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RESEARCH ARTICLE

Machinery Adoption and Its Effect on Maize Productivity among Smallholder Farmers in Western Kenya: Evidence from the Chisel Harrow Tillage Practice

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Abstract: A major component of contemporary agriculture is machinery. Nonetheless, in Kenya and other African nations, the rate of adoption of agricultural machinery remains quite low. Understanding the fundamental causes and their impacts on agricultural output is crucial. Using data collected from a household survey of 1,499 farmers in Western Kenya, this study employed the endogenous switching regression model to examine the use of chisel harrows and their effects on maize production. Results show that the adoption of the chisel harrow was positively impacted by factors such as farm size, credit accessibility, gender, extension contact, and education attainment, while factors such as age and market proximity had a negative impact. The yield per hectare was higher for adopters than for non-adopters. According to the counterfactual analysis results, those who utilized chisel harrow tools were able to achieve a higher yield (1512 kg/ha) than they would have if they had not used the equipment (1099 kg/ha). The average maize yield per hectare increased by 413 kg and 217 kg for adopters and non-adopters, respectively, when chisel harrows were used. It is concluded that while training and field demonstrations may also be held to increase farmers' understanding of the benefits of the chisel harrow, encouraging farmers to adopt the tool has the potential to improve low production in the surveyed regions.

Keywords: Machinery; Chisel harrow; Endogenous switching regression model; Maize productivity

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1. Introduction

Twenty percent of the GDP in sub-Saharan Africa (SSA) comes from agriculture, which also employs sixty-seven percent of the labor force and provides the primary means of subsistence for the needy. The improved agricultural technologies are suggested to reduce poverty and increase food security for smallholder farmers [1]. The adoption of improved agricultural technology, such as machinery, is a key factor in promoting the transition from low-productivity subsistence agriculture to a high-productivity economy, thereby reducing poverty and hunger [2]. For a continent that presently faces food and nutrition shortages, improvement in agricultural production is still a vital issue.

The least mechanized agricultural systems worldwide are found in Sub-Saharan Africa [3]. Accessibility has increased more slowly in Africa compared to other emerging regions. It is estimated that the SSA Farmers own only a tenth as many automated tools per acre of land [4]. This makes sense in a sector where smallholder farming predominates. Mechanization, however, is a potent and practical tool for smallholder farmers to increase production, as demonstrated by several recent initiatives implemented throughout the SSA [5–8]. Research from Kenya indicates that small-scale farmers' agricultural productivity is enhanced by tractor availability significantly more than by other inputs like fertilizer [9]. Delivering mechanization to smallholders is increasingly seen as a potent strategy to enhance agricultural output sustainably, while yields in Sub-Saharan Africa (SSA) continue to drift around 56% of the global average.

Since its introduction by the Portuguese in the 16th century, maize (*Zea mays*) farming has been a longstanding practice in the nation. Over time, maize has steadily supplanted native foods as Kenyan's primary staple meal [10]. In addition, a number of government initiatives, including research on agricultural mechanization, technological advancements, and innovations along value chains, have been developed to boost production in order to help the countries attain food security and self-sufficiency [11]. In the last two years, the use of improved varieties has significantly increased, but the use of labor- and land-saving technologies, like machinery and conservation practices, have lagged behind [12].

Although the adoption of conservation tillage (CT) techniques is extremely slow, they have the ability to stabilize and raise agricultural yields over time [13]. A non-tillage tool that preserves soil fertility and structure is the chisel harrow [14] (Figure 1). A chisel harrow is a farming tool for deep tillage. Its primary goal is to leave crop residue on the soil's surface while aerating and loosening the soil. Chisel harrows do not turn or invert the soil, in contrast to many other tillage-implements. Additionally, it works well to reduce crop residue disturbance and soil erosion [15]. The method of disc plowing, which has been linked to soil disturbance, uses the operational part's revolutionary movement to break down the soil [16]. Over the past decades, Kenya has extended the use of disc plows nationally. Since 2010, the government and development organizations have been pushing the chisel harrow as a disc plow substitute because of its comparative advantages, e.g., compared to disc plows, these implements cause less soil disturbance, maintain soil structure, and reduce erosion [17].

Figure 1. Land preparation of smallholder farmers in western Kenya using chisel harrow.

The adoption of improved seed types and fertilizers in East and Southern Africa has been discussed in much literature. The return of input subsidies has generated a range of studies supporting that their costs can be higher compared to the benefits [18–21]. that subsidies can crowd out the private sector [22], and that they are often used for political purposes [23].

Twelve African nations, including Ethiopia, Malawi, Mali, Morocco, Rwanda, Tanzania, and Zambia, etc., were mentioned in the African Union Commission's 2021 report as having shown significant growth in mechanized agriculture and achieving increased productivity as a result. Unfortunately, Kenyan agricultural mechanization has not gotten the same attention. The majority of smallholder farmers still rely on animal traction to carry out their farming activities, with an average of 28 tractors per 1,000 hectares [24]. One of the best methods for managing soil in a non-tillage system is the chisel-harrow technique [25]. Compared to moldboard plow treatment, chisel harrow-cultivated soil had higher levels of total nitrogen and organic carbon (SOC) [26]. Despite these numerous empirical studies, many farmers in Kenya have yet to adopt the chisel harrow on a large scale, which is concerning. Moreover, there is still a lack of empirical analysis on the effect of chisel harrow technology on crop productivity.

The purpose of this study is to investigate the factors influencing the adoption of chisel harrows and the effects of this technology on the productivity of maize produced by smallholder farmers in Bungoma County, Western Kenya. To address possible endogeneity caused by selection bias, the endogenous switching model is used. To conduct the analysis, 1499 farmers in Western Kenya provided data. Findings from the study are expected to provide conclusive evidence of the effects of chisel harrows on maize productivity and enhance the extension of machinery service experience in nations such as Kenya.

The article's remaining sections are arranged as follows: The literature review, conceptual framework, econometric process, and materials and methods are described in the next section. An explanation of the data used in this investigation comes next. The following section presents and discusses the findings, while the final section makes conclusions and policy recommendations.

