Research article

Socio-economic predictors, soil fertility knowledge domains and strategies for sustainable maize intensification in Embu County, Kenya

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ABSTRACT

Integrated Soil Fertility Management (ISFM) practices are widely recognized as crucial interventions but knowledge-intensive technologies for farmers in Sub-Saharan Africa (SSA). Very few studies have synthesized the knowledge gaps between small-holder practices and recommended ISFM packages. A farm survey was therefore carried out in Runyenjes sub-County of Embu to determine factors influencing the quality of ISFM knowledge considering inorganic fertilizer, organic manure, integrated soil inputs, and improved maize seeds. One hundred small-scale maize farmers were systematically sampled in Embu County, Kenya, using a cross-sectional survey design. The most significant factors shaping the quality of ISFM knowledge (p < 0.05) included gender, age, household size, land under maize, off-farm earnings, maize yield, members involved in farming, farming experience, education level, and farm size. Farmers recorded lower knowledge scores for technical ISFM themes including soil liming, soil testing, fertilizer types, fertilizer functions, curing of organic manure, compost manure management, crop spacing, combination ratios for integrated inputs, and the labor and cost-benefit implications of integrated inputs, revealing important ISFM knowledge gaps. High-quality knowledge of blended fertilizers and DAP use was associated with increased soil testing and soil liming knowledge, respectively. Multivariate analysis of ISFM knowledge items provided a high-quality understanding of the structure of ISFM knowledge among farmers in Embu County, which is useful in developing future ISFM dissemination strategies.

1. Introduction

Integrated Soil Fertility Management (ISFM) is defined as a set of soil fertility management practices which include the use of mineral fertilizers, improved germplasm, and organic soil amendments combined with the knowledge on how to adapt these practices to local conditions (Vanlauwe et al., 2010). ISFM aims to maximize agronomic use efficiency of applied nutrients and to enhance soil productivity (Vanlauwe et al., 2010). ISFM practices are linked in a series of steps including mineral fertilizer application, use of improved germplasm, incorporation of organic soil amendments, and local technology adaptation including the construction of terraces to prevent soil erosion (Adolwa et al., 2017). The key principle to the ISFM paradigm is that no single component of soil fertility management can lead to sustainable soil management (Marenya and Barrett, 2007). Rather than being input-intensive, the ISFM paradigm is a knowledge-driven process (Tittonell et al., 2008). ISFM practices aim to a) replenish soil nutrient pools, b) maximize on-farm recycling of nutrients, c) reduce nutrient losses to the environment, d) improve the efficiency of external inputs, e) make use of local and scientific knowledge, and f) integrate these components into technologies that enable sustainable natural resource management (Adolwa et al., 2017).

One of the main reasons for low ISFM adoption is the lack of adequate knowledge by small-holder farmers (Lambrecht et al., 2016; Mugwe et al., 2009a). Farmers have limited knowledge on appropriate soil management practices using locally available soil nutrient resources (Vandeplas et al., 2008; Mowo et al., 2006). In Sub-Saharan Africa, little fertilizer is used by farmers due to inadequate supply, unstable

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commodity prices, scarce financial resources, lack of credit facilities, and inadequate knowledge on its use (Kome et al., 2018; Dawoe et al., 2012). Knowledge of proper use and management of manure is limited but important because poor management of manure decreases its quality and efficacy (Ajayi et al., 2007). Maize yields in Kenya have remained low (approx. 1.5 t ha\(^{-1}\)) due to different factors, yet yields of 6 t ha\(^{-1}\) are possible with judicious management of soil resources (Ngetich et al., 2012; Jerenyama et al., 2000). Compared to conventional fertilizers, the smallholder farmers are likely to possess poor knowledge of recently blended, special, and evolving fertilizer types. Besides, the available fertilizer is often not the correct type required for various crops and most farmers are not familiar with its correct rates, the timing for application, and placement in the soil-plant continuum (Sanginga and Woomer, 2009). Better application of external inputs including fertilizers, lime, improved seed varieties, irrigation, and crop intensification, generated the ’Green Revolution’ in Asia and Latin America where substantial increases in crop yield was experienced since the 1960s (Fairhurst, 2012). During this period, per capita food production improved in North and West Africa regions, while it stagnated or declined in most parts of East, Central and Southern Africa (Pretty et al., 2011).

Improvement in agricultural productivity while minimizing negative ecosystem interactions is necessary to meet the global food requirement (Popp et al., 2014). Smallholder agriculture intensification can make substantial contributions to meeting this target because small-scale farmers account for a large proportion of global food production (Vanlauwe et al., 2014). Sustainable intensification approaches including ISFM encompasses combinations of soil-crop management techniques, requiring greater skills, efficient practices and knowledge by farmers (Pretty et al., 2011). Sustainable intensification entails productivity innovation including improved knowledge, use of improved varieties, fertilizer, and better crop management practices (Vanlauwe et al., 2014). ISFM has been shown to improve soil fertility and eventually increase yields (Kafesu et al., 2018; Kiboi et al., 2017; Vanlauwe et al., 2015; Mucheru-Muna et al., 2014; Mugwe et al., 2009b), but adoption has been low (Kamau et al., 2014; Kassie et al., 2013; Mugwe et al., 2009a) due to several socio-economic constraints including knowledge on how to integrate various organic and inorganic soil inputs into farming systems of the SSA region.

Limited access to timely and accurate information by small-scale farmers has been identified as a major hindrance to the improvement of rural agriculture in East Africa (Adolwa et al., 2010), West Africa (Andam et al., 2019; Adolwa et al., 2010), and Central Africa (Schut et al., 2016). This is more so for ISFM strategies which are knowledge-intensive and their adaptations and applications are diverse (Misiko and Ramisch, 2007). The nature and diversity of information that smallholder farmers have is not fully documented (Obala, 2013) as it has been disseminated by various researchers and extension workers at different times and may have been adapted over time by the end users. Even where it has been disseminated, the information is not adequately utilized (Adolwa et al., 2010), not easily available, and may be outdated (Sanginga and Woomer, 2009).

