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Do farmers benefit financially from adopting improved planted forages: Evidence from adoption of Brachiaria grass among smallholder dairy in Kenya

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Abstract

Current global trends in population growth, urbanization and a growing number of middle-class economy has resulted in increased demand for livestock and products more so dairy products. This necessitates the need for livestock producers to respond to the growing demand. However, farmers' efforts are further aggravated by the effects of climate change. The need for sustainable source of fodder arises to alleviate the situation at the same time offering farmers other opportunities to participate in fodder markets through adoption of climate-smart Brachiaria grass. In this article we estimate the opportunity cost of producing Brachiaria in favor of Napier grass using household survey data of dairy farmers in Kenya drier agro-ecological zones. We use full information endogenous switching regression to compute the opportunity cost by comparing the gross margins generated from Napier and Brachiaria grass. The findings reveal that face a higher opportunity cost of their fodder land by producing Napier in favor of Brachiaria. Further, adoption of Brachiaria is determined by age and experience of farmers in fodder production, herd size, breed type, perception on milk production, group membership and access to extension. The results highlight the need for widespread adoption through extension and technical support to farmers. This would also enable farmers participate in fodder markets and support their livelihood.

Keywords: Brachiaria grass; opportunity cost, gross margins; endogenous switching regression; planted fodder technology.

1. Introduction

Urbanization, increasing population and a growth in the middle-income class are driving a revolution in the livestock systems globally (White, Peters, & Horne, 2013). Continued economic growth and a change in consumer dietary preference leads to an increase in demand on livestock products specifically milk, meat and eggs (Bosire, Lannerstad, et al., 2016). Globally, it is projected that the number of urban dwellers will increase to 6.3 billion by year 2050. Moreover, 90% of the projected increase will come from Africa and Asia (United Nations, 2015). It is expected that with population growth, the demand for meat and milk products in Africa will double by year 2050 (Holechek, Cibils, Bengaly, & Kinyamario, 2016). In Kenya, the population is projected to reach 96 million with over 50% of the population living in urban areas by 2050 (Food and Agriculture Organzation, 2017). The ability of the African nations to feed the increased population raises serious concerns. Livestock production, specifically dairy, contributes significantly to the economy and livelihood of farmers. Efficient production of milk requires regular supply of quality fodder in adequate quantities (Nangole et al., 2011). [1]However, smallholder farmers are constrained by feed scarcity, associated with seasonality in rainfall, poor fodder production techniques, compromising feed quality, and limited land for fodder production. Therefore, intensification of livestock production systems need to be a crucial strategy in meeting the increased demand for milk prompted by changes in population growth, urbanization and diminishing land sizes.

Intensification of livestock production requires sustainable fodder production systems which are currently threatened by increased feed prices and prolonged drought (Fallis, 2015). Therefore, production of improved planted forages is a solution that can be pursued to alleviate the current situation. Brachiaria grass being [2]climate- smart fodder is being promoted by stakeholders in the livestock sector as an alternative fodder source. Previous research on Brachiaria indicate that it has high biomass production and nutritious herbage thus potential to increase livestock productivity (Holmann *et al*., 2004). It is able to improve nitrogen use efficiency, sequester carbon as well as adapt to drought and low fertile soils (Rao et al., 2014; Arango *et al*.,2014; Moreta *et al*., 2014).

[1] Feeding patterns are opportunistic in nature in that farmers react to changes in feed supply as opposed to stocking to minimize on risk (Nangole et al., 2011).

[2] Climate-smart agriculture implies sustainable agricultural production while addressing challenges of climate change (FAO, 2010).

Establishment of sustainable fodder systems would not only result in increased milk production but also increased income from sale of the fodder. Intensification of livestock production has resulted in increased use of off-farm feed resources and an emergence of feed and fodder markets (Bosire et al., 2016a; Nangole et al., 2011). Therefore, population growth and income results in an increase in demand for milk and thus increase demand for fodder (Bosire, et al., 2016b).

Several studies have assessed the potential of Brachiaria grass as a forage option (Machogu, 2013; Nguku, 2015; Njarui, Gichangi, Ghimire, & Muinga, 2016). Despite the nutritional and productivity benefits of Brachiaria identified in these studies little is known about its financial benefit as a fodder enterprise. Kassie et al., (2018) in their study on [3]push-pull technology that utilizes Brachiaria as a push crop attempted to quantify the benefits of Brachiaria but it was difficult as a result of frequent harvesting of fodder. The current study uses a gross margin analysis of Brachiaria as a fodder enterprise to quantify the financial benefits of adopting the fodder. Understanding the potential financial benefit from Brachiaria fodder production will be relevant in designing strategies for widespread adoption.

