Discover Soil

Research

Vegetation based climate solutions for soil management in smallholder farmlands of Kabale and Rubanda districts, Uganda

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Abstract
Understanding and appreciating climate solutions for soil management in smallholder farmlands are paramount. These climate solutions inform smallholder farmers' actions, choices, decisions and priorities to tackle specific climate change problems and opportunities. The study used structured and semi structured questionnaires to collect field data to ascertain smallholder farmers' knowledge about vegetation based climate solutions for soil management in Kabale and Rubanda districts, Uganda. A purposive sampling technique was used to collect data from 367 smallholder farmer household head respondents. Regression model, specifically linear to test multicollinearity and multinomial logistic and descriptive statistics was utilised to examine vegetation based climate solutions for soil management. Vegetation based climate solutions such as crop residues, selected trees, Napier grass and Seteria grass (dependent) and gender, age and marital status, and level of education information (independent) were determined predictor variables. The findings revealed that both genders, males (51.5%) and females (48.5%), witnessed climate change as demonstrated in Fig. 2. The chi-square test ($\chi^2 = 376.337$) indicated a significant difference between smallholder farmers' implementing climate solutions. The study observed positive Kendall's tau (0.357 and 0.118) and a *p*-value (0.002 and 0.289) of temperature and rainfall respectively. Most farmers (69.2%) relied on fellow farmers as a major source of climate information to manage soil and enhance soil fertility. Vegetation based climate solutions 33.8%, (planting Napier grass, selected tree species, and crop residues) were revealed as suitable and effective soil management interventions to control soil erosion and fertility improvement in smallholder farmlands. Climate solutions were significantly influenced by level of education (0.000) and farmland size (0.001) at 0.05. Therefore, there is a need to incorporate vegetation based climate solutions into government development programmes and agendas to enhance soil fertility and erosion management in smallholder farmers' farmlands with a focus on livelihood improvement through increasing crop yields and hunger alleviation.

Keywords Soil management · Soil degradation · Climate solution

1 Introduction

Climate change (CC) significantly affects global and national development programs [1, 2]. Sadly, CC affects farming more than any other enterprise worldwide [3, 4]. The shocks and impacts of CC on soil degradation are predicted to be more harmful than good because they compromise farming systems, cause drastic reduction of individual farmer

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food production, and can accelerate hunger and poverty in agrarian communities [3–6]. Global food production is threatened by CC owing to rainfall, temperature variability, and unreliability [7]. CC affects rural people's household income and livelihoods which are highly linked to owning small pieces of farmlands ranging from 0.1 to 1.5 hectares because of rampant reductions in food production, causing food insecurity and hunger [8]. This puts small pieces of farmland under pressure of continuous cultivation seasons in and seasons out and renders farmlands infertile to produce enough food to feed the ever increasing population [9, 10].

The Intergovernmental Panel on Climate Change (IPCC), working groups noted that continuous and repetitive occurrences of harsh climatic events coupled with unreliable rainfall patterns, lead to irregular and intense hurricanes, heat waves, hailstorms, floods, wildfires, and droughts [2, 11]. The outcome compromises the even distribution of water quantity and quality [12], needed for crop and animal growth and production thereby affecting communities' livelihoods and infrastructure development [2, 13, 14]. High altitude landscape resources, particularly hilly and mountainous areas, are mainly affected by heavy rains that accelerate soil erosion, flooding, and massive deposits of sediments which compromise the integrity of fragile environmental services such as food and water [15, 16]. The possible outcome encourages disease outbreaks in humans, crops, and animals from contaminated soil, and water and eventually affects the integrity of communities' livelihood and environmental sustainably [13, 17, 18].

Smallholder farmers' inability to take up climate solutions is due to limited knowledge and skills, access to practical natural resources management interventions, and resources to control and manage CC shocks and risks in their communities [6, 19, 20]. Lack of information on climate and weather patterns hinders smallholder farmers from preparing CC interventions to implement appropriate strategies and solutions that combat CC effects on their farmlands [21, 22]. In Uganda, particularly in Kigezi sub-region, some studies predicted CC impacts on food productivity and adaptation strategies [23]. However, limited studies have been done to establish local historical climatic data and vegetation based climate solutions for soil management in smallholder farmlands. The study considered smallholder farmers' demographic and socioeconomic characteristics, vegetative climatic solutions, sources of soil management, and climatic information to determine effective climate solutions that enhance soil management in smallholder farmlands. Therefore, it was imperative to understand whether the current vegetation based climate solutions are proving consistent and effective in soil management in Kabale and Rubanda districts.

2 Materials and methods

2.1 Description of the study area

The study was conducted from September 2022 to October 2023 in Kabale, and Rubanda districts, southern western Uganda (Fig. 1). The study's total population was 4452, with 742 households and total land coverage of 703.114 km^2, according to Uganda Bureau of Statistics [24]. The study was specifically conducted in sub counties of Rubaya, Butanda, Kahugye, Kamuganguzi, and Kitumbu from Kabale district. The study included sub counties from the Rubanda district were Kacerere Town Council, Muko, Rubanda Town Council, and Bubale [24]. The area receives an annual average temperature of 17.5 ± 2.5 °C and an annual average rainfall of 1200 to 1600 mm [25]. Key informant interviews were conducted to get a clear and deeper understanding of soil management solutions from eleven (21) extension officers. The extension officers included agricultural officers from nine (9) sub counties, two (2) environmental officers, two (2) natural resources officers, two (2) district production officers, six (5) NGO project officers (extension) implementing soil and environmental management projects from Kabale and Rubanda districts and one (1) research institute official. Soils in the study area are vulnerable and susceptible to soil erosion due to steep slopes and land use activities and this accelerates soil infertility. According to [24], Kigezi highland soils are experiencing unmatched modification and degradation caused by anthropogenic factors and climate variability. Due to rapid population growth, demand for agricultural land has drastically increased, leading to rapid conversion of highland vulnerable soils to agricultural space [24]. This phenomenon has resulted in loss of soil fertility from steep slopes (uplands and middle lands) to lowlands (valleys), forcing smallholder farmers to encroach on virgin forested and wetland ecosystems to practice agriculture [26].

