1. Introduction

Declining soil fertility is a serious problem across sub-Saharan Africa, and a persistent constraint to agricultural production especially in low potential areas, thus posing a major threat to food security and rural livelihoods (Corbeels et al., 2000; Onduru et al., 2001; UNDESA, 2013; Vanlauwe et al., 2017). Many studies indicate that some soils are losing their capacity to provide food and other essential ecosystem services especially in Africa (e.g. Ajayi, 2007; Kiboi et al., 2019; Marenya and Barrett, 2007; Sileshi et al., 2019) due to land degradation and fertility depletion resulting partly from poor soil management practices, over-cultivation and excessive population pressure on soil (FAO et al., 2017).

More than 83% of Africa’s 874 million hectares of arable land (58% of the global arable land) is reported to face serious fertility problems, with more than 75% of the farmlands being classified as severely depleted due to poor soil management practices on the fragile soils, and thus require costly investments to ensure sustained productivity (FAO, 2002).

Many parts in sub-Saharan Africa (SSA) are characterized by highly diversified soils in terms of their chemical, physical, biological characteristics, history and their response to inputs (AGRA, 2009; Chukwuka and Omotayo, 2009). The predominant soils include Arenosols (21.5%),...
Cambisols (10.8%), Ferralsols (10.4%), and Leptosols (17.5%) (Tully et al., 2015). These soils are characterized by deficiency in key elements including nitrogen, phosphorous, carbon and sulphur (Chianu et al., 2012; Krah et al., 2019). They are highly susceptible to erosion because of lack of binding agents such as humus (attributable to low organic matter); they have high phosphorus fixing ability requiring resource poor farmers to apply phosphorus fertilizers more often; and they are generally shallow (e.g. Leptosols) and thus lose soil moisture very easily (Shepherd and Walsh, 2007).

Soil health is a critical ingredient in the effort to address food security challenges, while ensuring environmental sustainability, in the face of a bulging human population (Kurgat et al., 2018).

The integrated soil fertility (ISFM) approach proposed by Vanlauwe et al. (2010a) demonstrates complementarity of the various farm management practices such as inorganic fertilizer and organic resources. The efficiency in agricultural production can be maximized through integration and combination of different components of sustainable soil fertility management based on the biophysical characteristics of the farm (Mugwe et al., 2009). ISFM entails the application of soil fertility management practices and the knowledge to adapt these to the local conditions. It involves simultaneous application of multiple practices in managing soil fertility in an integrated formula to harness from the complementarities among the management practices (Marenya and Barrett, 2007). The ISFM approach is a departure from the belief that each fertilizer is the ‘surest bet’ for success in agriculture (Vanlauwe et al., 2017). It includes the limited and smart use of inorganic fertilizers, application of manure and improved crop varieties, the conservation of soils and their biota coupled with the know-how to adapt these practices to local environment for optimal output and agronomic efficiency of the supplied crop nutrients (Sanginga and Woomer, 2009; Vanlauwe et al., 2010b). ISFM is built on the philosophy that no single soil fertility management technique can stand on its own in satisfying the requisites of increased soil fertility management (Marenya and Barrett, 2007; Place et al., 2003), and that some practices, such as fertilizer type, are site-specific (Adolwa et al., 2019).

However, adaptation of the various fertility management techniques appears to be a challenge as demonstrated by low adoption (Yengoh, 2012). Majority of farming systems in Africa are characterized by low use of inorganic fertilizers, estimated at 21 kg (nutrients) per ha of harvested land per year. The average for sub-Saharan Africa is even lower, i.e. 9 kg per ha of arable land, compared to 200 kg per ha in developed countries.

In Kenya, application rates vary across ecological zones (Oseko and Dienny, 2015), and much less fertilizer is used in the production of food crops (Makokha et al., 2001).

Evidence suggest that farmers’ adoption of technologies vary based on a range of socio-economic, biophysical and institutional factors (Asrat et al., 2004; Nigussie et al., 2017) as well as knowledge and skills on best agricultural practices (Muhanj et al., 2011). Generally, the low adoption of agricultural technology among smallholder farmers in SSA has been attributed to lack of enabling resources (Mugwe et al., 2009; Shikuku et al., 2017) including physical and capital endowments (Marenya and Barrett, 2007; Teshome et al., 2016) such as land (Adimassu et al., 2016), size of livestock units (Adimassu et al., 2014; Asrat et al., 2004), agricultural extension services (Paudel and Thapa, 2004) and credit (Tiwari et al., 2008). Other determinants include family size and on-farm labour (Adimassu et al., 2014; Asrat et al., 2004).

Many studies have explored the adoption of ISFM techniques across various countries and regions, e.g. Mponela et al. (2016) in Southern Africa, Adimassu et al. (2016) in Ethiopia, Ajayi (2007) in Southern Africa, Chinangwa (2006) in Malawi, and Marenya and Barrett (2007) in Kenya. However, understanding the determinants of soil fertility management practices especially in Kenya has received little attention, as a few of these studies have focused on the Kenyan context.

The aim of this paper is to evaluate soil fertility management strategies used by farmers in the Eastern region of Mount Kenya. It explores the various soil fertility management strategies employed by farmers, and examines the correlation between socio-economic, institutional characteristics and the decision to invest in a given soil fertility management practice.

2. Methodology

2.1. Description of the study area

The study was conducted in Mount Kenya East, including 2 counties (Figure 1), namely Meru (0’02’60.00” N 37’37’59.99” E) and Tharaka Nithi (0’17’60.00” N 38’00’00.00” E). The counties are located almost in the middle of the country, on the eastern slopes of Mount Kenya, about 200 km north of the Kenyan capital, Nairobi. The primary land use is rainfed agriculture, with farming dominated mostly by smallholder farmers and diverse agricultural production.

![Figure 1](image_url) Study area on the map of Kenya (a) and location of the study sites within Meru and Tharaka Nithi counties (b).
Meru’s total land area is about 7,000 km², of which more than a quarter is protected forests, with a population of 1,535,635 (KNBS, 2019). Tharaka Nithi County population is estimated at 391,300 people with a land area 2,564 km². Meru has a Human development index (HDI) of 0.57% slightly higher than the national average of 0.56% (CIDP, 2018), while Tharaka Nithi has a HDI of 0.55% (CIDP, 2018).

