



Significance of Carbon Farming for Improved Household Incomes in Baringo County, Kenya

*¹Kiprop John, ¹Sumukwo Joel & ²Odwor Paul

¹University of Eldoret, School of Environmental Sciences and Natural Resource Management, Department of Environmental Planning, Sustainability and Geo-Informatics

¹University of Eldoret, School of Environmental Sciences and Natural Resource Management, Department of Environmental Planning, Sustainability and Geo-Informatics

²University of Eldoret, School of Economics and Management Sciences, Department of Economics

*Corresponding E-mail: kipjkiprop@gmail.com

Abstract

Baringo County experiences high poverty rates of 40 percent which is above national rates of 36 percent. Climate change has aggravated this by negatively impacting farm productivity especially because of the high dependency on farming. Despite this, sustainable carbon farming is with potential of generating income through carbon trade. This study analysed the significance of agroforestry in generating carbon incomes among households in the county. It used survey data of 380 households collected mainly through stratified random sampling. The two sub-counties of Eldama Ravine and Baringo central were chosen for this study because of their ecological diversity, economic significance, and vulnerability to climate change. The results showed majority (56%) of the smallholder farmers had very low awareness on carbon farming and selling of carbon credits. In spite of this, a majority (90%) of them had implemented farming activities that would meet the threshold for carbon trading. Among the 90% of respondents that practiced carbon farming, a majority of them (43%) practiced exotic and indigenous tree agroforestry, and 37% did fruit farming agroforestry. Results also indicate that the area provides an annual carbon sequestration of approximately 25,982.2 tCO₂e/year, translating to an annual carbon income of 259,822 USD/year (KSh. 33,776,860), or USD. 56.98 (KSh. 7,407.4) per month. In conclusion, carbon farming and trading presents potential tangible income to smallholder farmers in Baringo County. This study recommends for improved sensitization of farmers on carbon farming and its potential in enhancing household incomes.

Keywords: Climate Change, Agroforestry, Carbon farming

INTRODUCTION

In developing countries like Kenya, traditional, smallholder agriculture has been a mainstay of livelihoods for decades, this important role is currently facing challenges of climate change and is exasperated with the ever-increasing human population besides industrialization (Altieri and Nicholls, 2017; Tschora and Cherubini, 2019). In the previous 3 decades, agriculture has remained central to Kenya's economic development, constituting 28% to the country's gross domestic product (GDP) and accounting for 65% of Kenya's total exports earnings (Climate-Smart Agriculture in Kenya 2015). Majority (80 percent) of the world's most economically disadvantaged individuals reside in rural areas and rely on agriculture as their primary source of livelihood (Zerssa *et al.*, 2021). The rural economy is most vulnerable to climatic variability due to its high-dependency on rain-fed agriculture for livelihood.

Baringo County experiences high poverty rates of 40 percent which is above national rates of 36 percent (KNBS, 2020). Climate change has aggravated this by negatively impacting farm productivity especially because of the high dependency on farming. Despite this, sustainable carbon farming has potential of generating income through carbon trade. Without practicing carbon farming in the Arid and Semi-Arid Lands of Baringo, there is likelihood of the smallholder farmers continuing experiencing low farm productivity and worsening of food insecurity and poverty.

The objective is to analyse the significance of carbon farming for improving household incomes among smallholder farmers in Baringo County, Kenya. Research hypothesis is: there is no significant relationship between agroforestry farming and generation of carbon incomes for household incomes. By exploring the potential of carbon farming on

income improvement, this study intends to contribute valuable insights to the existing body of knowledge by giving information for policy decision-making on any necessary policy gaps for sustainable farming in rural areas.

MATERIALS AND METHODS

Baringo county provides strategic significance to this study by providing various agro-ecological zones, showing the climatic vulnerability.

