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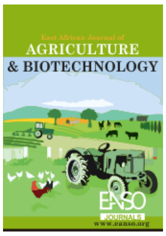

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Original Article

Smallholder Farmers' Management Practices and Perceived Constraints to Robusta Coffee Production in Mid-Altitude Zones of Central Uganda

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Climate-Smart Agricultural Practices, Production Constraints, Rainfall Thresholds, Rainfall Variability, Sustainable Robusta Coffee Production.

ABSTRACT

Despite its importance, Robusta coffee production in the mid-altitude zone of central Uganda is threatened by climate variability, especially erratic rainfall, which reduces coffee yield and increases the yield gap. Upscaling climate-smart management practices can narrow the yield gap. The study aimed to identify climate-smart management practices conducted by farmers in adapting Robusta coffee to climate variability and closing the yield gap, and to identify the major perceived constraints to Robusta coffee production under varying rainfall thresholds. Primary data from a cross-sectional survey on farmers' management practices and perceived constraints, collected from 150 randomly sampled coffee farm households, were analysed using descriptive and inferential statistics in Stata and R software. Results indicate more households are conducting mechanical weed control (100%), de-suckering (98%), pruning (74%), and shade management (51%). Though less than half of households conduct manuring (48%), herbicide (44%), fertiliser use (22%), water for irrigation (19%), pesticide use (13%), and soil erosion control measures (24%). A significant number ($p=0.0011$) of households still use indigenous local planting types, primarily in areas with low rainfall. Nevertheless, more households were using climate-smart practices at moderate than at high and low rainfall thresholds. The main perceived constraints across thresholds included drought and erratic rains, lack of access, and expensive inputs, pests, and diseases. Consequently, the study recommends policy interventions on expediting the provision of quality planting materials, greater access to modern and affordable forms of irrigation, judicious use of fertilisers, manure, pesticides, and developing guidelines for identification and control of Robusta coffee pests and diseases, and increased education to scale out climate-smart practices. These would sustainably increase Robusta coffee productivity, narrow the yield gap, and aid Uganda in achieving its target of 1.2 million tons and US$1.5B year-1 by 2030.

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INTRODUCTION

Globally, coffee (*Coffea spp.)* is a commercially significant crop, widely traded in over 50 countries. In Uganda, it is a strategic income-generating crop (National Planning Authority, 2020). For instance, in 2023/2024, 6.13 million bags of coffee were exported, earning US$1.44B (UCDA, 2024), while in 2024/2025, up to 7.77 million bags earned Uganda US$2.22B (MAAIF, 2025; UCDA, 2025). It is a major source of income for smallholder farmers. Both Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) are the main species grown (Melorose *et al.*, 2015; UCDA, 2019a). However, Uganda is the second largest global Robusta coffee producer, where the crop accounts for over 80% of the production and export volumes (UCDA, 2019a). Nonetheless, coffee production and productivity are low (UCDA, 2017), mainly due to climate variability and low use of climate-smart agricultural practices (APs) (Jassogne *et al.,* 2012). For instance, there is low fertiliser use at an average of 1kg ha^{-1} with only about 9% (25,616 ha) nationwide (Sunday & Ocen, 2015). Besides low fertiliser use, small-holder coffee farms use less external inputs, especially improved coffee lines, manure, mulches, herbicides, and pesticides (Ahmed *et al.,* 2013; Ronalds *et al.*, 2023).

Moreover, farmers lack the credit and incentives to optimally apply these external inputs (Nyombi *et al.*, 2006). In addition, the majority of coffee farms use fewer soil conservation measures to replenish the inherently poor soils, which leads to negative nutrient balances. Hence, the low yields achieved at the farm level, averaging 500 kg ha^{-1} (UCDA, 2016), compared to 3,500 kg ha^{-1} in Vietnam and Brazil (Haggar & Schepp, 2012), where the use of improved varieties, fertilisers, and water led to 100% and 30% yield increase, respectively (Sachs *et al.*, 2019). The low yields affect farmers' incomes and threaten their livelihoods. Nevertheless, Uganda has a great opportunity to increase coffee production amidst rainfall variability if management practices such as irrigation, fertiliser and pesticide use, replacing old trees with improved coffee lines, and increased tree care are adopted (Sachs *et al.*, 2019). Even with rainfall variability, adequate use of climate-smart APs will sustain Robusta coffee productivity and maintain incomes generated from the targeted 1.2 million tons (20 million bags), worth US$1.5B year^{-1}, and reduce the

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vicious circle of poverty that affects smallholder producers.

Research further indicates that over 90% of coffee farmers are smallholders with limited resources and susceptible to climate variability (Sachs e*t al.,* 2019). The majority depend on natural soil fertility and rain-fed agriculture, which creates several production constraints amidst erratic rains and increased drought scenarios. Coffee farmers use climate-smart agricultural practices depending on their knowledge, skills, access to technology, economic status, and investment capacity (Nyombi *et al.*, 2006). Yet, studies have associated the use of climate-smart agricultural practices with increased and stabilised coffee production and reduced pest and disease prevalence (Bhattarai *et al*., 2017; Cerda *et al*., 2017; 2015; Liebig *et al.*, 2016). There is therefore a need to explore farmers' climate-smart agricultural practices and perceived constraints to increasing the quantity and quality of Robusta coffee produced.

