Int.J.Curr.Res.Aca.Rev.2022; 10(02): 9-27

EXCELLENT PUBLISHERS

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 10 Number 02 (February-2022)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2022.1002.002

Coffee Yield Gap Assessment among adopters and Non-adopters of Improved Coffee Varieties in Mbinga and Mbozi Districts, Tanzania

Leonard Kiwelu[1*] and Philip Damasand Zena Mpenda[2]

[1]*Department of Agricultural Economics and Agribusiness,*
[2]*Department of Food and Resource Economics, School of Agricultural Economics and Business Studies (SAEBS), Sokoine University of Agriculture (SUA), Morogoro, Tanzania*

**Corresponding author*

Abstract

This study aimed at understanding factors causing the yield gap among smallholders in the study area and propose possible interventions to increase coffee productivity from the current level of 300 kg ha^{-1}for Arabica coffee to optima level of 2000 kg ha^{-1}for improved and 1000 kg ha^{-1}for traditional coffee varieties. The primary data were collected from 122 adopters and 198 non-adopters of improved coffee varieties using a semi-structured questionnaire. The Soil Analysis for Fertility Evaluation and Recommendation on Nutrient Application to Coffee (SAFERNAC) model were used to analyse the coffee yield gap while linear regression (OLS) model was used to determine factors influencing coffee yield. The adoption rate of adopters of improved coffee varieties is 38 %. The average yield attained by adopters is 1235 kgha^{-1}and non-adopters is 513 kg ha^{-1}. The yield gap from farmers' records is 2286 kg ha^{-1}and 791 kg ha^{-1}non-adopters. The yield gap from research data and farmers' records was 765 kg ha^{-1}and 487 kg ha^{-1}for adopters and non-adopters respectively. However, the finding from the SAFERNAC model showed that actual yield for Igamba and Ihanda wards are above the model. The main factors positively influencing coffee yield and statistically significant were type of coffee variety planted, plant population, access extension services, fertilizer applications, pruning and amount of fertilizer applied (gmtree^{-1}). The factors that negatively influencing coffee yield and statistically significant is an expansion of a new coffee farm. It is therefore recommended that farmers should be provided with right training by extension officers on coffee farming so as to minimize the coffee yield gap and increase productivity.

Article Info

Received: 02 January 2022
Accepted: 31 January 2022
Available Online: 20 February 2022

Keywords

Coffee, adopters and non-adopters, coffee varieties, the coffee yield gap.

Introduction

The current world coffee demand is estimated to exceed production due to increase in global coffee consumption (ICO, 2019a). Increase in coffee productivity is one of the thrusts aimed at transforming the economic growth and development of coffee producers in Tanzania (TCB, 2012). This thrust can be attained through promotion and dissemination of improved coffee varieties and farmer encouraged to adopt good agricultural practices (GAPs) pertaining coffee production (Bertin *et al.*, 2012; Diro & Erko, 2019 and TaCRI, 2011). In Tanzania 90% of coffee is produced by smallholder farmers with average productivity of producing 250 to 300 kg ha^{-1}for Arabica coffee and 450 kg ha^{-1}for Robusta coffee (BOT, 2017). Coffee productivity from other countries such as Kenya stands at 302 kg ha^{-1} (ICO, 2019a), Ethiopia 802 kg ha^{-1}(Bickford, 2019), Rwanda 880 kg ha^{-1} (Nzeyimana, 2018) and Uganda 2100 kg ha^{-1} (ICO, 2019b) is relatively higher than in Tanzania. In general, it can be argued that coffee yield from smallholder farmers in Tanzania is low despite Tanzania having coffee varieties with the potential of producing 2000 kg $ha^{-1}$for improved and 1000 kg $ha^{-1}$for traditional coffee varieties(Kilambo *et al.,* 2015). Progressive promotion of high-yielding coffee varieties and advocating the implementation of good agricultural practices (GAPs) were expected to increase coffee yield and close the yield gap. Despite the higher yield in research trials empirical evidence on how the varieties are performing under farmers management is limited. The paucity of this data on the yield gap and the factors causing it hinder researchers, policy makers and other stakeholders to come up with strategies that can contribute to minimize the yield gap. The yield gap analysis method was used by this study to understand the factors causing the coffee yield gap among smallholder farmers in the study area. Understanding yield gap is very crucial for it can assist in crop yield predictions since yield potential shows the probable future productivity to be achieved.The information on cause of yield gap can be used by researchers, policy makers and other stakeholders to enhance crop production through promoting strategies to minimize yield gap among smallholder farmers in the study area.

Theoretical, Empirical and Conceptual Frameworks

Theoretical Framework

Agricultural production economics is concerned primarily with economic theory as it relates to the producer of agricultural commodities (Debertin, 1986). The major concerns in agricultural production economics among other goals and objectives of the farm manager, choice of outputs to be produced, allocation of resources among outputs. The theory of utility maximization has been used extensively to explain the preference of inputs by farmers (Muellbauer, 1974). This theory predicts that farm productivity, measured by marginal factor products, will differ over farms using different levels of inputs. This theory considers a simplified view of the economy in which production output is determined by the amount of input involved and the amount of capital invested. The strategies of increasing the coffee production in Tanzania include encouraging investment in the promotion of improved coffee varieties and farmer training on implementation of good agricultural practices such as farm rehabilitation, application of fertilizers, control of coffee pests and diseases using recommended pesticides, and fungicides (TCB, 2012). Therefore, this theory is useful as the basic framework for understanding the causes of the yield gap resulting from utilizing the major inputs of coffee production in the study area.

The Empirical Framework

Different approaches such as field experiment (van Ittersum *et al.,* 2013), crop growth simulation models (Lu & Fan, 2013; and van Bussel *et al.,* 2015), socio-economic survey (Tamene *et al.,* 2016), and precision agriculture (Schulthess *et al.,* 2013; Tittonell and Giller, 2013) have been used to assess farmers' yields and yield gaps between households. The field experiments approach is used to compare farmers' yield 'control' and research yield within the experimental plots (van Ittersum *et al.,* 2013). This approach does not set the optimum yields to the level attainable by farmers and the limited number of test locations makes it difficult to upscale to larger areas (Tittonell and Giller, 2013). Crop growth simulation models (Lu and Fan, 2013; and van Bussel *et al.,* 2015), compare the potential yield with actual yield but require intensive data for model input, calibration, and validation (van Ittersum *et al.,* 2013). Precision agriculture which is fast and accurate is used to measure the yield of plots in real-time but it is more technology-intensive (Tittonell and Giller, 2013). Socio-economic survey capture yield harvested by smallholder farmers and corresponding agronomic/management practices depends much on farmers' memory and it is time-saving (Tamene *et al.,* 2016). Because this is a cross-sectional study that depends on much of the data reported by farmers, this study, therefore, opts to use the socio-economic survey because the nature of data collected from the study area depended on farmers' records.

