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Farmers' knowledge, attitude, and motivation for adoption of climate-smart agroforestry in two contrasting agroecosystems of Rwanda

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ABSTRACT

Globally, the experiences show that climate-smart agroforestry (CSAF) can contribute to sustainable agricultural growth and rural transformation while tackling climate change. This study evaluated the interplay between farmers' knowledge, attitude, and motivation to adopt CSAF. The study used data from 381 farmers surveyed in Bugesera and Rulindo regions, Rwanda. Bugesera, in the semi-arid savannah lowlands, and Rulindo, in the temperate central highlands, were purposively selected for their distinct physiographic features. A questionnaire was used to collect the data and descriptive statistics, Pearson correlation, and binomial logistic regression were performed for data analysis. The results from the correlation analysis showed that various revealed factors, including gender, civil status, education, household size, household poverty level (*ubudehe*), farm size, farmers' experience in CSAF, ownership of radio and mobile phone, livestock herd size, farm-river distance, training, and extension visits, influenced farmers' knowledge in adopting CSAF. The most significant positive correlation was found between owning a mobile phone and farmers' knowledge, while the weakest positive correlation existed between farmers' gender and their knowledge of CSAF. These factors equally affected farmers' attitudes, except for statistically insignificant gender. The most significant positive correlation was between owning a mobile phone and farmers' attitudes, while the weakest was between extension visits and farmers' attitudes towards CSAF. Further, results revealed a positively significant relationship between the farmers' ages and their motivation to adopt CSAF. Additionally, the binomial logit regression analysis showed that farmers knowledgeable with CSAF were 2.5 times more likely to practice CSAF than farmers without such knowledge. Moreover, being motivated by CSAF benefits increased the likelihood of adopting CSAF by 0.6 times compared to unmotivated farmers. By filling the gap in understanding farmers' knowledge, attitudes, and motivations toward CSAF adoption, this study contributes to advancing sustainable agricultural practices in Rwanda. It provides a blueprint for similar initiatives elsewhere.

1. Introduction

World figures indicate that in more than 40 % of the world's agricultural lands (Zomer et al., 2016), at least 10 % is covered by trees. The assessment from the land use outlook shows that geographical disparities exist in tree cover types among agricultural farms and forestry stands (Dewi et al., 2017; van Noordwijk, 2019). Globally, especially in developing countries, climate-smart agroforestry (CSAF) has been proven to be a natural resource management tool, that can contribute to rural transformation, positively impacting the economy and livelihoods in rural areas (van Noordwijk, 2020). The CSAF concept emerged from the earlier farming approach termed agroforestry (AF) which focuses on combining crops, trees, and livestock at the farm level (Van Noordwijk et al., 2018) to diversify farm commodities and supply to households. Revolutionizing AF to climate change, the new farming approach—CSAF—is taking shape. It incorporates trees among crops to diversify and optimize farm utilities, and production and safeguard the environment while tackling climate change (van Noordwijk, 2020).

Introduced as an evolution of traditional tree-on-farm farming practices (agroforestry), CSAF addresses environmental concerns,

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productivity issues, and the growing threat of global warming (Ntawuruhunga et al., 2023). Consequently, CSAF represents a novel approach that integrates trees with crops, providing a dual benefit of increased agricultural productivity and resilience against climate change. CSAF is a new farming approach that evolved from the age-old farming practice of combining crops with trees (agroforestry) on the same farmland while addressing climate change challenges. This smart farming approach is considered an affordable, low-input technology, scientifically demonstrated to increase farm productivity while ensuring sustainability in sub-Saharan Africa (SSA) (Garrity, 2012). In their report, the United Nations Development Program (UNDP) (2016) emphasized that adverse impacts of climate change undermine countries' ability to achieve sustainable development. Accordingly, the Food and Agriculture Organization of the United Nations (FAO) inaugurated a new farming approach to conservation agriculture termed "climate-smart agriculture"—a unified approach to improve food production while coping with the adverse effects of climate change. Therefore, CSAF is one "climate-smart agriculture" added approach as a joint effort to improve agricultural production to meet the world population's needs, degrading arable lands, and biodiversity (Ntawuruhunga et al., 2023). CSAF as sustainable land stewardship can be one of the solutions to food insecurity, biodiversity loss, and environmental and ecosystem degradation. Gradually, CSAF is receiving increasing attention from researchers as a sustainable land management option because of its ecological, climate resilience, economic, and social attributes (Ndoli et al., 2021).

Several studies have stressed the importance, relevance, and benefits generated by incorporating CSAF in farming including (i) building resilience, (ii) increasing soil carbon and improving soil health, (iii) providing fodder and shade for sustainable livestock production and (iv) diversifying human diets and economic opportunities (Rosenstock et al., 2019). On top of the list, we add that CSAF can be recognized as a way to combat forest decline. A comprehensive literature review reveals that an impressive range of benefits can be attributed to CSAF practices, such as agricultural diversification, genetic conservation, carbon capture, catchment protection, and rehabilitation, strengthening of agricultural infrastructure, increased self-sufficiency in timber and bioenergy, reduced need for food imports, poverty reduction, improvement in the nutritional status of people and associated health benefits, improved utilization of degraded and marginal cropping land, improved wildlife habitat, and landscape amenity (Harrison et al., 2016). Although some studies (Bichier et al., 2000; Young, 2002; Newaj and Dhyani, 2008; McAdam et al., 2009) did not directly show evidence of improvement in food security induced by CSAF farming practices, they found their positive impact on ecosystem services, improved productivity and socio-economic compared to monoculture. Most studies have focused on CSAF systems about ecosystem services, with less emphasis on their effects on food security and income generation.

Climate instability compromises food security with unprecedented effects through increased hunger and poor nutrition in countries with meager resources. Farmers incorporate trees among crops on farms instead of monoculture termed «climate-smart agroforestry (CSAF)» to improve food production. This novel farming approach has the potential to sustain farming, diversify farm outputs, and protect the environment while tackling climate change. In poor-resource countries, agriculture is critical in the primary sector in which most of the population depends for their livelihoods. For example in Rwanda where agriculture contributes 25 % of the country's gross domestic product (GDP) (Republic of Rwanda, 2023), studying mixed factors influencing CSAF uptake and promotion is essential.

The major parts of Rwanda are rural and agricultural development is among the top priorities alongside tourism in regional economic development. Agriculture is the mainstay of Rwanda's economy and sustains the livelihoods mainly in the countryside. Agriculture lies in the hands of smallholder farmers. They constitute approximately 2.3 million agriculture households (80 % of the total estimated households in the country) ((National Institute of Statistics of Rwanda (NISR), 2021)). They work hard to ensure their families are food secure, supply the local markets, and implement the country's land use consolidation program. However, the inability of farmers to access resources is the main challenge that hinders them from practicing sustainable productive farming. Land is in higher demand than other forms of physical capital (Awuor et al., 2023). Unfortunately, land productivity is reversed by climate change, causing large-scale disasters, and posing risks to overall agricultural productivity.

Overpopulation and climate instability demoralize farmers who rely on rainfed subsistence farming (Tokede et al., 2020). Modernizing farming through innovative smart farming technologies, such as CSAF, offers promising solutions (Jairo and Korir, 2019). CSAF integrates trees on farms to address climate change challenges while enhancing agricultural productivity. Patel et al. (2024) reported that globally CSAF is practiced in over 130 countries, encompassing various approaches like taungya farming and silvopasture (Ndomba et al., 2015). Numerous findings show the agronomic and economic benefits of CSAF (Franzel et al., 2001). Farmers practice CSAF to reap various benefits such as fuel, fruits, ornament, shade, soil fertility and protection, and windbreaks (live fences) while safeguarding the environment and improving food security. Trees enter the value chains in tree-farm production systems such as CSAF, ensuring sustainability via transformation through value addition for planned use in construction, paper production, woodworking, etc. CSAF can be a pillar of effective agriculture and sustainable community livelihoods and development if adopted at scale.

The role of farmers' knowledge is key in CSAF adoption. Knowledge may be acquired from formal education, communication from extension services, or experience accumulation in the farming practice. With this knowledge, farmers are likely to embrace sustainable farming practices and innovative technologies and navigate the challenges of climate change patterns while focusing on market demands. In some respects, an emphasis on innovative farming practices that apply local and scientific knowledge is much encouraged.

Farmers' knowledge is the level of know-how farmers have about farming novelties like CSAF, and what utilities and outcomes are such as yield, products, and indirect benefits such as environmental protection, and associated costs such as inputs, and risks (Tokede et al., 2020). Generally, farmers acquire practical knowledge, know-how, and skills through technology transfer. Transfer of technology to farmers is an integral part of the extension process which involves disseminating technical innovation and know-how to farmers.

Profitable farming operates within rational decisions where farmers transform farming into business. The level of farmers' knowledge about CSAF will likely influence their attitudes towards these novel farming practices. Before forming an attitude towards new technology, in the framework of the adoption-decision process, the adoption-decision is the 3rd and last step in a process that begins with the individual gaining knowledge about the new technology (Sahin, 2006). Farmers' attitude denotes their perceptions, predisposition, and willingness to embrace CSAF. Attitudes significantly influence farmers' adoption decisions (Prokopy et al., 2008; Kallas et al., 2010) when included in adoption studies as explanatory variables. For policymakers, it can provide useful insight to identify different farmers' attitudinal typologies to simplify and effectively represent the heterogeneity of such attitudes (Valbuena et al., 2008; Daloğlu et al., 2014). As a result, determining the relationships between these attitudinal typologies and the farm/farmer characteristics provides a more practical focus for policy interventions to support and upscale the adoption of new technologies and practices (Boon and Meilby, 2007). A relatively positive attitude towards CSAF practices will elevate the probability of uptake and a relatively negative attitude will reduce the likelihood of its uptake. Segmenting the farming population has become an increasingly popular tool for developing and targeting extension programs to particular farmer segments or groups (Schwarz et al., 2009). To a large extent, change is more likely to occur amongst those where it fits with attitudes (Pike, 2008). Farmers' knowledge of CSAF will likely mold their attitudes toward this farming practice (Tokede et al., 2020). Studies showed that social factors correlate with motivation to adopt new technology (Dalmiyatun et al., 2017). In Rwanda, despite land fragmentation due to the growing population, smallholder farming is common practice and farmers practice CSAF with limited scientific knowledge of local contexts (biophysical and socioeconomic features) that affect food production and their livelihood (Bishaw et al., 2013; Jemal et al., 2018; Amare et al., 2019).

Even though the adoption of trees on farmlands provides several opportunities as a potential source of income, the main motivation for smallholder farmers to grow trees on less than 1ha for 80 % of farmlands in Rwanda is largely unknown (NISR, 2010). Farmers' decisions to plant trees on their farms depend largely on several factors such as biophysical, socioeconomic, agroclimatic, and household characteristics. Local factors are important to consider when investigating why farmers grow trees on farms since they are regional-specific and cannot be easily generalized on all agricultural landscapes, at national, regional, and global scales (Ndayambaje et al., 2012). Smart farming can provide a positive contribution to sustainable agriculture with the introduction of technologies and practices that have the potential to mitigate climate threats. Technology adoption research through a better understanding of individual adoption decisions can assist decision-makers in realizing this potential via better policy design and targeting (O'Shea et al., 2018). Knowledge, attitudes, and motivation of potential adopters are some of the important characteristics influencing these decisions. Thus, identifying groups or typologies of farmers with these three typologies and their associated farm/farmer characteristics can inform policy to discern the untapped potential of CSAF, to encourage the adoption and upscale of CSAF practices.