Over the past few decades, Uganda's increase in coffee production has been primarily attributed to the expansion of acreage rather than to an increase in productivity per unit area. Furthermore, several coffee studies focus on pests and diseases, yet farmer management practices play an important role in the management of biotic constraints, increasing coffee yields, and reducing yield gaps. In addition, the National Agricultural Research Organisation (NARO) has promoted several management practices aimed at doubling coffee yield to at least 1200kg $ha^{-1,}$ but the uptake by farmers is still low, as implied in the high yield gaps (Nakyagaba *et al.,* 2024). Besides, farmers' climate-smart management practices and perceived constraints are not well documented, especially in areas with high, moderate, and low rainfall variations in the mid-altitude zone of central Uganda. Therefore, information on the extent of use of climate-smart agricultural practices (APs) and perceived constraints by small farmers is vital to sustainably adapt coffee to rainfall variability and other major production constraints, thereby increasing yield.

The central region, the nucleus of Robusta coffee production, is already experiencing climate variability due to warmer temperatures (Nandozi *et al.*, 2012), which are associated with several constraints, especially yield decline. Biophysical constraints to yield were highlighted by Nakyagaba *et al.* (2024). This study aimed to identify climate-smart management practices conducted by smallholder farmers and their perceived constraints in adapting Robusta coffee production to rainfall variation in the mid-altitude zone of central Uganda. The study addressed the following questions: (i) What climate-smart practices do farmers use in adapting Robusta coffee production to rainfall variation? (ii) What are the main perceived constraints farmers face in the varying rainfall thresholds? (iii) To recommend climate-smart practices for sustainable Robusta coffee production amidst rainfall variability. The study hypothesised that the amount of rainfall received in an area influences farmers' management practices and the magnitude of perceived constraints in Robusta coffee production. Evidence was generated through a cross-sectional household survey conducted with 150 coffee farm households. The results provided primary information on the extent of agricultural practices used by small farm households and the main production constraints perceived. The results from the study are key for researchers, policy makers and development workers involved in development and generating useful knowledge and technologies, and dissemination of climate-smart agricultural practices for sustainable Robusta coffee production. The generated evidence-based strategies will increase the adoption of climate-smart practices amidst rainfall variability. It will also go a long way in sustainably achieving Uganda's target of 1.2 million metric tons (20 million bags) and US$1.5B $year^{-1}$.

MATERIALS AND METHODS

Description of the Study Area and Survey Sites

The household survey was conducted in Greater Luweero, one of the major Robusta coffee-growing regions, within three districts of

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Luweero, Nakaseke, and Nakasongola in the mid-altitude (1,008 and 1200 meters above sea level (masl)) zone of central Uganda (the Lake Victoria Crescent Agroecological Zone (LVCAZ)), an area of about 9,206 km^2. Rainfall thresholds in the study area were characterised using long-term WorldClim rainfall from www.worldclim.org (Fick & Hijmans, 2017) as indicated by Nakyagaba *et al.* (2024). Greater Luweero is at 31°E, 32°E, and 0.5°N, 1.3°N. The area is described as sub-humid tropical modified equatorial Savana with spatial rainfall between 700 to 1500 mm year^{-1} (Lwasa *et al.*, 2011; Köppen-Geiger, 2016; Nandozi *et al.*, 2012). The soils are considered old, low to medium fertility ferrasols under continuous cultivation, while thresholds were used as a proxy for climate variability.

Sampling Design and Data Collection

A descriptive household survey was carried out on the basis of a random sample of 150 coffee farmers from the neighbouring districts of Luweero, Nakaseke, and Nakasongola, central Uganda. The coffee farmers were randomly selected from a list of registered farmer groups under the Hans R. Neumann Stiftung (HRNS). A handheld Geographical Positioning System (GPS) was used to capture the geographical location (latitude and longitude) of each household surveyed (Fig. 1). The sample included approximately 50 small-scale coffee farm households from each rainfall threshold (Nakyagaba *et al.,* 2024) (Table 1).

Figure 1: Map Showing the Study Area and Sampled Households Georeferenced in Greater Luweero. The Dots in the Enlarged Area are Sampled Coffee Farm Households

