owners, the land commission, and women leaders; training CRS field agents and government extension staff in BDL, who in turn train women's groups; developing degraded land (physical components) through food for work; planting seedlings and annual crops at the onset of the rainy season; and finally, monitoring and supporting women's groups throughout the life of the project.

Owing to its simplicity and positive attributes, its potential for mass adoption is very high. The BDL reclaims the hidden potential of lateritic soils physically by increasing infiltration and water harvesting and biologically through the planting of hardy woody species and annual income generation. In doing so, the land is protected against further degradation while expanding the productivity of land and water, thus bringing economic benefits to women farmers. The BDL deals not only with desertification and climate change but also with women's empowerment (Fatondji et al., 2013). BDL is highly significant in regions where extreme pressure is exerted on scarce and fragile arable lands to produce more food for a rapidly growing population under climatic variation (Angrist and Pischke, 2009).

Figure 1 presents the impact pathway tracked in this study. The BDL program restores degraded land fertility and makes it available to women for cropping. Participation in this land-enhancing technology program is expected to increase the agricultural land area available for participant households and improve soil fertility and land productivity. Due to land availability and productivity improvements, household production and food availability are expected to increase. Households can increase the land area allocated to certain crops or produce new crops. Holding other things constant, an increase in production will improve women's income and food consumption. Therefore, women's self-worth, empowerment, and welfare, as well as household welfare, are expected to improve.

3. Conceptual framework

3.1. Decision to participate in BDL and selection bias

Suppose that women choose among T_i land-enhancing technologies, including BDL, a combination of soil scarification and indigenous water-harvesting methods in order to produce

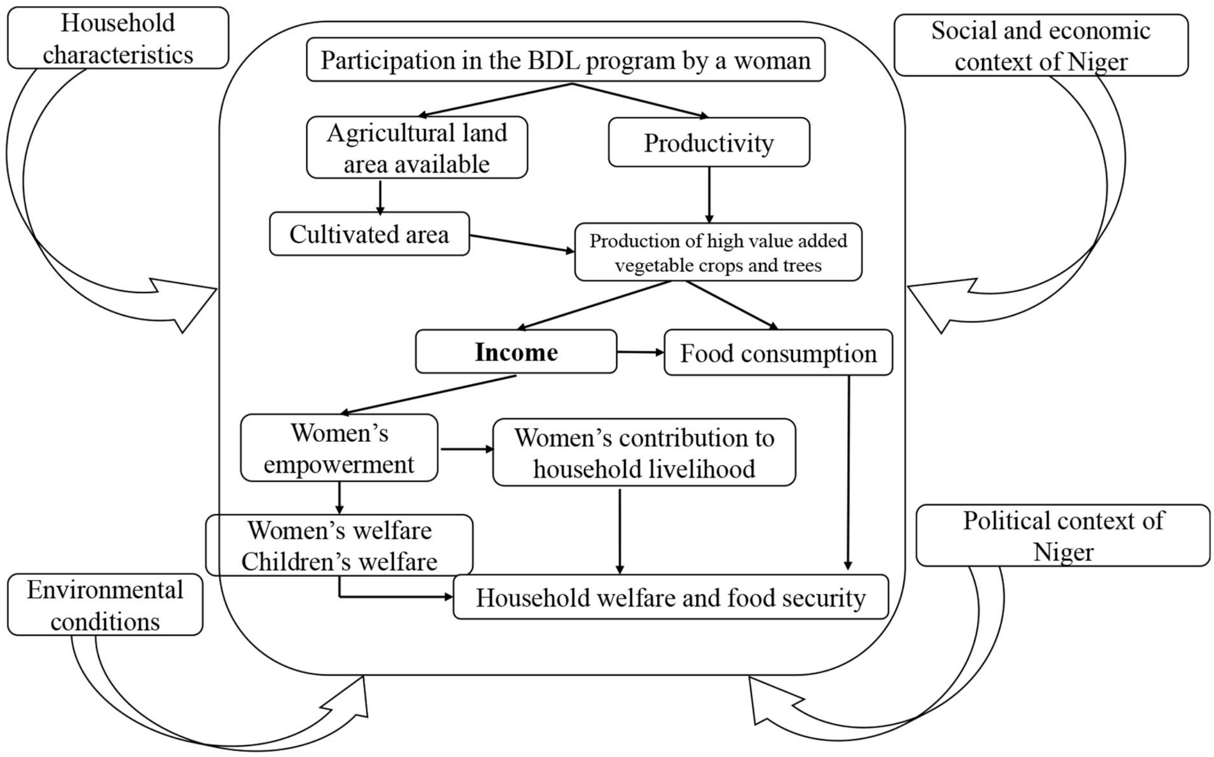

FIGURE 1
Impact pathway.