The study intends to provide empirical evidence on the financial benefit of Brachiaria and the agribusiness opportunity it creates for farmers to diversify their farm income sources from fodder production. Findings from this study will enable farmers expand their fodder production and participate in the feed and fodder markets. Additionally, it will give an opportunity to the urban dairy farmers to sustainably produce milk even without land for fodder. This will consequently result to achievement of sustainable development goal number one of ending poverty and promote sustainable agricultural development (Ngoma, 2018).

2. Methodology

2.1 Theoretical Analysis of Farmers adoption process

Considering farmers as rational, they aim to maximize their welfare given a combination of constraints. Following the theory of expected utility developed by Daniel Bernoulli, the decision by a farmer to adopt a technology; in this case Brachiaria, given the risk and uncertainties within their biophysical environment is based on a comparison of the expected utility of maximizing

[3] Push-Pull technology was developed by International Centre for Insect Physiology and Ecology (ICIPE) as a conservation agriculture method to control for maize stem borer and striga weeds in maize production.

profit (Schoemaker, 1982). Theory of expected utility has motivated several studies on farmer's decision making (Oglethorpe, 1995; Babcock and Hennessy, 1996; Gomez-Limon *et al.,* 2004). Farmers will adopt a technology if the expected utility from adoption (U_a) is greater than for non-adoption (U_n) (Kassie, Teklewold, Jaleta, Marenya, & Erenstein, 2015).

Following Asfaw et al., (2012) utility from adopting Brachiaria can be modelled as link between the adoption decision and expected benefits. Thus, the adoption decision is a dichotomous choice component that is determined by observable characteristics Z_i and a stochastic error term ε_i that is unobservable (Greene, 2003). Such that:

$$I_i^* = \beta Z_i + \varepsilon_i, \quad I_i = 1 \; if \; I^* > 0 \qquad (1)$$

where I_i is a binary variable that equals 1 if household *I* adopts Brachiaria and 0 if otherwise, β is a vector of parameters to be estimated, Z_i is a vector of household characteristics and ε_i is the error term. The error term is unobservable, hence it is assumed to be normally distributed.

The probability of adopting Brachiaria can then be estimated as follows:

$$\Pr(I_i = 1) = \Pr(I_i^* > 0) = 1 - D(-\beta Z_i) \qquad (2)$$

where *D* is the cumulative distribution function for ε_i. The assumption on the functional form for D guides on the different models used in estimation. A probit model is applied when the distribution is assumed to be normal and a logit model for a logistic distribution (Green 2003).

2.2 Model specification

Following Wale, Mburu, & Estrella, (2006), the opportunity cost approach was adopted. The approach compares the gross margins generated from planting Brachiaria grass and Napier grass. The gross margin (GM) from Brachiaria as the next best alternative on use of farmers' fodder land, the opportunity cost will be computed as follows:

$$OPPORTUNITY\ COST = (GM_{Brachiaria} - GM_{Nappier\ Grass}) \qquad (3)$$

The study then proceeds to use an econometric approach to compare the counterfactual outcomes (gross margins per acre) and compute the opportunity cost of growing Brachiaria.

Computing the opportunity cost associated with adopting Brachiaria grass in favor of other planted forages (in this case Napier grass) would require one to have information on what adopters would have gained had they not adopted and what non-adopters would have earned had they adopted. Use of counterfactual outcomes poses the problem of missing data because one farmer cannot be observed growing both Brachiaria and Napier grass (Kassie et al., 2018; Ngoma, 2018).

Moreover, selection bias may arise as result of self-selection into adoption. Observable and unobservable covariates that simultaneously affect adoption and the outcomes could also lead to selection bias. Adopters and non-adopters may be different with respect to observable characteristics such as proximity to inputs markets, education, extension access and resource endowment. However, unobservable characteristics (such as managerial ability, self-motivation and business acumen) may result in inconsistent estimates of the true effect of technology adoption on our outcome variable.

Existence of sample selection renders Ordinary Least Square (OLS) method biased. An alternative method would be PSM but its implementation is likely to be hindered by the unobservable variables which lead to self-selection into adoption. Another alternative method is the difference-in difference approach which cannot be executed using cross-sectional data available for this study (Wooldridge, 2010). Therefore, endogenous switching regression (ESR) was used to overcome the selection bias yielding consistent estimates on the opportunity cost of adopting Brachiaria based on actual and counterfactual outcomes (Lokshin & Sajaia, 2004). It is a variant of the instrumental variable (IV) method (Abdulai & Huffman, 2014; Carter & Milon, 2005; Di Falco & Bulte, 2013; Kassie et al., 2015; Shiferaw, Kassie, Jaleta, & Yirga, 2014; Teklewold, Kassie, Shiferaw, & Köhlin, 2013).

