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Research article

Is adoption of modern dairy farming technologies interrelated? A case of smallholder dairy farmers in Meru county, Kenya

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ABSTRACT

Attempts have been made to promote the adoption of modern dairy farming technologies (MDFT). However, the adoption of these technologies largely remains underutilized. This study aimed to analyze the determinants of the adoption of MDFTs in Meru County. Using purposive and proportionate sampling techniques from 355 smallholder dairy farmers in Meru County, Kenya, this study analyzed the factors that facilitate or impede the adoption of MDFTs. We use a Multivariate probit (MVP) to evaluate adoption decisions by dairy farm households facing multiple MDFTs. The results reveal a significant correlation among the eight MDFTs suggesting that modern technologies are interrelated. The MVP model results indicate that household income, education level, number of extension contacts, access to credit, farmer group membership, farming experience and livestock monetary value had positive effect on the adoption of MDFTs. Education level and extension contacts had a positive influence on the adoption of fodder establishment and preservation technologies. Farming experience in dairy farming had a positive effect on the adoption of well-structured and clean sleeping areas, and the growth of Rhodes grass. Household income had a positive effect on the growth of Rhodes grass and feed mixture. This work illustrates a need for a policy implication and insight into a need for the county government and private milk processing companies to increase extension frequency to enhance the adoption of MDFTs. Additionally, there is a need to increase access to affordable credit, this should be considered by the government by establishing strengthening a smallholder low-interest and efficient local credit schemes and institutions.

1. Introduction

Globally the agricultural sector plays a strategic role in improving the availability of food and achieving food security [1]. However, while there is general agreement on the increased global demand for food to be expected in the coming decades, there is uncertainty surrounding global agriculture's capacity to service this demand through an expansion in the food supply [2]. Better food provision ensured by increasing agricultural production and expanding the range of agricultural land use seems to be a possible method to eradicate hunger [3]. The dairy sector plays an important role in helping to nourish the world, producing 881 million tonnes of milk in 2021, a number that increases every year [4]. More than 80 % of the world's population, or about 6 billion people, regularly consume

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liquid milk or other dairy products. Approximately 150 million households around the globe are engaged in milk production [4].

In most developing countries, milk is produced primarily by smallholders, and milk production contributes to household livelihoods, food security and nutrition [5] Modern dairy farming technologies ensure farmers experience higher milk yields, higher production efficiency and reduced labor costs. Despite the merits of the technologies, adoption levels of these technologies have been low among smallholders in developing countries [6]. Milk provides relatively quick returns for smallholder producers and is an important source of cash income [7]. However, the existing dairy farming technologies and knowledge is inadequate to enable smallholder farmers to produce milk that meets the demand in the market [8]. Common MDFTs such as the adoption of milking machines and new breeds of dairy animals are capital intensive limiting their adoption levels [9]. This shows the need to expand investments in agricultural research and extension systems in developing countries to improve the dairy sector [10].

In addition, there is a need to invest in dairy farming technologies that will push African agriculture toward higher production without severe environmental degradation [11]. The transfer of technology from developed to developing countries should be promoted to support compatible modern dairy practices. This is to minimize technology gaps and overcome knowledge barriers [12]. A deeper comprehension of the barriers that stifle small-scale dairy farmers' adoption decisions of the MDFT is essential for creating pro-poor policies that might encourage and stimulate its adoption and raise milk yield. Notwithstanding the multiple benefits of adopting the MDFT, it is unclear why the adoption rate is still very low. Also unclear from the existing body of literature what are the underlying determinants of MDFT adoption. Furthermore, we consider eight MDFTs as farmers adopt many of these technologies simultaneously to boost farm productivity. The eight MDFTs considered in this study are correlated in three aspects namely; fodder establishment technologies (FET) fodder preservation technology (FPT) and dairy equipment technology (DET) aspect missing in the existing literature.

In Kenya, the dairy industry accounts for 14 % of agricultural Gross Domestic Product [4]. The industry supports a range of actors including farmers, milk traders, processors, consumers and several service providers. The dairy industry is regarded as a successful and vibrant industry due to the increasing domestic milk production, processing capacity, per capita milk consumption and export potential [13]. It supports the poor and smallholders who own one to three cows. There is potential for growth of the dairy sub-sector domestically and regionally to meet the growing need for whole, raw, low-fat, and skimmed milk. For instance, Kenya's per capita milk consumption of 110 L per year is the highest in Sub-Saharan Africa and it is expected to rise to 130 L per year by 2030 (National Dairy Master Plan, 2010–2030).