While existing research on technology adoption and farmers' knowledge, attitudinal, and motivational typologies are useful, they remain largely research-context-specific (Karali et al., 2013; Sulemana and James, 2014). To the best of our knowledge, the intertwined relationships between farmers' knowledge, attitude, and motivational factors and the adoption of CSAF have not been holistically explored to understand and fix challenges inherent to these practices. Thus, this study aimed to fill this gap by (i) assessing the knowledge, attitude, and motivational factors regarding CSAF; and (ii) determining the association between farmers' knowledge, attitude, and motivational factors and the adoption of CSAF.

Doing so provides policymakers and different stakeholders with a more informed view of how farmers' knowledge, attitudes, and motivation can be utilized to improve the targeting of policy incentives, upscaling the CSAF in the future, and improve farmers' livelihoods in rural areas. This is built on the assumption that adequate farmers' knowledge of CSAF, positive attitude towards CSAF, and motivation will enhance its uptake, adoption, promotion, and benefits. Employing the bespoke survey and taking Rwanda as a case study, this paper adds to existing agricultural technology adoption research by identifying farmer knowledge, attitudinal and motivational typologies, and variables associated with such typologies.

2. Conceptual framework

Farm/farmer characteristics and typologies are significant drivers of farmers adopting sustainable farming practices. Farm/farmer characteristics such as farm size and farmer age and typology such as knowledge, attitude, and motivation may influence farmers' decisions for CSAF adoption. However, many other biophysical and socio-economic factors are likely drivers of adoption (Aker, 2011). Typically, one of the main reasons is that farming systems are heterogeneous, and thus farm-level decisions and the contexts in which these decisions are made may differ significantly (Dessart et al., 2019; Brown et al., 2021). To some extent, extension services are grounded on using knowledge to disseminate new technologies among farmers. Farmers accept recommendations once they perceive potential benefits from implementing such recommendations (Chavas and Nauges, 2020). Simultaneously, this truth doesn't tell the whole story. Since farmers operate in biophysical, socioeconomic, and cultural environments, other factors may play a significant role in determining if farmers will accept and eventually adopt recommended technologies, as illustrated in Fig. 1.

Farmers operate in a complex environment and are influenced by factors, such as biophysical conditions, farm structure and capacity, socio-demographic characteristics, economic status, and farmers' attitudes and beliefs (Siebert et al., 2006; Mills et al., 2017). Recognizing this complexity, it is apparent that while economic incentives may influence farmers to adopt, farmers' risk aversion and capacity to implement new technology, can combine with other factors such as farm structure and context to inform their motivations. This may suggest that farm/farmer characteristics commonly used to explain the adoption have a different impact across multiple stages (O'Shea et al., 2018). Also, this may suggest that the fact that farm recommendations are useful and free may not necessarily mean that farmers will automatically accept or implement them (Osawe and Curtis, 2024). At the same time, the decision to adopt may be deeper if farmers trust the source, quality, and level of advice. Thus, understanding the interplay of knowledge, attitudes, and motivating factors including the context in which farmers' decisions are taken, can provide vital evidence for improving and advancing sustainable agricultural practices. Thus, the impact of farm/farmer characteristics and farmer typologies extends to multiple points within this process (and in this instance, for innovative orientation, productivity orientation, and environmentalism).

3. Materials and methods

3.1. Study area

Rwanda is a rural economy in East Africa. Its fundamental challenge is the growing population on a fragile and eroding land, exacerbated by climate change risks (Republic of Rwanda, 2022). The study focused on two agroecological zones of Rwanda: Bugesera (eastern semi-arid savannah lowland zone) and Rulindo (temperate zone of the central highlands).

The lowland Bugesera is part of the eastern savannah semi-arid area between Latitude $1^{0}37'56''$ S and $2^{0}13'9''$ S and Longitude $29^{0}21'0''$ E and $30^{0}18'0''$ E. It has a surface area of 1337 sqkm. The registered annual average temperature is between 26 and 29 °C. Its landscapes vary from 1100 to 1780m above sea level. Its annual precipitations vary between 700–1100 mm. Bugesera is part of the drier plains in eastern Rwanda covered with savannah grasslands and scattered woody trees, notably acacia (Fig. 2).

The upland Rulindo is part of the temperate zone of the central highlands between Latitude $1^{0}44'$S and Longitude $29^{0}59'$E. It is an upland area mostly characterized by mountainous landscapes. It has a surface area of 567 sqkm. Its relief is formed of steep slopes with an elevation of 1470–2200 m above sea level. It harbors food crop farming on hillslopes and vegetables in valleys with woodlot trees of eucalyptus, some grevillea, and calliandra scattered on farmlands. The registered mean annual temperature is 19 °C., while the annual precipitation is 1243.3 mm (Fig. 2).

These areas were purposively sampled based on their agroclimatic conditions and the farming practices inherent to these separate zones. In Bugesera, soil fertility is depleted of major soil nutrients due to overexploitation, decreased organic matter, and high acidity (Mukashema et al., 2022). In Bugesera, agriculture is mostly rain-fed and subject to the caprices of meteorological patterns (Rwanyiziri and Rugema, 2013). Although endowed with abundant lakes, water is scarce for farming due to a lack of irrigation infrastructure and equipment to help needy farmers, especially in the dry season. Consequently, smallholder farmers have little means to increase productivity and graduate from poverty (ibid.). Climate change and concomitant trends in climate variability make agricultural production in this region, unpredictable from one

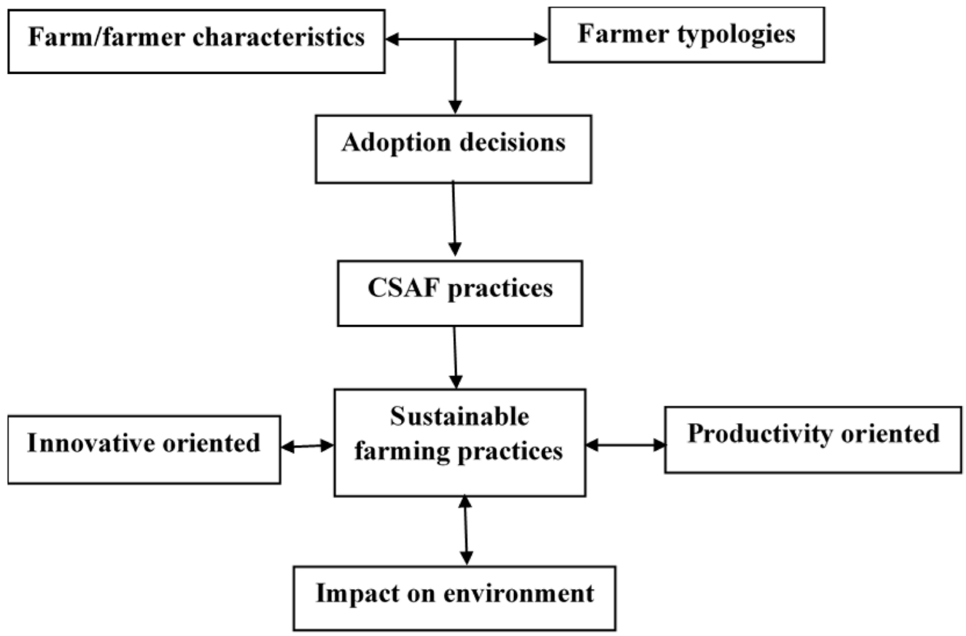

Fig. 1. Framework of farmer adoption of CSAF for sustainable farming practices. Adopted from Osawe and Curtis (2024).

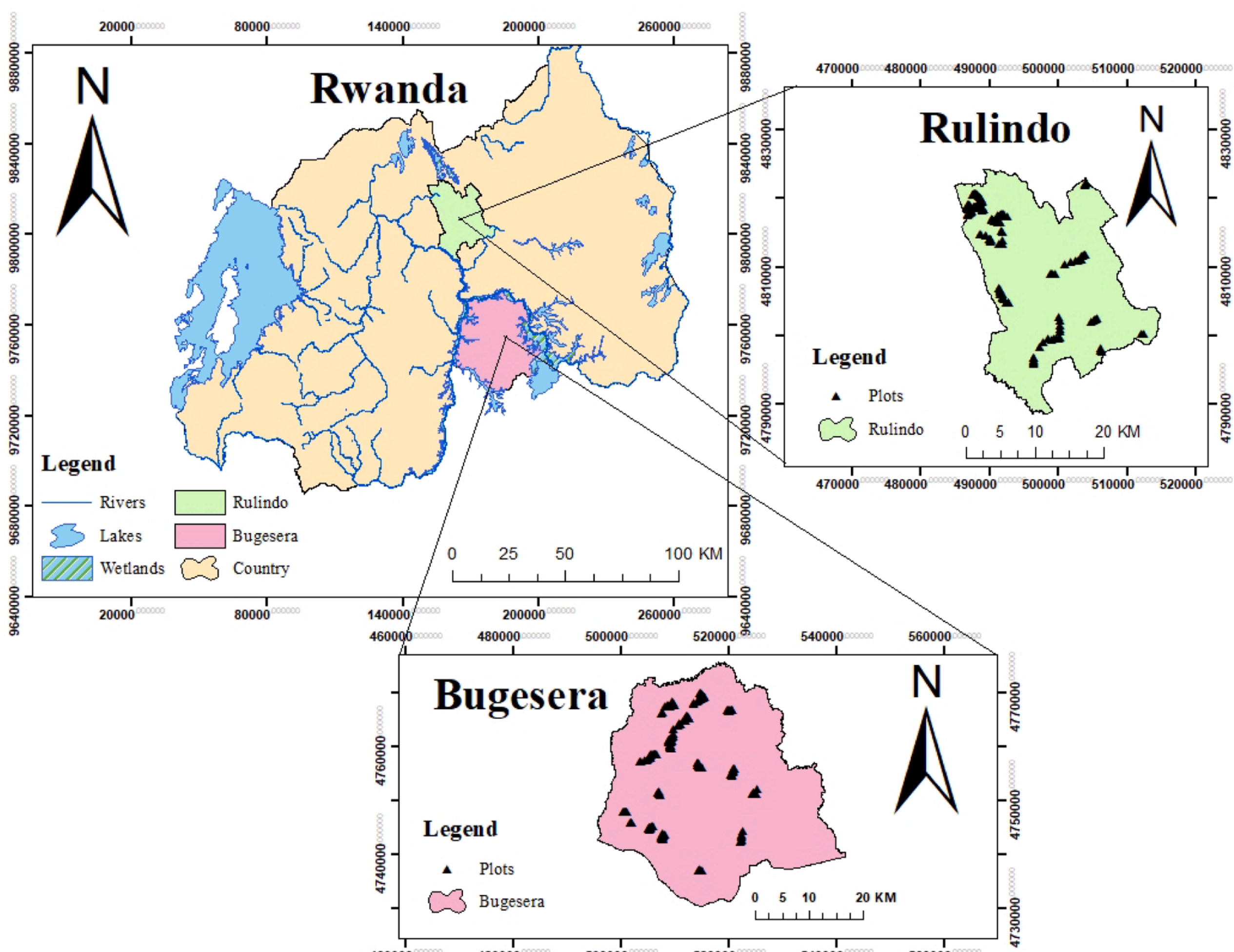

Fig. 2. Map of Rwanda with study areas (Bugesera and Rulindo) (adapted after CGIS).

season to another. Droughts and extreme temperatures plague this region. Rulindo is rural and comprised of steep hills and valleys, with springs and rivers in canyons, serving as the traditional water sources (Ndolimana and Nahayo, 2021). Farmers in this area are predominantly vegetable growers. They rely on rainfall while much of the water runs off from its steep hills owing to the area's mountainous landscape where floods are commonplace (FAO-Rwanda, 2020). As such, the two regions are afflicted with food shortages whenever dramatic climate changes occur (Habiyaremye et al., 2022).