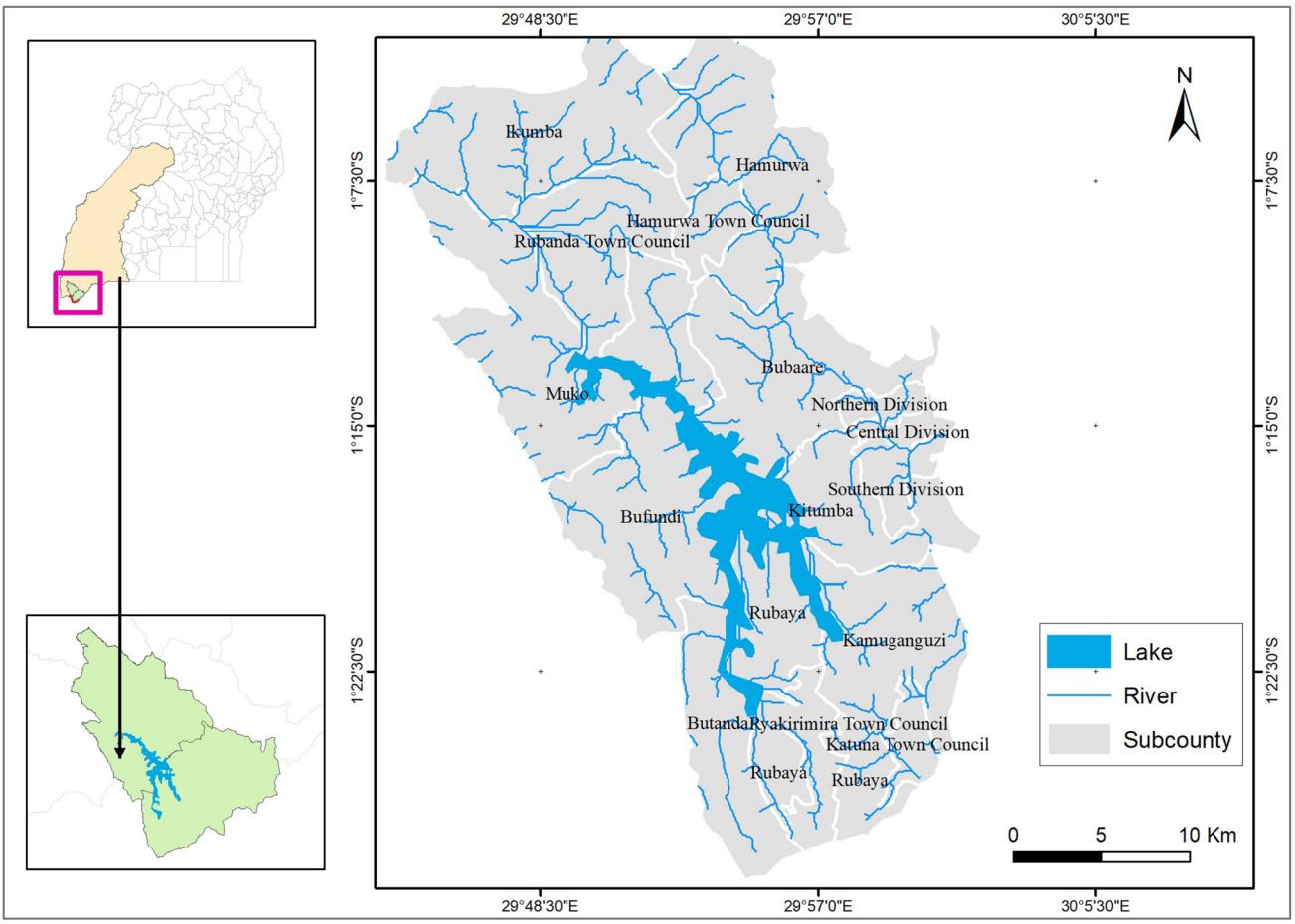


Fig. 1 Study area

2.2 Sampling methods and data collection

Multistage random sampling technique was utilised to select target smallholder farmer household head respondents. A pilot study was conducted in the study area to pre-test research tools' reliability and credibility considering target respondents before actual data collection. Structured and semi structured questionnaires involving closed and open ended questions were used to collect data from target respondents through face to face interviews. Key informant interviews were conducted to get a clear and deeper understanding of soil management interventions from agricultural officers, community development officers from each selected sub county, environmental officers, natural resources officers, district production officers, NGO extension officers implementing soil and environmental management projects and research institute officials from Kabale and Rubanda districts. A total of 367 respondents (smallholder farmer household heads) were derived from 8217 target populations guided by Cochran's formula at 95% confidence level and 0.05 margin error [27]. Climatic data were obtained from Kabale district metrological station department to understand climate scenarios (temperature and precipitation) from 1981 to 2021. The rainfall and temperature data were considered because climatic variables directly influence soil management, crop growth, and food production [28].

2.3 Data analysis

Descriptive statistics were done using SPSS software version 26.0. The statistical software analysed and presented socioeconomic demographic characteristics, and climate solutions implemented by smallholder farmers. Socioeconomic

characteristics and climate solutions interventions were analysed using a multinomial logistic regression model. Predictor variables such as vegetation based climate solutions such as crop residues, selected trees, Napier grass and Seteria grass (dependent variables) and gender, age and marital status, and level of education (independent variables) were used to determine effective climate solutions and rainfall and temperature data were presented by line graphs. Excel XSTAT were used to analyse rainfall and temperature data to test Mann–Kendall's tau, *p*-value and Sen's slope.