Dairy technologies encompass the use of hybrid animals, improved feed technology and improved management, artificial insemination, value addition, and vaccination among others [14]. Dairy farming in Meru County's rural areas is mainly from a smallholder farming system managed using traditional production methods characterized by poor breeds, poor feeding, poor housing conditions, inferior health care services, and low capital investment. The effect of several technologies such as improved feed production and conservation, clean milk production and use of concentrate minerals and salts among others would be beneficial to improve dairy production. Understanding the extent of adoption of dairy technologies is critical to success of the development and implementation of policies and programmes in dairy industry development.

A study conducted in Kenya by Ref. [15] examined the factors influencing smallholder dairy farmers Technical Dairy Innovations (TDIs) such as improved cow feeding and health management among smallholder dairy farmers established that; the education level of the household head, number of dairy cows, and access to credit positively influenced the adoption of TDIs while farm size, household income and dairy information access positively influenced the adoption intensity of TDIs. Also, a study conducted in Tanga region, Tanzania by Ref. [16] established that positive community attitude and recognition of ecological benefits by smallholder farmers positively and significantly influenced adoption of improved forages in dairy production systems.

However, institutional factors like market conditions negatively affected the adoption of improved forage in the region. A study by Ref. [17] on smallholder dairy farmers in rural Bangladesh considered four improved DFTs namely; concentrate feed, deworming, artificial insemination, and vaccination. In this study, access to extension contacts and information access to farmers through radio and television positively influenced the adoption of these improved technologies. Animal welfare is considerably becoming vital in dairy animals' production. In developing countries, the welfare status of animals can range from the feeds given to the animals to the sleeping area as a way of boosting milk yields [18].

Most smallholder dairy farmers keep their animals under zero grazing units constructed primarily using wood and metallic rails. Fodder scarcity and low quality have affected the productivity of dairy animals in Kenya. Increased education levels and herd size were found to positively influence the adoption of multiple technologies among dairy farms in Ethiopia that employed negative binomial regression [19]. High-quality feed promotes growth, reproduction and overall animal health [20]. Access to extension services was found to have a significant effect on the uptake of crossbred cows DFT among smallholder farmers in Manipur [21]. A study by Ref. [22] that evaluated the measurement of production inefficiency and inefficiency heterogeneity setting results and results analyzed using maximum likelihood frontier model results showed inefficiency was overestimated when heterogeneity is not accounted for suggesting technology heterogeneity dominates inefficiency heterogeneity when tabulating conditional and unconditional probabilities.

Dairy farming plays an imperative role in the study area due to the reason for small land holding size that diversifies farmers to engage in crop and livestock-integrated mixed farming systems [23]. In addition, it is an important farming enterprise in the area due to its agro-ecological characteristics [24]. For instance, Imenti South has 40,000 dairy cattle and 37,000 households produce an average of 2100 L/cow/year [25]. This is slightly above the national average of 1800 L/cow/year documented in the national dairy master plan [23]. Improved dairy feed technologies promotion efforts have been made by different organizations because the County has potential and is close to urban market centers and there is a presence of milk cooperatives in the area. To increase the milk supply for users and milk collector cooperatives, dairy feed technologies have been disseminated to dairy farmers for a long time [23].

Dissemination of technologies and training has been offered to farmers and professionals by government and other non-governmental organizations [26]. However, there is scanty information on the factors influencing the adoption of these dairy feed technologies since the adoption of these technologies is still low. Therefore, this forms the basis of this study to evaluate the factors affecting dairy farming technology adoption among smallholder dairy farmers in Meru County, Kenya.

The current study adds to the expanding body of research on adoption which has been widely done [19,27–29]. Our study addresses the following specific research questions.

Q1. What factors determine the adoption of dairy farming technologies among smallholder farmers in Meru County?

Q2. Do smallholder dairy farmers in Meru county adopt MDFTs simultaneously?