Figure 1. Map of the study area showing location of Runyenjes sub-County in Kenya.
| ISFM knowledge type | Survey ISFM knowledge items                                                                 |
|---------------------|-----------------------------------------------------------------------------------------------|
|                     | Fertilizer                                                                                   |
|                     | - Inorganic fertilizer is the quickest and surest way of nutrient supply                       |
|                     | - Important to purchase fertilizer well labeled and at recognized dealers                      |
|                     | - Inorganic fertilizer provides more accurate supply of specific nutrients                     |
|                     | - DAP (diammonium phosphate) is important to maize                                             |
|                     | - Timely application during growth stages result in fertilizer use efficiency                  |
|                     | - Blended fertilizer provides a more correct ratio of nutrients                               |
|                     | - Correct amount and type of inorganic fertilizer is important                                |
|                     | - Applied as top dressing in moist soil                                                       |
|                     | - I know the recommended types of fertilizer for my maize                                      |
|                     | - NPK 23:23:0 and CAN (calcium ammonium nitrate) use can achieve goal produce                 |
|                     | - Determination of soil fertility level is important before fertilization                      |
|                     | - Liming to correct soil acidity is important                                                 |
|                     | - Manure should be taken directly to farm                                                     |
|                     | - Green manure important to maize                                                             |
|                     | - Compost manure made near maize farm                                                         |
|                     | - 6 to 8 weeks sufficient to prepare compost                                                  |
|                     | - Organic manure                                                                             |
|                     | - Manure improves soil characteristics                                                        |
|                     | - I know how to prepare and use manure                                                        |
|                     | - Manure management necessary to obtain high quality                                           |
|                     | - Local seeds from previous yields discouraged                                                 |
|                     | - Integrated soil inputs                                                                     |
|                     | - Appropriate combination has best effect on soil fertility                                   |
|                     | - Seeds are acquired from authorized dealers                                                  |
|                     | - Manure management necessary to obtain high quality                                           |
|                     | - Local seeds from previous yields discouraged                                                 |
|                     | - Improved seeds                                                                             |
|                     | - Improved seeds adapted to local soil and climate                                             |
|                     | - Improved seeds more responsive to nutrients                                                 |
|                     | - Improved seeds resistant to pest and diseases                                                |
|                     | - Improved yields are realized with improved seeds                                             |
|                     | - Improved seeds more responsive to nutrients                                                 |
|                     | - Improved seeds resistant to pest and diseases                                                |
|                     | - Improved yields are realized with improved seeds                                             |
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|                     | - Improved yields are realized with improved seeds                                             |
Past studies focusing on ISFM knowledge held by farmers have tended to classify farmer knowledge in broad terms, without sufficient attempts to explore specific thematic knowledge by farmers. General agricultural knowledge entails farmer awareness of a broad range of functional aspects of farming practices, while technical knowledge (explicit knowledge) is associated with the skills and knowledge needed to perform specific farming practices such as combining soil inputs appropriately (Hess, 2006). In efforts to promote sustainable agricultural intensification and efficient agricultural practices, it is necessary to explore specific forms of ISFM knowledge held by small-holder farmers (Desbiez et al., 2004). How farmers combine different agricultural technologies is crucial because this can determine how concepts such as ISFM are put into practice, which is very important for success in bringing about agricultural productivity growth and sustainability (Lambrecht et al., 2016).

While ISFM systems are widely recognized to be knowledge-intensive technologies for small-holders (Espacios et al., 2017; Lambrecht et al., 2016; Misiko and Ramisch, 2007), studies synthesizing the knowledge gaps between existing farmer practices and recommended ISFM packages are lacking. There is evidence to suggest that there is lack of suitable mechanisms for transferring available knowledge on ISFM concepts from researchers to farmers in ways that promote innovation and sustainable adoption (Mapfumo, 2011). Therefore, the objectives of the study were to i) assess factors that influenced farmers’ ISFM knowledge quality and ii) to elucidate the structure of farmer ISFM knowledge under maize-based farming systems in Runyenjes sub-county, Kenya. The study will be useful in developing future ISFM dissemination approaches, sensitive to small-holder inherent characteristics and farm socio-economic settings in diverse maize cropping systems.

2. Methodology

2.1. Description of the study area

The following study was carried out in Runyenjes sub-county in Embu County of Kenya (study area map, Figure 1). Runyenjes sub-county lies in the Upper Midland semi-humid zone, at an altitude of approximately 1,200-2,070 m above sea level (Jaetzold et al., 2007). The annual mean temperature ranges from 12 °C to 27 °C. Rainfall distribution is bimodal with long rains commencing from mid-March to May while short rains occur between October and December, with the average annual rainfall ranging between 1,000–2,000 mm. The soils are deep, well-drained Humic Nitisols of volcanic origin with moderate to high fertility. The soils soil texture class is clay, with an average of 11% (sand) and 12.7% (silt), while the soil organic carbon content averages 2.8% (Njue et al., 2020). Runyenjes covers 149 km², out of which 96.26 km² is arable land with an average farm size holding of 0.4–0.8 ha (Jaetzold et al., 2007). The farming systems are complex smallholder farms that are intensively managed, consisting of an integration of crops, trees, and livestock. The main subsistence crops include maize (Zea mays), beans (Phaseolus vulgaris), yams (Dioscorea spp), cassava (Manihot esculenta), millet (Eleusine coracana), sorghum (Sorghum spp.), and bananas (Musa spp). The main cash crops include tea (Camellia sinensis), coffee (Coffee spp), cotton (Gossypium spp), and macadamia nuts (Macadamia spp). The main livestock in the region includes cattle, goats, sheep, and poultry. Runyenjes sub-county represents typical agricultural systems in the East African Highlands that require sustainable intensification and efficient use of agricultural resources (Vanlauwe et al., 2016). This is due to low and unpredictable crop yields, changing climates (Morton, 2007), land sub-division, expected population increases in the next 3 decades (United Nations, 2015), lack of fallowing land, and its proximity to the Mount Kenya forest ecosystem. Also, the sloppy terrain in Runyenjes stimulates conditions for soil erosion and degradation (Drechsel et al., 2001).

2.2. Sampling design and sample size

The study adopted a cross-sectional survey research design, using questionnaires and field observations to collect data from small-holder maize farmers. Runyenjes sub-County was purposefully selected because it is characterized by smallholder farmers who grow both subsistence and cash crops and a long term history of continued contacts with ISFM research and dissemination organizations including KALRO (Kenya Agricultural and Livestock Research Organisation), ICRAF (International Centre for Research in Agroforestry), CIAT (International Centre for Tropical Agriculture), Kenyatta University and IPNI (International Plant Nutrition Institute). The farm households were clustered into villages before sampling, while the number of households to be interviewed within each village was identified through proportionate sampling method after the total sample size was determined. The village population data were obtained from local administration offices to constitute the sampling frame. The farming households were arrived at through systematic random sampling where every 10th household head was interviewed. Ultimately, a sample size of 100 farmers was obtained using the formula below (Creative Research Systems (CRS), 2007).

