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Effects of circular agriculture practices on the profitability of maize in Nakuru County, Kenya.

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Abstract
Circular Agriculture practices have become the most effective strategies for enhancing profitability and economic sustainability. The agriculture sector can embrace circularity through the use of farming practices such as mixed crop-livestock, organic, and intercropping. However, there is limited information on the profitability of these farming practices within the context of circular agriculture. To fill this gap, this research examined the effects of circular agriculture practices on the profitability of maize in Nakuru County, Kenya. The data was collected through face-to-face interviews using a semi-structured questionnaire. We analyzed this data using gross margin analysis and multinomial logit. Using a multinomial endogenous switching regression model, significant variables such as age, farm size, household size, education, experience in farming, land tenure, information access, group membership, and access to credit facilities influenced the uptake of a choice of circular agriculture practices among smallholder farmers. The results for the gross margin analysis show that most of the circular agriculture practices were profitable. Furthermore, a combination of intercropping and mixed farming was the most profitable. The results for ATT and ATU were positive and negative, suggesting that some smallholder farmers achieved higher gross margins while others experienced losses depending on the circular agriculture they adopted. The average Treatment of Treated results indicate an income effect of 2176.01KES/acre for the adoption and implementation of a combination of mixed farming and intercropping followed by intercropping with 731.55KES/acre. Thus, it follows that farming experience, farm size, group membership, and access to credit have a significant influence on the uptake of circular agriculture practices. In addition, practicing a choice of more than one circular practice option can yield a higher gross margin for smallholder maize farmers. Therefore, this study recommends that agricultural policymakers should set comprehensive policies that target all age groups of farmers, ensure land entitlement, promote farmer group participation, provide training to farmers, and provide credit facilities that support circular agriculture farming.
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1. Introduction

At a time when the population is increasing rapidly, many countries are contributing to unsustainable patterns of resource extraction, production, and consumption. This reliance on the linear economic model by most organizations is likely to result in ecosystem disturbances (Ghisellini *et al*., 2020). In a linear economic model, raw materials are extracted and then converted into usable products until they are finally discarded as waste in the environment without recycling (Ellen MacArther Foundation, 2013). Each year, tons of raw resources are harvested and utilized worldwide, with minimal recycling efforts (Oberle *et al*., 2018). This model of use of resources does not bear in mind the demands of the future (Ellen MacArther Foundation, 2013). These reckless and inefficient uses of resources have severe consequences for the environment and human life, and such widespread use of finite resources is not economically feasible (CSIRO, 2021).

Furthermore, it restricts an ecosystem's ability to support living organisms. A transformation is necessary to minimize the loss of resources and to restore the ecosystem (Hassan *et al.,* 2019). As a result, a circular economic approach has been suggested as a prospective way of replacing the linear economic model and to ensure the sustainability of the ecosystem. In a circular economy, resources that could be discarded are instead reused, recycled or reprocessed within a closed-loop system (Koszewska, 2018). Additionally, this economic model allows the production of inputs resources from material previously perceived as waste. With this strategy, circularity of natural fibres, plants, animal by products and any biodegradable materials is guaranteed (WEF, 2021).

The principles of circular economy can be effectively integrated into a food system within the agribusiness sector. Moreover, circularity within the agriculture sector offers promising strategies for enhancing resource efficiency in the usage of resources and minimizing harm to the environment (Kuisma & Kahiluoto, 2017; Stegmann *et al*., 2020). It also offers a cycle that ensures, return, renewal, and reuse of agricultural waste, thereby lowering production costs. Furthermore, the implementation of circular economic practices in agriculture offers a practical solution to the challenge faced by smallholder farmers who are resource constrained and unable to afford production inputs. The idea of circular practices in agriculture ensures closed nutrient loops, reduces the need for external inputs, and reduces the environmental effect of discharges and runoff (FAO, 2021). Organic farming, intercropping, and mixed crop-livestock are examples of how the agriculture sector can implement circular principles.

These farming practices prioritise minimal reliance on external inputs while optimizing the utilization of available resources (Helgason *et al*., 2021). Through mixed crop livestock farming, an interconnected resource flow and a symbiotic relationship between farm enterprise is offered (Ellen MacArther Foundation, 2021). The integration of crop cultivation and animal husbandry enhances economic efficiency by promoting cost sharing between the two enterprises. In this context, utilization of organic manure from animal husbandry can reduce the need for inorganic fertilizers, thus reducing overall farm expenses. In mixed farming circularity, livestock waste can be repurposed as fertilizer in crop production. In addition, crop remains are used as feed for livestock production. This vital exchange of resources occurs repeatedly, establishing a circular flow, that ensure minimal waste. (Helgason *et al.,* 2021). Such practices minimize the use of external inputs, therefore promoting the use of local resources (Rayns *et al*., 2021). Furthermore, mixed crop and livestock farming tend to generate profitability by using locally available inputs (Ryschawy *et al*., 2014). According to Bell *et al*. (2021) the growing of crops and the rearing of animals reduces risks associated with market fluctuations.

