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Forage diversity and fertiliser adoption in Napier grass production among smallholder dairy farmers in Kenya

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Abstract

Feed scarcity is one of the major challenges affecting smallholder dairy production in Kenya. Forages are the foundation of livestock nutritional requirements; forage diversification and fertiliser are intensification options that can increase productivity. A sample of 316 and 313 smallholder farmers were surveyed in eastern midlands and central highlands of Kenya, respectively, to establish the types of forages cultivated and the factors that influence fertiliser adoption in Napier grass (*Cenchrus purpureus* Schumach.) production. Independent t-tests were applied to compare the effect of continuous variables on social economic and institutional characteristics between adopters and non-adopters on fertiliser and area allocated to different forages. Chi-square tests were used to compare nominal variables for the proportion of farmers growing different forages, criteria they consider in selection of suitable forages, and social economic and institutional characteristics of adopters and non-adopters of fertiliser. Binary logistic regression was used to determine factors that influence fertiliser adoption. The study revealed that forage diversification was low with Napier grass being the only forage cultivated by most farmers (~90 %). Urochloa (*Urochloa* spp), Rhodes grass (*Chloris gayana* Kunth.) and Guinea grass (*Megathyrsus maximus* Jaq.) were cultivated by less than 11 % of farmers. The fertiliser adoption rate was high (77 %) and was influenced by gender of household head, membership of groups, access to extension services and labour. Future research should focus on promoting of forage diversification and investigate quantity and fertiliser application regimes in order to enable development of appropriate advisory services.

Keywords: binary logistic, dairy cattle, forage diversification, livestock production, smallholder farmers, sown forages

1 Introduction

In Kenya, livestock plays an important role in the national economy with a direct contribution of around 42 % to the agricultural gross domestic product (GDP) and 12 % to the national GDP (World Bank, 2018). Demand for animal products, especially meat and milk, has been reported to increase faster than other agricultural products in Kenya due to increased income and population (Juma *et al.*, 2010; Gakige *et al.*, 2020). Milk demand was projected to increase by 85 % between 2010 and 2050 (Enahoro *et al.*, 2018). In the smallholder mixed crop-livestock system, livestock contribute to food and nutritional security, income generation, source of manure in crop production and social economic development (Behnke & Muthami, 2011). In the central highlands and eastern midlands regions, dairy farming plays an important role in the livelihoods of many farm households in generating income and employment (Njarui *et al.*, 2016). However, the sub-sector may not realize its full potential to meet rising demand due to several challenges.

One of the major constraints to dairy production is seasonal feed scarcity (Odero-Waitituh, 2017). Past studies in the major dairy production zones indicated that between 79 % and 99 % of farmers experience feed shortage during the year leading to low productivity (Njarui *et al.*, 2016). Although most households keep dairy cattle that have potential to produce high quantity of milk, daily milk produc-

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tion was noted to be generally low, averaging 8 kg per cow in central highlands (Muia *et al*., 2011) and 6 kg per cow in eastern midlands region (Mungube *et al*., 2014). The gap between the supply and demand for good quality forage continues to widen due to various constraints, including land limitations, lack of species adapted to different agro-ecological zones (AEZ) and poor management (Gachuiri *et al*., 2017). Rapid population growth and sub-division of land has decreased land available for feed production (Muyanga & Jayne, 2014). Climate change, characterised by low and erratic rainfall, frequent drought, and extreme temperatures, has exacerbated the situation (Ochieng *et al*., 2016; Kogo *et al*., 2021).

Forages are the foundation of livestock nutritional requirements and adequate forages of high nutritional quality are fundamental in ensuring increased livestock productivity (Cheema *et al*., 2011). Moreover, feed accounts for about 70 % of cost in livestock production. To improve livestock production and feed growing livestock population, forage production needs to increase.