3.2. Sampling and data collection

We selected a sample of 381 farmers from various villages in the Bugesera and Rulindo regions through the random sampling technique of the survey (Banyal et al., 2015). Data were collected from both primary and secondary sources. Primary data were obtained from the field through interviews with farmers on their farms. Secondary data were collected from published articles, scientific books, and policies on general conditions of the region, such as geographical aspects.

We applied a multi-stage sampling procedure combining purposive, stratified, and simple random sampling techniques. In the 1st stage, the two regions described above were purposively selected based on their agroecological zones (AEZs) (Table 1). In the 2nd stage, the two geographical zones were stratified using their elevation: the lowland (Bugesera) zone and the highland (Rulindo) zone. In the 3rd stage, different villages were selected based on information from extension officers about agricultural potential, accessibility, and high level of CSAF practices and production.

In determining the sample size (Table 2), this study used data published from the Rwanda Agricultural Household Survey Report 2020 (National Institute of Statistics of Rwanda, 2021). These data show that about 166,000 (45.60 %) from 364,000 (*N*) rural households in Bugesera and Rulindo are farmers. So, 381 (*n*) farmers were selected to form the total sample (Wonnacott and Wonnacott, 1969). Sampling intensity was proportionally allocated to each subsample based on farming population size. Increasingly, using the list of farmers selected for interview, a simple random sampling was used to select the sample units.

Lists of farmers from the selected villages were prepared with the assistance of village leaders and 381 farmers were randomly picked for interviews, of which, 193 farmers were from the Bugesera and 188 from the Rulindo. Interviews were organized with farmers on their farms.

The survey was conducted between April to September 2023. Before surveying the selected regions, the questionnaires were pre-tested on 11 random farmers from the two separate study areas ((Bugesera (6 farmers) and Rulindo (5 farmers)) and later revised to fit into the context of the local biophysical, climatic, and socio-economic situations. The original questionnaire was built on an Open Data Kit (ODK) software uploaded on an Android mobile device (tablet) under the ODK collect Application. The built form on ODK included the Global Positioning System (GPS) capturing the farm coordinates, socio-economic information, bio-physical information, etc. Additional information was captured through field measurements using e.g., a GPS area calculation application uploaded on an Android mobile phone for land area measurement, observations on the ground, and interviews with key informants (including local/village leaders, agriculture extension officers, and farmer groups).

We conducted interviews with household heads on their farms. Research variables included agroecological zone, altitude, gender, age, civil status, education, household size, *ubudehe* (household poverty level), farm size, farming experience in CSAF, owning a radio, owning a mobile phone, livestock size, farm-river distance, training, extension visits, farmer knowledge, attitude, and motivation in CSAF adoption. We collected the data using a semi-structured questionnaire and personal observation on the field. In addition, we conducted three focus group discussions (FGDs), with 8–12 participants. The discussion sessions focused on the knowledge, attitude, and motivational factors that drive farmers to adopt CSAF practices.

Table 2
Sampled sites and size.

Sites	Households	Farmer households	Sample size (*n*)	% sample
Bugesera	204,000	84,000	193	50.66
Rulindo	160,000	82,000	188	49.34
Total	364,000	166,000	381	100.00

We also interviewed the local government (districts), the Albertine Rift Conservation Society (ARCOS), and the model farmers to complement our findings. Two interviews were conducted with local officials (districts), one interview with an ARCOS staff, and two model farmers. These officials were contacted to acquire an overview of CSAF practices in the study areas.

We also used personal observation to collect information on the field. Using a diary and camera, we documented what we observed in the field about CSAF practices on the farms. This approach allowed us to observe and describe the CSAF structures and compare farmers' utterances with our observations in the field (Castle et al., 2022). On farms, we directly observed the general farm conditions and farming practices, types of CSAF practices available, tree components and configuration, and slope and soil erosion control. We also gathered secondary data to complete the findings of this research.

3.3. Data analysis

This paper analyzed the data using descriptive and inferential statistics in Microsoft Excel, Stata, and R software (Tokede et al., 2020). Descriptive statistics, correlation, and regression analyses were applied. Descriptive statistics were used to calculate frequency distribution, the mean, percentage, and standard deviation, describing the respondents' demographics and CSAF practice status and determine the farmers' knowledge, attitude, and motivational factors in the study areas. Inferential statistics were also performed such as the Pearson correlation test. The evaluation of whether significant differences existed between CSAF adopters and non-adopters (binary variables) was performed using a *t*-test. The coefficient correlation was used to test and compare the relationships between demographic data, knowledge, attitude, and motivational factors at a 5 % significance level. The outcome variables were investigated using the Frequency and Percentage Method (FPM) with the Rank Order of tested responses. A binomial regression model was utilized to test the association between the framers' knowledge, attitude, and motivation and the adoption of CSAF.

3.4. Model specification for knowledge, attitude, and motivation on the adoption of CSAF

3.4.1. Correlation analysis

Pearson correlation coefficients were estimated to ascertain the relationships between socioeconomic factors and farmers' knowledge, attitude, and motivation. Correlations between variables were

Table 1
Study area characteristics.

Site name	Site code	AEZ	Latitude (^{0}S)	Longitude (^{0}E)	Altitude (m.a.s.l.)	Mean annual temperature (°C)	Mean annual rainfall (mm)
Bugesera	BU	Eastern lowlands	2^{0}09′	30^{0}05′	1100–1780	39	943
Rulindo	RU	Central Highlands	1^{0}44′	29^{0}59′	1862–2438	19	1243.3

computed using the formula of Khanal (2015):

$$r_{xy} = \frac{\sum_{i=1}^{n}(X_i - \overline{X}_i)(Y_i - \overline{Y}_i)}{(n-1)_{S_x S_y}} \tag{1}$$

Where:

- $\overline{X}$ and $\overline{Y}$ are the sample means of X and Y,
- S_x and S_y are the sample standard deviation of X and Y, respectively.

3.4.2. Regression analysis

We performed a logistic regression model (Kabirigi et al., 2023), termed "logit" to ascertain how predictor variables (independent) influence the outcome variable (dependent). According to Sperandei (2014), the logit regression analysis is performed to compute a statistic (odds ratio) that estimates how changes observed in the dependent variables (binary outcomes) are associated with changes in predictor variables. In this study, the outcome variable was the adoption of CSAF (1 = adopting or 0 = not adopting). Input variables were farmers' knowledge, attitude, and motivational factors to adopt CSAF. The outcome variable–the adoption of CSAF–depicts heterogeneity in adoption among CSAF farmers (Kabirigi et al., 2023). The nature of the outcome variable imposed the kind of regression we had to perform. The data dictated the use of logistic regression. A logit regression can be binomial, ordinal, or multinomial (Kabirigi et al., 2023). As described in Table 1, the data show that the adoption of CSAF is a binary outcome. We therefore analyzed the data by performing a binomial logistic regression analysis. In this respect, we coded the outcome variables as "1″ and "0″ (1 = adopting, 0 = not adopting). This coding was chosen as it leads to the most straightforward interpretation of results. It is worth noting that this approach enables the quantification of the model parameter perturbations affecting the probability of occurrence of a certain binary outcome (Morotti and Grandi, 2017). Employing the response variable "adopt CSAF", the regression model is depicted as follows:

$$p_k(adopt\ CSAF) = \begin{cases} \left(\frac{1}{1+e^{-Z_k}}\right) for\ adopt\ CSAF_k = 1 \\ \left(1 - \frac{1}{1+e^{-Z_k}}\right) for\ adopt\ CSAF_k = 0 \end{cases} \tag{2}$$

With:

$$Z_k = \beta_0 + \beta_1 \times Knowledge + \beta_2 \times Attitude + \beta_3 \times Motivation \tag{3}$$

Ceteris paribus, the parameter β_i represents the expected average change in the response variable for a one-unit change in the explanatory variable. Therefore, we are modelling the response variable "adopt CSAF" as explained by knowledge, attitude, and motivational factors.

Odds ratios are computed to report the strength of association between an event (response variable) and one or more input variables (predictor variables) (Kabirigi et al., 2023). The formula (Muhamadi and Boz, 2021) was used to compute the odds ratios for all predictor variables:

$$Exp\beta\ or\ odds = \frac{P}{1-P} \tag{4}$$

We transformed results into odds ratios (OR) reflecting the increase or decrease in odds associated–ceteris paribus–with the influence change of the explanatory variable (Norton et al., 2018). Its interpretation is that–all other predictor variables being held constant–how many times the likelihood for the farmer with a high level of CSAF adoption increases for a single predictor when the predictor is increased by one unit. Of note, odds ratios measure how strongly an outcome is associated with its predictor. These measures have been extensively used in research to analyze and interpret results from logistic regression models (Sprince et al., 2003; Ohlmacher and Davis, 2003; Jasinski et al., 2005; Rautiainen et al., 2009; McDonald, 2014).

Three regression explanatory variables notably knowledge, attitude, and motivation were used in this study for the binary logistic regression model. Various techniques are used to select variables that fit the model. They include the stepwise approach that combines the forward collection and backward elimination of predictor variables, to be added or removed statistically, without disturbing the model prediction accuracy (Hosmer and Lemeshow, 2000). Reference groups were farmers without knowledge of CSAF farming, farmers with negative attitudes towards CSAF, and unmotivated farmers regarding CSAF practices. Our regression model reached a higher significance level by excluding the attitude variable, which did not satisfy the condition of model goodness-of-fit (Muhamadi and Boz, 2021).

4. Results

4.1. CSAF farming in Bugesera and Rulindo regions

Fig. 3 portrays the agricultural land with a CSAF system (a) and another farming system without CSAF (b). Beans planted under CSAF were luxuriant while crops in non-CSAF farming were exposed to heat stress and drought resulting in poor harvests.