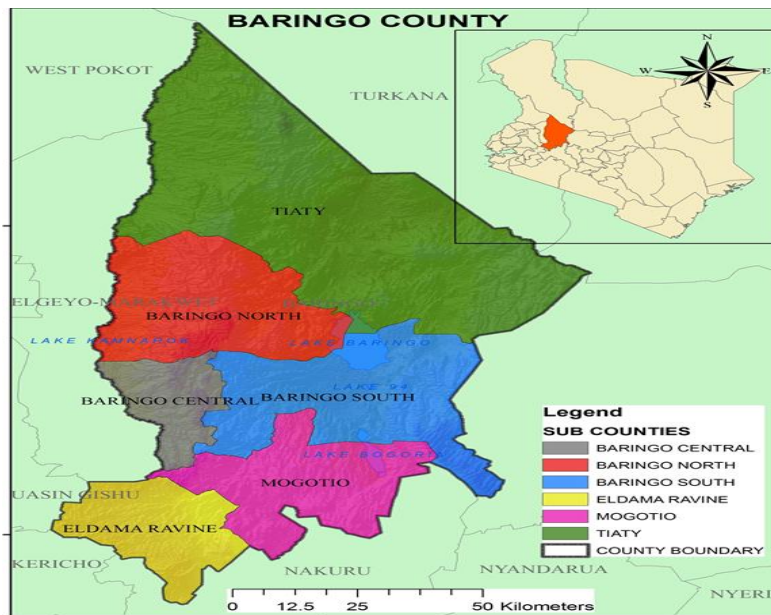


Figure 1: Map of Baringo County (Source: Baringo county CIDP 2023-27)

Eldama Ravine and Baringo Central sub-counties were selected due to relatively higher adoption rates of agroforestry compared to other sub-counties. These areas feature established tree-planting initiatives, mixed farming systems, and community-based conservation efforts, providing a suitable environment for examining agroforestry's contribution to carbon income generation through carbon credits.

Calculation of Carbon income/ credits using Benefit Transfer Approach

In the study, Benefit Transfer Approach (BTA) was used to estimate potential carbon income for households practicing agroforestry in Baringo County. The BTA is an economic valuation method used to estimate ecosystem service values, such as carbon sequestration benefits, by applying findings from existing studies to a similar context. Instead of conducting primary valuation research, carbon sequestration rates from comparable agroforestry studies in arid and semi-arid lands were utilized.

Research Design

This study applied a correlational research design in investigating relationships between variables without the researcher controlling or manipulating.

Target Population and Sampling Frame

The sampling frame in the study came from the 39,101 target respondents. The study used a purposeful sampling technique for the government officers and applied Stratified sampling technique to select local community respondents at the sub-county level, administrative location level and at the lowest unit of village level, while households selecting used random sampling technique. The sample size of 380 was obtained from the target population using the Krejcie & Morgan (1970).

Data Collection Procedures

A pilot study was conducted on a 10% (38 people) population according to Isaac, S., & Michael, W. B. (1995), at Mogotio sub-county to pre-test the instruments prior to conducting the actual study. The researcher trained research assistants on the content of the questionnaire, terminologies used and the general research expectations. This was to enhance their practical skills on administration of the research instrument.

Data Analysis

Data processing involved collection, recording, organizing, storing and adapting or altering to convert the raw data into useful information. Data processing therefore is comprised of six stages: collection, preparation, data input, processing, interpretation, and data storage. IBM SPSS (version 29) software was used to determine causal relationships between different variables. The data obtained from questionnaires, interviews, observations, document analysis and secondary data was subjected to descriptive and inferential statistical analysis such as multiple regression to determine the strength of association between independent variables and dependent variable.

RESULTS AND DISCUSSION

Socio-Economic and Demographic Information

Out of 380 administered questionnaires, 374 were returned fully, where 164 female and 210 male respondents, completed. This represents a 98 percent response rate which was deemed adequate for further analysis (Saass *et al.*, 2014).