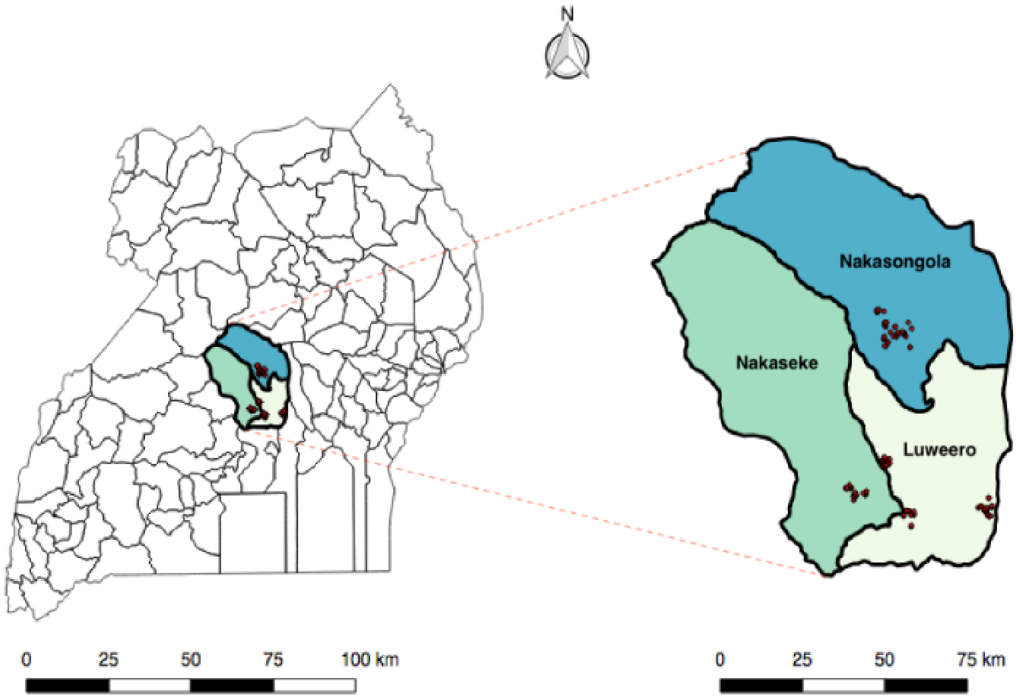

Table 1: **Number of Households Sampled for the Household Survey in Greater Luweero**

Rainfall threshold	District	Sub-county	No. of households
High	Luweero	Katikamu	25
High	Luweero	Luweero	25
Moderate	Luweero	Zirobwe	29
Moderate	Nakaseke	Nakaseke	26
Low	Nakasongola	Kakooge	45

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A detailed cross-sectional household survey research design was adopted using a pretested semi-structured questionnaire with closed and open-ended questions and face-to-face interviews to assess farmers' views. The questionnaire was pretested with selected households in Kawanda, Wakiso district, central Uganda, to improve its validity, reliability, and suitability. Farmers were requested to give their informed verbal consent before the interview. Appropriate confidentiality measures were followed. The information obtained was only used for this study. The questionnaire was individually administered to the heads of households or their spouses in a one-on-one conversation.

The study collected primary data on socioeconomic and demographic characteristics, climate-smart agricultural practices, and perceived constraints under varying rainfall. Data were specifically collected on: (i) household variables; socio-demographic characteristics of coffee farm households (gender/sex, farmer age, education level, marital status, land size, coffee plot acreage, number of coffee plots, number of years in coffee farming, age of coffee, and group membership); (ii) agricultural practices (mulching, pruning, coffee training, manure and fertilizer application, pesticides and herbicide use, de-suckering, stumping, irrigation, mechanical weeding, shade management, erosion control and types of coffee planting materials) in Robusta coffee production; (iii) farmer perceived constraints (iv) and the main perceived pests and disease constraints in areas with high, moderate and low rainfall thresholds. Open questions aimed to capture the views and perceptions, which were later coded for easy analysis.

Data Analysis

This study was exploratory, with both descriptive and inferential tests (parametric and nonparametric), which were appropriately applied in Stata and R software. The sociodemographic characteristics data were mainly quantitatively analysed using quantifiable methods. Frequencies, means, proportions/percentages, standard deviation, and standard errors were generated and summarised these descriptive statistics. The distribution of continuous variables was determined using the Wilks-Sapiro non-parametric method. Analysis of variance (ANOVA) and Fisher's test, and Kruskal-Wallis's tests were conducted to determine differences between means that were considered significant at a $p<0.05$ on normally distributed and non-normal data, respectively. The responses to open questions were classified on the basis of similarities in ideas. Qualitative categorical views and variables were subjected to univariate and bivariate statistical analysis. For the categorical nominal data, a Chi-square (χ^2) test of significance was used to compare the differences between categories. In addition, the logit model used the maximum likelihood method for binary dichotomous yes and no response data for farmer practices. Tables and figures summarised the findings based on valid responses.

RESULTS

Sociodemographic Information of Households

Analysis of the demographic and socioeconomic characteristics of smallholder households revealed significant differences ($p<0.05$). At least 50% of the respondents were under 51 years of age, with an average farmer age of 52.35 (SD 14.47) years, above the middle age (Table 2). However, respondents within the low rainfall threshold were significantly ($p=0.019$) younger than those within the high rainfall threshold. The number, size, and age of the coffee plots, and the number of years involved in coffee farming differed significantly ($p<0.05$) between the thresholds. The average size of the coffee plots considered was 0.64 ha (range 0.05 ha to 4.1 ha), which was significantly ($p=0.001$) different between the thresholds. The plot sizes were bigger in the moderate than low rainfall threshold. The age of the coffee plots also varied significantly ($p=0.043$) between thresholds, with an average of 20 years (range 3 - 65). In addition, the number of years in coffee production was significantly ($p<0.05$) higher at high than moderate and low thresholds. Most (90%, n=128) of the sampled farmers owned one to two coffee plots, but the

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majority (70%, n=100) of the respondents owned only one coffee plot. The moderate threshold had slightly larger and a higher number of coffee plots than the high and low thresholds. Generally, the low rainfall threshold had lower values for all demographic characteristics considered (Table 2).