In Kenya, there are only a few species of forages registered for commercialisation. This is primarily due to limited investment in forage research and development as priority is given to food crops. Lukuyu *et al*. (2011) reported that farmers in central and northern rift of Kenya mainly depend on Napier grass (*Cenchrus purpureus* Schumach.) for livestock basal feed. Cultivation of Napier grass has been promoted widely in the past by research organization, extension agents and non-governmental organisations. The over-reliance on Napier grass has made it susceptible to pests and diseases (Farrell *et al*., 2002). In smallholder farms of Kenya, infestation by smuts was found to reduce biomass yield by between 25 and 46 % (Farrell *et al*., 2000) and Napier head smut by 100 % (Mulaa *et al*., 2010). Further, Napier grass is not drought tolerant and has a relatively short productive lifespan of about 4–5 years.

Sustainable forage intensification based on improved forage species and better management practices for increased yields is needed to enhance feed availability. Forage intensification promotes an efficient use of land resources, leading to sustainable development and increased income (Delevatti *et al*., 2019). As available area is usually limited, forage diversification and use of fertiliser are intensification options that can increase yield and quality per unit of land. Diversification is an important mitigation strategy of avoiding over-reliance on a limited number of forage innovations. It increases species diversity and can contribute to enhanced forage productivity (Sanderson *et al*., 2004). Application of fertiliser is one of the most practical and effective ways to improve yield and nutritional quality of forage (Rahman *et al*., 2010). Several studies have shown that fertiliser inputs improved dry matter production of Napier grass (Dokbua *et al*., 2020; Hasyim *et al*., 2014; Pieterse & Rethman, 2002; Rahetlah *et al*., 2014; Zewdu *et al*., 2003) and the crude protein content (Zewdu *et al*., 2002). For example, Rahman *et al*. (2010) showed that application of fertiliser from 150 to 300 kg N ha^{-1} annually increased annual dry matter production of Napier from 4.9 to 6.2 t ha^{-1}. Inorganic or organic fertiliser is also a critical avenue for maintaining soil nutrient balance (Mugwe *et al*., 2009).

Due to diseases affecting Napier grass, there is a need to introduce other available forages to increase the basal feed for livestock. For example, Urochloa grasses have shown to increase milk production by between 15–40 % when fed to dairy cattle compared with locally grown feeds (Muinga *et al*., 2016). Unlike Napier grass, Urochloa is more versatile than Napier grass. While Napier grass is suitable for cut-and-carry feeding systems and for silage making, Urochloa is used in cut-and-carry system, grazed directly by livestock and is conserved as hay and silage. Therefore, Urochloa is a suitable alternative grass for integrating in the farming system for increasing resilient livestock, in addition to enlarging the forage diversification. Inclusion of forage legumes would also improve the feed quality in the system.

To promote new improved forage innovations and technologies such as fertiliser, there is a need to understand the existing diversity of cultivated forages and fertiliser use. Information on the current technologies being adopted by farmers is important to enable development of new dissemination strategies. However, no recent study exists on different types of cultivated forages and extent of fertiliser adoption for forages production among smallholder dairy farmers in semi-arid, sub-humid and humid environments of Kenya. Studies are mainly limited to diversity of fodder trees e.g. Gachuiri *et al*. (2017), Franzel *et al*. (2014) and Wambugu *et al*. (2011). The objective of this study was to establish the level of forage diversification and assess socio-economic and institutional factors that influence the adoption of fertiliser for Napier grass production in smallholder dairy farms in Kenya. The findings will contribute to the pool of existing knowledge on forage intensification based on forage diversification and fertiliser adoption among smallholder dairy farmers.

2 Materials and methods

2.1 *Description of study areas*

Two pilot regions, eastern midlands and central highlands were selected for the study since they represent diverse AEZ and biophysical characteristics. The central highlands range from sub-humid to humid, with well-distributed and reliable rainfall, making the region favourable for a wide range of forage species. The eastern midlands are generally semi-arid and experience erratic and unreliable rainfall with frequent droughts leading to low forage production and feed deficit. Inter-seasonal rainfall variation is large in eastern midlands with coefficient of variation of between 45–58 % (Keating *et al.*, 1992). In central highlands, dairy farming is a major enterprise for smallholder farmers and the region produces a large proportion of national milk supply in Kenya. In the eastern midlands, dairy farming is increasingly becoming important because of favourable milk prices. The study was conducted in Kangundo sub-County and Kirinyaga County in the eastern midlands and central highlands, respectively (Fig. 1). Kangundo is one of the seven sub-Counties of Machakos County and lies between latitude 1.07° and 1.43° South, and longitude 37.09° and 37.43° East, covering an area of 177 km^2. Kirinyaga County lies between latitudes 0°1’ and 0°40’ South and longitudes 37° and 38° East and covers 1,478 km^2.

