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Analysis of socioeconomic characteristics on coffee yield gap among smallholder farmers in Nyeri Central sub-county, Kenya

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Abstract

Kenya's coffee production has been declining over the years leading to decreased yields and making it hard for farmers to benefit from the sector. This has resulted in a considerable yield difference, with actual farmer yields far below the potential yields of station trials. This large yield gap reveals an enormous potential for yield improvement in coffee production. However, the large yield gap may be attributed to several factors, yet there is limited quantitative information on site-specific factors and the yield gap attributed to the factors. This study informs the knowledge gap by analysing the effect of socioeconomic characteristics on the coffee yield gap of smallholder farmers in Nyeri Central sub-county, Nyeri County. A cross-sectional research design was used, and a sample of 175 smallholder coffee farmers was drawn using the systematic random sampling technique. Data on socioeconomic characteristics was analysed using SPSS version 29, and their effect on the coffee yield gap was determined using a fractional logit regression model in STATA version 17. The findings noted that the yield gap index per variety was 88.54% for Ruiru 11, 93.78% for Batian, and 95.68% for SL 28. The model parameters indicated that the gender of the household head, schooling years, household size, and labour were negative but significant at $p<0.05$. This study concluded that smallholder coffee farmers were producing below their potential, as depicted by the large yield gap estimate. Therefore, feasible actions are required to close the existing yield gap, increase coffee yields, and enhance household food security.

Keywords: Smallholder coffee farmers; Socioeconomic characteristics; Yield gap; Potential yields; Actual farmer yields

1. Introduction

Coffee is grown in over 70 countries worldwide, with Brazil being the largest exporter, accounting for 38.12 million 60 kg bags of arabica coffee in 2021/22 [1]. Coffee, being a global commodity, provides many developing countries with foreign currency as they produce over 90% of the world's coffee production [2]. In Africa, coffee production accounts for an average of 30% of all the export profits of producing countries, with smallholder farmers generating 95% of the coffee [3,4]. Despite its economic importance, coffee yields in Africa are unstable, with annual production dropping by 0.1% on average while global yield increases by 1.3% [5]. As a result, the yield gap has increased at a rate of 3.8% per year on average, with the present realized yield being six times lower than the prospective yield [6].

Coffee is one of Kenya's most important agricultural exports, accounting for up to 0.4 % of world coffee production in 2019 [7]. However, the situation has changed considerably since the height of coffee output in 1988. Coffee production in the crop year 2021/2022 was 51.9 thousand metric tons, an increase from an approximated 34.5 thousand metric tons in the crop year 2020/2021 [8]. However, farm-level production remains below its potential of more than 30 kg per tree [9], which can be associated with different aspects, including a drop in global coffee prices, outdated farming

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practices, poor cooperative operation, the impact of coffee value chain features, climate change, delays between coffee cherry delivery and payment of small-scale growers, and conversion of coffee farms to more profitable enterprises and real estate projects, among others [10].

The fall in coffee yields has affected production, resulting in a wide yield gap that has severe consequences on smallholder farmers' livelihoods [11]. Actual coffee yields continue to lag behind farm trial and station trial yields, resulting in a large gap between smallholder farmers' potential productivity and the actual productivity achieved in different agro-ecological zones [12]. However, the large yield gap indicates significant difficulties faced by smallholder coffee farmers. It also reveals the great potential for yield improvement in Kenya's coffee production and the necessity to close the gap for the purpose of maintaining growth in average farmer yields. Hence, to sustain farmers' average yields and minimize the existing yield gap, a significant difference between farm-level yields and potential yields is necessary [13].

A household's socioeconomic characteristics determine its ability to practice high agricultural production [15]. Adequate information on farmers' socioeconomic characteristics may aid in estimating smallholder farmers' ability to produce optimal yields from the utilization of a set of inputs [16]. However, the majority of agronomic yield gap estimations focus on environmental and farm management aspects, while farmer traits and socioeconomic characteristics are rarely considered [17]. Despite the numerous studies conducted at the global, continental, and regional levels, the outcomes are broad, making it difficult for smallholder farmers to develop farm-level strategies that are suitable and attainable in an effort to minimize their yield gaps [18]. Furthermore, there exists insufficient information on coffee yield gaps based on direct farm management activities. As a result, understanding the socioeconomic characteristics influencing smallholder coffee farmers' yield gap is critical in efforts to narrow the existing yield gap.

