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The Relationship between Coffee and Climate Factors: Case of Rwanda

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ABSTRACT

Coffee is one of the most valuable cash crops in Rwanda. Coffee production in Rwanda stands high among three different export crops such as tea, pyrethrum, and was recently set as priority crop where more attention should be concentrated. This study estimates the impact of climate change and variation on coffee yield in Huye district, southern province of Rwanda. In this research both secondary and primary data were used and primary data were gathered from a random sample of 110 households in HUYE District. Coffee farmers were interviewed in August-September 2016 using structured questionnaires that were administered to household's heads via person-interviews. Climate data (temperature and precipitation) were collected from the Rwanda Meteorological Station located in RUBONA Station. The results from climate change model has revealed that approximately 74% of change in the coffee production during the last 17 years was explained by climate factors jointly. The results indicate that coffee farms near Huye Mountain are highly vulnerable to precipitation variation like erosion during heavy rain in March through May and drought from June through August.

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Introduction

Agriculture remains the backbone of Rwanda's economy. In 2016/2017 fiscal year (FY), the sector contributed 31% of the national GDP, generated 60 percent of the foreign exchange, provided 75 per cent of raw materials supplied to industries and provided about 45% of total Government revenues. Agriculture is also important for national food self-sufficiency, accounting for over 90% of all food consumed in the country. Currently, the agriculture sector accounts for a total of 3.342.779 farmers, among which 1.248.017 (37.3%) are involved in market led agriculture while 2.094.762 (62.7%) do farming for household consumption. Therefore, with the new ILO definition of employment, agriculture employs 41.8% of the total employment in Rwanda. Therefore, the agriculture sector is not only the driver of Rwanda's economy, but also the means of livelihood for the majority of Rwandan people (MINAGRI, 2017).

In Rwanda, agricultural production can be grouped into two main categories: staple crops (leguminous, cereals, roots, tubers and banana) and cash crops (coffee, tea, and pyrethrum). Since agricultural production in Rwanda depends almost exclusively on the quality of the rainy season and specific temperature ranges, it makes the country particularly vulnerable to climate variability and change. The increased frequency and duration of droughts, floods, landslides and erosion currently observed considerably decrease the country's food availability. Moreover, the changing patterns of precipitation and the extreme events of storms and droughts lead not only to a decline in land productivity but also to an increase of plant disease incidences in Agriculture.

Rwanda has come a long way on its vision towards a medium income country by 2020, with major achievements made in all sectors. In agriculture, the country has managed to achieve food security and has now embarked on commercializing the sector so that it can support employment creation, export diversification and overall socioeconomic transformation. However, climate change, threatens to undermine the achievements, especially in the agricultural sector which is highly sensitive to weather changes. Although Rwanda in particular and Africa in general, have contributed very little to global warming, they are disproportionately impacted by the negative impacts of climate change. Rwanda's agricultural sector is particularly vulnerable to climate change, given the country's relief, population density and over-dependency on agriculture. Fortunately, investing in adaptation measures can reduce the country's vulnerability and significantly lower the costs of responding to climate change (REMA, 2011).

The climate change is currently the major threat for agriculture sector due to the physical and biological nature and characteristics of the sector's production process. The risk of losses of income and productive means due to the adverse weather associated to climate change can significantly differ between farmers sharing a productive landscape. Moreover, the risk and risk aversion are likely to be important factors for the farmer's choice of production technology and inputs used. In the case of climate change, the major change in risk is the increased climatic variability and the increased risk of large losses due to extreme weather and flooding (Alpizar et al., 2010).

Rwanda has a biannual rainy season. The long rain begins in March and ends in May while the short rainy season lasts from September to November. From September to October during the short rainy season, coffee trees bloom and pollinate. The cherries then grow into maturity during the dry season. Harvesting is carried out in mid-April to early July. After the harvest, pruning is carried out before the next blooming. Additionally, weeding is necessary in rainy season due to the rampant growth of weeds, and pest control is needed in dryer seasons to stop the spread of pests and disease (MINAGRI, 2012).

Rwanda possesses nearly ideal growing conditions for Arabica coffee. Rich volcanic soils, high altitudes that slow bean development and favor taste enhancement, adequate rainfall, and clement temperatures are key parameters shared by Rwanda and other renowned coffee origins. While coffee is produced throughout Rwanda, with the exception of the northeast and extreme southeast corners, production is concentrated in the central and western parts of the country. Coffee is not exempt from the adverse effects of climate change; in fact coffee is a highly climate-sensitive plant requiring specific weather patterns (rainfall, temperature, sunshine, wind behavior).The production of coffee, the most valuable tropical export crop worldwide, has been recently affected by increasing temperatures and consequent damages due to a variety of pests and diseases (Jaramillo et al., 2011).

A changing climate will have serious impacts on the availability of these natural resources and will limit options for rural households that depend on natural resources for producing food for consumption. The volume of coffee production in Rwanda varies dramatically from year to year. While production naturally fluctuates every other year, the overall production trend is a down. In 2009, production stood at 14,000 MT, a drastic drop to half of the 2004 peak level of 28,000 MT. Fluctuation in production volume exists for every province but the overall production level is declining. This resulted from the aging of coffee trees, the inappropriate use of fertilizers, continuous climate change and variability, as well as agrochemicals (MINAGRI, 2012).