2. Background

The relationship between tillage and crop yield is multifaceted and contingent on various factors. Tillage practices, such as breaking up compacted soil for improved aeration and root growth, can positively influence crop yield by enhancing nutrient uptake. Additionally, tillage can aid in weed control and erosion prevention, further supporting higher yields. However, the impact of tillage is nuanced, as improper practices may lead to moisture loss, disruption of soil microbial communities, and reduced soil fertility. Conservation tillage approaches, which minimize soil disturbance and promote sustainable practices, have emerged as alternatives to mitigate potential negative effects. Striking a balance between soil management and conservation practices is crucial for optimizing crop yield while preserving long-term soil health and environmental sustainability [27–30].

To improve agricultural mechanization, the Kenyan government has launched a few initiatives. These include creating a National Agricultural Mechanization Policy, encouraging public-private partnerships, investing in research and development for adapted technologies, training and capacity-building programs, tractor programs to increase access for smallholder farmers, financing options and subsidies to lower the cost of machinery, support for extension services to disseminate information, and infrastructure development to ease the movement of agricultural machinery [31]. All of these initiatives are meant to boost productivity, encourage the adoption of contemporary farming methods, and enhance Kenyan farmers' standard of living [32].

Conventional tillage is the most widely utilized tillage technique in Kenya, which makes up about 80% of the country [33]. One of the main obstacles to the technique for small-scale farmers is finding enough agricultural leftovers for mulch [34]. Many areas as well as sub-Saharan Africa have similar issues [35–37]. Farmers that use conventional tillage also have to deal with issues including degraded soil, decreased crop yields, and higher production costs [38]. In Kenya, conservation tillage has been encouraged, particularly around Mount Kenya and the western part of the country [39]. However, the impact on crop productivity remains unclear despite the fact that some small-scale farmers are gradually implementing this tillage technique. To better understand the effects of conservation tillage on the crop, this paper analyzed the effect of chisel harrow on maize yield. This could give farmers and other land users information about the viability of using a chisel harrow technology to increase crop yields sustainably while having the least amount of detrimental effects on the soil.

A body of literature has found that conservation tillage techniques yield more than that used conventional tillage techniques [40,41]. Conservation tillage lowers the cost of cultivation by assisting farmers in using fewer inputs during crop production [42]. As a result of burning less diesel fuel to prepare the ground and plant wheat also lowers carbon emissions [43]. By lowering energy costs and enhancing soil and water quality, the empirical study of zero-tillage techniques utilizing chisel harrows has shown significant agronomic and financial benefits while also decreasing agriculture's environmental footprint [44]. Concerns have been raised in a growing number of studies, though, regarding the viability of CT techniques for sub-Saharan African smallholder farmers. Numerous studies have questioned CT's ability to improve soil through carbon sequestration [45–47]. In the context of various small-holder farms and farming systems, scholars dispute the practical application of CT [48,49]. Another empirical analysis indicated that CT principles are not always regarded as the initial step towards resolving the main productivity barriers that frequently prevent CT implementation [50].

A chisel harrow is commonly recognized as a tool for conservation tillage, particularly when employed in ways that adhere to conservation principles [51]. While the chisel harrow is not a no-till method in the same sense as direct seeding, which requires less disturbance of the soil, it is specifically made to cause less disturbance of the soil than traditional plowing methods. It is skilled at managing crop residues by absorbing them into the soil; consequently, it creates a protective layer that enhances soil surface moisture retention and lowers erosion [52]. Furthermore, by loosening up compacted layers and promoting the development of soil aggregates, the chisel harrow improves soil structure [53]. Many smallholder farmers are now adopting the use of these implements due to their benefits; however, it is unknown how they will affect crop productivity. As a result, the impact of chisel harrow technology on maize yield is investigated in this study.

As shown in Figure 2, the socio-demographic characteristics of maize farmers, including age, gender, education, household size, farm size, and off-farm income, as well as institutional factors like extension contact, group membership, and credit accessibility, were assumed to have an impact on farmers' decisions to use chisel harrow technology in this study. It is expected that these elements would affect a farmer's choice of whether to use chisel harrow technology.

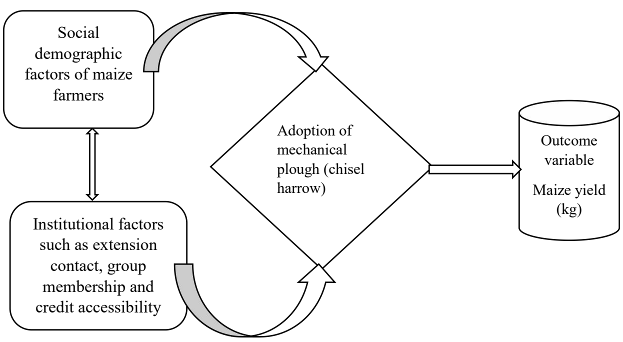

Figure 2. Analytical framework for chisel harrow adoption and how it affects maize productivity.

By breaking up compacted soil, the chisel harrow facilitates enhanced nutrient uptake and overall plant vigor, contributing to increased yield. Additionally. The residue cover also helps retain soil moisture, which is crucial, particularly in dry periods, leading to improved yields, especially in regions with erratic rainfall patterns. Lastly, the weed-suppressing effect of the residue cover enables maize plants to utilize nutrients and sunlight more efficiently, further enhancing overall yield. Therefore, it was expected that the chisel harrow would boost maize yield through these agronomic and soil management mechanisms.

The purpose of this study is to ascertain whether minimum-tillage practice has effects on crop productivity by examining the influence of chisel harrow adoption on maize output. Policy-makers have a foundation upon which they can decide on agricultural mechanization when these crucial elements are present in farm tools. Researchers ought to prioritize their future research endeavors based on the favorable example that this kind of investigation establishes.

3. Materials and Methods

The choice to adopt a new technology may be made based on several factors, including the assessment of the risks and relative productivity of adoption. Farmers' perceptions of risk and utility vary based on their cognitive abilities, which are shaped by a variety of socio-demographic factors, as shown in Figure 3. For instance, age can influence the adoption of chisel harrow technology positively or negatively [54]. Age, which is linked to many years of agricultural experience, may positively impact the adoption decision. Farmers with richer experience about machine adoption lie in their ability to make informed decisions, manage risks effectively, adapt to new technologies, utilize a diverse skill set, leverage networks for knowledge sharing, manage finances prudently, enhance operational efficiency, access credit, and demonstrate environmental awareness [55].