The Conceptual Framework

The conceptual framework developed in this study focuses on three main components which include the agronomic, socio-economic, and institutional factors that influence coffee yield. Agronomic factors such as weeding, pest and disease control, coffee varieties planted, plant population, application of fertilizer, and farm expansion were analysed to determine their influence on coffee yield. The socio-economic factors such as level of education which was hypothesized to influence farmers' adoption and implementation of good agronomic practices was also considered as an important variable that might influence coffee yield. Institutional factors including access to extension services were among the key variables of analysis which in one way or another, influence coffee yield. It was hypothesized that the farmers who access extension services get a higher yield than others. From these sets of variables, the yield gap among smallholder farmers was determined and the factors influencing the level of coffee yield were analysed as indicated Fig 1.

Materials and Methods

Description of the Study Area

This study was conducted in Mbozi and Mbinga Districts (Fig 3.2). The two Districts produce about 50% of the total Arabica coffee produced in Tanzania. Mbozi District lies between 8°45'0" S and 32°45'0" E.

It is bordered to the North by Chunya District, to the East by Mbeya Urban and Ileje Districts, to the South by Zambia, and to the West by Rukwa Region. Mbozi District lies between 900 and 2750 metres above the sea level receiving an average rainfall between 1350 mm and 1550 mm per annum while temperatures range between 20°C and 28°C.

The major food crops grown in the area include maize, paddy, sorghum, finger millet, bulrush millet, sweet potatoes, Irish potatoes, groundnuts, and beans while the cash crops grown are coffee, avocado, simsim, and sunflower. The common types of livestock owned include cattle, goats, sheep, pigs, poultry, donkeys, and turkeys (MDC, 2010).

Mbinga District lies between 10°49'60" S and 34°49'60" E. The District is bordered to the north by Njombe Region, to the east by Songea Rural and Songea Urban Districts, to the South by Mozambique, and to the west by Lake Nyasa. Mbinga District lies between 900 and 1350 metres above sea level; with some points in the highland reaching over 2000 metres above sea level.

The District receives average rainfall between 1200 and 1500 mm per annum; while temperatures range between 13°C in the highland and 30°C on the lakeshore. The major crops in the District include maize, sorghum, coconut, bananas, beans, cassava, finger millet, and cash crops include coffee, cashew, tobacco, and Avocado (a new emerging cash crop). Likewise, smallholder farmers deal with livestock keeping, beekeeping, fish farming, and lumbering of hardwood. The common types of livestock owned include cattle, goats, sheep, pigs, and poultry.

Research Design and Sampling Techniques

The present study employed a cross-sectional research design to collect data from two major Arabica coffee producing in Mbinga and Mbozi Districts. In this design, all data collected from the sampled population is done at a single point in time. A multi-stage sampling procedure was used at the first stage to select Arabica-producing wards and villages from Mbinga and Mbozi Districts. Secondly, a random sampling method was applied in selecting wards and villages where coffee is grown. The third stage involved random sampling of villages with adopters of improved coffee varieties and non-adopters (farmers planted traditional coffee varieties). The traditional coffee varieties were distributed to farmers for free by TCB under Coffee Development Programme (CDP) from 1998 to 2003. Finally, random sampling was applied in selecting coffee households growing improved and traditional coffee varieties. A required sample size of respondents was proportionally selected from the list of coffee growers developed in the third stage per village following Krejcie, (1970) formula as presented in equation 1. The final dataset consists of a random sample size of 320 (Table 1)coffee producers, 122 of which are adopters of improved coffee and 198 were non-adopters.

$$S = \frac{X^2 NP(1-P)}{d^2(N-1)+X^2 P(1-P)} \quad \ldots (1)$$

Where: S= Required sample size, X =z value (assumed to be 1.96 for 95% confidence level), N = Population size, P = Population proportion (assumed to be 0.5 since this would provide the maximum sample size), d = degree of accuracy (5%), expressed as a proportion (0.05). Accordingly, the Mbozi district consists of 930 households, and the Mbinga district consists of 990 households, making a total of 1920 target households.

$$n = \frac{1.96^2 x 1920 x 0.5 x 0.5}{0.05^2 x (1920-1)+(1.96^2 x 0.5 x 0.5)} = 320$$

Data Collection

Secondary data collection

Secondary data such as trends of coffee production and auction price, the contribution of coffee to the national economy were collected from various agricultural economic journals and research reports, books, and other publications related to the coffee sector to provide the necessary support to the primary data accumulated.

Primary data collection

A sample of 320 farmers was taken randomly from various villages in Mbinga and Mbozi districts and primary data were collected for the 2019/20 crop season from household heads owning traditional coffee varieties and improved coffee varieties using a semi-structured questionnaire. The information collected includes household demographic characteristics such as sex, age, family size, number of years in the formal education of the household head, household labour capacity; institutional factors such as access to extension services and group membership; farm characteristics such as type of coffee varieties planted and plant population.

Focus group discussion (FGDs)

Focus Group Discussions (FGDs) were conducted to collect primary data. A total of 42 participants were involved in making two groups from each district; one for those with improved varieties and the other for those with traditional varieties making a total of four groups.

Each group had comprised 7 to 8 participants (including 1 to 2 females) who were purposively selected among coffee producers. Participants in FGDs were different from those involved in questionnaire interviews. The rationale for the choice of focus group discussion method was that it helped to capture more information on factors affecting coffee yield among adopters and non-adopters of improved coffee varieties and to validate some information gathered during primary data collection from the households in the study area.

Key informant interviews (KIIs)

Key Informants' Interview (KIIs) was conducted to collect primary data. Key informants included ward extension staff, local leaders one from each ward in the study area respectively, District Coffee Subject Matter Specialist (DCSMS), and TaCRI extension officer to make a total of nine KIIs in the discussions from each district to obtain their opinion on factors affecting coffee yield among adopters and non-adopters of improved coffee varieties and to validate some information gathered during primary data collection from the households and focus group discussions.