Carbon Farming for Improved Household Incomes

This section aimed to examine influence of agroforestry on generating carbon incomes. It provides detailed analysis on the following factors: perceptions and influence of agroforestry in generation of carbon incomes, potential household income, and regression analysis carbon incomes.



Figure 1: Agroforestry Alongside Coffee Farming (Left); and Alongside Tea Farming (Right)

Perceptions on Importance of Agroforestry in Generating Carbon Incomes

The respondents were asked on importance of agroforestry in generating carbon incomes, and majority of them (56%) either objected or they were uncertain. Only 163 respondents (44%) affirmed that agroforestry was important in generation of carbon incomes. (Figure 2).

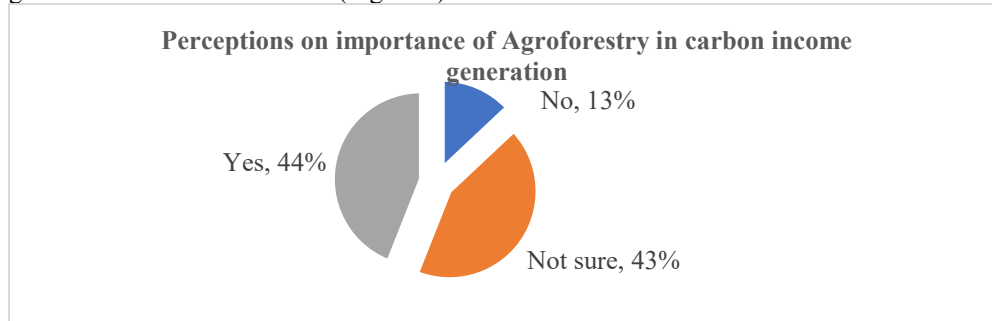


Figure 2: Perceptions on importance of Agroforestry in carbon income generation

These results implied that most smallholder farmers had very low awareness on carbon farming and selling of carbon credits. It therefore means that sensitization was required on carbon farming and trading. Among the farmers that affirmed the importance of agroforestry in carbon income generation listed the following ways that agroforestry would lead to carbon income generation: Absorption of carbon dioxide by reducing amount of greenhouse gases, climate change mitigation and land management practice; increase in biodiversity; improved soil health and soil fertility hence increase in agricultural productivity; Participation in carbon markets and selling carbon credits; The higher the tree biomass, the more the carbon income.

Practicing of Carbon Farming by Smallholder Farmers

When the farmers were asked whether they had practiced carbon farming before, 90% affirmed, while 10% had never practiced any carbon farming-related activity (Figure 3). Majority of them (51%) had experience of practicing for a period of 1 year to 10 years. In the seven (7) sub-locations where the study was conducted, both Riwo sub-location and Kirobon sub-location of Baringo central sub-county and Eldama Ravine sub-county, respectively, all (100%) of the respondents practiced carbon farming-related activities. Solian sub-location had the least percentage (52%) of respondents practicing carbon farming-related activities. (Figure 3).

This meant that the farmers may not have traded on any carbon credits but they implemented farming activities that would meet the threshold for trading on carbon farming in all the sub-locations of the study area. This is evidenced by Figure 5 that shows only 13 out of the 374 respondents (6 female and 7 male), equivalent to 3%, that had benefitted from actual generation of carbon incomes through sell of carbon credits. Most of the types of carbon farming-related activities (80%) were agroforestry practiced through planting exotic and indigenous tree species and fruit farming.