3 Results

3.1 Smallholder farmers' socioeconomic information

The majority of smallholder farmers who participated in the study were male (51.5%) and female (48.5%). The average age range of respondents was between 40 and 59 years (47.4%) and 20–29 (1.6%) respondents were the lowest age range record. Majority of respondents had attained primary level of education 40.3% compared to 5.4% who had attained post primary education level (tertiary). Married smallholder farmers (92.4%) were the majority of respondents, and divorced smallholder farmers (1.9%) were the least recorded respondents. The study revealed commonly grown combination of crops in the study area, such as beans and potatoes (Bp 56.4%) maize and peas (Mp 5.2%), were the least grown crops. 38.7% of farmers had farmlands equivalent to half hectare (1/2) compared to 4.1% of farmers whose farmland was equivalent to three hectares or more (3+) which represented a small percentage of all farmland sizes. Majority of farmers (63.5%) had received their land either through inheritance, purchase, or both while a small percentage (14.4%) had inherited farmland (Table 1). "*Smallholder farmers acknowledged that land ownership is acquired through individual buying*

Table 1 Smallholder farmers' demographic and socioeconomic information

Questions	Measures	Frequency	Percent (%)	Cumulative %
Gender	Female	178	48.5	48.5
	Male	189	51.5	100.0
Age categories	20–29	6	1.6	1.6
	30–39	66	18.0	19.6
	40–49	87	23.7	43.3
	50–59	87	23.7	67.0
	60–69	75	20.4	87.5
	70+	46	12.5	100.0
Education level	None	138	37.6	37.6
	Primary	148	40.3	77.9
	Post-primary	81	22.1	100.0
Marital status	Divorced	7	1.9	1.9
	Married	339	92.4	94.3
	Single	9	2.5	96.7
	Widowed	12	3.3	100.0
Crops grown	Bean and Sorghum	28	7.6	7.6
	Bean, maize and Peas	19	5.2	12.8
	Bean, maize, Peas and Banana	113	30.8	43.6
	Beans and peas	207	56.4	100.0
Farm size	1/4 hectare	67	18.3	18.3
	1/2 hectare	142	38.7	56.9
	1 hectare	61	16.6	73.6
	1–2 hectares	59	16.1	89.6
	2–3 hectares	23	6.3	95.9
	3+ hectares	15	4.1	100.0
Land tenure	Bought	81	22.1	22.1
	Inheritance	53	14.4	36.5
	Inheritance and bought	233	63.5	100.0

Table 2 Mann–Kendall trend test for rainfall

Kendall's tau	0.118
S	92
Var(S)	7366.667
p-value (Two-tailed)	0.289
alpha	0.05

Table 3 Mann–Kendall trend test for temperature

Kendall's tau	0.357
S	326.000
Var(S)	5424.667
p-value (two-tailed)	0.002
alpha	0.05

or is given freely by their parents as a gift". Smallholder farmers' gender, age, land tenure, marital status and education level should be considered when designing effective soil erosion control and soil management strategies.

3.2 Climate variability and change

3.2.1 Rainfall

The findings recorded a positive Kendall's tau value (0.118), suggesting a weak upward trend in rainfall pattern from 1981 to 2021 (Table 2). The *p*-value (0.289) was greater than 0.05 significance level indicating that the trend is not statistically significant. Based on this information, the data does not provide enough evidence to conclude that an increase and decrease in rainfall trend over the last 40 years. The absence of statistically significant rainfall trends suggests that variability observed in rainfall patterns is influenced by short term rainfall fluctuations rather than long term changes. This affects soil health and erosion control solutions in hilly slopes and terrains since Kabale and Rubanda districts are prone to soil erosion.

3.2.2 Temperature

The findings observed a positive Kendall's tau value (0.357), indicating an upward (increase) trend in temperature from 1981 to 2021 (Table 3). The *p*-value (0.002) was below significance level (0.05), suggesting that this upward trend is statistically significant. Based on observed information, the findings imply that average temperatures provide enough evidence of consistent rise from 1981 to 2021. The significant temperature upward trend emphasizes the need for proactive solutions to address climate change impacts. The significant upward trend in temperature (1981 to 2021) has profound implications for soil health and erosion control for sustainable soil resource management.

Based on the findings of the study, the results provide insights to long term changes in rainfall and temperature for soil health management (Fig. 2). The rainfall Sen's slope (5.364 mm/year) suggests an increase in rainfall from 1981 to 2021 (Table 4). The lack of statistical significance (*p*-value = 0.289) indicates that the trend is not too strong. The slight rainfall increase trend could result in seasonal variability or extreme rainfall events which can intensify soil erosion in hilly landscapes. The increased rainfall support water availability and farmers can adopt improved strategies and solutions for water harvesting structures and drainage systems to manage potential excess runoff and soil erosion in farmlands. Routine monitoring to determine whether observed rainfall patterns increase represents long term rainfall shifts or natural variability.

The statistically significant temperature Sen's slope (0.029 °C/year) showed a consistent rise in temperature from 1981 to 2021 (Table 4). Higher temperatures increase rapid organic matter decomposition process, and reduce soil fertility levels and soil ability to retain soil moisture and nutrients. These factors affect and compromise efforts of soil health enhancement in smallholder farmlands. Rising temperatures further intensify evapotranspiration, and reduce soil moisture and vegetation cover. This exposes soil to erosion during rainy seasons with high rainfall intensity in hilly landscapes.