2. Material and methods

This study was carried out in Nyeri Central sub-county, Nyeri County. Nyeri County lies between longitudes 36° 38' east and 37° 20' east and between the Equator 0° and latitude 0° 38' south at an altitude of 3,076 m–5,199 m above sea level. The County experiences long rains that run from March to May (1200-1600 mm) and short rains experienced in October to December (500-1500 mm). The County is endowed with lightly acidic soils and temperatures between 12.8 °C to 20.8 °C [19]. Nyeri County is the second-producing County in Kenya and, hence, is considered a suitable area for this study. Nyeri Central sub-county was selected due to the identification of challenges faced by farmers, such as majority of farmers turning away from coffee production to other agricultural activities, which lowered the coffee output of the sub-county.

The study employed a cross-sectional research design and through the systematic random sampling technique, a sample of 175 smallholder coffee farmers was drawn. A semi-structured questionnaire was used for the study with its validity determined by the academic supervisors and the experts in the coffee sector. The reliability of the research instrument was also determined using the split half method. Primary data on coffee farmers' socioeconomic characteristics was collected and analyzed. Two approaches were used in data analysis: descriptive statistics and a fractional logit regression model performed using STATA and SPSS.

2.1. Estimation of Coffee Yield Gap

During the determination of coffee yield gap, the difference between the experimental yields obtained at Kenya Agriculture Livestock Research Organisation (KALRO)- Coffee Research Institute (CRI) and actual yields realized by farmers mainly attributed to agronomic practices was computed. The results of the station trials conducted at KARLO-CRI were employed as a reference standard so as to obtain a broad measure of possible yields. The difference between the benchmark and the average farmer yields offered relevant insights into the possibility of increasing production [20]. The degree of yield gap was inversely related to the yield potential which was the reference point. The yield gap was estimated as follows:

$$\text{Yield Gap (Yg)} = \text{Potential research yield}(P_{(ry)}) - \text{Average farmer yields}(A_{(fy)}) \quad (1)$$

The yield gap was also expressed as the yield gap index using equation 2 below:

$$I_{(yg)} = \left[\frac{P_{(ry)} - A_{(fy)}}{P_{(ry)}} \times 100\%\right] \quad (2)$$

where;

- $I_{(yg)}$- Yield gap index.
- $P_{(ry)}$- Potential research yields
- $A_{(fy)}$- Actual farmers' yields

2.2. *Econometric Model Specification*

A fractional logit regression was performed to determine the effect of socioeconomic characteristics on the coffee yield gap. The fractional logit regression is a generalized method for fractional outcome variables. It was used due to the limited value of the coffee yield gap index, which ranged between 0 and 1. Anteneh and Endalew [21] and Gallani *et al*. [22] reported that any response variable informing of an index, ratio, rates, or quotas is best explained using the fractional outcome regression models. The model has also been used in various studies to examine the relationship between a fractional outcome and exogenous variables [21]. The regression model takes the form shown in equation (3) as generated by Papke and Wooldridge [23].

$$E(y_i/x_i) = g(x_i\beta) \quad (3)$$

where;

- y_i- Dependent variable (coffee yield gap index).
- X_i- Explanatory variables of observation *i*.
- β- Regression coefficient.
- $g(.)$- Distribution function.
- $0 \leq y_i \leq 1$- Denotes the range of the dependent variable.

To estimate the model parameters, the fractional regression model log-likelihood was maximized using the form:

$$\ln L(\beta) = \sum_{i=1}^{N} w_i y_i \ln[g(x_i\beta)] + w_i(1 - y_i)\ln[1 - g(x_i\beta)] \quad (4)$$

where;

- y_i- Dependent variable (coffee yield gap index).
- N- Sample size.
- x_i- Explanatory variables of observation *i*.
- w_i- Optional weight.