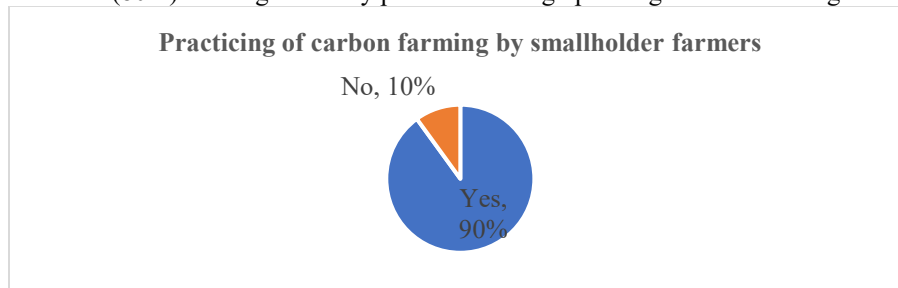


Figure 3: Practicing of Carbon Farming by Smallholder Farmers

The explanation of high percentage (90%) is that carbon farming aligns with traditional farming methods, such as agroforestry, minimal tillage, and water conservation, which many farmers had already been practicing, even if not explicitly labeled as "carbon farming." Additionally, the adoption of these practices were driven by economic incentives, environmental benefits, and increasing climate variability, which necessitates more sustainable farming

approaches. The 10% of farmers who reported to have never involved in carbon farming-related activities indicated the presence of barriers to adoption, such as lack of awareness, inadequate technical support, financial constraints, or land tenure issues. They might be engaged in conventional farming techniques without climate-smart principles, relevant training and incentives.

The implication of these results is that while carbon farming adoption was high, there was still need for targeted interventions to reach the remaining farmers who had not yet adopted these practices.

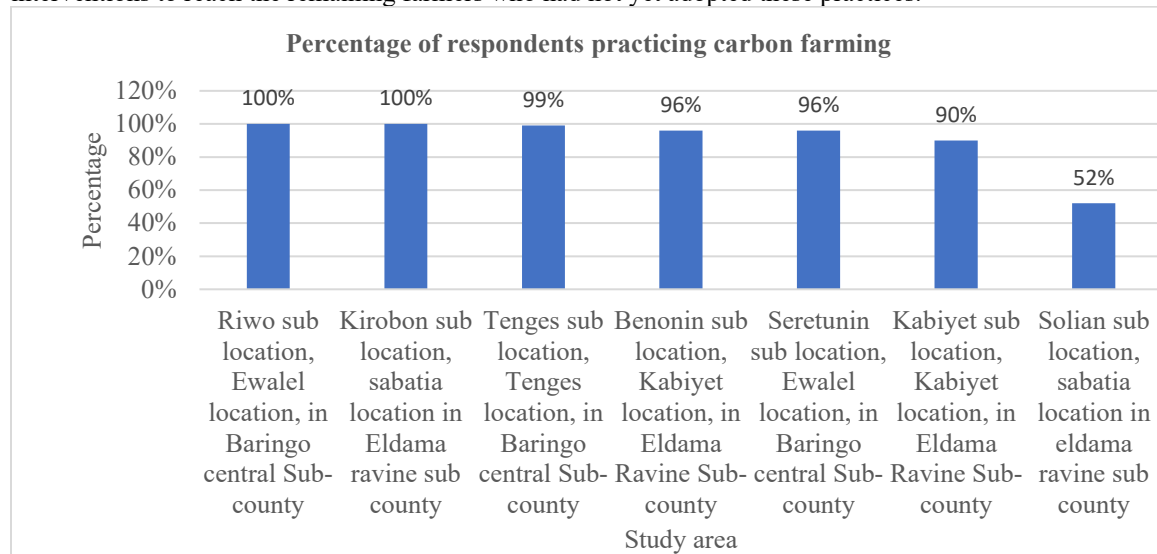


Figure 4: Percentage of Respondents Practicing Carbon Farming

The findings also show a variation in adoption rates across different sub-locations. Notably, Riwo and Kirobon sub-locations in Baringo Central and Eldama Ravine sub-counties recorded a 100% adoption rate, indicating that all respondents in these areas engaged in carbon farming-related activities. This could be attributed to effective extension services, favorable agro-ecological conditions, and active community participation in climate-friendly farming initiatives in these sub-locations. Additionally, these areas had better access to information, incentives, and technical support from government agencies, NGOs, and private sector actors involved in promoting carbon farming. On the other hand, Solian sub-location had the lowest adoption rate at 52%, suggesting possible barriers to participation in carbon farming-related activities. These barriers could include limited access to climate information, financial constraints, lack of awareness, or socio-economic and cultural factors that influenced farming decisions.