Moreover, circular agriculture practice, such as intercropping can help smallholder farmers to use resources wisely, and to improve productivity. By growing more than one crop on the same piece of land farmers are able lower production costs and ensuring high productivity. A key advantage of intercropping is that plants can share water and nutrients for growth, thereby ensuring efficient use of resources. Furthermore, with intercropping farmers can save cost in production and maximize returns (Guo *et al*., 2006; Ngwira *et al*., 2013). Crops grown together in an intercropping system can increase climate resilience by promoting efficiency in form space, nutrient usage, and water usage. Another important aspect of circular agriculture, also considered an alternative to linear farming, is organic farming. Organic farming practices aim at reducing the amount of inorganic input used in farming. (Helgason *et al*., 2021). In addition, practicing organic farming offers rural employment opportunities as it necessitates a higher labour input (Finley *et al*., 2017; Helgason *et al*., 2021). These farming practices that apply circular principles empowering smallholder farmers through profit maximization, which is promising and necessary for sustainability. Additionally, circular agriculture presents an appealing solution to the employment challenges impacting mostly youths and woman (Helgason *et al*., 2021).

Additionally, circular agriculture ensures that local biodiversity is also protected as the farm use local resources reducing the need for expansion into virgin land (Ellen MacArther Foundation, 2021). Practises associated with Circular agriculture such as mixed farming, organic farming, and intercropping can yield high profitability while simultaneously promoting sustainability in business (Gunes & Guldal, 2019). Additionally, these circular practices ensure the resilience of business model resilience in case of strong seasonal price fluctuations. While circular farming has the potential to reduce production costs, it also contributes to environment protection (Abad-Segura *et al*., 2020; Valverde *et al*., 2021; Helgason *et al*., 2021). Circular economy activities contribute to multiple objectives, such as increasing net profit, income generation, strengthening financial stability through diversification, and using internal inputs (Mitrofanenko *et al*., 2021).

The commitment to advancing circular agriculture is even higher in Kenya, where the government and other NGO are implementing programs to support circular agriculture (Netherlands Enterprise Agency 2021). In support of circular agriculture, the government of Kenya, in partnership with other NGOs such as with Kenya Organic Agriculture Network (KOAN), has trained and provided extension services to around 5000 farmers in Nakuru County to promote circular agriculture practices. Although most governments are supporting the transition to a circular economy in the agriculture sector, they have not provided guidance on the profitability of most of these circular agricultural practices, and yet this is one of the primary motivating factors that can encourage farmers to uptake circular agriculture. Furthermore, existing information on circular agriculture have focused much on environmental sustainability (Sun and Li, 2022, Helgason *et al*., 2021, Mitrofanenko, et al 2021) often overlooking the agribusiness aspect of these principles. To trigger the widespread adoption of circular agricultural practices among smallholder farmers, information regarding the profitability of circular

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agriculture practices to smallholder farmers will have to be categorically spelled out. Additionally, comprehensive information on circular agriculture will help the government of Kenya and other nations to come up with polies that support circular agriculture

2. Materials and Methods

2.1 Study Area

The study was conducted in Nakuru County. The study area is dominated by smallholder farmers that rely on farming as their source of livelihood. The county is situated along the longitudinal coordinates of 35°28' and 35°36' east and the latitudinal coordinates of 0°13' and 1°10' south. The county has a total of 11 sub-counties, which are Njoro, Naivasha, Gilgil, Nakuru Town West, Bahati, Molo, Rongai, Subukia, Kuresoi South, and Subukia. In addition, the county has a total of 55 wards. The main agricultural activities that take place in the county include cash crop farming, food crop cultivation, fish farming, animal production, and beekeeping. With these activities, smallholder farmers generate income and ensure food security for the county. Additionally, in Nakuru county, the designated land area for food crops is 243,711.06 hectares, while the area allocated for cash crops is 71,416.35 hectares. Most smallholder farmers in the county have a land size below 0.8 hectares (CIDP, 2018-2022). One of the goals of the county government is to improve productivity by supporting smallholder farmers and creating market linkages.