The significance of this study lies in two main areas: first, it examines techniques that acknowledge the interdependence of various dairy practices and simultaneously analyzes the decision to adopt MDFTs. It determines how the various technologies correlate with each other and how such correlations can be explained. It also aids in the formulation of development practitioners' and policymakers' strategies for advancing MDFTs. Second, the study focuses on the relative significance of MDFT classified as sweet potato vines, rhodes grass, lucerne hay, silage, milking machines, feed mixture, and clean soft sleeping areas that have not been considered in previous literature and are the most prevalent among smallholder farmers in this area. The following sections are structured procedurally starting with the econometric framework and estimation strategies, then a summary of the study area, sample size and sampling, results and discussions and lastly conclusion and recommendations.

2. Econometric framework and estimation strategy

Due to agricultural complexities and in particular the dairy sector, farmers must adopt several strategies and technologies to address present day dynamic dairy sector challenges. Adoption of simultaneous multivariate technologies is inevitable among dairy farmers, [30]. The dairy farming technologies adopted by farmers are interrelated; as adoption of one of the technologies leads to adoption of others.

2.1. *Multivariate probit model*

This econometric specification used the MVP model to analyze the determinants of dairy farming technologies adoption among smallholder dairy farmers in Meru County, the adoption of specific technologies is not independent of other technological choices on the same farm. The MVP accounts for the error term correlation. The MVP simultaneously models the relationship between a set of

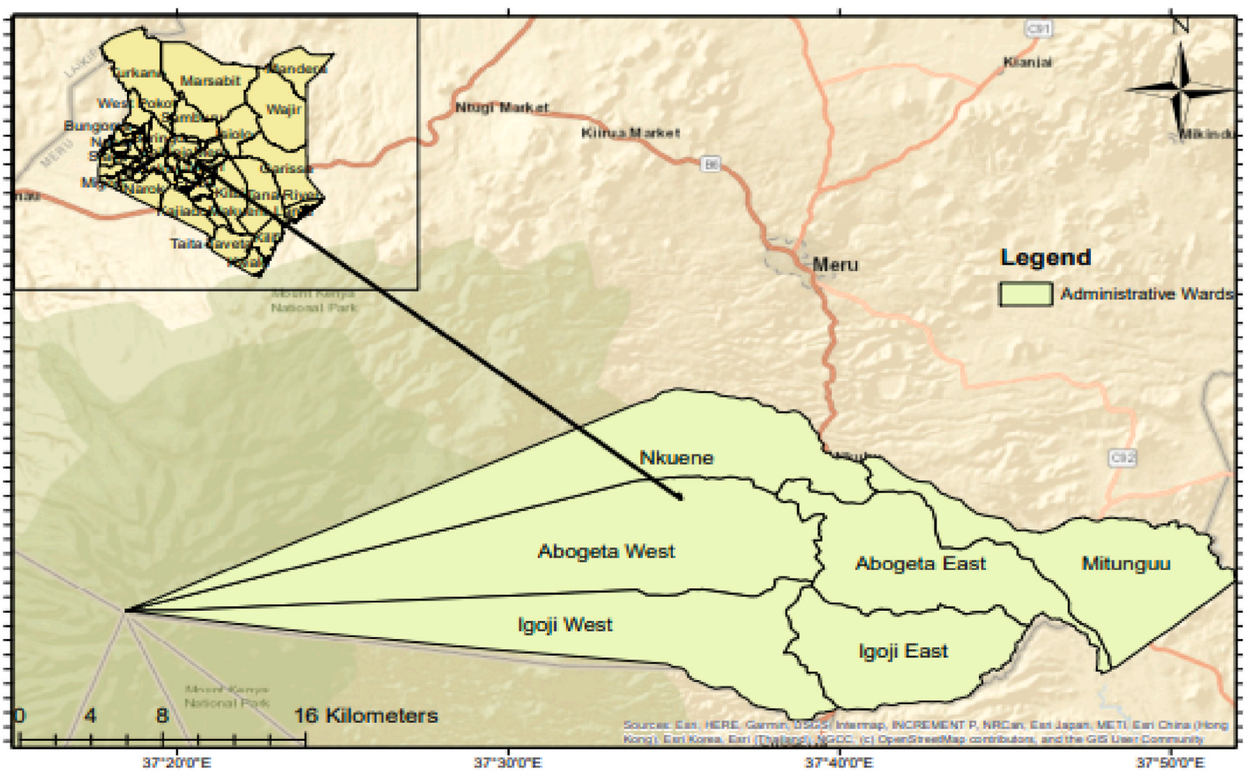

Fig. 1. Map of the study area (authors source, 2023).