The implication of these findings is that carbon farming had gained significant traction in most areas, but disparities in adoption rates across sub-locations highlighted the need for targeted interventions.

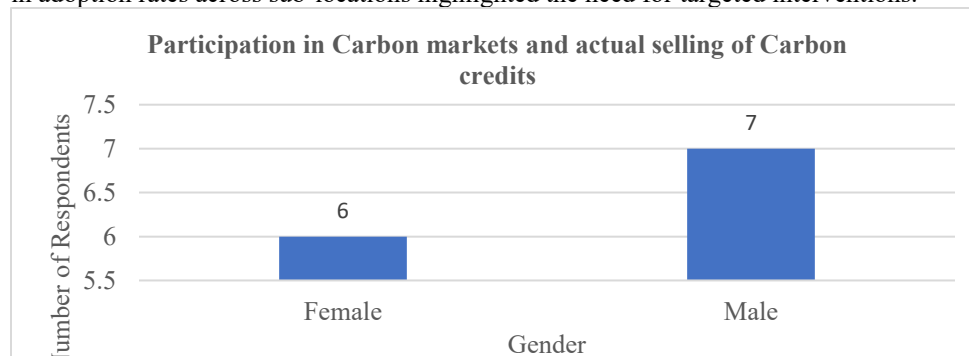


Figure 5: Participation in Carbon Markets and Actual Selling of Carbon Credits

While the percentage of smallholder farmers practicing carbon farming was very high, at an average of 90% in the Sub-locations, the percentage of them that had benefitted from actual generation of carbon incomes through sell of carbon credits, was very low, at 3% (i.e. 13 respondents). This discrepancy suggests that while many smallholder farmers were actively engaging in carbon farming related practices, they faced substantial barriers in monetizing these efforts through carbon markets.

One of the key challenges identified is the complexity of carbon trading and high transaction costs. The process of selling carbon credits involves rigorous verification, certification, and registration procedures, which require technical expertise, financial resources, and institutional support. The smallholder farmers, who lacked specialized knowledge and financial capacity, struggled to navigate these requirements, limiting their ability to access carbon markets. Additionally, limited access to carbon credit buyers further hindered participation. The carbon market typically favored large-scale projects, making it difficult for smallholder farmers to compete unless they were organized into cooperatives or benefit from intermediaries who could facilitate the transactions.

The implication of these findings is that while carbon farming had great potential for improving farmer incomes and enhancing climate resilience, its benefits remained largely unrealized without proper support systems. To bridge this gap, there was a need for capacity-building initiatives to educate farmers on carbon market dynamics, financial support mechanisms to offset high transaction costs, and policy interventions to simplify the process of carbon credit certification and sales. Furthermore, the creation of farmer cooperatives or partnerships with organizations specializing in carbon finance could help lower individual costs and improve market access. Innovative solutions such as digital platforms for carbon credit trading, government incentives, and public-private partnerships could also enhance participation and ensure that smallholder farmers received fair compensation for their carbon sequestration efforts.

Influence of Agroforestry Practices on Carbon Income Generation

A question was posed to the respondents to rank the four main types of agroforestry on their potentials towards carbon income generation. Planting of exotic, drought-tolerant agroforestry tree species (95%); indigenous drought-tolerant tree species (90); Fruit farming (89%); and, Planting of fodder trees (84%). (Figure 6).