crops and maximize their consumption of food and non-food items utility, subject to some constraints on available resources and technologies. For woman i, the utility associated with participation or not in the BDL program is U_{iP} and U_{iN}, respectively. Participation in BDL is only known to the researcher, while the preferred net utility of women is known to them. The net utility can be represented by $U_i = U_{iP} - U_{iN}$ and expressed in a latent variable framework with respect to household characteristics as

$$T_i^* = X_i\alpha + \varepsilon_i , \qquad T_i = 1\left[T_i^* > 0\right] \quad (1)$$

where T_i is a binary variable equal to 1 for women who participate in BDL and 0 otherwise; X is a vector of observable factors that influence the decision to participate in BDL (participant, farm, and household characteristics); α is a vector of parameters to be estimated; and ε is the error term and is assumed to be normally distributed with mean zero and variance σ_ε^2. The term ε captures the measurement errors and unobserved factors that may influence the decision to participate in BDL. The probability of participating in BDL can be expressed as follows:

$$\Pr(T=1) = \Pr\left(T_i^* > 0\right) = \Pr\left(\varepsilon_i > -\alpha' X_i\right) = 1 - F\left(-\alpha' X_i\right) \quad (2)$$

where F denotes the cumulative distribution function of ε. In our estimation, Equation (2) is estimated using a probit model and presents the determinants of participation in BDL. For the impact of participation in BDL on income, suppose that women's income is a linear function of farm and household characteristics as follows:

$$Y_i = \beta Z_i' + \gamma T_i + \mu_i \quad (3)$$

where Y represents women's income; Z is a vector of the characteristics of participants, farms, and households; T is participation status whose probability is estimated in Equation (2); β and γ are parameters to be estimated; and μ is a random error term. All the factors in Z are observable variables and are declared by farmers. However, unobserved variables, such as women's managerial abilities, innate technical skills, risk behavior, and social networking, may also influence the dependent variable and are captured in the error term μ. The estimation of Equation (3) with ordinary least squares can cause bias because of the possible correlation between the two error terms ($corr(\varepsilon, \mu) \neq 0$). In other words, a potential selection bias may occur when the unobservable factors (μ) of Equation (3) influence the unobservable factors (ε) of Equation (1). This selection bias problem is overcome in a randomized control trial design, in which women are assigned randomly to participant and control groups such that participation in the program is the only difference between participants and non-participants (Heckman and Vytlacil, 2005; Angrist and Pischke, 2009; Asfaw et al., 2012; Abdulai, 2016). However, women's participation in the BDL program is a non-random experimental design, and participants self-selected themselves into the program, which gives rise to a selection bias problem. In this case, propensity score matching, which is commonly used in impact assessment frameworks, can be used to address the selection bias problem. A major deficiency of this approach is that it fails to account for unobservable factors (Heckman et al., 1998; Abadie and Imbens, 2006). Another approach is the use of instrumental variables to assign individuals to participant and control groups using a two-stage estimation technique. However, the instrumental variable approach generates heteroskedastic residuals (Lokshin and Sajaia, 2004) that cannot allow consistent standard error estimation without cumbersome adjustments (Abdulai, 2016). Lokshin and Sajaia (2004) proposed using a full information maximum likelihood technique as a consistent solution. This approach overcomes the two-stage estimation and allows for the simultaneous estimation of the determinants (Equation 1) and impact (Equation 3) while accounting efficiently for both observable and unobservable factors. This estimation technique was implemented through endogenous switching regression (ESR).

Endogenous switching regression, developed by Lokshin and Sajaia (2004), was used in this study to estimate the determinants and impact of participation in the BDL program. This approach has been used in several empirical impact evaluation studies to address selection bias (Kassie et al., 2014; Kleemann et al., 2014; Alem et al., 2015; Debela et al., 2015; Mmbando et al., 2015; Abdulai, 2016). In the first stage, Equation (1) was estimated, and the determinant factors of participation in BDL were identified. In the second stage, Equation (3) was used to determine the impact of participation in BDL. Two separate regimes for participants and non-participants were specified as follows:

$$Y_1 = Z_1\beta_1 + \mu_1 \qquad \text{if } T_i = 1 \qquad (4a)$$
$$Y_0 = Z_0\beta_0 + \mu_0 \qquad \text{if } T_i = 0 \qquad (4b)$$

where Y_1 and Y_0 represent the income of the participants and non-participants, respectively. The variable Z is a vector of explanatory variables, β is a vector of model parameters to be estimated, and μ is the error term that is assumed to be normally distributed. The ESR structure is such that Equations (1) and (3) overlap and use the same list of explanatory variables, meaning that vectors X and Z contain the same list of variables. However, for estimation purposes, at least one variable, X, should be dropped from Z. The missing variable in the outcome equation acts as an identifying instrument (Di Falco et al., 2011). To be valid, it should influence the decision to participate in BDL but not directly influence the income. Institutional support, estimated by the number of years of partnership between Savings and Internal Lending Communities (SILC), was used as an instrumental variable. This variable was expected to influence participation in BDL but not directly the income. Conceptually, participation in the BDL program relates to its relationship with SILC. Vector Z in Equations (4a) and (4b) accounts only for selection bias due to observable factors. ESR uses an omitted variable problem framework to address selection bias due to unobservable factors. The inverse Mills ratios or selectivity terms (λ_1 and λ_0) from the selection equation and the covariance terms ($\sigma_1$and σ_0) are substituted into (4a) and (4b) to obtain Equations (5a) and (5b) as follows (Heckman, 1979):