A recent study by SEI (2009) found that existing climate variability has significant economic costs in Rwanda, at least one % of GDP per year if not addressed. This is already borne out through frequent extreme weather events such as floods and droughts that cause major socio-economic impacts and reduce economic growth. However, little is known with regard to the impact of climate on coffee production in Rwanda. A low yield was reported in 2007 and climate variability was quoted among the causes (MINAGRI, 2008). Insufficient rainfall in the last three months of 2006 (the period of coffee flowering) proceeding the short dry season in the first two months of 2007 was recorded. The reduced rainfall was also poorly distributed across coffee growing regions in Rwanda.

The changing patterns of precipitation and temperature, as well as the more frequent appearances of extreme events like floods and droughts, lead to a decline in soil fertility and productivity, as well as an increase in incidences of plant diseases (Ngabitsinze et al., 2011). In addition, Rwanda is a country with high dependence on coffee production in the sense of that coffee is among the three major export products accounting for 24% of the country's total exports and valued at $57 million (NISR, 2014). So, the importance of climate change adaptation can be emphasized by taking the coffee sector as an example and priority.

Recently, the National Coffee Development Strategy has set a target aiming to double the coffee production by 2020, but does not consider the potential threat of climate change and climate variability to the success of this strategy, despite the known impacts of La Nina droughts on coffee productivity. At present, there appear to be very few initiatives on adaptation and mitigation of climate change in the coffee sector of Rwanda. Due to the fact that coffee is a very climate-sensitive plant in terms of productivity and cherries quality (Ngabitsinze et al., 2011), there is a need to find out and implement the very serious adaptation measures (strategies) in order to preserve the benefits that coffee generates by using the most appropriate environmental friendly practices and to preserve this value and optimize further economic opportunities.

Therefore, the purpose of this research is to assess the impact of climate change on Rwandan coffee production in the coffee sector of Rwanda. And it is indeed focused on Rwandan coffee since it is one of the major priority crops in the country which has the big share on the country's revenue and has been reportedly mentioned as the most affected crop in the last years.

Materials and Methods

This section presents our methods describing the main characteristics of the scoping study and the applied techniques of data collection and data analysis.

Description of the Study Area

This study was conducted in Huye District which borders with Nyanza district in the North, Gisagara in the East and South, Nyaruguru in the South West and Nyamagabe in the North West (Figure 1). The hilly landscape protrudes from East to West but develops into a steep hilly and mountainous area as one moves towards the West and North West. Maraba Sector of Huye District was selected for this research. The selection of this area was based on the suitable condition for growing Arabica coffee as demonstrated by the number of coffee trees grown in this area ranging between 500,001- 849,267 in these sectors (Maraba and Kigoma) where the study lies, and also the number of coffee washing stations found in the study area. In addition, the study area hosts two best coffee cooperatives in Rwanda known as Abahuzamugambi (MARABA) and Koperative y'Abahinzi ba Kawa ba Karaba (KOAKAKA) (Dusenge, 2009). Moreover, the district hosts two institutions that carry out research in various field namely Rwanda Agricultural Board (RAB), former Rwanda Agricultural Research institute (ISAR) and National University of Rwanda (NUR). Plus, the selection of this area was also based on the variability in climate conditions (i.e. rainfall, temperature, and dry periods). Features of the physical environment, topography and soil for example were also considered to be important since they reflect the cause and effect of changes in climate conditions. More importantly, the disparity in households' ability to engage in cash crops depends on agro-ecological conditions.

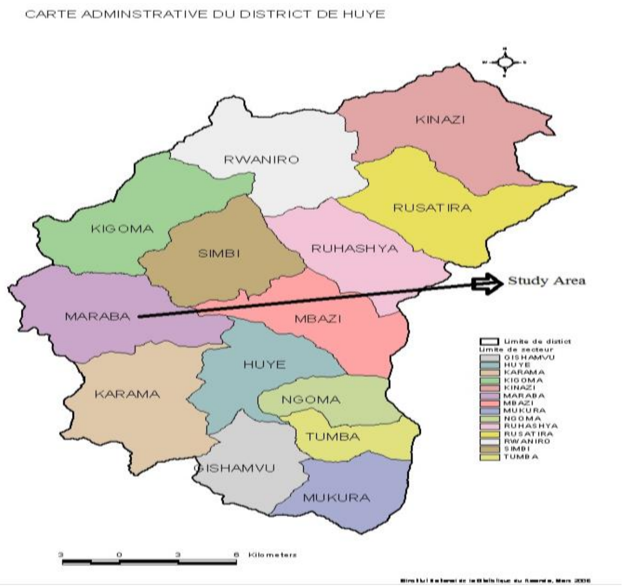

Figure 1 Study area

Regarding the physical characteristics of the study area, altitude ranges between 1.400-2.100m, rainfall ranges between 1.000-2.000mm, temperature ranges between 17-22°C (average) and the soil type is moist. This climate set-up is highly characteristic of the topography of Rwanda. Moreover, the high geomorphologic and climatic variability made the selected sites ideally suited to assess the impact of climate variability on small-scale cash cropping systems in Rwanda. The region is also characterized by sub-equatorial temperate climate with an average temperature fluctuating around 20°C throughout the year. The area has four climatic seasons: long period of rainfall (Mid-February and May); long dry period (mid-June and September); short rainy period (Mid-September and December) and a short dry season (January-mid February). The rainy season is characterized by heavy rainfall of about 1.400 mm per year. Its soils are the *kaolisol* type, inherently fertile but prone to infertility due to erosion (MINALOC, 2012; MINIRENA, 2016). Soil fertility is low due to leaching and continuous cropping without sufficient replenishment.