The lessons learned from the literature on the adoption of new agricultural technology shed light on the factors that contribute to the minimal adoption of chisel harrow technology, such as the costs and benefits of adoption, household and farm sizes, poor credit access, and a lack of market knowledge. Although there is a vast amount of empirical literature on the adoption and application of technology in Sub-Saharan Africa (SSA), few studies have examined the impact of chisel plough technologies on maize productivity among farmers.

3.1 Data Collection and Study Area

In western Kenya's Bungoma County, data for this study was gathered throughout the 2021–2022 growing season (Figure 4). Ten sub-counties make up Bungoma County: Webuye West, Webuye East, Kanduyi, Lugari, Mt. Elgon, Kimilili, Sirisia, Kibuchai, Bumula, and Tongaren. The research site is situated at an alti-

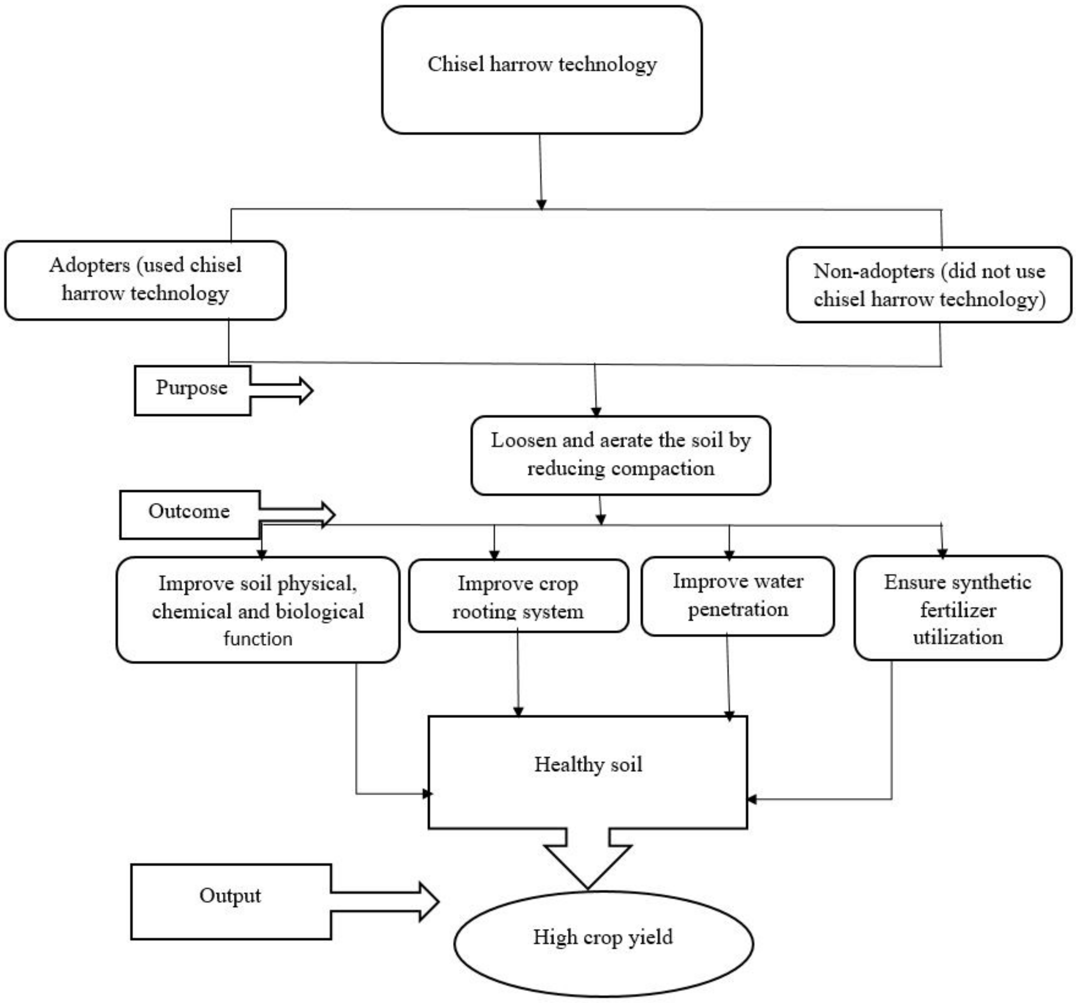

Figure 3. Conceptual framework.

tude of 4728.6 feet, or 1441.3 meters, above sea level. The west coast of Bungoma County is marine, with high summer temperatures (Classification Cfb). The average annual temperature of the county is –0.48% lower than that of Kenya, at 22.02 °C (71.64 °F). Bungoma experiences 280.45 wet days (76.84% of the time) and approximately 199.89 millimeters (7.87 inches) of precipitation yearly. Subsistence agriculture is the dominant activity, and the primary food and cash crop in this area is maize [56]. Due to climate change, agricultural productivity has declined over time. Food security has been compromised as a result, making a more extensive population face poverty. Most farmers in this region heavily rely on rainfall, which can be unreliable. The main climatic dangers influencing agricultural production in this county include moisture stress, planting season fluctuations, excessive and irregular rainfall, and high temperatures. The high population has also been a significant constraint, contributing to a decline in agricultural productivity. This is due to the fragmentation of land into smaller units. Another major challenge experienced by the county is that most modern farming technologies are expensive, and farmers cannot afford to adopt them due to resource constraints. The study employed multistage sample procedures as part of its sampling strategy. Bungoma County was first chosen because of its shift from traditional to climate-smart agriculture. Numerous non-governmental organizations (NGOs) that are presently active in the area have an impact on this. For over 4 years, Machinery Ring Kenya, a German-based NGO, has been working with farmers to improve farm productivity, soil health, and technology transfer.

In the second step, two sub-counties within Bungoma County were selected, namely Kimilili and Tongaren. It was considered that the geography and planting and harvesting seasons of these two sites were comparable.