Data Analysis

Coffee yield estimation among smallholder farmers

The survey data were subjected to descriptive and inferential analyses. Data collected through farmer interviews were coded and analysed using the SPSS whereby descriptive statistics (i.e., frequencies, percentages, means, minimum and maximum values of variables) were determined. The coffee yield reported by farmers recall were converted to standard unit conversion factors of which for this study was kg $ha^{-1}$and findings were compared using a t-test of difference in means to establish if there is any statistically significant difference between yield obtained by smallholder farmers with improved coffee varieties and those with traditional coffee varieties.

Yield gap analysis

Lobell *et al.*, (2009); and Tamene *et al.*, (2016) defined the yield gap as the difference between the maximum farmer yields (attainable yield) and the average farmer yields. The farmer Yield gap (Yg) was computed as the difference between the maximum farmer yield potential and the estimated average yield which were derived from the yield data of the current socio-economic survey.

The Yield gap (Yg) was computed as a quantitative difference between an average research yield (generally reported from research trials) and average farmers yield (generally: obtained from acceptable farmer management practices) over some specified spatial and temporal scale holding other crop attributes remain constant (Sadras, 2015).

The research yields data from research records published by Tanzania Coffee Research Institute (TaCRI) reports. The average farmer yield was obtained from the socio-economic survey data collected from January to April 2020 in the study area.

Therefore, this study computed the farmer's yield gap as the difference between the maximum yield and average yield from data obtained from farmers. Also, yield gap Yg (kg ha^{-1}) was calculated as the difference between the estimated national average research yield (Yr) and the average farmers' yield obtained from the socio-economic survey data collected from the study area under farmers' management practices (Yf).

$$Y_g = MaxY_f - Y_f \quad \ldots (2)$$

Where: Y_g =Yield gap, $MaxY_f$ = Maximum farmers yield (kg ha^{-1}) and Y_f = the average farmers' yield (kg ha^{-1}).

$$Y_g = Y_r - Y_f \quad \ldots (3)$$

Where: Y_g =Yield gap (kg ha^{-1}), Y_r = research yield (kg ha^{-1}) and Y_f = the average farmers' yield (kg ha^{-1}).

The t-test analysis for the two categories of respondents of adopters and non-adopters of improved coffee varieties was done to establish if there is any statistically significant difference between the yield gap.

This study also employed a Soil Analysis for Fertility Evaluation and Recommendation on Nutrient Application to Coffee (SAFERNAC) which is a yield simulation model used to predict the yield parchment considering soil properties such as Organic Carbon (OC), total nitrogen (N), available phosphorus (P) and exchangeable potassium (K) and pH water). This model was developed by Tanzania Coffee Research Institute, Sokoine University of Agriculture, and Wageningen University of Netherlands (Maro, 2014). The data were averages of five wards which are Utiri (12), Kilimani (11), Ihanda (2), Igamba (5) and Isansa (6).

Estimation of factors affecting coffee yield

The factors affecting coffee yield were investigated by regression analysis using the Ordinary Least Square (OLS) technique. This method has been widely used in yield gap studies to show specific factors influencing crop yields (Greene, 2003). The OLS technique was employed since the dependent variable was a continuous random variable and the independent variables were either continuous or categorical, taking into consideration regression modelling assumptions. The linkages among coffee productivity and its factors were modelled to establish the important policy variables. Generally, linear function, f(.), was specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \cdots + \beta_{12} X_{12} + e \quad \ldots (4)$$

Where:

Y = coffee yield of ith crop (kg ha^{-1}),

X_1 =Education level of the coffee farmer was categorized into literates and illiterates (+): We predicted a positive relationship between this variable and coffee yield since an educated farmer can evaluate the improved production practices and make informed technical and economical choices to increase adoption.

X_2 = Frequency of weeding of the coffee farm by the coffee farmer (+): Weeds normally compete with the coffee tree for water and nutrients (Maro, 2014 and TaCRI, 2011). Therefore, the higher the weed control frequency, the better for the plant to develop and produce more output and yield.

X_3 = Fertilizer application. The fertilizer variable was assumed to be a dummy variable which takes the value 1 if the coffee farmer applied fertilizer to his/her farm, and otherwise takes the value 0 (+): In Tanzania, cultivation of coffee on a piece of land has been found to result in soil fertility decline due to soil nutrient mining (Maro, 2014 and Robinson, 1961). Thus, applying fertilizer to such soils can replenish the depleted soil nutrients and hence, increase coffee output and yield.

X_4 = Frequency of spraying against coffee pests such as White coffee stem borer, mealy-bug, green scale, and snail by the coffee farmer (+); These pests attack the coffee trees by feeding on the succulent foliage and in extreme cases causing death, leading to a reduction in coffee output and yield. It has been recommended by Magina, (2011) and TaCRI, (2011) for farmers to spray against these pests with insecticides 4 times per annum to ensure the effective control of the pests. Therefore, it was posited that high spraying frequencies result in ineffective pest control, leading to output and yield increases.

X_5 = Frequency of spraying against Coffee Berry Diseases (CBD) and Coffee Leaf Rust CLR disease by the farmer (+); CBD and CLR disease can destroy more than half of the crop, particularly traditional varieties.

It has been recommended to farmers by Kilambo *et al.*, (2015) and TaCRI, (2011) to spray against CBD and CLR with fungicides, 6-9 times per annum to ensure effective control of the disease. Thus, it was assumed that high spraying frequencies could lead to effective control of CBD and CLR, resulting in increased output and yield.

X_6 = Age of coffee farm (years) (-); The older the farm, the higher the probability that coffee output and productivity will decrease, causing discouragement in farm maintenance.

X_7 = Coffee variety planted by the coffee farmer. The coffee variety variable which was considered continuous missing was scored by giving a value 1 if the farmer planted Improved variety, a value 0 if the farmer planted traditional variety (+): Improved coffee variety, which is early-bearing and high-yielding and currently recommended to farmers, is an improved variety over the traditional variety. Thus, it is anticipated that a farmer planting improved coffee varieties could produce a higher coffee yield than those with traditional varieties.

X_8 = Plant population per ha (+): The number of coffee trees per unit area was assumed to positively influence yield because as an increase in plant population per unit area the management and resources allocations would contribute to increasing the coffee output.

X_9 = Frequency of extension visits by the extension officer (0 = no visit, 1 = at least one visit) (+): The more frequent the exposure of a farmer to extension information of new improved production practices, the more likely he/she can be convinced to adopt the appropriate technologies to increase yield.