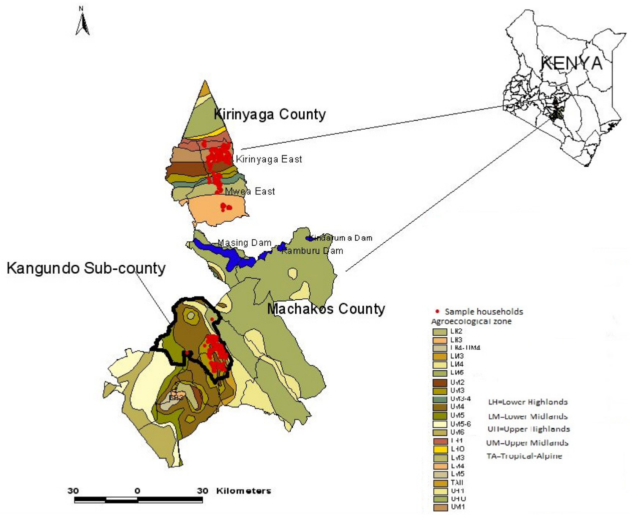

Fig. 1: *Map showing the study areas.*

2.1.1 Kangundo sub-County

The sub-County is characterised by low to medium altitude, rising from 800 to 1600 m above sea level (asl) at Kanzokea hills and Kanzalu ranges. The climate is highly influenced by the seasonal shift and intensity of the low pressure Inter-Tropical Convergence Zone. Rainfall is bimodal with two distinct rainy seasons; the long rains occurring from March to May and short rains from October to December. There is a long dry season from June to mid-October, which results in cessation of forage growth and reduced nutritive quality. The mean annual rainfall is around 800 mm but in the hill masses, it increases to 1050 mm. The temperatures vary from 14 °C to 29 °C with February and September being the hottest and July and August the coolest months. The major soils are Luvisols, Acrisols and Ferralsols (Simpson *et al.*, 1996). These soils are often shallow and contain low organic matter and high sand content.

The farming system is characterised by low-input smallholder crop-livestock production. The main cash crops are coffee in the Upper Midlands (UM) and horticultural fruit trees in the Lower Midlands (LM) AEZ. Maize is the most important cereal and is commonly intercropped with beans, cowpeas and pigeon peas. The main livestock include cattle, goats and poultry. Commercial dairy cattle farming is based mainly on crosses of European breeds and local zebu cattle under zero-grazing feeding system.

2.1.2 Kirinyaga County

The altitude ranges from 1200 to 1700 m asl but on the northern side it rises to 5,200 m at the top of Mt. Kenya. The climate is influenced by the position on the windward side of Mt Kenya. The rainfall pattern is similar to that of Kangundo but the region receives more rainfall. The average annual rainfall increases from 800 mm in the low eastern plains of Mwea to about 2200 mm on the northern parts, towards Mt Kenya. Temperature ranges from 12 °C to a maximum of 27 °C.

The major soil type is Humic Nitosols (Jaetzold *et al.*, 2006). These soils are deep, fertile, and are suitable for forage production. The county is very rich in term of agriculture, with tea, coffee and horticulture being the major cash crops. In Kenya it is the major producer of rice, which is cultivated under irrigation in the lowland areas. Commercial dairy farming is dominant and is an important enterprise for smallholder farmers.

2.2 Data sources

Both primary and secondary sources of data were used in this study. Primary data were collected from a baseline household survey using a structured questionnaire, focus group discussions and key informant interviews. Secondary data were obtained from published literature in journals, books, conference proceedings and annual reports.