Description of Maraba Coffee Cooperative (Abahuzamugambi ba Kawa)

In the local language (Kinyarwanda), Abahuzamugambi Ba kawa means ('together we work in coffee'). That given name is very fitting because this cooperative was the first cooperative to build coffee washing station in Rwanda after the devastating 1994 genocide and it has since become a refreshing symbol of hope and progress in the community and coffee sector. Presumably, all of the cooperative members are small scale producers who typically own less than a quarter of a hectare of land, where they cultivate an average of 250-300 coffee trees each along with other subsistence food crops such as cassava, beans, Irish potatoes and beans. By selling their coffee to Abahuzamugambi ba kawa Maraba, these small scale farmers are able to combine their harvests into large enough quantities for export and process cherries centrally. Before the proliferation of washing stations and cooperatives in Rwanda such as Abahuzamugambi ba kawa Maraba, the norm in Rwanda was for small farmers to sell semi-processed cherries to a middleman - and the market was dominated by a single exporter. This commodity-focused system - coupled with declining world prices in the 1990s brought severe hardship to farmers, and some of them abandoned coffee entirely.

With regards to rainfall and temperature variation, coffee which is grown further East will suffer from insufficient rains (i.e.,<1.400 mm, while the range of favorable rain is between 1.400 and 2.000 mm). Abahuzamugambi Ba Kawa Cooperative Huye mountain coffees (Sovu and Kabuye coffees) therefore enjoy favourable rainfall because they receive at least 1.460 mm of precipitation per year. High yields and good quality are also registered in the Huye mountain chain, which has been proven by successes in the Golden Cup in 2007 and the Cup of Excellence® (CoE) in 2008.

Huye mountain coffee has a temperature tolerance ranges between 15°C and 25°C. The average temperature in the mountain chain is estimated at around 16°C, whereas in the east of Maraba, the temperature goes up to 22°C. However, the effect of temperature on production is less notable than that of changes in rainfall (Ngabitsinze et al., 2011).

Data and Sampling Techniques

Farm household data: Primary and secondary data were used in this study where the primary data were obtained from surveys of coffee producers located in Huye county, southern province of Rwanda. The study has targeted the most important cooperative in coffee production in this region. The secondary data used in the research are the statistics taken from the relevant institutions and organizations, articles, thesis, research report, etc.

Several sampling procedures were used to select the desired sample size. The study was conducted within the sample size of 110 households with 60 and 50 members and non-members of coffee cooperative respectively drawn using stratified sampling (Table 1). In order to be sure of all coffee growers in the study area, the lists of all members of cooperative were obtained from the leaders of the cooperatives and lists for non-members were obtained from agronomists of sectors (divisions). A simple random sampling was used for sample size selection. Therefore, total of 110 respondents were selected from MARABA sector of Huye district for this research. However, simple random sampling is used to determine the sample size and the formula based on the average was used (Yamane 2009).

$$n=\frac{N(ZS)^2}{Nd^2+(ZS)^2}$$

In this formula;
n : Sample size
N : Population size
Z : Selected confidence level depending on z value
S : Standard deviation
d : Adopted deviation quantity (sensitiveness)

Here,
N=3.480,
%95 With confidence level α=1-0.95=0.05,
Z(α/2=0.025)=1.96
From the mean %5 with deviation
d= Mean×0.05 = 0.16×0.05
d=0.024 ha
n=104

Climate data: In this study, the secondary data were obtained from Rwanda Meteorological Services (RMS) and have included temperature (°C) and rainfall (mm), Wind (m/sec) and Humidity (%) from 1999 to 2015 year. The study has considered only the Southern province of Rwanda and did not take into consideration all Rwandan climate data since almost each region of the country has its particularity in climate variation. Also the types of adaptation strategies taken by households in response to multiple risks may vary from a region to another region within country depending on local climate conditions, natural resource aspects, and the patterns of agricultural and livestock activities even the economic situation of the household. The study has used temperature and rainfall data for respective data collection year and their long term values as have been applied in previous studies such as Sarker et al. (2012), Fezzi et al. (2014) and Kabubo-Mariara and Karanja (2007) to assess effects of climate change on agricultural production in Subsaharian Africa. I have included the long term climate variables (moving average for 17 years) assuming that past climate shocks may still influence future agricultural yield in the current moments. The coffee yield data were obtained from the National Institute of Statistics of Rwanda (NISR) and Rwanda National Export Board (NAEB).