$$Y_1 = Z_1\beta_1 + \sigma_{1\varepsilon}\lambda_1 + \epsilon_1 \qquad \text{if } T_i = 1 \qquad (5a)$$
$$Y_0 = Z_0\beta_0 + \sigma_{0\varepsilon}\lambda_0 + \epsilon_0 \qquad \text{if } T_i = 0 \qquad (5b)$$

where ϵ_1 and ϵ_0 are error terms with conditional zero means. The selectivity terms (i.e., λ_1 and λ_0) in Equations (5a) and (5b) are correct for selection bias owing to unobservable factors. The expected income of women who participated in the BDL program and the expected income of the counterfactual hypothetical cases in which participants did not participate can be predicted from the estimated model. The change in women participants' income due to participation in BDL can then be estimated by comparing expected income and their counterfactuals, as indicated in Table 1.

3.2. Survey design and data

This study was conducted in the regions of Maradi and Zinder in Niger (Figure 2). The Maradi region is in the south-central part of Niger. It covers an area of 41,796 km^2, and its population was estimated to be 206,414 inhabitants in 2012. Approximately 72% of the Maradi area is agricultural land, 25% is pastoral land, and 3% is forest land. Two types of climates were observed in the region: a Sahelian climate in the north, characterized by an average annual rainfall between 200 and 300 mm, and a Sahelo-Sudanese climate in the south, characterized by an average annual rainfall between 500 and 600 mm. The Zinder region is a desert located between 12°50' and 16°30' latitude north and 7°30° and 13° longitude east. It covers an area of 145,430 km^2 with an estimated population of 321,809 in 2012. The rainfall decreases from south to north, with an average of ∼425 mm.

BDL technologies were spread by CRS, an international NGO supported by the ICRISAT under a joint project. The survey was implemented in twelve districts, including nine districts in the Kantche region of Zinder and three districts in the Mayahi region of Maradi. The design of this study is shown in Figure 3. Two-stage selection sampling was used. At the village level, only villages with SILC groups were considered. Among the SILC villages, some women participated in the

TABLE 1 Conditional expectations and treatment effects.

	Participants' profile	Non-participants' profile	Treatment effects
Participants	(a) $E(Y_1 \mid T=1)$	(c) $E(Y_0 \mid T=1)$	ATT
Non-participants	(d) $E(Y_1 \mid T=0)$	(b) $E(Y_0 \mid T=0)$	ATU
Heterogeneity effects	BH1	BH2	TH

(a) and (b) represent the conditional expectations, and (c) and (d) represent the counterfactual hypothetical cases.

$(a) = X_1\beta_1 + \sigma_{\epsilon_1\varepsilon}\lambda_1$ (6)

$(b) = X_0\beta_0 + \sigma_{\epsilon_0\varepsilon}\lambda_0$ (7)

$(c) = X_1\beta_0 + \sigma_{\epsilon_0\varepsilon}\lambda_1$ (8)

$(d) = X_0\beta_1 + \sigma_{\epsilon_1\varepsilon}\lambda_0$ (9)

ATT = average treatment on treated [average effect of participation in BDL on participants (a-c)].

$ATT = E(Y_1|T=1) - E(Y_0|T=1) = X_1(\beta_1 - \beta_0) + \lambda_1(\epsilon_1\varepsilon - \epsilon_0\varepsilon)$ (10)

ATU = Average treatment on untreated [average effect of participation in BDL on non-participants (d-b)].

$ATU = E(Y_1|T=0) - E(Y_0|T=0) = X_0(\beta_1 - \beta_0) + \lambda_0(\epsilon_1\varepsilon - \epsilon_0\varepsilon)$ (11)

BH1 = heterogeneity effects for participants (a-d).

BH2 = heterogeneity effects for non-participants (c-b).

TH = (ATT – ATU), transitional heterogeneity.