2.3 Sampling technique and sample size determination

A multistage stratified sampling procedure was employed for selection of farmers. At the first stage, two diverse regions in-terms of agro-ecology i.e., eastern midlands and central highlands, were purposively selected where farmers practice mixed crop-livestock farming with a significant dairy cattle component. In the second stage, two administrative areas were selected. In Kangundo, the study was conducted in UM 2, 3, 4, and LM 3 and 4 while in Kirinyaga County it was in Lower Highlands (LH) 1, UM 1, 2, 3, 4, LM 3 and 4 (Table 1). In the third stage, a systematic random sampling using probability proportional to sample size as applied by Beshir (2014) was used to select farmers with dairy cattle from a list compiled by agricultural extension officers for each AEZ. This resulted in a sample size of 316 and 313 farmers in Kangundo sub-County and Kirinyaga County, respectively (Table 1).

2.4 *Data collection*

The data was collected using a structured questionnaire after pre-testing and modification to ensure that all the relevant questions were well framed. The social economic data collected covered characteristics of households head including age, gender and level of education, household total income, land size, importance of livestock to food security and use of hired labour while the institutional data included distance to market, group membership and access to extension services and credit. Other data included sown forage species, area allocated to different farm enterprises, selection criteria for suitable forages and use of fertiliser for Napier. Monthly income was derived by aggregating on-farm and off-farm income. Farmers used the Likert scale of 1 to 10 (1 = least important, 10 = most important) to indicate the importance of livestock for household food security. Farmers were requested to provide up to three plant attributes they considered important when selecting suitable forages for their livestock. Adoption reflected a household's decision to apply either inorganic or organic fertiliser or a combination of both during the past two wet seasons prior to the survey. Napier grass was selected for assessment of fertiliser application because it was widely cultivated in both regions. A collective name, 'Urochloa' was used for the local and improved germplasm of Urochloa grasses. The interviews were conducted in either English, Swahili or local language through face to face interviews during individual visits and observations. Trained enumerators, mostly young researchers, and students under supervision collected the data in Jan. and Feb. 2018. The household head or the most senior member of the household present was interviewed and the data recorded in questionnaire sheets.

2.5 *Statistical analysis*

Data analysis was carried out using the IBM Statistical Package for Social Sciences (SPSS) Statistics for Windows version 20 (IBMC, 2011). Descriptive statistics on the mean, standard deviation (SD), and percentages were generated for the different variables. Independent t-tests were applied to compare continuous variables on social economic characteristics between adopters and non-adopters of fertiliser and on area allocated to different forages. Chi-square tests (χ^2) were used to compare nominal variables for the proportion of farmers growing different forages, criteria they consider in selection of suitable forages between sites and social economic characteristics of adopters and non-adopters of fertiliser.

2.6 *Determinants of fertiliser use on Napier grass*

Binary logistic regression was conducted to determine factors that influenced households' decision to use fertiliser on Napier grass. The model is specified as:

$$ln(P - i/(1 - P_i)) = X_t = \varepsilon$$

where X_t is the index reflecting the combined effect of independent X variables that prevent or promote adoption of fertiliser. The dependent variable is the natural log of the probability of using fertiliser (P) divided by the probability of not using fertiliser ($1 - P$), b is the slope and ε is the error term.

The index level can be specified as:

$$X_t = \beta_0 + \beta_i X_i + ... + \beta_n X_n + \varepsilon$$

Where $X_i \dots X_n$ are the independent variables, β_0 is the intercept, β_i is the slope associated with the i^{th} independent variable and ε is the error term.

The dependent variable was adoption of fertiliser with a value of 1 for households that apply fertiliser to Napier grass and 0 for non-adopters. Adopters were households that used either organic or inorganic fertiliser or both types of fertilisers in Napier grass while the non-adopters were households that did not apply any form of fertiliser. The model was estimated using the maximum likelihood method in IBM SPSS Statistics for Windows version 20 software (IBMC, 2011). The independent variables hypothesized to influence the adoption of fertiliser were selected following literature on farm investment theory (Feder *et al.*, 1985). These were gender, age and education of household, income, distance to market, membership of farmers group, land size, important of livestock to food security, use of hired labour, access to extension services and credit.