| Table 2. Definition of multinomial regression variables. |
|----------------------------------------------------------|
| **Variables**                | **Definition**                      |
| **Dependent variables**      |                                          |
| ISFM knowledge levels        | Low, Medium, High                    |
| **Independent variables**    |                                          |
| Age of HH (years)            | Continuous variable                  |
| Gender of HH                  | 0 = Male, 1 = Female                  |
| Education of H               | 1 = None, 2 = Primary, 3 = Secondary, 4 = Tertiary |
| Farming experience (years)   | Continuous                            |
| Household size (number)      | Continuous                            |
| HH members in farming        | Continuous                            |
| Enough HH labour             | 0 = No, 1 = Yes                       |
| Total maize land (acres)     | Continuous variable                   |
| Training in ISFM strategies  | 0 = No, 1 = Yes                       |
| Off farm earnings (Kshs)     | Continuous                            |
| Total land owned (acres)     | Continuous                            |
| Yield in t ha⁻¹              | Continuous                            |
| House-hold monthly income (Kshs) | Continuous                      |
| Months of HH food security   | Continuous                            |
\[ S = \frac{Z^2p(1-p)}{c^2} \]

where: \( S \) = Sample size, \( Z = Z \) value (e.g. 1.96 for 95% confidence level), \( p \) = percentage of picking a choice, expressed as decimal (0.5), \( c \) = confidence interval, expressed as decimal (0.098). Pre-testing of the questionnaire was done with 15 respondents not included in the main survey (15% of the sample), after which appropriate modifications and adaptations were made to the questionnaire. To determine farmers’ ISFM...
knowledge levels, a five-point Likert scale analysis of 42 items was used under 4 ISFM themes including inorganic fertilizer (12 items), organic fertilizer (15 items), integrated soil inputs (7 items), and improved seed knowledge (9 items). The items were rated using the following scale (1 = strongly disagree, 2 = disagree, 3 = not sure, 4 = agree, 5 = strongly agree). Each set of ISFM questions was subjected to a reliability test using Cronbach’s alpha (Cronbach, 1951). All sets of test questions having a coefficient greater than 0.7 showed that the sets were reliable for the ISFM knowledge research model. Knowledge levels were considered to be moderate (means rounded off = 3), high (>3), or low (<3) after they were aggregated within ISFM themes for each farmer. The questions were classified into general and technical ISFM themes as shown in Table 1.

2.3. Data analysis

To address the first objective of the study, multinomial logistic regression was used to estimate the influence of socio-demographic variables on ISFM knowledge levels (Table 2). The regression model was appropriate because ISFM knowledge categories (response variables)
were classified at 3 levels (Low, moderate, and high). Descriptive statistics and cross-tabulations were used to relate socio-demographic characteristics with ISFM knowledge levels for each ISFM theme. ANOVAs were used to test mean differences (numeric variables) while Chi-square tests were used to establish linkages between categorical variables and ISFM knowledge levels. Dot charts plotted using R procedures (ggpubr package, ggdotchart procedure) were used to display ISFM knowledge mean scores. Table 2 is a description of the multimonial regression model variables.

Multinomial regression was used to describe data and to explain the relationship between dependent ISFM knowledge variables and socio-economic (interval or ratio scale) independent variables using the following function in SPSS version 22, resulting in 4 multinomial regression models (Equation 1).

\[
y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots + \beta_nX_n + \epsilon
\]

-where \(\epsilon\) is a random error with a mean of zero and a constant standard deviation \(\sigma\) and where \(X_1,...,X_n\) represents a vector of socio-economic predictors influencing ISFM knowledge levels (Table 2).

Multivariate analysis using PCA (Principal Component Analysis) was used to examine the knowledge structure and inter-relationships within general and technical ISFM themes (resulting in 4 PCAs) by reducing original variables into a few uncorrelated (orthogonal) dimensions. This analysis was relevant for the second objective of the study (objective 2), which sought to examine the ISFM knowledge structure among farmers. The data was verified for missing entries and outlier values after which multivariate analysis was implemented. A correlation matrix was used in the decomposition through the Varimax rotation procedure, and components with an Eigen value of >1 were retained for interpretation. To interpret variables in the rotated component matrices, a loading cut-off point of 0.4 was used (Comrey and Lee, 1992) since this magnitude of correlation (loadings) is considered to be sufficient. R (FactoMineR package) and SPSS procedures were used to implement the multivariate models and to generate biplots (factoextra package, R). Only PC1 and PC2 were plotted in the biplots because they explained the most important portions of variation in the reduced ISFM item sets.

2.4. Ethical considerations

The following study has followed ethical guidelines recommended by the office of Research Ethics at Kenyatta University. This included undergoing through a Research Ethics review process after which informed consent was obtained from interviewed farmers. The study respected the anonymity of participants and voluntary participation was maintained throughout the process. During the research, enumerators were briefed on issues of professionalism, etiquette, respondent privacy, voluntary participation and disclosure following standard research ethics principles.

3. Results

3.1. Knowledge levels of ISFM strategies

Most farmers strongly believed that inorganic fertilizer was the quickest and surest nutrient supply method for maize (4.68). The farmers also strongly agreed that it was important to purchase fertilizers from approved dealers (4.60) (Figure 2a). The knowledge of soil liming was lowest among farmers (3.21), followed by knowledge of soil fertility before fertilization (3.80), use of NPK and CAN (3.87), and the recommended fertilizer types for maize (3.90). A high proportion (94%) of small-holders used inorganic fertilizer for maize farming out of which 46% had high knowledge levels, 41% (moderate) and 7% had low knowledge level of fertilizer use.

### Table 3. Descriptive characteristics of ISFM knowledge levels and socio-economic characteristics.

| Parameters                              | Response categories | ISFM knowledge level | X² (P value) |
|-----------------------------------------|---------------------|----------------------|-------------|
|                                        |                     | Low                 | Moderate    | High        |
| Education of head                       | No education        | 3 (18.8)            | 10 (62.5)   | 3 (18.8)    | 0.046*      |
|                                        | Primary             | 5 (11.1)            | 19 (42.2)   | 21 (46.7)   |
|                                        | Secondary           | 0 (0.0)             | 12 (36.4)   | 21 (63.6)   |
|                                        | Tertiary            | 0 (0.0)             | 5 (83.3)    | 1 (16.7)    |
| Size of household                       | No education        | 6 (4)               | 5 (2)       | 5 (2)       | 0.024*      |
|                                        |                     |                      |             |             |
| **Manure**                              |                     |                      |             |             |
| Off farm income (KSh)                   | <10,000             | 3 (3.8)             | 20 (25.3)   | 56 (70.9)   | 0.091*      |
|                                        | 10,000 to 30,000    | 0 (0.0)             | 7 (38.9)    | 11 (61.1)   |
|                                        | >30,000             | 1 (33.3)            | 0 (0.0)     | 2 (66.7)    |
| Farming experience (years)              | 40.8 (8.6)          | 27.3 (18.3)         | 31.0 (17.0) | 0.054*      |
| **Integrated soil inputs**              |                     |                      |             |             |
| Occupation of head                      | Farming             | 5 (6.6)             | 37 (48.7)   | 34 (44.7)   | 0.047*      |
|                                        | Business/employed   | 3 (12.5)            | 5 (20.8)    | 16 (66.7)   |
| **Improved seeds**                      | Occupation of head  | 1 (1.3)             | 27 (34.2)   | 51 (64.6)   | 0.028*      |
|                                        | Business/employed   | 2 (9.5)             | 11 (52.4)   | 8 (38.1)    |
| Off farm earnings (KSh)                 | <10,000             | 3 (3.9)             | 28 (36.4)   | 46 (59.7)   | 0.007*      |
|                                        | 10,000 to 30,000    | 0 (0.0)             | 10 (55.6)   | 8 (44.4)    |
|                                        | >30,000             | 0 (0.0)             | 0 (0.0)     | 5 (100.0)   |
| Enough household labour                 | Yes                 | 1 (4.8)             | 12 (57.1)   | 8 (38.1)    | 0.09*       |
|                                        | No                  | 2 (2.6)             | 24 (31.2)   | 51 (66.2)   |
| Farming experience (years)              | 36.7 (5.8)          | 30.5 (18.5)         | 29.7 (16.9) | 0.054*      |

Values are arranged as counts and row percentages (in parenthesis) for categorical parameters. For numeric parameters (household size and farming experience), values are means and standard deviations (in parenthesis).