X_{10} = Pruning coffee tree (+): It is anticipated that proper coffee pruning will contribute to increase in coffee yield. Pruning is recommended three times in a season (TaCRI, 2011).

X_{11} = Quantity of fungicides applied to coffee farms measured in kg ha^{-1}(+): It is hypothesized that the higher the number of fungicides applied, the more effective will be the control of CBD and CLR disease which tends to decrease coffee output and yield. X_{12} = Coffee farm expansion measured in ha (-): Coffee farm expansion for coffee production is predicted to be negatively related to yield as new coffee farms require a high number of inputs such as liming because in the study area the soil pH is low which require to be regulated by applying liming which could require extra financial resource.

X_{13} = Quantity of fertilizers applied to coffee farms measured in gm/tree (+): It is hypothesized that the higher amount of fertilizers applied per tree as recommended, the more productivity gained from a coffee tree.

e = Error term: It is assumed the error term is independent and normally distributed with mean zero (0) and known variance (σ^2)

β_0 = Intercept, $\beta_1 \ldots \beta$ = Regression Coefficient.

Results and Discussion

Adoption Rate of Improved Coffee Varieties

The findings as provided in Table 2 indicate that the overall rate of adoption of improved coffee varieties is 38% which represent smallholder farmers planted improved coffee varieties and 62% of respondents planted traditional coffee varieties. The findings imply that the rate of adoption of improved coffee varieties has increased from 20% reported by (Mhando, 2017 and TaCRI, 2017). The possible explanation for this increase can be attributed to the current government directives that require coffee seedlings multiplied by TaCRI and local government authorities to be distributed to farmers for free or, it may be attributed to the increased capacity of TaCRI to multiply coffee seedlings by using seeds rather than depending clonal propagations methods.

Coffee Yield Analysis

The findings in Table 3 show that, for the 2019/20 crop season, the overall average coffee yield from smallholder farmers who adopted improved coffee varieties is 1235 kg ha^{-1}and 513 kg ha^{-1}for non-adopters and statistically significant (t=9.8084, p = 0.000). The finding also showed that the average yield for adopters of improved coffee varieties in the Mbinga district is 1272 kg ha^{-1}and non-adopters is 549 kg ha^{-1}which is statistically significant (t=6.5903, p = 0.000) whereas the average yield in the Mbozi district for adopters is 1182kg ha^{-1}and non-adopters is 487 kg ha^{-1}which is also statistically significant (t=6.8964, p = 0.000). From these findings, it can be concluded that adopters of improved coffee varieties gain higher yields than non-adopters. According to (Kilambo *et al.*, 2015 and Maro, 2014), improved coffee varieties producing an average yield of 2000 kg ha^{-1}and traditional coffee varieties produce an average of 1000 kg ha^{-1}under GAPs. These findings support Diro, (2019) and Wu, (2005) who reported that farmers who adopted improved varieties gain higher yield (t=9.8084, p = 0.000) than those with traditional varieties.

Estimation of Coffee Yield Gap

The coffee yield gap analysis using farmer yield record

Farmer practices yield gap was computed by subtracting the maximum yield (kg ha^{-1}) and the average yield (kg ha^{-1}) as expressed in Table 4. The overall findings showed that the yield gap of adopters of improved coffee varieties is 2286 kg ha^{-1}equivalent to 65 % and non-adopters are 791 kg ha^{-1}equivalent to 61 % which means that adopters in the study attain 35 % of the potential yield and non-adopters attain 39 %. Furthermore, the findings indicated that the yield gap for adopters of improved coffee varieties in the Mbinga district is 1886 kg $ha^{-1}$and in the Mbozi district is 2339 kg ha^{-1}equivalent to 60 % and 66 % respectively whereas the yield gap for non-adopters in Mbinga district is 755 kg ha^{-1} and 710 kg ha^{-1}in Mbozi district equivalent to 58 % to 59 %. During the focus group discussion, it was reported that erratic rainfall triggers early flowering for improved coffee varieties than traditional coffee varieties but the fruit abort after a long drought. The key informants also reported that, during a good crop season, farmers with improved varieties lack enough money to pay labour for picking hence substantial crop loss occurred. The findings imply that the huge yield gap among adopters in the study area can be associated with the two mentioned factors of climate change and lack of capital but with the addition of the factors associated with farmer management practices and the different types of improved coffee varieties planted by adopters which have different yield potential (Annex 1).

The coffee yield gap analysis using research yield and farmers yield data

The findings in Table 5 indicate that the overall yield gap among adopters of improved coffee varieties in the study area is 765 kg ha^{-1}equivalent to 38 % to attain the research yield which implies that smallholder farmers attain 62 % of the potential yield. The findings also showed that the mean difference between farmers' yield and yield gap is statistically significant (t=28.048, p = 0.000). Furthermore, the findings showed that the yield gap for non-adopters is 487 kg ha^{-1}equivalent to 49% which reflects that farmers gain 51 % of the potential yield from the traditional coffee varieties. The mean difference between farmers' yield and yield gap is statistically significant (t=17.143, p = 0.000).

The analysis also indicated that in the Mbinga district the yield gap for adopters is 728 kg ha^{-1}which is 36 % of the potential research yield and is statistically significant (t= 21.229, p = 0.000) implying that farmers produce about 64 % whereas the yield gap for non-adopters was 458 kg ha^{-1}constituting 46 % of the potential yield is statistically significant (t= 10.300, p = 0.000) which imply that farmer produces 54 %. Likewise, the yield gap for adopters in the Mbozi district is 818 kg ha^{-1}(t= 18.240, p = 0.000) equivalent to 41 % of the potential yield and farmers only attain 59 % of the potential yield while the yield gap for non-adopters was 513 kg ha^{-1}statistically significant (t= 13.806, p = 0.000) which is equivalent to 51 % implying that farmer can produce 49 % of the potential yield in the study area. The difference in yield gap among smallholder farmers could be explained that research field trials are well managed than farmers farms hence farmers yield is low because of various factors including implementation of GAPs which combined timely wedding, pruning, fertilizer application, control of coffee pests, and diseases (Tamene *et al.*, 2016 and Mondal, 2011).