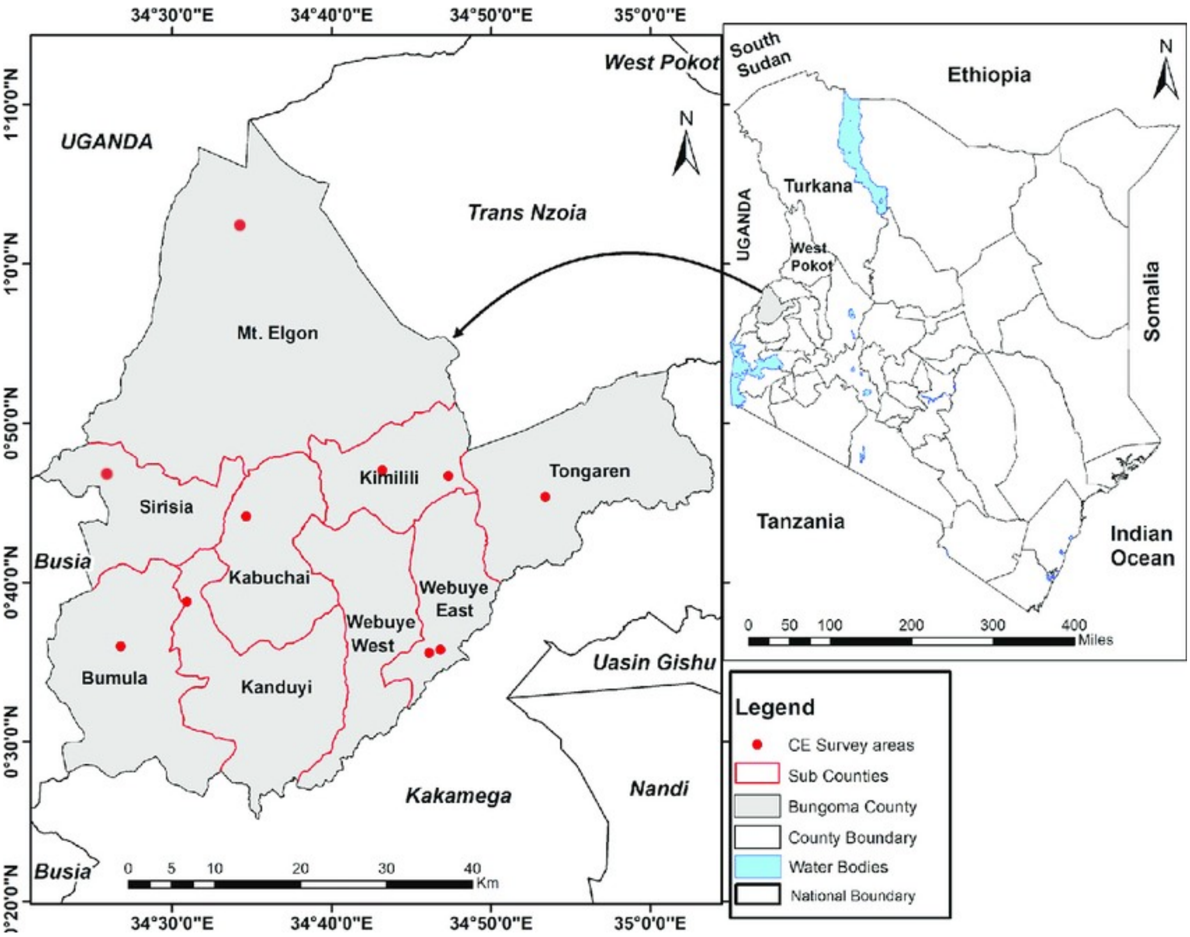

Figure 4. Map of the study area, Bungoma County, Western Kenya.

Using the assistance of agricultural officers in the eight sub-counties, a random selection process was carried out in the third stage. Climate-smart agriculture approaches and agricultural mechanization are realistically implemented in these sub-counties. The sample households were selected from each sub-county.

Agricultural field officers and skilled research assistants who had conducted a pre-survey and could speak the local languages well conducted the household survey. Both quantitative and qualitative data were gathered using focus groups, key informant interviews, semi-structured questionnaires, and direct observation [57]. The questionnaire and checklist were pre-tested to make sure they were accurate and valid before data collection. This made it possible to restructure the questions before gathering a large amount of data. Based on the limitations found in the pretest, the questionnaires and checklist were then enhanced and modified for the real interview. This was critical to capturing farmers' understanding of the questions and obtaining accurate information. The socio-economic features of the farmers' sources of income were among the details found in the data gathered from primary and secondary sources. Secondary data were gathered from a range of sources, including published publications and policy-related working documents, in addition to the primary household survey.

3.2 Model Specification

Selective bias, e.g. self-selection, is one of the problems in adoption behavior research. Usually, the propensity score matching (PSM) method is used for correction, but it can only deal with the observed but not the unobserved covariates. In the analysis, the endogenous switching regression model (ESR) was used [58]. The ESR was developed to deal with unobserved variables as missing values and estimate the selection equation and the result equation, respectively [59]. In contrast to Heckman's two-step method, which solely concentrates on observable equations. There are typically two steps of estimation in an ESR model. The first step involves estimating the selection equation for farmers' chisel-harrow service using a probit or logit model. To calculate the change in productivity brought about by farmers using chisel harrows, a determination equation of maize productivity was constructed in the second stage. To be more precise, the ESR model evaluates the following three equations simultaneously:

The Behavior Equation (using a chisel harrow or not),

$$M_j^* = \beta X_j + \varepsilon_j$$
$$M_j = 1\ if\ M_j^* > 0\ and\ 0\ if\ otherwise \tag{1}$$

M_j^* represents unobserved variables (or latent) for adopting chisel harrow technology, while M is an observed variable (M = 1 if the farmer adopted it and 0 if otherwise). Using a production function, as follows, the second stage's outcome equations for the chisel harrow's impact on maize productivity were estimated:

$$\mathrm{M} = f(Y, \beta, X) + \varepsilon_j \tag{2}$$

where M represents the log form of maize yield; Y denotes the adoption of chisel harrow technology; β represents parameter vectors to be estimated; and X is a set of covariates variables (age, gender, farm size, credit accessibility, rainfall index, education level, off-farm income, household size, insurance, experience, machine access, hire labor, subsidy, distance to input/output market and group membership) used in the model as expressed in the below Equations (3a) and (3b).