Apart from the above, different varieties of agroforestry were being grown in the study area. These included the following: Apple, Passion, Avocado, Gravellia, Cypress, Pine, Croton trees, Podo, Nandi flame, Neem tree, Coffee, Vegetables, Beans, Meru oak, Mango trees, Pawpaw, Citrus, Oranges, Guavas, Boma Rhodes grass, Nappier grass, Cassava, Banana, Macadamia, White supporter, Fodder plants (e.g. Lucerne, Calliandra), Eucalyptus, Tree tomato, and Desmodium.

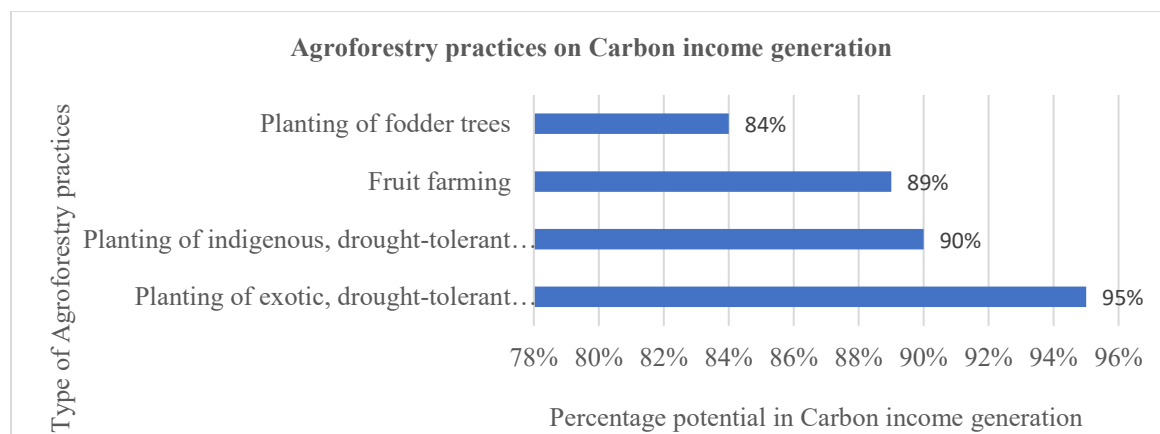


Figure 6: Agroforestry Practices on Carbon Income Generation



These results implied that all the four ranked types of agroforestry had high potential to generate carbon income. Hence, all the four needed to be promoted in the area.

The ANOVA and Multivariate Analysis on Agroforestry and Generation of Household Carbon Incomes

Table 1 shows R-squared value of 0.545, meaning that the agroforestry-related independent variables, such as fruit farming, planting of fodder trees, and planting of drought-tolerant trees, together explain 54.5% of the variation in household carbon income. This suggests a moderate model fit, with 45.5% of the variation in carbon income attributable to other factors that are not included in this model. These findings are supported studies, such as Quandt (2020) and Chemura et al. (2021), who emphasized agroforestry's role in climate resilience and income diversification. Tschora & Cherubini (2020), noted that agroforestry systems offered significant mitigation and livelihood co-benefits through carbon sequestration and improved soil health.

Table 1: Model Summary Agroforestry and Carbon Incomes

Model	R	R Square	Adjusted Square	R Std. Error of the Estimate
1	0.681 ^a	0.545	0.538	0.470

a. Predictors: (Constant), Agroforestry generates_Carbon_Income

The results of the ANOVA test in Table 2 show that the regression model examining the relationship between agroforestry practices and carbon income generation is statistically significant. The F-calculated value is 416.290, which is greater than the F-critical value of 3.912 at the 0.05 significance level. This suggests that the model provides a better fit to the data than a model with no predictors. The p-value is 0.000, which is well below 0.05. This confirms that the regression model is highly significant and that the combined agroforestry predictors reliably explain variations in carbon income generation among smallholder farmers in Baringo county. This result confirms that agroforestry practices, such as fruit farming, fodder trees, and drought-tolerant species (exotic and indigenous), collectively have a statistically significant impact on carbon income generation. These findings align with studies by Chemura et al. (2021) and Quandt (2020) who reported that agroforestry enhances both carbon sequestration and farmers' income streams. Tschora & Cherubini (2020), who emphasized that integrating trees into farming systems provides long-term ecological and economic benefits.