The coffee yield gap analysis using SAFERNAC model

Soil fertility data from 36 georeferenced points of Utiri (12), Kilimani (11), Ihanda (2), Igamba (5), and Isansa (6) in two districts were fed into the model under two distinct approaches – a combination of seven tons of organic (manure) and 80 kg $ha^{-1}$of inorganic (NPK) fertilizers. The simulated yields were descriptively compared per ward (Annex 3.2). The finding presented in Fig. 3.3 indicated that the SAFERNAC actual yield for Igamba and Ihanda were above the model while the yield for Isansa, Kilimani, and Utiri was below the model. The finding implies that there is no significant mean difference for the model and the farmer's yield except for Ihanda wards. The possible reason can be attributed to data variation which is based on farmers' memory rather than farmers' record. However, the analysis still shows the actual yield reported by farmers is lower than the yield simulated by the model.

The Factors of Coffee Yieldamong Smallholder Farmers

The findings from Ordinary Least Square (OLS) regression analysis as presented in Table 6 indicated that the F-statistics of 34.02 was significant (P = 0.000), indicating a strong relationship between the independent variables on the dependent variables for respondents.

The R squire was 0.7188 implying 71.88% of coffee yield variations among smallholder farmers is explained by the factors combined. The finding in Table 7 showed that coefficient of the coffee variety planted by the coffee farmer is 330.79 (t= 1.930, p = 0.055) implying a positive relationship between coffee yield and type of coffee varieties planted by respondents. The varieties were scored with 1 for improved varieties and 0 for traditional varieties.

Table.1 Sample Districts and Number of Sample Households

District	Approx. sub-pop. (20-30% are coffee farmers)	Sampling fraction	Sub-sample	Improved varieties	Traditional varieties
Mbozi	930	0.48	155	49	106
Mbinga	990	0.52	165	73	92
Total	**1920**		**320**	**122**	**198**

Table.2 Rate of adoption of improved coffee varieties

Description	Nº of Adopters	Rate in %	Nº of Non - adopters	Rate in %	Total number of respondents
Mbozi	49	32	106	68	155
Mbinga	73	44	92	56	165
Grand total	**122**	**38**	**198**	**62**	**320**

Table.3 Coffee yield attained by smallholder farmers (kg ha^{-1})

Descriptions	Mbinga		Mbozi		All	
	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter
Mean	1272	549	1182	487	1235	513
Maximum	3158	1304	3521	1197	3521	1304
Minimum	312	100	266	116	266	100
Std. Dev	691	291	705	283	695	287
t-test	6.5903		6.8964		9.8084	
Sign.	0.0000		0.0000		0.0000	

Table.4 Yield gap estimated using farmer yield record from the study area

Descriptions	Mbinga		Mbozi		All	
	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter
Meanin kg ha^{-1}	1272	549	1182	487	1235	513
Maximumin kg ha^{-1}	3158	1304	3521	1197	3521	1304
Yield gapin kg ha^{-1}	1886	755	2339	710	2286	791
% of yield gap to maximum	60	58	66	59	65	61
% farmer yield to maximum	40	42	34	41	35	39

Table.5 The yield gap analysis (kg ha^{-1}) in the study area

Descriptions	Overall		Mbinga District		Mbozi District	
	Adopters (n=122)	None-adopters (n=102)	Adopters (n=72)	None-adopters (n=44)	Adopters (n=50)	None-adopters (n=58)
Farmer's yield	1235	513	1272	542	1182	487
Research Yield	2000	1000	2000	1000	2000	1000
Yield gap	765	487	728	458	818	513
% yield gap to research yield	38	49	36	46	41	51
% farmers yield to research yield	62	51	64	54	59	49
t-test	28.048	17.143	21.229	10.3000	18.240	13.806
sign	0.000	0.000	0.000	0.000	0.000	0.000

Table.6 The descriptive summary of the factors included the OLS model

Source	SS	df	MS	Number of obs	=	187
				F(13, 173)	=	34.02
Model	56841779	13	4372445	Prob > F	=	0.000
Residual	22234872	173	128525.3	R-squared	=	0.7188
				Adj R-squared	=	0.6977
Total	79076650	186	425143.3	Root MSE	=	358.5

Table.7 Liner regression model on factors affecting coffee yield

Coffee yield (kg ha-1)	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Level of education	-101.77	66.09	-1.540	0.125	-232.21	28.67
coffee variety planted	330.79	171.54	1.930	0.055	-7.78	669.36
Age of coffee tree	12.90	14.40	0.900	0.371	-15.51	41.31
Plant population	0.23	0.02	11.140	0.000	0.19	0.27
Access extension services	145.88	54.17	2.690	0.008	38.96	252.79
Frequency weeding	-31.26	40.68	-0.770	0.443	-111.56	49.03
Fertilizer applications	168.63	51.38	3.280	0.001	67.23	270.04
Pest control	6.21	5.18	1.200	0.232	-4.01	16.44
Control coffee diseases	-42.54	36.42	-1.170	0.244	-114.42	29.35
Pruning	238.34	77.73	3.070	0.003	84.91	391.77
Fertilizer applied (gm/tree)	1.59	0.60	2.630	0.009	0.40	2.78
Amount of fungicide applied	-51.87	74.84	-0.690	0.489	-199.58	95.84
Expansion of coffee farm (ha)	-59.54	23.55	-2.530	0.012	-106.02	-13.05
_cons	-867.46	349.32	-2.480	0.014	-1556.95	-177.98