$$Regime\ 1: M_{1j} = \alpha_1 G_j + v_{1j}\ if\ M_j = 1 \tag{3a}$$

$$Regime\ 2: M_{2j} = \alpha_1 G_j + v_{2j}\ if\ M_j = 0 \tag{3b}$$

where M_{1j} and M_{2j} is the log of the maize yield in regime 1 and regime 2, respectively: G_j is a vector of covariates that hypothetically are the determinant of maize yield; v_1 and v_2 are the stochastic error terms. It is assumed that the error terms have a trivariate normal distribution with a covariance matrix and zero mean:

$$Cov(v_{1j}, v_{2j}, \varepsilon_j)\begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{1\varepsilon} \\ \sigma_{12} & \sigma_2^2 & \sigma_{2\varepsilon} \\ \sigma_{1\varepsilon} & \sigma_{2\varepsilon} & \sigma_\varepsilon^2 \end{bmatrix} \tag{4}$$

where

$\sigma_1^2 = var(v_1)$; $\sigma_2^2 = (v_2)$; $\sigma_\varepsilon^2 = var(\varepsilon_1)$; $\sigma_{12} = cov(v_1 v_2)$; $\sigma_{1\varepsilon} = cov(v_1\varepsilon_j)$; $\sigma_{2\varepsilon} = cov(v_2\varepsilon_j)$; σ_ε^2 (*variance of the error term in the selection equation*)

The ESR model's estimation results demonstrate the varying effects of several parameters on the productivity of maize grown by farmers who use chisel harrows versus those who do not. However, the estimated coefficient of the ESR model and the counter factual analysis framework must be used to assess the total impact of the chisel harrow on farmers' productivity. The average treatment effect of the chisel harrow on farmers' maize productivity may be calculated by comparing the expected maize productivity of the households that adopt the chisel harrow with the households that did not adopt the chisel harrow in the real and counter factual scenarios. The following is the description of the adopters of the chisel (treatment group)'s expected maize productivity:

$$E(v_{1j}|Y_j = 1) = E(v_{1j}|\varepsilon_j > -X_j\beta) = \sigma_{1\varepsilon}\left[\frac{\theta(X_j\beta/\sigma)}{1-\varphi(X_j\beta/\sigma)}\right] \equiv \beta_{1\varepsilon}\gamma_1 \tag{5a}$$

For the households in the control group (those who did not use a chisel), the expected maize productivity is as follows:

$$E(v_{2j}|Y_j = 0) = E(v_{2j}|\varepsilon_j > -X_j\beta) = \sigma_{2\varepsilon}\left[\frac{\theta(X_j\beta/\sigma)}{1-\varphi(X_j\beta/\sigma)}\right] \equiv \beta_{2\varepsilon}\gamma_2 \tag{5b}$$

If chisel-harrow consumers choose not to use the service, the following is the expected production of maize:

$$E(v_{2j}|Y_j = 1) = E(v_{2j}|\varepsilon_j > -X_j\beta) = \sigma_{2\varepsilon}\left[\frac{\theta(X_j\beta/\sigma)}{1-\varphi(X_j\beta/\sigma)}\right] \equiv \beta_{2\varepsilon}\gamma_2 \tag{6a}$$

If non-users of chisel harrows choose to employ them, the following is the expected level of maize productivity:

$$E(v_{1j}|Y_j = 0) = E(v_{1j}|\varepsilon_j > -X_j\beta) = \sigma_{1\varepsilon}\left[\frac{\theta(X_j\beta/\sigma)}{1-\varphi(X_j\beta/\sigma)}\right] \equiv \beta_{1\varepsilon}\gamma_1 \tag{6b}$$

The difference between Equations (5a) and (6a) can therefore be used to represent the average treatment impact on farmers' maize productivity who use the chisel harrow (ATT). That means that the difference between Equations (5b) and (6b) is the average treatment effect of the maize productivity of the farmers who did not use the chisel harrow (ATU). Ultimately, this study will examine the average treatment effect of chisel harrow on maize productivity using the average values of ATT and ATU.

3.3 Instrumental Variables Selection

Previous research has demonstrated that there is an endogeneity problem with the causal effect of extension contact because certain unobservable variables, like the individual characteristics of farmers, like their risk aversion, entrepreneurial spirit, or specialized knowledge of alternative farming practices, may affect both the demand for extension services and farm productivity [60]. Unobserved differences in farmers' access to resources, machinery, and modern agricultural technology may have an impact on agricultural outcomes as well as their propensity to request extension services [61]. The decision to seek extension services and the adoption of new farming practices can be influenced by social networks and peer pressure among farmers [62]. Furthermore, farmers' intrinsic desire to enhance their farming methods or their proactive approach to information gathering may have an impact on both their likelihood to seek out extension contact and crop productivity [63].

Evidence also shows that there exists endogeneity issues with the causal effect of market information. For example, the adoption of agricultural technologies, which may not be fully taken into account in the dataset, may have an impact on the use of market information as well as farming outcomes [64]. Unobserved disparities in farmers' experience, education, and agricultural expertise may have an impact on how well they use market data and make farming decisions [65]. The choice to seek out market information and the financial performance of farming operations may be impacted by unobservable differences in market access and infrastructure, such as transportation and storage facilities [66]. Another study also indicated that crop performance and market information demand (e.g., for weather forecasting) may be impacted by unreported changes in local climate conditions or micro-climates that are not fully captured in the data [67].

4. Results and Discussion

4.1 Descriptive Statistics

The mean differences in household characteristics by chisel harrow usage are presented in Table 1. Regarding the age of the household heads of the two groups, adopters had a mean age of 46 years, while non-adopters had a mean age of 54 years. In terms of the gender of the household head of adopters, 60% were male, while for the non-adopters, 40% were male. The findings show that male-headed households have higher access to productive resources and information which increases the chances of using chisel harrows. The farm size was statistically different among the two groups of farmers at a 1% significance level with adopters and non-adopters owning 2.2 hectares and 1.4 hectares of land, respectively. This result indicates that ownership of large parcels of land encourages farmers to adopt the use of chisel harrows in their farming.

Access to credit is an important factor in farm mechanization since it enables farmers to purchase or hire chisel harrows. The association between chisel harrow adoption and access to credit is statistically significant at 1%, whereby 62% of the adopters had access to credit whereas only 38% of non-adopters had access to credit. Access to credit is better for the adopters' households than for the non-adopters. With regards to the education level of the two groups, there were significant differences at the 1% significance level, whereby the adopters were more educated than non-adopters. Formal education is a human capital development factor that enhances individuals' capability to acquire and apply new information. This suggests that farmers who obtain high education levels are more likely to use chisel harrows.