The full information maximum likelihood endogenous switching regression uses a two-step estimation procedure to estimate treatment effects yielding consistent standard errors by simultaneously estimating the selection and outcome models (Lokshin & Sajaia, 2004; Semykina & Wooldridge, 2010). The first stage of the estimation is a probit model for the adoption decision (selection equation) for Brachiaria and computation of the inverse Mills ratios for controlling selection bias. Second stage is an OLS that involves use of the inverse Mills ratio as a regressor to estimate the opportunity cost Brachiaria adoption. Following equation (1) we can model the selection equation as:

$$I_i^* = \beta Z_i + \varepsilon_i \; with \; I_i = \begin{cases} 1 \; if \; \beta Z_i + \varepsilon_i > 0 \\ 0 \; otherwise \end{cases} \qquad (4)$$

where Z_i is a vector of household characteristics that influence adoption of Brachiaria. This includes age of the household head (years); sex of the household head; years of schooling of household head (completed years); dairy farming experience (years); experience in fodder production (years); household size (members living and eating in the same household); main source of income is binary (1 = off-farm; 0 = farm); farm size (in acres); land tenure is a binary variable referring to type of land ownership (1 = owned with title; 0 = otherwise) TLU (tropical livestock unit) measures the herd size; breed type (1 = exotic breed; 0 = otherwise); cash crop farming is a binary variable (1 = farming cash crop; 0 = otherwise); perception on milk production; group membership; credit access; and access to extension. The explanatory variables used in the adoption equation is based on adoption literature for agricultural technology (Abdulai & Huffman, 2014; Kassie et al., 2018; Khan et al., 2014; Murage, Pittchar, Midega, Onyango, & Khan, 2015; Shiferaw et al., 2014; Wale et al., 2006).

β is a vector of parameters to be estimated whereas ε_i is the error. The second stage involves estimating separate equations for each outcome (gross margins) for two regimes; adopters and non-adopters (Rees & Maddala, 1985):

$$Y_1 = \alpha_1 X_1 + \varepsilon_1 \; if I_i = 1 \qquad (5)$$

$$Y_0 = \alpha_0 X_0 + \varepsilon_0 \; if I_i = 0 \qquad (6)$$

where Y_1 and Y_0 are outcome measures (gross margins) for adopters and non-adopters of Brachiaria, respectively. Gross margins were computed in Ksh per acre per year given Brachiaria and Napier grass are harvested after an interval of 3-4 months. Gross margins were computed as gross revenue of the respective fodder less variable costs of inputs. X_j $(j = 1,0)$ is a vector of covariates that affect the gross margins. The covariates includes the same variables used in the selection equation. α_j $(j = 1,0)$ is a vector of parameters to be estimated and ε_j is a vector of error terms.

Asfaw et al., (2012) notes that self-selection into adoption may result in nonzero covariance between the error terms of the selection eq. (1) and outcome eqs. (5) and (6). Given the assumption of the endogenous switching framework of a [4]trivariate normal distribution with zero mean and nonzero covariance on the error terms, the matrix can be modelled as:

$$corr(\varepsilon_i \varepsilon_1 \varepsilon_0) = \Sigma = \begin{pmatrix} \sigma_{\varepsilon}^2 & \sigma_{\varepsilon\varepsilon 1} & \sigma_{\varepsilon\varepsilon 0} \\ \sigma_{\varepsilon 1\varepsilon} & \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1\varepsilon 0} \\ \sigma_{\varepsilon 0\varepsilon} & \sigma_{\varepsilon 0\varepsilon 1} & \sigma_{\varepsilon 0}^2 \end{pmatrix} \qquad (7)$$

where σ_{ε}^2, $\sigma_{\varepsilon 1}^2$and $\sigma_{\varepsilon 0}^2$ are variances of the error terms from the selection and outcome equations respectively. $\sigma_{\varepsilon 1\varepsilon}$ is the covariance between ε_i and ε_1, $\sigma_{\varepsilon 0\varepsilon}$ is the covariance between ε_i and ε_0. $\sigma_{\varepsilon 1\varepsilon 0}$ is the covariance between ε_1 and ε_0 but is never defined as Y_1 and Y_0 are not observed simultaneously. Therefore, the expected values of the error terms for equation (5) and (6) is given by:

$$E(\varepsilon_1|I_i = 1) = E(\varepsilon_1|\varepsilon_i > -\beta Z_i) = \sigma_{\varepsilon 1\varepsilon}\frac{\phi(\beta Z_i)}{\Phi(\beta Z_i)} = \sigma_{\varepsilon 1\varepsilon}\lambda_1 \qquad (8)$$

$$E(\varepsilon_0|I_i = 0) = E(\varepsilon_0|\varepsilon_i \leq -\beta Z_i) = \sigma_{\varepsilon 0\varepsilon}\frac{-\phi(\beta Z_i)}{1-\Phi(\beta Z_i)} = \sigma_{\varepsilon 0\varepsilon}\lambda_0 \qquad (9)$$

where ϕ is a standard normal probability density function and Φ is standard normal cumulative function. λ_1 and λ_0 are ratios representing the inverse Mills ratios for adopters and non-adopters that is to be included in the outcome eqs. (5) and (6) (Wooldridge, 2015).

Although the covariates in the selection and outcome equations overlap, we instrumented selection into adoption of Brachiaria with group membership and perception on Brachiaria. These instruments were omitted in the outcome equations (5) and (6). The instruments are related to access to information and have been used before by Abdulai & Huffman, (2014).

2.3 Estimating the opportunity cost

Incorporating the inverse Mills ratios computed in the selection equation in the outcome equation we get;

$$Y_1 = \alpha_1 X_1 + \sigma_{\varepsilon 1\varepsilon}\lambda_1 + \mu_1 \quad if I_i = 1 \qquad (10)$$

$$Y_0 = \alpha_0 X_0 + \sigma_{\varepsilon 0\varepsilon}\lambda_0 + \mu_0 \quad if I_i = 0 \qquad (11)$$

[4] The trivariate distribution refers to error terms in the selection and outcome equations of the endogenous switching regression.

The endogenous switching regression model was estimated using *movestay* Stata command by Lokshin and Sajaia (2004).

Following Kuntashula & Mungatana, (2013), we can estimate the opportunity cost from eqs. (10) and (11):

$$E(Y_1|I_i = 1) = \alpha_1 X_1 + \sigma_{\varepsilon 1\varepsilon}\lambda_1 \quad (12)$$

$$E(Y_0|I_i = 0) = \alpha_0 X_0 + \sigma_{\varepsilon 0\varepsilon}\lambda_0 \quad (13)$$

$$E(Y_0|I_i = 1) = \alpha_0 X_1 + \sigma_{\varepsilon 0\varepsilon}\lambda_1 \quad (14)$$

$$E(Y_1|I_i = 0) = \alpha_1 X_0 + \sigma_{\varepsilon 1\varepsilon}\lambda_0 \quad (15)$$

Equations (12) and (13) are the observed outcomes conditional on Brachiaria grass adoption and non-adoption. Equation (14) is the counterfactual outcome for non-adopters had they adopted, whereas equation (15) is the counterfactual outcome for adopters had they not adopted. The average treatment effect on the treated (opportunity cost for adopters/ATT) is the difference between equations (12) and (14) (Di Falco & Bulte, 2013; Heckman, 2017);

$$ATT = E(Y_1|I_i = 1) - E(Y_0|I_i = 1)$$

$$= X_1(\alpha_1 - \alpha_0) + \lambda_1(\sigma\varepsilon_1\varepsilon - \sigma\varepsilon_0\varepsilon \quad (16)$$

The opportunity cost for non-adopters given by average treatment effect on the untreated (ATU) is the difference between eqs. (15) and (13);

$$ATU = E(Y_1|I_i = 0) - E(Y_0|I_i = 0)$$

$$= X_0(\alpha_1 - \alpha_0) + \lambda_0(\sigma\varepsilon_1\varepsilon - \sigma\varepsilon_0\varepsilon \quad (17)$$

To determine if the opportunity cost of Brachiaria is greater or smaller for adopters had they not adopted or non-adopters had they adopted, the transitional heterogeneity effects given by the difference between ATT and ATU are computed. If gross margin foregone is zero, producers of Napier grass have nothing to regret in terms of returns from the activity.