The region is characterised by a bi-modal rainfall pattern, with longer rains occurring between March to May, and the shorter rains between October to December. There is high variation in rainfall which increases from east to west, with the annual mean rainfall ranging from 300 mm to 2,500 mm. The region’s altitude spans from 300 m (low hills) to 5,199 m (the peak of Mt. Kenya) above sea level. Temperatures range between 8 °C and 32 °C.

Tea and coffee are the major cash crops in the region. Major food crops grown include white corn (maize), bananas, and potatoes. Horticultural crops include fruits (such as mangoes, passion fruit, avocados, watermelon, nuts and pineapples), vegetables (such as snow peas and French beans) and flower farming (cut flowers) (Muriu-Ng’ang’a et al., 2017; Shisanya et al., 2009).

Livestock farming is equally an important means of livelihood, with dairy and beef cattle, goats, sheep and poultry being the most important livestock in the region. Livestock is also an important source of manure. The community also derives livelihood from lumbering. The area is characterized by the presence of a number of trees, which are the major trees used for timber, fuel and charcoal (CIDP, 2018; County Government of Tharaka-Nithi, 2013).

The dominant Reference soil groups based on WRB (IUSS Working Group, WRB, 2015) include Nitisols, Ferralsols, Regosols, Vertisols and Phaeozems, as documented by the KENSOTER map (1:1M) and database (Dijkshoorn, 2007). These soils are generally acidic, heavily leached with low levels of base saturation and organic carbon (Mugwe et al., 2009; Njoroge and Kimani, 2001). Most of the soils in Tharaka-Nithi are mainly sandy loam and shallow (Muriu-Ng’ang’a et al., 2017).

The choice of the study area was informed by fact that the region is considered a high agricultural productivity zone attributed to favourable climatic conditions and fertile soils. Nonetheless, the declining soil fertility, reduction of agricultural land, lack of protection of catchment areas and environmental degradation are expected to pose major threats to the community’s livelihood (MoALF, 2016) thus the importance for this study.

### 2.2. Sampling size and procedure

The data used in this study was obtained through questionnaires and interviews conducted between January–March 2019. Farmers from two Counties (Meru and Tharaka Nithi), were purposively sampled. A total of 106 farmers from Meru (80) and Tharaka Nithi (26) were sampled for questionnaire survey. Cochran’s formula (1963) described in Wawire et al. (2017) was used to determine the sample size.

Multi-stage sampling procedure was used to identify 19 County wards from which farmers were selected through systematic random sampling.

The household survey was conducted through a face-to-face administration of the questionnaire (FARM Household questionnaire) to the household heads and responses filled in by the enumerators. Data collected include demographic, socio-economic, institutional data and soil fertility management practices (Table 1). Semi-structured interviews (Patton, 2002) for farmers (Farmer interview) and extension officers (Agricultural extension interview) were used to supplement data obtained through questionnaires. A total of 9 farmers and 7 extension officers were interviewed. Five of the seven extension staff were drawn from County government agricultural officers, while the rest (2) were Tea Extension Service Assistants from Kinoro and Imenti tea factory.

### Table 1. Definition of the independent and dependent variables used in the analysis.

| Variables | Definition and measurement |
|-----------|-----------------------------|
| **Independent variables** | |
| Gender | Gender of the household head (0 = female, 1 = male) |
| Age | Age of household head, 1 = young (less than 40), 2 = old (above 40 years) |
| Education | Household head education level (1 = below high school, 2 = above high school) |
| Farming as primary occupation | Whether farming was the primary occupation (0 = no, 1 = yes) |
| Farming experience | Years in farming (1 = below 20, 2 = above 20) |
| Contact with extension in the last 5 years | Contact with agricultural extension providers in the last 5 years (0 = no, 1 = yes) |
| Access to soil information | Access to training on soil management (0 = no, 1 = yes) |
| Access to Soil analysis | Access to soil testing services (0 = no, 1 = yes) |
| Credit information | Farmer has ever received credit information (0 = no, 1 = yes) |
| Crop information | Farmer has ever received crop information (0 = no, 1 = yes) |
| Agribusiness information | Farmer has ever received agribusiness information (0 = no, 1 = yes) |
| County | Farm location (1 = Meru, 2 = Tharaka Nithi) |
| Livestock | Own livestock (0 = no, 1 = yes) |
| Family size | Number of people in the family |
| Farm size | Total size of landholding cultivated by household (in acres) |
| Household income | Annual household income (on-farm and off-farm) |
| Work force | Number of household members actively involved in farming |
| Tropical livestock units (TLU) | Aggregated livestock assets |
| **Dependent variables** | |
| Slash-no-burn | Practice slash-and-no-burn (0 = no, 1 = yes) |
| Residue burn | Burns crop residue (0 = no, 1 = yes) |
| Residue application | Incorporates crop residues (0 = no, 1 = yes) |
| Agroforestry | Integrates trees on the crop farm (0 = no, 1 = yes) |
| Manure | Apply manure (0 = no, 1 = yes) |
| inorganic fertilizer | Apply inorganic fertilizer (0 = no, 1 = yes) |
| Minimum tillage | Practice minimum tillage (0 = no, 1 = yes) |
| Fallowing | Practice fallowing (0 = no, 1 = yes) |
Purposive sampling method was used for the selection of interviewees. While selection of extension personnel was based on availability, the choice of farmers for interview was based on the recommendation of the extension workers within their jurisdiction. Interviews with farmers focused on household's demographic and socio-economic data, farming enterprises, soil fertility management practices and access to agricultural information, while interviews with extension officers covered the themes on agricultural activities in the area, information delivery and access, soil information and fertility and agricultural incentives, were conducted face to face and by phone and lasted an average of 40 min. Notes were taken during each interview and some interviews were also recorded. Based on the notes and recordings, summaries were prepared for further analysis.

The questionnaire administration and interviews were carried out following the main ethical principles of social science research and an informed consent was obtained from the participants in each case. The fieldwork was approved by the Ad Hoc Ethical Committee of the Doctoral School of Environmental Sciences of Szent István University, Hungary, in accordance with the Code on Research Ethics of the Hungarian Academy of Sciences, and the European Code of Conduct for Scientific Integrity.