3 Results

3.1 *Forage diversification*

Farmers had sown different types of forage grasses in their farms, namely, Napier grass, Rhodes grass (*Chloris*

Table 1: *Distribution of sample respondents across agro-ecological zones.*

Site	Agro-ecological zone	Altitude (m asl)	Annual rainfall (mm)	Number of dairy farmers*	Household head		
					Number of males	Number of females	Total
Kangundo sub-county	Upper Midlands 2	1400-1770	1000	214	8	4	12
	Upper Midlands 3	1400-1830	1050	1775	83	23	106
	Upper Midlands 4	1340-1830	950	221	76	18	94
	Lower Midlands 3	1160-1350	850	1520	65	26	91
	Lower Midlands 4	1160-1280	800	1576	12	1	13
Kirinyaga county	Lower Highlands 1	1760-2130	1900	255	11	5	16
	Upper Midlands 1	1520-1820	1550	2794	142	29	171
	Upper Midlands 2	1400-1580	1400	540	27	7	34
	Upper Midlands 3	1310-1400	1200	224	9	4	13
	Upper Midlands 4	1280-1340	1070	340	18	3	21
	Lower Midlands 3	1220-1280	850	400	19	6	25
	Lower Midlands 4	1090-1220	750	547	27	6	33
Total				10406	497	132	629

* Sources: Extension office, Ministry of Agriculture, Livestock and Fisheries

Table 2: *Proportion of farmers growing different types of forages in Kangundo sub-County (n=316) and Kirinyaga County (n=313).*

Forage species	Farmers (%)		χ^2	*P*
	Kangundo	Kirinyaga		
Urochloa grass	11.4	2.2	20.89	0.000
Guinea grass	0.6	0.0	20.0	0.157
Rhodes grass	2.5	1.3	1.35	0.246
Napier grass	91.4	90.4	0.84	0.667

gayana Kunth.), Guinea grass (*Megathyrsus maximus* Jacq.) and Urochloa grass (*Urochloa* spp.) (Table 2). In both areas Napier grass was most widely cultivated by over 90 % of households. Less than 11 % of farmers had cultivated Urochloa, Rhodes and Guinea grass. Only for Urochloa grass a significantly higher (χ^2 = 20.89, $P = 0.000$) proportion of farmers in Kangundo had planted more than in Kirinyaga County. Most of the farmers had also planted some leguminous forage trees, mainly *Calliandra* spp. or *Leucaena* spp. within the homestead or along the farm boundaries, but no active management was undertaken for forage purposes.

The farmers surveyed based their forage choice on seven plant attributes (Table 3), which can be grouped into three categories; agronomic characteristics, ecological adaptation and benefits to livestock production. At both sites most farmers preferred forages that gave high milk yield followed by forages that produced high herbage. High growth rate and high palatability were also important selection criteria. A higher (χ^2 = 11.42, $P = 0.001$) proportion of farmers in Kirinyaga (66.2 %) preferred forages with higher growth rate than in Kangundo (53 %). On the other hand, a higher (χ^2 = 25.75, $P = 0.000$) proportion of farmers (57.5 %) in Kangundo preferred forages that were drought tolerant than in Kirinyaga (37 %). Easy to harvest, pest and diseases resistance were ranked lowly and were not different ($P > 0.05$) between the sites.