covariates and each of the different technologies, while allowing unobserved and unmeasured factors to be correlated. Correlation between different adoption decisions may be due to technological complementarities and substitutability. The MVP model consists of eight binary choice equations, namely sweet potato, rhode grass, lucern, silage, hay, milking machine, feed mixture and clean soft. We therefore have eight dependents binary variables. Considering 355 households facing a decision on whether or not to adopt the variable DFTs. Let U_0 represent the benefits the farmer from whether or not to adopt the available DFTs. use of traditional dairy farming methods, and let uk represent the benefits of adopting the eight technologies. The multivariate probit model is specified as below;

$$Y_{ipk} = X_{ip}\beta_k + +\varepsilon_{ip} \quad (1)$$

Y_{ipk} Refers to the net benefit that farmer derives from adopting the K^{th} MDFTs. X refers to the latent explanatory variables which comprise of socio-economic and institutional factors. ε refers to the error term. The observed binary outcome equation for each technology adopted is described below:

$$Y_{ipk} = \{1 \; if \; Y_{ipk} > 0, and \; 0 \; otherwise\} \quad (2)$$

3. Study area, sampling, data collection and variable description

The study was conducted in Meru County. The county borders four other counties, namely, Isiolo to the north, Tharaka Nithi to the southwest Nyeri to the southwest and Laikipia to the west the area lies between latitudes 300 and 5199 m above sea level the climate is cool and warm. Meru County comprises nine sub-counties. The current study was based in the Imenti South sub-county. (Fig. 1). Imenti South Sub-County was selected based on its dominance in dairy farming. The Sub-County has a total population of 206,506 [31]. The Sub-County lies between latitude 00° N and 05° N and longitude 35° E and 37° E. The temperatures in the area range between 12.4 °C to 24.5 °C with an average rainfall ranging from 800 mm to 2000 mm per annum [32]. The long rains occur between the months of March and June while the short rains fall between October to December. The main cash crops grown in the area are tea and coffee. The main food crops grown include banana, maize, sorghum, cassava and millet. Due to the small portion of land owned, farmers have turned to practice substantial dairy keeping. The main livestock in the area are cattle, goats, pigs, sheep poultry and rabbits. The main dairy cow breeds available in the region are Friesian, Ayrshire, Jersey and Holstein Friesian with an average of 2–3 dairy cows per household [26].

3.1. Target population and sample size

This study considered 37,000 dairy farming households in Imenti South Sub County [23]. This consisted of the smallholder farmers in dairy groups and those who did not belong to any group. The sample size was calculated using the [33] as shown below;

$$n = \left(\frac{p(1-p)}{\frac{e2}{z2} + \frac{P(1-P)}{N}} \right) \Big/ \text{R}$$

Where n is sample size, N-is 37,000, P is the estimated variance (0.3), e is the desired precision (0.05), z is the confidence level (95 % = 1.96) and R is the response rate 90 % (0.9). The sample size was calculated as;

$$n = [0.3(1-0.3) \div (0.05^2 / 1.96^2) + (0.21 / 37,000)] \div 0.9[0.21 \div 0.000] \div 0.9000 = 355 \text{ dairy farming households.}$$

3.2. Sampling technique and data collection

The sampling of dairy farmers in the study area was selected using purposive and proportionate sampling techniques. Imenti South sub-county was selected purposively due to its dominance in dairy farming, unlike the other eight sub-counties of Meru County. Additionally, the area ecological zones favor the implementation of MDFTs. In the first stage, the village units in the six wards were selected purposively based on the dominance of dairy farming. Secondly probability proportionate to size technique was used to determine the number of dairy farming households to be interviewed in each selected village unit. The number of dairy farming

Table 1
Imenti South (study area) wards, village units No. and their sample sizes.