4.2. Description of demographic surveyed data

The demographic survey data show the characteristics of the sampled participants helping to have the global picture of respondents. As portrayed in Table 3, adopters have large livestock herd sizes and received training on CSAF. On average, adopters were aged 44 years against 43 years for non-adopters.

4.3. Farmers' knowledge of CSAF

Table 4 highlights different aspects regarding the knowledge of farmers about CSAF that were deemed important to advance investigation in this study. The majority (65.88 %) of farmers in study areas know that CSAF systems contribute to soil fertility and erosion control, 65.35 % know that tree cultivars used for CSAF include fruits and fodder, 64.57 % know that CSAF maximizes land usage, 63.25 % know that CSAF contributes to improved income and food security, whereas 62.20 % know that CSAF involves crop-tree integration, as portrayed by rank order of tested responses. These results imply that farmers had good knowledge about CSAF, with an average of 64.25 % in the study areas. It may be inferred that more than half (50 %) of survey participants have adequate knowledge of CSAF. Therefore, more exposure needs to be given to the farmers to increase the uptake and adoption levels of CSAF.

4.4. Farmers' attitude towards CSAF and its benefits

Results from farmers' attitudes towards CSAF (Table 5) showed that 66.93 % of respondents concurred with the statement that the overall income/benefits from CSAF are more than pure agriculture and forestry, 66.14% agreed to the statement that CSAF improves the agro-ecosystem's micro-climate, 65.62 % agreed to the statement that every farmer should practice CSAF, 65.35 % agreed to the statement that CSAF reduces the incidence of total crop failure, whereas 64.57 % of respondents endorsed the statement that CSAF helps farmers to become self-reliant in timber, fuel, fruits, and fodder as portrayed by per rank order of tested responses. On average, farmers had a positive attitude towards CSAF (65.72 %) in the study areas.

4.5. Motivational factors influencing CSAF practices

Regarding factors of motivation for CSAF adoption, results indicated that 46.72 %, 45.93 %, 45.41 %, 45.14 %, and 35.96 % of surveyed farmers expressed that high financial returns, utilization of unproductive lands, environmental amelioration, availability of incentives

(a) (b)

Fig. 3. CSAF and non-CSAF farms in research locations: (a) CSAF farm in research locations; (b) non-CSAF farm in research locations.

Table 3
Demographic description of CSAF adopters and non-adopters and mean differences.

Variables	Adopters	Non-adopters	Variation	P > |t|
AEZ (1/0)	0.51(0.50)	0.50(0.50)	0.01	0.773
Altitude (m)	1640.47 (239.28)	1640.05 (219.68)	0.42	0.986
Gender (1/0)	0. 67(0.50)	0.66(0.98)	0.01	0.884
Age (years)	44.19(15.05)	42.85(14.67)	1.34	0.384
Civil status (1/0)	0.70(0.45)	0.77(0.42)	−0.07	0.154
Education (1/0)	0.56(0.49)	0.57(0.49)	−0.01	0.888
Household size (counts)	3.99(1.86)	4.09(1.86)	−0.1	0.589
"*Ubudehe*" (1/0)	0.58(0.49)	0.54(0.50)	0.04	0.451
Farm area (ha)	1.15(1.62)	1.04(1.21)	0.11	0.464
Experience (years)	2.48(3.13)	2.50(3.42)	−0.02	0.965
Radio (1/0)	0.50(0.50)	0.48(0.50)	0.02	0.675
Mobile phone (1/0)	0.73(0.44)	0.71(0.45)	0.02	0.663
Livestock (counts)	1.81(6.32)	0.98(1.70)	**0.83****	0.069
Farm-river distance (<500m/>500m)	0.12(0.33)	0.14(0.35)	−0.02	0.591
Training (1/0)	0.18(0.39)	0.11(0.31)	**0.07***	0.043
HH Ext. visit (1/0)	0.24(0.43)	0.18(0.39)	0.06	0.166

* Significant at 0.05;
** Significant at 0.1.
Bold values mean emphasizing the statistically significant values.

(seedlings and other inputs), and cottage industry development were, respectively, the highly motivating factors in influencing adoption of CSAF practices as per rank order of test responses (Table 6).

The 'high financial returns' factor is top-ranked and highly motivating for adopting CSAF in the farmlands. The 'Utilization of unproductive lands' factor is ranked second in the same ranking order. The other motivational factors like 'environmental amelioration', 'availability of incentives (seedlings and other inputs)', and 'cottage industry development' were in order of 3rd, 4th' and 5th position, respectively.

Table 4
Farmers' knowledge of CSAF in surveyed areas (n = 381).

	True (%)	False (%)	Rank order
CSAF involves crop-tree integration	62.20	37.80	**5**
Tree cultivars used for CSAF include fruit, fodder	65.35	34.65	**2**
CSAF systems contribute to soil fertility and erosion control	65.88	34.12	**1**
CSAF maximizes land usage	64.57	35.43	**3**
CSAF contributes to improved income and food security	63.25	36.75	**4**
Average	**64.25**	**35.75**	

Table 5
Farmers' attitude towards CSAF and its benefits in surveyed areas (n = 381).

	Agree (%)	Disagree (%)	Rank order
CSAF helps farmers to become self-reliant on fuel, fodder, timber, and fruits	64.57	35.43	**5**
Overall income/benefits from CSAF is more than pure agriculture and forestry	66.93	33.07	**1**
CSAF reduces the incidence of total crop failure	65.35	34.65	**4**
CSAF improves the micro-climate of the area	66.14	33.86	**2**
Every farmer should practice CSAF	65.62	34.38	**3**
Average	**65.72**	**34.28**	

4.6. Farmers' constraints in maintaining on-farm tree growth

In Rwanda, CSAF adoption is facing many constraints among farmers. As shown in Table 7, constraints are site-specific owing to inherent local climatic conditions. Of the 381 farmers interviewed, 'no problem' was ranked number one, and most respondents were reported in the Rulindo area (83.58 %). The 'termites' constraint was ranked second by farmers and the majority were reported from the Bugesera area (98.69 %) followed by 'water stress' and the majority reported in

Table 6
Motivational factors for CSAF uptake in surveyed areas (n = 381).

Factors of farmers' motivation	Highly motivating (%)	Moderately motivating (%)	Least motivating (%)	Rank order
High financial returns	46.72	27.56	25.72	**1**
Utilization of unproductive lands	45.93	29.40	24.67	**2**
Availability of incentives (seedlings & other inputs)	45.14	28.61	26.25	**4**
Cottage industry development	35.96	25.46	38.58	**5**
Environmental amelioration	45.41	29.13	25.46	**3**
Average	**43.83**	**28.03**	**28.14**	

Bugesera (100.00 %), 'poor tree adaptation' with the majority in Bugesera (85.85 %), 'tree diseases' with majority in Bugesera (89.74 %), 'browsing animals' with majority of respondents in Bugesera (93.75 %), and 'soil compaction' with majority of respondents in Bugesera (72.73 %).

4.7. Relationship between demographic characteristics, knowledge, attitude, and motivation

The Pearson correlation analysis results (Table 8), obtained from the bivariate test, showed positively significant relationships, although small, between gender (rho = 0.098, $p < 0.1$), civil status (rho = 0.163, $p < 0.01$), education (rho = 0.203, $p < 0.01$), household size (rho = 0.174, $p < 0.01$), *ubudehe* (rho = 0.267, $p < 0.01$), farm size (rho = 0.264, $p < 0.01$), experience in CSAF (rho = 0.304, $p < 0.01$), possession of radio (rho = 0.235, $p < 0.01$), owning a mobile phone (rho = 0.339, $p<0.01$), livestock herd size (rho = 0.113, $p < 0.05$), farm-river distance (rho = 0.127, $p < 0.05$), training (rho = 0.135, $p < 0.01$), extension visits (rho = 0.118, $p < 0.05$) and knowledge of the farmers on CSAF practices. The strongest positive relationship was observed between owning a mobile phone and knowledge (rho = 0.339, $p < 0.01$). Instead, the weakest positive relationship was witnessed between farmers' gender and knowledge in CSAF (rho = 0.098, $p < 0.1$).

Positively significant relationships were also found between civil status (rho = 0.144, $p < 0.01$), education (rho = 0.178, $p < 0.01$), household size (rho = 0.105, $p < 0.05$), *ubudehe* (rho = 0.250, $p < 0.01$), farm size (rho = 0.231, $p < 0.01$), experience in CSAF (rho = 0.328, $p<0.01$), possession of radio (rho = 0.216, $p < 0.01$), owning a mobile phone (rho = 0.348, $p < 0.01$), livestock herd size (rho = 0.105, $p < 0.05$), farm-river distance (rho = 0.138, $p < 0.01$), training (rho = 0.129, $p < 0.05$), extension visits (rho = 0.099, $p < 0.1$) and attitude of the farmers towards CSAF practices. The strongest positive relationship was observed between owning a mobile phone and attitude (rho = 0.348, $p < 0.01$). The weakest positive relationship was between extension visits and farmers' attitudes towards CSAF (rho = 0.099, $p < 0.1$).

Additionally, the results showed a positive and significant relationship between the age of the farmers (rho = 0.107, $p<0.05$) and motivational factors to adopt CSAF.

Also, on the one hand, farmers with positive knowledge of CSAF reported a positive attitude towards CSAF practices. However, no significant correlations were found between AEZ, altitude and knowledge, attitude, and motivational factors to adopt CSAF.

Table 7
Constraints in maintaining on-farm tree growth in surveyed areas (n = 381).

Constraints	Bugesera (lowlands)		Rulindo (highlands)		Total		
	Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	**Rank order**
No problem	33	16.42	168	83.58	201	100.00	**1**
Termites	151	98.69	2	1.31	153	100.00	**2**
Water stress	115	100.00	0	0.00	115	100.00	**3**
Poor adaptation	91	85.85	15	14.15	106	100.00	**4**
Browsing animals	15	93.75	1	6.25	16	100.00	**6**
Soil compaction	8	72.73	3	27.27	11	100.00	**7**
Diseases	35	89.74	4	10.26	39	100.00	**5**

Table 8
Relationship between demographic data, knowledge, attitude, and motivational factors.

Variable	Knowledge (*rho*)	p-value	Attitude (*rho*)	p-value	Motivation (*rho*)	p-value
AEZ	0.004	0.926	0.048	0.342	−0.081	0.113
Altitude	−0.026	0.611	−0.038	0.449	0.054	0.293
Gender	0.098[c]	0.055	0.042	0.410	−0.047	0.355
Age	−0.116[b]	0.022	−0.166[a]	0.001	0.107[b]	0.036
Civil status	0.163[a]	0.001	0.144[a]	0.004	−0.133[a]	0.009
Education	0.203[a]	0.000	0.178[a]	0.000	−0.211[a]	0.000
Household size	0.174[a]	0.000	0.105[b]	0.039	−0.095[c]	0.062
"*Ubudehe*"	0.267[a]	0.000	0.250[a]	0.000	−0.289[a]	0.000
Farm area	0.264[a]	0.000	0.231[a]	0.000	−0.212[a]	0.000
Experience	0.304[a]	0.000	0.328[a]	0.000	−0.290[a]	0.000
Radio	0.235[a]	0.000	0.216[a]	0.000	−0.224[a]	0.000
Mobile phone	0.339[a]	0.000	0.348[a]	0.000	−0.244[a]	0.000
Livestock	0.113[b]	0.026	0.105[b]	0.039	−0.071	0.161
Farm-river distance	0.127[b]	0.013	0.138[a]	0.006	−0.081	0.111
Training	0.135[a]	0.008	0.129[b]	0.011	−0.208[a]	0.000
HH Ext. visit	0.118[b]	0.020	0.099[c]	0.052	−0.183[a]	0.000

Note:
[a] significant at 0.01,
[b] significant at 0.05, and
[c] significant at 0.1.