3 Sampling and data collection

Data was collected from Siaya and Makueni counties as examples of the drier medium potential agro-ecological zones in Kenya; where commercialized dairy farming and Brachiaria adoption continue to be promoted by the Government of Kenya and ILRI as a development partner. Sampling targeted dairy farmers who had grown Brachiaria grass for at least twelve months. This criterion was meant to enable gross margin computation by excluding farmers who had not harvested Brachiaria for at least one year cycle. For control group, the study targeted dairy farmers in neighboring villages who had not planted Brachiaria and used Napier grass (*Pennisetum purpureum (L.)* Schumach.).

We used a multi-stage sampling in three stages. First we purposely chose sub-counties and a location where dairy and fodder production are carried out. Second, in each location, with the help of extension officers and lead farmers, we generated two lists of dairy farmers; those who had planted Brachiaria and those who had not. Subsequently, in the third stage respondents were randomly sampled from the two lists using proportionate to size approach resulting in 132 and 105 farmers in Siaya and Makueni Counties respectively and a total sample of 237. Data was collected and entered using computer aided personal interviews application CS Pro version 7.1 program. The data included demographic, socio-economic and institutional factors that affect adoption of Brachiaria and gross margin analysis for Napier and Brachiaria grass.

4 Results and discussion

4.1 Descriptive Statistics

The descriptive statistics in table 1 indicate that all dairy farmers sampled were on average 56 years old, 77% of the households being male-headed with 10 years of formal schooling. Additionally, the farmers sampled on average had 10-12 years of experience in dairy and fodder production. On average families had about 6 members. This implies that on average households had significant levels of human capital (physical and technical). Moreover, there were significant differences between adopters and non-adopters in terms of age. Adopters were older than non-adopters suggesting that youth participation in fodder and dairy enterprise was still low.

Farm sizes averaged about 3.62 acres, majority of farmers (62%) having ownership (with title) to the land. There is significant differences between adopters and non-adopters in terms of farm size. Land is an indicator of wealth and adopters had bigger land sizes. Therefore, they are more likely to allocate land for establishment of fodder. Furthermore, herd size given by Tropical Livestock Unit (TLU) averaged about 7.58 units with significant differences between adopters and non-adopters. Adopters of Brachiaria had a bigger herd size compared non-adopters by 3.68 units. Moreover, adopters had more of exotic breeds compared to non-adopters who had more of indigenous breeds. The findings suggests that adopters are at a more advanced stage in the process of operating dairy as a commercial enterprise

On average, 40% of farmers used part of their land for cash crop such as sugarcane and sisal diversifying their farm income stream in Siaya and Makueni respectively. Majority of household (70%) earned their income mainly from off-farm activities such as formal and informal employment, business and remittances. There is also significant difference in main source of income between adopters and non-adopters with adopters deriving their income more from off-farm activities. About 48% of the farmers acquired credit for both agricultural and personal use. Farmers attributed the low access to credit on high interest rates on loans and payback plans that do not favor their nature of farming. Their farming is characterized by seasonality and irregular cash flow which cannot service a loan that requires monthly payments. There is significant difference in terms of access to credit with adopters having more access to credit than non-adopters. This can be attributed to the resource endowment of adopters and their ability to adhere to stringent requirements on loans.

About 73% of farmers belonged to social groups and had received extension service (63%) on dairy and fodder production at least more than once in 2017/2018. There were also significant differences in group membership and access to extension between adopters and non-adopters. The findings imply that adopters have better access to information and social service, and higher social capital. There is also a significant difference on perception of Brachiaria on milk production suggesting that they had more information on benefits of Brachiaria compared to non-adopters.

On average Brachiaria has a gross margin of Ksh 99,210.89 per acre annually compared to an annual Ksh 44,876.01 per acre from Napier grass suggesting Brachiaria is superior to Napier grass.