Table 2: Sociodemographic Characteristics of Small-holder Coffee Farm Households (Continuous) in the Greater Luweero

Household characteristics	Overall mean	High	Moderate	Low	*p-value*
Age of respondents	52.35 (SD 14.47)	57.18[a]	51.0[a]	49.0[b]	0.019*
Coffee plot size (ha)	0.64 (range 0.05 - 4.1)	0.60[ab]	0.82[b]	0.46[ac]	0.001***
Coffee plot age (years)	20 (range 3 - 65)	23.67[a]	20.08[a]	16.02[ac]	0.043*
Years in coffee farming		27.67	26.09	18.63	0.013*
No. coffee plots		1.47	1.61	1.12	0.003**

******<0.001 **P<0.005 *P<0.05**

Means followed by the same letters in the rows indicate that there are no significant (p>0.05) differences (p> 0.05) (p> 0.05), while different letters in the row indicate significant (p<0.05) differences (p <0.05) (p <0.05).

Results further indicate that the majority of the respondents were male farmers, and the number varied significantly (*p*=0.001) between genders. Sixty-one percent (n=87) were male and 39% (n = 55) were female. Although most (61%, n=87) of the farmers had reached primary education, 33% (n=46) had secondary education; 4% (n=6) had no formal education, and only 2% (n=3) had reached tertiary education. Hence, the education levels of the respondents were generally low. Besides, education levels differed significantly (p=0.035) between categories. In addition, the majority (90%, n=128) of the respondents belonged to farmer groups/organisations (Table 3).

Table 3: Sociodemographic Characteristics of Small-holder Coffee-farm Households (category) in Greater Luweero

Variable	Category	Overall Freq.	Proportions per threshold			
			High	Moderate	Low	*p-value*
Sex of Respondent	Female (Women)	55	50	78	51	0001**
	Male (Men)	87	48	22	49	
Education level of farmers	Non-formal	6	6	4	2	0.035*
	Primary (1-7)	87	50	53	82	
	Secondary (8-13)	46	40	42	13	
	Tertiary/college	3	2	2	2	
Group m/ship		128	78	100	100	NS

NS = Not Significant **P<0.005 *P<0.05

Climate-Smart Agricultural Practices in the Production of Robusta Coffee in Greater Luweero

The results from interviewing farm households indicated that several agricultural practices are used in Robusta coffee production, with significant (p<0.05) variation between coffee farm households (Figure 2). Nevertheless, there was a low percentage of coffee farmers using vital climate-smart practices that increase soil fertility, improve yields, and reduce pests and diseases. For example, less than 50% of the households interviewed use manure (48%, n=68), inorganic fertilizer (21%, n=30), mulch (22%, n=31), erosion control (25%, n = 35), pesticide (13%, n=19), herbicides (44%, n=62) and stumping (20%, n=28) in coffee production. The majority (more than 50%) of farmers use simple basic agricultural practices (APs) like mechanical weeding (100%, n = 142), de-suckering (98%, n=139), and coffee pruning (74%, n=105). At least 50% of households manage their

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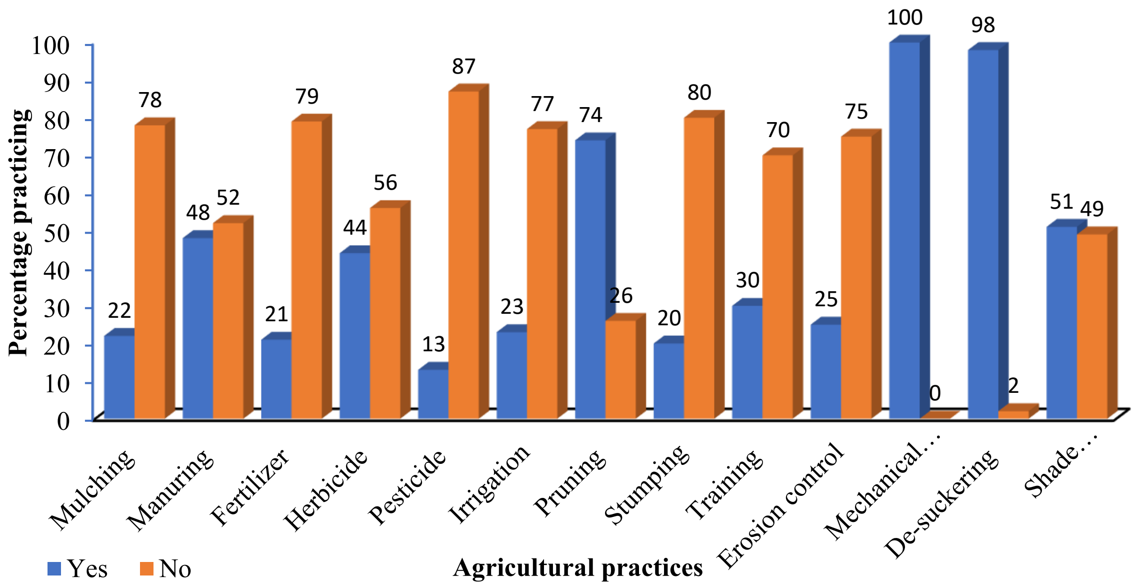
agroforestry shade. All (100) farmers do mechanical weeding using a slasher and or a hand hoe.