4.8. Effect of farmers' knowledge, attitude, and factors of motivation on CSAF adoption

We used a binary logistic regression model to establish the effects of knowledge, attitude, and motivational factors on the adoption of CSAF (Table 9). The post-estimation diagnostic tests were performed to check and ascertain the model's goodness-of-fit (GOF) (Table 9). A statistically significant Pearson χ^2 test score (p-value = 0.2539) indicated a good fit for the model. The likelihood ratio chi-square test score showed that the model was statistically significant and had a strong explanatory power (p-value = 0.000).

After the omission of the most highly correlated variable (attitude), the multicollinearity was eliminated since the variance inflation factors (VIFs) reflected a 1.73 average, well below the recommended threshold (Table 10).

Using a 5 % statistical significance level, results showed that both knowledge and motivational factors significantly influenced CSAF adoption.

The effect of farmers' knowledge on CSAF adoption was statistically significant (Table 11). The odds ratio for knowing CSAF (resulting from training in CSAF farming) shows that—ceteris paribus—farmers knowledgeable of CSAF were 2.5 times more likely to adopt CSAF than farmers without knowledge of CSAF farming.

Similarly, the impact of farmers' motivating factors on CSAF adoption was statistically significant (Table 11). Holding all other variables constant, the odds ratio for being motivated by CSAF benefits was 0.6 times more likely to practice CSAF than unmotivated farmers for CSAF uptake.

5. Discussion

This study investigated how factors (knowledge, attitude, and motivation) impact the adoption of CSAF practices among rural farmers. Results confirm that modelling the influence of knowledge, attitude, and motivational factors improves the understanding of farmers' adoption decisions on CSAF at the cross-site level. The attitude variable was highly correlated with other variables. It was omitted from the regression model as a rule for logit regression which imposes a multicollinearity check before running the regression (Daoud, 2017).

5.1. CSAF and non-CSAF farms in research locations

Results showed that, in general, CSAF practice serves as a cover for arable crops and also replenishes soil nutrients. Trees grown under CSAF farming (especially fruit trees) also contribute to ecological restoration and provide additional income to farmers (Fig. 3). In this regard, CSAF can be one of the solutions to climate change and sustainable agricultural growth in rural areas (Desmiwati et al., 2021).

5.2. Underlying farm/farmer characteristics associated with adoption decisions

Results showed that in the study areas, a relative proportion of farmers adopted CSAF on their farms. Through the adoption of CSAF, farmers have acquired inputs such as fruit tree seedlings and nature tree seedlings (particularly during the recurring annual National Tree Planting Day held on 28th October), training on fruit production, tree nursery establishment and management, and forestry management. Other justified reasons for adopting CSAF as reported by the farmers were the engagement in alternative and additional income sourcing.

Table 9
Result of goodness-of-fit (GOF) test.

N	DF	Pearson chi^2(88)	Prob > chi^2
381	91	99.52	0.2539

Table 10
Collinearity statistics.

Independent variables	VIF	Tolerance (1/VIF)
Average knowledge	1.73	0.576864
Average motivation	1.73	0.576864
Mean VIF	1.73	

Table 11
Summarized logistic regression analysis results.

Significant predictors	OR	SE	Z	P>|z|	95 % CI of OR
Average knowledge	2.573	0. 483	5.03	0.000*	1.780–3.720
Average motivation	0.631	0. 049	−5.81	0.000*	0.540–0.737

OR = odd ratio, SE = standard error, CI = confidence interval
Wald chi2(2) = 35.53 Number of respondents = 381
Prob > chi2 = 0.0000 Log likelihood = −243.51257

* significant at 0.01.
Note: The attitude variable was dropped from the regression model.

5.3. Farmers' knowledge and CSAF adoption decisions

Results revealed that farmers in the study areas had good knowledge (64.25 %) of CSAF practices. Most respondents agreed with all 5 statements regarding knowledge of CSAF practices. The positive knowledge reflected in respondents may result from the sensitization and extension programs imparted to farmers. For example, in farmer field schools (FFS), farmers are exposed to on-farm techniques adapted to the site characteristics they can master and specific farm management skills. Knowledge acquisition by farmers of a novel farming skill is paramount for upscaling any new technology (Munthali et al., 2019). Weir and Knight (2004) opined that agricultural education provides farmers with specific knowledge about farming practices and an increased ability to receive order and understand information. This view is shared by Padhy and Jena (2015) on education's positive effect on agricultural productivity, while specific agricultural education may place a greater emphasis on production (Mathijs, 2003). Subsequently, education would entail a more innovative and production-focused attitude.

5.4. Farmers' attitudes and csaf adoption decisions

Results also showed that farmers had a positive attitude (65.72 %) towards CSAF practices in the study areas. Positive attitudes and perceptions toward innovation can drive farmers to accept and embrace it (Munthali et al., 2019). Practioners' positive attitude towards an innovation would trigger the likelihood of its adoption and vice versa (Meijer et al., 2015). Understanding farmers' attitudes toward the latest farming technologies is key for devising related policies, plans, and programs (Marcus, 2001; Dolisca et al., 2006; Lee et al., 2009). Based on the above results, most farmers are willing to adopt CSAF practices as an indication that the opportunities for upscaling it are foreseen and immense (Munthali et al., 2019). In their study, parallel results were found by Tega and Bojago (2023), in Sodo Zuria District, Ethiopia that farmers had a positive perception of adopting CSAF practices as a means to meet their basic needs in terms of fuel wood, fruits, fodder, timber, and vegetables, but also accepting that these practices are critical for the farmer community to adopt and upscale.

5.5. Farmers' motivation and CSAF adoption decisions

This study also revealed that on average all the items investigated fall in the highly motivating (43.83 %) category followed by the least motivating (28.14 %) and the motivating (28.03 %) category. Banyal et al. (2015) found similar results that people need economic incentives as the motivating force for growing farm trees. It insinuates that, despite hurdles and risks, CSAF adoption can be promoted in farming systems if the results from the interviewed items are given due consideration. Increased scientific research and extension in CSAF may be a far-reaching milestone in stimulating and promoting the adoption of CSAF among farmers. These findings corroborate Banyal et al. (2011) who reported similar results. Concurrently, while conducting a similar study among the farming communities in the hills of Himachal Pradesh, Uppal and Pathania (2008) reached the same conclusion. Additionally, it was found in this study that farmers are reluctant to specialize in the sole activity of CSAF due to smaller landholdings. They mainly single out CSAF for fruits, fuelwood, fodder, stakes for climbing crops, and timber requirements. Across landscapes, rare farmers adopted pure woodlot practices on farms for commercial purposes. Most observed pure woodlots on hills were government natural and planted forests. The rest and the majority of farmers practiced subsistence CSAF. Farmers are willing and ready to practice CSAF suited to the specific climatic conditions of their agroecosystems but are not practicing due to limited land sizes.

5.6. Farmers' constraints in CSAF adoption decisions

This study also isolated major constraints hindering the development of CSAF in respective agroecosystems. All the major constraints were recorded in Bugesera and by order of severity, they include termite nuisance, water stress, poor tree adaptation, tree diseases, browsing animals, and soil compaction. No respondent in Rulindo mentioned any of the six predefined variable constraints. These constraints are associated with climatic conditions. These results are attributed to the fact that Bugesera is a lowland, a semi-arid zone characterized by water stresses due to increased erratic rainfalls and prolonged dry spells. Nonetheless, this region is rich in water bodies such as lakes and marshlands. Agriculture development opportunities are possible with farming mechanization such as irrigation schemes being put in place to overcome these challenges. O'Shea et al. (2018) emphasized that due to the heterogeneous nature of farms, individual farms operate under varying agronomic constraints resulting in differing production systems with unique production and cost functions, and particular efficiencies within their production systems.

5.7. Farm/farmer characteristics and knowledge, attitudes, and motivation

The study findings highlighted favorable relationships between various factors and farmers' knowledge of CSAF practices, including gender, civil status, education, household size, *ubudehe*, farm size, CSAF experience, possession of radio, owning a mobile phone, livestock herd size, farm-river distance, training, and extension visits. Specifically, owning a mobile phone showed the strongest positive correlation, indicating its role in providing farmers with vital information on climate shock events, agricultural practices, weather forecasts, market information, and government schemes. Conversely, the weakest positive relationship was observed between gender and CSAF knowledge, suggesting the presence of gender disparities in agricultural education and knowledge transfer. Quisumbing et al. (2014) and Zossou et al. (2017) support this notion, underlining the need to improve gender-responsive-agricultural extension systems to make women thrive in agriculture value chains. As Rwanda's population continues to rely on subsistence farming, strengthening government extension services, particularly targeting female farmers, is crucial. Revisiting the hiring process to include more female extension agents can accelerate knowledge transfer and dissemination among female farmers. This option is possible as proven by the successful initiatives in India, Ghana, and Ethiopia (Adesiji et al., 2013). In these contexts, when interacting with same-sex extension officers, female farmers felt more comfortable and secure in exposing their challenges and assimilating the apprenticeship (Asante et al., 2010). Such initiatives and efforts are important for promoting gender equality and advancing sustainable agricultural practices in Rwanda.

Moreover, results showed an inverse relationship between farmers' age and knowledge of CSAF practices. This implies that CSAF practices constitute a novelty in modern farming: the younger generation is more likely to know these practices than the elders. These findings concur with O'Shea et al. (2018) who stressed that older farmers are considered more risk-averse and less likely to adopt new technology due to uncertainty about new technologies. Concurrently, Stanley et al. (2006) proved that younger farmers (below 30) are more likely to face constraints to adoption due to emerging family commitments, savings, and debts.

Also, significantly positive relationships were detected between civil status, education, household size, *ubudehe*, farm size, farmers' experience in CSAF, possession of radio, owning a mobile phone, livestock herd size, farm-river distance, training, and extension visits, and the attitude of farmers towards CSAF practices. Specifically, the strongest positive relationship was observed between owning a mobile phone and attitude. This trend can be attributed to the proliferation of mobile phone-based agro-advisory services (MPBAS) in recent years (Reddy et al., 2021). Communication technologies of mobile phones have become indispensable tools for populations (urban and rural), facilitating timely access to crucial farming information (weather forecasts, insect infestation). A series of studies (Samatha, 2011; Shankaraiah and Narayanaswamy, 2012; Jayanthi, 2016) have expounded farmers' favorable attitudes towards mobile phone ownership, underlining that mobile phones provide valuable insights and assist farmers in farming decision-making.