Fig.1 Conceptual framework developed by author

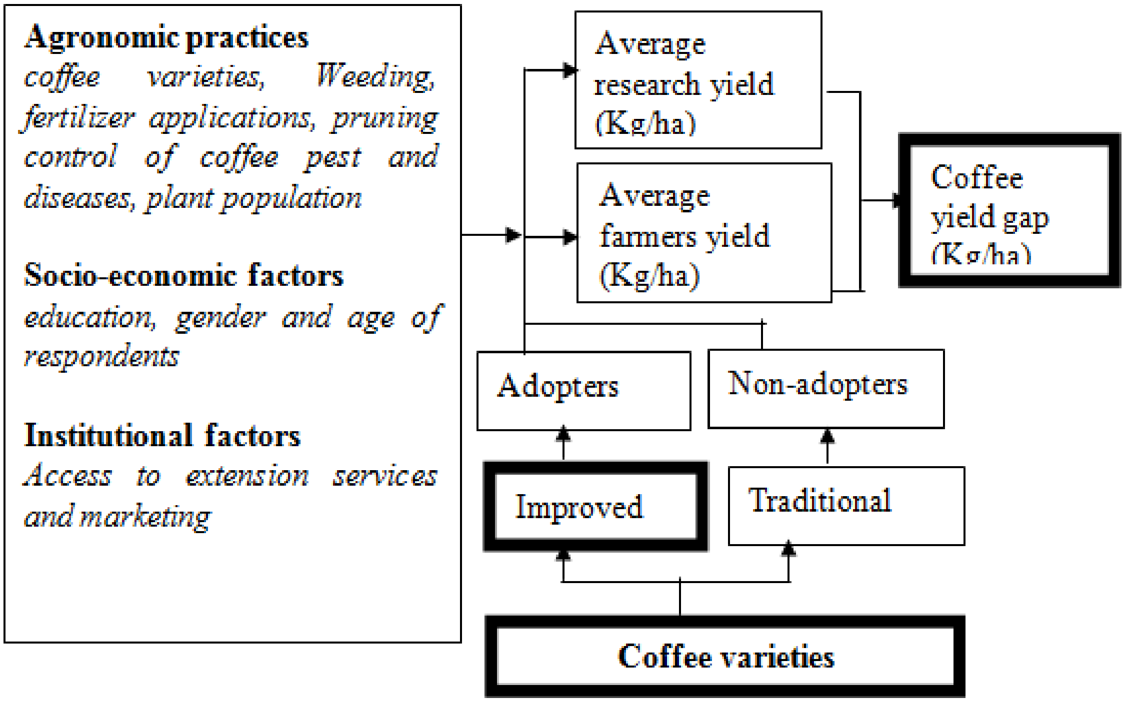


Fig.2 Map of Tanzania showing Mbozi District and Mbinga districts study site

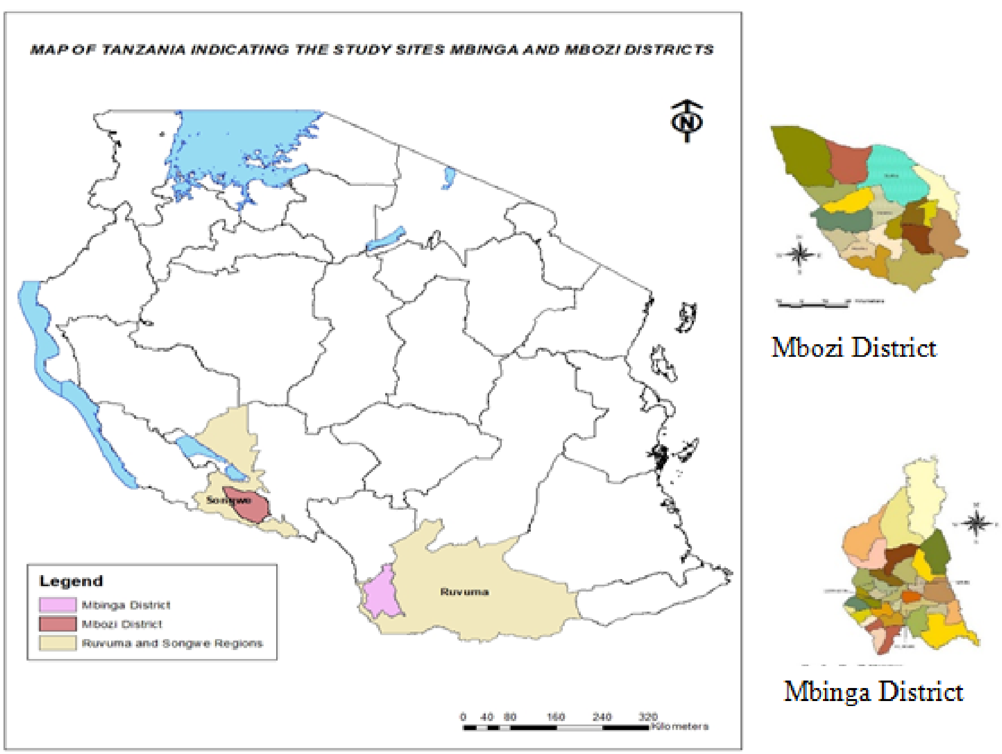
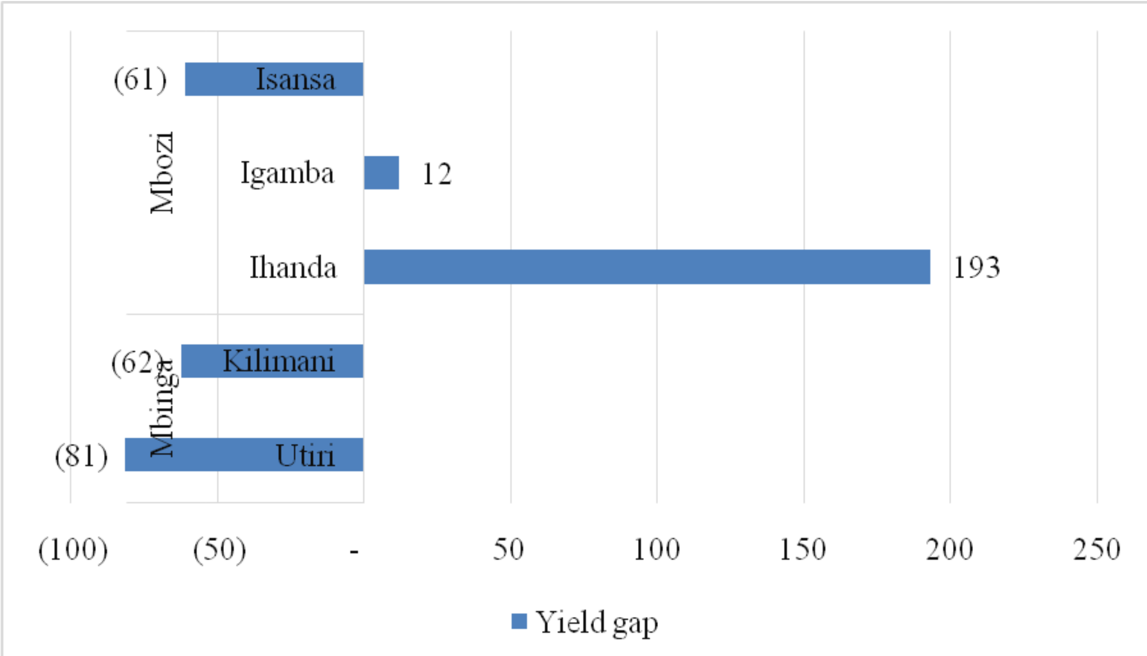


Fig.3 The Coffee Yield Gap Analysis using SAFERNAC model



Therefore, the improved coffee varieties produced high yield than traditional coffee varieties and this can possibly be associated with the attributes of these varieties such as early-bearing, high-yielding, and resistance of coffee diseases like CBD and CLR for improved varieties as opposed to traditional varieties (Kilambo *et al.,* 2015 and Mtenga, 2016).