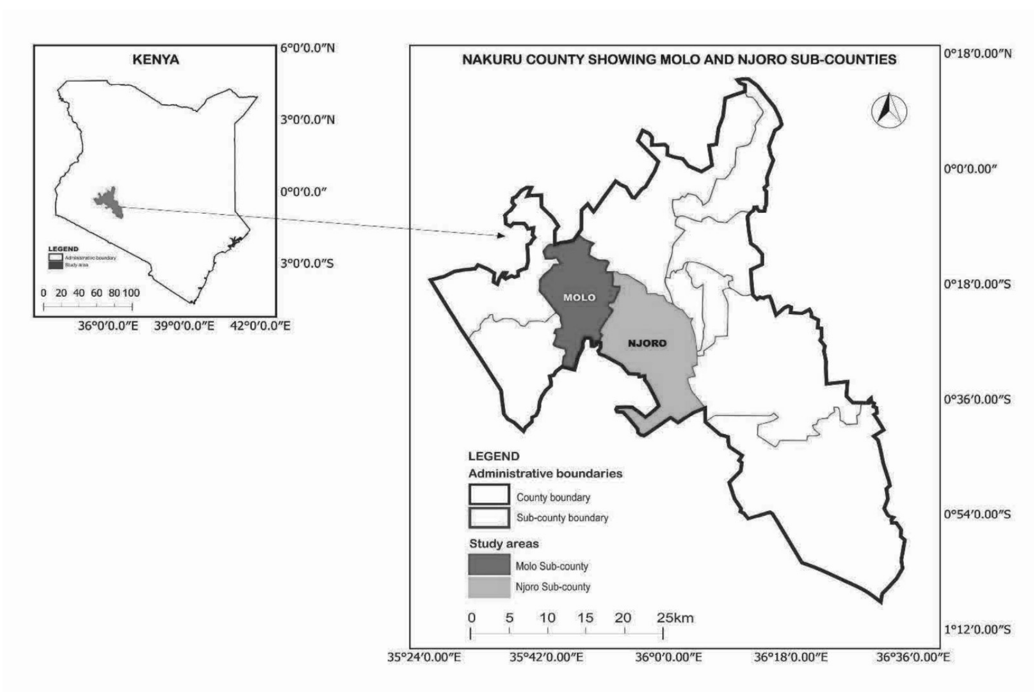

Figure 1: Map of the Study Area

2.2 Sampling Design

A sample of respondents for the study was determine using, a multistage sampling technique. First of all, Nakuru County was purposively selected because 60% of the population within the county is involved in agriculture (both crop and animal husbandry). Furthermore, smallholder farmers in Nakuru County have not fully incorporated circular agriculture practices. In addition, Kenya Organic Agriculture Network (KOAN) and other organizations have trained and provided extension services to around 5000 farmers in Nakuru County towards the promotion of circular agricultural practices. Second, two sub counties Njoro and Molo, characterized by the highest number of farmers, were purposefully selected. Thirdly, systematic sampling in each sub-county follows, the Kth sampling interval list provided by the sub-county agricultural officer.

. $K = \frac{N}{n}$ K- is the sampling interval. N – is the total number of farmers in the cluster n- is the sample size in each Cluster.

2.3 Sample design and Data sources

Primary data was used. In the collection of primary data, semi-structured questionnaires were directly administered to the smallholder farmers in the study area. Questionnaires consisted of all closed and open-ended questions. The researcher used semi-structured questionnaires to allow the respondents to elaborate on specific issues related to circular agricultural practices and omit or add any aspect of the pre-planned questions. This format allowed for a more open and flexible approach, which allowed the researcher to explore areas that may not have been considered during the planning stages. The study used gross margin analysis with a multinomial switching endogenous equation to determine the effects of circular agriculture practices on the profitability of maize farming in Nakuru County.

2.4 Gross Margin Model specification

The gross margin analysis is an important analytical tool used to assess the profitability of different farming practices. A gross margin analysis was used to determine the profitability of different circular agriculture practices. Gross margin is a measure of the economic return on investment in a product or service. It can be calculated by subtracting the difference between the value of output and the total variable costs. Furthermore, the analysis can be used to evaluate the performance of a crop under different farming practices. Gross margin is the difference between income from circular practices and variable costs incurred in production. For each specific case, costs, prices, and managerial assumptions are made. Gross margin analysis for the maize produced under mixed farming, organic farming, and intercropping was calculated. The gross margin was calculated using the following model:

$$\prod i = \sum_{i-1}^{i=n} PyY - \sum_{i-1}^{i=n} PxX \text{ ....Equation 1}$$

where; $\prod i$ = Profit and loss (gross margin) P*y* = Price of output of maize sold

Y = Quantity of output of maize crop produced

$\sum_{i-1}^{i=n} PyY$= Total benefits from the sales of maize produced

$Px =$ Cost of inputs in production.

X = Quantity of inputs in production

$\sum_{i-1}^{i=n} PxX =$ Total costs incurred by the farmer in maize production.

2.5 Multinomial endogenous switching regression Specification

A multinomial endogenous switching regression model was used to determine the effect of circular agricultural practices on smallholder farmers' profitability in Nakuru County, Kenya. The model permits the determination of choices of circular farming practice and the impact of choices on profitability with provision for self-selection correction and addressing the endogeneity problem arising from factors that can only be observed indirectly. Multinomial endogenous switching regression allows controlling for observed and unobserved heterogeneity associated with the single practice of circular agriculture.