Table 1: Demographic and socio-economic characteristics of sampled households

Explanatory Variables	Mean			t-test	
	Control n=126	Treatment n=111	Overall	Sig. (2-tailed)	χ^2-value
Socioeconomic					
Sex of household head (1= male 0 = female)	0.77 (0.422)	0.77 (0.42)	0.77 (0.42)		0.01
Age of household head (years)	54.2 (13.94)	58.85 (13.12)	56.38 (13.38)	2.70***	
Formal schooling by household head (Years)	10.33 (8.93)	10.71 (3.62)	10.51 (6.96)	0.43	
Dairy Farming experience (Years)	11.04 (13.94)	12.65 (11.16)	11.79 (12.18)	1.01	
Experience in Fodder production (Years)	9.99 (8.83)	10.14 (10.23)	10.05 (9.49)	0.12	
Household size (Count)	5.58 (2.4)	5.9 (2.91)	5.74 (2.65)	0.9337	
Main Source of household income (1= Off-Farm 0 = Farm)	0.66 (0.48)	0.76 (0.43)	0.70 (0.46)		2.72*
Farm Characteristics					
Farm size (acres)	2.96 (2.82)	4.37 (5.22)	3.62 (4.17)	2.62***	
Land Tenure (1=owned with title 0=otherwise)	0.56 (0.50)	0.69 (0.46)	0.62 (0.49)		4.78**
[1]Tropical Livestock Unit (TLU)	6 (4.2)	9.36 (9.20)	7.58 (7.18)	3.68***	
Breed Type (1= exotic breed 0 = otherwise)	0.61 (0.49)	0.91 (0.29)	0.75 (0.43)		28.18***
Cash crop farming	0.37 (0.48)	0.44 (0.5)	0.4 (0.49)		1.43
Farmer perception					
Perception on milk productivity	3.45 (0.68)	4.27 (0.55)	3.83 (0.74)		100.30***
Institutional Variables					
Group membership (1= yes 0 = no)	0.6 (0.49)	0.87 (0.33)	0.73 (0.44)		21.94***
Access to credit (1= yes 0 = no)	0.3 (0.46)	0.4 (0.5)	0.37 (0.48)		5.60**
Access to extension (1= yes 0 = no)	0.60 (0.49)	0.84 (0.37)	0.63 (0.48)		47.88***
Outcome Variable					
Gross Margin per acre (Ksh)	44876.01 (46618.65)	99210.89 (85421.02)		6.15***	

Source: Survey Data 2018

1. The tropical livestock unit (TLU) conversion factor is based on Storck et al. (1991): sheep and goat = 0.13, cow and ox = 1, calf = 0.25, weaned calf = 0.34
2. ***, ** and * represent significance at 1%, 5% and 10% probability levels, respectively. (Standard deviation) in parentheses
3. Land tenure refers to ownership of land (with and without title)

4.2 Determinants of Brachiaria Grass adoption

The first stage of the endogenous switching model is a probit regression that evaluates factors that influence adoption of Brachiaria grass and results are presented in table 2. The first two column is a normal probit while the last two columns show the joint probit estimated using endogenous switching regression.

Table 2: Determinants adoption of Brachiaria (probit model)

	Independent Probit model for Adoption		**Joint Estimated Probit**	
Variables	**Coef.**	**Std err**	**Coef.**	**Std err**
Constant	-7.636***	1.042	-7.321***	1.005
Socioeconomic				
Sex of household head (1= male 0 = female)	0.022	0.26	-0.041	0.26
Age of household head (years)	0.023**	0.01	0.020**	0.01
Years of schooling of household head (Years Completed)	-0.02	0.019	-0.017	0.018
Dairy Farming experience (Years)	0.004	0.011	0.004	0.011
Experience in Fodder production	-0.032**	0.016	-0.034**	0.016
Household size (Count)	0.005	0.042	-0.002	0.0421
Main Source of household income (1= OffFarm 0 = Farm)	0.041	0.244	0.113	0.2462
Farm Characteristics				
Farm size (acres)	-0.018	0.044	-0.006	0.046
Land Tenure (1=owned with title 0=otherwise)	0.086	0.242	0.042	0.242
Tropical Livestock Unit (TLU)	0.064***	0.024	0.065***	0.025
Breed Type (1= local 2 = cross-breed 3= pure breed	0.751***	0.194	0.706***	0.189
Cash crop farming	-0.116	0.232	-0.079	0.229
Farmer perception				
Perception on milk productivity	1.036**	0.169	1.02***	0.166
Institutional				
Group membership (1= yes 0 = no)	0.618**	0.282	0.537**	0.269
Access to credit (1= yes 0 = no)	0.145	0.22	0.174	0.221
Access to extension (1= yes 0 = no)	0.448*	0.25	0.48**	0.245
Number of observations	237		237	

Source: Survey Data 2018

***, ** and * represent significance at 1%, 5% and 10% probability levels, respectively.

The coefficient for age is positive and significant implying that older farmers are more likely to adopt Brachiaria than younger farmers. This concurs with previous findings by Asfaw et al., (2012) who suggested the role of experience (associated with age) in adoption of improved pigeonpea in Tanzania. Additionally, benefits from established fodder are not immediate in comparison to oneseason crops such as maize. Moreover, it requires a longer time period to realize the returns (Holmann et al., 2004). In fodder production enterprises the benefits can be manifested in an improvement in milk production or from a year's sale of the fodder. Older farmers therefore would be patient enough to invest in fodder and wait later to reap the benefits compared to younger farmers. The coefficient for years of experience in fodder production is negative and significant suggesting farmers who have more experience in fodder production are less likely to adopt Brachiaria. This is likely because farmers with more experience have technical knowledge on fodder production from the alternatives they have tried over the years compared to farmers who are initiating fodder production using new fodder technology.