2.3. Methods of data analysis

2.3.1. Descriptive analysis

Descriptive statistics were generated using frequency distributions and means. Summary of categorical variables including gender, education, location, type of farming and information access were analysed using frequencies. Continuous variables, namely, household size, off-farm farm labour and livestock size were summarized using means and standard deviation.

The proportion of farmers using (indicated by YES in the table) individual technologies was obtained using IBM SPSS. Bar charts showing both the overall adoption in the study area and the comparison between the 2 counties, were generated using Excel. In the latter case (comparison charts), error bars were included to determine significant differences between the 2 sites.

2.3.2. Correlation matrix of ISFM practices

To examine the inter-relationship (complementarity or substitutability) in the application of different soil fertility management practices, correlation matrix (CM) was generated using Factor Analysis (with principal components extraction method) in SPSS. Categorical variables with binary responses have often been treated as continuous variables (e.g. Sileshi et al., 2019) allowing for the application of factor analysis. CM is used to present intercorrelations between the investigated variables, and is thus considered the starting point of factor analysis (Field, 2000). This was followed by cluster analysis to identify combination patterns of soil fertility practices among farmers.

2.3.3. Clustering of soil fertility technologies

One of the goals of cluster analysis (also called data segmentation) is to group or split a collection of objects into subsets (clusters). Using this approach, we are able to see how farmers combine (adopt) a subset of practices from a given package of fertility management practices (Mponela et al., 2016). Hierarchical clustering (HC) is the most common type of clustering used to segment objects based on their similarity (Murtagh and Legendre, 2014). We used Ward's method of hierarchical clustering to separate the fertility management practices into classes (Mponela et al., 2016). The various clusters are a product of maximum variance for the different fertility management practices usage across farms (IBM, 2013). The least dissimilar (closest) pairs of clusters are agglomerated by Ward's clustering. The agglomeration values are represented by the height of the dendrogram node. The node heights also indicate the existence of a real relationship between the clusters based on ultrametric distances (Mponela et al., 2016). The node's height within the plot is proportional to the value of the intergroup dissimilarity between its 2 daughters (Hastie et al., 2009). All clusters exhibiting fewer similar observations are plotted on the top nodes at lower height (Mponela et al., 2016; Murtagh and Legendre, 2014).

In this study, we limit the application of cluster analysis to the separation of soil fertility technology classes, with the aim of visualizing combination patterns of these practices. Technologies within the same cluster can either complement or substitute each other (Mponela et al., 2016).

2.3.4. Variables explaining adoption of ISFM techniques

Fisher's exact test (FT) and Welch's t-test (WT) were used to examine the significance of associations between the explanatory variables and investment in the different types of soil fertility management practices. The decision for practice or non-practice of a particular fertility management practice, is a binary decision that can be subjected to binary choice models. Dichotomous outcomes, namely, practice or non-practice, is associated with a set of explanatory socioeconomic characteristics (such as individual resource endowments) that are hypothesized to influence the outcome (Muriu-Ng’a et al., 2017; Noltze et al., 2012).

Qualitative data from interviews were analysed using thematic analysis. This is an independent descriptive method generally described as a technique for identifying, analysing and reporting patterns (or themes) contained within the dataset. Thematic analysis (TA) presents a theoretically flexible technique of analysing qualitative data (Braun and Clarke, 2006) and aid in validation of responses from other approaches such as questionnaires.

3. Results

3.1. Household demographics and socio-economic factors

The average age of the household heads was 47 years with majority (60.4%) of the farmers aged above 40 years (Table 2). The mean household size was about 5 people, with an estimated on-farm labour (household members actively involved in farming) of about three persons. The mean household farm size was three acres (1.21 ha), with farmers owning an average of two tropical livestock unit (TLU). Less than 10% of the farmers (9.4%) had attained higher level education (Table 3). Farming was the primary activity for majority of the, with most of them practising mixed farming.

3.2. Use of ISFM practices in Meru and Tharaka Nithi

The most popular practices included manure and inorganic fertilizer application (Figure 2). Agroforestry and residue application were also used quite extensively. There were no significant differences in the adoption of soil fertility practices between the 2 counties.

3.3. Relationship between soil fertility technologies

Results of correlation matrix (Table 4) show strong positive associations between various practices, suggesting a complementarity relationship among them. There was a very strong significant correlation between inorganic fertilizer and manure application. The negative correlation between Residue burn and agroforestry could be explained by the fact that falling leaves from the farm trees are used on the farm as mulch.

3.4. Combination of soil fertility management practices

Three groups consisting a set of technologies adopted by farmers were determined as visualized by the Ward linkage dendrogram (Figure 3). Cluster 1 consists of fertilizer and manure application and agroforestry. Fallowing, residue burn and slash-and-no-burn defined cluster 2. Cluster 3 was characterized by residue application and minimum tillage.
3.5. Determinants of soil fertility management strategy

The empirical results obtained from the Fisher’s exact test and Welch’s t test models are presented in Table 5 and Table 6, respectively. Adoption of minimum tillage was associated with access to soil information. Implementation of fallowing was correlated with contact with extension and household size. Adoption of manure application was associated with the household size and the number of livestock units. Both residue burn and crop residue application were correlated with farm size. There was a significant relationship between residue burn and income. The decision to implement slash-no-burn was related to the age of the household, family size and access to livestock husbandry information. There was correlation between agroforestry and access to extension information, household size, number of livestock units.

The relationship between socioeconomic characteristics and access to institution or agencies was also examined (Table 7). The household head’s age was significant in determining access to agricultural extension and agribusiness training. Access to soil information significantly varied across the two counties.

4. Discussion

4.1. Household demographic and socio-economic characteristics

Results of demographic characteristics show that most of the farmers were above the age of 40, with an average of 47, and the eldest farmer aged 85. This suggests a relatively older farming community, considering that Kenya is generally a youthful country with a median age of 20 years (KNBS, 2019), and more than 20% of the population is aged between 25-39. The scenario supports the position that youths are shunning agriculture in preference for formal employment (CIDP, 2018). While the average household in the study area stood at five persons, the mean for members actively involved on the farm was estimated at three persons, affirming farmers view of labour shortage as reported during interviews.

