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Farmers' knowledge and Practices of Soil Conservation Techniques in Smallholder Farming Systems of Northern Kabare, East of D.R. Congo

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ABSTRACT

Understanding local knowledge and practices of soil and water conservation is essential for designing and implementing cost-effective and sustainable erosion control programs, and thus reducing soil erosion's adverse impacts on agricultural lands. This study investigated the farmers' perceptions of soil erosion challenges, knowledge on erosion management, and practices implemented in smallholder farms in northern Kabare, South-Kivu province, eastern Democratic Republic of Congo (DRC). Data was collected through individual interviews with 257 randomly selected farmers, coupled with focus group discussions. Results showed that soil erosion was a common phenomenon in more than three-quarters (76%) of surveyed farms. Eleven soil conservation techniques (SCTs) were known by farmers, of which, only six were routinely implemented on farms: mulching (36% farms), continuous or tied ridges (26% farms), hedges (19% farms), channels and drains (10% farms), infiltration ditches (4% farms), and terraces (2% farms). The effectiveness of each soil conservation strategy at the farm level depended on the number of techniques simultaneously practiced by a farmer, the farm location along the slope, the integration of livestock into farming systems, the farmer's main activity and income level, and more importantly, the farmer knowledge on soil erosion control measures. Farmer participation in farmers' associations (or cooperatives) was instrumental in his/her ability to control erosion at the farm level in the study area. This study was one of the few that tackled the role played by farmers' perceptions on the adoption of SCTs in eastern DRC and opens an avenue in developing programs associating scientific and indigenous knowledge for sustainable soil erosion control.

1. Introduction

Soil erosion is a process that involves detachment, transport, and sedimentation or settling of soil particles (Lal and Stewart, 1992; Subramanya, 2005; Lal, 2008). It is one of the most predominant land degradations in the Democratic Republic of Congo (DRC), particularly in the eastern mountainous areas where it is experienced in both urban and rural areas (Mushi et al., 2019; Heri-Kazi and Bielders, 2021). Sheet erosion dominates throughout the country, while gully erosion is common in the eastern cities (e.g., Bukavu, Beni, and Butembo), in the western cities (e.g., Kikwit and Kinshasa), and along rivers (Ilombe, 2019). The frequency of soil erosion seems to have accelerated in recent decades (Kabantu et al., 2018), probably due to land over-use, uncontrolled construction, and rapid deforestation. On farmlands, accelerated soil erosion could be associated with inappropriate agricultural practices, mining, climate change, and rainfall aggressivity (Chuma et al., 2021a; Chuma et al., 2021b). In the eastern part of DRC, consequences of soil erosion comprise declining soil productivity, which underlies food insecurity, low incomes, and poverty among rural populations (Li and Fang, 2016; Tyukavina et al., 2018; Mushi et al., 2019). Therefore, soil

Abbreviations: DRC, Democratic Republic of the Congo; INERA, Institut National d'Etude et Recherche Agronomiques; PNKB, Kahuzi Biega National Park; NGO, Non Governmental Organization; OM, Organic matter; WRB, World Reference Base for Soil Resources; SCT, Soil conservation techniques; IFK, Indigenous Farmer Knowledge.

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improvement and conservation through the application of appropriate techniques are necessary, not only to maintain soil functions but also food security, which is largely dependent on agriculture.

Soil conservation techniques (SCTs) have a long history in Sub-Saharan Africa (SSA). Local techniques such as ridging, ditches (of all the types), hedges, terraces, etc. were known since the pre-colonial era in several kingdoms and civilizations (Shetta et al., 1999). During the colonial period until the 1970s (in DRC and particularly in the province of South-Kivu), soil management was under state coordination through the "Mission de Lutte Antiérosive" (MAE) program. MAE imposed very demanding SCTs in terms of manpower and surface area (such as terraces, agroforestry, ditches, etc.) (Lunze, 1992). These erosion control programs were launched on a large scale in areas with high agricultural potential production of industrial crops such as tea, coffee, cinchona, cotton, etc. (Lunze, 1992). A few years later (after decolonization), these techniques were abandoned and farmers reverted to less demanding techniques, sometimes poorly mastered, which increased erosion problems in the study area (Scoones, 1996; Junge et al., 2009).

Other soil management programs were initiated (in the 1970s) to promote the old techniques and introduce new ones at the same time. Their impacts were positive and nowadays the remainders are still visible. Conscious of the erosion adverse impact, perceived through major alterations of the natural environment, farmers of Kabare have adapted to erosion by implementing soil and water conservation techniques. However, these initiatives depended on farmers for implementation and use (Carel and Tondeur, 1986; Lunze, 1992).

To increase the resilience of the population in Kabare, several local and international non-governmental organizations (NGOs) have set up soil improvement and conservation projects. However, most of them did not address the issue of sustainability, promotion of practices, and their appropriation by the local population once the project cease. Thus, at the end of the project interventions, the traceability of their impact and promotion of techniques in farms other than those in which they were initially tested were difficult to perceive. This was partly attributed to the promotion of SCTs that were not within the technical and financial reach of Kabare farmers given their high implementation costs, effectiveness problems in local agro-ecological conditions, and the arduousness of implementation (UEA-Mercy Corps, 2018).

This study focuses on the Kabare territory, in South-Kivu province, a densely populated area among the eight territories of the province and which is characterized by a rapid and high soil degradation rate. That high population density, steep topography, and high climate aggressivity increase pressure on land resources, and the frequency of natural hazard risks. Mean soil loss in the region is estimated at ~11 to 40 t per hectare yearly (Lunze, 2013). As a consequence, predominant "low fertility" or "poor soils" do not allow sufficient crop cover to ensure effective conservation. In addition, these soils are poor in organic matter (OM), over-used, are mostly found on hilly, steeply sloping lands that are very susceptible to erosion (Heri-Kazi and Bielders, 2021). All these underline the crucial role that adequate implementation of SCTs would play in Kabare.

It is increasingly recognized that adequate soil and water conservation is a prerequisite for implementing successful agricultural development programs in the Kabare highlands. Pypers et al. (2011) and Sanginga and Woomer (2009) suggested that sustainable land management (SLM) in Kabare should seek to increase agricultural production through both traditional and innovative systems while improving resilience to land and climate threats. Taking into account local (or indigenous) knowledge in solving agricultural challenges is increasingly being recognized and suggested for greater effectiveness of actions and their sustainability (Ngara et al., 2013). Dominics and Fuchaka (2016) and Alemu et al. (2019) demonstrated that indigenous farmer knowledge (IFK) is an important resource that contributes to increase effectiveness, efficiency, and sustainability in natural resources conservation, including soil and water, particularly in developing countries. A direct link is, therefore, established between IFK and resource management. While defining IFK as inner knowledge to a culture, a community, based on decision-making from many years of experience, Rohana et al. (2008) showed that the dissemination of many agricultural techniques and technologies have failed in rural areas because they overlook the preferences, skills, and knowledge-based on local societies. Therefore, IFKs are important not only for farmers but also to agricultural scientists and extensionists as mentioned by Kerven and Sikana (1988) and Mupangwa et al. (2006) in Zambia and Zimbabwe, respectively. In the case of the Sub-Saharan African region, Mulat (2013) and Rijn Van et al. (2015) pointed out that IFK is of ecological importance, in which water and soil conservation techniques are integral parts of farming systems.

A better understanding of local knowledge is a key for success in any planning and implementation of agricultural development activities. This work was conducted to assess farmers' knowledge of soil and water conservation practices and their effectiveness in reducing soil losses in smallholder farming systems of Northern Kabare. It analysed the effect of the socioeconomic profile of smallholder farmers in the study area on SCTs practiced as well as the relationship between the knowledge acquired by farmers on erosion management and the effectiveness in SCTs implementation.

2. Materials and methods

2.1. Study area

2.1.1. Location

This study was conducted in the province of South-Kivu, eastern DRC. It was particularly implemented in six northern districts (locally referred to as "groupements") of Kabare territory: Bushumba, Bushushu, Kalwa, Lemera, Mabingu, and Mushweshwe. The study area is located between the Lake Kivu (East), the Kahuzi-Biega National Park (PNKB) (at the West and North), and Bukavu City (South) (Fig. 1). The northern part of Kabare was chosen due to its rapid population growth rate and high density, the significant role of agricultural activities in households' livelihood and the territory gross domestic product (GDP) in general. Kabare is also among areas experiencing the highest soil degradation and depletion rate in DRC (Murphy et al., 2015).

2.1.2. Climate

Kabare territory is characterized by a humid tropical climate tempered by elevation. According to the Köppen-Geiger classification, it is of *Aw3* climate type. The region benefits from two seasons: the rainy season with nine months (from September to May) and the dry season with three months (from June to August) (Chuma et al., 2021c). The rainy season is divided into three cropping seasons: the season A which goes from mid-September to January; the season B from mid-February to June; and the Season C from July to mid-September (only for flooded inland valleys and wetlands) (Chuma et al., 2021c).