*Significant at 10% probability level.
Most farmers strongly agreed that manure improved soil physical characteristics although their nutrient release rate was slow (4.83). The farmers strongly acknowledged that good manure management was essential in ensuring good manure quality (Figure 2b). They also recognized that ready manure should be well decomposed without visible organic materials (detritus). The farmers recorded good knowledge of agroforestry in soil erosion control, but the role of agroforestry in green manures received a lower score. The findings indicated that more technical aspects tended to receive lower scorings in regards to organic manure, including the sufficient duration to prepare compost (3.4) and the need to prepare compost near farms to minimize nutrient losses (3.4). Seventy-eight percent (78%) of respondents used organic manure for maize cultivation from which 54% had high knowledge, 20% (moderate) and 4% had low knowledge levels.

Farmers readily recognized that appropriate combinations of organic and inorganic inputs were necessary to improve soil fertility (4.68). Farmers also recognized that combining fertilizers (inorganic input) with organic manure resulted in a more balanced nutrient supply (3.98) and higher maize yield (Figure 3a). However, they recorded lower scores regarding the economic implications, labor implications, and recommended rates for integrated soil inputs. Seventy-six percent (76%) of the respondents used integrated soil inputs for maize cultivation. Out of the farmers interviewed, 39% had high knowledge, 30% (moderate) while 7% had low knowledge levels of integrated soil inputs. There was no significant linkage between use and knowledge of combined inputs ($\chi^2 = 0.186$, $p = 0.911$).

Farmers highly rated planting of 2 seeds per hole for thinning after emergence (3.8), implying that they had sufficient knowledge of this recommended practice (Figure 2b). The farmers also assigned higher rates to the importance of purchasing well-labeled seeds from approved input dealers (3.7) and to the adaptability of improved seeds for local soils and climates. Farmers recorded lower knowledge scores for the recommended maize seed spacing and the unsuitability of recycled seeds from the previous harvests for high maize yields. A majority (92%) of farmers used improved seeds in maize cultivation. Fifty-eight percent (58%) had high knowledge, 31% (moderate) and 3% (low) regarding improved seeds. Among non-users, 1% had high knowledge, 7% had low knowledge levels of integrated soil inputs. There was no significant linkage between use and knowledge of improved seeds ($\chi^2 = 9.055$, $p = 0.011$).

### 3.2. Distribution of ISFM knowledge

Education of the household head ($p = 0.046$) and household size ($p = 0.025$) were significantly correlated with knowledge regarding inorganic fertilizer (Table 3). Off-farm earnings and farming experience were significantly linked with farmer quality of knowledge on manure use. Occupation of the household head ($p = 0.047$) was significantly associated with knowledge in integrated soil inputs for maize production. This implies a likelihood of those households who were farming having high knowledge in combined inputs compared to those in other forms of occupation. Occupation of the household head ($p = 0.028$), off-farm earnings ($p = 0.007$), household labor ($p = 0.09$) and farming experience ($p = 0.054$) significantly influenced the knowledge of improved seeds (Table 3).

### 3.3. Regression of ISFM knowledge and socio-economic factors

The land area under maize ($B = -2.365$, Odds = 3.705) and off farm income ($B = -1.130$, Odds = 5.130) were significant negative predictors of farmer’s quality of knowledge on inorganic fertilizer (Table 4). The significant predictors influencing whether farmer’s knowledge level was moderate relative to high in relation to fertilizer use (Table 4) included gender ($B = -2.188$, Odds = 3.106), education ($B = -1.810$, Odds = 3.317), household size ($B = -0.386$, Odds = 3.528), land area under maize ($B = -2.365$, Odds = 3.705), off farm income ($B = -1.130$, Odds = 5.130), and maize yield ($B = 1.995$, Odds = 3.794).

Training on manure management was the only variable that was found to be significant in determining whether farmers had moderate relative to high knowledge levels in manure utilization (Table 4). Regression analysis indicated that gender ($B = 2.323$, Odds = 2.780), household members in farming ($B = -1.366$, Odds = 6.057), maize yield ($B = -1.008$, Odds = 3.792) and off-farm incomes ($B = -0.576$, Odds = 4.152) were significant predictors for low relative to high knowledge in integrated soil inputs. The model predicted that age ($B = -0.084$, Odds = 4.285), number of household members engaged in farming ($B = 1.071$, Odds = 4.3) and farming experience ($B = 0.071$, Odds = 3.638) were significant predictors of moderate relative to high knowledge of integrated soil inputs (Table 4). Findings showed that household size ($B = -0.382$, Odds = 3.862) was a significant predictor of low relative to high knowledge in improved seeds. The model also showed that education ($B = -1.487$, Odds = 3.862), total land owned ($B = 1.758$, Odds = 3.259), and land area under maize ($B = -2.787$, Odds = 3.719) were significant predictors.

| Independent variables | Inorganic fertilizer | Manure | Integrated soil inputs | Improved seeds |
|-----------------------|----------------------|--------|------------------------|----------------|
|                       | $\beta$, sig         |        | $\beta$, sig           | $\beta$, sig   |
|                       | Low, Moderate        |        | Low, Moderate          | Low, Moderate  |
| Intercept             | 12.249               | 12.372 | 5.551                  | 1.214          | 0.21                | 2.135                | 8.539               | 11.216              |
| Gender                | -1.828               | -2.188*| 0.799                  | 0              | 2.323*              | 1.127                | -0.144              | -0.156              |
| Age                   | -0.082               | -0.067 | 0.046                  | 0.001          | -0.062              | -0.084**             | 0.025               | -0.027              |
| Education             | -2.000               | -1.810*| 0.559                  | -0.575         | -0.439              | -0.056               | -1.019              | -1.487**            |
| House hold size       | -0.104               | -0.386*| 0.026                  | -0.062         | -0.356              | -0.29                | -0.382*             | -0.315              |
| Farm experience       | 0.102                | 0.047  | 0.011                  | -0.012         | 0.069               | 0.071*               | -0.045              | -0.044              |
| Off-farm income       | -1.130**             | -0.477*| 0.004                  | 0.038          | -0.576*             | -0.277               | 0.08                | -0.094              |
| Yield                 | 1.359                | 1.995* | 0.088                  | -0.05          | -1.008*             | -0.634               | 0.799               | 0.812               |
| Farm size             | -0.053               | 0.205  | 0.031                  | 0.091          | -0.100              | -0.008               | 0.573               | 1.758*              |
| Maize land area       | -2.365*              | -1.112*| 0.016                  | -0.482         | -4.263              | -1.765***            | 0.178               | 2.787**             |
| Training              | -0.047               | 1.103  | 1.077                  | 1.765***       |                    |                     | -1.153              | -0.102              |
| Monthly income        | 0.113                | 0.259  | 0.24                   | 0.078          |                     |                     |                     |                     |
| Occupation            | 1.189                | 0.903  | 0.31                   | -0.733         |                     |                     |                     |                     |
| Labour                | 1.366**              | 1.071**| -1.716                 | -0.282         |                     |                     |                     |                     |