Table 2. Socio-economic characteristics of the sampled households in Mount Kenya East (continuous variables).

| Variable                              | Min | Max  | Mean  | Std. Dev |
|---------------------------------------|-----|------|-------|----------|
| Number of members in the household    | 1   | 11   | 5.06  | 1.78     |
| Size of farm in acres                 | 0.25| 15   | 3.19  | 2.98     |
| Number of household members actively involved in farming | 1 | 7   | 2.73  | 1.44     |
| Age of the household head (in years)  | 22  | 85   | 47.22 | 14.91    |
| Tropical Livestock units (TLU)        | 0   | 9.57 | 2.47  | 2.12     |
| TOTAL INCOME (Ksh)                    | 7,000.00 | 2,640,000.00 | 271,668.63 | 478,456.97 |

1 Kenya shilling (Ksh) = 0.0101 USD based on the average exchange rate at the time of data collection (March 2019).

Table 3. Socio-economic characteristics of the sampled households in Mount Kenya (categorical variables).

| Variables                          | Frequency | Percent |
|------------------------------------|-----------|---------|
| Gender                             |           |         |
| Male                               | 57        | 53.8    |
| Female                             | 49        | 46.2    |
| Age (years)                        |           |         |
| Below 40                           | 42        | 39.6    |
| Above 40                           | 64        | 60.4    |
| Education level                    |           |         |
| Never attended                     | 3         | 2.8     |
| Primary                            | 48        | 45.3    |
| Secondary                          | 45        | 42.5    |
| Above secondary                    | 10        | 9.4     |
| County                             |           |         |
| Meru                               | 80        | 75.5    |
| Tharaka Nithi                      | 26        | 24.5    |
| Primary occupation                 |           |         |
| Farming                            | 97        | 91.5    |
| Others                             | 9         | 8.5     |
| Type of farming                    |           |         |
| Crop farming (only)                | 6         | 5.7     |
| Mixed (crop and livestock)         | 100       | 94.3    |
| Farming experience (Years)         |           |         |
| Less than 20                       | 54        | 50.9    |
| More than 20                       | 52        | 49.1    |
| Extension contact                  |           |         |
| Yes                                | 46        | 43.3    |
| No                                 | 60        | 56.6    |
| Access to soil information         |           |         |
| Yes                                | 11        | 10.4    |
| No                                 | 95        | 89.6    |
| Access to Soil analysis            |           |         |
| Yes                                | 18        | 17      |
| No                                 | 88        | 83      |
| Credit information                 |           |         |
| Yes                                | 10        | 9.4     |
| No                                 | 96        | 90.6    |
| Crop information                   |           |         |
| Yes                                | 23        | 21.7    |
| No                                 | 83        | 78.3    |
| Agribusiness information           |           |         |
| Yes                                | 4         | 3.8     |
| No                                 | 102       | 96.2    |
| Livestock                          |           |         |
| Yes                                | 21        | 19.8    |
| No                                 | 85        | 80.2    |
Less than 10% of the farmers in Meru and Tharaka Nithi had attained higher education level. Technology adoption has been shown to be influenced by literacy (Mponela et al., 2016). Farmers with ability to read and write are presumed to have higher capacity to capture and synthesize technical information that characterizes some of the ISFM technologies (Marenya and Barrett, 2007). However, access to training from agricultural extension providers can compensate for inadequate formal training through awareness creation training (Mponela et al., 2016). Our results, however, indicate low contact with extension providers and extension-related information packages, including soil testing and training on soil fertility management, crop and livestock husbandry. Lack of financial education and training in agribusiness, could also be a hindrance to farmers participation in production for the market, and thus low adoption of superior technologies (Chianu et al., 2012). Household farm size ranged from 0.25-15 acres, with an average of 3 acres. The size of land owned by a household is a key driver in the adoption of agricultural technology. The general premise is that farmers with large farm size are more likely to invest in farming technologies than their counterparts with small farms (Chianu et al., 2012).

Our results indicate that about half of the farmers had more than 20 years of farming experience. Studies show that experience in farming is likely to influence farmer’s decision to adopt a given technique. Farmers with little or no experience tend to be risk-averse, and will tend to try out as few techniques as possible (Mponela et al., 2016).

There was no relationship between gender and adoption of ISFM techniques. Gender has been identified by several studies as a key determinant of technology adoption (Chianu et al., 2012; Marenya and Barrett, 2007; Mponela et al., 2016). In a study by Mponela et al. (2016), male farmers were more likely to combine inorganic fertilizers and...
manure compared to women. This variation could be attributed to differences in accessibility to resources between men and women (Njuki et al., 2008). Our results would suggest equal access to resources across gender.

### 4.2. Adoption of ISFM practices

Fertilizer and manure were used by the highest proportion of households (93.4%). This could be attributed to a number of reasons, including their immediate returns (of course when accompanied with the use of improved seed varieties) (Holden and Mangisoni, 2013). Increased fertilizer uptake is also stimulated by availability of government subsidy programmes (Odhiambo Ochola and Fengying, 2015). However, as observed during the interviews the programme is marred with a myriad of bottlenecks including inefficiency and distortion of subsidy programme (Birch, 2018) and high market fertilizer price (Chianu et al., 2012) among other factors, explain the generally low and irregular adoption rate (Ariga and Jayne, 2011; Wawire et al., 2020). High use of manure is alluded to the mixed crop-livestock farming system which is practiced by most of the farmers. However, the available manure is inadequate (Nalivata et al., 2017) due to low quantity of livestock (averaged at 2.5 units) owned by households. Farmers in Meru and Tharaka Nithi supplemented on-farm produced manure with local purchases. The manure used is often of poor quality due to poor manure management practices which lead to nutrient loss (Makokha et al., 2001; Ndambi et al., 2019).

The wide adoption of agroforestry is a good illustration of farmers employing a particular practice to address a specific need (Mponela et al., 2016). Meru and Tharaka Nithi have a generally rugged terrain, thus susceptible to soil and land degradation. Agroforestry is one of the most promoted campaigns for sustainable agriculture that can curb soil degradation processes, maintain soil fertility and mitigate the region against declining agricultural production. The practice is also key in preserving the ecosystem (Blaser et al., 2017). According to responses from the interviews, farmers in the study area argued that the falling leaves increased soil organic matter, and tree roots were important in holding the soil together to prevent soil erosion. However, interviews with extension officers indicated that poor-resource farmers resort to lumbering as an alternative source of energy for cooking or timber and charcoal for selling (evident from the widespread of timber yards in the various shopping centres in the region).

