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Effects of Crop Diversification on Food Crop Productivity Among Smallholder Coffee Farmers in Kirinyaga County, Kenya

Micheni Pauline Kananu[1, *], Gathungu Geofrey Kingori[2], Dennis K. Muriithi[3], Ngeretha Njoki Ann[4]

[1]Department of Agribusiness Management, Agricultural Economics and Agricultural Education and Extension, Faculty of Agriculture, Chuka University, Chuka, Kenya

[2]Department of Plant Sciences, Faculty of Agriculture, Chuka University, Chuka, Kenya

[3]Department of Physical Sciences, Faculty of Science, Engineering and Technology, Chuka University, Chuka, Kenya

[4]Department of Business Administration, Faculty of Business Studies, Chuka University, Chuka, Kenya

Email address:

kananumicheni@gmail.com (Micheni Pauline Kananu)

[*]Corresponding author

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Abstract: Crop production increases food security and nutrition, and enhances livelihoods of rural populace in Kenya. There is a low levels of crops productivity in Kirinyaga County, and there is need to increase the production to feed the expanding population. This study aimed to analyze the effects of crop diversification on smallholder coffee farmers' selected crops productivity in Kirinyaga Central and East Sub-Counties. The study was guided by utility maximization theory and response variables' nature. The study was done in three agro-ecological zones (UM1, UM2, UM3) using a descriptive research design to collect smallholder coffee farmers' household data on effects of crop diversification. A multistage sampling techniques was used to obtain a sample size of 408. Structured questionnaires were administered using Kobo toolbox to obtain data and Fractional Regression model was used to analyze data. The study found out that the average food crop productivity was 0.379, indicating low level. The study also found that there was a relationship between choice of crop diversification and selected crop productivity at $p=0.000<0.05$. Landscape heterogeneity (5.7%), crop rotation (13.4%), crop species diversity (56.6%) and land size (10.5%) were found to positively influence crops productivity whereas it was negatively influenced by agro ecological zones (AEZs) (4.4%). In conclusion, the study established that crop species diversity is the greatest contributor to crop productivity while agro-ecological zones (AEZs) negatively influenced it. The study recommends that extension providers be well trained, their content revised and supported financially to implement extension programs and policies that promote adoption of crop diversification strategies which enhances yield.

Keywords: Smallholder Farmer, Crop Diversification, Crop Productivity, Partial Factor Productivity

1. Introduction

1.1. Background Information

Crop production is still the single most important productive sector in most African countries, in terms of its share in gross domestic product (30-40%) and number of people it employs (65-70%) [1]. Also, small farms dominate production in Africa and about 70-80% of them own less than 2 hectares of land. However, crop productivity in Africa particularly is generally on the decline, and governments imports food of about US$ 60 billion, with cereals accounting for US$ 25 billion per year [2]. In Africa, although crops cultivated play a key role in enhancing food security, yields produced of many staple crops are still far below their agronomic potentials with output increases being attributed largely to area expansion [3]. African population has been growing at a very high rate and by 2050 it's expected to reach 2.48 billion from the current 1.46 billion [4], therefore the produce from the agriculture sector cannot feed its citizens. To end hunger by 2025, African head of states and government 2014 Malabo declaration made commitment to double productivity and improve nutrition [5].

Results under different geographical areas showed that a one degree Celsius increase in global average temperature lowered world average yields of wheat, corn, rice, and soybeans by 6%, 7.4%, 3.2%, and 3.1%, respectively [6]. In Africa, Asia and Latin America, climate parameters such as heightened temperatures, rising atmospheric CO_2 concentrations and changing precipitation patterns increase crop pests and diseases and pose a serious risk of crop economic losses [7]. Savary [8]) noted that losses of about 30% of global food production are caused by crop pests and diseases owing to changes in climate. Daudu [9] found out that smallholder farmers in Africa live in environmentally fragile areas that have undergone ecosystem degradation making them highly vulnerable to climate change owing to their high dependence on ecosystem goods and services for crop productivity. It is reported that Ethiopia loses about 1 billion tons of topsoil annually while Nigeria records 30 million tons of soil loss per year due to soil erosion [10]. In Sub-Saharan Africa, many countries have weakness in crops productivity due to poor soils, pests and diseases, weeds and limited use of essential inputs such as improved seeds and farming technologies [11]

It is possible that to maximize land productivity some strategies need to be adopted such as soil management and fertility, selecting crop varieties well-suited for specific soil and climatic conditions of land, rotating crops, sustainable land use practices like agroforestry systems and staying informed about the latest agricultural research, techniques and best practices [12]. To improve crop yields, there is need to focus on making the appropriate productivity enhancing technologies available to farmers such as crop diversification which are currently suboptimal. Chen [13] reported that adapting diversifying strategies through combined activities like crop species diversity, crop varietal diversity, intercropping and rotating crops could be effective in dealing with the increasing number of unpredictable extreme weather conditions. According to Vernooy [14] diversity among and within crop species and varieties facilitates ecosystem functioning and the provision of ecosystem services, which acts as a buffer against crop failure. Diverse crop system then, is an important technique that may be used to boost future food productivity growth in agriculture by improving the efficient use of natural resource, growing crops that are resilient to changes in climate and maintaining environmental sustainability [15].