Available climatic data (1960–2015) from two Kabare weather stations are presented in Fig. 2. The average annual rainfall and temperature were 1601±154 mm and 19.67±2.3 °C, respectively. Compared to 2021 data, climate parameters have not changed much during the last 55 years (C.V: 9.6% for precipitation and 12% for temperature). The maximum intensity of rainfall is between 5 and 10 mm per minute. The topography (elevation), the presence of Lake Kivu, and the forests (PNKB and Nyungwe) explain the mild change in climate of the study area. Relief diversity and elevation lead to a microclimate that induces different traditional production systems. Precipitation increases with elevation and more when moving closer to the Lake Kivu (Muhindo et al., 2014; NCEA, 2018).

2.1.3. Soil, hydrology, and vegetation

Ferralsols, Cambisols, Nitisols, and Acrisols are the most dominant soil unities. Steep slopes are dominant across the territory, though

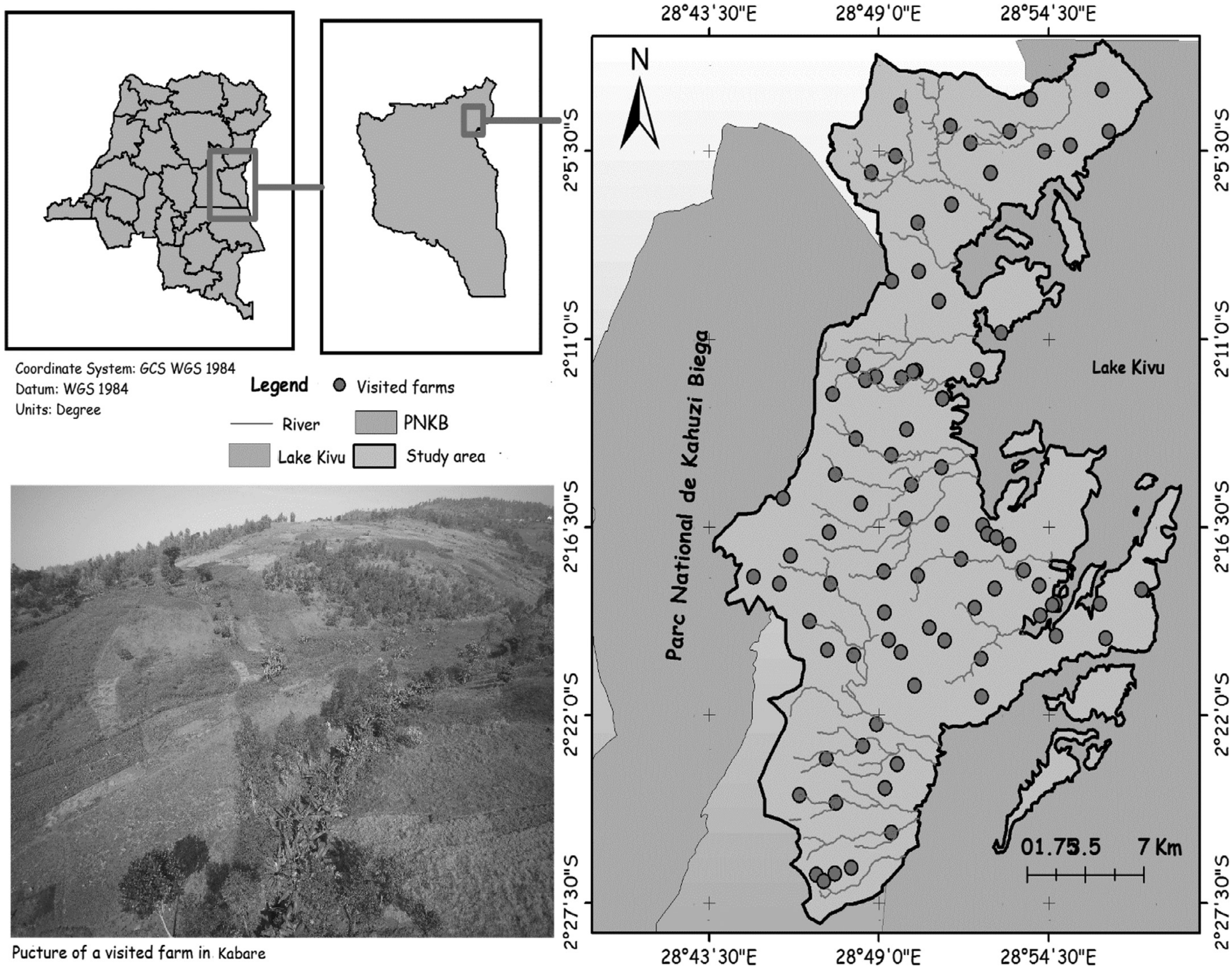

Fig. 1. Study area location in the South-Kivu province, eastern DRC (dots on the map represent the surveyed farms).

around the Lake Kivu, there are alluvial inland valleys with a fairly interesting structure (Mulielu, 2014; Chuma et al., 2021c). These areas are productive and suitable for vegetable production. Lower depth soils are observed on hills and composed of schistose and clayey soils. Classified as recent volcanic (towards the north in the vicinity of the PNKB), the soils originate from old volcanic substrates mainly of basaltic type. Gully erosion and landslides are currently observed in those areas and have shaped the entire region. Man activities (deforestation, over-grazing, and over-use of agricultural land) have also added further anthropogenic pressure leading to soil erosion.

Five main catchments are found in the study area: Mushweshwe-Irambi, Birava, Bushumba-Nyamununi, Lwiro, Bughore, and Cinjoma. Several streams are observed along the hillsides and have mostly their sources in the PNKB forest; the main ones are Nyawarongo at Irhambi-Katana, Badibanga at Bugorhe, Mpungwe at Mudaka, Mpombe and Murhundu at Bushwira, and Kanzinzi at Bugobe.

Several studies reported losses of the vegetation cover and high land use and land cover (LULC) changes in the South-Kivu province, with a rather important speed in Kabare. Analysis of LULC from 1995 to 2018 (**Supplementary Figure 1**) showed a reduction of farmlands (coffee, cassava, banana, and tea plantations) and forest cover (secondary forest: 15%) and an increase of dwellings and settlements (12%) and bare soils (33%) (Chuma, 2019).

2.2. Methods

2.2.1. Sampling and data collection

A household survey, using a semi-structured questionnaire, was conducted during the season A of 2018 (from September 2017 to February 2018). Data related to socioeconomic information, known and practiced SCTs, constraints in implementing these SCTs, and the determinants of their effectiveness on erosion control were recorded. Before data collection, a pre-survey was conducted to familiarize with local authorities, to determine suitable areas for surveys and to define a representative sample size for each selected district. Surveys were also coupled with focus group discussions and secondary data from chiefdom reports. As the total number of farmers in the study area was unknown, a random sample of 257 farmers was selected. The sample size for each district is presented in Table 1.

Data were collected through direct on-farm observations, individual interviews with farmers, and focus group meetings with resource-persons, including local authorities, leaders of farmers' organizations, chiefdom and territory agronomists, etc. For on-farm observations, transects were made following the topography of each district (from the bottom to the top through the hillsides) to identify soil and water management practices (SCTs) used in each district following the slope gradient: in the bottom, on the slope, and at the hilltop. If the number of farms