Residue application is common practice due to the readily available crop residues upon harvesting. However, farmers are faced with a trade-off dilemma because of the multiple uses of residue including feeding animals (fodder) and as fuel, thus only a small amount of residue is incorporated into the soil which is insufficient in replenishing nutrient outflow (Bekunda et al., 2005). Because of the competing needs for residue, the recorded low cases of residue burn are expected. Nevertheless, burning of crop residues is considered (albeit by few farmers) as not only efficient in field preparation for next cropping, but also helps in preserving field hygiene by controlling the spread of diseases (Bonanomi et al., 2007; Wang et al., 2019). However, burning of residues and vegetation has been shown to decrease microbial biomass carbon (MBC) at least on the surface depth impacting directly on soil microbial biomass by killing the microorganisms. However, the effect of burning depends on the intensity of fire (Wang et al., 2019). In their separate research, Scharenbroch et al. (2012) and Alcaniz et al. (2016) found that in fact, slash burning resulted in about 30% increase in soil total C. However, this depends on the time frame.

A moderate proportion of households employed minimum tillage—an important practice meant to minimize soil disturbance and mitigate it from soil erosion. Similarly, some areas in the region are characterized by generally friable and deep soils (Dijkshoorn, 2007), that may not warrant continued tillage. Soil workability has severely been identified as a key soil fertility indicator (Kome et al., 2018).
Fallowing was among the least adopted practice. This is expected due to the increasing demand for land occasioned by a bulging population, and thus almost all the available agricultural land is cultivated throughout the year. Fallowing is critical in rebuilding soil productivity through biomass accumulation and nitrogen fixation (Mponela et al., 2016). The low adoption of fallowing also explains the minimal use of residue burn and slash-no-burn practices, which would only be applicable in fallowed lands with regenerated vegetation. Slashing is a traditional silvicultural practice commonly used for clearing vegetation (for virgin fields) or harvest residues in forest plantations (Wang et al., 2019). Slash-and-no-burn exists among households with relatively large pieces of land, with low labour supply to support seamless cropping.

4.3. Combination and interrelationships among ISFM practices

Based on the hierarchical clustering dendrogram (Figure 3), ISFM techniques were separated into 3 classes: 1) fertilizer, manure and agroforestry; 2) residue burn, slash-no-burn and fallowing; and 3) residue application and minimum tillage. This implies that farmers only adopt a subset of practices which could be attributed to various reasons, including financial constraints, lack of technical capacity and (in) compatibility of social, physical and cultural environment.

Similar farmers employed a technological set comprising of fertilizer, manure use and agroforestry (cluster 1) as shown by Figure 3. Strong positive correlations between these practices affirm their complementarity (Place et al., 2003). Manure and fertilizer are the most common practices (Figure 2) due to their near-immediate results of providing plant nutrients within the same season of application. Agroforestry, on the other hand, is critical not only in enhancing soil fertility, but also to protect the soil from erosion and degradation which are the most important threats in the area due to its rugged terrain.

Fallowing, residue burn and residue-no-burn were practiced by similar farmers (cluster 2). One of the explanations for this association is that vegetation clearing is common in farming systems where land is left fallow for a given period of time. In which case, the farmer may employ either residue burn or slash-no-burn, depending on the availability of labour and technology for land preparation, thus the positive correlation (Table 3). Resource-constrained farmers would often opt for residue burn to clear the land.

As seen in Figure 3, the Euclidean distance between clusters show that residue application and minimum tillage (both in cluster 3) are likely to

![Dendrogram using Ward Linkage](Image)

Figure 3. Dendrograms showing common combinations of ISFM technologies among smallholder farmers in Mount Kenya East region.
be adopted by the same group of farmers, demonstrating their complementarity nature. This can be affirmed by the strong positive correlation between the 2 practices (as shown in Table 3). Residue application is a critical alternative for weed control on farms that practise zero or minimum tillage. It is thus logical to conclude that preferences for a particular set of technologies can be explained by the intention of the farmer to address a specific soil constraint (Mponela et al., 2016), more so in seriously depleted soils or in areas with prevalent soil erosion.

4.4. Determinants of ISFM practices

Manure use was strongly correlated with on-farm labour and livestock unit at \( p < 0.01 \). The manure used on the farm is largely on-farm sourced, and as such, it is influenced by livestock ownership. This finding corroborates previous studies, e.g. (Shikuku et al., 2017). Transportation and application of manure requires sufficient labour input. Several studies have demonstrated that areas near the homestead have benefited more from manure application (Adimassu et al., 2016; Muthamia et al., 2011; Tittoua et al., 2005), a fact that could be attributed to the amount of labour required. These findings corroborate other empirical studies which have established a positive effect of large family size and economically active population on investment in labour-intensive land management activities (Adimassu et al., 2016; Gebremedhin and Swinton, 2003).

Inorganic fertilizer application was also influenced by family size and on-farm labour. These results are inconsistent with a research by Makoka et al. (2001) which investigated determinants of fertilizer and manure use for maize production in Kenya. In their findings, labour was found to only significantly influence manure application but not fertilizer. Our findings could be attributed to the long distance farmers have to travel to the market centre or the National Cereals and Produce Board (NCPB) centres (the government’s fertilizer distribution centres). Interviews also showed that farmers’ access to fertilizer was hampered by long distance to NCPB centres.

The positive correlation of livestock unit and agroforestry could be explained by the fact that the leaves of some tree species are used as animal fodder especially during dry season. Fodder trees have increasingly served as an important source of livestock feed in various farming systems in Africa and have been used mostly to feed dairy cows in the highlands of Eastern Africa (Franzel et al., 2014). In fact, there have been increasing campaigns among researchers and extension providers, in collaboration with farmers in promoting fodder tree practices in various countries (Franzel et al., 2014).