Model Specification

Every household has its own way of reacting or making any decision at every faced situation. Moreover, households' adaptation decisions in response to weather variability and consequently their welfare outcomes are jointly determined. Households make decisions on what types of adaptation practices to adopt in response to weather shocks and observed changes in long-term climate trends, which in turn affect household incomes (controlling for other factors (Bandyopadhyay et al. 2011). Therefore, the structural model approach, which simultaneously models both adaptation choices and their impact on household welfare, is helpful in analyzing farm-level adaptation behavior. Due to a nonlinear relationship between coffee yield and climate variables, this study has adopted a natural logarithmic function in order to estimate the relationship between coffee and climate change in the study area and to make estimates more interpretable (Equation 1). The results from crop research show that yield response to weather and climate is highly non-linear and there are significant interaction effects between temperature and rainfall (Welch et al. 2010). We have, therefore, included interaction terms between annual temperature and rainfall based on phonological period of coffee crop as independent variable in the model. However, as stated by Fezzi et al. (2014), most Ricardian studies in Kenya (e.g Kabubo-Mariara and Karanja 2007) do not account for such interaction between temperature and rainfall.

Table 1 The Distribution of Sample size in MARABA

	Total Cooperative members	Total non-Cooperative Members	Total coffee farmers
Population (N)	1.898	1.582	3.480
%	54.54	45.46	100
Sample size (n)	60	50	110

General Coffee-yield climate relationship Model

$$LnCYield=\alpha_0+\alpha_1 LnAvMaxT(H,R)+\alpha_2 LnAvMinT(H,R)+\alpha_3 LnAVRain(F,B)+\alpha 4LnTotRain(F,B)+\alpha 5LnTotAnRain+\varepsilon \quad (1)$$

CYield : Total coffee yield (kg/ha)
AvMaxT(H,R) : Average maximum temperature during ripening and harvesting (°C)
AvMinT(H,R) : Average minimum temperature during ripening and harvesting (°C)
AVRain(F,B) : Average precipitation during flowering and blossoming (mm)
TotRain(F,B) : Represents the total precipitation during flowering and blossoming (mm)
TotAnRain : Represents the total annual precipitation (mm)

The α_0, is the Y intercept while $\alpha_1$and $\alpha_8$are the slope coefficients to be estimated and ε the error terms. In this model, the slope coefficient measures the % age change in Y for a given absolute change in the value of the regressor (Gujarati 2007).

Results and Discussions

Characteristics of Farmers

Farmer and farm characteristics identification is one of the instrument to the research because they reflect the social status of the target population. Our sample consists of both male and female-headed households (Table 2). For the total households interviewed, the proportion of male headed households was 81% and female headed households was 19%. There is a quite big difference between the proportions of gender in coffee production in Rwanda which may be due to the importance given to coffee crop in recent years. Moreover, this crop requires a lot of intensive care which could probably and in most cases be achieved by the men's efforts. Education level of the coffee farmers was very critical such that only 61 % have got at least primary education and 39% of the total interviewed farmers have not got any formal education and therefore are illiterate.

About 91.7% of the coffee cooperative members are male while 8.3% are females. It is clear that 56.7% of the coffee cooperative members are primary school graduates. 68% of non-cooperative member are male. Most of the non-cooperative member (60%) were graduated from primary school (Table 2). This shows that education level of coffee farmers is very low and therefore sufficient knowledge and skills are needed to make coffee production a more productive sector. The implication is that more should be done to raise coffee farmer's education level since coffee farming requires more adequate knowledge and skills in order to make it a more prolific industry.

Farmers' Awareness About Climate Change Over the Last 10 Years

The Results presented in the Table 3 indicate that 100% of interviewed households have perceived changes in climate in the last 10 years, from which 98.2% have seen less rain, 98.2% have seen more rain, 96.4% have seen frequent drought, 99.1% have seen more frequent floods, 97.3% have seen the delay in the starting of the rainy season, 95.5% have seen that the rainy season ended sooner, 63.6% no change in hot days and 46.4% have seen the increase in warm and hot days. Regarding adaptation to perceived changes in climate, 100% of households reported having implemented at least one adaptation strategy that include the increase in the quantity of chemical inputs usage, use best agronomic practices (terraces, fodder cultivation, erosion control), found off-farm jobs, enterprise diversification, reinforce water harvesting techniques, changes in crops or crop varieties and adoption of soil conservation and agroforestry practices.

Consequences of Climate Change Over the Last 10 Years

In this research, a number of consequences encountered by coffee farmers were identified and their severity according to the farmers' perception was defined using the Likert scale. Table 4 indicates the percentage of farmers and their responses to each of the consequences. 94.5% of respondent considered soil degradation as a very important issues, 76.4% of the respondent considered erosion, 72.7% of respondent considered drought, 65.5% of the respondents considered floods, 48.2% of them considered epidemics, 42.7% of respondents considered crop diseases as very important issues over the last 10 years and health problems was the least important over last ten years with only 15.5% of respondents.

Table 2 Farmer's gender and literacy level

Farmer's Characteristics		Coop Member		Non Coop Member		Total	
		N	%	N	%	N	%
Gender	Male	55	91.7	34	68	89	80.9
	Female	5	8.3	16	32	21	19.1
	Total	60	100.0	50	100	110	100.0
	No formal schooling	20	33,.3	23	46	43	39.1
Education level	Primary school	34	56.7	26	52	60	54.5
	Secondary school	5	8.3	1	2	6	5.5
	University	1	1.7	0	0	1	0.9
	Total	60	100.0	50	100	110	100.0

Table 3 Farmers' awareness about climate change in last 10 years

Farmers' awareness	Coop Member (N=60)		Non Coop Member (N=50)		Total (N=110)	
	N	%	N	%	N	%
No change in rain	11	18.3	0	0	11	10.0
Less rain	58	96.7	50	100	108	98.2
More rain	58	96.7	50	100	108	98.2
More frequent drought	56	93.3	50	100	106	96.4
More frequent floods	59	98.3	50	100	109	99.1
Delay in the start of the rainy season	57	95.0	50	100	107	97.3
The rainy season ends sooner	55	91.7	50	100	105	95.5
No change in number of hot days	21	35.0	49	98	70	63.6
Increase in hot days	30	50.0	21	42	51	46.4
Decline in hot days	21	35.0	1	0.02	22	20.0

*Multiple responses questions.