Farmers use cultivar mixture derived from genetic diversity to boost crop yield [16] offer yield stability [17], manage diseases [18], boosts resource utilization and efficiency [19], promote soil health by reducing soil erosion [20] and enhancing fertility [21] as well as stopping the spread of pests and diseases [22]. It is possible that the choice of crop varieties or cultivars boosts crop productivity since they are genetically improved for high yielding, disease resistance, pest tolerance, drought resistance and high nutrient use efficiency. Marcos-Pérez [21] observed that intercropping resulted to higher total production per area than monocrops where (Land Equivalent Ratio) LER values were larger than one. It is possible that use of intercropping techniques boost soil fertility, which enhances management of land use and produces crops with a profitable yield. Further, Metwally [23] found that heavy crop density led to LER values of 1.22 and 1.28 for maize produced for grain and peanut plants, respectively in Egypt. This implies that 22% and 28% additional land area would be required by sole cropping systems to equal the yields of intercrops.

Diverse landscape heterogeneity promotes ecological and biodiversity functions like natural pest management and pollination which increase fruit and seed production while, also influencing access to resources like water and fertile soils [24]. In contrast, human activities such as deforestation or urbanization can reduce landscape heterogeneity and negatively affect crop yields [25]. Changes in land use can result in soil degradation, decreased water availability and biodiversity loss, all of which decrease crop yields [26], thus there is need to practice sustainable land practices. Larger land sizes can also offer more resources such as soil, water and sunlight, which is essential for crop growth, which leads them to support higher crop yields [27]. Furthermore, Agro-ecological zones (AEZS) can have a significant influence on food crop productivity, as different crops have different requirements for soil, water, temperature, and other environmental factors [28], and Adjei [29] noted that the type and quality of soil in an AEZ can significantly affect crop productivity for example crops like yams and cassava increase yields in less fertile and well drained soils.

Strategies of diversified cropping system have been well emphasized by public policies but not well practiced in Kenya. Most agricultural producers are smallholder farmers and most are incapable of diversifying their crops due to the nature of their farms such as quality of soil, land size, infrastructure of irrigation and local unsuitable environmental conditions [30]. Past studies have showed that to increase crop productivity, the main focus would be on agricultural intensification (yield per unit area) rather than expansion of the cultivated area [31]. However, In Kirinyaga Central and Kirinyaga East Sub-Counties, there is low level of food crop productivity. Crop diversification strategies are not widely adopted in the study area despite its vital effectiveness in increasing food crop productivity among smallholder coffee farmers. To achieve sustainable development goal (SDG) 12, there is need for government to emphasize on policies regarding sustainable agriculture and responsible resource management, which are fundamental for achieving sustainable food crop productivity. The study tests the hypothesis that there is no statistically significant influence of choice of crop diversification strategies on selected crops productivity among smallholder coffee farmers in Kirinyaga Central and Kirinyaga East Sub-Counties.

1.2. Conceptual and Theoretical Framework

The conceptual framework for this paper was built upon the crop diversification strategies on how they influence crop productivity under uncertainties of climate change to improve farmers' livelihoods. According to Taylor & Adelman [32] farmers base their decision to diversify crops on the agricultural household. Crop diversification is said to involve choices on production strategies. By use of Random Utility Model (RUM), the choice of smallholder farmers for crop diversification strategies can be envisioned. This is due to the fact that it is excellent at modeling discrete choice decisions. Subject to the input constraints brought on by household production (total cropped area, crop diversification technologies) and output produced (crop productivity) maximizes farm households' utility. The ability of the factors of production to produce output is measured by productivity. Crop productivity is a quantitative indicator of crop yield within a certain field area where efficient use of natural resources like soil and water, pest and disease management, efficient farm management practices and the introduction of novel crop varieties make significant contributions to increased plant productivity [33].

Realistically, a household would choose one or more crop diversification strategies from among the available alternatives. If U_{i1} represent the utility farmer *i* receives from participating in crop diversification and U_{i0} be the utility for non-participation. If X_1 be a vector of crop diversification strategies such as intercropping, crop rotation, crop species diversity, crop variety diversity, landscape heterogeneity, agro-ecological zone and land size and if ε_i be the error term. Based on state to participation, the utility of farmer *i* can be estimated as follows:

$$\{U_{i1} = f(X_{i1}) + \varepsilon_{i1}\} \text{ Participation} \quad (1)$$

$$\{U_{i0} = f(X_{i0}) + \varepsilon_{i0}\} \text{ Non-participation} \quad (2)$$

Farmer *i* will choose to participate in crop diversification only if the utility derived from participating is greater than the utility from not participating. That is, a smallholder farmer adopts crop diversification if ($U_{i1} > U_{i0}$). The only thing that can be observed is characteristics of household and attributes of the alternatives as faced by the decision-maker since utilities are not observable. The following latent structure model for participation in crop diversification can express the utilities.

$$Z_i^* = \gamma X_i + \varepsilon_i \quad (3)$$

where;

Z_i^* is a binary variable that has a value of 1 for engagement in crop diversification and a value of 0 for non-participation. Explanatory variables chosen based on the literature are X_i [34].