The multinomial endogenous regression model follows two steps: the multinomial adoption selection model and the multinomial endogenous switching regression model. A multinomial adoption selection model was used in this first stage of evaluating the impact of circular agriculture practices on smallholder farmers' profitability. In this assumption, smallholder farmers aim to maximize their profit. U_i, by comparing different circular agriculture practices *m* and finding one that benefits them most in terms of revenues and income. In this case, the requirement for smallholder farmer *i* is to select any choice of agriculture circular practice, *j*, over any alternative circular practice *m is that.* $U_{ij} > U_{Im}$ and m≠j or equivalently $\Delta U_{im} = U_{ij} - U_{im} > 0$ and m≠j. The expected profit, U_{ij}^*, that the smallholder farmer derives from the use of practices *j* is a latent variable determined by observed characteristics (X_i) and unobserved characteristics (ε_{ij})

$U_{ij}^* = X_i\beta_j + \varepsilon_{ij}$ ………………………………………………………. Equation 2

X_i will represent observed exogenous variables and ε_{ij} will represent unobserved characteristics. Let (*I*) be the index that represents farmers' choice of circular Agriculture practice, such as:

$$1=\begin{cases} 1 iff U_{i1}^* > \max(\ ) \; or < 0 \\ \quad m \neq j \\ \qquad\qquad for\ all\ m \neq j \\ j\ iff U_{ij}^* > \max(U_{im}^*) or\ \eta_{ij} < 0 \\ \quad m \neq J \end{cases}$$ ………………….Equation 3

where $\eta_{ij} = max_{m\neq j}\ (U_{im}^* - U_{ij}^*) <0$. The equation number implies that if practice *j* yields a higher expected profit than any other packages then the ith farmer will adopt circular practice *j* to maximize his expected profit (Bourguignon *et al*., 2007). $m \neq j$, that is, if $\eta_{ij} = \max\left(U_{ij}^* - U_{im}^*\right) > 0$. With the assumption that ε is independently distributed, the probability that farmer I with characteristic x selecting practice *j* can be represented by a multinomial logit model (Mcfadden, 1973).

$$P_{ij} = pr\left(\eta_{ij} < 0X_i\right) = \frac{\exp(x_i\beta_j)}{\sum_{m=1}^{J}\exp(x_i\beta_m)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

In the second stage a multinomial endogenous switching regression model was used a multinomial endogenous switching regression model was used to determine the effects of circular agricultural practice on smallholder farmer's income using the Average Treatment of the treated (ATT). It was assumed that smallholders face *j* regimes with the best categories for the non-use of circular agricultural practice denoted by *j* =0. Each farmer uptake at least one or more circular agriculture practices *(j* = 1, …, 3). The result Equation for each possible regime j is specified as follows:

$$\begin{cases} \text{Regime } 1 := Z_i\alpha_i + \quad u_{i1} \text{ if } 1 = 1 \\ \qquad\qquad \vdots \\ \text{Regime J}: \; Q_{iJ} = Z_i\alpha_i + u_{iJ} \text{ if } 1 = J \end{cases}$$ …………………………………...Equation 5

Q_{ij} represented the outcome variable of the *ith* smallholder farmers in the regime j, and the error term (u's) are distributed with $E\ (U_{ij}|XZ) = 0$ and var ($U_{ij}|X,z)=Q_j^2$. Q_{ij} is observed if practice *j* is used which occurs when $U_{ij}^* > \max\ (U_{IM}^*)$. If the ε's and u's are not independent, OLS estimates in Equation 5 will be biased. Consistent estimation of αj requires the inclusion of the selection correction terms of the alternative packages in Equation 5. The DM model assumes the following linearity assumption:

$E9(\ U_{IJ}\ \varepsilon_{i1} \ldots\ldots\ldots.. \varepsilon_{ij}) = \ Q_j \sum_{m\neq j}^{J} r_j\,(\varepsilon_{im-} E\,(\varepsilon_{im}))$………………………Equation 6[th]

$\sum_m j$ =1rj=0 (by construction of the correlation between u's and $\varepsilon's$ sums to zero). Based on this assumption the multinomial ESR in Equation 5 can be represented as:

$$\begin{cases} Regime\ 1: \; Q_{il} = Z_i\alpha_1 + \sigma_1\lambda_1 + \omega_{il}\ if\ \ I\ = 1 \\ \qquad\qquad \vdots \\ Regime\ J\ Q_{ij} = Z_i\alpha_J + \sigma_J\lambda_j + \omega_{ij}\ \ if\ I = J \\ \qquad\qquad \vdots \end{cases}$$ ……………………………..Equation 7