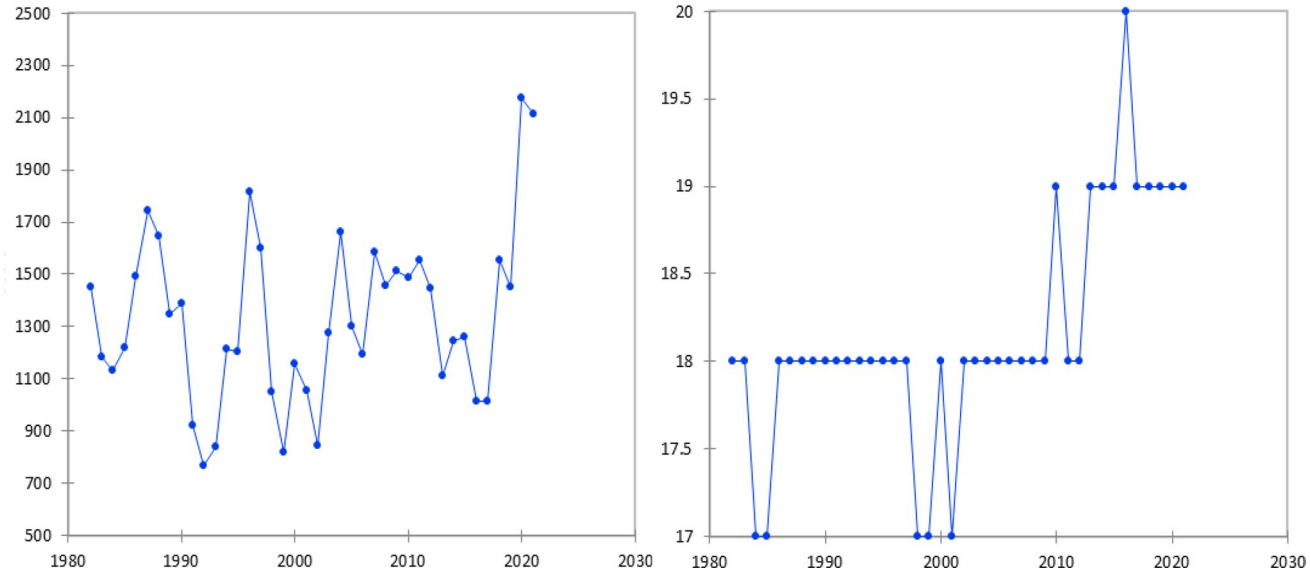


Fig. 2 Rainfall and temperature trend from 1981 to 2021

Table 4 Sen's slope for rainfall and temperature

Test	Kendall's tau	*p*-value	Sen's slope
Rainfall	0.118	0.289	5.364
Temperature	0.357	0.002	0.029

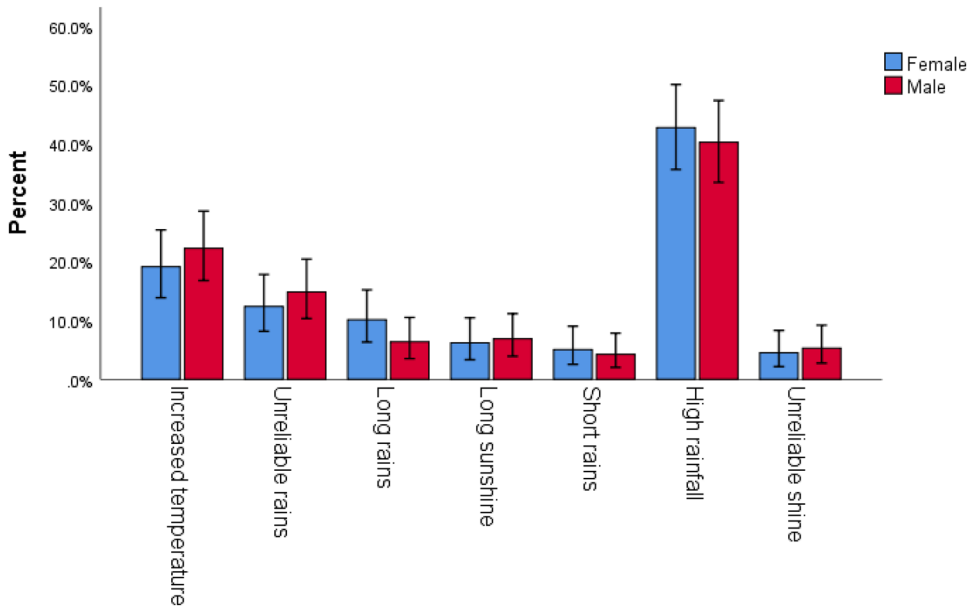


Fig. 3 Local climate monitoring indicators

The warming trends emphasise the need to integrate climate resilience solutions into soil management and agriculture to mitigate impacts on soil and agricultural productivity.

3.3 Smallholder farmers' response to indicators of climate change

The findings of the study revealed that majority respondents reported high rainfall (41%) and increased temperature (25%) as major climate change predictor indicators (Fig. 3). This was based on amount of rainfall and temperature

smallholder farmers observed per day in a year. These indicators accelerate soil erosion, floods and drought, affect planting and harvesting seasons, and compromise the quality of crop harvests and produce due to increased rainfall and temperatures. Farmers further noted that unpredictable and inconsistent rainfall, and short rainy and dry seasons, make their seasonal crop planting and harvesting cycles inconsistent due to climate variations.

3.4 Sources of climate information

Most farmers relied on fellow farmers 69.2% as a major source of climatic information to control soil erosion, and soil management to improve soil fertility than local radio sources (14.7%) (Fig. 4). The low access to climatic information from local radio broadcast programs to share current agricultural climatic information and technical advice indicates that radio coverage and accessibility are limited, and not affordable to farmers. The generated information indicates a large gap between formal sources of agricultural information and farmers such as radio and extension officers. This hinders the dissemination of current climatic information to smallholder farmers to implement innovations that enhance soil fertility and control soil erosion in their farmland. This calls for the need to provide current climatic information, increase information accessibility, and availability, and encourage farmers to always use the available agricultural information frequently to sustain farmlands' fertility to get enough food and increase income.