Conversely, a weakest positive relationship was found between the extension visits and farmers' attitudes towards CSAF. This denotes an effectiveness gap in the agricultural extension services provided by policy-making, often unavailable and limited in the study areas (Sebeho and Stevens, 2019). Similar sentiments were echoed in empirical study findings from other regions. For instance, Maake et al. (2022) found that farmers in the Gauteng region of South Africa perceived extension and advisory services as limited, inadequate, and ineffective, deterring agricultural transformation. Studies conducted in Kilindi District, Tanzania (Mcharo, 2013) and Kaduna State, Nigeria (Onwuka et al., 2017) reported similar inadequacies in public extension and advisory services. Properly organized and implemented extension services are crucial for agricultural transformation, catalyzing the improvement of farmers' knowledge, attitudes, and skills to increase, sustain, and diversify farm returns (Oladele, 2004).

Adesiji et al. (2013) found comparable results when they examined the relationship between female farmers and their perceived attitudes towards advisory services in Southwestern Nigeria. They found that, due to poor accessibility and lack of extension personnel and mass media, women primarily relied on their husbands, friends, and neighbors for information. From this logic of events, the importance of enhancing access to and effectiveness of extension services cannot be overemphasized, particularly for marginalized groups like women farmers, to foster sustainable agricultural practices.

Further, the results showed a significant positive relationship between the farmers' age and the motivational factors to adopt CSAF. Motivation can be understood as a motive that triggers people to act and behave in certain manners. Farmers who have agreed to adopt CSAF on their farms may be influenced by social factors (Dalmiyatun et al., 2017) such as gender, age, household size, education, farming experience, etc. Dalmiyatun et al. (2017) opined that farmers in the productive age bracket are likely to accept, adopt, and embrace science and technology. Leveraging multiple knowledge systems (local and scientific) to achieve higher farming results is in tune with intensifying awareness and motivation of farmers to adopt innovative farming practices.

In either case, these results concur with Meijer et al. (2015) findings that farmers' knowledge, attitude, and motivation are affected by socioeconomic factors such as age, gender, civil status, education, membership in farmer organizations, and environmental, institutional, and political factors.

5.8. *Effect of farmers' knowledge, attitude, and factors of motivation on CSAF adoption*

Farmers with good knowledge about CSAF practices ensured a higher probability of adoption capability (Zaca et al., 2023). This finding concurs with Tokede et al. (2020) and Ahmad et al. (2023) who affirmed that genuine knowledge of farmers predisposes them to make informed decisions for the uptake and adoption of CSAF practices. Also, Tokede et al. (2020) asserted that the adequate knowledge of farmers may influence the adoption of CSAF practices. Comparable results by Fischer and Vasseur (2002), Sood and Mitchell (2004), Zubair and Garforth (2006), Sileshi et al. (2008), McGinty et al. (2008) and Mekoya et al. (2008) also confirmed that increased farmers' knowledge propels the adoption of CSAF practices. The odds ratio for knowing CSAF showed that farmers who were knowledgeable about CSAF were 2.5 times more likely to adopt CSAF than farmers without knowledge of CSAF farming. Therefore, educating farmers about the benefits of integrating trees among crops, and environmental and economic benefits could increase tree cover with transformational impacts on farming systems (Zaca et al., 2023). Surveyed farmers who perceived CSAF practices as a sustainable profitable farming business were likely to adopt CSAF practices.

Similarly, the odds ratio for being motivated by CSAF benefits was 0.6 times more likely to adopt CSAF than unmotivated farmers for CSAF uptake. Dalmiyatun et al. (2017) found comparable results and reported that, in Java, rice farmers were motivated by the quality of harvests and anticipated high returns. Milne (2006) added that CSAF adoption offers significant opportunities for poor households in the tropics such as livelihood improvement through nutritional and economic security.

6. Conclusion

The study analyzed the relationship between knowledge, attitude, and motivation among farmers regarding climate-smart agroforestry (CSAF) adoption in two distinct climatic zones of Bugesera and Rulindo regions in Rwanda.

Findings indicate that most participating farmers possess adequate knowledge and positive attitudes towards CSAF adoption. They view it as a means to fulfill their essential needs such as fruits, fuelwood, fodder, shade, timber, and other forest resources while safeguarding the environment. Many farmers in the study areas have already adopted CSAF practices.

The study underscores the influence of demographic characteristics such as gender, civil status, education, household size, *ubudehe*, farm size, CSAF experience, possession of radio, owning a mobile phone, livestock herd size, farm-river distance, training, and extension visits on farmers' knowledge and attitudes towards CSAF adoption. Moreover, age emerged as a significant factor influencing farmers' motivation to adopt CSAF.

Results highlight that farmers with greater knowledge of CSAF practices are likely to adopt them, while those perceiving CSAF as profitable farming systems show higher adoption rates. Identified constraints in Bugesera include termite nuisance, water stress, poor tree adaptation, tree diseases, browsing animals, and soil compaction, all of which are climate-specific challenges.

The results of this study provide valuable insights for decision-makers, scientists, researchers, stakeholders, and rural planners. They are a foundation for informed decision-making and policy formulation to promote CSAF adoption and address region-specific challenges. Scientific communication, facilitated through farmer field schools and mobile communication technologies, is recommended for further adoption of CSAF. Additionally, capacity-building initiatives for farmers, led by extension services, should incorporate the findings of this study to ensure effective dissemination of knowledge on CSAF practices, thereby contributing to food security and poverty alleviation efforts.

Therefore, by filling the gap in understanding farmers' knowledge, attitudes, and motivations toward CSAF adoption, this study contributes to advancing sustainable agricultural practices in Rwanda and provides a blueprint for similar initiatives elsewhere. It underscores the importance of comprehensive adoption studies and informed policy interventions to drive positive agricultural transformation and improve farmers' livelihoods.

One limitation of this study is that the data are cross-sectional and might not correctly capture farmers' characteristics and decisions in response to their adoption of CSAF and variations in a cross-site comparative study. While important, knowledge, attitudes, and motivational factors have received less attention, possibly because they are more difficult to measure than quantitative variables such as farmer age and farm size. Future research should provide information on existing CSAF models and technologies in cross-climatic zones and their potential to procure more products, services, and income.

Ethical statements

This study was reviewed and approved by Professor Maulid W. Mwatawala, the Vice-Chancellor of Sokoine University of Agriculture on behalf of the Tanzania Commission of Science and Technology [approval number: SUA/ADM/R.1/8/851, dated 16th March 2022]. Informed consent was obtained from all participants in the study.

CRediT authorship contribution statement

Donatien Ntawuruhunga: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Edwin Estomii Ngowi:** Writing – review & editing, Visualization, Validation, Supervision, Data curation. **Halima Omari Mangi:** Writing – review & editing, Validation, Supervision, Data curation. **Raymond John Salanga:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Data curation. **Kenneth Lynch Leonard:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

Adesiji, G.B., Kehinde, F.B., Omotesho, K.F, 2013a. Women farmers' attitudes towards agricultural extension services in southwestern Nigeria. Nigerian Journal of Rural Extension and Development 7 (1), 23–28.

Adesiji, G.B., Kehinde, F.B., Omotesho, K.F., 2013b. Women farmers' attitudes towards agricultural extension services in southwestern Nigeria. Nigerian Journal of Rural Extension and Development 7 (1), 23–28.

Ahmad, S., Xu, H., Ekanayake, E., 2023. Socioeconomic determinants and perceptions of smallholder farmers towards agroforestry adoption in northern irrigated plain, Pakistan. Land 12, 813. https://doi.org/10.3390/land12040813.

Aker, J., 2011. Dial "a" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. Agricultural Economics 42 (6), 631–647. https://doi.org/10.1111/j.1574-0862.2011.00545.x.

Amare, D., Wondie, M., Mekuria, W., Darr, D., 2019. Agroforestry of smallholder farmers in Ethiopia: practices and Benefits. Small-scale Forestry 18 (1), 39–56. https://doi.org/10.1007/s11842-018-9405-6.

Asante, F.A., Banful, A.B., Cohen, M.J., Gaff, P., Gayathridevi, K.G., Horowitz, L., Lemma, M., Mogues, T., Palaniswamy, N., Paulos, Z., Raabe, K., Randriamamonjy, J., Sekher, M., Sun, Y., Tadesse, F., 2010. Gender and Governance in Agricultural extension services: insight from India, Ghana and Ethiopia. World Bank. https://doi.org/10.1596/978-0-8213-7658-4.

Awuor, F.J., Macharia, I.N., Mulwa, R.M., 2023. Adoption and intensity of integrated agriculture aquaculture among smallholder fish farmers in Kenya. Frontiers in Sustainable Food Systems 7, 1181502. https://doi.org/10.3389/fsufs.2023.1181502.

Banyal, R., Masoodi, N.A., Masoodi, T.H., Sharma, L.K., Gangoo, S.A., 2011. Knowledge and attitude of farmers towards agroforestry practices in North Kashmir- a case study. Indian Forester 137 (2), 377–1381.

Banyal, R., Mugloo, J.A., Mugal, A.H., Dutt, V., Zaffar, S.N., 2015. Perception of farmers' attitude and knowledge towards agroforestry sector in North Kashmir. Journal of Tree Sciences 34 (2), 35–41.

Bichier, P., Greenberg, R., Angón, A.C., 2000. The conservation value for birds of cacao plantations with diverse planted shade in Tabasco, Mexico. Animal conservation 3 (2), 105–112.

Bishaw, B., Neufeldt, H., Mowo, J., Abdelkadir, A., Muriuki, J., Dalle, G., Assefa, T., Guillozet, K., Kassa, H., Dawson, K., Luedeling, E., Mbow, C., 2013. Farmers ' Strategies for adapting to and mitigating climate variability and change through agroforestry in Ethiopia and Kenya. Oregon State University, OR, USA: Forestry Communications Group, Oregon State University, Corvallis.

Boon, T.E., Meilby, H., 2007. Describing management attitudes to guide forest policy implementation. Small-scale forestry 6 (1), 79–92.

Brown, C., Kovács, E., Herzon, I., Villamayor-Tomas, S., Albizua, A., Galanaki, A., Grammatikopoulou, I., McCracken, D., Olsson, J.A., Zinngrebe, Y., 2021. Simplistic understandings of farmer motivations could undermine the environmental potential of the common agricultural policy. Land Use Policy 101, 105136. https://doi.org/10.1016/j.landusepol.2020.105136.

Castle, S.E., Miller, D.C., Merten, N., Ordonez, P.J., Baylis, K., 2022. Evidence for the impacts of agroforestry on ecosystem services and human well-being in high-income countries: a systematic map. Environmental Evidence. https://doi.org/10.1186/s13750-022-00260-4.

Chavas, J.P., Nauges, C., 2020. Uncertainty, learning, and technology adoption in agriculture. Applied Economic Perspectives and Policy 42 (1), 42–53. https://doi.org/10.1002/aepp.13003.