Table 3: *Criteria considered by farmers when selecting suitable forage for livestock in Kangundo sub-County (KG; n=316) and Kirinyaga County (KR; n=313).*

Criteria	Farmers (%)		χ^2	*P*
	KG	KR		
High herbage yield	70.9	70.7	0.003	0.957
High growth rate	53.0	66.2	11.42	0.001
Easy to harvest	12.4	16.2	1.91	0.167
Drought tolerant	57.5	37.3	25.73	0.000
Pest and disease resistance	10.2	7.6	1.23	0.268
Highly palatable to livestock	45.7	50.6	1.53	0.217
Livestock produce high milk yield when fed the forage	76.2	78.0	0.300	0.584

3.2 *Fertiliser adoption in forage production*

Of the 629 respondents interviewed, 486 farm households applied fertiliser to Napier grass, indicating an adoption rate

Table 4: *Social-economic and institutional characteristics of adopter and non-adopters of fertiliser use in forage production.*

		Adopters (n=486)	*Non-adopters (n=143)*		
Characteristics	*Unit*	*Mean*	*Mean*	*T*	*p*
Age of household head	Years	55.4	57.1	-1.36	0.063
Distance to nearest market	Kilometres	2.00	1.95	0.28	0.777
Monthly income	Kshs.	28267	22014	2.40	0.017
Land size	Hectares	1.24	1.21	0.21	0.836
Importance of livestock to household food security	1-10*	7.1	6.5	3.57	0.000
	Code	*Percent*	*Percent*	χ^2	*p*
Gender of household head	Male	80.9	72.7	4.41	0.036
	Female	19.1	27.3		
Education of household head	None	3.3	2.1	0.54	0.463
	Educated	96.7	97.9		
Use of hired labour	Yes	37.0	7.7	45.00	0.000
	No	63.0	92.3		
Access to extension services	Yes	38.9	17.5	22.56	0.000
	No	61.1	82.5		
Membership of agricultural group	Yes	60.5	43.4	13.21	0.000
	No	39.5	56.6		
Access to agricultural credit	Yes	38.1	28.0	4.90	0.027
	No	61.9	72.0		

* 1 = least important; 10 = most important.

of 77.3 %. The adopters had higher monthly income and regarded livestock more important for household food security than non-adopters (Table 4). There were also significant differences between adopters and non-adopters based on gender, use of hired labour, membership of agricultural group and access to extension services and credit.

Table 5 shows the estimated coefficients of the binary logistic regression model with the level of significance. The model accounted for 78.2 % of the total variation for the adoption of fertiliser. The model Chi-square was highly significant ($\chi^2 = 99.94$, ($p = 0.000$) indicating that the explanatory variables jointly contribute to explaining the variation in decision of farmers to adopt fertiliser. The fertiliser adoption was influenced by gender of household head, membership of agricultural group, use of hired labour and access to extension services.

Gender of household head was positively ($\beta = 0.512$) and significantly ($p = 0.042$) associated with application of fertiliser to forages, indicating that male headed households were 1.668 times more likely to use fertiliser than female headed households. Membership of an agricultural group was positively ($\beta = 0.459$) and significantly ($p = 0.038$) associated with adoption of fertiliser, suggesting that households who were members of farmers group were 1.582 times more likely to adopt fertiliser than non-members.

Similarly, use of hired labour was positively ($\beta = 2.175$) and significantly ($p = 0.000$) associated with adoption of fertiliser, indicating that households who had hired labour were 8.8 times more likely to adopt fertiliser than households that did not. Access to extension services was also positively ($\beta = 0.965$) and significantly (($p = 0.000$) associated with fertiliser adoption, households who had access to extension services were 2.626 times more likely to adopt fertiliser than households without access.

3.3 Land allocation for forages production

Generally, the land size at both sites was small with households in Kangundo owning more ($p = 0.031$) land (1.36 ha) than their counterparts in Kirinyaga (1.10 ha) (Table 6). Most of the land was allocated to cash and food crops with a considerable part under fallow. The area allocated to sown forages averaged about 0.20 ha at each site, accounting for 14.7 % and 18.2 % of total land owned by household in Kangundo and Kirinyaga, respectively.