Where σ_j is the covariance between u's, $\varepsilon' s$, and λ's represents the inverse Mill Ratio computed by estimating the probabilities of equation 4. Where ρ indicates the correlation coefficient of the error term and it is expected to be a zero. Based on the multinomial choice selection, there are J-1 selection correlation terms for each alternative circular practice. The standard error in Equation 5 accounts for heteroscedasticity arising from the regressor (λ_j). ATT can be computed in the actual and counterfactual scenarios as given in Equation 6: Adopters with adoption (actual adoption observed in the sample):

$$\begin{cases} E(Q_{i2} \mid 1 = 2) = Z_i\alpha_2 + Q_2\lambda_2 \\ \vdots \\ E(Q_{ij} \mid 1 = J) = Z_i\alpha_J + \sigma_J\lambda_J \end{cases}$$ ……………………………………….Equation 8

Counterfactual (Adopters had they believed not to adopt)

$$\begin{cases} E(Q_{i1} \mid 1 = 2) = Z_i\alpha_1 + \sigma_1\lambda_2 \\ \vdots \\ E(Q_{i1} \mid 1 = J) = Z_i\alpha_1 + \sigma_1\lambda_J \end{cases}$$ …………………………………………Equation 9

To generate unbiased estimates of the ATT, the expected values are used. Equation (8a) -(9a) or Equation (8b)–(9b) is the difference that represent ATT. For example, the difference between Equation (8a) and (9a) is given as: For instance, the following represents the difference between Equation (8a) and (9a):

ATT = E | Q_{i2}| 1=2|-E|Q_{i1} |1=2| =$Z_i(\alpha_2 - \alpha_1) + \lambda_2(\sigma_2 - \sigma_1$……Equation 10

To the right side of the equation 14, the first term denotes the expected change in the adopter's mean outcome if the adopters' characteristics had the same returns as non-adopters i.e., if the adopters too, had the same characteristics as non-adopters. Λj denotes the selection term that accounts for all possible effects of differences in unobserved variables.

3. Results and Discussion

3.1 Gross margin for different circular Agriculture farming practices

Table 1 shows the net returns of maize grown using a choice of circular agricultural practices (mixed farming, intercropping, organic farming) or a combination of each of these practices. The results of the study in Table 1 show that farmers using all the choices of circular agriculture practices, mixed (crop-livestock), organic, and intercropping farming practices had the highest yield in maize production. In addition, farmers who practice a choice combination of mixed (crop-livestock) and intercropping farming practices had the second highest yield in maize farming (Table 1). Specifically, it is noted that practicing organic farming as a single circular agriculture practice resulted in the lowest yield among all the practices. Furthermore, the results in Table 1 show that practicing a choice combination of all circular agriculture practices proved to generate the highest revenue for the farmer. In addition, results in Table 1 show that practicing a choice combination of all circular practices had the highest total mean variable cost.

Maize grown under a choice combination of Intercropping and mixed farming proved to be the most profitable circular agriculture practice. In addition, a circular practice of mixed farming had the second highest profitability of 31009 Kenya shillings (table 1). A choice combination of all the circular agriculture practices was third in terms of profitability (Table 1). Out of all the circular practices, practicing organic farming as a single practice proved to be the least profitable (Table 1).

Table 2: Gross Margin for Various circular agricultural practices

CP	Intercrop	Mixed	Org	Inter_ Mix	Inter_ Org	Mix_Org	All	f-value
Yield	1240	1572	1050	2457	1260	1849	2681	36.90***
	(557)	(547)	(316)	(914)	(525)	(607)	(810)	
Total Revenue	41348	52397	35000	81913	42000	62042	89368	36.85***
	(18556)	(18246)	(10536)	(30452)	(17493)	(20554)	(26992)	
Total Variable	12846	21387	18733	50593	16865	37138	62826	78.89***
Cost	(7364)	(148)	(12876)	(20965)	(7476)	(10307)	(18054)	
GM	28502	31009	16267	31320	25135	24904	26542	1.49
	(15761)	(17640)	(7497)	(14528)	(11449)	(12879)	(11577)	

*, **, ***, indicates the level of significance at 10%, 5% and 1% respectively, () parenthesis represents standard deviation, Note: M means Mixed Farming, O Organic Farming, M_O Mixed Organic, I_O Intercropping Organic, I_M Intercropping Mixed Farming, M_0_I Mixed Farming Organic Farming Intercropping.

3.2 Multinomial endogenous switching regression model econometric results and discussion: Determinants of Circular Agricultural Practices

Table 2 shows the choice combination of circular agriculture practices and the variable factors influencing their adoption. The findings show that the age variable was negatively associated with the choice of combination (mixed farming and intercropping) at a 5% significance level. This suggests that as the farmer ages up, the probability of adopting a combination of mixed and intercropping also decreases. The research findings correspond with those of Aurangozeb (2019), who concluded that age has a negative and significant impact on the usage of integrated homestead farming innovations. However, the research findings are contrary to Pauline (2023), who reported that the age of the farmer was positively associated with the choices of responses to climatic stressors in Tanzania. In contrast, Hawas and Degaga (2023) and Ghimire *et al.* (2015) found that the age variable was statistically insignificant in the uptake of improved farming technology and the growing of improved rice varieties in rural farming households.