The mean household size of adopters and non-adopters was 5.16 and 3.97 persons, respectively. The association between chisel harrow adoption and household size was statistically significant at a 1%. The larger the household (family), the more family members it has. More family members mean they have more social connections from a social capital perspective. As a result, the family can obtain more information, particularly about new technologies, e.g., in this case, chisel-harrow technology, which enhances adoption. Farmers' ability to insure their machines is a crucial factor in machine adoption, like chisel harrows. Among the adopters, 56% of the respondents had insured their agricultural machines in contrast to only 37% of non-adopters. The association between the adoption of chisel harrows and the insurance of machines is statistically significant at 1%.

The mean experience in maize farming was statistically different at 1% significance level, with 67% of adopters and 34% of non-adopters having been practicing agriculture for more than 10 years. Farmers can benefit from the use of the chisel harrow if they have access to that machine. Among the adopters' households, 69% had access to agricultural machines, whereas among the non-adopters households, 29% had access to agricultural machines. Many adopters had more access to agricultural machines than non-adopters. The association between chisel harrow usage and access to agricultural machines was statistically significant at 1%.

Most non-adopters (55%) hired labor during the cropping season, compared to 40% of adopters. Since the chisel harrow is made to require less manual labor for tasks related to cultivation and field preparation, non-adopters hire more laborers than adopters. Moreover, fair benefit distribution within the household is also ensured by a larger household. Distance from the household to the output market is often used to proxy for the ease of access to the market and hence the transportation cost. The mean distance of households to the output market was longer for non-adopters at 3 kilometers, whereas for adopters it was 2 kilometers. Group membership can play a significant role in facilitating farmers' access to machinery. Among adopters, 59% of the respondents belonged to farmer groups, in contrast to 36% of non-adopters. The association between chisel-harrow adoption and group membership is statistically significant at 1%. It is thus evident that the usage of chisel harrow in households is influenced by membership in a farmers' group. Finally, only 38% of the non-adopters had access to market information, compared to 40% of the adopters.

Table 1. Descriptive statistics of smallholder maize farmers.

Variables	**Variable Description**	**Adopters**		**Non-adopters**		**Difference**	**Real Mean Difference**
		Mean	SD	Mean	SD	t-test	Mean
Outcome variables							
Maize yield	Total maize yield in kg/hectares	1512	167	1210	106	–36.74***	302
Independent variables							
Age	Age of the households head in number of years	45.85	9.7	54.04	6.79	16.76***	-8.19
Gender	Gender of household head 1 = male, 0 = otherwise	0.60	0.49	0.40	0.49	–7.57***	0.20
Farm size	Size of land owned by a household in hectares	2.22	1.40	1.44	0.95	–10.07***	0.78
Credit accessibility	Whether household have access to credit during their cropping season 1 = yes, 0 = otherwise	0.62	0.49	0.38	0.49	–8.99***	0.24
Rainfall index	Whether household receive enough rainfall during cropping season 1 = enough, 0 = otherwise	0.29	0.46	0.30	0.50	0.28	–0.01
Education level	Education level of household head 0 = primary, 1 = secondary, 2 = post-secondary	0.95	0.73	0.44	0.42	–14.39***	0.51
Off-farm income	If household involved in any form of non-agricultural activities 1 = yes, 0 = otherwise	0.43	0.49	0.40	0.49	–1.06	0.03
Household size	Total number of individuals in the household	5.16	1.35	3.97	0.97	–12.85***	1.19
Insurance	If household has insurance for any agricultural machine 1 = insured, 0 = otherwise	0.56	0.48	0.37	0.50	–7.04***	0.19
Experience	If the household head has been practicing agriculture for more than 10 years 1 = yes, 0 = otherwise	0.67	0.47	0.34	0.47	–12.73***	0.33
Machine access	If the household have access to agricultural machines 1 = yes, 0 = otherwise	0.69	0.46	0.29	0.45	–15.66***	0.40

Table 1 continued

Variables	Variable Description	Adopters		Non-adopters		Difference	Real Mean Difference
		Mean	SD	Mean	SD	t-test	Mean
Hire labor	If the household hired labor during cropping season 1 = yes, 0 = otherwise	0.40	0.49	0.55	0.49	5.46***	–0.15
Subsidy	Whether household gets government subsidy when purchase farm input 1 = yes, 0 = otherwise.	0.29	0.45	0.28	0.45	–0.22	0.01
Distance to input/output market	Distance from the household to input/out market in Kilometers	2.0	1.14	3.40	0.88	22.64***	–1.4
Group membership	Whether household joined in any farmer group 1 = yes, 0 = otherwise	0.59	0.49	0.36	0.80	–8.55***	0.10
Instrumental variables							
Market information	Whether household had access to market information 1 = yes, 0 = otherwise	0.40	0.48	0.38	0.48	–0.61	0.02
Extension contact	Whether household had access to extension services 1 = yes, 0 = otherwise	0.48	0.50	0.27	0.45	–7.88***	0.27
No. of observations		1006		493			

Note: ***, **, * denote significant levels at 1%, 5%, and 10%, respectively.

4.2 Factors Explaining the Adoption of Chisel Harrow

A probit regression model was used to determine the factors influencing the adoption of chisel harrow among maize farmers and results are presented in Table 2. For a better interpretation [68], we computed the marginal effects. Based on the results, the use of the chisel harrow has a considerable impact on the probability of adopting the chisel harrow.

The age of the household head had a negative effect on the adoption of the chisel harrow, with an additional age reducing its adoption by 0.9%. This result shows that an additional year to the age of the household head is associated with a lower probability of that household using chisel harrow in maize farming. The age of the household head plays an important role in technology adoption, and the results indicate that adopters were younger than non-adopters, possibly because young farmers tend to be innovative and risk-takers and thus would try to use technologies more than older household heads. These results are in conformity with Bhandari et al. [69] who found that older farmers tend to be more risk-averse and have low energy levels to mechanize their farm. The farm size had a positive effect on the adoption of the chisel harrow, with each additional hectare increasing its adoption by 3.7%. This result shows that the adoption of agricultural machinery, such as the chisel harrow, is influenced by farm size. A larger farm is associated with a higher probability of adopting the chisel harrow. Larger farms often benefit from economies of scale, enabling them to absorb the high initial costs of machinery and capitalize on operational efficiency. These results are in conformity with previous findings [70] that a household's decision to adopt new technology is significantly responsive to farm size. The distance to the input-output market had a negative effect on the adoption of the chisel harrow, with an additional 1-kilometer increase in market-to-household farm distance reducing the probability of adopting the chisel harrow by 8.6%. Shorter distances result in reduced transportation costs, improved access to repair services, and better information flow about new technologies. This finding aligns with previous research [71] that emphasizes the significance of the distance to input/output markets as a crucial factor affecting the economic, logistical, and informational aspects that influence the decision to adopt agricultural machinery. Therefore, farms closer to the market are more likely to adopt new machinery.