Table 5: *Parameter estimates for variables influencing application of fertiliser in forages.*

Explanatory variables	*Parameter estimates (β)*	*Wald statistics*	*p-value*	*Odd ratio Exp (β)*
Gender of household head (1=male, 0=female)	0.512	4.127	0.042	1.668
Age of household head (years)	-0.009	1.183	0.277	0.991
Education of household head (0=none 1=educated)	-0.702	1.009	0.315	0.495
Monthly income (Ksh.)	0.000	0.409	0.523	1.000
Distance to nearest market (km)	0.013	0.041	0.839	1.013
Membership to farmer group (0=no, 1=yes)	0.459	4.308	0.038	1.582
Land size (hectares)	-0.119	3.033	0.082	0.888
Importance of livestock for household food security (1-10)*	0.110	3.701	0.054	1.116
Use of hired labour (0=no, 1=yes)	2.175	34.816	0.000	8.800
Access to extension services (0=no, 1=yes)	0.965	12.883	0.000	2.626
Access to credit (0=no, 1=yes)	0.270	1.355	0.244	1.309
Constant	0.423	0.204	0.651	1.526
Model chi-square		99.94	0.000	
Overall cases correctly predicted		78.2 %		
Sample size		629		

* 1 = least important; 10 = most important.

Table 6: *Area (ha) allocated to sown forages relative to other farm enterprises in Kangundo sub-County (n=316) and Kirinyaga County (n=313).*

	Kangundo		*Kirinyaga*			
Farm enterprise	*mean*	*SD*	*mean*	*SD*	*t*	*p*
Land holding	1.36	1.78	1.10	1.12	4.66	0.031
Homestead	0.15	0.23	0.12	0.08	5.19	0.023
Food crops	0.55	0.60	0.43	0.58	6.30	0.012
Cash crops	0.33	0.43	0.43	0.46	6.83	0.009
Fallow land	0.62	2.23	0.21	0.34	1.56	0.214
Sown forages	0.20	0.20	0.20	0.50	0.001	0.971

SD: standard deviation

4 Discussion

4.1 Forage diversification

Plant diversity is an important ingredient of stable environments and sustainable production systems (Anowarul-Islam & Ashilenje, 2018). Among the countries in the eastern Africa region, Kenya is regarded as a major centre of diversity for many grasses cultivated in the tropics (Boonman, 1993). However, in this study forage diversification was limited, with Napier grass being the only cultivated forage in most households. The grass is widely grown because it is high yielding and easy to establish (Mwendia *et al.*, 2006). As priority is given to food crops to improve food security, research and extension have put limited emphasis on forages which has contributed to lack of knowledge about other suitable forage species. The relatively higher proportion of farmers who had sown Urochloa grass in Kangundo was attributed to promotion of the grass since 2014 (Gatheru *et al.*, 2017), whereas in Kirinyaga no promotion had been undertaken. Research on Urochloa grass in Kenya was initiated in 2011 to improve livestock feed availability. Although Rhodes grass is a major commercial grass in Kenya and is more suitable for drier areas, it was not widely sown even in Kangundo due to limited seed availability.

The involvement of farmers in the research process can lead to increased adoption of improved forages (Garcia *et al.*, 2019) as it helps to identify their preference. Generally, farmers considered several plant attributes before they decide which type of forages to plant, as also observed by Belete *et al.* (2018) in Ethiopia. Besides selecting forages that meet livestock nutrition requirements, farmers are keen on forages that are resilient to abiotic and biotic stresses. Based on climate variation, there were similarities and disparities in criteria for selecting forages between the two sites. For example, Kangundo receives less rainfall and drought is more common than in Kirinyaga, consequently, a high proportion of farmers in Kangundo preferred forages that are drought tolerant. The selection criteria based on milk yield and high biomass production were highly ranked at both sites because farmers are commercially oriented and high milk production leads to high income. High yielding forages were important to maximize production from the small land sizes to bridge the feed gap.

4.2 *Factors affecting adoption of fertiliser*

Several authors have shown that application of fertilisers increases forage yield. The large proportion of farmers who adopted fertilisers was attributed to the fact that fertiliser enabled high forage production and increased profitability. Although the study did not investigate the quantity of fertiliser applied, generally the amounts used are a fraction of the recommended rates as farmers give priority to food crop production and fertilisers are expensive.