In addition, this study also found that age has a positive and significant association with the adoption of all three circular agriculture practices (mixed, organic, and intercropping farming) (Table 2). Conforming to the perspective studies by Kolapo and Kolapo (2023); Choudhary *et al*. (2018); Das *et al*. (2017); Das *et al*. (2020) also found age having a positive and significant effect on farming practices. Contrary to these findings, Ali and Erenstein (2017), Wekesa *et al.* (2018), and Gebre *et al*. (2023) found that age of the farmer having a negative and significant relation with the adoption of farming strategies.

The results of the multinomial logit model indicate that household size positively and significantly influences the adoption of mixed farming at a 5% level (Table 2). This suggests that families with many family members are more likely to uptake mixed farming as a circular agriculture practice.

The study's findings are in line with those reported by Gebre *et al*. (2023 who reported household size having a positive and significant effect on farming practices. However, the results tend to differ from the findings of Ngongi and Urassa (2014) who reported a negative effect, suggesting that families with large household size are more likely to experience food insecurity.

Education level of farmers was found to have a positive association with mixed farming as circular agriculture practice at a 1% significant level, indicating that smallholder farmers with more education adopt mixed farming than those who are less educated. When a farmer becomes more educated, they tend to be more aware of farming practices that help in maximizing returns, environmental sustainability, and ensuring soil fertility (Ali & Erenstein 2017; Nor Diana *et al*., 2022. Other authors have reported different findings from our results. Parvathi

(2018) reported that years of schooling had a negative and significant relationship with practicing mixed crop-livestock farming. In a study by Putra *et al*. (2019); Mekuria and Mekonnen (2018); the level of education was found to be statistically insignificant in the uptake of mixed farming practices.

Table 3: Selection Parameter Estimates (Multinomial Logit Model -First Stage)

Variable	M	O	M_O	I_O	I_M	M_O_I
Age	-0.3231	-0.2915	0.0701	-1.3111	-0.4180**	0.7936*
	(0.2556)	(0.9047)	(0.3381)	(0.9151)	(0.1955)	(0.4283)
Gender	0.4497	0.4056	-0.0813	17.4414	0.3368	0.4386
	(0.3724)	(1.3944)	(0.4895)	(1568)	(0.2835)	(0.6031)
Maritalstatus	-0.4360	-2.1356	0.0146	0.2564	-0.0737	-0.1826
	(0.4301)	(2.9690)	(0.4161)	(3.0830)	(0.2616)	(0.5672)
Hhsize	0.5127**	0.7114	0.2098	1.2688	0.3310	-0.1366
	(0.2542)	(1.0335)	(0.3301)	(0.7704)	(0.2035)	(0.4520)
Educ	0.7106***	-0.3724	0.3711	-0.4983	-0.1417	0.0910
	(0.2585)	(1.0335)	(0.3404)	(1.0061)	(0.2054)	(0.3659)
Farmexperience	0.3565**	13.9612	0.2027	1.0941	0.3583**	0.0803
	(0.1890)	(1183.601)	(0.2505)	(0.9745)	(0.1395)	(0.3027)
Farm size	0.9391***	1.2711***	0.7691***	0.3556	0.9130***	1.0441***
	(0.1840)	(0.3816)	(0.2199)	(0.5850)	(0.1705)	(0.2057)
Landtenure	-0.6879**	-0.1632	-0.5013	-15.3667	-0.6659***	-0.6314
	(0.3040)	(0.7558)	(0.3927)	(2119.947)	(0.2230)	(0.4849)
Training	0.7630	-1.8169	0.1368	0.4763	-0.7174	-0.1082
	(0.5529)	(4736.178)	(0.7971)	(1.7999)	(0.4972)	(1.4348)
Extension	0.1249	0.3701	0.5120	-15.5819	0.2869	-0.1743
	(0.4286)	(1.4379)	(0.5341)	(1907.898)	(0.3379)	(0.6560)
Accessinfo	-1.0517**	16.2051	-0.5871	-1.7928	-0.2812	0.5667
	(0.4786)	(3196.78)	(0.6540)	(1.4633)	(0.4330)	(1.1133)
Groupmemb	0.6046*	1.0560	1.1050***	0.2439	0.5105*	0.5328
	(0.3425)	(0.8033)	(0.3788)	(0.8724)	(0.2859)	(0.6422)
Access_credit	-0.1370	1.0730	-0.3021	1.0135	0.3983	1.8856***
	(0.5366)	(1.4673)	(0.7232)	(1.4730)	(0.4014)	(0.6135)
Cons	-4.0950	-86.6162	-5.0677	-6.6279	-0.5643	-7.6742
	(1.4694)	(6874.85)	(1.885)	(2636.88)	(1.0109)	(2.5844)