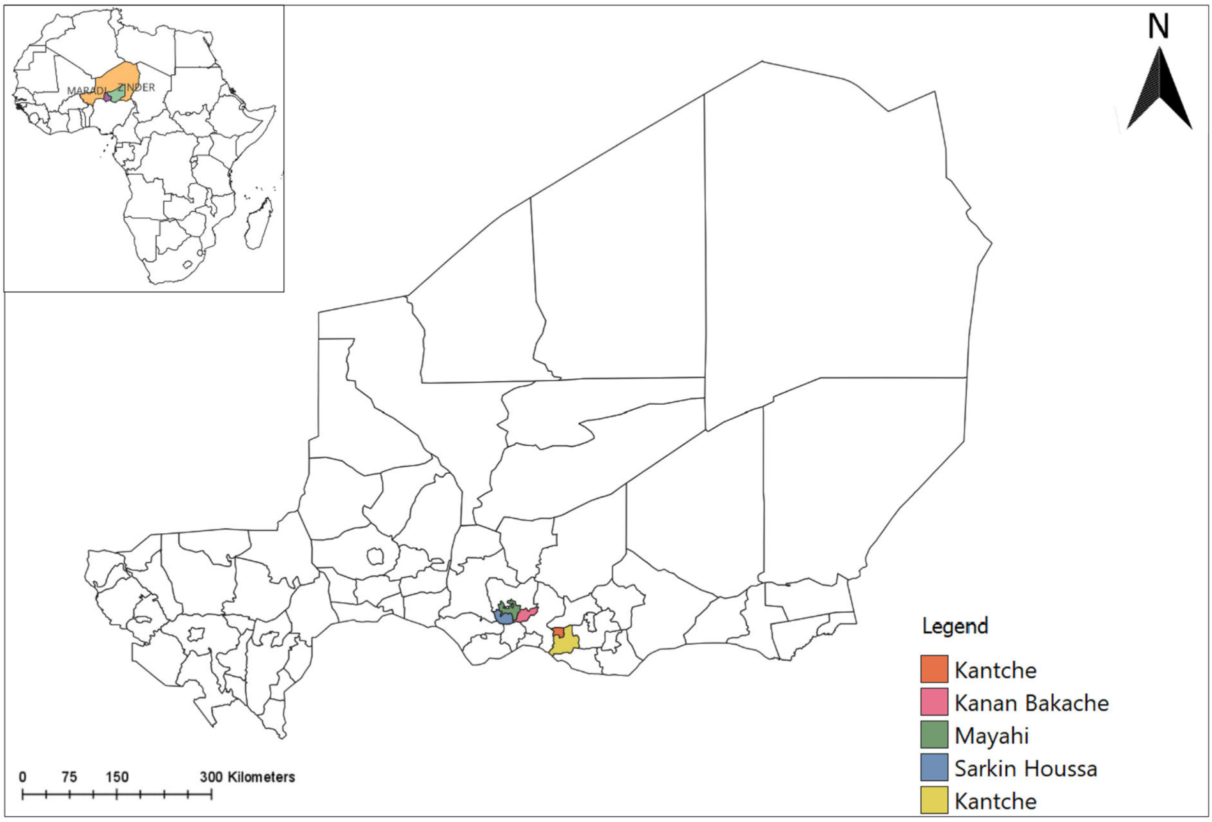

FIGURE 2
Study area.

BDL program, while others did not. A total of 27 villages were randomly selected, including twenty-five BDL villages and two non-BDL villages. Only women were targeted at the farm level. In total, 1,205 women farmers were randomly selected: 28% in the Maradi region and 72% in the Zinder region. The sample included 826 participants in the BDL program (69%) and 379 non-participants (31%). Among the non-participants, 333 were from BDL villages, and 46 were from non-BDL villages.

Data were collected in 2015 using focus group discussions with women's groups to identify and describe the technologies