3.5 Soil amendments

The majority of farmers 62.9% preferred to use a combination of compost and livestock organic manure to enhance soil fertility, water retention, and crop yield, compared to use of only compost manure12.8% in their farmlands (Fig. 5). A comparable number of farmers 89 (24.3%) reported that they used petrochemical fertilizers to enhance soil fertility. This practice can put farmers' and consumers' health at stake and cause environmental degradation and, hence, loss of biodiversity, such as insects and earthworms. The few farmers who used compost manure only were due to its accessibility, affordability, and effectiveness compared to petrochemical fertilizers that come with environmental and human health costs.

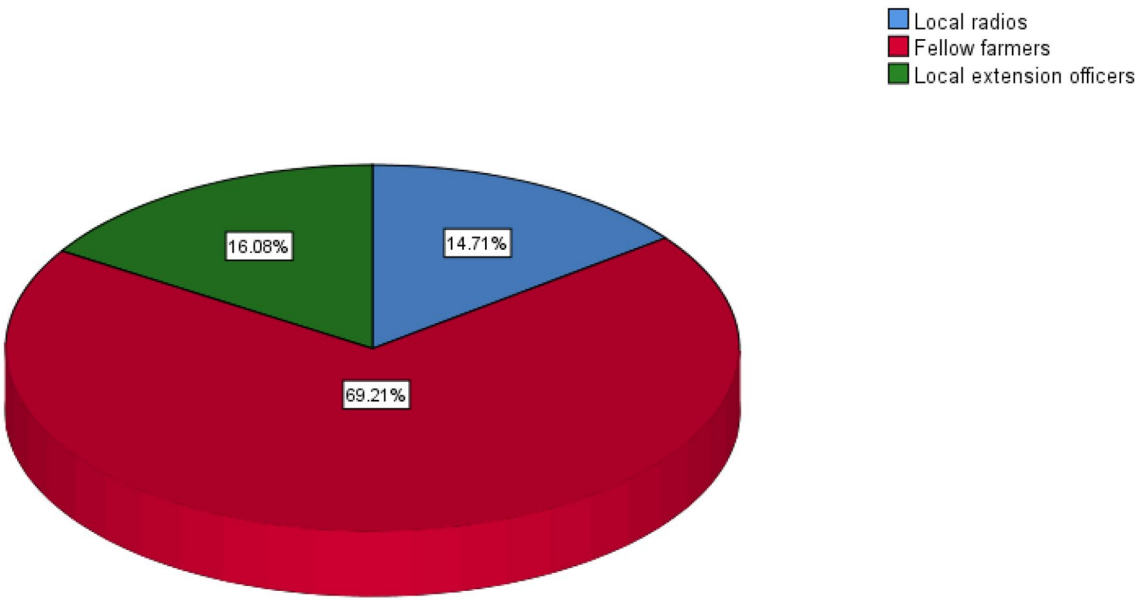


Fig. 4 Sources of climate information

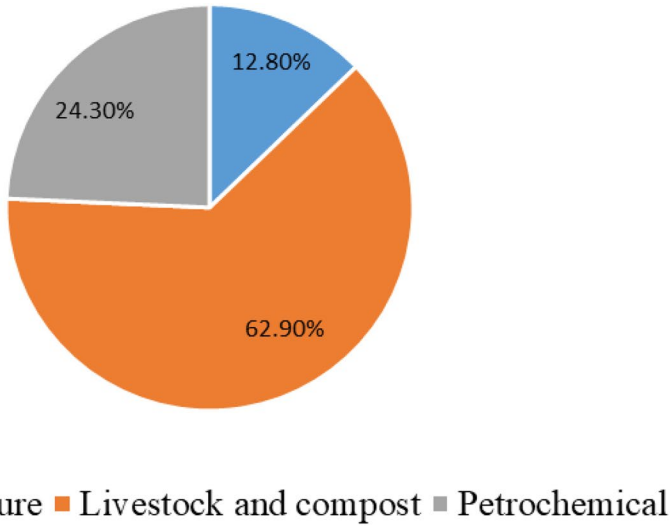


Fig. 5 Sources of soil amendments (Manure and F Fertilizers)

3.6 Vegetation based climate solution

Farmland size (0.007) showed a strong statistical significance to the dependent predictor value. Based on the study's findings, the tolerance values were close to 1 indicating low multicollinearity and no problem. The fact that all the variance inflation factor (VIF) values were less than 10 but close to 1 confirms that no multicollinearity issues were observed (Table 5). Therefore, no multicollinearity issues were observed by the model tolerance and VIF values.

Table 5 Multicollinearity to test correlation between independent variables

MODEL 1	Coefficients						
	Unstandardised coefficients		Standardised coefficients			Collinearity statistics	
	B	Std. Error	Beta	t	Sig	Tolerance	VIF
(Constant)	3.131	0.580		5.403	0.000		
Gender	−0.095	0.163	−0.031	−0.586	0.558	0.987	1.013
Age	0.054	0.061	0.046	0.884	0.377	0.978	1.022
Marital status	−0.093	0.197	−0.025	−0.476	0.635	0.999	1.001
Education level	0.104	0.094	0.058	1.104	0.271	0.990	1.010
Farmland size	0.161	0.060	0.141	2.706	0.007	0.995	1.005

Dependent variable: vegetative climate solutions on farmlands

Table 6 Vegetation based climate solution as a climate solution

Variables	N	Marginal percentage
Crop residues	66	18.0%
Napier	16	4.4%
Napier and crop residues	77	21%
Napier, seteria grasses crop residues	25	6.8%
Napier, setaria grasses crop residues and trees	33	9%
Napier grass, crop residues and selected trees	124	33.8%
Setaria, grasses, crop residues and selected trees	26	7.1%
Total	367	100.0