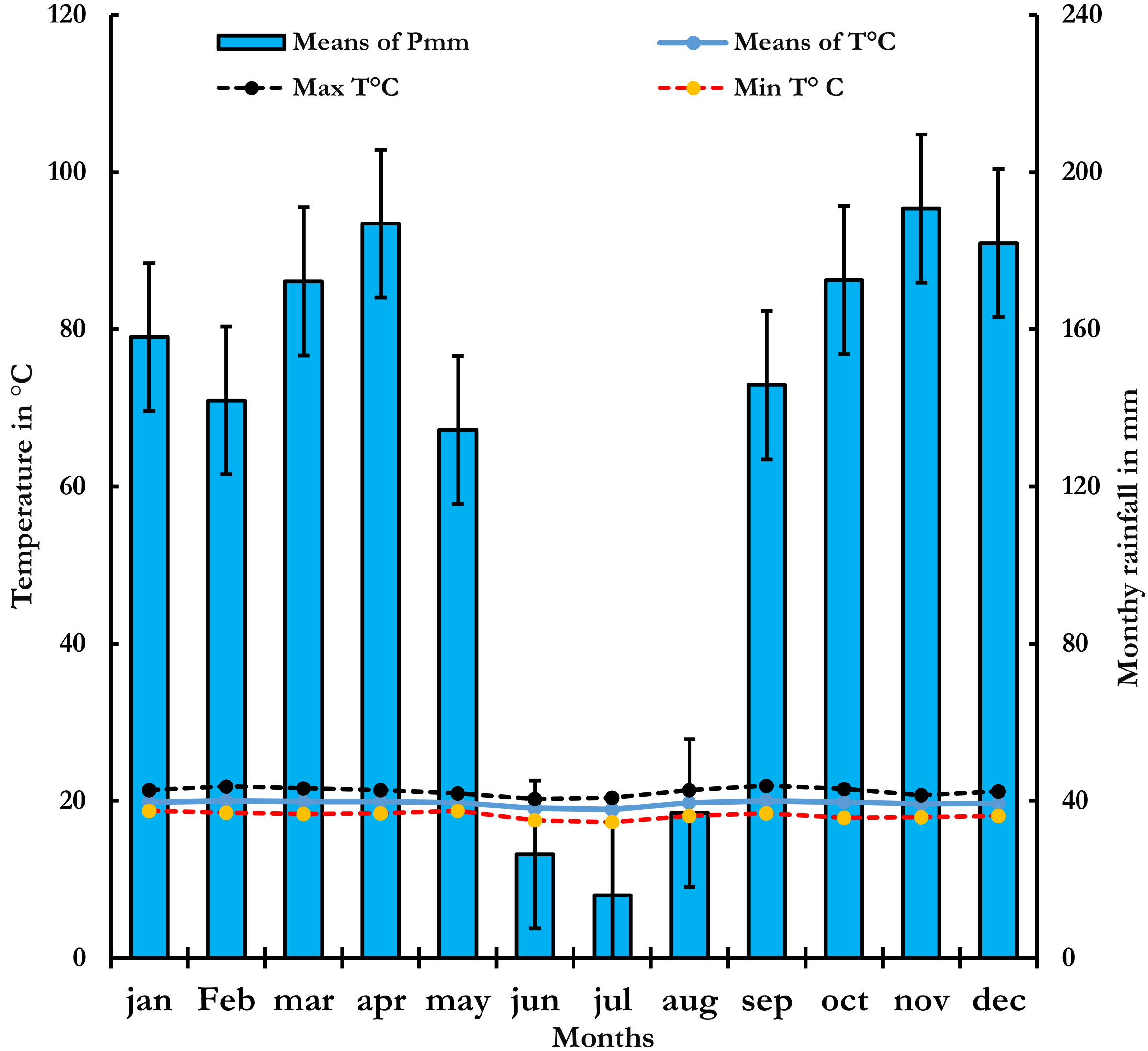

Fig. 2. Trends in annual rainfall and temperatures in northern Kabare from 1950 to 2015 (bars above each column are representing standard deviations).

Table 1
Sample size per selected districts/ “groupements” in northern Kabare.

Zones	Sample size	Percentage (%)
Bushumba	61	23.7
Bushushu	30	11.7
Kalwa	49	19.1
Lemera	36	14.0
Mabingu	46	17.9
Mushweshwe	35	13.6
Total	**257**	**100**

found on the transect did not reach the target per village, farms near the transect were included. Also, whenever it was difficult to reach the target field, it was replaced by the closest one. The state of erosion in the selected farms was assessed using two levels (1=“*presence or accelerated*” and 0=“*absence or very weak*”). Value 1 was given to farms with rill and gully erosion, while 0 was given to low sheet erosion or non-eroded farms. Besides, observations on the terrain topography, land cover, expansion of agricultural land degradation, grazing, and currently applied SCTs were also recorded. Information related to problems of land degradation, local indicators (of land degradation), and constraints in SCT implementation were also assessed. Focus groups were organized to get a global view on the erosion situation. A group of 15 farmers was randomly selected for every focus group discussion. Other complementary or missing information (not contained on the survey questionnaire) and other relevant farmers’ points of view were recorded throughout the survey. This farmers’ global opinion (view) allowed identifying the community’s perception of different practices used to manage agricultural lands. The key topics developed during group discussions were: soil management, soil erosion, SCTs, food security, and agricultural productivity.

2.3. Data analysis

Descriptive statistical analysis was performed on all variables to assess the general trend of collected data. Chi-square (χ^2) test was used to assess the dependence/independence among practiced or known SCTs and presence/absence of erosion, socioeconomic factors and constraints to use of SCTs. The decision was taken following a probability threshold of 5%. To describe and figure out the link between adopted SCTs and farmers’ socioeconomic characteristics, we performed a Multiple Correspondence Analysis (MCA). Since data were presented as individual × variables, MCA outcome became comparable with the Principal Component Analysis (PCA) (R Core Team, 2019). Individuals were made of the surveyed farms (257) and assessed variables (15) included farmers’ socioeconomic characteristics, presence/absence of erosion, the use/or not of SCTs, and the farm location. The analysis, therefore, con-

Table 2
Socioeconomic characteristics of smallholder farmers in northern Kabare, eastern DRC.

Characteristics	Modalities	Respondents (n = 257)	Percentage (%)
Age	*< 35 years*	66	25.7
	35 – 50 years	93	36.2
	> 50 years	98	38.1
Sex	*Male*	129	50.2
	Female	128	49.8
Education level	*Illiterate*	104	40.5
	Primary	66	25.7
	Secondary	81	31.5
	University	18	2.3
Farm tenure status	*Rental (Bwasa)*	24	9.3
	Metayage (Kalinzi)	11	4.3
	Ownership	222	86.4
Farmer economic level*	*Rich*	34	13.2
	Medium	134	52.1
	Poor	89	34.6
Membership to farmers' association	*Yes*	88	34.2
	No	169	65.8
Main activity of household head	*State agent*	8	3.1
	Farmer	223	86.8
	Trader	17	3.5
	*Others***	8	6.6
Marital status	*Single*	10	3.8
	Married	229	89.1
	Widowed	18	7.1

* **:** The economic level of the household was assessed by the assets held on the holding (brick house = rich, wooden house = average or in clay = poor; in possession of a vehicle = rich, bicycle or motorbike = average, without means of transport = poor), **: other activities corresponded to: servant in a factory, carpenter, salaried labor on a holding, mine diggers, etc.

sisted of looking for an association between the variables and their modalities. Additional quantitative variables were added to the analysis as supplementary variables (age, seniority, number of owned fields, the total farm size, the distance between household and the field, etc.). In fact, MCA is a data-reduction method applied to such variables to derive a smaller set of non-correlated principal components. Although the number of key variables was reduced, the variability of the dataset was largely preserved. The common core idea to all component analyses such as the MCA is to describe dataset using a small number of uncorrelated variables while retaining as much information as possible (Chandra and Shang, 2019). It is a method of summarizing a large number of qualitative variables into a small number of synthetic variables to better characterize the relationships between the initial variables of the dataset. During analysis, the economic status of the household's head was difficult to determine. Therefore, to assess the economic status, three variables were combined: the number of animals in livestock, the type of house (in bricks, wooded or concrete, and non fired bricks or earth materials), and owned means of transport (bicycle, motorcycle, or vehicle). A farmer was considered as "rich" when he/she owned a brick house and/or had a vehicle as a means of transport, and had cattle for livestock. A farmer was classified as "poor" if he/she lived in an earthen house, had no means of transport, and practiced or had no mini-livestock. The other types of farmers were classified as intermediate or "average". R Studio and R 3.2.3 (Chandra and Shang, 2019) were used for statistical analyses.

3. Results

3.1. Socioeconomic characteristics of farmer households in northern Kabare

The socioeconomic characteristics of surveyed farmers in northern Kabare are presented in Table 2.

It shows that across districts, 87% of farmers had agriculture as the main economic activity; almost half of the farmers were women (~49%), with ~38.1% having >50 years old while 36.2% of farmers had 35–50 years old. Most farmers were married (~89.1%) and had a low level of formal education: ~40.5% of them were illiterate and ~25.7% had a primary education level. From an economic point of view and based on the combination of three economic variables, most farmers were classified as of "*average*" economic level (~52%), i.e., owned a bicycle or motorbike for transport or had a wooded or concrete house, including boards. More than half of the farmers were not members of farmers' associations or cooperatives (~65.8%). Only 34.2% of farmers had a favorable attitude towards training courses commonly organized by local farmers' support structures. Three land tenure statuses existed in northern Kabare: ownership (~86.4%), the "Bwasa" (9.3%), which is a precarious renting contract, and the "Kalinzi" or sharecropping (4.3%).

3.2. Technical characteristics and agricultural practices observed on farmlands in northern Kabare

The technical characteristics and agricultural practices on farmlands in northern Kabare are presented in Table 3. Five crops were predominant: cassava (39.3%), banana (33%), common beans (14.8%), and maize (12.8%). The polycropping farming system (82%) was the most practiced by Kabare farmers. More than half of these farmers had less than one hectare (~50.9%) while only 18.3% had more than 2 hectares.

The number of farms owned depended on grown crops ($p<0.05$); bananas were mainly grown in a single field (51%) and sometimes in two (33%) while common beans could be practiced in three (30%), two (30%), and eight (20%) farms by a single household. Mini-livestock was practiced in ~25.7% of farms, while large livestock (cattle) was practiced by a few farmers classified as "rich" (23.7%). Most farmers had 10–30 years of seniority in farming (61.9%). Households often cultivated several fields (up to 8 farms, with an average of 2.3 fields) to meet food and financial needs. Types of practiced livestock depended on farm size, types of exploitation, and monthly incomes. These farms were generally located far from the farmer household as it could take ~28 min (by foot) to reach them. Cassava is a staple crop in Kabare, it was grown by farmers with one (35%), three (30%), and four fields (30%). These farmlands were mostly located on hillsides (~50.9%) than inland valleys (37.4%) and hilltops (11.7%).

Table 3
Structural characteristics of smallholder farms in northern Kabare, eastern DRC.