Table 2. Marginal effect of chisel harrow adoption.

Variables	Agricultural Machine Adoption	
	Coef.	SE
Age	–0.009***	0.008
Farm size	0.037***	0.007
Distance to input/output market	–0.086***	0.006
Household size	0.031***	0.004
Gender	0.079***	0.015
Credit accessibility	0.074***	0.015
Hired labor	–0.059***	0.014
Off farm income	0.290*	0.015
Group membership	0.074***	0.015
Rainfall	0.006	0.016
Machine access	0.096***	0.014
Market information	0.009	0.015
Extension contact	0.075***	0.015
Experience	0.092***	0.015
Insurance	0.085***	0.015
Education	0.092***	0.012
Subsidy	0.008	0.16
Number of observations	1499	

Note: ***, **, * denote significant levels at 1%, 5%, and 10% respectively.

Household size has a positive effect on the adoption of the chisel harrow, with a larger household size increasing the probability of adopting the chisel harrow by 3.1%. The larger the household (family), the more family members it has. More family members mean they have more social connections from a social capital perspective. As a result, the family can obtain more information, particularly about new technologies, e.g., in this case, chisel-harrow technology, which enhances adoption [72] indicating that larger households had a higher probability of adopting maize drying technologies. Gender positively influences the adoption of chisel harrow at 7.9%. This may imply that socio-cultural and economic dynamics and traditional gender roles impact access to resources and influence labor allocation, affecting the perceived need for and utilization of machinery. This is consistent with previous literature [73] that households headed by males are more likely to adopt agricultural machines. Credit accessibility had a positive effect on the adoption of the chisel harrow at 7.4%. Credit accessibility is a key determinant in the adoption of farm machinery, enabling farmers to overcome financial barriers, adopt advanced technologies, and enhance overall productivity and sustainability in agriculture. This finding is in conformity with previous findings [74] indicating that farmers with access to credit are more likely to adopt new agricultural inputs. Extension contact had a positive effect on machine adoption at 7.5%. Access to extension services increases the adoption rate by 7.5%. This implies that extension contact positively influences the adoption of the chisel harrow by providing essential information and training. The holistic support offered by extension services contributes to farmers' understanding, confidence, and successful integration of the chisel harrow into their farming practices. This is consistent with the findings [75] that extension services increase the probability of adopting conservation tillage by farmers.

Experience had a positive effect on the adoption of the chisel harrow at 9.2%. Experience serves as a key determinant in the adoption of agricultural machinery, such as the chisel harrow, by influencing farmers' knowledge, skills, risk perception, and learning from past experiences. The collective impact of these factors contributes to a farmer's readiness to embrace new technologies in agriculture. This finding is consistent with previous literature [76] indicating that farmers with more experience adopted modern rice technology more easily. Education had a positive effect on the adoption of the chisel harrow at 9.2%. A higher level of education increases the adoption rate by 9.2%. Education positively influences the adoption of new agricultural technology by enhancing knowledge, technological literacy, decision-making skills, risk management, adaptability, and access to information. The cumulative effect of these factors contributes to a more receptive and proactive approach to incorporating innovative technologies into farming practices. This finding is consistent with the study [77] indicating that a lower level of education was a barrier to technology adoption.

4.3 Effect of Chisel Harrow on Maize Productivity

To determine the effect of the chisel harrow on maize yield performance, the endogenous switching regression model was utilized for the study. The yield and output equations were jointly estimated using the selection equation that explains farmers' use of chisel harrows. The endogenous switching regression model's estimation results for the use of chisel harrows are shown in Table 4. The primary focus of this discussion will be on columns (a) and (b), which display the results of the outcome equations (maize yield) for adopters and non-adopters, respectively. For the probit model to be correctly identified, the yield outcome function cannot contain any of the following three variables: machine accessibility, extension contact, and marketing information. It was discovered that these factors had no direct impact on maize output. The age of smallholder maize farmers using chisel harrow technology has a negative impact on their productivity. The odds ratio showed that an increase in the age of smallholder farmers by one year would result in a decrease in the maize yield by a factor of 0.321. These results are in line with those of Aregay, F.A., et al. [78] who discovered that adopters of enhanced technology saw a decrease in rice yield based on household age.

Maize yields in two groups are significantly and negatively impacted by their distance to the market. This suggests that a significant factor in explaining the differences in maize productivity between chisel-harrow adopters and non-adopters is the distance to market. The negative indicator indicates that a household's choice to use or not use a chisel harrow may not result in a higher yield of maize, regardless of how far away the market is. This is in line with the research that discovered a substantial and negative correlation between the distance of households to the market and the results of their adoption or non-adoption of climate change adaptation techniques in terms of maize production [79]. The productivity of farmers' maize crops was generally increased using chisel harrow technology, and this treatment effect is significant at the 1% statistical level.

Table 5 displays the maize yield data for Bungoma County smallholder farm families that used chisel harrows and those that did not. The table below shows the observed yield outcomes for adopters if they had chosen not to employ a chisel harrow and the yield outcomes for non-adopters if they had chosen to do so. According to the data, the observed yield outcomes for chisel harrow adopters and non-adopters are, respectively, 1512 kg and 1211 kg. If one were to compare the actual results between chisel harrow adopters and non-adopters, adopters would achieve 301 kg more maize yield than non-adopters (adopters yield less than non-adopters yield). Because these groupings have unobserved diverse traits, doing so would be incorrect. The table indicates that smallholder farm households that were adopters would have had significantly lower counterfactual yield outcome levels had they not used chisel harrow. On the other hand, the expected yield outcome has increased by 413 kg due to the treatment (adopters). Conversely, if non-adopters had employed chisel harrows, the expected yield would have increased by 217 kg.