Table 7 Model fitting information

Model	Model fitting criteria	Likelihood ratio tests		
	−2 Log likelihood	Chi-square	df	Sig
Intercept only	915.887			
Final	795.781	120.106	85	0.007

Table 8 Likelihood ratio tests

Effect	Model fitting criteria	Likelihood ratio tests		
	−2 Log likelihood of reduced model	Chi-square	df	Sig
Intercept	795.781	0.000	0	
Gender	800.318	4.537	5	0.475
Age	811.051	15.270	25	0.935
Marital status	816.221	20.439	15	0.156
Education Level	838.942	43.161	15	0.000
Farmland size	837.999	42.218	25	0.001

3.6.1 Multinomial logistic regression model

The findings of the study indicated that planting Napier grasses, selected tree species, and crop residues (33.8%) control soil erosion cases compared to growing only Napier grass (4.4%) on farmlands (Table 6). Smallholder farmers further revealed that implementing a combination of climate solutions for soil management slows down runoff, traps sediment, enhances soil organic matter and increases soil porosity and infiltration in farmlands. Farmlands without these solutions expose soil to water erosion and sun (heat waves) and greatly contribute to soil infertility a mean contributor to soil degradation.

3.6.2 Model Fitting Information

Model fitting criteria -2 log-likelihood is a measure of data that fits in the model considering the lower values a better fit. The study's findings revealed that the final model had lower −2 log likelihood values of 795.781 than the intercept model with only 915.887 indicating that there was better data fit in the model. The chi-square value result was 120.106 and degrees of freedom (df = 85) were used to calculate the *p*-value of the likelihood ratio test, the *p*-value was recorded as 0.007 indicating that there was a statistically significant difference implying that the final model provides a better fit to the data than the intercept model only (Table 7).

3.6.3 Likelihood ratio tests

The findings of the study revealed that education level and Farmland size were statistically significant at 0.05. These effects had a significant value of 0.000 and 0.001 respectively indicating that predictor variables were important outcome variables. The rest of variables had a *p*-value greater than 0.05 indicating that they were not statistically significant and could not improve the model fit over the reduced model with only intercept terms. There was therefore no relationship between gender (0.475), age (0.935) and marital status (0.156) of the respondents (0.05>) and outcome data variables (Table 8). The larger the chi-square and the smaller the *p*-value (sig), the more important the model variable is to predict the outcome. Based on the findings of the study, education level and Farmland size significantly contributed to model fit improvement.

4 Discussion

4.1 Smallholder farmers' demographic and socioeconomic information

The study findings recorded the highest number of male respondents (51.5%) as key players in implementation of soil management interventions [29]. This was observed during data collection and insights from female respondents who

narrated that "*males are energetic in selection of suitable tree species and planting, sourcing of Napier grass planting shoots and callindra seedlings*" [30]. Female respondents (48.5%) play a significant role in soil enhancement and management through preparation of domestic manure and stocking livestock manure and male counterparts support females in currying manure to gardens to improve soil fertility [31]. It was further observed that both genders support each other in sustainable agricultural activities that support soil management such as crop planting, weeding, and harvesting. This was attributed to cooperation among genders and limited finances to support implementation of climate solutions that control soil erosion and soil fertility improvement in their farmlands to get high agricultural yields.

The results of this study revealed that farmers in the age category 40 and 59 years (47.4%) confirmed that climate change is real [30, 32, 33]. Smallholder farmers further noted that they face unreliable rainfall, floods, soil erosion, and long dry spells challenges [33–35]. This narrative is backed by the analyzed climatic data of 1999 and 2020. There was very low rainfall (443 mm) with a maximum temperature (33 °C), and very high rainfall (1614 mm) and low temperature (11 °C), respectively. This is sufficient evidence to support farmers' arguments, together with available literature [33]. However, smallholder farmers in age category below 29 years claimed that they had never witnessed climate change effects, indicating that young population is not aware of climate change effects. Most of respondents were in age working category [30]. Although there is availability of labour to support implementation of climate solutions, respondents indicated that there are still numerous challenges to implement climate solutions [36, 37]. The noted problems ranged from limited access to climate solutions inputs, land shortage, extension services, and financial resources [30, 37].

A significant number of respondents (40.3%) had a primary level of education. Research indicates that education significantly contributes to the successful implementation of soil management interventions in smallholder communities [38, 39]. This is attributed to higher acceptability and adoption of new technologies and dissemination among relatively educated farmers (elementary levels and beyond) [30]. Investment in formal education, especially for smallholder farmers significantly increases aceptability of soil management interventions that stabilise soil fertility to increase agricultural productivity and fight hunger and poverty among rural communities. The relevance and inclusivity of formal education among smallholder farmers greatly address soil degradation and community needs [2, 13, 40].

The study recorded half hectares, 38.7% as the largest farmland size owned by individual smallholder farmers households. It was reported that overpopulation is putting the available farmland at stake of over cultivation, poor agronomic practices, and land fragmentation to gift their children. Continuous subdivision of available farmland for sale to pay school fees for their children or give away to older children after getting married was noticed practice [41, 42]. Farmers revealed that these practices affect the available farmland and render it unproductive and unsustainable to support food production to fight poverty, and hunger regardless of farmland scarcity [34, 43]. Farmers further noted that climate change and its associated effects are adding salt to a wound by increasing incidences of soil erosion, floods and drought thereby escalating soil degradation problems [42, 44]. The introduction of logically researched vegetative climate solutions regardless of farmland size can address the reported challenges to increase agricultural productivity in smallholder farmers' communities.

A combination of farmlands inherited from smallholder farmer parents and buying (63.5) was the highest noted record during data collection. Selected tree species, grasses and crop residues left in farmlands after crop harvesting were observed in these farmlands [38, 42]. Land ownership proved to be a major factor in soil management among smallholder farmers [45]. Smallholder farmers revealed that they invested a lot of time and financial resources to restock, maintain, and introduce new soil management interventions on their farmlands to safeguard soil erosion and fertility improvement [45]. Soil management under elderly care was vulnerable to soil degradation because they lacked vegetative soil management interventions, financial resources and technical support [45]. This situation puts smallholder elderly farmers at the stake of food insecurity, poverty, disease outbreaks like Kwashiorkor, and malnutrition [42, 46, 47].