Characteristics	*Modalities*	Respondents (Max - min)	Percentage (%) (Mean)
Crops grown	*Banana*	85	33.0
	Common bean	38	14.8
	Maize	33	12.8
	Cassava	101	39.3
Cropping systems	*Monocropping*	46	18.0
	Polycropping	211	82.0
Farm size (ha)	*< 0.5 ha*	131	50.9
	0.5 to 2 ha	79	30.8
	> 2 ha	47	18.3
Field position on slope	*Hillsides*	131	50.9
	Valley (flat)	96	37.4
	Hilltop	30	11.7
Livestock types	*Mini-livestock*	66	25.7
	Cattle	61	23.7
	None	130	50.6
Seniority in farming activity	*< 10 years (recent)*	68	26.5
	10 to 30 years (medium)	159	61.9
	>30 years (old)	30	11.6
Farm-to-house distance (in minutes)		180 - 1	28.6
Number of farms owned		8 - 1	2.3

3.3. Erosion control techniques (ECTs) known and practiced by smallholder farmers in northern Kabare

The inventory of practiced and known SCTs by farmers in northern Kabare is presented in Fig. 3. In total, 11 SCTs were known by smallholder farmers while only six were practiced in the study area. The most known SCTs were: ridges (92%), channels or piping (88.3%), and mulching (73%). Techniques such as Zaï (3%), half-moon (1.3%), and water retention pond (0%) were not well-known by farmers. Mulching (36%) was the most common technique used, followed by ridges (continuous or tied) (26%), hedges (19%), and channels (10%). The crop association or polyculture as practiced in Kabare was also cited as an effective erosion control technique. Infiltration ditches (4%) and terraces (2%) were very weakly practiced. Only 9% of farms had no SCTs and were mostly those in inland valleys. These techniques were often combined in the field to increase their effectiveness. Two (25%) up to three (35%) SCTs were often practiced simultaneously on a single farm.

Mulching (Fig. 4**e,f**) faced challenges of availability of materials (straw) to use and attracted rodents (rats) in the cassava fields and fungal diseases for other crops. However, it allowed suppress weed.

Channels (Pipes) (Fig. 4**d**) were primarily used to separate plots and farms. However, as they are laid in the slope direction, they become the preferred paths for runoff and developed over time into large rills and small gullies. Their setting (implementation) cost was high and sometimes required tools such as wheelbarrows, trident, spade and fork, rake, and silhouette that were unavailable in farmer areas or unaffordable to most farmers.

Hedges were popular on farms located in northern Kabare. They were often made of multipurpose species, including *Tripsacum laxum, T. andersonii, Tithonia diversifolia, Dracaena afromontana, Calliandra calothyrsus, Leucaena leucocephala, Brachiaria ruzisiensis, Pennisetum purpureum, Setara sphacelata*, etc. However, hedges were constrained by the accessibility to planting materials, which rose the cost of their installation. On one hand, other major constraints were the narrowness of farmer fields, which did not facilitate their installation because they reduced the space occupied by main crops. On the other hand, they provided advantages such as their high effectiveness in controlling erosion as attested by 76% of farmers, and their subsequent use as green manure or fodder.

Ridges (continuous or tied): Practiced only for some crops such as roots and tuber crops. Establishing ridges was an integral part of the technical itinerary of most farmers (25%) and in nearly 72% of cassava farms. Some farmers recognized them as SCTs, while others practiced them as a "routine" farming activity with no intention of soil conservation.

Terraces: Rarely found Kabare (2%), terraces were mainly observed in some coffee and tea plantations and especially in Mabingu. Constraints in applying this technique were the high cost of implementation, the lack of information on how to conduct it, and the time it takes for terraces to control soil erosion.

Association/polycropping system: This was widely practiced in farms located in northern Kabare (82%). Farmers were accustomed to practice two or more crops simultaneously on the same field. According to their perception, this practice significantly reduces soil erosion. In fact, this is not a normal crop association but rather a polyculture (without following a specific structure, succession, or spacing). Mixed cropping of banana, cassava, and legumes reduced erosion for a long period of the year due to their high and permanent soil coverage. The integration of legumes (soybean, pea, and common bean) improved also soil fertility through atmospheric nitrogen fixation, which is favorable for the growth and development of cereals, including maize and sorghum. Unfortunately, fungal and viral diseases significantly affect banana and cassava crops and impact the system sustainability.

3.3. Determinants of the effectiveness of erosion control techniques in smallholder farms in northern Kabare

Results of the logistic regression model (LRM) on the effectiveness of SCTs in reducing erosion are presented in Table 4. Effectiveness was assessed by the occurrence in fields of sheet erosion, rills, and gullies.

The LRM showed that several factors affected the effectiveness of SCTs in northern Kabare. These determinants were classified into socioeconomic and technical factors. Among those factors, the household economic status, land tenure status, main activity of the household's head, his/her education level, gender (sex), age, and integration of crop-livestock, and cropping system were the most determining factors of SCTs effectiveness. Other factors such as the types of crops and practiced SCTs, the membership to a farmers' association, training on SCTs, and the location of the farm vis-à-vis the slope gradient influenced the SCTs effectiveness in Kabare.

(a) Influence of socioeconomic characteristics on farmer perception of erosion

The result from the MCA linking 15 variables showed an inertia of 1.59. Two axes (F1: 36.05% and F2: 12.97%) were selected and explained 49% of the variance (Fig. 5 and **Supplementary Figure 2a**).

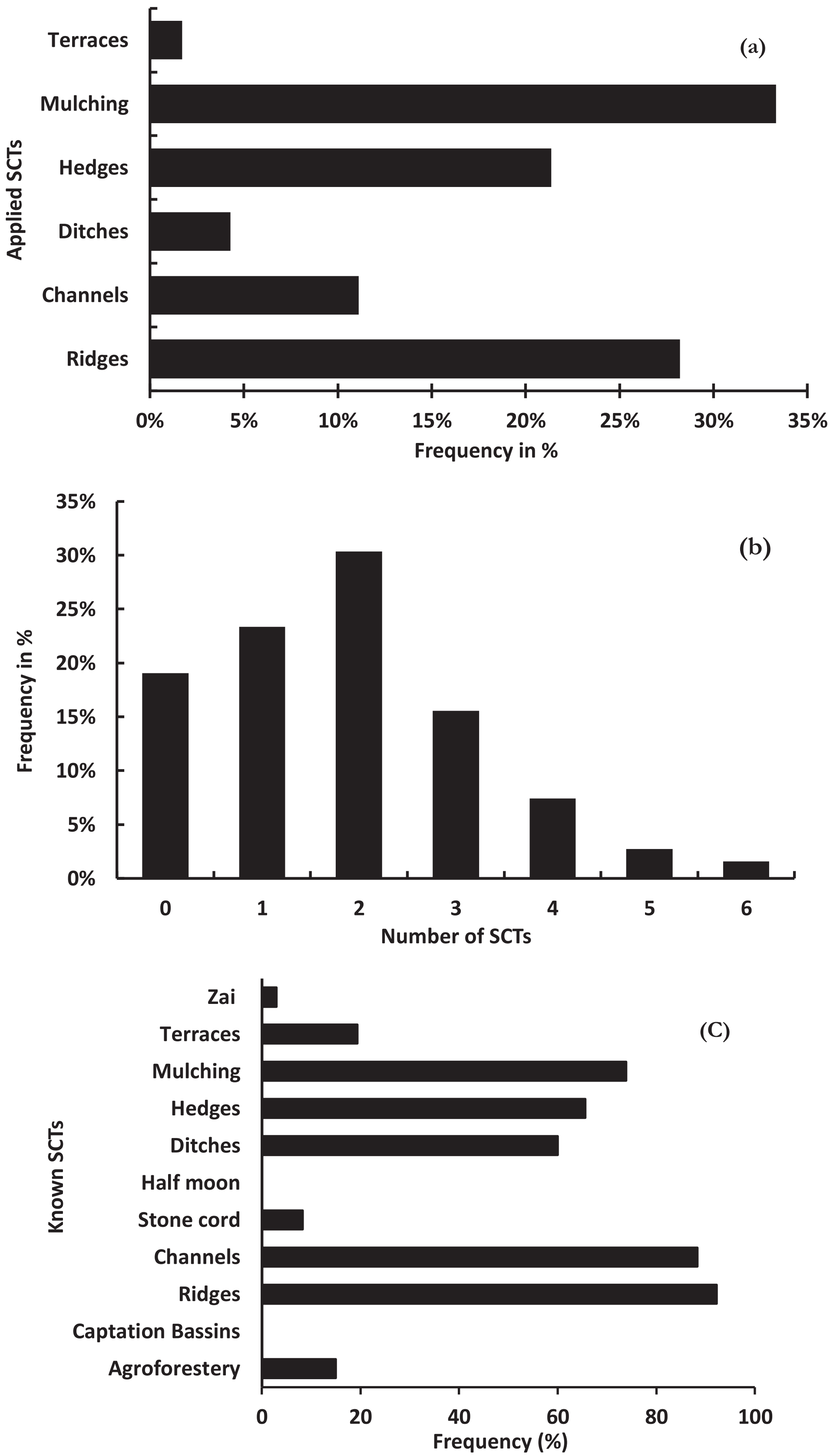

Fig. 3. Soil Conservation Techniques (SCTs) practiced (**a**), frequency of SCTs use (**b**), and known SCTs by smallholder farmers (**c**) in northern Kabare, eastern DRC.