Reference category is high knowledge level, **Significant at 5% probability level, *Significant at 10% probability level.
predictors of moderate relative to high knowledge in the use of improved seeds (Table 4).

3.4. ISFM knowledge structure and associations

The multivariate analysis explained 63% of the total variation of inorganic fertilizer use knowledge (Figure 4a), while the first and second components explained 33% of the variation. Five principal components were extracted from 12 fertilizer knowledge variables (Table 5).

“Blended fertilizer provides correct nutrient ratio” (IF_5), “Important to determine soil fertility before fertilization” (IF_7), “Timely application results in fertilizer-use efficiency” (FUE) (IF_3), “Purchasing labeled fertilizer from approved dealers” (IF_8) and “Need to top-dress when soils are wet” (IF_6) were closely correlated to fertilizer knowledge variables in component 1. “Correct amount and type of inorganic fertilizer is important” (IF_4) and “NPK 23:23:0 and CAN achieves goal produces” (IF_12) were negatively related with each other. IF_4 signified more specific knowledge of fertilizer concepts by farmers. “Importance of liming to correct acidity” (IF_9) and “DAP is important to maize” (IF_11) were highly correlated and represented component 4. Farmers with high knowledge of soil liming recorded high-quality knowledge on DAP use.

“Inorganic fertilizer is the quickest way of nutrient supply” (IF_1) and “Fertilizers represent a more accurate supply of specific nutrients” (IF_2) were highly correlated and consisted of component 2, implying that farmers who perceived fertilizers as a quick way of nutrient supply agreed that fertilizers represented more accurate nutrient supplies.

The multivariate model for organic fertilizer explained 65% of the total variation in organic fertilizer knowledge scores after 6 non-correlated components or synthetic knowledge variables were extracted (Table 6) from a set of 15 questions (Figure 4b).

The first component consisted of positive loadings from “Manure should be taken directly from the cowshed to the farm” (OM_15), “Ready manure is loose, dry and has no smell” (OM_10), “Good management is necessary to obtain quality manure” (OM_3), “Agroforestry trees control soil erosion and runoff” (OM_14) and a negative loading from “FYM (farmyard manure) is covered during curing to avoid nutrient losses” (OM_4). Farmers with high scores on OM_15 (“Manure should be taken directly from cowshed to the farm”) also recorded high scores on OM_10 (“Ready manure is loose, dry and has no smell”), as both represented technical knowledge of manure management and organic material decomposition principles. The second component included a negative correlation of OM_2 (“I know the proper method of preparation and use”)...
with OM_12 (“Biomass transfer is labor-intensive compared to agroforestry trees”) and OM_6 (“Ready manure should not have visible detritus”). This dimension represented contrasting knowledge between more specific organic fertilizer themes (“Biomass transfer is labor-intensive compared to agroforestry trees”, “Ready manure should not have visible detritus”) and more general or functional organic manure themes (“I know the proper method of manure preparation and use”).

The third component was described by positive correlations between “6–8 weeks is sufficient to prepare compost” (OM_9), “Proper incorporation ensures no burning of seeds when dry” (OM_7), and “Improves soil physical characteristics” (OM_1). This shows that farmer scores in these technical ISFM domains shared a close response pattern and correlation structure. Component 4 was described by knowledge of soil erosion and leaching control benefits of organic technologies as signified by positive correlations between OM_5 (“Cowshed covered to prevent leaching of nutrients”) and OM_13 (“Agroforestry controls erosion and runoff”).

“Manure is made close to farm to minimize losses” (OM_8) was poorly associated with OM_11 (“Green manure is important for maize crop”), implying that farmer knowledge of composted/livestock manure was poorly associated with that of green manures.

The multivariate model for integrated soil input raw scores consisted of 7 original variables and 3 factors explaining 75% of the total variance (Figure 4c, Table 7).

The first dimension included “Appropriate combinations are the best way of affecting soil fertility” (IFOM_2), “50% of maize yield increase can be attributed to appropriate fertilization” (IFOM_1), and “Combining inputs provides a more balanced nutrient supply” (IFOM_4). The second component comprised of “Combination ratio should be 1:1 or 50/50” (IFOM_3). Component 3 was consisted of contributions from “Labor-intensive to use combined than

### Table 5. Principal Component loadings of inorganic fertilizer knowledge scores.

| Code | Variable descriptions                                      | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 | Component 7 |
|------|------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| IF_5 | Blended fertilizer provides a more correct ratio of nutrients | 0.723       |             |             |             |             |             |             |
| IF_7 | Determination of soil fertility level is important before fertilization | 0.648       |             |             |             |             |             |             |
| IF_3 | Timely application during growth stages result in fertilizer use efficiency | 0.606       |             |             |             |             |             |             |
| IF_8 | Important to purchase well labeled fertilizer from recognized dealers | 0.598       |             |             |             |             |             |             |
| IF_6 | N-fertilizers are applied as top-dressing when soils are moist | 0.550       |             |             |             |             |             |             |
| IF_1 | Inorganic fertilizer is the quickest and surest way of soil and plant nutrient supply | 0.839       |             |             |             |             |             |             |
| IF_2 | Inorganic fertilizer provides more accurate supply of specific nutrients | 0.803       |             |             |             |             |             |             |
| IF_10 | I know the recommended types of fertilizer for my maize |             |             |             |             |             |             | 0.665       |
| IF_4 | Correct amount and type of inorganic fertilizer is important |             |             | 0.636       |             |             |             |             |
| IF_9 | Liming to correct soil acidity is important |             |             | 0.771       |             |             |             |             |
| IF_11 | DAP is important to my maize crop |             | 0.578       |             |             |             |             |             |
| IF_12 | NPK 23:23:0 and CAN use can achieve goal produce |             |             |             |             |             |             | 0.811       |