4.2 Climatic variability and change

Although no significant long term trend was detected, annual rainfall variability remains a great concern for smallholder farmers. Rainy seasons with excessive rainfall can lead to increased soil erosion, and nutrient leaching whereas years with lower rainfall can result in soil moisture loss (dryness), loss of vegetation cover and crops, and increased soil erosion vulnerability [48]. Implementation of integrated soil management solutions mitigates impacts of rainfall variabilities in smallholder farmlands and affects crop yields [49]. These solutions can include conservation agriculture, terracing, contour bunds, water harvesting technologies (check dams and trenches), and ecosystem reforestation to enhance soil health. These solutions can reduce erosion on steep slopes, allow rainwater infiltration, reduce runoff velocity, enhance soil organic matter, and improve agricultural productivity. Furthermore, smallholder farmers' training on soil climate

resilience to manage rainfall variability and continuously monitoring rainfall patterns is critical to detect emerging trends and refine solutions.

Rising temperatures intensify existing soil ecological challenges such as degradation due to the nature of terrain, and this necessitates proactive solutions [50]. The rise in temperature increases the rate of organic matter decomposition [51]. This factor reduces soil's capacity to retain soil nutrients and moisture and directly affects crop productivity [51]. A decline in organic matter renders soils less productive, and resilient to environmental stressors. This poses significant challenges to smallholder farmers who cannot afford external fertilizers to enhance their soil fertility [52]. Higher temperatures increase evapotranspiration and significantly reduce soil moisture [50]. Crops and vegetation may suffer from water stress due to prolonged dry spells and reduced ground cover [52]. Vegetation cover protects soil from direct raindrop impacts to stabilise soil [51]. The decline in vegetation cover exposes soil to erosive forces that accelerate soil degradation [51]. Soil moisture deficit/loss reduces crop yields, and limits soil's ability to support soil biota activities essential for nutrient cycling and aggregation to improve soil structure [50, 51].

Whereas rainfall trend remains uncertain, the significant temperature rise emphasises the urgent need and solutions for soil resilience against climate variability. These solutions can include vegetation based climate solutions to mitigate impacts of climate change ensure environmental stability and improve smallholder livelihoods [53]. Mulching and cover crops regulate soil evaporation and moisture retention. Terracing, contour farming, agroforestry and systems reforestation provide shade, reduce soil surface temperature, and enhance carbon sequestration [54]. Cultivation of drought tolerant/resistant crop varieties and efficient irrigation systems sustain crop productivity under stressing temperatures [52]. Furthermore, smallholder farmers' training in climate adaptation solutions to manage high temperatures and continuously monitor rainfall and temperature identify emerging trends and events that impact soil health and erosion and refine climate solutions [51]. Incorporation of temperature rise consideration into soil management solutions can safeguard soil stability and agricultural productivity. These solutions can enhance soil resilience to climate variability and ensure sustainable agricultural productivity for future generations.

4.3 Climate change information and indicators

Agriculture in Uganda depends solely on seasonal rainfall and temperature for crop growth [55, 56]. Due to seasonal weather and climate variability, farmers find it difficult to plan correctly to grow crops and register poor yields because of crop diseases and pests that compromise crop productivity, quality, and quantity [35, 56, 57]. Smallholder farmers revealed that they face unregulated (increased) temperatures (25%) and inconsistent (high) rainfall (41%), which affect soil integrity to support agricultural productivity [36, 56]. Poor seed varieties, lack of organic manure, and extension services were among other noted challenges faced by smallholder farmers to implement climate solutions [6, 22, 36, 58]. Addressing these challenges can greatly improve soil productivity through enforcement and implementation of vegetative climate solution investments to achieve sustainable soil management and high crop productivity.

Smallholder farmers revealed that an increase in rainfall compromises crop yields, and increases chances of crop rotting in gardens [21]. Furthermore, farmers noted that climate change affect the quality and quantity of crops produced, and high cost of investment in fixing these challenges through planting selected trees such as calliandra, grevillea, and Leucaena leucocephala in susceptible farmlands [59, 60]. Drought incidences were reported to prematurely destroy crops and introduce crop pests and disease, especially in seasonal crops such as beans, maize, and sorghum [61]. Farmers further noted that when they plant early or late, seeds cannot germinate properly, show low flowering, and high fruit fall, making it difficult for farmers to cope with climate change [61]. All this hinders climate solution investments and makes agriculture enterprises unbearable and difficult because they increase variability of crop yields, and seed varieties to growth, and facilitate food insecurity, hunger, and poverty [2, 40, 61]. Inclusive investment in climate solutions can greatly contribute to finding possible solutions to these challenges to cope with weather and climate crises.

Figure 1 showed climatic information trends from 1981 to 2021, and it clearly showed a significant change in terms of rise in temperature and rainfall (443 to 1614 mm and 11 to 33 ℃). The climatic information trend showed high rainfall variation and low-temperature fluctuations, indicating that temperatures did not deviate significantly from their averages over the years [36]. These findings concur with [21, 59], climatic information comparison over the four decades. Smallholder farmers noted that it is very difficult to access climate-related information because they do not have access to extension services and radio gadgets broadcasting climate and agricultural related programs [22, 62]. It was revealed that the government and other development partners use specific radio stations to share climatic information like weather forecasting, and smallholder farmers lack radio gargets to listen to those programs. Contrary to what smallholder farmers reported, Government officials (key informants) revealed that they use media to communicate and disseminate climate

information including extension services to smallholder farmers through promoting sustainable agricultural practices including soil management interventions to address soil degradation, crop diseases and pest control interventions [22, 62]. Sharing climatic information with smallholder farmers plays a central role in determining when and how to plan for climate change shocks and risks [40]. During preparation of agricultural fields for planting, harvesting, and post-harvest activities requires enough knowledge and climate information to determine rate of crop growth success, weeding, and soil fertility management through the application of soil amendments such as organic manure.