Fig. 4. SCTs practiced in northern Kabare: (**a**) maintained terraces, (**b**) old terraces not maintained, (**c**) ridges, (**d**) channels, (**e**) lines of hedges coupled with straw, (**f**) mulching in cassava farm, (**g**) infiltration pit beginning to accumulate sediment (left) and rill creation in the bean field (right), (**h**) *Tripsacum laxum* hedges combined with infiltration pit on hillside farms.

Table 4
Logistic regression of factors determining SCTs effectiveness in northern Kabare, eastern DRC.

Factors	Coeff.	St. err	|Z-sc| χ^2	*p*-value
Socioeconomic				
Gender (sex)	−0.09	0.179	3.38	*0.04303**
Marital status	0.034	0.181	1.29	*0.4960ns*
Age	−0.014	0.02	2.93	*0.0482**
Household economic level	*0.127*	*0.023*	*10.56*	*<0.0001***
Household head main activity	*0.032*	*0.002*	*32.58*	*<0.0001***
Techniques				
Number of farms	−0.041	0.003	3.82	*0.4840ns*
Farm (s) tenure status	−0.072	0.0775	13.10	*0.0221**
Crops grown	0.0575	0.0641	9.48	*0.0396**
Erosion control technique used	0.1499	0.0248	9.48	*0.0395**
House-to-farm distance	−0.002	0.0033	3.73	*0.563ns*
Farm position on slope	0.1568	0.0248	7.26	*0.0272**
Number of SCTs practiced	0.2258	0.0641	37.58	*0.0001***
Types of livestock	0.1255	0.1167	45.98	*0.0001***
Related to farmer knowledge				
Membership to farmer association	0.2083	0.0047	36.45	*0.0001***
Education level of the household head	*0.0996*	*0.1440*	*9.58*	*0.0431**
Training on SCTs	0.1547	0.0748	42.27	*0.0001***
Number of observations 257				
Wald Chi^2 46.58				
Prob>Chi^2 0.000				
Pseudo R^2 0.371				

ns : not significant, * and ** : significant at 5% and 1% probability thresholds, respectively.

Five and four variables contributed significantly to the formation of F1 and F2, respectively. F1 grouped farmers according to their socioeconomic status, while F2 grouped farmers based on erosion control techniques.

Fig. 5 shows that farmlands, where erosion was present, were those not integrating livestock with crops, or practicing mini-livestock (chickens, ducks, guinea pigs, cavy, etc.); growing maize and cassava, and mainly located on hillsides or at the hilltop. Erosion was also pronounced on farmlands where owners had no formal education and were poor, and therefore, unable to afford effective or expensive soil management practices such as continuous ditches and terraces. On the other hand, farmlands, where erosion was least severe, were those practicing polycropping systems, where owners had an advanced education level and were actively involved in local farmer organizations and associations. Generally classified as riches, those farmers had long activity history (seniority) and were involved in rearing livestock. Difference was observed between agricultural activities, used SCTs, and farmer gender ($\chi 2$= 3.38, p = 0.043). Men practiced not only industrial crops that generate high incomes but also SCTs requiring energy such as terraces, ditches, and channels; while women practiced mainly annual crops (vegetables, common beans, maize, sweet potatoes, etc.) to meet household food needs. Techniques that do not require sufficient physical effort were left to women (ridges, mulching, quickset hedges).

(b) Effects of indigenous farmer knowledge (IFK) on erosion in smallholder farms in northern Kabare

Indigenous farmer knowledge (IFK) in northern Kabare was assessed following and combining three parameters, including education level, membership in a local farmers' association, and the farmer's participation in training courses on SCTs organized by the governmental (National Institute for Agronomic Studies and Research (INERA), Provincial Division of Agriculture, Aquaculture and Livestock (IPAPEL), etc.) or non-governmental organizations (NGOs). Fig. 6 shows a correlation between the farmer's education level and the occurrence of soil erosion on farms. Farms that were owned by highly educated farmers experienced less erosion (63% for university-level) compared with those with illiterates (38%) and primary education level (40%) (χ^2= 9.589, df=1, p = 0.043).

The knowledge acquired at school and their ability to understand certain phenomena enabled educated farmers to adopt, improve and perpetuate the SCTs. The same trend was observed for farmers belonging to a local farmers' association (χ^2 = 10.107, df=1, p = 0.039). Farmers without erosion (58%) problems in their farms were mainly members of associations. Indeed, farmers' associations were the main sources of knowledge and the best way of knowledge transmission. Training courses conducted by local and international organizations working in the study area were actually under farmers' association. Nearly 60% of farms where erosion was absent were the ones owned by farmers who have received at least one training course on SCTs (χ^2= 37.581, df=1, $p<$0.001). The main trainers were INERA-Mulungu and IITA-Kalambo (among other research centers), while international and local NGOs supporting those farmers were mainly Mercy Corps, CAB, ASOP, FH (Food for the Hungry), World Vision, and Diobass-Kivu, etc.

(c) Influence of erosion control techniques (ECTs) on water erosion on farmlands

Results on the correlation between the number of SCTs simultaneously practiced and the occurrence of erosion in farmer fields are presented in Fig. 7 (**a** and **b**). From Fig. 7, it can be realized that the more SCTs were combined, the less the erosion occurred in farmer fields (χ^2= 42.27, df=5, $p<$0.001).

However, the erosion control effectiveness depended on the SCTs used (χ^2= 37.27, df=5 $p<$0.001) (Fig. 8). Farmlands without SCTs (92%) were prone to erosion. In contrast, the prevalence was significantly reduced at ∼60% when 3 SCTs were combined and at ∼20% when 5 to 6 SCTs were simultaneously used. Hedges combined with ridges were the most effective erosion control technique in northern Kabare. The combination of techniques, therefore, appeared to be an effective way of reducing erosion. Farmers using hedges (76%) did not suffer from water erosion. Unfortunately, only 20% of farmers used them.

Contrary to farmers' opinions that terraces were effective in controlling erosions, the field observations demonstrated the opposite, as only 38% of farms with terraces were protected against erosion. Therefore, no correlation was established between setting the terraces and the decrease in the prevalence of erosion (χ^2= 3.4, df=1, p = 0.175). It should be noted that these terraces (Fig. 4**a**) were established in the 1970s. As they require more financial costs for their establishment and maintenance, they have been gradually abandoned and consequently it affected their effectiveness.

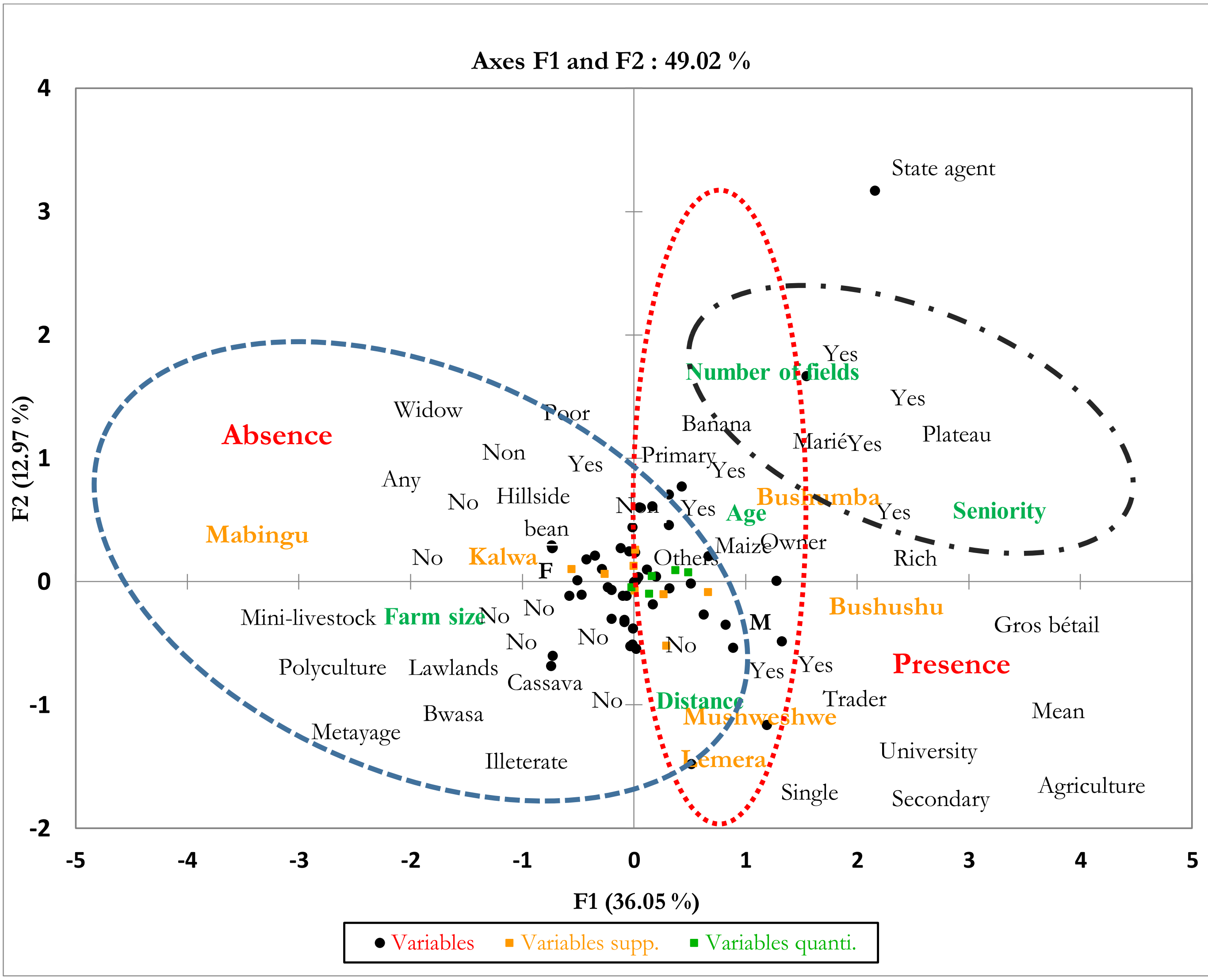

Fig. 5. Biplot from Multiple Component Analysis (MCA) among socioeconomic and technical characteristics of smallholder farms and applied SCTs in northern Kabare, eastern DRC.