**Eigen values**: 1.5 1.3 1.1 1.1 1.1 1.0

**Proportion of variance**: 19.2 14.2 10.6 10.3 8.7

**Cumulative variance**: 19.2 33.4 44.0 54.3 63.0

**Extraction Method**: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization.

### Table 6. Principal Component loadings of organic fertilizer knowledge scores.

| Code | Variable descriptions                                      | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 | Component 7 |
|------|------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| OM_15 | Manure should be taken directly from cowshed to the farm | 0.740       |             |             |             |             |             |             |
| OM_10 | Ready manure is loose dry and has no smell | 0.674       |             |             |             |             |             |             |
| OM_4  | Farmyard manure should be covered during curing to avoid nutrient losses | -0.626      |             |             |             |             |             |             |
| OM_14 | Agroforestry trees control soil erosion and runoff | -0.588      |             |             |             |             |             |             |
| OM_3  | Good manure management is necessary to obtain high quality manure | 0.438       |             |             |             |             |             |             |
| OM_2  | I know the proper method of preparation and use of fertilizer | -0.735      |             |             |             |             |             |             |
| OM_12 | Biomass transfer is labour intensive compared to planting agroforestry trees within farm | 0.595       |             |             |             |             |             |             |
| OM_6  | Ready manure should not have materials such as grass and leaves visible | 0.542       |             |             |             |             |             |             |
| OM_9  | 6–8 weeks is sufficient to prepare compost | 0.717       |             |             |             |             |             |             |
| OM_7  | Proper incorporation of manure will ensure no burning of seeds when dry | 0.693       |             |             |             |             |             |             |
| OM_1  | Organic fertilizer releases nutrients slowly but improves soil physical characteristics | 0.463       |             |             |             |             |             |             |
| OM_5  | Cowshed covered to prevent leaching of nutrients during rains | 0.783       |             |             |             |             |             |             |
| OM_13 | Agroforestry trees also control erosion and runoff | 0.562       |             |             |             |             |             |             |
| OM_8  | Compost manure made at location close to farm to minimize losses | 0.874       |             |             |             |             |             |             |
| OM_11 | Incorporation of green manure is important to maize crop | 0.860       |             |             |             |             |             |             |

**Eigen values**: 1.7 1.5 1.2 1.1 1.1 1.0

**Proportion of variance**: 19.1 14.7 9.9 8.7 7.5 5.2

**Cumulative variance**: 19.1 33.8 43.7 52.4 59.9 65.0

**Extraction Method**: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization.
Table 7. Principal Component loadings of integrated soil inputs knowledge scores.

| Code | Variable descriptions                                                                 | Component 1 | Component 2 | Component 3 |
|------|----------------------------------------------------------------------------------------|-------------|-------------|-------------|
| IFOM_2 | Appropriate combinations of organic and inorganic fertilizer best way of effecting soil fertility | 0.848       |             |             |
| IFOM_1 | 50% maize yield increase can be attributed to efficient fertilization                   | 0.802       |             |             |
| IFOM_4 | Combining both organic and inorganic fertilizer provides a more balanced nutrient supply | 0.739       |             |             |
| IFOM_5 | Ratio of combining organic and inorganic fertilizer should be 1:1 or 50/50              |             | 0.903       |             |
| IFOM_6 | Combined inorganic and organic fertilizer should be half the recommended rates         | 0.891       |             |             |
| IFOM_3 | Cheaper to use both inorganic and inorganic fertilizer than inorganic fertilizer alone | 0.532       |             |             |
| IFOM_7 | Labor intensive to use combined inputs than inorganic fertilizer alone                  |             |             | 0.944       |

**Eigen values**

| Proportion of variance | Cumulative variance |
|------------------------|---------------------|
| 35.2                   | 11.3                |
| 61.2                   | 75.5                |

**Extraction Method:** Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization.

Table 8. Principal Component loadings of improved seed knowledge scores.

| Code | Variable descriptions                                                                 | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 |
|------|----------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|
| SEED_8 | Improved maize seeds from authorized dealers are more adapted to local soils and climate | 0.851       |             |             |             |             |
| SEED_5 | It is important to plant 2 seeds per hole to allow thinning after emergence           | 0.682       |             |             |             |             |
| SEED_1 | Large yield increases are realized with improved seeds use                             | 0.501       |             |             |             |             |
| SEED_3 | 75cm by 25cm is the recommended planting space for maize                               |             | -0.792     |             |             |             |
| SEED_7 | Improved seeds are more responsive to nutrients than local maize seeds                  | 0.773       |             |             |             |             |
| SEED_2 | Maize spacing important to reduce competition for water and nutrients                  |             |             |             | 0.857       |             |
| SEED_4 | It is important to acquire improved seeds from authorized dealers                      |             |             |             |             | 0.828       |
| SEED_6 | Using seeds from previous yields will ensure maintenance of good yields                 |             |             |             |             | -0.690      |
| SEED_9 | Improved maize seeds are more resistant to pests and diseases than local maize seed varieties |             |             |             |             | 0.941       |

**Eigen values**

| Proportion of variance | Cumulative variance |
|------------------------|---------------------|
| 20.4                   | 12.3                |
| 37.2                   | 51.0                |
| 50.1                   | 63.4                |
| 63.4                   | 74.6                |

**Extraction Method:** Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization.

inorganic fertilizer alone” (IFOM_7) and was distinct as a knowledge dimension that was poorly associated with other knowledge variables and domains. This was most closely associated, though weakly, with IFOM_2 (“Appropriate combinations are the best way of affecting soil fertility”) than any other variable.

The multivariate model explained 75% of the total variation in improved seed knowledge, resulting in 5 orthogonal factors (Figure 4d, Table 8).

The first component was comprised of SEED_8 (“Improved maize seeds are better adapted to local soils and climate”), SEED_5 (“Should plant 2 seeds per hole to allow thinning”), and SEED_1 (“Yield increases can be realized using improved seeds”) scores. SEED_3 (“The recommended spacing for maize is 75 cm by 25 cm”) and SEED_7 (“Improved seeds are more responsive to applied nutrients than local seeds”) were negatively related in terms of their scoring structures. SEED_2 (“Adequate spacing is important to reduce plant competition”) was distinct as a knowledge dimension that was poorly related to other seed knowledge variables. Component 4 was a contrast between SEED_4 (“Important to acquire improved seeds from authorized dealers”) and SEED_6 (“Using seeds from previous yields ensures good yields”), a finding that was expected. SEED_9 (“Improved seeds are more resistant to pests and diseases than local seeds”) represented farmer knowledge on pests and diseases about improved seeds which was poorly related with other seed knowledge variables and dimensions, hence it was the only variable consisting of PC 5 (Table 8).