Meanwhile, the findings showed that the coefficient of plant population per ha is positive 0.23 (t= 11.140, p = 0.000) which means that the adequate number of populations per unit area influences coffee yield. According to TaCRI (2020), the average number of coffee plants per ha is 2000 plants for improved varieties planted in a space of 2 metres by 2.5 metres and 1330 plants for traditional coffee varieties planted in a space of 2.74 metres by 2.74 metres. Furthermore, the coefficient for access to extension services is 145.88 (t = 2.690, p = 0.008) influence coffee yield. Different scholars, Ghimire *et al.,* (2015); Lugandu, (2013), and Teferi *et al.,* (2015) documented that, farmer access to extension services helps in improving farm management practices hence increasing coffee yield.

Furthermore, the findings revealed that the coefficient of fertilizers application is 168.63 (t=3.280, p = 0.001) influences coffee yield. The application of fertilizers can contribute positively to increasing soil nutrients which have a direct impact on proper crop growth, yield, bean size cup quality, and eventually high price (Maro, 2014 and Robinson, 1961). Thus, applying fertilizers to such soils can replenish the depleted soil nutrients and hence, increase coffee output and yield. The analysis indicated a statistically significant interaction between fertilizer and coffee yield of 1.59 (t=2.630, p = 0.009) influence coffee yield. The finding indicated that the average amount of fertilizers applied by adopters is 175 $gtree^{-1}$ and 58 g $tree^{-1}$ by non-adopters. According to TaCRI, (2011), 150 $gtree^{-1}$ to 300 g $tree^{-1}$ of fertilizers is recommended in a season depending on the amount of crop estimated in the current season. The findings also showed a positive relationship between coffee pruning and yield 238.34 (t=3.070, p = 0.003). According to TaCRI, (2011), coffee pruning is recommended three times a season. However, the coefficient of land expansion for the coffee farm (ha) showed a negative relationship of 59.54 (t=-2.530, p = 0.012) between coffee yield and coffee farm expansion which was expected.

Recommendations

The current world coffee demand is estimated to exceed production due to increase in global coffee consumption which is an opportunity for coffee producing countries like Tanzania to increase its production. Yield gap analysis method is an increasingly popular concept used to understand the factors that influence productivity to meet the increasing demand for agricultural products in the market. Coffee productivity in Tanzania is still low despite of having coffee varieties with the potential of producing more yield. This study aimed at understanding factors causing the yield gap among smallholders in the study area and proposing possible interventions to increase coffee productivity. The study shows that the rate of adoption of improved coffee varieties has increased from 20 % reported in 2017/18 to 38 % in 2019/20. The average coffee yield for adopters is 1235 kg $ha^{-1}$and non-adopters is 513 kg ha^{-1} The yield gap for adopters using farmers' records is 2286 kg ha^{-1}equivalent to 65 % and the yield gap for non-adopters is 791 kg ha^{-1}equivalent to 61 %. However, the yield gap using farmers'' records and research data for adopters is 765 kg ha^{-1} equivalent to 38% for non-adopters is 487 kg ha^{-1}equivalent to 49%.

The regression analysis indicated that the coffee yield among smallholder farmers is positively influenced by several factors including, coffee variety planted, plant population, access extension services, fertilizer applications, pruning, and amount of fertilizer applied ($gmtree^{-1}$).

Meanwhile, the finding showed that the yield is also negatively influenced by the expansion of new coffee farms, level of education, frequency of weeding, and control of coffee diseases. The indication of a high yield gap among adopters of improved coffee varieties in the study area which was associated with planting different types of improved coffee varieties in the farm with different levels of productivity call the need to develop a clear catalogue for seedlings distributions and mapping.

Meanwhile, the huge yield gap among smallholder farmers both adopters and non-adopters, are a key challenge to TaCRI, TCB, Ministry of Agriculture, and LGAs to encourage farmers to adopt yield-increasing strategies which will contribute to minimizing the coffee yield gap. Among the recommended strategies include: access to extension services to provide right extension training to farmers related to implementation of good agronomic practices such as proper fertilizers application, planting recommended coffee varieties and plant population per unit area.

Acknowledgements

I would like to express my special gratitude and appreciation to Tanzania Coffee Research Institute (TaCRI), Coffee stakeholders, and the Government of Tanzania for funding the research work.

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How to cite this article:

Leonard Kiwelu and Philip Damasand Zena Mpenda. 2022. Coffee Yield Gap Assessment Among Adopters and Non-adopters of Improved Coffee Varieties in Mbinga and Mbozi Districts, Tanzania. *Int.J.Curr.Res.Aca.Rev.* 10(02), 9-27. doi: https://doi.org/10.20546/ijcrar.2022.1002.002

Annex.1 List of coffee varieties and their average productivity

Name of variety	Descriptions	Yield (Kg ha-1)
N39-1	Arabica Hybrid tall varieties September 2005	2058
N39-2		2708
N39-3		2763
N39-4		1961
N39-5		2633
N39-6		2891
N39-7		2526
KP423-1		2225
KP423-3		1578
KP423-2	Arabica Hybrid tall varieties January 2011	1851
N39-8	Arabica Hybrid tall varieties Second generation January 2012	2000
N39-9		2700
N39-10		2400
N39-11		2700
N39-12		2400
TaCRI 1F	Arabica Hybrid compact varieties December 2013	6000
TaCRI 3F		5050
TaCRI 4F		4800
TaCRI 6F		6000
N39	Traditional coffee varieties	1000