*, **, ***, denotes significance level at 10%, 5% and 1% respectively, ( ) denotes standard error

Note: M means Mixed Farming, O Organic Farming, M_O Mixed Organic, I_O Intercropping Organic, I_M Intercropping Mixed Farming, M_0_I Mixed Farming Organic Farming Intercropping

Farming experience positively and significantly influenced mixed and intercropping farming at a 5% level. The results imply that farmers' preference for intercropping and mixed farming increases with their farming experience. Farming experience helps smallholder farmers make more effective decisions in choosing the best practices of circular agriculture. The results of the study are consistent with those of Assefa *et al*. (2020); Choudhary *et al*. (2018); and Kolapo and Kolapo (2023), who found a positive correlation between farming experience and conservation agriculture. However, other studies have reported different results from our findings. For instance, a study conducted by Zakari *et al*. (2022) concluded that farming experience had a negative impact on the uptake of improved agriculture practices. Bongole *et al*. (2020) also found that farming experience was insignificant in farmers' decision to use climate-smart agriculture practices.

Farm size was found to have a positive and significant influence on the adoption of a choice combination of circular farming practices: mixed farming; organic farming; mixed and organic; intercropping and mixed farming; and mixed organic and intercropping at 1% level (Table 2). This implies that circular agriculture practices are more likely to be adopted by smallholder farmers with larger farms. Smallholder farmers with large farm sizes are more likely to adopt new agricultural technologies (Marie *et al*., 2020).

Land ownership, including its size, is the most important resource in farming, therefore farmers who have access to both land and resources are better equipped to implement techniques needed in farming (Kassa & Abdi, 2022). The study results draw attention, particularly to land tenure that had a negative and significant impact on a choice of mixed farming, intercropping, and mixed farming at 5% and 1 % levels, respectively. Lawry *et al*. (2014) noted that although land tenure may be a pre-condition for farm investments that foster productivity and increase farm incomes, it is also an obstacle for women and youths to access land, as well as being responsible for the displacement of the poor farmers. However, other researchers tend to contradict our findings. For example, in a study by Mamkwe (2013), land ownership was found to be positively and significantly influencing the adoption of conservation agriculture, meaning farmers who own land have a greater chance of adopting conservation agriculture compared to those who rent.

Information access negatively and significantly influence the adoption of mixed farming at 5% significant level. This shows that farmers are less likely to adopt mixed farming as a circular agriculture practice in a situation when information about mixed farming is available. The explanation may be that these farmers are more interested in information that helps in maximizing profit. Helgason *et al*. (2021) cited that modern farming practices such as monoculture practices and intensive farming methods, which aim at maximizing profitability over environmental protection, have displaced circular farming practices.

Group membership had a positive and significant effect at 10%, 10%, and 1% for the choice of mixed, both mixed farming and organic farming, and intercropping, respectively. The results of this study are in line with those of Wekesa *et al*. (2018), who reported that group membership positively affected the use of packages such as crop and field management, and crop and field management, risk reduction. Smallholder farmers in groups can share ideas from each other's experiences (Kumar *et al*., 2019). In addition, Kolapo and Kolapo (2023) reported a positive association between group membership and the adoption of conservation agricultural packages. Farmer group associations enable the dissemination of information among farmers (Baiyegunhi *et al*., 2019; Ghimire & Huang, 2015; Kolapo & Kolapo, 2023). Farmers trust their fellow farmers who have embraced a farming technology; hence, farmers' group associations promote information sharing among farmers (Baiyegunhi *et al*., 2019; Ghimire & Huang, 2015; Kolapo & Kolapo, 2023).

Access to credit positively and significantly influences a choice of all three circular agriculture practices, mixed organic, and intercropping farming. Credit access encourages farmers to venture into a choice of all three circular agricultural practices. Financing agriculture activities in the form of loans or other credits is a useful tool for sustainable agricultural development (Assogba *et al*., 2017). Provision of credit to smallholder farmers enables them to meet the costs involved in practicing circular agriculture. Wekesa *et al*. (2018) found that the provision of credit facilities to smallholder farmers positively and significantly influenced good crop management practices and risk reduction.

According to a study by Shiferaw *et al*. (2015), lack of credit access by smallholder farmers was found to have a negative impact on the use of improved seeds and fertilizers, implying that households with limited credit are less likely to uptake climate-smart agriculture practices. However, other researchers disagree with the research findings. For example, a study by Kolapo and Kolapo (2023) found access to credit has a neutral relationship with the use of a choice of packages of conservation agriculture. Wekesa *et al*, (2018) further concluded that the provision of credit to farmers may encourage them to use the credit for other purposes not related to farming.