4. Discussion

4.1. Socio-demographic and structural characteristics of households in Kabare

In northern Kabare, agricultural activities were practiced by all age classes and genders; both men and women were equally involved in crop production. However, differences were observed between men and women in terms of choice of agricultural speculations and SCTs adopted. Men preferred cash crops (often perennial) such as coffee, banana, tea, cinchona, sugar cane, and citrus fruits; while women turned to subsistence crops such as beans, corn, sweet potatoes, amaranths, etc. This trend confirmed previous findings in eastern DRC that women and men differ in their choice of agricultural speculations and the production destination. Generally, men's involvement in agriculture are motivated by the final destination of the product, whereas women are attached to subsistence crops (Doss, 2002; Furaha et al., 2014; Mondo et al., 2019; Mugumaarhahama et al., 2021). Differences were observed between SCTs practiced by men and women. SCTs requiring energy and financial means such as terraces, ditches, and channels were for men, whereas ridges, mulching, and hedges were put in place by women. This is partly because women generally have limited financial and land resources compared to men counterpart (Doss, 2002; 2018; Mugumaarhahama et al., 2021). In addition, subsistence crops grown by women are unlikely to pay for the investments that some of these SCTs would require. The farmers' education level was low in Kabare. This handicaps efforts by organizations disseminating agricultural innovations in the region. A close relationship was established between the level of education and the likelihood of adopting agricultural innovations in eastern DRC since education facilitates the understanding of instructions from extension services (Abdulai and Huffman, 2005; Dontsop-Nguezet et al., 2016; Gregory and Sewando, 2013; Sauer and Zilberman, 2009; Mondo et al., 2019, 2020; Mugumaarhahama et al., 2021). In addition, Mondo et al. (2019) showed that education in Kabare predisposed people to belong to agricultural associations as educated farmers are often targeted by NGOs to facilitate the dissemination of agricultural technologies.

The majority of smallholder farmers in northern Kabare were poor to medium in terms of financial resources. Low to medium and non-farm annual incomes prevailing in Kabare have not influenced the practiced SCTs; they were not sufficient to allow farmers to finance SCTs schemes alone, i.e. the labor and expertise of village development agents. Thus, it would be difficult to adopt expensive and tedious techniques such as terraces, ditches, (and sometimes even hedges) within the reach of small-

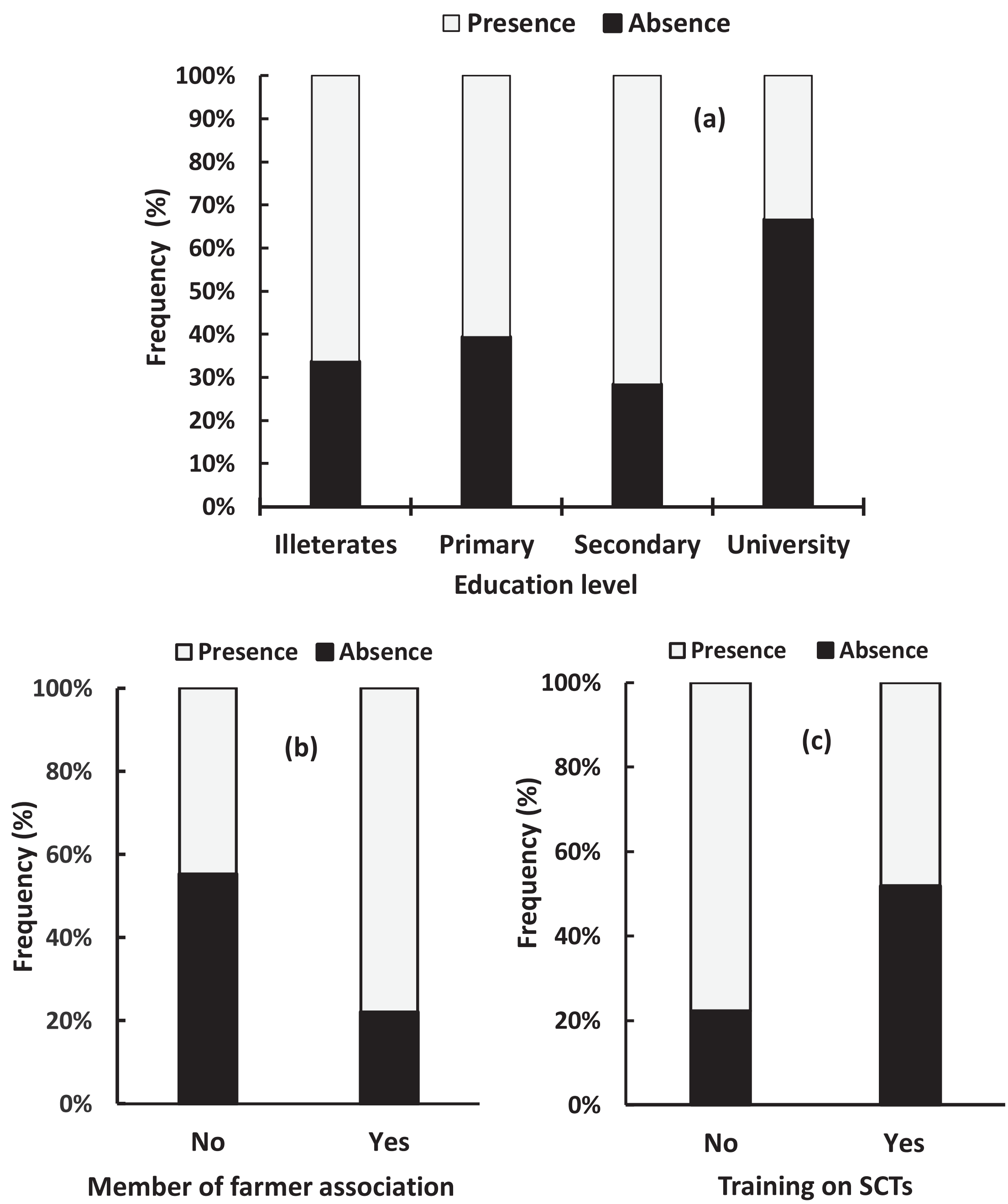

Fig. 6. Correlation between farmer's education level (a), participation to training on SCTs (b) and membership to a local farmers' association (c) and the presence/absence of soil erosion in farms in northern Kabare, eastern DRC.

holder farmers in the study area. The few farmers classified as 'rich' employed labor in exchange for money or food. Practicing only one SCT was inefficient, and therefore, combining control practices should be encouraged at the hill scale by integrating community works between farmers since the financial and technical means of smallholder farmers do not allow them to be engaged in some techniques. These results corroborate those of Keil et al. (2005). The same trend was observed about land tenure and status. The positive influence of land tenure on SCTs was in line with the findings by Kabunga et al. (2011) and Astrat et al. (2004). No-owner farmers were not ready to use SCTs and protect land that they did not own or that they were not sure to exploit the following seasons. These farmlands were, therefore, more exposed to soil erosion and thus disposed their households to food insecurity (Furaha et al., 2014). Soil degradation by water erosion has important implications not only for household poverty but also, and above all for food insecurity and consequently on the households' vulnerability. Empirical evidence has consistently shown that the overall effects of land degradation on food security are negative (Demel, 2001; Berry et al., 2003; Sileshi et al., 2019).

The age of the household head affected the type of practiced SCTs and has a marginal negative effect on the efficiency of used SCTs, probably due to the education level and information and technology access that tend to be observed for the younger than older farmers (Barbero et al., 2016; Mondo et al., 2019; Mugumaarhahama et al., 2021).