Figure 2: The Proportion of Farmers Using Specific Robusta Coffee Climate-smart Management Practices in Greater Luweero



There was a significant ($p<0.05$) difference between rainfall thresholds in the use of Climate-smart management practices. A higher proportion of vital climate-smart practices like pruning, manuring, erosion control, fertiliser, insecticides, and herbicide use was higher at moderate than high and low rainfall thresholds. However, the low rainfall threshold had more households using water for irrigation, stump removal, and de-suckering. On the other hand, the high rainfall thresholds had more farmers using mulching, staking, and managing agroforestry shade. The results also indicate that few farmers generally performed coffee pruning (24%), stumping (20%), irrigation (23%), and erosion control (25%). However, the erosion control measures were significantly ($p<0.05$) higher at the moderate than high and low rainfall thresholds, while shade management was significantly ($p<0.05$) higher at the high than moderate threshold. Although there was no significance ($p>0.05$) between the thresholds in the use of water, a slightly higher number of farmers at the low rainfall threshold were using water to irrigate their coffee (Table 4).

Further, the majority of coffee farmers in Greater Luweero use a mixture of both indigenous and improved coffee planting materials, but only 48% (n=68) use improved coffee planting materials. A significant ($p=0.001$) number of farmers (50%) use local/indigenous transplants, followed by the elite (33%), and a lower percentage (15%) use clonal coffee seedlings (Figure 3). Furthermore, no respondent within the low rainfall threshold was using clonal coffee cuttings. The majority of the respondents using clonal coffee seedlings were from a high, followed by moderate, and none from a low rainfall threshold. However, the types of planting materials did not vary significantly between thresholds.

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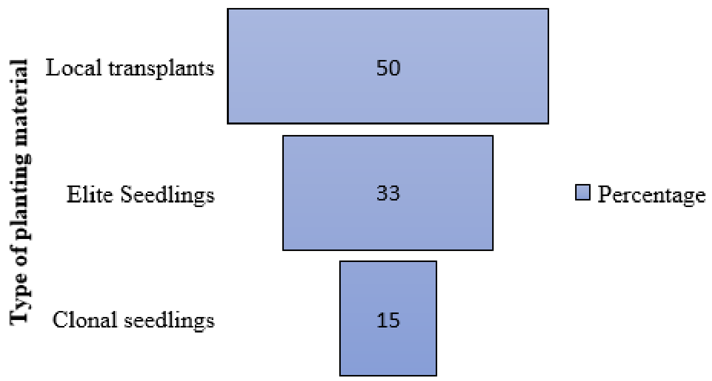
Table 4: Proportion of Households Conducting Selected Coffee Management Practices along a Rainfall Gradient in the Greater Luweero

Management practice	Proportion per threshold			*p* -Value
	High (n=50)	Moderate (n=55)	Low (n=45)	
Mulching	36	20	11	**0.010***
Manuring	38	45	17	**0.003****
Fertilizer usage	23	24	20	0.908
Herbicide application	41	60	27	**0.003****
Insecticide application	6	27	5	**0.001****
Water use/ irrigation	18	18	33	0.132
Coffee pruning	71	82	62	0.090
Coffee stumping	12	20	27	0.209
Coffee training	29	31	31	0.955
Coffee staking	76	62	29	**0.0001*****
Erosion control	29	31	11	**0.048***
Coffee weeding	100	100	100	
De-suckering	96	100	98	0.332
Shade tree management	65	24	29	**0.001****

***P<0.0005 **P<0.005 *P<0.05

Figure 3: Percentage of Farmers Using Specific Coffee Planting Materials in Greater Luweero



Description of the Main Perceived Constraints in Robusta Coffee Production

Respondents perceived several constraints to coffee production, but most of them were associated with weather, biophysical, and socioeconomic factors. Common constraints reported included drought and erratic rainfall, lack of access and capital to acquire inputs, fluctuating coffee prices, lack of and expensive labour to weed, make trenches, harvest and dry coffee, diseases, especially coffee wilt, low coffee yields, and pests such as BCTB. A higher proportion of respondents within the low rainfall threshold were constrained by drought and coffee wilt disease. Higher price fluctuations and labour shortages were reported in the high threshold. Whereas, a higher proportion of respondents in the moderate threshold indicated lack of access and expensive input as the main constraints (Table 5).