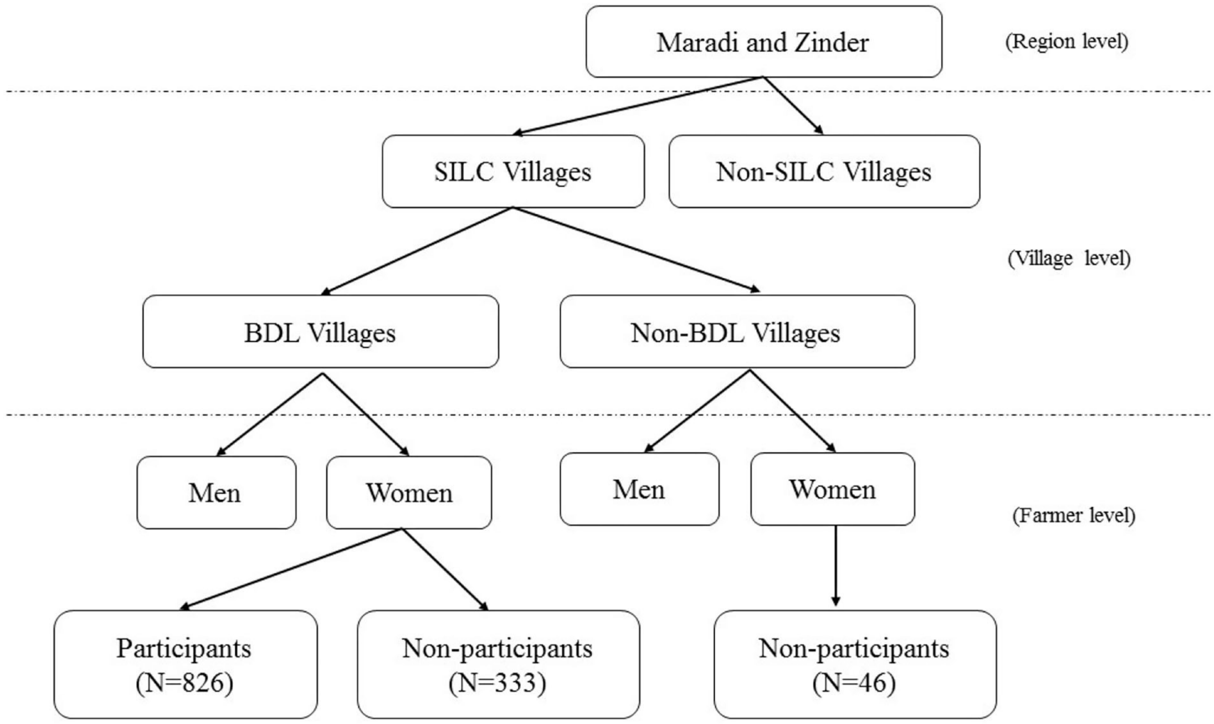

FIGURE 3
Research sampling design.

and evaluate the constraints and opportunities of BDL. In addition, individual questionnaires were used to collect socioeconomic and demographic data, as well as farmers' household livelihoods.

3.3. Outcome variable

A woman's annual income in FCFA[2] was used as a proxy for the women's welfare indicator. Income data were collected for the 12 months preceding the survey. It was self-reported by the respondents based on income from different income-generating activities per month and then aggregated to an annual scale. On average, participants in the BDL program received 77,039 FCFA per year compared to 80,732 FCFA for non-participants. This difference was not statistically different from zero.

3.4. Exploratory variables

Several paradigms based on factors influencing decision-making have been used in the literature to explain farmers' decisions to adopt new agricultural technology (Negatu and Parikh, 1999; Moumouni et al., 2013). Three categories of factors are likely to influence the decision to adopt new agricultural technologies: the characteristics of the technology, the characteristics of farmers and their households, and economic and institutional factors. In this study, we combined household characteristics, economics, and institutional factors to explain the decision to participate in BDL and the impact assessment. The independent variables used in the models are listed in Table 2. For convenience, the variables were classified into five categories, namely, participant characteristics, household characteristics, household welfare, institutional support, and location.

Table 2 shows that participants and non-participants are statistically different on five characteristics, including household size, income before participation in the BDL program, number of livestock (chickens) in the household, and relationship with SILC. On average, there were eight persons in participant households against seven in non-participant households. Before the implementation of the BDL program, non-participant households had more FCFA 12,630 in annual income than participant households. In addition, on average, there was one more livestock (chicken) in non-participant households than in participant households. Participants had a long-term relationship with SILC: 6 years of collaboration against about 1 year for non-participants. About 21% of participants lived

2 US$1 = 588.23 in 2015.

TABLE 2 Data description.

Variable	Participant		Non-participant		
	Mean	SD	Mean	SD	Difference
Outcome variable					
Income after BDL (FCFA[a])	77,039	147,730	80,732	119,164	−3,693
Participants characteristics					
Age of participant	37.11	12.80	35.79	13.42	1.3
Education (years of schooling)	0.84	1.60	0.72	1.37	0.13
Household characteristics					
Sex of household head (dummy, one for female)	0.94	0.25	0.92	0.28	0.02
Age of household head (years)	48.71	13.54	47.85	14.70	0.86
Household size (number of persons)	8.35	7.35	7.37	5.13	0.98**
Number of women in the household	1.64	2.52	1.50	1.61	0.14
Household wealth					
Income before BDL (FCFA[a])	50,643	86,198	63,275	104,109	12,631**
Available area for the household (ha)	0.91	2.73	1.05	1.31	0.13
Number of sheep	0.83	1.47	0.89	1.60	0.06
Number of chickens	2.08	4.02	3.21	6.26	1.13***
Institutional support					
Number of years of collaboration with SILC and PASAM	6.28	2,69	0.63	2.79	5.64***
Location					
Living in Maradi region (dummy, one for Maradi)	0.21	0.41	0.44	0.50	0.23***

***Indicates significance at 1% level.
**Indicates significance at 5%.
[a]US$1 = 588.23 in 2015.

in the Maradi region. The proportion of non-participants in that region was two times than that of participants. These five variables are included in the model to control for selection bias.

4. Results

The section 4.1 highlights the model specification and validity test. The section 4.2. presents the determinants of participation in land-enhancing technology, and finally, the impact of BDL participation is discussed in more detail.