Dalmiyatun, T., Eddy, B.T., Sumekar, W., Mardiningsih, D., 2017. Motivation of farmers to cultivate organic rice in central java. *International Symposium on Food and Agro-biodiversity (ISFA)*. In: IOP Conf. Series: Earth and Environmental Science, 102, 012043. https://doi.org/10.1088/1755-1315/102/1/012043.

Daloğlu, I., Nassauer, J.I., Riolo, R.L., Scavia, D., 2014. Development of a farmer typology of agricultural conservation behavior in the American Corn Belt. Agricultural Systems 129, 93–102.

Daoud, J., 2017. Multicollinearity and Regression Analysis. Journal of Physics 949, 012009. https://doi.org/10.1088/1742-6596/949/1/012009.

Desmiwati, D., Veriasa, T.O., Aminah, A., Safitri, A.D., Wisudayati, T.A., Hendarto, K.A., Royani, H., Dewi, K.H., Raharjo, S.N.I., Sari, D.R., 2021. Contribution of agroforestry systems to farmer income in state forest areas: a case study of Parungpanjang, Indonesia. Forest and Society 5, 109–119. https://doi.org/10.24259/fs.v5i1.11223.

Dessart, F.J., Barreiro-Hurlé, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. European Review of Agricultural Economics 46 (3), 417–471. https://doi.org/10.1093/erae/jbz019.

Dewi, S., van Noordwijk, M., Zulkarnain, M.T., Dwiputra, A., Hyman, G., Prabhu, R., Gitz, V., Nasi, R., 2017. Tropical forest-transition landscapes: a portfolio for studying people, tree crops and agro-ecological change in context. International journal of biodiversity science ecosystem services and management 13 (1), 312–329. https://doi.org/10.1080/21513732.2017.1360394.

Dolisca, F., Carter, D.R., McDaniel, J.M., Shannon, D.A., Jolly, C.M., 2006. Factors influencing farmers' participation in forestry management programs: a case study from Haiti. Forest Ecology and Management 236, 324–331.

FAO-Rwanda. (2020). Retrieved 11 21, 2024, from https://www.fao.org/rwanda/news/detail-events/ar/c/1270875/.

Fischer, A., Vasseur, L, 2002. Smallholder perceptions of agroforestry projects in Panama. Agroforestry Systems 54 (2), 103–113.

Franzel, S., Cooper, P., Denning, G.L., 2001. Scaling up the benefits of agroforestry research: lessons learned and research challenges. Development in Practice 11 (4), 524–534.

Garrity, D., 2012. Agroforestry and the future of global land use. In: Nair, P.G. (Ed.), Agroforestry - the future of Global Land Use. Springer Netherlands, Dordrecht, the Netherlands, pp. 21–27.

Habiyaremye, C., Ndayiramije, O., D'Alpoim Guedes, J., Murphy, K.M., 2022. Assessing the adaptability of Quinoa and Millet in two agroecological zones of Rwanda. Frontiers in Sustainable Food Systems 6. https://doi.org/10.3389/fsufs.2022.850280.

Harrison, S., Karim, S., Alauddin, M., Harrison, R., 2016. The contribution of agroforestry to economic development in Fiji and Vanuatu. In: Harrison, S.K. (Ed.), Promoting Sustainable Agriculture and Agroforestry to Replace Unproductive Land Use in Fiji and Vanuatu. Australian Centre for International Agricultural Research, Canberra, ACT, pp. 9–18.

Hosmer, D.W., Lemeshow, S., 2000. Applied logistic regression, 2nd Edition ed. John Wiley & Sons, Inc, New York, USA. Retrieved from. https://onlinelibrary.wiley.com/doi/book/10.1002/0471722146.

Jairo, M., Korir, E., 2019. Climate knowledge, adaptation and intensity of adaptation strategies among farmers in the slopes of Mount Kenya. Journal of Climatology and Weather Forecasting 7, 246.

Jasinski, E., Morton, D., DeFries, R., Shimabukuro, Y., Anderson, L., Hansen, M., 2005. Physical landscape correlates of the expansion of mechanized agriculture in mato grosso, Brazil. Earth Interactions 9 (16), 1–18. https://doi.org/10.1175/EI143.1.

Jayanthi, M., 2016. Ph.D. Thesis. CoimbatoreCentre for Agricultural and Rural Development Studies, Tamil Nadu Agricultural University.

Jemal, O., Callo-Concha, D., van Noordwijk, M., 2018. Local Agroforestry Practices for Food and Nutrition Security of Smallholder Farm Households in Southwestern Ethiopia. Sustainability 10, 2722.

Kabirigi, M., Sekabira, H., Sun, Z., Hermans, F., 2023. The use of mobile phones and the heterogeneity of banana farmers in Rwanda. Environment, Development and Sustainability 25, 5315–5335. https://doi.org/10.1007/s10668-022-02268-9.

Kallas, Z., Serra, T., Gil, J.M., 2010. Farmers' objectives as determinants of organic farming adoption: the case of Catalonian vineyard production. Agricultural Economics 1 (1), 69–95.

Karali, E., Brunner, B., Doherty, R., Hersperger, A.M., Rounsevell, M.D., 2013. The effect of farmer attitudes and objectives on the heterogeneity of farm attributes and management in Switzerland. Human Ecology 41 (6), 915–926.

Khanal, B., 2015. Correlation of climatic factors with cereal crops yield: a study from historical data of Morang district, Nepal. The Journal of Agriculture and Environment 16. https://doi.org/10.3126/aej.v16i0.19837.

Lee, T.M., Sodhi, N.S., Prawiradilaga, D.M., 2009. Determinants of local people's attitude toward conservation and the consequential effects on illegal resource harvesting in the protected areas of Sulawesi Indonesia. Environmental Conservation 36, 157–170.

Maake, M.M.S., Antwi, M.A., 2022. Farmer's perceptions of effectiveness of public agricultural extension services in South Africa: an exploratory analysis of associated factors. Agriculture and Food Security 11 (34). https://doi.org/10.1186/s40066-022-00372-7.

Marcus, R., 2001. Seeing the forest for the trees: integrated conservation and development projects and local perceptions of conservation in Madagascar. Human Ecology 29, 381–397.

Mathijs, E., 2003. Social capital and farmers' willingness to adopt countryside stewardship schemes. Outlook on agriculture 32 (1), 13–16.

McAdam, J.H., Burgess, P.J., Graves, A.R., Rigueiro-Rodríguez, A., Mosquera-Losada, M. R., 2009. Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A.M.-L. (Ed.), Agroforestry in Europe Current Status and Future Prospects. Springer Science + Business Media B.V, Dordrecht, pp. 21–41.

McDonald, J., 2014. Handbook of biological statistics, 3rd ed. Sparky House Publishing, Baltimore, Maryland, USA. Retrieved from McDONALD, J. H. Handbook of biological statistics.

McGinty, M., Swisher, M., Alavalapati, J., 2008. Agroforestry adoption and maintenance: self-efficacy, attitudes and socio-economic factors. Agroforestry Systems 73 (2), 99–108.

Mcharo, A., 2013. Perception of farmers on perceived effectiveness of agricultural extension agents in knowledge transfer to maize growers in Kilindi District. Master Dissertation. Sokoine University of Agriculture, Morogoro, Tanzania.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W., Nieuwenhuis, M., 2015a. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. International Journal of Agricultural Sustainability 13, 40–54.

Meijer, S.S., Catacutan, D., Sileshi, G.W., Nieuwenhuis, M., 2015b. Tree planting by smallholder farmers in Malawi: using the theory of planned behaviour to examine the relationship between attitudes and behaviour. Journal of Environmental Psychology 43, 1–12.

Mekoya, A., Oosting, S., Fernanez-Rivers, S., Van det, Zijpp, 2008. Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. Agroforestry Systems 73 (2), 141–153.

Mills, J., Gaskell, P., Ingram, J., Dwyer, J., Reed, M., Short, C., 2017. Engaging farmers in environmental management through a better understanding of behaviour. Agriculture and Human Values 34 (2), 283–299. https://doi.org/10.1007/s10460.

Milne, G., 2006. Unlocking opportunities for forest-dependent people in India, agriculture and rural development sector unit, south Asia region. The World Bank/Oxford University Press, New Delhi, India.

Morotti, S., Grandi, E., 2017. Logistic regression analysis of populations of electrophysiological models to assess proarrythmic risk. MethodsX 4, 25–34.

Muhamadi, S., Boz, I., 2021. Determinants of Rulindo tea farmers' perception towards organic farming: a MASS::stepAIC( ) approach. Ciência Rural 51 (6), e20200695.

Mukashema, A., Ngoga, T.G., Nyandwi, E., Kanobana, M., Sihimbiro, F., Coroner, S., 2022. Spatial Distribution of Agricultural Land, Soil Fertility and Crop Suitability For

Bugesera District. Technical report. Ministry of Agriculture and Animal Resources (MINAGRI - TECAN), Kigali, Rwanda.

Munthali, M.G., Mng'omba, S., Chisale, H., Njoloma, J., Nyoka, B.I., Sato, G., 2019. Farmers' knowledge, attitudes and perceptions towards timber out-grower schemes in selected districts of Malawi. Southern Forests. https://doi.org/10.2989/20702620.2019.1615236.

Ndayambaje, J.D., Heijman, W.J., Mohren, G., 2012. Households determinants of tree planting on farms in Rural Rwanda. Small-scale Forestry 11 (4), 477–508. https://doi.org/10.1007/s11842-012-9196-0.

Ndoli, A., Mukuralinda, A., Schut, A.G.T., Iiyama, M., Ndayambaje, J.D., Mowo, J., Giller, G., K, E., Baudron, F, 2021. On-farm trees are a safety net for the poorest households rather than a major contributor to food security in Rwanda. Food Security 13 (3), 685–699. https://doi.org/10.1007/s12571-020-01138-4.

Ndolimana, E., Nahayo, L., 2021. Mapping water distribution in grouped settlements of Rulindo district, northern province of Rwanda. International Journal of Advances in Engineering and Management 3 (8), 1612–1627. https://doi.org/10.35629/5252-030816121627.

Ndomba, O.A., Bakengesa, S., Petro, R., Maguzu, J., Chamshama, S.A.O., Kiimu, H.R., Lema, M., 2015. Perils of taungya to the productivity of forest plantations and need for modification: case study of meru forest plantation in Tanzania. International Journal of Agriculture and Forestry 5 (5), 267–275. https://doi.org/10.5923/j.ijaf.20150505.01.

Newaj, R., Dhyani, S.K., 2008. Agroforestry for carbon sequestration: scope and present status. Indian Journal of Agroforestry 10, 1–9.

NISR, 2010. National agricultural survey 2008 (NAS 2008). NISR, Kigali, Rwanda.

NISR, 2021. Agricultural household survey 2020. National Institute of Statistics of Rwanda, Kigali, Rwanda.

Norton, E.C., Dowd, B.E., Maciejewski, M.L., 2018. Odds Ratios-Current Best Practice and Use. Jama 320 (1), 84–85. https://doi.org/10.1001/jama.2018.6971.