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Table 5: The Main Perceived Constraints in Robusta Coffee Production along a Rainfall Gradient in Greater Luweero

Limitation	Proportion (%) of respondents (n=142)		
	High	Moderate	Low
Drought and erratic rains	17	16	40
Lack of access and capital to acquire inputs	11	24	10
Low, poor, & fluctuating coffee prices	26	12	4
Labour shortage	21	12	1
Diseases (Coffee wilt)	2	6	20
Low coffee yields	4	7	7
Insect pests (BCTB)	6	5	4

The Main Perceived Coffee Pests and Diseases in Greater Luweero

The main coffee pest reported by farmers was BCTB, largely in high (69% (n=38)) and lowest (53%) within the low rainfall threshold. Only 24% (n=24) of the respondents indicated mealy bugs as a limitation within the moderate rainfall threshold. However, most farm households (91%) within the low rainfall threshold perceived coffee wilt as the main coffee disease (Table 6).

Table 6: The Main Perceived Pests and Diseases of Robusta Coffee along a Rainfall Gradient in Greater Luweero

Major pests and diseases	Proportion (%) Responses (n=142)		
	High	Moderate	Low
Black Coffee Twig Borer	69	60	53
Mealybugs	8	24	3
Other pests	23	16	43
Coffee wilt	70	74	91
Coffee blister	23	23	4
Root diseases	4	0	0
Other diseases	4	3	4

DISCUSSION

Based on the results of the study and the hypothesis, the rainfall gradient influenced the management practices conducted by coffee households and the magnitude of the constraints in Robusta coffee production. Vital yield enhancement climate-smart practices were practised by more households in moderate than in high and low rainfall thresholds. Generally, productivity-enhancing APs that increase coffee yields, narrow the yield gap, and adapt Robusta coffee to rainfall variability were practised by less than 50% of coffee farm households (Figure 2 and Table 4). Although the soils in the study area are generally of low fertility (Nakyagaba *et al*., 2024; Nyombi *et al*., 2006), fertiliser use was limited (Figure 2 and Table 4). This low fertiliser use may be directly related to the constraint of lack of access and expensive inputs, mainly in the moderate threshold (Table 5). Only about 21% of interviewed coffee farm households used fertilisers, less than 24% indicated by MAAIF (2010), but higher than 0.85% national fertiliser users in coffee production (Sunday & Ocen, 2015). Yet, good soil fertility management practices were developed and recommended to coffee farmers by NARO (MAAIF, 2010). Similarly, the fertiliser use for low and high rainfall thresholds was not significantly ($p<0.05$) different, but less than that recorded by MAAIF (2010). Largely, the low rainfall threshold had lower fertiliser users than the other thresholds. Besides, the number of coffee households using NPK fertiliser was attributed to the donation of fertiliser for demonstration coffee plots from Hans R. Neuman Shifting (HRNS), the partner organisation. Hence, a few coffee farm households indicated that they buy fertilisers for their coffee fields. Yet, the achievable coffee yield

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of 2000 kg ha^{-1} is associated with increased fertiliser use (Bekunda, 1999). Hence, need to adopt climate-smart practices like adequate fertiliser use for sustainable Robusta coffee production.

Equally, manure was used by less than 50% of the coffee farm households, with a significantly ($p<0.5$) higher number in the moderate than high and low rainfall thresholds, and much lower numbers in the low rainfall threshold. Yet, previous research indicated manures as a vital fertility amendment applied in coffee production, and associated with over 50% coffee yield increase (Bekunda, 1999; Kiyingi & Gwali, 2012). Manure and mineral fertiliser application are associated with several benefits, especially improved productivity, increased yields and adaptation to climate variability (Belay *et al.*, 2017; Mulinde *et al.*, 2019).

However, the low use of climate-smart practices like fertilisers and manure across the rainfall thresholds deters efforts to adapt Robusta coffee to rainfall variability and achieve the target of 1.2 million metric tons (20 million bags) and the predicted income of US$1.5B $year^{-1}$. Yet, research indicates soil parameters as the most Robusta yield-constraining factor in the varying rainfall thresholds (Nakyagaba *et al.,* 2024). Although less than a quarter of coffee farm households were using mulches, the high rainfall threshold had a significantly ($p<0.05$) higher number of farmers using mulch than those in the low rainfall threshold. The low level of mulching, especially in the low threshold, may be related to the high cost and scarcity of materials, and the termite effect (Asten *et al.*, 2012). Besides, the coffee wilt disease emergence affected the recycling of potassium-rich coffee husks, which were traditionally used in the mulching of Robusta coffee fields. There is therefore a need for judicious use of fertilisers, manures, and mulches if coffee yields are to increase and the targets are to be sustainably achieved.