4.1. Model validation

Table 3 presents the results of the selection and outcome equations jointly estimated using the full information maximum likelihood approach.[3] Selection equation (Equation 1) is reported in column 1, while the outcome equations of participants (Equation 4a) and non-participants (Equation 4b) are shown in Columns 2 and 3, respectively. As indicated in the conceptual framework, at least one variable of the selection equation should be removed from the outcome equation for estimation. The Institutional support variable, shown by the number of years of collaboration between SILC, is conceptually relevant as an instrumental variable in the selection equation. This variable significantly affects the decision to participate in the BDL program, but there is no significant relationship between this variable and the income model. In addition, the sex and age of household heads are not statistically significant in outcome equations, and they negatively affect the stability of the model. This implies that these variables were consistently estimated in the other explanatory variables (Wooldridge, 2010) and were removed from the selection equation accordingly.

The likelihood-ratio tests for joint independence of the three equations indicate that the null hypothesis of no correlation between selection and outcome equations was rejected at a 1% level of significance. The selection and outcome equations are highly dependent and must be estimated jointly. The

3 The full information maximum likelihood was estimated using command *movestay* of Lokshin and Sajaia (2004).

TABLE 3 Full information maximum likelihood estimation of endogenous switching regression.

Variables	Participation to BDL (Equation 1)		Income of participants (Equation 4a)		Income of non-participants (Equation 4b)	
	Coef.	SE	Coef.	SE	Coef.	SE
Income before BDL (FCFA)	0.00***	0.00	1.21***	0.16	0.78***	0.20
Household size (number of persons)	0.03***	0.02	1,335.99	661.04	−1,463.88	390.71
Education level (number of years of schooling)	0.11	0.08	1,641.42***	91.86	616.74	1,419.48
Available land area for the household (ha)	0.10	0.09	−1,882.77**	987.05	−7,194.5***	1,867.12
Age of participant (years)	0.02***	0.01	98.90	158.36	83.42	125.47
Living in Maradi region (dummy, one for Maradi)	−0.64***	0.10	996.13	3,824.64	−6,221.59	3,789.82
Number of sheep in the household	0.01	0.02	−608.86	1,570.55	3,050.92***	171
Number of chicken in the household	0.00	0.00	−34.91	69.93	1,353.70	1,697.21
Number of women in the household	−0.12***	0.04	−1,139.99	119.50	4,855.93***	993.14
Number of children under 5 years old	−0.01***	0.00	1,646.66	3,334.04	1,828.55	2,291.80
Sex of household head (dummy, one for male)	−0.53***	0.09				
Age of household head (years)	−0.02**	0.01				
Institutional support (number of years of collaboration with SILC)	0.65***	0.12				
Constant	−1.34***	0.09	−8,165.9***	1,394.41	27,273.6***	5,586.74
$\ln\sigma_1$			11.56***	0.01		
ρ_1			0.79***	0,03		
$\ln\sigma_2$					11.04***	0.00
ρ_2					−0.00	0.05
Log likelihood: −14,096.76						
Wald test of independence equations: $\text{Chi}^2(1) = 168.63$***						
Number of observations = 1,089						

***, **Indicate significant level at 1 and 5%, respectively.

correlation coefficient rho (ρ) between the selection equation of the BDL program and the income equation for participants was statistically significant. This indicates that selection bias due to unobservable factors in participation in the BDL program, and the use of ESR, which accounts for both observable and unobservable factors, is relevant and appropriate for this study (Lokshin and Sajaia, 2004). The positive sign of ρ_1 between the equation selection and participant income suggests a negative selection bias. In other words, women with higher incomes are less likely to participate in the BDL program. Coefficient ρ_2 between the selection equation and the non-participants equation is negative, null, and non-significant, suggesting that non-participants are better off in their non-participant status. Hypothetical participation in the BDL does not improve actual non-participant income. A non-participation regime is best for non-participants.

4.2. Determinants of participation in BDL program and income

Following Abdulai (2016), the results of Equation (1) in Column 1 of Table 3 can be interpreted as a normal probit. A total of nine factors were found to be determinants of participation in the BDL program. Specifically, income level before participation in BDL, household size, age of participants, location, number of women in the household, number of children under 5 years old, sex of household head, age of household head, and institutional support are factors that explain participation in this land-enhancing program. The coefficients of institutional support, age of participants, household size, and income level before the BDL program positively affected participation in the program. In other words, these variables increase the probability of women participating in the use of land-enhancing technologies. In contrast, the number of women in the household, number of children under 5 years old, living in the Maradi region, sex, and age of the household head negatively affected participation and likely reduced the probability of women participating in the BDL program. Living in the Maradi region or in a household headed by a woman limits the likelihood of participating in the BDL program. Similarly, the probability of participating in BDL decreases when the number of women present in the household, children under 5 years old, or the age of the household head increases.