Table 4 Consequences of climate change over the last 10 years.

Consequences	Mean*	Std. Deviation	%					
			1	2	3	4	5	Total
Soil degradation	1.08	0.431	94.5	4.50	0.00	0.00	0.90	100.0
Erosion	1.24	0.427	76.4	23.60	0.00	0.00	0.00	100.0
Drought	1.29	0.495	72.7	25.50	1.80	0.00	0.00	100.0
Floods	1.45	0.737	65.5	26.40	6.40	0.90	0.90	100.0
Epidemics	1.69	0.763	48.2	35.50	15.50	0.9	0.00	100.0
Crop diseases	1.75	0.780	42.7	41.80	12.70	2.7	0.00	100.0
Health problems	2.99	1.088	15.5	10.00	37.30	34.5	2.70	100.0

*Likert scale: Very important =1; Important=2; Neutral=3; Little important=4; Not important=5

Table 5 Climate risk coping strategies applied in coffee farming

Risk Strategies	Mean*	Std. Dev.	%					
			1	2	3	4	5	Total
Erosion control	1.20	0.521	82.70	16.40	0.90	0.00	0.00	100
Use of pesticides and agronomy practices	1.67	0.791	45.50	47.30	3.60	1.80	1.80	100
Timely farming	1.80	0.764	40.00	40.90	18.20	0.90	0.00	100
Technical floods protection	2.54	0.992	9.10	48.20	30.00	5.50	7.30	100
Buy crop insurance	4.60	0.837	0.90	4.50	3.60	15.50	75.50	100
Rainwater harvesting techniques	2.19	0.840	19.10	49.10	27.30	2.70	1.80	100
Fallows	2.67	0.314	23.60	24.50	24.50	15.50	11.80	100
Invest in soil and water conservation	2.18	0.756	18.20	48.20	30.90	2.70	0.00	100
Fodder cultivation	2.21	0.920	24.50	39.10	27.30	9.10	0.00	100
Plant shed trees	2.55	0.842	12.70	30.00	47.30	10.00	0.00	100
Increase livestock	3.12	0.916	5.50	14.50	48.20	26.40	5.50	100
Reduce livestock	3.61	0.059	2.70	12.70	28.20	33.60	22.70	100
Change from crop to livestock	3.04	0.928	4.50	24.50	36.40	31.80	2.70	100
Change crop variety	2.43	0.113	21.80	38.20	18,20	19.10	0.00	100
Migrate to another area	3.63	0.937	0.90	12.70	25.50	44.50	16.40	100
Irrigation techniques	4.54	0.686	2.70	2.70	32.70	61.80	0.00	100
Find Off-farm jobs	3.57	0.943	0.90	12.70	30.90	39.10	16.40	100

Likert scale: Very important =1; Important=2; Neutral=3; Little important=4; Not important=5

Climate Risk Coping Strategies Applied by Coffee Farmers

In our study, a number of climate risk coping strategies applied by coffee producers in the study area were identified and their severity according to the farmers' perception was defined using the likert scale. The Table 5 shows clearly the percentage of farmers and their responses to each of the strategy applied in their farming activities. 82.7% of respondents have applied soil erosion control and they consider as a very important strategy (1. 20), followed by 47.3% who use pesticides and agronomy practices (1.67) and lastly 40% who use timely farming (1.8). In addition, 49% of respondents have applied rainwater harvesting techniques and they consider it as an important strategy (2.19), both Invest in soil and water conservation and technical floods protection have got the same (48.2%) and considered important, the least important strategy was change crop variety (2.43). According to the coffee farmers crop insurance and irrigation techniques were found not important and they have the highest mean value 4.6 and 4.54 respectively.

Climate- Coffee Relationship

When regressing the climate data, it is not advisable to include every month, because there might be a high correlation between adjacent months (Pradeep and Robert, 2008). In this study, I explored several ways of defining three-month average seasons. And, I grouped the coffee development cycle in order to use climate data relating to the critical growing period of coffee. Consequently, coffee flowering (blossom), crop expanding and maturing, coffee ripening and harvesting period were chosen as they reflect the most sensitive behavior of the crop against the climate change and variability.

Previous studies used different units of time, such as months, phonological periods and growing seasons, for climate variables. For example Ozkan and Akcaoz (2002); in their study on impacts of climate factors on yields for selected crops in Southern Turkey, have used climate factors especially temperature during planting, flowering and harvesting time and confirmed that climate plays an important role in deviations of crops yield (wheat, maize and cotton). However, this study has used total annual rainfall because the total annual precipitation is able to capture the net effect of the entire range of the development process by which coffee yield are affected by climate (Lobell and Field, 2007). Also in their study on exploring the relationship between climate change and rice yield in Bangladesh using time series data. Sarker et al. (2012), have used climate data grouped according to the specific growing season and phonological period of rice crop. In our study, flowering (blossoming) was assigned to September and October, crop expanding was assigned to November to January, crop maturing was assigned to February to March, and ripening and harvesting were assigned to April to July. These seasonal definitions were chosen because they provided the best fit with the data and reflected the mid-point for key sunny and rainy seasons in the sample and hence they reflect the growing behavior of coffee.