The function g(.) is a logit distribution expressed as:

$$g(x_i\beta) = \frac{e^{x_i\beta}}{1+e^{x_i\beta}} \quad (5)$$

The result of the empirical specification of the fractional regression model is:

$$E(y_i/x_i) = g(u_i) = \beta_0 + \sum_{k=1}^{N} \beta_k x_{ik} + e_i \quad (6)$$

where;

- $E(.)$- Denotes the variance operator.
- Y_i- Dependent variable.
- X_i- Explanatory variables of observation *i.*
- N- Sample size.
- U_i- Represents variables included in the equation
- β_k - The unknown parameter to be computed.
- X_{ik} - The independent variables.
- e_i- Represents the error term.

Thereafter, a post-estimation analysis for the tests of the marginal effects was performed so as to determine the level of change caused by the independent variables on the dependent variable. The rationale for considering the identified

factors was based on the previous yield gap and coffee production literature. The expected positive or negative sign of the model coefficients signified the change of the explanatory variable on the explained variable.

3. Results and discussion

3.1. Descriptive Statistics of Smallholder Coffee Farmers Socioeconomic Characteristics

This study determined the descriptives of socioeconomic characteristics among the smallholder coffee farmers in Nyeri Central sub-county, Nyeri County (Table 1). The study findings detailed that the mean age of smallholder coffee farmers was 60.19 years, which implied that the smallholder coffee farming cluster was skewed towards the aged, who were likely to be inefficient and less healthy. This may have lowered their production, considering the labor-intensive coffee activities. Further, the high elderly involvement in coffee farming was most likely due to access to and control of household resources, including land, capital, equipment, and collateral to obtain loans. Also, it can be attributed to the rural-urban migration of young people and the engagement of youths in competing enterprises such as horticulture, dairy, business activities, and formal employment.

Table 1 Summary of Socioeconomic Characteristics among Smallholder Coffee Farmers

Variable	Mean	Std. Dev.	Min	Max
Age (years)	60.192	13.039	31	80
Schooling years	12.801	4.421	0	20
Household size	4	1.659	2	10
Income from coffee	37063.820	22381.300	10000	92000
Size of land owned (ha)	0.779	0.486	0.202	2.226
Land under coffee (ha)	0.260	0.150	0.130	0.809
Years of farming experience	26.071	14.042	7	60
Casual labour	4	2.359	0	12
Family Labour	3	1.829	0	9
Permanent Labour	1	0.393	0	2

NOTE: Std. Dev. = Standard Deviation, Min= Minimum, Max= Maximum

The level of education was determined in terms of schooling years, which revealed an average of 13 years, which translated to the attainment of a secondary level of education among the smallholder coffee farmers. This revealed that the smallholder farmers were able to profitably run their coffee farming enterprise as they received some formal education. This may be due to their ability to assimilate information and influence decisions in terms of income investment, management practices, land use, and input use. Also, an average of 4 members lived in each household, which most probably influenced coffee production levels through the approximation of available family labor supply for coffee activities. However, during the study, it was observed that not all the available family labor was used in coffee production, most likely due to involvement in other major activities such as food crop production, dairy farming, and business engagements.

The income from coffee farming was approximated to be Kes 37,063.820 per acre, which was found to affect farmers' investment in good agricultural practices that would improve the quality and quantity produced. In addition, the mean land size was 0.779 ha, which reveals a direct relationship between land owned and the land under coffee as farmers allocated smaller proportions of land to coffee due to small land sizes owned. Also, land fit for agricultural production was limited, which most probably was due to land fragmentation, resulting in uneconomical lands for coffee production.

The average smallholder farmers' farming experience was 26 years, which implies that the farmers had a lot of experience and most probably had better decision-making, reduced production losses, and better management of inputs. The labour distribution suggested that most coffee operations are carried out by casual labourers, which is attributed to the seasonal nature of coffee agronomic activities such as pruning, weeding, spraying against pests and diseases and application of organic and inorganic fertilisers.