Table 4. Maximum likelihood estimation of the ESR for adoption of chisel harrow.

Model	**Selection Equation**	**Endogenous Switching Regression**	
Dependent variable		Adopters (a)	Non-adopters (b)
Age	–0.063*** (0.006)	–0.321 (0.593)	1.80 (0.787)
Farm size	0.255*** (0.050)	3.522 (4.024)	–1.567 (5.304)
Gender	0.528*** (0.103)	–13.600 (10.876)	–26.868*** (10.339)
Credit accessibility	0.520*** (0.103)	15.454 (11.072)	–14.553 (10.463)
Distance to market	–0.587*** (0.054)	–8.850 (5.322)	1.439 (6.303)
Hired labor	–0.411*** (0.102)	–8.553 (10.828)	2.411 (9.603)
Off-farm income	0.197 (0.104)	–7.003 (10.710)	7.185 (9.875)
Group membership	0.491*** (0.102)	28.184*** (10.825)	–7.090 (10.667)
Experience	0.619*** (0.103)	–4.121 (111.977)	3.036 (10.909)
Household size	0.209*** (0.029)	–1.153 (3.249)	–0.305 (3.088)
Insurance	0.498*** (0.105)	–3.492 (10.823)	8.714 (10.353)
Education	0.636*** (0.088)	–9.715 (7.645)	–2.910 (10.042)
Subsidies	0.045 (0.112)	4.974 (11.598)	–8.20 (10.693)
Extension contacts	0.524*** (0.112)		
Machine accessibility	0.647*** (0.102)		
Market information	0.069 (0.103)		
Constant	1.636 (0.416)	1541.909*** (37.891)	1149.128*** (52.773)
∂_i		165.175 (3.698)	105.587 (3.782
ρ_i		0.090*** (0.127)	–0.323*** (0.143)
LR test of independent. equations: rho 1 = rho 0 Prob > chi2 = 0.0320		chi2(1) = 4.46	

Note: *, **, *** denote significance levels at 10%, 5% and 1%, respectively. Standard errors are reported in parenthesis.

Table 5 illustrates how potential heterogeneity effects between chisel harrow adopters and non-adopters were adjusted for. The non-adopters should have achieved an 85 kg lower yield per hectare than the adopters if they had chosen to become adopters. This suggests that smallholder adopters would still benefit them in comparison to non-adopters. This implies that perhaps new adopters would have to get established to have similar returns as their counterparts. The data indicates that adopters would have been projected to realize a yield outcome of 111 kg more than non-adopters if they had chosen to be non-adopters. Given that chisel harrow users can achieve higher crop yields than their counterparts because of significant heterogeneity sources (less soil disturbance, better soil moisture conservation, and decreased surface runoff), the transitional heterogeneity of 196 kg indicates that these users should expect to have more maize yield.

Table 5. Conditional expectations, treatment, and heterogeneity.

Sub-sample	Decision Stage		Treatment Effects	
	Adopting (1006)	Non-adopting (493)		
Adopters	(a)1512	(c)1099	TT	413***
Non-adopters	(d)1428	(b)1211	TU	217***
Heterogeneity effects	$BH_1 = 85$	$BH_2 = -111$	TH = 196	

Note: *, **, *** denote significance levels at 10%, 5% and 1%, respectively. Standard errors are reported in parenthesis.

5. Conclusions

Agricultural mechanization has been one of the most important pathways to enhance agricultural productivity in the past decades across developing countries. However, the adoption of new technology is still very low in sub-Saharan Africa. Poor extension service, a low level of education, and the cost of machine acquisition among smallholder farmers have been the major causes of the low adoption rate. We therefore examined the adaptive behavior of chisel harrow and explored its effect on the productivity of maize using household surveys collected from 1499 farmers in Bungoma County, Western Kenya. The productivities of chisel-harrow adopters and non-adopters were estimated using an endogenous switching regression model.

We find that a variety of factors, including farmers' age, gender, experience, farm size, group membership, and education, all have an impact on the adoption of chisel harrows. It was discovered that smallholder farmers who used chisel harrows had higher maize yield productivity when certain factors were considered. The variables of maize production among smallholder farmers were found to influence adoption, including the gender of the head of the family. The maize productivity in the surveyed region was improved considerably because of using chisel harrows, according to the outcome of the endogenous switching model.

Findings from the study may have some policy implications for Kenya's agricultural development. First, encouraging smallholder farmers to use chisel harrows in their tillage techniques can have a real positive impact on crop output. Given this, agricultural mechanization should also benefit from the fertilizer subsidy measures implemented by Kenya's current national government. The government could promote the importation and manufacturing of agro-machines and provide free interest on loan facilities for the agro-machines. Furthermore, an increase in loan lending amounts, making the loan lending process easier, etc. are also highly appreciable. There is a need for the government to further concentrate on the extension of Farm Access Market Road (FARM) to allow machines access to farms. Incentives (in any form) should be delivered to deserving farmers, irrespective of their political affiliation or political party.

Effective policy measures such as improving farmers' education and the deployment of extension officers to rural areas by the Ministry of Agriculture to offer training to farmers on the most suitable agro-machines should be promoted. Since most of the land is too small to be mechanized, the government needs to raise public awareness of the consequences of subdivision and strengthen the laws governing land tenure. Create demonstration farms equipped with modern machinery to highlight the benefits of mechanization. Farmers can observe first-hand how these innovations boost productivity and efficiency in this situation. By using contracting services, smallholder farmers in particular can profit from mechanization without having to cope with the challenges of owning machinery. To identify the elements influencing the chisel harrow's adoption and its impact on maize productivity, the study concentrated on a small number of variables. Consequently, more factors should be included in future studies to better examine the adaptive behavior of chisel harrow and its impact on maize output. Panel data and popular methods such as DID and RDD should also be included in future studies to enable more accurate comparisons between chisel harrow adopters and non-adopters.

Author Contributions

Edwin Mumah: Conceptualization, Methodology, Formal analysis, Data curation, Writing—original draft. Yu Hong: Methodology, Resources, Supervision, Writing—review & editing. Yangfen Chen: Conceptualization, Methodology, Resources, Writing—review & editing, Supervision, Funding acquisition.

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Data Availability

The data is available upon request from the corresponding author.

Conflict of 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.

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