Regarding the income impact results of Equations (4a) and (4b) in Table 3, two similarities and three differences can be observed between the participant and non-participant models. In terms of similarity, income before BDL has a positive and significant coefficient, both in Equations (2) and (3). Similarly, the land area available for the household has a negative and significant coefficient in Equations (2) and (3). In terms of the difference between the two equations, the number of years of education positively affects the income of participants but has no effect on non-participant income. The number of chicken heads and the number of women in the household positively affected the income of non-participants but did not affect participants' income.

4.3. Impact of participation in BDL program on income

Table 4 presents an estimation of the impact of participation in BDL on women's annual income. This table contains four key pieces of information such as the conditional income of participants and non-participants, counterfactuals for participants and non-participants, treatment effect on participants (ATT) and non-participants (ATU), and treatment effect in the percentage of potential outcome mean (POM).[4] On average, women participating in the BDL program have about 75,353 FCFA (US$151).[5] If participants had not participated in the BDL program, they would have an average annual income of 66,065 FCFA (US$132). Therefore, there is a difference of 9,288 FCFA (US$19), which is a consequence of participation in the BDL program. This gain represents an annual income increase of 14% due to participation in the BDL program. For non-participants, the average annual income was 77,482 FCFA (US$155). If the non-participants had participated, their average income would be 59,114 FCFA (US$118). This represents a loss of 18,368 FCFA (US$37). In other words, if the non-participants had participated in BDL program, their income would have been reduced by 31%, suggesting that non-participants are better off in their current situation.

4 Treatment effect in percentage of POM = impact (income gain due to participation)/the potential income she would obtain if she did not participate in BDL program.

5 US$1 = 499 FCFA during the period of the study in 2015.

TABLE 4 Income conditional expectation and effects of participation in BDL.

	Participant women	Non-participant women
Income with participation (FCFA[a])	75,352.84*** (3,732.49)	59,114.16*** (6,973.23)
Income with non-participation (FCFA[a])	66,064.82*** (2,517.75)	77,481.74*** (4,148.80)
ATT (FCFA[a])	9,288.02*** (1,580.7)	–
ATU (FCFA[a])	–	−8,367.61*** (3,629.44)
Treatment effects (% of POM)	14.06	−31.07

***Significant, respectively, at 1, 5, and 10%.
Robust standard error in parenthesis.
POM stands for potential outcome mean.
[a]US$1 equaled 588.23 FCFA in 2015.

5. Discussion

The objective of this study was to analyze the determinants and impact of participation in a BDL program on rural women's income. Land-enhancing technology has targeted only rural women in degraded land areas in Niger. The decision to participate in the program was voluntary. The findings indicate that, *ceteris paribus*, the likelihood of participating in the BDL program is positively and significantly correlated with institutional support, age of participants, household size, and annual income before participation in the program. In contrast, the number of women in the household, the number of children under 5 years old living in the Maradi region, sex, and age of the household head negatively and significantly influenced the decision to participate. Previous studies on the determinants of the adoption of agricultural technology have shown the importance of institutional support in adoption decisions. By analyzing factors influencing the adoption of land-enhancing technologies in the same country, Niger, Baidu-Forson (1999) concluded that improving technical support, which demonstrates the risk reduction capacities of land-enhancing technologies, stimulates the adoption of these technologies. Mazvimavi and Twomlow (2009) conducted a similar study in Zimbabwe and reported the significant influence of institutional support on the adoption intensity of land-enhancing technologies. NGO staff have become an important source of technical support in promoting technology and working closely with farmers.

The relationship between rural farmers' ages and the adoption of new agricultural technologies is not constant in the literature. Previous studies have reported the negative impact of farmers' age on the adoption of land-enhancing or conservation technologies (Baidu-Forson, 1999; Abdulai, 2016). The trend is such that one can infer that older farmers are less willing to adopt improved land-enhancing technologies. This effect can also be mixed, as concluded by Lapar and Pandey (1999), who studied the adoption of upland soil conservation technologies in the Philippines. The special case of women in the adoption of land-enhancing technologies has not yet been discussed in the literature. In this study, both the age of the household head and the age of the women participating were used in the estimations. The effect of the age of the household head is negative, significant, and consistent with the literature. Regarding the age of the participants, the likelihood of participation in the BDL program increased when the participant's age increased. This result can be explained by the fact that farmers become more skillful, through learning-by-doing, and more risk averse as they become older (Mazvimavi and Twomlow, 2009).

A negative and significant relationship between the sex of the household head (male) and the likelihood of participating in the BDL program was found, which is in line with previous studies. Mazvimavi and Twomlow (2009) concluded that male-headed households were more likely to adopt technology. The most convincing explanation for the results of this study can be deduced from Ahmed et al. (2009) and Ahmed et al. (2014). Ahmed et al. (2014) showed that the welfare of women and girls within a rural household depends on the sex of the household head. The welfare of women and girls may be lower than that of their male counterparts in households headed by men. Less food and lower-quality food consumption have been reported for women in households headed by men (Ahmed et al., 2009). Thus, the livelihood of women living in female-headed households is better than those living in male-headed households. This finding justifies why women in female-headed households are less willing to participate in the BDL because they are less needy. In addition, female household heads in rural areas of sub-Saharan Africa are relatively old (57 years old in this study) and generally widowed (67% in this study). In addition, it is uncommon to find many adult females in female-headed households. Thus, female-headed households have one adult woman in general who is old and not open to participate in an agricultural innovation program like BDL.