In order to achieve this research, monthly data on maximum temperature, minimum temperature and total rainfall were obtained from the Rwanda Meteorological Station (RMS) 2016 for Southern Station (ISAR RUBONA Station) which cover the period of 1999-2015 period. These monthly data were then converted as the average of the development periods of coffee crop. Since coffee is a perennial crop and almost all coffee trees were found very old, we did not include the planting period of coffee. We have instead started from flowering, Expanding and maturing, and ripening and harvesting. Therefore, the climate variables are represented by maximum and minimum average temperature and total rainfall for the growing seasons of coffee for the 1999–2015 period. Aggregate coffee yield data for the same time period (1999–2015) were obtained from National Agriculture Export Board (NAEB) and FAO (NAEB, 2016; FAO, 2017). The summary statistics for all of the data are presented in Table 6 and 7. This table also illustrates the fundamental climatic characteristics during coffee growing seasons in Rwanda.

Test for Multicollinearity

According to Kennedy (1985), for no continuous variables, a value of 0.8 or higher in absolute terms in one of the correlation coefficients indicates a high correlation between the two independent variables. Gujarati (1995) contributed also by arguing that if the Variance Inflation Factor (VIF) of a variable exceeds 10 (this will happen if R^2 exceeds 0.90), that variable is said to be highly collinear (rule of thumb) and it can be concluded that multicollinearity is a problem. Therefore, two techniques that are the contingency coefficients to test for dummy variables (Gujarati 2003) and Variation Inflation Factors (VIF) for discrete variables and for continuous variables. Similarly, Variance Inflation Factor (VIF) is used to test for presence of multicollinearity by estimating Ordinary Least Squares (OLS) regressions with each of the climate variables on coffee production.

Table 6 Climate factors according to the phenological period of coffee production

Phenologic period	Climate factors	N	Min	Max	Mean	Std.Dev.
Expanding (Nov-Jan)	Max_Temp (°C)	17	23.76	26.20	24.52	0.577
	Min_Temp (°C)	17	13.27	16.73	14.48	0.901
	Total_Rain (mm / Mo)	17	58.28	199.24	128.76	34.122
	Aver_Rain(mm/Mo)	17	17.05	19.01	18.07	0.554
Maturing (Feb-March)	Max_ Temp (°C)	17	23.58	26.25	25.125	0.584
	Min_ Temp (°C)	17	12.95	16.55	14.18	0.867
	Total_Rain (mm / ay)	17	64.85	176.15	114.26	33.609
	Aver_Rain (mm / ay)	17	129.70	352.30	227.68	67.469
Flowering (Sept-Oct)	Max_ Temp (°C)	17	23.60	26.23	25.12	0.667
	Min_ Temp (°C)	17	13.45	15.90	14.517	0.766
	Total_Rain (mm / Mo)	17	180.80	602.50	327.07	106.25
	Aver_Rain (mm / Mo)	17	60.27	200.83	109.02	35.41
Harvest (Apr-July)	Max_ Temp (°C)	17	23.27	25.75	24.74	0.606
	Min_Temp (°C)	17	13.35	15.58	14.15	0.586
	Total_Rain (mm / Mo)	17	40.50	334.30	160.73	77.59
	Aver_Rain (mm / Mo)	17	10.13	83.58	40.18	19.398
Total Annual Rainfall	(mm)	17	524.90	1684.40	1078.00	270.89

Source: RMS 2016; NAEB 2016

Table 7 Climate data in the study area

Yıl	Coffee Yield (kg/ha)	Max. Temp (°C)	Min. Temp (°C)	Total Temp (°C)	Mean Temp (°C)	Total Monthly Rain (mm/mo)	Average Rain (mm/mo)	Total Annual Rain (mm/mo)
1999	7034	25.406	13.97	39.03	19.51	296.50	71.74	810.26
2000	6999	25.57	13.86	39.43	19.71	307.30	62.50	840.08
2001	7064	24.29	13.47	37.76	18.88	602.50	140.37	1521.18
2002	6938	25.11	14.69	39.80	19.90	203.50	115.38	601.46
2003	6903	24.89	14.48	39.38	19.69	476.50	96.79	1234.31
2004	6902	24.99	14.49	39.48	19.74	288.00	95.69	796.60
2005	6277	25.42	14.35	39.77	19.88	202.50	73.32	594.48
2006	7227	24.89	14.65	39.52	19.76	385.60	111.03	1019.26
2007	4606	25.05	15.50	40.55	20.28	257.00	78.57	720.67
2008	4831	25.56	14.49	40.05	20.03	180.80	43.74	543.19
2009	6720	16.78	7.95	24.73	12.37	308.86	45.76	839.39
2010	5686	17.26	8.56	25.82	12.60	308.86	58.35	835.23
2011	5838	22.29	12.83	35.12	17.56	435.70	104.43	1134.73
2012	4788	24.73	13.75	38.48	19.24	304.50	96.87	830.78
2013	4359	25.12	14.12	39.23	19.62	302.20	104.45	831.11
2014	4457	24.68	14.23	38.91	19.45	302.10	76.20	825.05
2015	4565	24.88	15.39	40.27	20.13	397.00	93.25	1056.33

Source: FAOSTAT 2016; RMS 2016; NAEB 2016

Among the variables selected for regression the highest value of VIF was 2.079. Following Maddala (2000), variables that had VIF<5 were considered to have no multicollinearity. Based upon the results presented in Table 8, we reject the stated hypothesis that there is multicollinearity problem among the explanatory variables, implying that the independent variables were not collinear since the calculated VIF are lower than the threshold set by the previous economists.