4. Discussions

4.1. Socio-demographic predictors and ISFM farmer knowledge

Misiko and Ramisch (2007) pointed out that adoption of ISFM strategies is affected strongly by the farmers’ knowledge and socio-economic factors. In agreement with our current results, Macharia et al. (2014) observed that adoption and knowledge of inorganic fertilizer in the Central Highlands of Kenya were high. The fertilizer benefits (including its’ convenience and better yields) and high cost, could have prompted farmers to seek more knowledge about fertilizers (Macharia et al., 2014). The high knowledge levels for organic manure could be a function of availability and easy access because livestock was commonly reared in over 80% of households (FAO, 2018). More so, concerns by farmers regarding the limitations in quality and quantity of animal manure (Mugwe et al., 2009a) may have created the urge to look for information on how to improve the manures thus increasing their knowledge levels.

Over 70% of the farmers used inorganic fertilizer and animal manure on separate plots, without any attempt to integrate the two. This could be due to a lack of awareness of the benefits of integrating inputs because...
most farmers possessed moderate levels of knowledge. Several studies indicate that awareness and use of soil inputs is more common compared to their integrations. In Central Kenya, over 90% of farmers used sole manure, while 87% integrated manure with fertilizer (Mwaura et al., 2021). In addition, a declining frequency and land area trend were observed when multiple organic/inorganic input combinations were included (Mugwe et al., 2008). Farmers did not fully embrace improved maize seeds in the study area, thus they continued recycling seeds from previous seasons. Ogada et al. (2014) reported that about 40% (lowlands) to 80% (highlands) of farmers used improved maize seeds, with some farmers using saved hybrid seeds or local seed varieties. Whereas the use of inorganic fertilizer, manure, and their combination were not strongly a function of knowledge level, improved seed adoption was strongly associated with ISFM knowledge levels. This implies that capacity building is needed to enhance use of improved seeds by farmers.

The willingness of a household to use fertilizer is shaped by the household's level of knowledge and skills regarding fertilizer technologies and their capacity to evaluate potential gains from fertilizer (Mapilama, 2011). The low relative to high knowledge levels for inorganic fertilizer among farmers with small farms could be attributed to the fact that smaller farms could reduce farmers' motivation and resources to acquire inorganic fertilizers. Farmers with large land areas are more likely to adopt inorganic fertilizer and other advanced agricultural technologies (Kanyenji et al., 2020; Murithi et al., 2018; Manda et al., 2016). Small farms may indicate a low level of resource endowment in a house-hold and low income flows from agriculture because the harvested quantities and marketable output surpluses are minimal (N'ang'a et al., 2016). Mapila et al. (2012) found that although inorganic fertilizer use offers an option for increasing agricultural production, it does not always provide a comprehensive solution especially where maize farms are small.

Households without off-farm income were more likely to have a low relative to a high level of knowledge in inorganic fertilizer compared to farms with off-farm incomes. This is probably because off-farm income predisposes farmers to resources needed to make higher investments in soil fertility and the likelihood that they will seek quality knowledge to ensure the success of such investments. The findings are consistent with previous results showing that farmers with off-farm incomes had more resources to the acquisition of farm inputs soil-crop knowledge (Martey et al., 2014; Barrett, 2016; Marenya and Barrett, 2007).

Female-headed households had a moderate relative to a high level of knowledge about inorganic fertilizer compared to male-headed households. Macharia et al. (2014) reported that female household heads were likely to have less knowledge on inorganic fertilizer compared to their male counterparts. Although males control most household resources including decisions related to cash income, it is the females who are left to take care of the farm work (Waithaka et al., 2007). This makes females more likely to be aware of information on new technologies as they implement them.

Educated farmers had moderate relative to high knowledge levels in fertilizer use while training was positively associated with a farmer having moderate relative to high knowledge levels in manure use. This means that a farmer with training in manure was more likely to have a moderate relative to a high level of knowledge in manure. Educated farmers are likely to decipher information, seek and apply more specialized or explicit knowledge compared to less-educated farmers. This agrees with Ndiritu et al. (2014) and Kamau et al. (2014) who observed that education levels of households are likely to be more aware of new technologies. Small households were more likely to have moderate relative to high knowledge levels in mineral fertilizer use, because large households need to produce more food and are more likely to seek better crop production knowledge. Farmers with low education were more likely to have moderate relative to high knowledge in improved maize seeds. This agrees with Adolwa et al. (2012) who noted that the process of information seeking and its accessibility generally requires the information seeker to have attained some level of literacy and knowledge.

Farmers with small farms were more likely to have moderate relative to high knowledge of inorganic fertilizer and improved seeds. Mugi-Nengera et al. (2016) and Macharia et al. (2014) reported that land size was a significant predictor for farmer knowledge levels. Given the resource constraints of smallholder farmers in Africa, they are probably only able to allocate minimal resources for improved agricultural techniques. Vanlauwe et al. (2012) and Ajayi et al. (2007) explained that ISFM investments by a household are closely related to the household’s level of resource endowment. Marenya and Barrett (2007) stated that unobserved constraints and shadow prices facing households vary systematically with farm size.

Households with more members involved in farming were more likely to have low relative to high knowledge levels in integrated soil inputs. This could be because large households demand more resources, thus less effort is set aside in seeking knowledge. Smaller households were more likely to have low relative to high knowledge levels in improved seeds, which could be associated with lower food requirements which might hinder the quest for knowledge to increase maize yield.

Findings showed that younger farmers were more likely to have moderate relative to high knowledge in integrated soil inputs. This agrees with Macharia et al. (2014) and Geta et al. (2013) who reported younger farmers having less experience to give them sufficient knowledge on integrated inputs as opposed to older counterparts. A household with a large number of members involved in farming was more likely to have a moderate relative to a high level of knowledge in integrated soil inputs. Though more members can provide labor, the large households may incur more expenditure resulting in minimal resources for farm investments (Waithaka et al., 2007) including knowledge. Farmers with more farming experience were more likely to have moderate relative to high knowledge in integrated soil amendments similar to findings by Akinola et al. (2010).

4.2. ISFM knowledge structure

Across the ISFM themes that were investigated, farmers recorded lower average knowledge scores in technical themes compared to general ISFM themes. The topics which recorded lower scores included soil liming, soil testing, fertilizer types, fertilizer functions, curing organic manure, compost management, seed spacing, combination ratios for integrated soil inputs, and the labor and cost-benefit implications of integrating inputs, revealing key ISFM knowledge gaps. In contrast, there were higher knowledge scores associated with general ISFM themes. The technical domains are important facets for successful ISFM (Sanginga and Woomer, 2009) and sustainable agricultural intensification in the SSA region, thus efforts are needed to improve the quality of knowledge in these domains. In other global regions, practices that have contributed to increasing the response of fertilizer include soil testing, specific fertilizer blends suitable for farmer conditions, ameliorating soil acidity, better fertilizer application methods, and adjustment of plant populations to suit farmer micro-locations (Sheahan et al., 2012).