Table 2: ANOVA for Agroforestry and Carbon Incomes

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.905	1	12.905	416.290	.000 ^b
	Residual	10.774	344	0.031		
	Total	23.679	345			

a. Dependent Variable: Carbon Income Generation

b. Predictors: (Constant), Agroforestry generates Carbon Income

Table 3 shows the regression model for determining the influence of agroforestry on carbon income generation as expressed below:

$$Y = 1.696 + 0.267X$$

Where:



Y = Carbon Income Generation

X = Agroforestry

The unstandardized coefficient (B) of 0.267 implies that for every one-unit increase in agroforestry practice, carbon income generation increases by 0.267 units, holding other variables constant. The t-value = 4.794 and the p-value = 0.000, which is less than 0.05, indicate that this relationship is statistically significant. These results demonstrate that agroforestry practices significantly contribute to increased carbon income among smallholder farmers. The findings agree with Quandt et al. (2022), who emphasized agroforestry's dual role in environmental conservation and income generation, and Chemura et al. (2021) and Tschora & Cherubini (2020), who confirmed that agroforestry improves both carbon sequestration and economic resilience.

Table 3: Coefficients for Agroforestry and Carbon Incomes

Model	Unstandardized Coefficients		Standardized Coefficients		Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta	t		Lower Bound	Upper Bound
1 (Constant)	1.696	0.467		3.632	0.003	0.478	2.314
Agroforestry	0.267	0.055	0.559	4.794	0.000	0.160	0.375

a. Dependent Variable: Carbon Income_Generation

In conclusion, therefore, given the R^2 value of 0.545 and a statistically significant regression model and also as supported by ANOVA results that showed F-calculated value of 416.290 which was greater than the F-critical value of 3.912 and p-value of 0.000 which is below the 0.05, the study rejects the null hypothesis. Agroforestry practices are thus confirmed as important contributors to household carbon income generation in Baringo County.

Potential Household Carbon Incomes

In this study, the Benefit Transfer Approach (BTA) was employed to estimate the potential carbon income for households practicing agroforestry in Baringo County, by applying findings from existing studies to a similar context. Therefore, carbon sequestration rates from comparable agroforestry studies in arid and semi-arid lands were utilized. Studies have been conducted in arid and semi-arid regions of Machakos, West Pokot and Tana River, Kenya, which are ASAL areas like Baringo County, focusing on agroforestry and socioeconomic and environmental impacts.

The total land size that was already under agroforestry in the study area was 177.56 Ha. The farmers intended to set aside additional 144.8 Ha of land, for additional agroforestry having understood the potential of generating carbon income from carbon farming, so total land under agroforestry is 322.36Ha. The number of households was 39,101 households.

In Eldama Ravine and Baringo Central, farmers have increasingly adopted the cultivation of fruit trees such as avocado (*Persea americana*), papaya (*Carica papaya*), macadamia (*Macadamia integrifolia*), and guava (*Psidium guajava*), not only for their economic and nutritional benefits but also for their potential in carbon sequestration (Muthuri et al., 2023). Studies have shown that mango and avocado trees store significant amounts of carbon in above-ground biomass, averaging 10.5 ± 2.9 Mg C ha⁻¹ (i.e. 38.54 tCO₂e/ha) and 9.7 ± 2.5 Mg C ha⁻¹, (i.e. 35.56 tCO₂e/ha) respectively. The values of carbon estimates for both mango (10.5 Mg C ha⁻¹) (38.54 tCO₂e/ha) and avocado (9.7 Mg C ha⁻¹) (35.56 tCO₂e/ha) are within the range of agroforestry systems in semi-arid (9 Mg C ha⁻¹) and sub-humid (21 Mg C ha⁻¹) tropics in Africa (Naik et al., 2019) but lower than estimates for tropical forest ecosystems.