2. Methodology

2.1. Description of the Study Area

The research study was conducted in two Kirinyaga Sub-Counties (Kirinyaga East and Kirinyaga Central) chosen from a total of five Sub-Counties in Kirinyaga County in the Central highlands of Kenya. The area lies between Longitude 37° 10' 0'' E and 37°30' 0'' E and latitudes 0°10' 0'' S and 0° 40'0'' S. The two Sub-Counties are divided into three coffee agro-ecological zones [Upper Midland 1 which is Coffee-tea zone, Upper midland 2 (the main coffee zone) and Upper midland 3 (marginal coffee zone]. The area's rainfall pattern is bimodal, meaning that it has two different rainy seasons, with heavy rainfall between March to May with average of 2146 mm, and a reasonable amount of rainfall from October to November averaging 1212 mm. The temperature of the area is between 18.4°C to 30.3°C. Most of the areas in Kirinyaga East and Central Sub-Counties are highly populated. The area is characterized by rapid population growth, and crop productivity has dramatically reduced over the last three decades [35]. Agriculture is the main source of food and income especially for rural dwellers, where they grow a variety of both perennial and annual crops such as coffee (*Coffee spp*), tea (*Camellia sinensis L*), maize (*Zea mays*), beans (*Phaseolus vulgaris L*), bananas (*Musa spp*), sweet potatoes (*Ipomea batatas L*), vegetables and fruits [35]. The selection of these two Sub-Counties in Kirinyaga was informed by their relatively visible involvement in agricultural activities and potential of growing a diverse range of food crops.

2.2. Research Design

Descriptive research design was used in the study. Without changing the study's settings, descriptive survey research design provides a thorough investigation of the question at hand in a short amount of time

2.3. Research Instrument and Data Collection

The study involved collecting data on crop diversification strategies like intercropping, crop rotation, crop species diversity, crop varietal diversity and landscape heterogeneity as well as on selected crops production within the households. The study targeted smallholder coffee producers. A sample size of 408 smallholder coffee producer households was sampled using multistage sampling technique. The procedure involved stratifying the three AEZs in the two areas of study from which 12 administrative wards were purposively selected and a proportionate to size sampling randomly obtained the respondents. The coffee producer inclusion criteria were orientation towards those holding less than 2 hectares of land, grew coffee and had potential to diversify to food crops or were already diversifying in the last five years. Local administrators (village elders) and agricultural extension officers were involved in aiding the tracing of potential respondent households. This was also used as a strategy for increasing the response rate. An electronically structured questionnaire designed in Kobo Toolbox was used for data collection due to safety. The questionnaire was administered by duly trained enumerators using Kobo Collect mobile application. Therefore, prior to data collection, enumerators underwent training and later conducted a pilot study in Runyenjes Sub-County, Embu County to pretest the questionnaire in order to prepare them in conducting the actual survey. Both paper and electronic format questionnaire were used for training enumerators with the aim of providing safeguard for instances of mobile gadgets failure during data collection. In cases where the paper questionnaire was used in data collection, the resultant data was fed into the Kobo Collect application once the concerned enumerator completed their day's allocation. To enrich the study, additional notes (to capture observations) were made in notebooks that were provided for the enumerators during the survey. Once the survey was done, data was sent to the Kobo Toolbox server which was easily downloaded and sent to Stata 15 for cleaning and pre-estimation analysis.

2.4. Data Analysis

In this study STATA version 15 was used to analyze data where descriptive statistics such as mean, standard deviations, percentages and frequencies were used. Fractional regression model was used to estimate the inferential statistics which will show the effects of crop diversification on smallholder coffee producers' selected crop productivity among smallholder coffee farmers in Kirinyaga Central and Kirinyaga East Sub-Counties.

2.5. Fractional Probit Regression Model Specification

In this study, a fractional regression model was employed to estimate the effect of crop diversification on smallholder coffee producers' sustainable crop productivity. Crop productivity, which is the dependent variable, was calculated using partial factor productivity (PFP). PFP gauges crop productivity in relation to an increase in just one particular input, such as land [36]. Partial factor productivity calculates the proportion of quantity produced (output) in relation to total cropped area (input), is used to assess productivity in crops directly [33] according to the following formula:

$$\text{PFP (kgs/ha)} = \frac{\sum \text{Quantity of crops yields (Kgs)}}{\sum \text{total cropped area (ha)}} \quad (4)$$

Decline in partial factor productivity for cropped land may be attributed to small land size, infertile and unhealthy soils, droughts and soil pests and diseases. Higher partial productivity might be due to larger land size, fertile and healthy soils, higher uptake and more utilization of natural resources in soils, reduced pests and diseases, and increased efficiency of soil nutrients which are taken up by the crop and utilized to produce seeds. Moreover, the indirect measure of PFP is the proportion of the total worth (monetary) of harvested crop yields to total area cropped. Further, Total factor productivity (TFP), which calculates the likelihood of input or output substitution and incorporating technical efficiency is another approach to assess productivity [37]. PFP has a range of 0 to 1, hence was opted for a fractional regression model because the outcome variable can take on any value within a unit interval [38]. The Tobit model has been used in other research, but it will be excluded in this study because its application is inappropriate when data are defined exclusively in unit intervals. Natural consequences of individual choices are the ones that make boundaries of a fractional variable and not any kind of censorship [39].