The location of farmers is important in the decision-making process to adopt land-enhancing technology. This study revealed a significant relationship between the location and the likelihood of participating in the BDL program. Living in the Maradi region reduces the probability of participating in the BDL program, while living in the Zinder region increases the probability of participating in the BDL program. Baidu-Forson (1999) indicated that the probability and intensity of the adoption of land-enhancing technologies are likely to be high in locations that have large percentages of degraded farmlands. This is the case in the Zinder region, where land degradation is an important challenge for enhancing land productivity (Fatondji et al., 2013). Another relevant factor for participating in the BDL program is household size. The effect on the decision to participate in BDL was positive (Table 3). In addition, the number of children under 5 years of age had a negative and significant effect on the likelihood of women participating in the BDL program. The number of children under 5 years of age is then a limiting factor for women's participation in the BDL program, as women are responsible for taking care of children. This finding extends the existing literature on the determinants of new agricultural technology in general and land-enhancing technologies. This suggests that land-enhancing technologies may not target women who have children under 5 years of age unless special arrangements are made to give them time to take care of their children.

Although this study, to the best of our knowledge, is the first attempt to estimate the economic impact of the BDL program and the impact of land-enhancing technology exclusively on women's welfare, some previous studies have already provided an overview of the results trend. Similar studies have reported a positive impact of the use of land-enhancing technologies on the livelihoods of users. Moussa et al. (2016) analyzed the economics of land degradation and improvement in Niger and concluded that every US dollar invested in taking action returns about US$6. Abdulai (2016) estimated the impact of the adoption of conservation agriculture technology in Zambia and found that the adoption of this technology contributed significantly to the reduction of household poverty. Regarding the findings on the impact of participation in BDL in this study, the following three main results were obtained: participation in BDL has a positive impact on participants' income (+14%); non-participants had no interest in participating as they would lose 31% of their income; and the impact of participation in BDL widely varies across regions. Non-participants were relatively richer than participants. For example, before the advent of BDL, the income of non-participants was higher than that of participants by 25% (Table 2). In addition, non-participants had more livestock than participants. Therefore, it can be inferred that BDL is a pro-poor technology that is not beneficial to all women farmers. This study makes a critical contribution to the literature on land-enhancing technologies. It suggests that the impact of land-enhancing technologies, such as BDL, is closely linked to spatial, economic, environmental, temporal, and cultural contexts (Sallu et al., 2010; Orchard et al., 2017). Accordingly, land-enhancing technologies should target locations that have large percentages of degraded farmlands (Baidu-Forson, 1999) and the poorest farmers.

6. Conclusion and policy implications

In the dryland areas of Sub-Saharan African countries, land degradation is a major constraint that leads to a reduction in arable land availability, a decline in agricultural productivity, and, consequently, a rise in poverty. Niger is one of the most affected countries in West Africa, where most of the rural population depends heavily on agriculture and livestock for income. Women farmers are the most vulnerable to poverty because of their limited access to land for farming. The BDL technology was introduced in 2013 to restore degraded land and make it available for women to contribute to their empowerment. This study investigated the adoption of this technology and its impact on women's purchasing power. To control for observed and unobserved factors, ESR was used to estimate the participation effect.

The findings show that factors including institutional support, age of participants, and household size positively affect the likelihood of women using the BDL technology. In contrast, factors such as the sex of the household head, age of the household head, location (Maradi region), and the number of children under 5 years old tend to reduce the probability of using the technology. Furthermore, it was shown that adoption of the technology led to an income increase of 14% for users, while non-users (less poor than users) would lose about 31% of their income in the case of adoption. In addition, the impact of adopting BDL technology varies across locations.

This study has two main policy implications. First, land-enhancing technologies, in general, and BDL technology should not target women who are caregivers of children under 5 years of age unless special arrangements are made to give them time to take care of their children. Taking this recommendation into account would stimulate the adoption of land-enhancing technologies by women. Second, land-enhancing technologies should target locations with large percentages of degraded farmlands, especially those of the poorest rural farmers. Since land-enhancing technologies may have a dynamic impact, an area of further study would be the use of panel data to capture the change across years.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

AS: conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft, and writing—review and editing. JQ: conceptualization, data collection, and coordination. AB: methodology, software, validation, formal analysis, data curation, and writing—original draft. JL: methodology, validation, formal analysis, and writing—original draft. DF: conceptualization, data collection, and technology implementation. LD: formal analysis, data curation, and writing—original draft. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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