Seitova and Stamkulova (2017) and Schut et al. (2016) showed that lack of knowledge by farmers was a major limiting factor for ISFM, agricultural productivity and sustainable intensification in Rwanda and Eastern Europe, respectively. The findings appear to be well substantiated by Schut et al. (2016) who reported poor knowledge of production techniques, inadequate farmer sensitization, limited knowledge of ISFM practices, and poor knowledge of ISFM profitability and potential benefits. In Kenya, Rwanda, inappropriate ISFM and IPM (Integrated Pest Management) coupled with challenges in the extension system limited farm productivity innovation (Schut et al., 2016). Farmers in South Kazakhstan were not fully aware of ISFM principles attributed to the wide communication gap between farmers and other stakeholders in agricultural knowledge and innovation systems (Seitova and Stamkulova, 2017). Jambo et al. (2019) showed that farmer knowledge structure and motivation for sustainable intensification followed a similar pattern,
with more general topics receiving higher scores compared to more explicit aspects that received lower average scores.

Sanginga and Woomer (2009) observed that the most important aspects of ISFM in SSA smallholder farming systems encompasses technical ISFM domains including (i) appropriate use of mineral fertilizers and liming, (ii) efficient management of organic resources, (iii) incorporation of nitrogen-fixing legumes into farming systems and (iv) adequate protection of soils, their biota, and soil organic matter. About inorganic inputs, the highly scored items represented more general ISFM topics, while scores tended to decline with more specific and technical aspects relating to fertilizers. The knowledge scores for integrated inputs also showed higher scores for general themes including appropriate combinations being the best way to improve soil fertility, while specific aspects including combination ratios and cost-labor implications of integrating inputs received lower knowledge scores. Low ISFM knowledge results from different situations, but it is partly a result of communication gaps between farmers and other agricultural stakeholders (Adolwa et al., 2017; Sanginga and Woomer, 2009).

The PCA on inorganic fertilizer knowledge signified highly specialized fertilizer knowledge domains. Farmers with high knowledge levels in a particular type of knowledge-intensive domain were likely to be knowledgeable in other types of explicit fertilizer knowledge, including fertilizer blending and the need for soil testing before fertilization and top dressing. A study by Bwambale (2015) in Uganda showed that none of the farmers conducted soil tests to evaluate the fertility before using fertilizers due to lack of knowledge and resources. Farmers who were knowledgeable in blended fertilizers were also conversant with determining soil fertility before fertilization. Additionally, farmers with high DAP use knowledge were more knowledgeable in soil liming.

Regarding organic manure use, the first dimension signified knowledge of organic manure management principles. The knowledge of transferring manure directly from the cowshed to the farm was correlated with knowledge on ready manure for use, good manure management and the role of agroforestry in erosion control. Knowledge of the suitable duration required to cure manure was associated with knowledge on proper incorporation and the role of manure in soil physical characteristics, while the knowledge of erosion control and leaching minimization benefits of organic manure use was associated.

A set of farmers recognized the importance of integrating soil inputs on soil fertility, nutrient supply, and maize yield. These farmers recognized more technical (explicit knowledge) aspects relating to integrated inputs including combination ratios and the cost/benefit implications of input combinations which were internally correlated, though the mean scores for these set of variables were low. Farmers with high-quality knowledge on input combination ratios were likely to have a good quality of knowledge in their cost implications as well as their economic benefits. This group of farmers was knowledgeable on more technical ISFM themes and could be important in initiatives to scale-up ISFM and sustainable intensification because they can constitute lead farmers in ISFM training and field exchange programs. Improved seed knowledge was related to dimensions describing seed local adaptability and agronomic knowledge scores which were correlated. Farmers recognized that quality seeds from recommended dealers were better than saved seeds which may not ensure reliable maize yields. Farmer knowledge on pests and diseases represented a distinct knowledge domain that was not correlated with other seed knowledge variables.

Lambrecht et al. (2016) reported a similar multivariate pattern of ISFM knowledge and adoption among farmers in Central Africa (DR Congo), with resource-intensive technologies (improved cassava, row cropping and mineral fertilizer) and less resource-intensive technologies (improved legume and maize) being internally correlated and simultaneously or sequentially associated. Row cropping and fertilizers represent appropriate agronomic practices in the ISFM paradigm and are knowledge-intensive, labor-intensive, and resource-intensive for farmers in DR Congo (Lambrecht et al., 2016).

The study findings have practical implications for scaling up in terms of development of farmer training materials. It is clear that more investments and focus should be directed towards technical ISFM themes because the domains are necessary for prosperous ISFM initiatives in the SSA farming systems. Wanjiku et al. (2010) recommended more practical and field-oriented approaches for agricultural training activities (approximately 80% content), with supporting theoretical content (approximately 20%). The study findings provide a framework to structure ISFM training materials because correlated ISFM concepts can be packaged into ISFM thematic groups for enhanced field delivery. The multivariate analyses revealed 3 to 6 independent factors indicating correlated knowledge patterns within the factors.

The following ISFM knowledge research model was based on small-scale maize farmers in the central highlands of Kenya which represents critical agro-ecosystems of the SSA region requiring sustainable management of soils and environmental resources. The findings are applicable in highland farming systems which include a sufficient level of farm input and technology integrations. While ISFM technologies encompass a wide range of inputs and cropping systems, the following study was focused on maize-based small-holder systems with integrations of fertilizer, manure, and improved seeds. Related research on specific thematic ISFM knowledge in diverse cropping systems is insufficient which could have lent useful insights for the current study. Nonetheless, the study has attempted a unique approach to characterize the ISFM knowledge structure held by small-scale farmers using knowledge classification tools. Future research in diverse crops, farming systems, and ISFM technologies is needed. This can provide further evidence and recommendations to enhance ISFM and sustainable intensification of agricultural practices in the SSA region.

5. Conclusions and recommendations

The evidence from this study suggests that ISFM efforts should consider farmers’ knowledge, age, labor availability, education, training, income, land distribution, and gender dynamics. Whereas education, farming experience, training, and gender can influence farmer explicit knowledge and decision-making in ISFM, land distribution, labor, and income structures are proxy measures for resource availability which can moderate access to ISFM resources and knowledge.

The study has obtained comprehensive results depicting the essential ISFM knowledge structure among farmers, which can be generalized in similar agro-ecosystems of the SSA region. The technical facets including knowledge of fertilizer combination ratios, are key for successful ISFM and sustainable intensification of maize production. Therefore, efforts are needed to improve farmer quality of knowledge in these domains. This research provides an entry point and framework for the development of ISFM training materials, including generation and organization of content because ISFM concepts that were correlated can be grouped into field packages for enhanced delivery. Farmers with high-quality ISFM knowledge can make key contributions towards dissemination in multiple agro-ecological settings of the SSA region.

Declarations

Author contribution statement

Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Monicah Wanjiku Mucheru-Muna, Mildred Achieng Ada, Jayne Njeri Mugwe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Franklin Somoni Mairura: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Esther Mugi-Ngenga: Performed the experiments. Shammie Zingore: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper. James Kinyua Mutegi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article supplemental material/references in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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