Average rainfall during flowering period was automatically removed by SPSS because of multicollinearity problem that would arise from including two linear correlated variables. In coffee climate relationship model, econometric results presented in Table 9 show that except the total rainfall during flowering of coffee, all other climate factors such as maximum and min temperature during coffee ripening and harvesting, and total annual rainfall were statistically significant as it was expected. By performing the joint test (the F test), we have found that all climate variables included in the model have a joint effect on the coffee yield.

The results presented in the Table 9 show that the variable average maximum temperature has had a positive and significant effect on Coffee yield along 17 years since the P value was statistically significant. However our finding contrast with the findings of (FAO 2011) which has set 23.5°C as threshold and said that the excess temperature beyond maximum would be detrimental to coffee production. On the other hand, the average minimum temperature has a negative coefficient which implies a significant effect of coffee yield. Even though the average minimum temperature in the study area was 14.15 which is also is in good range of the temperature requirement of coffee, the average minimum temperature was found negative and significantly impacted the coffee yield .This is probably due to other factors which jointly have an impact on the coffee yield such as: fertilizers application, agronomic practices, timely weeding, mulching, etc. This study again confirms the finding of (Ozkan and Akcaoz 2002), who in their study on impacts of climate factors on yields for selected crops in Southern Turkey, have found that climate factors especially temperature during planting, flowering and harvesting time plays an important role in deviations of crops yield (wheat, maize and cotton).

The total annual rainfall was found significant and positively impacted the overall coffee yield. This is so meaningful because the total annual rainfall range calculated in our study 1684mm lies in the optimum annual rainfall range is 1200-1800 mm for Arabica coffee (Alègre 1959). However, the monthly average rainfall was automatically excluded because of collinearity problem which would arise in rainfall variables. Also the VIF was calculated in order to test for multicollinearity and we found no problem of multicollinearity among independent variables. The total rainfall during three critical months was not statistically significant due to the fact that the total rainfall was 603mm which is below the minimum 750mm tolerable for coffee growth (FAO 2011). Also it means that the amount of precipitation during this period has nothing to do with coffee yield during the specified period of coffee growth.

Table 8 Variance inflation factors for continuous explanatory variables in the model

Variable	VIF	Tolerance
LNAVMAXTEMP_H	1.772	0.564
LNAVMINTEMP_H	1.636	0.61
LNTOTRAINFALL_F	1.814	0.551
LNTOTANRAINFALL	2.079	0.481

Table 9 Results from regression model (SPSS)

Variable	Coeff.	Std. Error	t	P value	Tolerance	VIF
Constant	-7.394	3.9	-1.89	0.084		
LNAVMAXTEMP	6.675	1.348	4.95	0.000***	0.564	1.772
LNAVMINTEMP	-3.106	0.716	4.34	0.001***	0.611	1.636
LNTOTMONRAIN	-0.164	0.128	-1.29	0.225	0.551	1.814
LNTOTANRAIN	0.555	0.152	3.655	0.004***	0.481	2.079

***, **, * significance levels at 1, 5 and 10 % respectively, R^2: 0,74, Adjusted R^2: 0.649, Durbin Watson:1.705

Our results clearly indicate that climate has a non-linear relationship with coffee, which is consistent with previous findings (Kabubo-Mariara and Karanja, 2007; Fezzi and Bateman, 2013). Also the findings from our econometric model show that the coefficients associated with temperature are much larger than those for rainfall, confirming the findings of Kabubo-Mariara and Karanja (2007) and Dinar et al. (2008) that temperature as a contributor to global warming is much more important than rainfall.

In addition, the calculated R squared (R^2 =74%) was found high means that the great part of changes in coffee yield in past 17 years is explained by the change in climate factors (temperature and rainfall). Also, coffee exhibits a strong positive interaction between rainfall and temperature because coffee production significantly depends on stable temperatures and consistent rainfall patterns. The optimum mean annual temperature range for Arabica coffee is 18-21°C (Alègre, 1959). High temperatures above 23°C, development and ripening of fruits are accelerated, often leading to loss of quality (Camargo, 1985). A relatively high temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers (Camargo, 1985).This is also consistent with previous research which stated that temperature may limit the successful economic exploitation of the coffee crop, in part because coffee growth is particularly affected by both high and low temperatures (Barros et al., 1997; Silva et al., 2004). Consequently, higher temperatures improve living conditions for pests and diseases. Increasing pest attacks lead to the loss of quality of the coffee beans or even to the destruction of yield and plants.

$$\underset{(3.9)}{Cyield=-7.394}+\underset{(1.348)}{6.675}AvMaxT(H,R)-\underset{(0.716)}{3.106}AvMinT(H,R)-\underset{(0.128)}{0.164}TotRain(F,B)+\underset{(0.152)}{0.555}TotAnRain$$