On the other hand, UTNWF (2023) in a study conducted in upper Tana watershed indicated that Avocado (*Persea americana*) was mainly grown for its fruit for human but surplus fruit was also an important food source for pigs and other livestock. The study also indicated that the carbon potential for Avocado was 32 tC/ha (117 tCO₂e/ha) from biomass and 13 tC/ha from soil carbon. The average land size for the target households was 0.4 Ha per household, while the average carbon price was about USD. 10 per tonne.

Considering that the land productivity and species of agroforestry trees grown in the study area were about 60% of that of upper Tana watershed, as indicated by UTNWF (2023), and 40% equivalent to those in humid areas, where carbon potential for Avocado was indicated to be 9.7 Mg C ha⁻¹ (35.56 tCO₂e/ha) as indicated by Naik et al. (2019), this study adopted an average carbon potential of 80.6 tCO₂e/ha.

Therefore, the potential household income was calculated as follows:

1. Total carbon sequestration potential:

The formula below was used to calculate the total potential carbon sequestration:

$$y = X_1 \times X_2$$

Where,

y = Total carbon sequestration for all land

X₁ = Total land under Agroforestry (322.36 Ha).

X₂ = Average carbon sequestration potential (80.6 tCO₂e/ha).

Therefore, Total carbon sequestration for all land (y) = 322.36 Ha x 80.6 tCO₂e/ha = 25,982.2 tCO₂e/ year.

1. Total carbon income:

The total carbon income:

$$y = X_1 \times X_2$$

Where,

y = Total Carbon income

X₁ = Total carbon sequestration for all land (25,982.2 tCO₂e/ year)

X₂ = Carbon price (10 USD/ tCO₂e)

Therefore, Total carbon income (y) = 25,982.2 tCO₂e/year x 10 USD/ tCO₂e = 259,822 USD/year.

2. Carbon Income per Household:

The carbon income per household: $y = \frac{X_1}{X_2}$

Where,

y = Average Carbon income per Household per year

X₁ = Total Carbon income (USD. 259,822)

X₂ = Total number of households (380 households)

Therefore, Average Carbon income per Household per year:

$$= \frac{\text{Total Carbon income}}{\text{Total number of households}} = 683.7 \text{ USD/ household/ year}$$

Therefore, the Average Carbon income per Household per Month:

$$= \frac{\text{Average Carbon income per Household per year}}{\text{Number of months in a year}} = 56.98 \text{ USD(KSh. 7,407.4)/ household/ month}$$

CONCLUSIONS AND RECOMMENDATIONS

The importance of agroforestry in generating carbon income for household incomes was predicted through ANOVA test and multiple regression from agroforestry, indigenous drought tolerant agroforestry trees, exotic drought tolerant agroforestry trees, fruit farming and fodder trees, which indicated that the five variables statistically significantly predicted Carbon incomes. The study findings were concomitant to other studies (Quandt, 2020 and Chemura, *et al.* 2021), which found out that in Kenya, farmers had highlighted how they were able to increase resilience to drought through the planting of drought-tolerant tree species.

In conclusion, the findings indicate that fruit trees alone provided an annual carbon sequestration of approximately 25,982.2 tCO₂e/ year, translating to an annual carbon income of 259,822 USD/year (KSh. 33,776,860), or USD. 56.98



(KSh. 7,407.4) per month. This highlights the tangible income potential of carbon farming and trading for Baringo county smallholder farmers. Therefore, null hypothesis is rejected.

We recommend that since majority of the smallholder farmers had very low awareness on carbon farming and selling of carbon credits, there is need to enhance smallholder farmers' participation in carbon farming, awareness creation and capacity building should be prioritized through training programs, community workshops, and educational materials on carbon credits and agroforestry benefits.

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