A model of the mean of the dependent variable y is called a fractional regression which is explained by a vector $1*k$ of independent variables $X \equiv (X_1, X_2, ..., X_n)$ that spans the range of $0 \le y \le 1$. y_i can be measured as a continuous variable and does not need to be converted to categories. Therefore, the population model is:

$$E(y_i/X_i) = G(X_i\beta) \quad (5)$$

where;

For all $X \in \mathbb{R}$, the known function $G(X_i\beta)$ meets the condition $0 \le G(X_i\beta) \le 1$. Non-linear least squares (NLS) can be used to reliably estimate β in Equation 5. When $0 \le y \le 1$, Var (Y_i/X_i) is not likely to be constant suggesting that the model has heteroscedasticity [40]. The log-likelihood function is given by:

$$lnL = \sum_{i=1}^{N} w_i y\, ln\{g(X_i\beta)\} + W_i(1-y) ln\{g(X_i\beta)\} \quad (6)$$

where;

y_i is the dependent variable and can appear on the RHS in each other's equations, and matrix of Y_i coefficients must be upper triangular. Note that $y=g(y^*) =1\{y^*>0\}$. lnL (log-likelihood function) is maximized leading to formation of reduced form equations of FPM which have cumulative distribution functions (CDF) of the standard normal distribution as the link function; N is the sample size, and W_i represents the ideal weights. Link function (g) induces the likelihoods for each possible outcome (household PFP level) to be less or equal to a specific value. The probit model is referenced by the functional form of g (.) in the current study, which is equal to;

$$\Phi\ (X_i\beta) \quad (7)$$

where;

X_i are the covariates for individual i, and Φ is the standard normal cumulative density function.

The functional form of Fractional probit model as postulated by Wooldridge [41] is:

$$Y_i = \Phi\ (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \varepsilon_i) \quad (8)$$

where;

Y_i is the marginal productivity (PFP) of the households

β_0 = Intercept and β_1 to β_7 are parameters to be estimated by the model

ε_i is the error term

X_1= Intercropping

X_2= Crop rotation

X_3=crop species diversity

X_4= Varietal diversity

X_5=Landscape heterogeneity

X_6= Agro-ecological zone

X_7=Land size

Non-linear least squares (NLS) estimates, heteroscedasticity-robust standard errors, and test statistics can all be obtained using the quasi-likelihood estimation approach, which is a less constrained form of MLE methods. Also, the model assumed that the conditional mean was correct in that it includes relevant variables and fits non linearities.

Description of explained and explanatory variables with their expected signs are hypothesized to explain the effects of crop diversification on crop productivity (Table 1).

Table 1. *Description of explanatory variables and expectation of sign.*

Variables	Variable Unit and Measurement	Expected sign
Dependent Variable		
PFP	Partial Factor Productivity (0 - 1)	+/-
Independent Variables		
Intercropping	HH practicing intercropping (1=Yes, 0=No)	+
MOI	Market orientation index	+
CSM	Crop specific marketability	+
Crop rotation	HH practicing rotation (1=Yes, 0=No)	+/-
Crop species diversity	HH with crop species diversity 1=Yes, 0=No)	+
Crop varietal diversity	HH with crop varietal diversity 1=Yes, 0=No	+
Landscape heterogeneity	HH with patches on the farm landscape (1=Yes, 0=No)	+/-
Agro-ecological zone	Agro-ecology (1=UM_1, 2=UM_2, 3=UM_3)	+/-
Land size	Land operated for farming (ha)	+/-

+/- indicates that listed variables of crop diversification were expected to affect PFP positively or negatively.

3. Results and Discussions

3.1. Descriptive Findings of Crop Diversification Strategies

This study measured food crop productivity using partial factor productivity which is equal to the total yield per cropped area. The findings of this study showed that the average food crop productivity was 0.379 with standard deviation of 0.077 and 20.32% coefficient of variation (Table 2). This implies that there was low crop productivity among smallholder farmers, which meant that they may have obtained low yields per land area cropped. The findings of this study are in line with those of Tadele [12], who noted that global contribution of cassava, sweet potato and banana in Africa was only 52%, 17% and 15%, respectively to global production mainly caused by biotic and abiotic stresses, inefficient input use and policy-related problems. There is need therefore for farmers to be trained on efficient land use systems such as crop diversifications strategies by extension officers, which may have the possibility of increasing crop yields.

Table 21. *Variable definition and descriptive statistics.*

Variable	Exp sign	Mean	SD	CV (%)
Dependent Variable				
Crop Productivity (PFP) (Total quantity of crop produced per ha)		0.379	0.077	20.32
Independent Variables				
Landscape heterogeneity	+/-	0.658	0.175	26.60
Crop rotation	+	0.544	0.139	25.55
Crop varietal diversity	+	0.781	0.214	27.40
Intercropping	+/-	0.798	0.202	25.31
Crop species diversity	+	0.948	0.223	23.52
Agro-ecological zones (UM1, UM2 and UM3)	+/-	2.002	0.498	24.87
Land size (Ha)	+	1.591	0.407	25.58

+/- signs indicates that listed variables of crop diversification were expected to affect PFP positively or negatively.