The results also reflect a low use of pesticides and agrochemicals, with only 13% of households using pesticides as compared to 21% indicated by the national survey (UBOS, 2020). Similarly, there was significantly ($p<0.05$) higher agrochemicals (herbicides and pesticides) use at the moderate than high and low rainfall thresholds. The low use of agrochemicals in high and low thresholds may be due to constraints indicated in Table 5 and other financial limitations. Yet, the judicious use of agrochemicals in weeds, pests, and disease management under climate variability was indicated (Mulinde *et al.*, 2019; Munyuli *et al.*, 2017; Verhagen *et al.*, 2013). Agrochemicals improve the quality and quantity of coffee and can narrow the yield gap indicated by Nakyagaba *et al.* (2024). Hence, they are essential climate-smart practices in adapting Robusta coffee production to rainfall variability and related constraints.

Results indicate that over 60% of households pruned their coffee. Besides, more households pruned their coffee within the moderate than the low rainfall threshold. Coffee pruning would be important in the study area, where the average age of coffee fields is 20 years (Table 2). Although previous research indicates that coffee pruning and stumping are the basis for yield improvement in old coffee gardens (Asten *et al.*, 2012; Avelino *et al.*, 2004; Avelino *et al.*, 2012; Coats & Gelfman, 2019; Sachs *et al.,* 2019; Verhagen *et al.*, 2013), there were no significant ($p>0.05$) differences between households under rainfall thresholds. However, improper coffee pruning can cause biennial growth, reduce yield, cause death, and lead to unhealthy coffee trees (Constantinides & Mchugh, 2004).

Additionally, the low water use observed in the study area may be due to the inaccessibility of the water points during the dry period for both domestic and agricultural use. Nevertheless, the observed overall percentage (23%) was higher than the 0.9% national estimate, the 17.5% estimate for central Uganda, and 2% indicated by MAAIF (2010). The low irrigation levels imply that coffee is always affected by moisture stress and drought during the dry season. For example, there may be increased flower abortion, reduced coffee yield, quality, and increased coffee pest prevalence (Constantinides & Mchugh, 2004;

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Verhagen *et al.*, 2013). Drought reduces coffee production and affects the country's export volumes (UCDA, 2017). For example, a recommendation to increase irrigated area from 15,000 ha to 400,000 ha by 2040 was made by the World Bank (2015). Furthermore, inadequate erosion control measures, especially at a low rainfall threshold, can lead to low soil moisture and nutrients (Van Der Vossen, 2005). Therefore, it is necessary to promote affordable and accessible irrigation technologies and/ or infrastructure, as well as robust erosion control strategies that can manage erratic rainfall and adapt coffee to climate variability.

Furthermore, our study revealed limited use of improved planting materials (Figure 3), especially in low rainfall thresholds. Although several improved coffee lines have been developed by the National Coffee Research Institute, NaCORI (UCDA, 2019b), they are not widely used in the study area. Old-fashioned plant types (locally taken from the wild or growing coffee bushes) that farm households commonly use in the low rainfall threshold have a low genetic production potential and are susceptible to common pests and diseases, especially coffee wilt disease (ICO, 2015). Though our results are not different from the 23% improved seed use observed at the national level (UBOS, 2020). The low use could be associated with the constraint of high coffee wilt indicated in the low rainfall threshold (Table 6). The poor coffee genotypes create challenges in increasing yields in the observed small coffee plots (Table 2). Nonetheless, the use of improved, drought-tolerant and high-yielding coffee varieties adapted to climate change and resistant to associated pests and diseases is important in the sustainable climate-smart production of quality coffee (Alemu & Dufera, 2017). Quality planting materials are also a sure way to mitigate climate variability (UCDA, 2019b) and a guarantee to increase coffee yields despite weather uncertainties. Greater gains and long-term benefits are expected in reducing the impact of climate variability if early maturing, high-yield, drought-tolerant, and disease-resistant coffee lines are combined with climate-smart agricultural practices (Belay *et al.,* 2017; Groenen, 2018; ICO, 2015). Some farmers in the low rainfall area tend to prefer elite planting materials because they say these types have a long tap root and tend to resist drought than the clonal counterparts, and when they survive coffee wilt disease, they tend to stay longer in the garden before stumping. Nevertheless, improved planting materials will go a long way to reduce the impact of rainfall variability experienced by small-scale farmers and sustainably adapt coffee to climate-related constraints.

On the other hand, drought and unpredictable rainfall were the main constraints perceived by households in this study (Table 5), especially at the low rainfall threshold. Although the use of climate-smart practices would be the best option to overcome the associated negative effects from drought, this may be influenced by other observed constraints (Table 5), especially in high rainfall threshold areas, where the average age of farmers is higher (57.18 years) (Table 2). The lack of labour may have affected the use of climate-smart practices like manure and soil erosion control measures, which require more energy. The constraint of poor market access may also affect the level of use of improved practices due to the increase in marketing risks (Mwololo &Ajambo, 2019). Fluctuating coffee prices are a major constraint in coffee production and marketing (Diro *et al.,* 2019). Besides, low access to agricultural credit was a constraint to households, mainly in the moderate rainfall threshold (Table 5), which had a slightly higher number of households using climate-smart practices like mineral fertilisers, manure, herbicides, insecticides, and other inputs (Table 4). This lack of access to inputs may cause small farmers to resort to poor agricultural practices (Keating *et al.*, 2010). Low fertiliser use aggravates soil fertility decline, which could be the reason for low coffee productivity that affects the country's target of 20 million bags per year (Nakyagaba *et al.,* 2024). To sustainably increase and maintain coffee productivity per unit area amidst increasing population pressure on land and climate variability, external inputs are essential.