3.2. Preferred Coffee Varieties among the Smallholder Coffee Farmers

Nyeri County was found to grow different varieties of coffee (table 2); however, the high preference for the SL 28 variety in the Nyeri Central sub-county was probably due to its excellent quality and heavy cherry, as reported by the majority of the farmers. In spite of this, it was observed that some farmers were improving their traditional varieties (SL 28) through grafting with the improved varieties, especially using Ruiru 11. This was due to the reduced costs of management and increased yields, as Ruiru 11 was reported to be high-yielding and disease-resistant.

Table 2 Coffee Varieties Grown by Smallholder Coffee Farmers

Variety	Frequency	Percent
SL 28	125	80.13
Ruiru 11	14	8.97
Combination of Ruiru 11 and SL 28	8	5.13
Batian	3	1.92
Combination of SL 28, Batian and Ruiru 11	3	1.92
Combination of Batian and SL 28	2	1.28
Combination of Ruiru 11 and Batian	1	0.64
Total	156	100

3.3. Yield Gap Estimation among Smallholder Farmers

The yield gap experienced by the smallholder coffee farmers was estimated by comparing actual yields obtained by the farmers with yield data from Kenya Agriculture Livestock Research Organisation (KALRO)- Coffee Research Institute (CRI). The research data from KARLO-CRI showed that arabica coffee varieties grown in Kenya (SL 28, Batian, and Ruiru 11) had a potential yield of up to 30 kilograms per tree. The average number of trees recommended per hectare for SL 28, K7, and SL 34 (traditional varieties) is 1,330, 2,500 for Ruiru 11, and 1,900 for Batian (improved varieties) [KARLO, 2019]. The average farmer yield for the three years was used as a reference for farmers' attainable Yield.

The study findings (table 3) revealed a large yield gap where farmers with traditional coffee varieties (SL28) had a wider yield gap compared to those farmers with improved varieties (Ruiru 11 and Batian). The study findings also imply that growing an improved variety of Ruiru 11 is better than the improved variety of Batian in an effort to minimize the yield gap, as Ruiru 11 had higher yields and a lower yield gap compared to Batian. This large coffee yield gap estimate may have been influenced by varieties of coffee grown, low contact with extension officers, which resulted in poor implementation of recommended agronomic practices, and lack of credit access to boost production. This study's findings also imply that there is a large exploitable gap, as revealed by the yield gap index, that may be crucial in increasing coffee productivity, hence reducing the yield gap.

Table 3 A Summary of Yields, Yield Gap, and Yield Gap Index

Variety	Improved Variety		Traditional Variety (SL28)
	Ruiru 11	Batian	
Research Yields (kg/ha)	75000	57000	39900
Farmer's Yield (kg/ha)	8593.920	3545.277	1722.423
Yield Gap	66406.080	53454.722	38177.577
Yield Gap Index	88.540%	93.780%	95.680%

3.4. Fractional logit model of the effect of socioeconomic characteristics on coffee yield gap

This study hypothesized that socioeconomic characteristics would affect the coffee yield gap in the Nyeri Central sub-county. The fractional logit regression model used contained one dependent variable (coffee yield gap index), which was a factional outcome (0 to 1), and five explanatory variables, including the gender of household head, age, schooling

years, household size, and labor after dropping the household income, land size, and farming experience that was highly skewed and insignificant to the study. The model showed that the log pseudo likelihood was -103.552 where p=0.0015<0.05 implied that the independent variables strongly influenced the coffee yield gap. The coefficients also had positive and negative signs where: a positive sign inferred that an increase in the independent variable by one unit increased the coffee yield gap by a certain level, while the negative sign implied that a unit increase in the dependent variable decreased the coffee yield gap by a certain level.