Ntawuruhunga, D., Ngowi, E.E., Mangi, H.O., Salanga, R.J., Shikuku, K.M., 2023. Climate-smart agroforestry systems and practices: a systematic review of what works, what doesn't work, and why. Forest Policy and Economics 150, 102937. https://doi.org/10.1016/j.forpol.2023.102937.

O'Shea, R., O'Donoghue, C., Ryan, M., Breen, J., 2018. Understanding farmers: from adoption to attitudes. In: Paper prepared for presentation for the 166th EAAE Seminar: Sustainability in the Agri-Food Sector (August 30-31, 2018). National University of Ireland, Galway, Ireland.

Ohlmacher, G.C., Davis, J.C., 2003. Using multiple logistic regression and GIS technology to predict landslide hazard in northeast Kansas, USA. Engineering Geology 69 (3-4), 331–343. https://doi.org/10.1016/S0013-7952(03)00069-3.

Oladele, I., 2004. Effect of World Bank Loan withdrawal on the performance of agricultural extension in Nigeria. Nordic Journal of African Studies 13 (2), 141–145.

Onwuka, F.N., Otaokpukpu, J.N., Okonkwo, C.J., 2017. Effectiveness of extension services in enhancing the productivity, income and welfare of women farmers cooperatives in Kajuru local government area of Kaduna State. IIARD International Journal of Economics and Business Management 3 (8), 86–100.

Osawe, W., Curtis, J., 2024. An assessment of farmers' knowledge, attitudes and intentions towards water quality and pollution risk mitigation actions. Social Sciences & Humanities Open 9, 100858. https://doi.org/10.1016/j.ssaho.2024.100858.

Padhy, C., Jena, B.K., 2015. Effect of agricultural education on farmers efficiency: a review. International Journal of Engineering Technology, Management and Applied Sciences 3 (2), 247–258.

Patel, N., Sethi, T., Ravisankar, T., Sharma, S., Kumar, R., Pujar, G.S., Arulraj, M., Arunachalam, Handa, A.K., Suresh, R.S., Lesslie, A., Shaik, M., Das, S., Sreenivas, K., Bhanderi, R.J., Prabhu, R., Dhyani, S.K., Singh, R., Roy, P.S., Saigal, S., Kuma, 2024. Greening and restoration of wastelands with agroforestry. NITI Aayog, New Delhi, India.

Pike, T., 2008. Understanding behaviours in a farming context: bringing theoretical and applied evidence together from across DEFRA and highlighting policy relevance and implications for future research. Defra Agricultural Change and Environment Observatory Discussion Paper 1–29.

Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D., Baumgart-Getz, A., 2008. Determinants of agricultural best management practice adoption: evidence from the literature. Journal of Soil and Water Conservation 63 (5), 300–311.

Quisumbing, A.R., Meinzen-Dick, R., Raney, T.L., Croppenstedt, A., Behrman, J.A., Peterman, A., 2014. Gender in agriculture: closing the Knowledge Gap. Springer Netherlands. https://doi.org/10.1007/978-94-017-8616-4.

Rautiainen, R.H., Ledolter, J., Donham, K.J., Ohsfeldt, R.L., Zwerling, C., 2009. Risk factors for serious injury in Finnish agriculture. American journal of industrial medicine 52 (3), 419–428. https://doi.org/10.1002/ajim.20688.

Reddy, K.M.M., Rao, I.S., Srinivasulu, M., Kumar, G.D.S., Vidyasagar, G.E.C.H., 2021. Attitude of the farmers towards mobile phone-based agro-advisories in cotton cultivation. The Pharma Innovation Journal 10 (12), 1131–1133.

Republic of Rwanda, 2022. Environmental and social management framework for development of agroforestry and sustainable agriculture project under forestry investment programme (FIP) in Rwanda (ESMF). Ministry of Environment, Kigali, Rwanda.

Republic of Rwanda, 2023. Gross domestic product-2022. National Institute of Statistics of Rwanda, Kigali, Rwanda. https://doi.org/10.1787/factbook-2010-97-en.

Rosenstock, T.S., Wilkes, A., Jallo, C., Namoi, N., Bulusu, M., Suber, M., Mboi, D., Mulia, R., Simelton, E., Richards, M., Gurwick, N., Wollenberg, E.va., 2019. Making trees count: measurement and reporting of agroforestry in UNFCCC national communications of non-Annex I countries. Agriculture, Ecosystems and Environment 284, 106569.

Rwanyiziri, G., Rugema, J., 2013. Climate change effects on food security in Rwanda: case study of wetland rice production in Bugesera District. Rwanda Journal 1 (1), 35–51.

Sahin, I., 2006. Detailed review of Rogers' diffusion of innovations theory and educational technology-related studies based on Rogers' theory. TOJET: The Turkish Online Journal of Educational Technology 5 (2).

Samatha, J. (2011). *Extent of use of information and communication technologies (ICTs) in selected crops by the farmers of Guntur district in Andhra Pradesh. M.Sc. (Ag.) Thesis.* Hyderabad: Acharya N. G. Ranga Agricultural.

Schwarz, I., McRae-Williams, P., Park, D., 2009. Identifying and utilising a farmer typology for targeted practice change programs: a case study of changing water supply in the Wimmera Mallee. Extension Farming Systems Journal 5 (1), 33.

Sebeho, M.A., Stevens, J.B., 2019. An overview of perceptions and attitudes towards extension service delivery in Fezile Dabi District, Free State Province. South African Journal of Agricultural Extension 47 (1). https://doi.org/10.17159/2413-3221/2019/v47n1a490.

Shankaraiah, N., Narayanaswamy, B.K., 2012. Attitude of farmers and scientists towards dissemination of technologies through mobile message service (MMS). Tropical Agricultural Research 24 (1), 31–41.

Siebert, R., Toogood, M., Knierim, A., 2006. Factors affecting European farmers' participation in biodiversity policies. Sociologia Ruralis 46 (4), 318–340. https://doi.org/10.1111/j.1467-9523.2006.00420.x.

Sileshi, G.W., Mafongoya, P.L., Akinnifesi, F.K., Phiri, E., Chinwa, P.W., Beedy, T., Makumda, W., 2008. Farmers' perceptions of tree mortality, pests and pest management practices in agroforestry in Malawi, Mozambique and Zambia. Agroforestry Systems 72 (2), 87–101.

Sood, K.K., Mitchell, C.P., 2004. Do socio- psychological factors matter in agroforestry planning? Lessons from smallholder traditional agroforestry systems. Small-scale Forestry 3 (2), 239–255.

Sperandei, S., 2014. Understanding logistic regression analysis. Biochemia Medica 24 (1), 12–18.

Sprince, N.L., Zwerling, C., Lynch, C.F., Whitten, P.S., Thu, K., Logsden-Sackett, N., Burmeister, L.F., Sandler, D.P., Alavanja, M.C.R., 2003. Risk factors for agricultural injury: a case-control analysis of Iowa farmers in the agricultural health study. Journal of agricultural safety and health 9 (1), 5–18. https://doi.org/10.13031/2013.12346.

Stanley, J., Clouston, B., Baker, R. (2006). *Understanding land manager constraints to the adoption of changed practices or technological innovations: literature review. Working Paper 1: Impediments to the Uptake of Market Based Instruments*. Retrieved 11 21, 2024, from https://api.semanticscholar.org/CorpusID:199396296.

Sulemana, I., James, H.S., 2014. Farmer identity, ethical attitudes and environmental practices. Ecological Economics 98, 49–61.

Tega, M., Bojago, E., 2023. Farmer's perceptions of agroforestry practices, contributions to rural household farm income, and their determinants in sodo zuria district, southern Ethiopia. International Journal of Forestry Research 2023, 19. https://doi.org/10.1155/2023/5439171.

Tokede, A.M., Banjo, A.A, Ahmad, A.O, Fatoki, O.A, Akanni, O.F., 2020. Farmers ' knowledge and attitude towards the adoption of agroforestry practices in akinyele local government area, Ibadan, Nigeria. Journal of Applied Sciences and Evironmental Management 20 (10), 1775–1780.

UNDP, 2016. UNDP support to the implementation of sustainable development goal 13. United Nations Development Program (UNDP), New York, NY, USA.

Uppal, R., Pathania, M.S, 2008. Adoption of agroforestry in hills of Himachal Himalayas. A case study. In: National symposium on Agroforestry knowledge for sustainability, climate moderation and challenges ahead. NRCAF, Jhansi, India, p. 111 *(15-17 December, 2008)*.

Valbuena, D., Verburg, P.H., Bregt, A.K., 2008. A method to define a typology for agent-based analysis in regional land-use research. Agriculture, Ecosystems & Environment 128 (1), 27–36.

van Noordwijk, M. (2019). *Sustainable development through trees on farms: agroforestry in its fifth decade.* (M. van Noordwijk, Ed.) Bogor, Indonesia: World Agroforestry (ICRAF).

van Noordwijk, M., 2020. Agroforestry as nexus of sustainable development goals. In: The 3rd International Conference in Agroforestry (ICAF) "Adopting Modern Agroforestry Toward Smart Social Forestry Program, 449. IOP Conference Series: Earth and Environmental Science, Yogyakarta, Indonesia, 012001. https://doi.org/10.1088/1755-1315/449/1/012001. *16-17 October 2019*.

Van Noordwijk, M., Duguma, L.A., Dewi, S., Leimona, B., Catacutan, D.C., Lusiana, B., Öborn, I., Hairiah, K., Minang, P.A., 2018. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? Current Opinion in Environmental Sustainability 34, 33–42.

Weir, S., Knight, J., 2004. Externality effects of education: dynamics of the adoption and diffusion of an innovation in rural Ethiopia. Economic development and cultural change 53 (1), 93–113.

Wonnacott, T.H., Wonnacott, R.J., 1969. Introductory Statistics, 5. Edition. John Wiley & Sons Inc.

Young, A., 2002. Effects of trees on soils-spring 2002 special supplement on agroforestry. In: Summer Conference Planned for August 8-11, 2002. The Natural Farmer, Titusville, NJ, USA, pp. 1–5.

Zaca, F.N., Ngidi, M.S.C, Chipfupa, U., Ojo, T.O., Managa, L.R., 2023. Factors Influencing the uptake of agroforestry practices among rural households: empirical evidence from the KwaZulu-Natal province, South Africa. Forests 14, 2056. https://doi.org/10.3390/f14102056.

Zomer, R.J., Neufeldt, Henry, Xu, H., Ahrends, J., Bossio, A., Trabucco, D., Noordwijk, A., Wang, M.V., 2016. Global tree cover and biomass carbon on

agricultural land: the contribution of agroforestry to global and national carbon budgets. Scientific Reports 6 (29987), 1–12. https://doi.org/10.1038/srep29987.
Zossou, E., Arouna, A., Diagne, A., Agboh-noameshie, R.A., 2017. Gender gap in acquisition and practice of agricultural knowledge: case study of rice farming in West Africa. Experimental Agriculture 53 (4), 566–577. https://doi.org/10.1017/S0014479716000582.
Zubair, M., Garforth, C, 2006. Farm level tree planting in Pakistan: the role of farmers' perceptions and attitudes. Agroforestry Systems 66 (3), 217–229.