On-farm labour family size, total annual household income, tropical livestock unit (TLU) and access to crop husbandry information were positively correlated with the implementation of agroforestry (tree retention on the farm). The influence of crop management information could be explained by the training received from agricultural extension providers on the proper farm management practices. The scenario is consistent with a long-held consensus that effective extension services is crucial in improving agricultural productivity through provision of information to farmers that guide them in optimal use of their limited resources (Muyanga and Jayne, 2006). However, responses from interviews with extension providers and farmers paints a gloomy picture of a deteriorating agency. On the flip side, the commodity-based extension dealing with the major cash crops (tea and coffee) tend to work well, understandably because these services are obviously motivated by profits (Muyanga and Jayne, 2006).

Minimum tillage was significantly influenced by livestock units and access to soil information. The influence of livestock unit could be explained by the complementarity of manure application and minimum tillage. Farmers implement both practices as a strategy to conserve moisture and minimize loss of nutrients (Mponela et al., 2016) protect soil aggregates, reduce soil loss and surface run-off (Turmel et al., 2015). The influence of access to soil information on the implementation of minimum tillage can be attributed to extension activities that include training of farmers on agronomic practices and soil conservation. Agricultural extension providers usually employ an integrated approach encompassing a range of activities (Muyanga and Jayne, 2006).

There was significant positive correlation between contact with extension and fallowing. Fallowing is critical in rebuilding soil productivity through biomass accumulation and nitrogen fixation (Mponela et al., 2016). Surprisingly, our findings did not establish a significant effect of farm size and household size on the decision to implement fallowing as has been demonstrated in previous related research (e.g. Teshome et al., 2016). This can be explained by the fact that fallowing was practiced by a very small proportion of farmers (as such the assumptions for analysis for some analysis models were not satisfied).

Our results indicate that slash-no-burn was practiced mostly by older farmers. This can be attributed to shortage of labour to support seamless cropping, or the relatively short planning horizon of the older household head (Nigussie et al., 2017). The significant negative correlation of age with access to extension and agribusiness information (Table 7), may imply that young farmers are more likely to seek for extension service and to approach agriculture as a business.

The positive correlation between access to livestock husbandry information and slash-no-burn can be explained by the fact that most of the farmers (with livestock) would usually harvest grass from the uncultivated fields to feed to the animals. During the survey we could observe farmers harvesting grass on the roadsides to supplement livestock feed.

5. Conclusion

The study has examined the demographic and socio-economic factors determining the adoption of selected ISFM practices used by smallholder farmers in Mount Kenya East region, and explored relationships among the practices and the combination patterns of these techniques. Fertilizer and manure application and agroforestry are the most common practices employed by farmers. The study established correlations between the various ISFM practices. Using hierarchical clustering dendrogram, ISFM techniques were separated into 3 sets indicating that households often adopted a bundle of technologies (which complement or substitute each other) as opposed to the entire ISFM package, based on their needs as well as resource constraints.

Results show that the decision to invest in fertility practices was significantly correlated with a number of farmers’ socio-economic, farm-related factors and institutional characteristics. On-farm labour and household size influenced manure and fertilizer adoption. Livestock quantity had a bearing on manure use. The relationship implies on the need to adapt the ISFM techniques to the local environment. Farmers have different assets which determine how they can apply techniques of their choice, and therefore exploring which practices make more sense depends on farmer’s assets such as capital and labour.

The findings of this study have several implications for programmes that promote fertility management strategies among resource-constrained farming communities. The significant relationship between access to extension and adoption of some ISFM practices, point to the continued importance of agricultural extension. Capacity building of extension providers by equipping them with skills on soil fertility management is crucial.

Resource endowment in terms of household income, farm size and livestock units imply the importance of capital in agriculture. Policymakers should formulate innovative financing opportunities to provide credit to farmers and promote profitable start-up projects among the youth. Socioeconomic characteristics, institutional support, policies and infrastructure influence farmers’ capacities to implement soil fertility management strategies. This demonstrates the need for policymakers to create enabling environment to facilitate their investment capacities in soil fertility management practices and enhance their economic incentives from ISFM investments.

A.W. Wawire et al. Heliyon 7 (2021) e06488
Declarations

Author contribution statement

Amos W. Wawire: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Adám Csorba: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Joszef A. Tóth, Evans Mutuma: Conceived and designed the experiments; Performed the experiments.

Erika Michelli: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Mark Szalai: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Eszter Kovács: Conceived and designed the experiments; Analyzed and interpreted the data.

Funding statement

This research was supported by the Ministry for Innovation and Technology within the framework of the Thematic Excellence Program 2020, Institutional Excellence Sub-Program (TKP2020-IKA-12) of Szent István University; and the stipendium Hungaricum Scholarship (award number 99674) through Tempus Public Public Foundation, Hungary.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2021.e06488.

Acknowledgements

We are grateful to the farmers and the Agricultural extension workers for participating in the questionnaire survey and the interviewees for sharing their knowledge and thoughts.

References

Adimassu, Z., Melkonnen, K., Yirga, C., Kessler, A., 2014. The effect of soil bunds on runoff, losses of soil and nutrients, and crop yield in the central highlands of Ethiopia. Land Degrad. Dev. 25, 554–564.

Adimassu, Z., Langan, S., Johnston, R., 2016. Understanding determinants of farmers’ investments in sustainable land management practices in Ethiopia: review and synthesis. Environ. Dev. Sustain.

Adolva, I.S., Schwarze, S., Buerkert, A., 2019. Impacts of integrated soil fertility management on yield and household income: the case of Tamale (Ghana) and Kakamega (Kenya). Ecol. Econ. 161, 186–192.

AGRA, 2009. Building on the New Momentum in African Agriculture. Nairobi, Ajayi, O., 2007. Adoption of renewable soil fertility replenishment technologies in the southern African region: lessons learnt and the way forward. Nat. Resour. Forum 31, 306–317.

Alcantar, M., Outeiro, L., Francois, M., Farguell, J., Úbeda, X., 2016. Long-term dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgri Massif, Catalonia, Spain). Sci. Total Environ. 572, 1329–1335.

Arita, J., Jayne, T.S., 2011. Fertilizer in Kenya: factors driving the increase in usage by smallholder farmers, 1990-2007. Ves Africa can success stories from. Dynam. Contrn. 269–288.

Asrat, P., Belay, K., Hamito, D., 2004. Determinants of farmers’ willingness to pay for soil conservation practices in the southeastern highlands of Ethiopia. Land Degrad. Dev. 15, 423–438.