The study findings revealed that landscape heterogeneity was practiced by 65.84% of the farmers whereas 34.16% (Table 3) could not due to small land sizes which inhibited them to practice. Majority of the respondents grew trees, hedges and cover crops to support beneficial predators, increase pollination and biocontrol. Lázaro [42] also observed that increasing landscape heterogeneity promoted the stability of pollinator richness and visit rates due to the availability of natural habitat, which kept almond production consistent. In accordance to the findings of this study, in order to increase crop yields, its crucial to maintain crop fields' natural and semi-natural environment that benefit pollinator diversity. Crop rotation was practiced by 54.4 % of the respondents with standard deviation of 0.139 (Table 3). Farmers reported that they practiced crop rotation to increase soil fertility, break lifecycle of pests and diseases and suppress weeds. This is in line with the observation of Terefie [43] who noted that crop rotation practices contribute towards maintenance of soil structure, microbial activity and improve nutrient use efficiency which are key for successful integrated soil fertility management (ISFM).

Table 3. *Crop diversification strategies.*

Crop Diversification Strategies	Description	Frequency	Percent.
Landscape heterogeneity	No	137	34.16
	Yes	264	65.84
Crop rotation	No	183	45.64
	Yes	218	54.36
Crop varietal diversity	No	88	21.95
	Yes	313	78.05
Intercropping	No	81	20.2
	Yes	320	79.8
Crop species diversity	No	21	5.24
	Yes	380	94.76

Majority of farmers in the study area grew diverse range of crop varieties (78.1%) [Table 2] for more yields since some were highly resistance to pests and diseases, high yielding, stabilized the destabilizing effects of variability in precipitation and low fertilizer requirements. This is in agreement with Yang [44] who revealed that cropping systems with mixed varietal arrangements were found to be more tolerant, particularly to biotic stresses. The findings of the study further showed that intercropping was practiced by 79.8% of the respondents during the study period (Table 2). In relation to the outcomes of this study, farmers intercropped for proper utilization of soil nutrients, reducing insect pests and diseases as well as decreasing weeds. According to Kumawat [45] legume intercropping improves soil structure and soil fertility by introducing nitrogen (N) via nitrogen fixation bacteria (BNF) and also increase Soil organic carbon (SOC). Further, Divya [46] found out that intercropping runner bean (*Phaseolus coccineus* L.) in maize had a lesser density of sedges and grassy weeds compared to pure stands of maize.

The findings of the study revealed that the mean farmers who diversified their crop species was 94.76 % (±0.223) [Table 2]. Farmers stated that they grew diverse crop species to stabilize production since they can obtain reliable source of food and maintain biodiversity, even in the face of environmental challenges. The findings of this study are consistent with those of Renard [47] who found out that crop species diversity reduced negative effects of droughts and high temperatures on calorific yields of crops through the moderating effect of ecosystem by enhanced biodiversity. Further, Ghimire [48] revealed that diverse cropping systems maintained soil biodiversity while improving retention and cycling of nutrients in USA. Further, the study findings showed that most of the respondents were found in the Upper Midland (UM2) (Table 2), which is the coffee zone of the AEZs that has potential to produce a wide range of food crops. Additionally, the average size of land among the respondents was 1.59 hectares (±0.41) [Table 2].

3.2. Descriptive Statistics of Crop Productivity

Crops Grown, Yield Harvested Per Hectare and Cropped Area

The survey pursued to gather information on crops grown by farmers in Kirinyaga East and Kirinyaga Central Sub-Counties. The study findings revealed that most farmers did not grow all selected crops and the average land size was 1.59 (±0.41) [Table 4]. The findings showed that the average cropped area for farms in the area of study was 0.58 (±0.13) [Table 4]. The findings showed that leafy and other vegetables were grown by around 37.66% and 23.19% of the respondents, respectively (Figure 1). The findings of this study agree with those of Ge [49] who reported that smallholder farmers in China allocated 13% of their farm to grow vegetables. Further, this study revealed that the average yield per hectare of the leafy and other vegetables was 15000 kg/ha and 21000 kg/ha, respectively, although very few farmers participated in growing of these crops. The findings further showed that the mean plot area for leafy vegetables was 0.16 ha (±0.04) while other vegetables mean acreage was 0.12 ha (Table 4).