Sampled wards	No of village units	Total hhs	Sampled hhs
Abogeta East	24	8970	86
Abogeta West	16	5980	57
Igoji East	22	4980	48
Igoji west	15	5606	54
Nkuene	16	9222	88
Mituguu	6	2242	22
TOTAL	99	37000	355

households from each ward was determined by applying the Proportion to size formula where the number of dairy farming households in each ward was divided by the total number of dairy farming households in all six wards and then multiplied by the sample size. A well-structured questionnaire was used to collect primary data from the smallholder dairy farmers. The data collected included adoption of dairy farming management practices such as fodder production of different categories such as sweet potato vines and silage, hay Rhodes grass, lucern and slage dairy farm equipment, improved breeds, and land acreage under fodder [Table 1]. shows the wards in Imenti South Sub-County and sampled households.

3.3. Variable description

The dependent variables considered in this study are outlined in [Table 2] comprising of dairy farming technologies namely; growing sweet potato vines, Rhodes grass, hay, silage, lucerne, usage of milking machine, clean and soft sleeping area and feed mixture while the independent variables will comprise of socio-economic and institutional factors such as age, gender, household size, farm size, access to credit and extension services among others.

Establishment of sweet potato vines and Rhodes grass is widely adopted by a sizeable number of dairy farmers as they help farmers cut on the feeding cost and these feeds boost milk yields. Silage is dry matter that has more energy and more digestible than hay and has high fiber content (15–27 %). Due to high digestibility its preferred by dairy farmers as it boosts milk output. Hay has a high protein content key to heifers and as well as dairy cows as it is essential in maintaining and repairing body tissues. Adoption of hay feed provides dairy cows with vitamins and minerals such as vitamins E, K and A.

Lucerne not only influences milk yield, but environmentally improves soil structure and reduces erosion. This technology is key to dairy farmers in the study area because it can tolerate drought during the dry season. Usage of milking machines extract milk from cows using a vacuum attached to the end of the teat to suck the milk and convey it to a container. In the study it was only adopted by few farmers who practice intensive dairy farming. The clean and soft sleeping area is a technology that ensures cows sleep in a draught-free and ambient area that is free of cow dung and urine. Lastly, feed mixture ensures that dairy cows are given feds with the right nutrients at the right time to boost milk yields.

4. Results and discussion

4.1. Descriptive statistics

The results presented in [Table 3] show the descriptive statistics of the respondents in the study area. The results indicate that 54.08 % of the interviewed respondents were male while 45.92 % were female farmers. The mean age of the farmers who practiced dairy farming and were interviewed was 59 years. This implies that majority of the farmers who had adopted the dairy farming technologies were aged and this might be due to long-term experience in the dairy sector. The mean household size among the respondents was 5 people. The mean number of years spent in school by the dairy farmers in the study area was 10 years and this implies that majority of the farmers who had adopted the dairy farming technologies had attained the basic secondary education. The results

Table 2
Variable definitions and measurements used in the MVP model.

Variable	Measurement
Dependent variable	
Sweet potato vines	Dummy (1 = yes, 0 = no)
Hay	Dummy (1 = yes, 0 = no)
Rhodes grass	Dummy (1 = yes, 0 = no)
Milking machine	Dummy (1 = yes, 0 = no)
Clean soft	Dummy (1 = yes, 0 = no)
Feed mixture	Dummy (1 = yes, 0 = no)
Lucerne	Dummy (1 = yes, 0 = no)
Silage	Dummy (1 = yes, 0 = no)
Independent variable	
Gender	Dummy (1 = yes 0 = no)
Age	Years
HH size	Number
Education level	years of schooling
Farming years	Years of experience
Feeding times	NO of times per day
Chaff cutter	Dummy (1 = yes 0 = no)
No. of extension contacts	Number of days
Livestock monitory value	Amount in KSH
Access to credit	Dummy (1 = yes, 0 = no)
Land ownership	1 = tile deed, 2 = without title deed
Household income	Amount in KSH
Milking times	No per day
Labour	1 = family, 2 = hired, 3 = both
Group membership	Dummy (1 = yes, 0 = no)

Table 3
Descriptive statistics analysis of smallholder dairy farmers in the study area.