Annex.2 Data set for computing yield gap using SAFERNAC model

PROFILE_NO	X	Y	Z	DISTRICT	DIVISION	WARD	OC_G_KG	N_G_KG	BRAY_1_P	K_MMOL_KG	PH_WATER	YBASE	YORG	YINORG	YCOMBI
TNS55	35.0604	-10.9132	1451	Mbinga	Mbinga Mjini	Utiri	34.30	2.50	48.000	8.30	6.57	467.48	623.00	842.36	844.71
TNS56	35.0573	-10.8824	1571	Mbinga	Mbinga Mjini	Utiri	25.60	1.50	1.000	6.20	5.81	487.46	694.99	1062.93	1039.99
TNS57	35.0600	-10.8663	1482	Mbinga	Mbinga Mjini	Utiri	25.70	1.30	34.000	3.00	5.56	387.85	608.93	894.20	948.66
TNS58	35.0775	-10.8526	1410	Mbinga	Mbinga Mjini	Utiri	39.70	1.90	40.500	2.50	5.47	279.96	630.42	772.80	891.41
TNS59	35.0575	-10.8322	1405	Mbinga	Mbinga Mjini	Utiri	36.80	1.80	22.000	4.20	5.53	412.80	691.51	874.00	968.57
TNS60	35.0729	-10.8947	1408	Mbinga	Mbinga Mjini	Utiri	32.60	1.70	23.000	2.10	5.88	278.21	557.37	733.83	828.27
TNS61	35.0389	-10.9034	1297	Mbinga	Mbinga Mjini	Utiri	37.20	1.80	17.000	2.40	5.29	277.98	557.80	726.31	815.17
TNS62	35.0118	-10.8837	1367	Mbinga	Mbinga Mjini	Utiri	43.70	2.40	13.000	2.60	5.28	262.72	582.53	716.33	805.94
TNS63	34.9871	-10.8859	1386	Mbinga	Mbinga Mjini	Utiri	38.40	2.00	4.000	3.90	5.51	364.33	618.48	788.20	847.33
TNS64	35.0283	-10.8407	1494	Mbinga	Mbinga Mjini	Utiri	38.30	2.20	7.000	4.80	5.67	386.78	571.72	773.53	795.55
TNS65	35.0109	-10.9152	1369	Mbinga	Mbinga Mjini	Utiri	28.50	1.80	2.500	10.40	5.47	444.26	593.83	837.62	822.02
TNS66	34.9809	-10.9208	1317	Mbinga	mbingaMjini	Utiri	31.70	1.80	2.000	2.20	5.91	251.40	457.11	651.03	674.63
TNS67	35.0606	-10.9753	1371	Mbinga	Mbinga Mjini	Kilimani	44.10	2.40	0.000	5.60	5.46	416.66	631.41	823.22	851.89
TNS68	35.04	-	151	Mbinga	Mbinga	Kilim	39.70	2.60	2.000	7.50	5.63	547.3	750.8	948.75	977.03

	16	10.9741	0		Mjini	ani						6	5		
TNS69	35.0407	-10.9919	1367	Mbinga	Mbinga Mjini	Kilimani	18.50	1.00	9.000	3.10	5.85	371.98	588.63	924.76	938.67
TNS70	35.0259	-11.0137	1152	Mbinga	Mbinga Mjini	Kilimani	44.00	3.00	36.000	4.10	5.91	378.57	685.21	819.17	907.33
TNS71	34.9913	-10.9943	1553	Mbinga	Mbinga Mjini	Kilimani	22.40	1.50	7.000	10.80	5.64	517.21	710.94	1049.77	1031.15
TNS72	34.9706	-10.9857	1366	Mbinga	Mbinga Mjini	Kilimani	16.00	0.90	18.000	7.10	5.71	327.85	557.74	1034.79	971.97
TNS73	34.9875	-11.0277	1286	Mbinga	Mbinga Mjini	Kilimani	18.60	1.30	26.000	7.10	5.58	469.24	675.91	1086.82	1041.25
TNS74	34.9963	-11.0422	1279	Mbinga	Mbinga Mjini	Kilimani	35.50	2.00	29.500	4.00	5.68	389.03	624.00	811.17	861.81
TNS75	35.0991	-10.9335	1258	Mbinga	Mbinga Mjini	Kilimani	17.80	1.40	10.000	12.80	5.54	628.11	837.77	1294.13	1229.91
TNS76	35.1062	-10.9763	1134	Mbinga	Mbinga Mjini	Kilimani	13.40	1.00	38.000	6.20	6.32	336.86	569.81	1066.42	997.23
TNS77	35.1357	-10.9822	1087	Mbinga	Mbinga Mjini	Kilimani	25.50	1.70	30.000	10.80	5.38	585.27	773.71	1107.50	1093.79
TNS175	32.8235	-9.1572	1589	Mbozi	Vwawa	Ihanda	18.20	1.10	6.500	9.20	4.81	298.70	451.92	734.05	703.87
TNS176	32.8695	-9.1707	1589	Mbozi	Vwawa	Ihanda	27.80	1.50	4.000	16.20	5.26	714.71	939.27	1424.00	1358.26
TNS190	32.9110	-8.8912	1517	Mbozi	Igamba	Igamba	25.80	1.30	4.000	11.60	5.89	477.50	657.47	910.60	893.55
TNS191	32.9413	-8.9380	1504	Mbozi	Igamba	Igamba	13.70	0.70	8.000	9.80	6.17	233.09	386.12	681.05	643.85
TNS192	32.9070	-8.9657	1613	Mbozi	Igamba	Igamba	23.30	1.10	1.500	10.10	5.83	362.96	513.85	774.84	751.54

TNS193	32.9170	-9.0263	1498	Mbozi	Igamba	Igamba	5.80	0.60	2.000	5.10	5.73	210.72	372.51	669.26	630.85
TNS194	32.9659	-8.9762	1494	Mbozi	Igamba	Igamba	11.70	0.50	5.000	5.40	5.84	190.90	381.48	658.49	630.56
TNS195	32.9716	-8.9150	1426	Mbozi	Igamba	Isansa	9.90	1.20	2.500	17.90	6.01	460.03	675.69	1080.31	1036.61
TNS196	33.0235	-8.9173	1335	Mbozi	Igamba	Isansa	16.90	1.40	18.000	22.80	5.96	316.26	468.48	759.01	722.49
TNS197	32.9926	-8.8206	1521	Mbozi	Igamba	Isansa	26.90	1.50	2.000	17.30	5.98	448.01	598.14	866.25	839.48
TNS198	32.9180	-8.8039	1553	Mbozi	Igamba	Isansa	23.70	1.20	2.000	19.40	6.02	395.87	548.57	836.36	803.57
TNS199	32.8580	-8.8634	1624	Mbozi	Igamba	Isansa	19.10	1.10	2.000	11.80	6.10	306.63	459.34	746.81	714.45
TNS200	32.8927	-8.8660	1624	Mbozi	Igamba	Isansa	17.40	0.80	2.000	14.30	5.58	323.54	544.39	985.37	954.43