Table 4. *Average area of crops grown.*

Cropped area (ha)	Mean	Std. Dev.	CV
Land size	1.59	0.41	25.79
Total cropped area	0.58	0.13	22.41
Leafy vegetable	0.16	0.04	25.00
Other vegetable	0.12	0.06	05.00
Fruits	0.14	0.03	21.43
Legumes	0.17	0.05	29.41
Cereals	0.18	0.05	27.78
Roots and tubers	0.13	0.03	23.08

CV is the Coefficient of variation in %

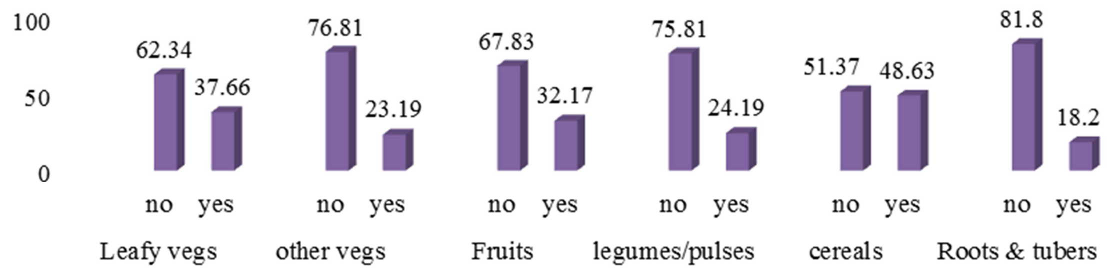

Figure 1. *percentage of farmers who produced food crops in the study area.*

The study findings showed that 62.34% and 76.81% of the respondents never grew leafy and other vegetables in the study area (Figure 1), that is why there was a great variation between minimum and maximum value of acreage. The findings indicate that the larger the cropped area, the more the production. Similarly, Mujuru [50] found out that the average farm area for leafy vegetables production was 0.1 ha in South Africa with average of 5983.19 kg/ha, which indicated that the production was a bit low. In contrast to the findings of this study, M'ithibutu [51] noted that half of the crop farmers were using between 66% to 100% of the total land for growing vegetables in Kirinyaga and Kiambu Counties for commercialization. Additionally, African indigenous vegetable yield increased by 4.4% for every increase in the land area cultivated [52].

Findings of this study indicated that fruit crops were grown by 32.17% of the farmers while 67.83% were not involved in growing fruits (Figure 1). The average yield of fruits per hectare was 13000 kg. The study's findings revealed that the mean plot area for fruit crops was 0.14 ha (±0.03) [Table 4]. The findings of this study concurred with those of Cyriaque [53] who found that majority of banana farmers were smallholders at 79.6% with acreage of less than 0.2 ha in Meru County. In contrast, the Kenyan average of banana plantations is 0.32 ha per farm, especially in Kisii, Nyamira and Embu Counties [54]. Further, USAID [55] reported that the average yield of avocado in Murang'a County was 27.93 tons per hectare. Therefore, based study findings farmers in Kirinyaga County allocated lesser land to banana and avocado production compared to the main crop producers' counties in Kenya.

The study's findings revealed that legumes and nuts were grown by 24.19% of the respondents while 75.81% did not farm the crops (Figure 1). It was observed that the mean cropped area for legumes and nuts was 0.17 ha with a mean yield of 700 kg/ha (Table 4). The findings indicated that despite the small portions of land allocated to this category of food crops, the production was a bit low. The low production could have been caused by low adoption of high-yielding crop varieties with less use of improved technology. From the findings presented by this study, it's advisable for farmers to increase the acreage towards legumes and nuts production and use improved varieties and technologies. The finding of this study contradicts those of Begum [56] who postulated that average common bean production was 22855 kg/ha in Bangladesh and productivity increased with farm size. Further, the findings of this study showed that the highest food group grown was cereal (maize) at 48.63% (Figure 1) with mean acreage of 0.18 ha (Table 4). It is possible that maize was the dominant food grown because it's a major staple food for most families, it's affordable and accessible, making it a critical source of nutrition. In addition, cereals are highly adaptable to different climatic and environmental conditions, they have a long shelf life and plays an essential role in the food systems.

This study's findings showed that the root and tubers were grown by only 18.20% of the respondents (Figure 1) with an acreage of 0.13 ha (±0.03) [Table 4]. The study findings indicated that a significant proportion of farmers grew root and tuber crops as a source of both food and money for their families, and they included potatoes, cassava, sweet potatoes, yams and arrow roots. During the study it was observed that the area allocated to root and tuber crops was very low compared to an average of 4.15 ha, 0.87 ha and 0.06 ha of land allocated to cassava, yam and cocoyam production, respectively in Nigeria according to [57]. Further, it was reported that root and tuber crops provide a rich source of carbohydrates, fibre, and essential vitamins and minerals, thus play a major role in maintaining healthy and balanced diet [58]. These crops are valued for their ability to grow in a different climatic and soil conditions, making them a reliable source of food [59]. Therefore, much attention should be accorded to these crops due to their role in food security and also some of them have been neglected and are classified as orphan crops. This study's findings imply that most producers undertake crop diversification as a major means of reducing food insecurity and income diversification, but most were at very low levels due to small land sizes.