4.4 Vegetation based climate solution

Vegetation based climate solution involves a combination of interventions that use plants and or crop residues to reinforce and enhance soil stability against soil erosion and soil fertility improvement. Planting of Napier grass, and selected tree species (Calliandra, and Grevelea) and, crop residues (33.8%) combinations were the main forms of climate solution used for soil management [63, 64]. Smallholder farmers noted that these interventions are useful in reducing the intensity of raindrops, soil erosion control, carbon stock, and organic matter sources, and promote water infiltration into the soil [7]. In addition, these interventions attract soil biota to enhance soil fertility after feeding on crop and plant residues, and construction materials such as timbers and poles [65]. Smallholder farmers revealed that vegetative solutions, "*are sources of bean stakes, livestock feeds or fodder and human food, fruits, fuel wood, medicinal products, mulch materials, control weeds, crop pests, and diseases*". Smallholder farmers revealed that sustaining vegetative solutions requires high initial financial resources, labour, advanced knowledge and skills and land resources [66–68].

The findings of the study revealed that education level and Farmland sizeland were statistically significant at 0.05 (0.000 and 0.001). However, gender (0.475), age (0.935) and marital status (0.156) of the respondents (0.05>) had a *p*-value greater than 0.05 indicating that they were not statistically significant [69]. This explains that these predictor variables were not relevant to show the variation in the model and adding the effects as predictors cannot improve the model fit or removing any effects from the model do not result in significant loss of model fit. The education level and Farmland sizeland highlight the significant importance of both knowledge and land resources in implementation of vegetation based climate solution interventions for soil management [23, 70]. Smallholder farmers with larger farms and higher education levels are more likely to accommodate more vegetation based climate solutions than small farmlands. This implies that extension officers, policymakers, and researchers can design interventions that support soil management in small farmlands [5, 71].

Since some of the demographic characteristics proved insignificant in shaping the implementation of vegetation based climate solutions. Technical and logistical support (training, education, awareness, tools, and resources) for smallholder farmers should be designed with a strong emphasis on accommodating smallholder farmers while considering their demographic characteristics. This encourages smallholder farmers to implement sustainable and effective vegetative climate solutions to solve soil degradation. Formulation of policies that are more effective and tailored to small sized farmlands should be incentivized and accessible to implement similar solutions. Provision of grants, tax incentives, and subsidies on products that encourage smallholder farmers to implement vegetative based climate solutions.

5 Conclusion

The implementation of vegetation based climate solutions was significantly influenced by level of education and farmland size to address soil degradation in farmlands. Planting of Napier grass, and selected tree species (Calliandra, and Grevillea) and, crop residues were proven effective soil management climate solutions. Access to climate information and knowledge about climate change indicators were essential for smallholder farmers to plan correctly during crop planting, weeding and harvesting seasons due to high rainfall and increased temperatures and this matched the climatic data trends. A combination of compost and livestock organic manure were the major soil amendments to enhance soil fertility for improved crop yields and resilience against climate variability change. Temperature indicated a statistically significant results, showing consistent increase in temperature from 1981 to 2021. To increase vegetation based climate solutions effectiveness and sustainability in the study area, introducing climate change awareness programmes, incentives, inputs, and financial support for smallholder farms that promote inclusive access to soil management tools is essential. The government and other development partners should encourage smallholder farmers to implement correctly researched soil management solutions, timely sharing of climatic information through extension services, and reinforce climate change development programs into agricultural and environmental laws and policies. This can

be achieved through incorporating smallholder farmers' knowledge to shape their understanding of climate change. Further research should explore the assessment of vegetation based climate solutions' impact on economic incentives and access to extension services to validate demographic variables' significance.

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Author contributions Author Contributions Statement. NJ conceptualized the study, designed research methodology, coordinated all research data collection and analysis interpretation, and drafted the manuscript. BK provided crucial academic supervision throughout the study, offering substantial intellectual input and critical revisions to the manuscript. MW supervised field activities and ensured data quality. All authors critically reviewed and approved the final version of the manuscript submitted for publication.

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Data availability The data supporting findings of this study were collected from farmlands and farmers as part of a PhD research project. Due to strict University data protection policies to safeguard privacy of individuals involved. The data are not publicly available now. The data can, however, be made available upon reasonable request, pending the successful completion of author's thesis examination and subject to the University's data sharing guidelines. Access requests can be directed to the corresponding author at juliusndemere@gmail.com.

Declarations

Ethics approval and consent to participate All the data collection protocols were approved by Université Félix Houphouët-Boigny, Côte-d'Ivoire research ethics committee. Before actual field data collection, the researcher applied for an introduction letter from graduate school University Felix Houphouet-Boigny's research ethics committee. The introduction letter was presented to National Council for Science and Technology in Uganda (NCST) to get a clearance letter for field data collection. The clearance letter from NCST and UFHB research ethics committee acted as a binding document between researchers, institutions, and communities during data collection and copies of both documents were presented to local authorities and respondents whenever requested during data collection. Participation of all respondents was purely voluntary since the study was not for commercial but for academic purposes.

Consent for publications All participants who participated in the study provided informed consent before their inclusion. The informant consent included but was not limited to information about the purpose of the study, procedures involved and benefits, and the right to withdraw at any time without penalty. Personal data including names, dates of birth, and other characteristics were anonymized to protect participant privacy. I therefore confirm that all data collection and analysis were performed following relevant guidelines and regulations.

Competing interests The authors declare no competing interests.

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