Cyield	: Represents the natural logarithms of total Coffee yield per hectare,
AvMaxT(H,R)	: Represents the average maximum temperature during ripening and harvesting
AvMinT(H,R)	: Represents the average minimum temperature during ripening and harvesting
TotRain(F,B)	: Represents the total precipitation during flowering and blossoming
TotAnRain	: Represents the total annual precipitation

Conclusion

This study estimates the impact of climate change and variation on coffee yield in Huye district, southern province of Rwanda. In this research, both secondary and primary data were used and 110 coffee farmers were interviewed in August-September 2016. Primary data were collected using structured questionnaires that were administered to the sample of households' heads via person-interviews and SPSS 20 (Statistical Program for Social Scientists) was used for data analysis. In order to get to our reliable results we have performed econometric analysis to estimate the effect of climate change on the coffee yield along 17 years.

The results from descriptive statistics show that 95% of interviewed coffee farmers have perceived changes in climate in the last 10 years, from which 85% have observed changes in temperature, 58% in the frequency rains, 54% in the seasonality of rains and 49% in the frequency and intensity of extreme events like droughts or flooding. In regards to the adaptation to climate change hazards, the study shows that some of environmental friendly and agronomic practices were adopted by coffee farmers such as terraces, anti-erosive holes, water harvesting, furrows, fodder cultivation, crop rotation and appropriate agro-chemicals usage.

The climate change model has revealed that climate factors jointly have had a significant effect on coffee production during the last 17 years since the coefficient of correlation (R^2) was 74%. The results show that coffee exhibited a positive relationship with maximum temperature during ripening of coffee, a negative relationship with the average minimum temperature during ripening, a strong positive relationship with total annual rainfall. Moreover the results indicate that coffee farms near Huye Mountain are highly vulnerable to precipitation variation like erosion during heavy rain in March through May and drought from June through August.

Despite its role in climate change and risk management, crop insurance was found almost not be known in coffee production of Rwanda. The study also found ambiguous evidence about the ability of irrigation usage to reduce crop vulnerability to precipitation variation since coffee is grown just in higher altitude of Huye Mountain where irrigation could be laborious even when water is available. But, this study suggests that proper cost benefit analysis ought to be done in order to measure the welfare value of different adaptation strategies applied in the region.

In terms of policy, results suggest that educational programs, from formal education or training or technical assistance to the coffee growers, are a channel through which government could promote adaptation to climate change and all possible risk arising in the coffee sector. Moreover the farmer's incentives and perceptions should be taken into consideration because they are the major drive of any adaptation decision about the farms. Therefore this study suggests that the government should take a leading role in raising awareness of farmers by mobilizing the crop insurance schemes in the coffee sectors of Rwanda.

Recommendations

Due to its importance in fighting against hunger in most of African countries including Rwanda, and due to the fact that most of agriculture sector in Sub-Saharan Africa is rain fed, the results of this study suggest that Government and all institutions (both public and private) are central for the climate change mitigation and adaption within agriculture sector in general and in coffee sector in particular. This study suggests that climatic change and absence of institutional instruments such as crop insurance, disaster payments make risk management strategies very critical for rural people especially coffee farmers. Due to sensitive nature of coffee crop to climate change and variability, we recommend that adaptation strategies to climatic conditions should be adopted in coffee sector in order to alleviate adverse impacts of climatic change.

Policy makers should focus efforts on reducing production risks providing climatic information in order to increase the awareness of coffee farmers and developing risk management institutions. Another lesson drawn from all three models is that local and sector-level patterns of soil and environment conservation can serve as a stimulus for further promotion of technology adoption under climate risk. Hence, if the general context in which farmers are allocating their land and investment decisions favors the conservation and technology adoption, all farmers will be more likely to move in the same direction as the Government agents wish. This implies that sector-level investments in extension, marketing pattern, and infrastructure that get a few farmers moving in the right direction will have a multiple effect in helping spread adoption of environmental friendly practices.

The findings of this research have revealed that the current situation of climate variability and change has had an adverse impact on the country's agricultural systems and the overall economy as well. The changing patterns of precipitation and temperature, as well as the more frequent appearances of extreme events like floods and droughts, lead to a decline in soil fertility and productivity, as well as an increase in incidences of plant diseases.

Since Rwanda is not equipped to cope with these climate risks, urgent action is needed to sustainably protect livelihoods and ecosystems. The specific areas for adaptation were determined based on the following identified shortcomings as were recommended by local leaders in the research region: lack of research and reliable climate data; limited knowledge about mitigation and adaptation strategies in general; poor farming and processing practices; restricted access to technologies; inadequate financial resources; and insufficient communication. The adaptation options accordingly formulated for implementation include: more effective distribution of inputs such as fertilizer and pesticides; investments in farming equipment; improvement of extension services and research; as well as restructuring of the institutional frameworks and development plans. This study suggests that climatic change and absence of institutional instruments such as crop insurance, disaster payments make risk management strategies very critical for rural people especially coffee farmers. Due to sensitive nature of coffee crop to climate change and variability, we recommend that adaptation strategies to climatic conditions should be adopted in coffee sector in order to alleviate adverse impacts of climatic change.

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