Bekunda, M., Ebyant, P., Nkonya, E., Mugendi, D., Msuky, J., 2005. Soil fertility status, management, and research in east Africa. Afr. J. Rural Dev. 20.

Birch, L., 2018. Agricultural Productivity in Kenya: Barriers and Opportunities. United Kingdom.

Blaser, W.J., Oppong, J., Yeboah, E., Six, J., 2017. Shade trees have limited benefits for soil fertility in coca agroforests. Agric. Ecosyst. Environ.

Bonanomi, G., Antignani, V., Pane, C., Scala, F., 2007. Biocontrol of soilborne fungal diseases with organic amendments. J. Plant Pathol. 89, 311–324.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 177–195.

Chianu, Jonn N., Chiana, Justina N., Mairura, F., 2012. Mineral fertilizers in the farming systems of sub-Saharan Africa. A review. Agron. Sustain. Dev. 32, 545–566.

Chinhwaga, L.L.R., 2006. Adoption of Soil Fertility Improvement Technologies Among Smallholder Farmers in Southern Malawi. Norwegian University of Life Sciences.

Chukwuka, K.S., Omotayo, E.O., 2009. Soil fertility restoration potential of tithonia green manure and water hyacinth compost on a nutrient depleted soil in South western Nigeria using Zea mays L. As test crop. Res. J. Soil Biol. 1, 20–30.

CiDP, 2018. Meru County Integrated Development Plan 2018-2022.

Corbeels, M., Shiferaw, A., Haile, M., 2000. Farmers’ Knowledge of Soil Fertility and Local Management Strategies in Tigray, Ethiopia (No. 10), Managing Africa’s Soils. County Government of Tharaka-Nithi. 2013. Tharaka Nithi county integrated development plan. In: County Integrated Development Plan (2013–2017).

Dijkstra, J., 2007. Soil and Terrain Database for Kenya (Ver. 2.0) (KENSOTER) [WWW Document]. URL. http://library.wur.nl/WebQuery/wurpubs/452214. (Accessed 17 March 2014).

FAO, IFAD, UNICEF, WFP, W., 2017. The State of Food Security and Nutrition in the World 2017. Building Resilience for Peace and Food Security. FAO, Rome, Italy.

FAO, 2002. Extending the area under sustainable land management and reliable water control systems. In: Comprehensive Africa Agriculture Development Programme. NEPAD, Rome, Italy.

Field, A., 2000. Discovering Statistics Using SPSS for Windows. Sage Publications, London – Thousand Oaks – New Delhi.

Franzel, S., Carsan, S., Lukoyu, B., Sinja, J., Wambuku, C., 2014. Flooded trees for improving livestock productivity and smallholder livelihoods in Africa. Curr. Opin. Environ. Sustain.

Ghreghemblin, B., Swinton, S.M., 2003. Land tenure security and public programs. Agric. Econ. 29, 69–84.

Hastie, T., Tibshirani, R., Friedman, J., 2009. Cluster Analysis. In: The Elements of Statistical Learning. Springer-Verlag., New York.

Holden, S., Mangisoni, J., 2013. Input subsidies and improved maize varieties in Malawi: what can we learn from the impacts in a drought year? In: Working, Pa (Ed.), Norwegian University of Life Sciences, Centre for Land Tenure Studies.

IBM, 2013. IBM SPSS Statistics for Windows, Version 22. IBM Corp, Armonk, N.Y., USA.

Kiboi, M.N., Ng'etich, K.F., Flessbach, A., Muriuki, A., Mugendi, D.N., 2019. Soil fertility inputs and tillage influence on maize crop performance and soil water content in the Central Highlands of Kenya. Agric. Water Manag. 217, 316–331.

KNBS, 2019. 2019 Kenya Population and Housing Census, 1. Population by County and Sub-County, Nairobi, Kenya.

Kome, G.K., Enang, R.K., Verima, B.P.K., 2018. Knowledge and management of soil fertility by farmers in western Cameroon. Geoderma. Reg.

Knh, K., Michelson, H., Perge, E., Jindal, R., 2019. Constraints to adopting soil fertility management practices in Malawi: a choice experiment approach. World Dev. 124, 104651.

Kurtg, B.K., Ngenoh, E., Bett, H.K., Stober, S., Mwong, S., Lotze-Campen, H., Rosenstock, T.S., 2018. Drivers of sustainable intensification in Kenyan rural and peri-urban vegetable production. Int. J. Agric. Sustain. 16, 385–398.

Makokha, S., Kimani, S., Mwangi, W., Verkuyl, H., Musumbi, F., 2001. Determinants of Fertilizer and Manure Use for Maize Production in Kitui District, Kenya.

Maremna, P.F., Barrett, C.B., 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. Food Pol. 32, 515–536.

MoALF, 2016. Climate Risk Profile for the Keny County Climate Risk Profile Series. The International Center for Tropical Agriculture (CIAT) and the Kenya Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

Mponela, P., Tavere, L., Ndengu, G., Magreta, R., Kihara, J., Mango, N., 2016. Determinants of integrated soil fertility management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Africa. Land Use Pol. 59, 38–48.

Mugendi, J., Mugendi, D., Macheru-Muna, M., Merckx, R., Chianu, J., Vanlauwe, B., 2009. Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. Exp. Agric. 45, 61–75.

Muhangi, G., Roothaert, R.L., Webo, C., Stanley, M., 2011. African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. Int. J. Agric. Sustain. 9, 194–202.

Muria-Ng’ang’a, F.W., Macheru-Muna, M., Waswa, F., Mairura, F.S., 2017. Socio-economic factors influencing utilization of rain water harvesting and saving technologies in Tharaka South, Eastern Kenya. Agric. Water Manag. 194, 150–159.

Murtagh, F., Legendre, P., 2014. Ward’s hierarchical agglomerative clustering method: which algorithm implements ward’s criterion? J. Classif. 31, 274–295.