3.3 Average Expected Gross Margins from Maize production in circular Agriculture farming

Table 2: Average Expected Gross Margins from Maize Production in Circular Agriculture Farming

Circular Practices		Associated with a circular practice	Not Associated with a circular practice	Treatment Effects ATT/ATU
MixFarming	Associated	30316.71	30808.05	ATT =-491.34
	Not Associated	28460.55	28090.53	ATU=370.02
Intercropping	Associated	29882.35	29168.81	ATT=731.55
	Not Associated	30011.06	29009.01	ATU=1002.05*
Organic Farm	Associated	25026.8	30876.86	ATT=-5850.06***
	Not Associated	23217.65	30295.46	ATU=-7077.81***
Intercr and Mix	Associated	31319.55	29143.54	ATT= 2176.01***
	Not Associated	30215.5	28374.78	ATU=1840.72***
Intercr and Org	Associated	25135	29925.72	ATT= -4790.72
	Not Associated	25942.28	29888.61	ATU= -3946.33**
Mix and Org	Associated	24904.17	29880.27	ATT =-4976.11**
	Not Associated	25828.92	29923.12	ATU =-4094.20
All practices	Associated	26542.11	31169.95	ATT =-4627.85*
	Not Associated	28619.37	29769.1	ATU =-1149.73

*, **, ***, indicates the significance level at 10%, 5% and 1% respectively.

The multinomial endogenous switching regression model that considered ATT and ATU effects was used to calculate the estimated average gross margin from maize production under various circular agricultural practices. A more precise and significant way of assessing value of a technology or a practice among farmers is the measure of the treatment. (Kolapo & Kolapo, 2023; Rosenbaum, 2002). Table 10 shows the results from the multinomial endogenous switching regression, Average Treatment on the treated (ATT) and Average Treatment Effect on the Untreated (ATU) of using a choice of circular agricultural practices. Based on the results in Table 10, smallholder farmers should be considered from two different perspectives: firstly, those utilizing a single circular agriculture approach such as Mixed farming, organic farming, and intercropping; secondly, those employing more than one or all three of these circular agriculture practices. Table 10 shows the positive and negative results for ATT and ATU, suggesting that some smallholder farmers achieved higher gross margins while others experienced losses depending on the circular agriculture farming practice they adopted. Smallholder farmers participating in more than one circular agriculture practice significantly increased their gross margin.

For the smallholder groups that were not practicing intercropping, (Untreated), their outcome would have increased by 1,002 Kenya shillings on average had they received treatment of intercropping. Smallholder farmers who were selected for organic farming (ATT) had their gross margin for maize reduce by Kenya shillings 5850, while if the untreated group for organic farming had received the treatment (ATU), the maize income would have decreased by Kenya shillings 7,077. For the smallholder farmers who were selected for both intercropping and mixed farming (ATT), their income increased by Kenya shillings 2,176 due to the treatment they received. On the other hand, the untreated group for this category (ATU), their income would have increased by. Kenya shillings 1,840 had they receive the treatment. For the smallholder farmers who did not receive treatment for both intercropping and organic farming (ATU), their income would have reduced by Kenya shillings. 3,946 had they receive the treatment. For the treatment group selected for mixed and organic farming (ATT), their farming choices reduced their gross margin by Kenya shillings. 4976. Lastly, for the smallholder farmers who carried out all the practices (ATT), their gross margin reduced by Kenya shillings. 4,627.

In conclusion, carrying out a combination of intercropping and mixed farming was the best practice for maize farmers since both the treatment and the counterfactual had a positive profit. These results is consistent with other studies, including Maitra *et al*. (2020), which indicated that intercropping maize-beans improved soil fertility and increased the income of small farmers.

4. Conclusion

From the study it can be concluded that age, farm size, household size, education, experience in farming, land tenure, information access, group membership, and access to credit facilities are the important variables that influence the uptake of a choice of circular agriculture practices among smallholder farmers. Engaging in circular agriculture practices results in high yields and profitability. Moreover, the use of multiple circular agriculture practices results in higher yields.

5. Recommendation

The study suggests that any public or public interventions aimed at promoting the adoption of circular agricultural practices should target socioeconomic factors such as age, education, farming experience, farm size, land tenure, training, credit access, group membership, and the distance between the farm and the marketplace. Additionally, the Government, along with NGO partners, and stakeholders, can support circular agriculture practices through the provision of credit facilities that are tied to specific circular agricultural practices. Moreover, there is a need to intensify training on circular agriculture practices while emphasizing its contribution to food, income, and environmental security. Lastly, farmers should be provided with various incentives to encourage the adoption of multiple circular agriculture practices to maximize profitability.

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7. Conflict of interest

The authors have no conflict of interest to declare.

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