Although the factors that determined fertiliser adoption could be related, the logistic regression used in the data analysis was based on independent variables and did not examine interactions between the variables on fertiliser adoption. Consequently the interpretation of the results was made in isolation of other variables. Use of hired labour was the most important factor that influenced fertiliser adoption followed by access to extension services while group membership was the least important. Adoption of new agricultural technologies often requires additional labour, particularly where mechanisation is limited. Hired labour was needed for crop production including fertiliser application to the forages. Consequently, presence of hired labour affected importantly fertiliser adoption. These results are similar to those of Beshir (2014) on adoption of agricultural technology.

Gender gaps on adoption of agricultural technologies have been widely studied in the past. In African countries including Kenya, female-headed households were less likely to use fertiliser compared to male-headed household because women are usually more constrained in resources, like access to land and other assets needed for production (Ali *et al.*, 2018). Beshir *et al.* (2012) had reported similar findings on adoption of sustainable agricultural technologies. Generally, men have more freedom of mobility and more access to information while women are normally occupied with domestic chores (Mutua-Mutuku *et al.*, 2017) and non-commercial activities. Until recently, the social settings and norms limited women from owing land in Kenya, but with the new constitution approved in 2010 women have the right to inherit land and own other property.

Group membership affected fertiliser adoption. Extension agents disseminate information on technologies often through farmers groups and associations. Thus, membership of agricultural groups increases access to information on productivity enhancing technologies. Moreover, groups share productive skills and can influence technology adoption decisions (Kassie *et al.*, 2013; Martey *et al.*, 2014).

Extension agents increase knowledge of farmers on new technologies, empowering them to make informed decision, which improves the chances of adoption (Abebe *et al.*, 2018; Tata & McNamara, 2018). Improved technology adoption as a result of access to extension services was also reported in Ghana (Ali *et al.*, 2018) and Uganda (Ekepu & Tirivanhu, 2016).

4.3 *Implication to feed supply*

Dairy cattle farming is an important source of income in Kenya but feed scarcity and quality are a barrier to high performance. Grasses generally form the major sources of feeds in livestock production systems. The study showed limited forage diversity with Napier grass being the major forage, but due to its quality limitations, Napier cannot provide all the nutrients required for high levels of dairy production. Studies by Bell *et al.* (2018) have demonstrated that livestock farms relying on only one forage source are prone to higher risk of feed gaps. Using a wider range of forage sources can greatly reduce feed gaps and allow more livestock per unit of land. Farmers with on average 0.20 ha of Napier grass can produce about 7 tonnes annually based on a potential annual DM yield of 35 t/ha. However, with the emergence of diseases, the yield is likely to be much lower. Furthermore, the yield of Napier grass from farmers' fields is usually a fraction of its potential due to suboptimal management. For example, Napier grass requires large amount of fertiliser to achieve high production, which is beyond the reach of many farmers. In addition, because the majority of farmers are unable to transform Napier grass into silage at optimal growth stage, the current cut-and-carry system produces overgrown Napier grass of poor quality. Farmers have diversified on other feed sources such as weeds from cropland, crop residues and purchased fodder. However, the quality of these feeds is often low. Although most of the farmers purchase commercial supplements, quantities are not sufficient. Competition for land is high and limits acquisition of more land for forage production. Intensification by integrating other productive, disease and drought tolerant forages and use of fertiliser is a viable option for increased productivity.

5 Conclusions

The study showed low forage diversification, with Napier grass being the main forage cultivated by most farmers. Only a small proportion of farmers cultivated other grasses such as Urochloa, Rhodes and Guinea grasses. Fertiliser adoption rate in Napier grass production was high and was influenced by gender of household head, membership of agricultural groups, use of hired labour and access to extension and advisory services. Use of hired labour was identified as the most critical factor that contributed to fertiliser adoption followed by access to extension services. Future research should focus on promoting other forages to increase forage diversity.

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Conflict of interest

The authors declare that they have no conflict of interest.

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