Muthiamia, J.M., Mugendi, D., Kung u., J.B., 2011. Within-farm variability in soil fertility management in smallholder farms of kirege location, central highlands of Kenya. In: Bationo, A., Waswa, B., Okeyo, J.M., Maina, F., Kihara, J. (Eds.), Innovations as Key to the Green Revolution in Africa. Springer, Dordrecht Heidelberg London New York, 707–716.
Shikuku, K.M., Winowiecki, L., Twyman, J., Eitzinger, A., Perez, J.G., Mwongera, C., A.W. Wawire et al. Heliyon 7 (2021) e06488

Shepherd, K., Walsh, M., 2007. Infrared spectroscopy

Sanginga, N., Woomer, P.L., 2009. Integrated Soil Fertility Management in Africa: Place, F., Barrett, C.B., Freeman, H.A., Ramisch, J.J., Vanlauwe, B., 2003. Prospects for

Onduru, D., de Jager, A., Gachini, G., Diop, J.-M., 2001. Exploring New Pathways for

Oseko, E., Dienya, T., 2015. Fertilizer consumption and fertilizer use by crop (Fubc) in

Odhiambo Ochola, R., Fengying, N., 2015. Evaluating the effects of fertilizer subsidy programmes on vulnerable farmers in Kenya. J. Agric. Ext. Rural Dev. 7, 192–201.

Onduru, D., de Jager, A., Gachini, G., Diop, J.-M., 2001. Exploring New Pathways for Innovative Soil Fertility Management in Kenya (No. 25). Managing Africa’s Soils, Oseko, E., Dinya, T., 2015. Fertilizer consumption and fertilizer use by crop (Fubc) in Kenya study conducted for Africarefertilizer.org.

Patton, M.Q., 2002. Qualitative Research and Evaluation Methods, third ed. Sage Publications, Thousand Oaks, CA.

Paudel, G., Thapa, G., 2004. Impact of social, institutional and ecological factors on land management practices in mountain watersheds of Nepal. Appl. Geogr. 24, 35–55.

Place, F., Barrett, C.B., Freeman, H.A., Ramisch, J.J., Vanlauwe, B., 2003. Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Pol. 28, 365–378.

Sangina, N., Woomer, P.L., 2009. Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, Nairobi.

Scharrenbroch, B.C., Nis, B., Jacobs, K.A., Bowles, M.J., 2012. Two decades of low-severity prescribed fire increases soil nutrient availability in a Midwestern, USA oak (Quercus) forest. Geoderma 183, 80–91.

Shepherd, K., Walsh, M., 2007. Infrared spectroscopy – enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. J. Near Infrared Spectrosc. 15, 1–20.

Shikuku, K.M., Winowiecki, L., Twyman, J., Eitzinger, A., Perez, J.G., Mwongera, C., Läderach, P., 2017. Smallholder farmers’ attitudes and determinants of adaptation to climate risks in East Africa. Clim. Risk Manag. 16, 234–245.

Shisanya, C.A., Mucheru, M.W., Mugendi, D.N., Kung’u, J.B., 2009. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. Soil Tillage Res. 103, 239–246.

Silesi, M., Kadigi, R., Mutasbazi, K., Sieber, S., 2019. Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. Int. Soil Water Conserv. Res.

Teshome, A., de Graaff, J., Kasie, M., 2016. Household-level determinants of soil and water conservation adoption phases: evidence from north-western Ethiopian highlands. Environ. Manage. 57, 620–636.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Shepherd, K.D., Giller, K.E., 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. Agric. Ecosyst. Environ. 110, 166–184.

Tiwari, K.R., Sitaula, B.K., Nyborg, I.L.P., Paudel, G.S., 2008. Determinants of farmers’ adoption of improved soil conservation technology in a Middle Mountain Watershed of Central Nepal. Environ. Manage. 42, 210–222.

Tully, K., Sullivan, C., Weil, R., Sanchez, P., 2015. The State of soil degradation in sub-Saharan Africa: Baselines, trajectories, and solutions. Sustainability 7 (6), 6523–6552.

Tursel, M.S., Speratti, A., Baudron, F., Verhulst, N., Govaerts, B., 2015. Crop residue management and soil health: a systems analysis. Agric. Syst. 134, 6–16.

UNDESA, 2013. World Population Prospects: the 2012 Revision, Medium Variant.

Vanlauwe, B., AbdelGadir, A.H., Adewopo, J., Adije-Nsiah, S., Ampadu-Boazye, T., Asare, R., Bajiyika, F., Basra, E., Bekunda, M., Coney, D., Dianda, M., Dountop, Nguere, P.M., Ehanayat, P., Hausner, S., Hueising, J., Jalisah, A., Jassogne, L., Kamai, N., Kamara, A., Kanampiu, F., Kebbla, A., Käste, K., Kreye, C., Larbi, A., Masso, C., Matungulu, P., Mohammed, I., Ndashungo, L., Nielsen, F., Nizigbeya, G., Pappers, P., Roosbroeck, D., Shut, M., Taulya, G., Thyhui, M., Uzokwe, V.N., van Asten, P., Wairigi, L., Ymerofack, M., Mutuaen, H.I.W., 2017. Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa. Int. J. Agric. Sustain. 15, 613–631.

Vanlauwe, B., Bationo, A., Chianu, J., 2010. Integrated Soil Fertility Management: Operational Definition and Consequences for Implementation and Dissemination. SAGE Journals.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Othokpehai, O., Pappers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., Sangina, N., 2010. Integrated soil fertility management: operational definition and consequences for implementation and dissemination. Outlook Agric. 39, 17–24.

Wang, Y., Liu, X., Yan, Q., Hu, Y., 2019. Catena Impacts of slash burning on soil carbon pools vary with slope position in a pine plantation in subtropical China. Catena 183, 245–249.

Wavire, A.W., Corbo, A., Toth, J.A., Michelli, E., 2020. Integration of manure and mineral fertilizers among smallholder farmers in Kenya: a pathway to sustainable soil fertility management and agricultural intensification. Int. J. Agric. Ext. Rural Dev. Stud. 7, 1–25.

Wavire, A.W., Wangia, S.M., Okello, J.I., 2017. Determinants of use of information and communication technologies in agriculture: the case of Kenya agricultural commodity exchange in Bungoma county. Kenyan. J. Agric. Sci. 9, 128.

Yengoh, G.T., 2012. Determinants of yield differences in small-scale food crop farming systems in Cameroon. Agric. Food Secur. 1, 1–19.