4.2. Erosion control techniques (SCTs) practiced in northern Kabare

Eleven SCTs were known but only six were actually practiced by northern Kabare farmers: ridges, mulching, channels, terraces, hedges,

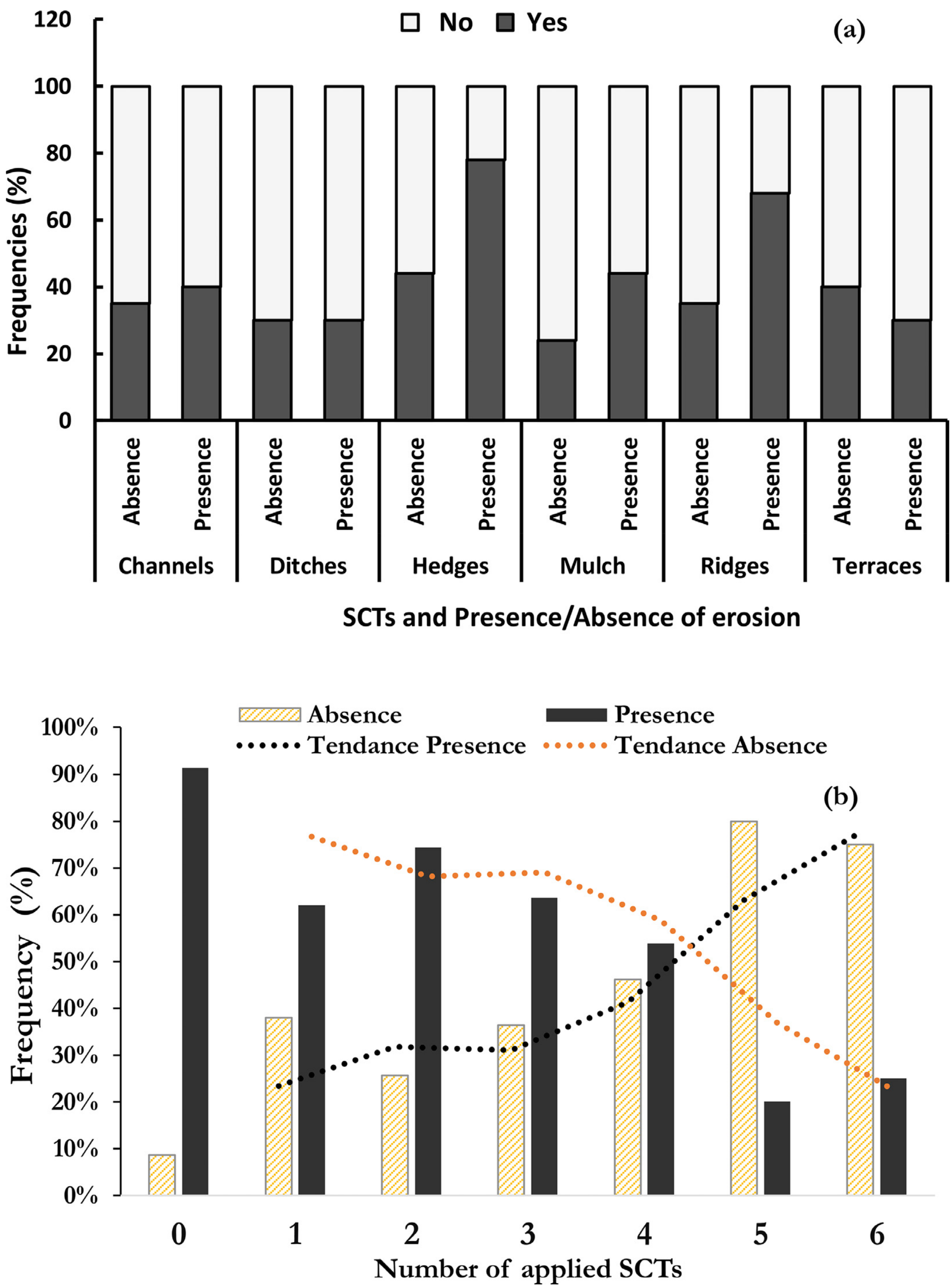

Fig. 7. Effects of SCTs (a) and the number of practiced SCTs per farm (b) on the occurrence (absence/presence) of soil erosion in surveyed farms in northern Kabare, eastern DRC.

and infiltration ditches. The mulching technique not only allowed reducing the soil erosion risk but also the evaporation and weed control. However, its major challenge was the availability of raw materials and the phytosanitary risk (source of phytopathogenic agents). Their effectiveness still needs assessment. There are labor- and time-demanding techniques such as terraces and infiltration ditches which were imposed by the colonial authorities. These are constrained by requirements (high cost and energy), and thus they were quickly abandoned by the smallholder farmers, who could not afford them based on the socioeconomic context of the region. Another constraint is the inadequate dissemination strategy: they were imposed by the colonial authorities instead of convincing farmers of their usefulness. According to Regis and Roy (2002), such a dissemination process should have followed three stages: motivation, training, and extension to farmers. These techniques were quickly promoted without making smallholder farmers aware of the negative consequences of soil erosion and, especially downstream, the types of infrastructure to be put in place. The training aimed at presenting and coaching farmers on the know-how to carry out these SCTs did not also follow. The limited use of SCTs could be attributed to a low education level and the precarious economic context of farmers who are afraid to invest in soil conservation (Adidja et al., 2018).

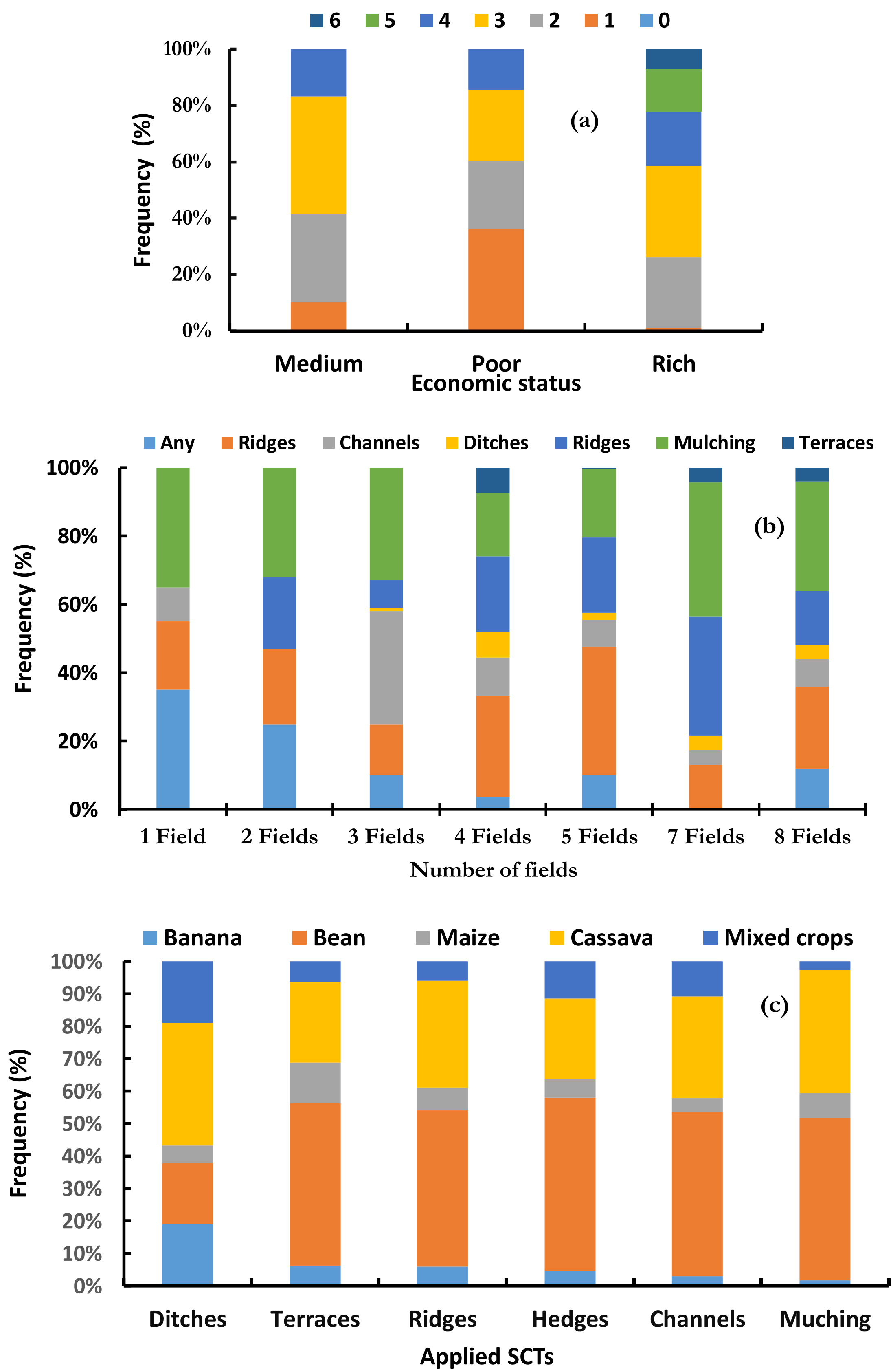

Fig. 8. Correlation between household's economic status (a), the number of fields per small householder farmer (b), the main crops produced, and (c) farm location along the slope gradient, and the number of applied SCTs.