Indicators of wealth of farmers (herd size given by TLU and breed type) were positive and significant implying that farmers with larger herd sizes and better breed types are more likely to adopt Brachiaria. The findings corroborates with those of Kassie et al., (2018); Khan et al., (2014); Murage et al., (2015a); Murage et al., (2015b) that ownership of dairy cattle increased adoption of push-pull technology in that they can utilize the Brachiaria produced. Therefore, ownership of productive resources such as livestock creates the need for farmers to source for adequate quantities of fodder even in feed scarcity periods.

Farmer's perception that Brachiaria increases milk productivity was significant and positive. If farmers perceive Brachiaria results in increased milk production then they are more likely to adopt Brachiaria. The results corroborate those of Murage et al., (2015b), who observed that farmers adopted push-pull that utilizes Brachiaria over the conventional one that uses Napier grass since it results in other benefits such as increased fodder in dry seasons and increased milk production. Murage et al., (2015b) notes that farmers preferred the technology as it resulted in increased cereal production, improvement in soil fertility and reduction in *Striga* weed infestation. Therefore, as noted by Adesina & Zinnah, (1993) farmers' perception on the attributes and effectiveness of a technology affects adoption of the technology.

The coefficient for group membership was positive and significant implying that membership to a social group increases the probability of adopting Brachiaria. The results points to the important role of social capital in adoption of technology. The findings are similar to those of Kassie et al., (2015) that farmers who were in social groups were more likely to adopt sustainable intensification practices such as improved crop varieties and fertilizer. Social networks facilitates flow of information such as new opportunities in farming, access to markets, finance and inputs. Social groups in a society act informal insurance to crisis such as lack of finance and food shortages (Quisumbing, 2003).

Access to extension was associated with adoption of Brachiaria in that farmers who had access to extension services were more likely to adopt the improved fodder. This is probably due to the fact that extension service facilitates awareness and flow of information, access to training on new technology and the benefits associated with it. The findings are consistent with those of Kassie et al., (2015) that access to extension service was associated with increased adoption of soil and water conservation technologies in East and Southern Africa.

4.3 Determinants of the magnitude of opportunity cost of adopting Brachiaria grass

As earlier noted, the mean gross margin (GM/acre) for Brachiaria is greater than GM/acre for Napier (table 1). Results of the second stage endogenous switching regression explaining the variation in opportunity cost (differences in the GM) are presented in table 3.

Table 3: Determinants of opportunity cost of growing Brachiaria

	Treatment		Control	
Variables	**Coef.**	**Std err**	**Coef.**	**Std err**
Constant	9.3492***	1.143	8.359***	0.506
Socioeconomic				
Sex of household head (1= male 0 = female)	0.402	0.265	0.149	0.2
Age of household head (years)	-0.002	0.012	0.001	0.007
Years of schooling of household head (Years Completed)	0.03	0.031	0.005	
Dairy Farming experience (Years)	0.002	0.015	0.005	0.009
Experience in Fodder production	0.006	0.017	0.005	0.014
Household size (Count)	-0.024	0.036	-0.062*	0.035
Main Source of household income (1= OffFarm 0 = Farm)	-0.052	0.261	0.488***	0.182
Farm Characteristics				
Farm size (acres)	0.122***	0.027	0.074**	0..035
Land Tenure (1=owned with & without title 0=leased in)	0.464*	0.256	-0.355**	0.183
TLU	-0.017	0.015	0.042*	0.025
Breed Type (1= local 2 = cross-breed 3= pure breed	0.041	0.204	0.437***	0.15
Cash crop farming	-0.065	0.212	-0.194	0.204
Institutional				
Access to credit (1= yes 0 = no)	0.121	0.209	-0.052	0.184
Access to extension (1= yes 0 = no)	-0.119	0.324	-0.057	0.197

r1r2	-0.282	0.315	0.629**	0.271
$\rho_1\rho_0$	-0.275	0.291	0.558**	0.187
LR test for joint independence		5.81**		
Log likelihood		-414.568		
Number of observation		237		

Source: Survey Data 2018
***, ** and * represent significance at 1%, 5% and 10% probability levels, respectively.