Variables	Frequency	Percentage
Gender (1 = Male 0 = Female)		
Male	192	54.08
Female	163	45.92
Household head age (years)	Mean = 59; Sdv = 13.78	Min = 30; Max = 90
Household size	Mean = 5.0; Sdv = 1.49	Min = 2; Max = 9
Education (years spent in school)	Mean = 10; Sdv = 4.67	Min = 0; Max = 17
Dairy cattle owned	Mean = 5; Sdv = 1.32	Min = 1; Max = 10
Farm size (acres)	Mean = 3.5; Sdv = 1.72	Min = 1; Max = 10
Feeding times per day	Mean = 1.4 Sdv = 0.49	Min = 1; Max = 2
Milking times per day	Mean = 2.0 Sdv 0.346	Min = 2; Max = 4
Dairy cows owned	Mean = 2.0; sdv 0.98	Min = 1; Max 13
Access to credit		
Yes	128	36.06
No	227	63.94
Group membership		
Yes	285	78.87
No	75	21.13

Authors Source Digital Data Survey (2023); Sdv = Standard Deviation

further indicate that the mean farm size was 3.5 acres implying that the dairy farmers had considerable piece of land from where they can grow animal feed such as sweet potato vines and Rhodes grass.

The mean number of dairy cattle owned by the smallholder farmers in the study area 2 cows. This points to the fact that many of the households have steady flow of milk throughout the year. Also, the average milking times and feeding times per day for the dairy cows among smallholder farmers in Meru County are two and once respectively. Farmers aim at maximizing their milk yields daily that is why they milk at least twice a day. Moreover, the majority (94.08 %) of the respondents who had adopted the dairy farming technologies had access to extension services while 5.92 % did not access the extension services. In addition, only 36.06 % of the respondents had access to affordable credit while 63.94 % had no access to affordable credit. This implies that dairy farmers inadequately access credit which is pivotal in adopting the DFT such as milking machines which are capital intensive.

4.1.1. The adoption rate of the eight modern dairy farming technologies

Out of the MDFTs considered in this study, hay and clean soft sleeping areas were the most widely adopted at 82.82 % and 76.90 % respectively [Table 4]. Farmers consider to have their dairy cows in a clean area that is draught and cow dung-free. Adoption rate of growing of sweet potato and Rhodes grass was 32.29 % and 28.53 % with farmers adopting sweet potato vines higher because they directly boost the dairy cows' yields.

Also, silage was adopted by 38.87 % of the smallholder dairy farmers. 23.38 % of the farmers grew Lucerne in their farms as it is drought tolerant. Usage of milking machines was the least adopted (2.54 %) by farmers probably because they are expensive and fit for large-scale dairy farmers. Furthermore, feed mixture was used by only 9.01 % of the dairy farmers.

4.2. Regression results

4.2.1. Adoption decisions: MVP model results

To determine the factors effecting the adoption of dairy farming technologies among smallholder farmers, a Multivariate probit model was used. The independent variables considered in the modeling include; Household age, gender of the respondent, farming experience, land ownership, number of milking times per day, labor, household income, extension contact, access to credit, market

Table 4
Frequencies of modern dairy technology adopted by farmers.

Dairy technology	Adoption rate (percentage)
Fodder establishment technologies	
Sweet potato vines	32.29
Rhodes grass	28.53
Lucerne	23.38
Fodder preservation technologies	
Hay	82.82
Silage	38.87
Dairy equipment technologies	
Milking machines	2.54
Clean soft	76.90
Feed mixture	9.01

Authors Source Digital Data Survey (2023) assessment and farmers group.

The results of the multivariate probit [Table 5] indicate that household size had a positive effect on adoption of the silage dairy farming technology at 5 % level of significance. The plausible explanation to this is that increased household size increases the family labor force which is key in silage cutting and conservation. This study is in line [19] with where family size was found to positively influence the adoption of dairy farming technologies (DFTs) among smallholder dairy farmers in Ethiopia.

The findings further review that, education level positively influenced the adoption of sweet potato vines, Rhodes grass, hay, lucerne, and silage dairy farming technologies. This indicates that more educated farmers know the need and net importance of adopting different dairy farming technologies to boost their milk yields. This study concurs with [6] study carried out in Central Ethiopia and data analyzed using the multinomial endogenous switching regression revealed that education level had a positive effect on the adoption of improved feed, breed and improved feeding conditions MDFTs.