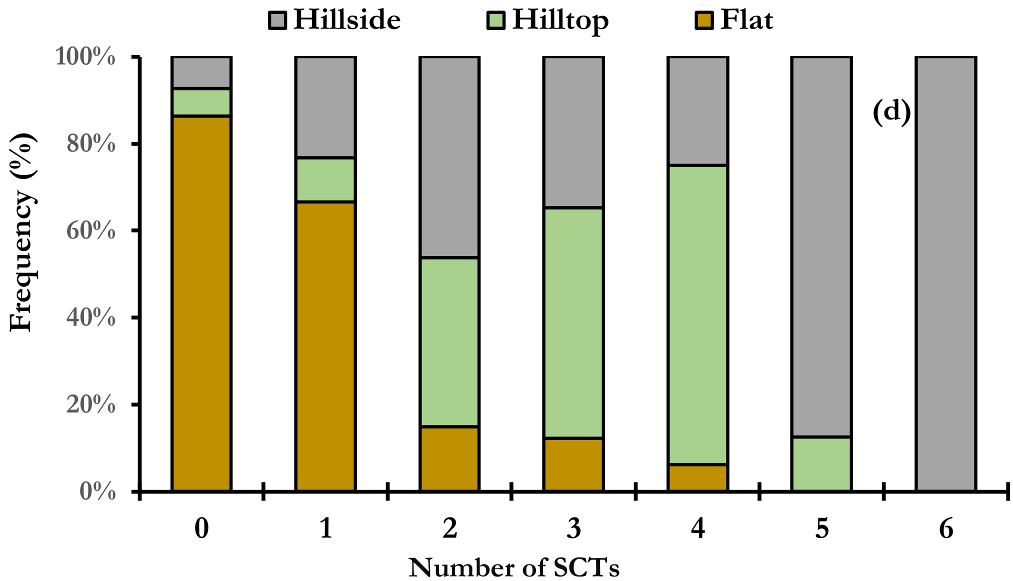

Fig. 8. Continued

Channels (pipes) played several roles, they were used as paths, boundaries between farms, or as preferred routes for runoff and thus erosion. They were put in place to protect farms from runoff on hillsides; however, they cause adverse effects on crops in downstream fields and constitute the primary source of small gullies. Conflicts between farmers often arise in these situations. The number of techniques practiced depended on farms. Banana farms were 80% protected by three techniques, whereas ~60% of farms growing other crops such as common beans and cassava only used and combined two SCTs. In terms of the number of fields, households with one or two fields practiced mulching and ridging or no SCT at all. The number of used SCTs depended on the households' economic level. Rich practiced more techniques than poor. The number of combined SCTs depended also on the farm size.

Results obtained showed that the presence of soil erosion depended on the field location along the hillslope. The most vulnerable farms were those on hillsides. Kevers and Ostyn (1955) suggested that in the region, land on slopes of less than 5% could be cultivated without SCTs; while 5–25% (farmland slope) require SCT measures; above 25% (slope limit), only grazing and reforestation should be applied. Thus, as in Kabare slopes are majorly >20%, it can be deduced that $^{>}$50% of arable lands should be protected with appropriate SCTs.

4.3. *Place of indigenous farmer knowledge (IFK) on erosion perception in northern Kabare*

Some farmers had significant experience in identifying soil problems, dynamics and causes of erosion and declining soil fertility. Such perception helped them to develop and use six SCTs. In addition, farmers classified their lands according to very specific criteria that were comparable to those found in other African regions and especially in eastern African countries. This has been reported by researchers working on land degradation and soil fertility and households' perception in countries like Ethiopia, Rwanda, and Kenya (e.g., Engdawork and Hans-rudolf, 2015). In Kabare, farmers classified their own farmlands according to soil erosion intensity and fertility level. At the same time, land use and land cover and species indicators of soil fertility were also linked to soil fertility and productivity. According to those farmers, the land topography (slope and aspect), rainfall intensity, the appearance of small gullies, or sheet erosion were the main signs of erosion occurrence. Such differences in perception of soil erosion problem had also been reported by Heri-Kazi and Bielders (2017). In fact, six erosion indicators were mentioned by farmers in eastern DRC (Heri-Kazi and Bielders, 2017) among them were the presence of gullies, reduction in the topsoil layer thickness, and loss of organic matter (OM). Gullies were not perceived as indicators of erosion and sometimes farmers were not aware of the impact of their cropping systems and agricultural practices on soil erosion development. Farmers tended to associate erosion with extreme rainfall events, forgetting that it is a continuous process (Brunner et al., 2008). Sileshi et al. (2019) concluded in showing that water and soil conservation practices contribute to the economic and social development of smallholder farmers and suggested that these practices should be considered as the main strategy to improve the means of subsidence and prevent land degradation. However, several factors explain the effectiveness of techniques in managing soil erosion. Kolawole (2013; 2013) showed that ten factors are strongly associated with the use of indigenous knowledge systems for soil fertility conservation by farmers in Ekiti State, Nigeria. Farmers' knowledge is still confronted with development organization of knowledge, which seems rather conservative. Their power and will are only exercised and rarely accept the rejection of alternatives (such as local knowledge already received by the local population). Biot et al. (1995) presented paradigms in the behavioral characteristics of peasants. They classify them into four classes ranging from "classical" to "agroecological". The best approach would, therefore, be an agro-ecological one that recognizes the place of indigeneous knowledge and their rights (through its bottom-up approach) by considering the farmer as the main factor in the process of building the knowledge base. Hence, a link is, therefore, established between organizations intervening in an area, the rural community, and the government. Unfortunately, in South-Kivu, the weak contribution of the state in soil and water management and conservation has been reported. These techniques can be classified as traditional farming techniques and as traditionally used by soil conservation projects.

Some authors showed that farmer knowledge is a balance between external (researchers and/or development organizations working in the area) and local (rural farmers) actors. However, this knowledge is based on the sharing of "empirical" facts. Often, in development projects where the participation of rural farmers was limited and/or excluded, the research was not relevant, and the development itself was not on rendezvous. Participation is more mutual and inclusive when farmer knowledge is integrated into the project process, the research is thus more focused on the needs of the beneficiaries (Winklerprins, 1999; Shetto, 1999; van Mensvoort, 1996; Alemu et al., 2019; Rijswijk et al., 2019). Farmer knowledge is a result of many years or even a lifetime experience in land management (Walker et al., 1995). These practices should be supplemented and improved rather than replaced by so-called modern techniques.

4.3. Farmers' organizations as a forum for knowledge exchange on SCTs

Results showed that membership in farmers' associations influenced the occurrence of soil erosion on farmlands. Members of a local farmer association exchange knowledge about, not only how to produce but also how to manage resources in the community. Those groups are places where the exchange of expertise on soil and water management and conservation are debated. Extension through collective or participatory training based on "farmer-to-farmer" or "farmer and researcher" approaches are recommended for any intervention in Kabare. Groups or association activities are important to enable farmers to learn because they have their own methods of teaching and understanding (Ingram, 2008). However, an individual visit accompanied by an agricultural advisor is one of the most important and effective means of communication to be suggested in Kabare. Thus, the role of an agricultural advisor remains of significant importance in the knowledge exchange, especially in regions such as northern Kabare where the rate of illiteracy and low education levels are high. Biot et al. (1995); Beshah (2003) and Cotler and Cuevas (2019) had presented the characteristics of the paradigm related to such a peasant behavior.

A framework can then be proposed to identify how farmers' knowledge will be understood and used by the development organizations working in the study area. For practical, ideological, and even methodological reasons, the knowledge paradigm must be put at the center of attention of any intervention. This promotion of knowledge should also promote the mother tongue of the area, as ~65% of smallholder farmers have low education level. It would be difficult for them to understand technical terms/concepts related to SCTs. Confusion can quickly arise both in terms of understanding and rhetoric. This is the case in our environment, where rill erosion is not recognized as a soil erosion type. It is, therefore, clear that in northern Kabare, these SCTs rather need to be improved. It is also the conviction of some authors that, whatever the degree of modernity and ingenuity of new techniques, rural farmers will continue and prefer to use "some knowledge" that belongs to them in time and space, as they deem appropriate to conserve their soils, whatever the new practice being disseminated (Kolawole, 2013, 2014).

Conclusion

This work assessed the knowledge and practices of soil erosion control techniques among smallholder farmers of northern Kabare, eastern DRC. From the results, we can conclude that 11 SCTs were known but only six were practiced by smallholder farmers (hedges, mulching, terraces, channels, ditches, and ridges). The effectiveness varied with techniques and farmer household's socioeconomic and technical conditions. Although farmers had generally low education level, training on SCTs through local farmer associations and cooperatives and NGOs enabled them to reduce erosion adverse effects at some extent. However, soil erosion occurred on more than three-quarters of farms and the influence of farmer knowledge on erosion in Kabare was noted. According to these results, existing SCTs should be recognized as such by extension services and should be improved rather than replaced by new ones. For any intervention in the study area, political decision-makers and NGOs should consider indigenous farmer knowledge (IFK) while building farmer capacities with continuous training on land degradation and restauration and when promoting the use of appropriate SCTs. We encourage that trainings be conducted under local associations, which were instrumental in SCTs knowledge dissemination. Factors such as the farmer's age, gender, annual income, the land tenure status, and the type of practiced livestock must be considered in designing effective erosion control programs in Kabare for sustainability.

Authors' contributions

GBC, JMM, and FSB designed the research; CBG, EMB, SBF, and BAN did data collection, performed the analysis, interpreted data, and wrote the original manuscript with significant inputs from JMM. GNM, GC, and CLB assisted in the analysis and interpretation of data and revised the manuscript. All authors read and approved the final manuscript.

Availability of data and materials

The authors want to declare that they can submit the data at whatever time based on request. The data used for the current study will be available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Funding

Not applicable.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2022.100516.

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