3.3. Fractional Probit Regression Model on the Effects of Crop Diversification on Selected Crops Productivity

Fractional regression model analysis was done at a 5% significant level to evaluate the hypothesis;

H_{01}: There is no statistically significant influence of choice of crop diversification on selected crop productivity among smallholder coffee farmers in Kirinyaga Central and Kirinyaga East Sub-Counties, Kenya

Based on the statistical significance of the model's Chi-square value, the relationship between the dependent variable and combination of independent factors was established. In this instance, the model Chi-square probability (7) = 77.75) was 0.000, which was less than the 0.05 level of significance. The null hypothesis, according to which there was no difference between the models with and without independent variables, was rejected (Table 5).

Table 5. *Results of fractional probit regression.*

Variables	Coeff.	Robust std. Err	P-value	z	Marginal Effects
Independent variable					
Partial factor productivity					
Independent variable					
Landscape heterogeneity	0.175**	0.064	0.006	2.734	0.057
Crop rotation	0.407***	0.065	0.000	6.262	0.134
Crop Varietal diversity	0.006	0.075	0.933	0.080	0.002

Variables	Coeff.	Robust std. Err	P-value	z	Marginal Effects
Intercropping	0.038	0.083	0.648	0.460	0.012
Crop species diversity	1.726***	0.393	0.000	4.392	0.566
Agro-ecological zones	-0.134**	0.050	0.007	-2.680	-0.044
Land size	0.321***	0.085	0.000	3.776	0.105
Constant	-2.876***	0.436	0.000	-6.596	

*Astericks **, and *** indicate statistical significance at 5%, and 1% probability levels, respectively. Wald* chi^2 (7)=77.75, Prob > Chi^2=0.000, Pseudo R^2=0.580, Log pseudolikelihood = -227.538, Number of obs. = 401

Consequently, there was enough data to conclude that there was a statistically significant relationship between household crop diversification and crop productivity at the 5% level of significance. Hence, all of the independent variables were significant in Fractional regression model since the model was good fit. The value of R^2 for the Fractional regression model analysis was 0.580 (Table 5), which means that this model explains 58% of the variation in the dependent variable. Fractional regression analysis of the hypothesized explanatory variables which this study presumed to affect the households' selected food crop productivity included: landscape heterogeneity, crop rotation, crop varietal diversity, intercropping, crop species diversity, agro-ecological zones and land size (Table 5).

3.3.1. Landscape Heterogeneity and Crop Productivity

There was a positive and significant relationship between landscape heterogeneity and crop productivity, indicating that an addition practice of landscape heterogeneity increased crop productivity by 5.7% at 5% significant level (Table 5). It is possible to increase crop yields per cropped area since landscape heterogeneity enhanced biodiversity which supports a diverse array of pollinators such as bees, butterflies, moths, birds and bats that play a critical role in the reproduction of crops. Further, diverse landscape heterogeneity can naturally regulate pest populations by promoting beneficial organisms such as predators, parasites, and insect-eating birds, which reduce use of synthetic pesticides. The findings of this study were in consonance with those of Raderschall [60] who found out that landscape crop diversity supported higher biodiversity that provided pollinators with sufficient food and nesting resources which increased bee densities leading to enhanced insect-pollinated faba bean yield and quality in Sweden. In accordance to Marja [61] increased landscape complexity enhances arthropods richness due to increased agri-environment schemes such as wildflower strips and grassy fields leading to increased nutrient cycling, pollination, biological pest control, and soil aeration which increased crop yields. Further, Nelson [62] reported that high levels of landscape diversity increased winter wheat, corn and soy yields by 28%, 7% and 5%, respectively in Kansas. It was possible for higher landscape diversity to increase crop production resilience under variable weather conditions.

3.3.2. Crop Rotation and Crop Productivity

During the study period, it was observed that crop rotation had a positive relationship with crop productivity at 1% significant level, where a 1-unit usage of crop rotation technique among smallholder farmers increased the level of crop productivity by 13.4% (Table 5). It is possible that crop rotation strategies were used to maintain soil fertility and suppress pests and diseases and maintained biodiversity by reducing the negative effects of mono-cropping. In relation to the observations of this study, Dang & Hung [63] observed that crop rotation improved soil organic carbon (SOC), total nitrogen (N_{tot}) and available phosphorus (P_{avail}) in the maize-mungbean-maize (MBM) and mungbean-chili-maize (BCM) crop rotation systems, thus it's very possible for crop rotation systems to improve soil quality properties which enhances soil fertility that promotes better use of nutrients, reduces weeds and disrupts lifecycle of crop pests and diseases. It is reported that rotating cotton and grain decreased harmful organisms such as pests like spiders by 3-4 times and diseases were decreased by 25-30% [64]. Based on the findings of this study, it's important for farmers to include crops that improve soil fertility and disease resistant into the rotation cycle. Farmers can also be encouraged to practice crop rotation since it reverses the soil ecosystem and loss of biodiversity functions stipulated by mono-cropping.