Based on the results of the study, experience in dairy farming has a positive and significant effect on the adoption of well-structured and clean sleeping areas for dairy cows and the growth of Rhodes grass. This because, farmers who have done dairy farming for several years comprehend the vitality of having clean and dry sleeping area for their cows. A study by Ref. [34] found that farming experience had a positive effect on the adoption of various agricultural technologies among smallholder farmers.

In addition, an increase in household income had a positive effect on the growth of Rhodes grass and feed mixture adoption among dairy farmers. This implies that households with income can buy different types of feeds for their dairy cows and mix them to boost their household milk yields. This result is in line with the conclusion of [35] who established that there is an increased likelihood for the adjustment of the agricultural production systems with an increase in farm income. A study by Ref. [36] also confirmed a statistically significant positive influence of farm income on the adoption of zero grazing as a dairy farming technology.

Several contacts with an extension agent positively and significantly influenced the adoption of planting Rhodes grass, usage of milking machines, Lucerne and silage DFTs at 1 %. This implies that contact frequency between farmers and extension officers helps farmers access information on DFTs from the government and Non-Governmental Organizations. It enables farmers to make relative decisions among the various technologies and select the one that suits their farm. This study collaborates with [37] where extension contacts were found to positively influence the adoption of improved dairy farming technologies such as crossbreed cows in the Wolaita zone, Southern Ethiopia.

An increase in farmers' access to credit increased the probability of farmers adopting clean and soft dairy farming technology. The

Table 5
Factors affecting adoption of dairy farming technologies.

Variable	sweet_potatosvines	hay	Rhodes_grass	Milking machine	Cleansoft	feed mixture	Lucern	silage
Gender	−0.085	0.14	−0.183	−0.351	0.164	0.176	−0.212	0.001
	(0.151)	(0.169)	(0.153)	(0.351)	(0.157)	(0.208)	(0.158)	(0.148)
Age	0.004	0.004	0.004	−0.009	−0.009	0.003	0.003	0.003
	(0.007)	(0.008)	(0.007)	(0.015)	(0.007)	(0.009)	(0.007)	(0.007)
HH Size	0.004	0.127	−0.051	0.116	0.062	−0.171	−0.107	0.160**
	(0.068)	(0.078)	(0.068)	(0.163)	(0.071)	(0.101)	(0.071)	(0.067)
Education_level	0.504[a]	0.236[b]	0.254[a]	0.280	0.044	0.044	0.212**	0.405***
	(0.094)	(0.104)	(0.092)	(0.197)	(0.094)	(0.121)	(0.096)	(0.091)
Farming years	−0.004	−0.016	0.008[a]	0.007	0.016[b]	−0.017	0.002	−0.001
	(0.009)	(0.010)	(0.009)	(0.020)	(0.010)	(0.014)	(0.010)	(0.010)
Feeding times	−0.086	−0.201	0.139	−0.037	0.127	−0.137	−0.157	−0.018
	(0.156)	(0.182)	(0.157)	(0.334)	(0.163)	(0.227)	(0.162)	(0.157)
Chaff cutter	−0.508*	0.285	0.742	9.424	−0.387	4.447	0.075	0.080
	(0.280)	(0.298)	(0.369)	(289.387)	(0.324)	(186.205)	(0.308)	(0.293)
No. of extension contacts	0.089	−0.085	0.300[a]	0.546[a]	0.183	−0.280	0.341[a]	0.348[a]
	(0.104)	(0.122)	(0.106)	(0.210)	(0.114)	(0.161)	(0.108)	(0.107)
Livestock monetary value	0.000	0.000	0.000[c]	−0.000	0.000	−0.000	0.000	0.000[c]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to credit	0.009	−0.031	−0.128	−0.533	0.329**	0.099	−0.011	0.099
	(0.160)	(0.183)	(0.164)	(0.398)	(0.173)	(0.229)	(0.168)	(0.157)
Land ownership	0.140	−0.182	0.187	0.503	0.200	−0.245	−0.044	0.214
	(0.175)	(0.191)	(0.174)	(0.386)	(0.188)	(0.251)	(0.183)	(0.168)
Household Income	0.000	−0.000	0.000[c]	0.000	−0.000	0.000[c]	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Milking times	0.766	0.134	−0.800	1.040	−0.071	−3.926	−0.676	−0.681
	(0.529)	(0.394)	(0.664)	(0.690)	(0.238)	(254.057)	(0.640)	(0.556)
Labor	0.118	0.085	−0.036	0.165	−0.210	0.096	0.079	0.061
	(0.110)	(0.128)	(0.107)	(0.223)	(0.111)	(0.157)	(0.113)	(0.106)
Group membership	0.001[b]	0.000	0.000	−0.000	0.000	−0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Observation	355	355	355	355	355	355	355	355