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However, the direct cost associated with these inputs, especially the cash, may have resulted in lower doses than recommended, as small farmer practices depend on available cash income (ICO, 2015).

Still, 62% of the households indicated BCTB as the main destructive pest of Robusta coffee in the study area, especially at high and low and moderate rainfall thresholds. Similar studies conducted in 2013 in the study area indicated more than 75% of BCTB incident rates and more than 5% of damage rates in greater Luweero (Kagezi *et al.*, 2013). Robusta coffee losses associated with BCTB at the national and export level were estimated at 8.6% in 2014 (Kagezi *et al.,* 2014). Likewise, 20% of the losses in Robusta coffee production in central Uganda were attributed to temperature-mediated increase in BCTB (Wang *et al.*, 2015). In 2017, Bukomeko *et al.* (2018) observed a 98% BCTB infestation in areas with high rainfall. Additionally, Nakyagaba *et al.* (2024) indicated high BCTB rates in high rainfall thresholds. Hence, the results for BCTB incidence are similar to those indicated by previous researchers. The BCTB pest, therefore, remains a major constraint to Robusta coffee production that needs to be managed to maintain productivity.

Generally, previous research has associated poor agricultural practices with increased BCTB pest prevalence (Kucel *et al*., 2014). Similarly, the results obtained may be associated with a low use of climate-smart practices at high and low rainfall thresholds. Research indicates that BCTB pests can be effectively managed using APs, such as coffee de-suckering, pruning, conservation of soil moisture, destruction of infested materials, and adequate fertilisation of the coffee crop (Constantinides & Mchugh, 2004). Therefore, farmers need to intensively practice these climate-smart practices as a way to reduce the BCTB pest and its effects on coffee productivity and yield. Nonetheless, households did not mention other coffee pests, such as coffee berry borer (CBB) and coffee diseases like coffee leaf rust, which are common in the study area (Nakyagaba *et al.,* 2024). This could be attributed to the inadequate information and limited knowledge of farmers to effectively identify, differentiate, and diagnose such constraints (Ahmed *et al.,* 2013; Liebig *et al.,* 2016). Additionally, farmers may not immediately understand the visual impact of CBB and coffee leaf rust disease on coffee yield and quality. Therefore, it is necessary to disseminate and equip coffee farmers with information on the identification and control of pests and diseases in Robusta coffee amidst climate variability and the drive for sustainably.

CONCLUSIONS AND RECOMMENDATIONS

This study aimed to identify farmers' management practices and perceived constraints to Robusta coffee production in high, moderate and low rainfall thresholds and recommend sustainable climate-smart practices in the mid-altitude zone of central Uganda. Although the Robusta coffee farmers in the mid-altitude zone of central Uganda are living a climate change reality, especially with rainfall variability, a few (less than 50%) Robusta coffee farm households carry out climate-smart agronomic practices. Most farmers are yet to use the recommended yield-enhancing climate-smart practices, such as fertilisers, irrigation, manure, mulching, herbicides and pesticides, pruning, improved clonal lines and stumping, which are vital to sustainable coffee production under the varying climate. The low number of farm households that carry out climate-smart practices at the low rainfall threshold deters efforts to increase coffee yields, close the yield gap, and sustainably achieve the 1.2 million tons (20 million 60 kg bags) and US$1.5B year^{-1}. Besides drought and unpredictable rains, the most significant socio-economic constraints include lack of access and expensive inputs, poor markets, pests, and diseases, which were the main perceived constraints to sustainable Robusta coffee production by farm households. The results from the study highlight the common management practices conducted by households that help in developing strategies and understanding how efforts geared toward creating awareness of the use of climate-smart agricultural practices in coffee production can sustainably

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improve productivity, yield, and narrow the coffee yield gap amid climate variability.

Therefore, based on the results, there is a need for strategic policies to invest and scale out climate-smart agricultural practices that improve productivity and resilience to climate variability and sustainably increase coffee production to uptake pathways. It pays to increase the number of farmers using resilient, quality, climate-smart planting materials by expediting their provision to replace the local/Nganda susceptible and low-yielding lines, which are common in the low rainfall threshold. There is also a need to spread information on coffee pests and disease identification, as well as control, with an emphasis on an integrated pest and disease management strategy.

Sensitisation, promotion, and judicious use of less costly and appropriate integrated climate-smart agricultural practices and external inputs, such as optimal water and affordable irrigation at critical growth stages, use of manure and fertiliser, and shade management, are recommended. Increasing access to financial services and subsidies on critical nutrient sources can significantly increase the use of improved technologies. The smallholder farmers' management practices and perceived constraints can go a long way in aligning the nation's coffee research policy to resilient production systems if Robusta coffee yield gaps on these smallholder coffee farms are to be narrowed and sustainably achieve the annual target of 1.2 million tons and US$1.5B year^{-1}.

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