3.3.3. Crop Species Diversity and Crop Productivity

Crop species diversity according to this study, positively and significantly influenced crop productivity at the 1% level of significance, where 1-unit increase in crop species on a farm increased crops yields by 56.6% (Table 5). Crop species mixtures may enhance soil microbes and predator population, hence increasing soil fertility and crop yields. The findings of this study are in agreement with those of Stefan [65] who found out that increase in crop diversity increased crop yield in 2 and 4-species mixtures by 15% and 35%, respectively. The findings concur with those of López - Angulo [66] who reported that higher plant species has a stabilizing effect on plant community productivity and boost agricultural yields may be due to ecological and revolutionary role of crop mixtures interactions. In addition, Weih [67] found out that some combinations of legumes and cereals in intercrops lowered yield variability compared to sole crops at field level. It is probable that asynchrony between species is a cause of productive stability. Further, Carydi [68] noted that high level of crop species diversity enhanced pollination in Greece since different plant species attract a variety of pollinators, resulting in increased seeds and larger fruits, which results to 50% increase in total yields. Conversely, it is reported that diversified cropping system might result in increased competition for water, soil nutrients and sunlight resources, resulting to in reduced yields of crops if not managed properly [69]. This could imply that crops with varying durations and growth habits with peak demand for nutrients are chosen to minimize competition among species.

3.3.4. Agro-Ecological Zones and Crop Productivity

It was observed during study period that agro-ecological zones (AEZs) significantly and negatively associated with crop productivity at 5% significant level. Increase in growing food crops to agro-ecological conditions that don't suit crop farming characteristics, such as biological and physical features by 1 unit decreases crop productivity by 4.4% (Table 5). This may have implied that crops require different soil types, climate, topography and nutrients to perform better. The observations of this study are consistent with those of Darko [70] who found out that soil conditions, rainfall patterns, temperatures and relative humidity in different agro-ecological environment had a significant impact on the growth and yield of sweet potatoes. It is possible that differences in location lead to variances in soil physical and chemical properties which influence the yields of sweet potato. Similarly, Ting [71] noted that maize and soybean yields declined due to extreme heat in suitable AEZs for crop growth, caused by climate change. This indicated that producers can alleviate the dry heat impact on maize and soybean yields through irrigation, changing planting times or using fast-maturing varieties. Further, in Zambia, maize production is increasingly threatened by changing crop pest such as African migratory locusts and Fall Armyworm and disease habitat suitability profiles in each AEZ due to climate change, eventually declining crop yields [72]. In relation to the outcomes of this study, it's important for farmers to understand specific conditions of AEZ and select crops and management practices that are well suited to those conditions.

3.3.5. Land Size and Crop Productivity

Land size was found to have a positive and significant effect on crop productivity during the study period at 1% level of significance. This indicated that farmers with relatively large farm size increased crop productivity compared to small-sized farms. On average, when all other variables are constant, additional of one hectare of land increased the probability of households' crop productivity by 10.5% (Table 5), where it is possible that farmers with large land sizes had enough space for practicing crop diversification strategies, such as increased landscape heterogeneity which might promote pollination services, provided resources to beneficial predators that decreased pests and pathogens, leading to increased efficiency and crop yields. The findings concur with those of Iyabo [73] who noted that the productivity of tomato increases with farm size due to modern technology adoption. In Contrast to this study observations, Mpanga [74] reported that smallholder farmers have great potential in adopting sustainable and regenerative agriculture techniques such as cover crop (27%), compost (26%) and crop rotation (23%) that produce high quality crops with minimal inputs. It is possible that smaller land sizes can actually have increased productivity per unit of land due to more intensive management and better use of resources.

3.3.6. Intercropping and Crop Productivity

Intercropping was found to positively influence crop productivity by 1.2% though not significant during the study period (Table 5). Intercropping allows for efficient use of available resources since different crops have different growth patterns and nutrient requirements, thus by growing complementary crops together resource utilization can be maximized. Kidane & Zegeye [33] observed a positive and significant effect of intercropping and crop productivity in Ethiopia which may have implied that through intercropping, households may be able to get additional harvest to the main crop compared to monocrop. It is possible for intercropping to enhance soil fertility through complementary nutrient uptake, since different crops have different root systems and nutrient requirements. Additionally, Madembo [75] noted that in Zimbabwe intercropping maize and pigeon pea stabilized and increased yields of both crops compared to sole maize yields. It is possible for intercropping strategy to increase soil fertility and reduce pests, since leguminous crops hosts some beneficial fauna groups such as lady beetles, ground beetles, lacewings and minute pirate bugs. Further, for farmers to successfully benefit from intercropping, they need to be trained on careful selection, appropriate crop combinations and proper management practices.

4. Conclusions and Recommendations

The study found low crop productivity in the study area. The study's findings concluded that crop species diversity was the most significant factor that influenced food crop productivity. Additionally, landscape heterogeneity, crop rotation and size of land were found to positively and significantly influence food crop productivity. However, there was a negative and significant relationship between agro-ecological zone and crop productivity. It is recommendable that government should support policies and programs that promote crop diversification strategies especially for small-land sized farmers, to reduce pests and diseases, improve soil fertility and enhance biodiversity which would eventually increase crop yields. More also, soil management and agronomy need to be emphasized in research and teaching to increase crop yields. Further, the research study calls for Kenyan Government and institutions to provide conducive environments for crop diversification to be practiced, as well as abide by the Maputo 2014 declaration to invest 10% of their national budget to agricultural research and development for improved farmers' livelihoods.

Competing Interests

"The authors declare no conflict of interest."

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