Standard errors in parentheses.
[a] $p < 0.01$.
[b] $p < 0.05$.
[c] $p < 0.1$.

probable reason for this that farmers who access affordable credit are better positioned to build standard dairy cow housing units that are well-ventilated and free from draught. Likewise, an increase in the amount of credit accessed positively increased the probability of farmers' adoption of agricultural technologies among smallholder dairy farmers [38]. A study by Ref. [39] reported similar findings on the effect of credit on the adoption of dairy farming technologies at the farm level in the Assam region, India. Also, livestock monetary value had a positive and significant on sweet potato vines, hay, clean soft, Lucerne and silage. This implies that farmers who have hybrid dairy cows have invested heavily in feeds.

Farmer's membership in a group had a positive effect on the adoption of sweet potato vine planting dairy farming technology. The results indicate that being a member of farmers group is advantageous to farmers because they can receive extension contacts in the groups and as well acts as a platform for them to learn the importance of feeding the dairy animals high-quality feeds to boost milk yields. In addition, farmers in groups can easily receive training on recommended dairy farming technologies. These findings agree with those of [40] that group membership has a positive influence on farmers' adoption of agricultural technologies among smallholder farmers. Membership in a group is part of the build-up of the social capital of farmers, since it influences access to public resources, particularly in rural areas [41]. Group membership also had positive effect on the adoption of improved feeding techniques DFTs among four selected European Countries namely France, Spain, Germany and Poland and the study employed the endogenous switching regression model [42].

5. Conclusions and recommendations

The dairy farming technologies considered in this study included sweet potato vines, hay, Rhodes grass, usage of milking machines, clean soft sleeping area, feed mixture, lucerne and silage. Adoption of these dairy farming technologies is positively influenced by dairy farming experience, access to extension, farmers' membership to groups, household income, household size, education level and access to credit.

The County government and other relevant stakeholders in the dairy sector should increase extension contact frequency among smallholder dairy farmers to promote various dairy farming technologies. This enhances better decision making and consequently boost the level of adoption of the dairy farming technologies among the smallholder farmers. There is a need to make credit facilities available and affordable to farmers by lowering the interest rate of loans acquired by farmers, thereby facilitating purchase of modern equipment used in dairy production. The government should also create policies that favor creation of new farmer cooperatives to ensure each dairy farmer has cooperative attachment as this will act as a leverage ground for information passage on new MDFTs.

Data availability statement

Data will be made available upon reasonable request from the corresponding author.

CRediT authorship contribution statement

Andrew Kimathi Kirimi: Formal analysis, Conceptualization. **Wilckyster Nyateko Nyarindo:** Writing – review & editing, Supervision, Methodology, Investigation. **Karambu Kiende Gatimbu:** Writing – review & editing, Supervision, Methodology, Formal analysis.

Declaration of competing interest

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

Appendix A. Covariance matrix of the multivariate probit (MVP) model for the 8 MDFTs adopted

	Sweet potatoes	Lucern	Rhodes	hay	silage	Cleansoft	Milk machine	Feed mixture
Sweet potatoes	1.0000							
Lucern	0.1327	1.0000						
Rhodes_grass	0.1376	0.0022	1.0000					
Hay	0.0523	0.0859	0.0063	1.0000				
Silage	0.2413	0.1807	0.2235	0.0901	1.0000			
Cleansoft	0.0004	0.0027	0.0378	0.0212	0.1261	1.0000		
Milking machine	0.1340	0.0933	0.1379	0.0839	0.1171	−0.0177	1.0000	
Feed mixture	0.0058	−0.0112	−0.1129	0.0059	0.0397	−0.0842	0.0572	1.0000

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