The model results revealed a negative but significant effect of the gender of the household head on the coffee yield gap, indicating a 0.0019 unit decrease in the coffee yield gap as a result of increased male household heads (Table 4). This infers that male household heads took investment decisions with regard to coffee production, including dedicating portions of land to coffee and using credits acquired to purchase farm inputs, which most likely contributed to the improved implementation of recommended agronomic practices, resulting in increased coffee production among the farmers. Similar findings were noted by Nibret and Ayalew [24] that an increase in male household heads resulted in increased coffee production and income.

Table 4 Fractional Logit Regression Output and Marginal Effect of Socioeconomic Characteristics

Yield Gap Index	Coefficient	Standard Error.	P>z	Marginal Effect
Gender of Household Head	-0.0083	0.0027	0.002	-0.0019**
Age	0.0001	0.0001	0.108	0.0000
Schooling Years	-0.0018	0.0008	0.024	-0.0004**
Household Size	-0.0018	0.0008	0.027	-0.0004**
Labor	-0.0017	0.0007	0.035	-0.0003**

NOTE: **Denote p-value significance at a 5% significance level

This study's findings showed a negative and significant effect between schooling years and the coffee yield gap, implying that a higher level of education among the farmers increased farmers' coffee production efficiency, which was likely to minimize the yield gap by 0.0004 units. It also implies that education most probably enhanced farmers' skills, which increased their implementation of agronomic practices, use of improved technologies, and application of recommended inputs, thus attaining high productivity. This study's findings concur with those of Ronald *et al.* [25], who reported that a higher level of education among the farmers was associated with a higher uptake of coffee-recommended management practices. This implied that the more years of schooling the coffee farmers had, the higher the adoption of better practices. Therefore, the more literate a coffee farmer was, the higher the chance that their yield gap would be low.

Further, the household size portrayed a negative and significant effect on the coffee yield gap, implying that an additional member of the household size would decrease the coffee yield gap by 0.0004 units (Table 4). Based on the study findings, the reduced coffee yield gap was probably due to the increase in farmers' investment in coffee production, especially by the male household heads, and increased labor availability that improved production significantly. Adane and Bewket [26] reported similar findings that household size in Southern Ethiopia negatively and significantly affected coffee quality and climate change adaptations. This was due to an increase in labor availability for coffee maintenance and harvesting that enabled farmers to adjust and protect their coffee against climate change. Hence, a large household size guaranteed the availability of family labor because, most probably, the individuals would participate in coffee activities.

The findings also indicated a negative and significant effect between labor and the coffee yield gap, revealing that an addition to the family labor would decrease the coffee yield gap by 0.0003 units (Table 4). This implies that family labor was probably more reliable and efficient than hired labor due to its readily availability and that it's an asset and source of wealth for the household. The findings are in agreement with those of Pereira *et al.* [27], who observed that family labor was significant and negatively contributed to coffee production in Brazil, thereby increasing yields achieved.

4. Conclusion and recommendation

This study concluded that the actual farmer's yields were far below their potential productivity, which resulted in a large yield gap for the improved and traditional varieties. The estimated large yield gap requires that feasible actions be undertaken to narrow the gap to a sizeable level so that farmers can benefit from coffee production. The coffee yields

can be increased by farmers acquiring higher levels of education, which would result in reduced yield gaps. The result shows that the more literate a farmer is, the lower the coffee yield gap. The majority of farmers who participated in coffee production were elderly and were considered weak and reluctant to implement the production information received, contributing to an increased yield gap. Therefore, cooperative societies and county stakeholders need to come up with strategies to increase the education level of farmers and provide opportunities for youth inclusion. This is because improving the education levels of farmers facilitates a better understanding of technologies and practices and their implementation through training, demonstrations, field benchmarking, and extension visits to farmers, among others. Additionally, onboarding energetic youth enhances the adoption of recommended practices and creativity in agricultural production.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declared no conflict of interest.

Statement of informed consent

This study sought for a written informed consent from farmers upon presenting a letter that informed the farmers the nature and use of the information that was to be provided. Permits and a written communication to the stakeholders and authorities in research and ministry of agriculture were also sought.

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