The estimates of coefficients of correlation between the error terms in the adoption equation and the outcome equation given by ($\rho1$, $\rho0$) is significant and positive only for the correlation between adoption equation and gross margin for Napier equation. This implies that Napier grass farmers get relatively lower gross margins than what Brachiaria grass farmer would have obtained. Therefore, the opportunity cost of growing Napier is higher than that of growing Brachiaria. Furthermore, the significance of the two systems of equations (r1r2) suggests evidence of self-selection in the adoption of Brachiaria and the justification for using endogenous switching model. Moreover, the likelihood ratio test for selection and outcome equations is significant implying there is dependence between the two system equations.

The results indicate that the opportunity cost of growing Napier in favor of Brachiaria increases with land tenure system. If farmers own the land with title they earn less gross margins from Napier compared to farmers who would lease land. This is probably because farmers with leased land would tend to use more inputs and maximize on the leased fodder land as opposed to when they own. On the contrary, the opportunity cost of growing Napier reduces with land sizes. Farmers with more land for their fodder tend to have more gross margins. The case is similar to ownership of larger herd sizes (TLU) and better breed type. More resource endowment makes it possible for farmers to invest and get higher gross margins on Napier. The results further indicates that having off-farm income sources tends to increase the gross margins from Napier thereby reducing the opportunity cost. Farmers are able to buy inputs such as fertilizer that results in higher yields from Napier and consequently earn more profit Mutoko, Ritho, Benhin & Mbatia, (2015) notes that farmers that earn off-farm income are able to get hired labor thus had better allocative efficiency in maize production. Furthermore, farmers have better financial capacity that enables them purchase farm inputs in good time. This contributes to higher output and returns and thus higher gross margins from Napier.

Family sizes a proxy for family labour increases the opportunity cost of growing Napier grass. This is probably because family members who provide primary family labour provide it beyond the optimal quantity since it is not paid a wage. Large families do not have comparative advantage in productive use of labour. Therefore, returns from Napier grass production are much lower compared to Brachiaria. This is consistent with the findings of Mutoko et al., (2015) who found that household size reduces the technical efficiency of farmers in producing maize.

4.4 Average effect of adopting Brachiaria grass

Table 4 presents the average gross margins for Brachiaria and Napier grass. To determine if the opportunity cost of Brachiaria is greater or smaller for adopters had they not adopted or non-adopters had they adopted, we computed the transitional heterogeneity effects given by the difference in opportunity for Brachiaria and Napier grass (ATT & ATU).

Table 4: Opportunity cost of growing Brachiaria grass

	Napier grass (Opportunity Cost)	Brachiaria grass (Opportunity Cost)	TH (ATT - ATU)
Annual Gross Margin per acre (Ksh)	57998.17 (57998.17)***	65996.33 (24466.27)***	7998.16

Source: Survey Data 2018
***, ** and * represent significance at 1%, 5% and 10% probability levels, respectively.

The transitional heterogeneity (TH) is positive (Ksh 7998) implying that there are systematic differences among the farmers. Farmers who actually adopted Brachiaria grass had higher gross margins and therefore have lower opportunity cost than Napier grass farmers. Therefore, Napier grass farmers are worse off compared to Brachiaria farmers if they are to consider fodder production as a business.

5 Conclusion and Policy implication

Climate-smart Brachiaria grass offers farmers in the drier agro-ecological zones with an opportunity of not only dairy production but also to participate in the emerging fodder markets. This study sought to determine the opportunity cost of producing Brachiaria grass compared to Napier grass production using endogenous switching regression approach.

Econometric results from the study indicate that farmers stand to benefit more financially from Brachiaria compared to Napier suggesting that there is need to expose more farmers to the technology. The empirical results from the study show that adoption of Brachiaria grass is significantly and positively influenced by age, asset endowment (given by herd size, type of breed), group membership, access to extension and farmers' perception on milk production. Similarly, the magnitude of the opportunity cost increased as result of land tenure system. Household size and asset endowment (farm size, breed type, herd size and off-farm income) reduced the magnitude of the opportunity cost of growing Brachiaria. These factors therefore indicate the need for increased fodder production knowledge and skills as a component of dairy management. Efforts are needed to strengthen extension services and existing rural collective institutions to create awareness and promote existences of improved fodder technology. There is need for an effective multi-stakeholder partnership to promote the technology and disseminate it to farmers.

This suggests further research on accessibility to seeds and seedlings for improved fodder. Similarly further research should also focus on improving farmers' access to fodder markets.

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Conflict of interest

The authors declare that we do not have any conflict of interest with the organization that sponsored the research.

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