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Factors influencing bean and maize yields in two contrasting agro-ecological zones in Rwanda

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ABSTRACT

Background: Climate is key input of rainfed agricultural. Climate variability and change has been the most important determinant of crop yield in Rwanda and the other parts of the world. However, understanding of the effect of climate variability on maize and beans at Rusizi and Nyagatare in Rwanda. The effect of climatic parameter on maize and beans yields scales was evaluated in order to provide basis for maize and beans crop monitoring and modelling.

Result: This paper argues that maize yield were declining at high levels at Rusizi compare to Nyagatare while beans were declining at high levels at Nyagatare compare to Rusizi. Dry spells and total rainfall high correlation coeffient shows the highest factors that affect yields of maize and beans during emergency stage of beans and flowering stage of maize at Nyagatare. Onset, cessation and total rainfall high correlation coeffient shows the highest impact that affect yields of maize and beans at Rusizi during SOND and MAM season.

Conclusion: The study has confirmed that East part of Rwanda (NYAGATARE) suffer from significant climate variability most dry spells and total rainfall which has huge implication on maize and beans yields compare to the other factors affecting crop yields of maize and beans in Nyagatare. While West of Rwanda (Rusizi) suffer from significant climate variability most total rainfall, onset and cessation which has huge implication on yields of beans and maize during MAM and SOND season.

Key Words: Annual crop yield, dry spell, onset, cessation rain days, rainfall patterns, Temperature patterns, crop stages.

1. Introduction

The agricultural sector has great potential to reduce poverty and ensure that growth is inclusive (Saarinen and Rogerson 2014).Since the scope to expand cultivable land area is limited (Ndayisaba, Guo et al. 2016),improved productivity of agriculture land and moving from subsistence to a commercialized sector is critical for income generation (Ndayisaba, Guo et al. 2016). To achieve this, Rwanda is strategically positioning itself emphasizing more on sectors with comparative advantage and supporting skills and knowledge for smallholder farmers(Kathiresan 2012). Poor communities in developing economies mainly depend on climate sensitive activities such as agriculture for their liverhood are particular vulnerable to climate change (Bryan, Ringler et al. 2013) .

Agriculture is reported to be the major of livelihood to a large number of Rwandan where small scale forming 80% of domestic production (Wen *et al.*, 2016). The sector employs close to 60% of the formal and informal labor force. On the average, the agriculture contributes about 33% of gross domestic production (GDP) of Rwanda, The main method used is rainfed with, only 0.2% practiced irrigation (Thebo *et al.*, 2014). In most tropical agriculture rain-fed systems, seasonal rainfall variability has profound effect on soil water variability, especially for crop production. In recent time, the change of rainfall distribution, inter-seasonal, dry spell, length of season and fluctuations have been reported to have resulted in reduction of crop production (Kassie *et al.*, 2014).

It has been reported that nearly three in four people living in rural areas depend on agriculture in one way or another (Rowhani *et al.*, 2011). Also it is estimated that climate change will cause a direct reduction in rural household consumption by 5-10% in 2050 and a reduction in real gross domestic production of 1.9-7.2% in Rwanda (Antwi-Agyei *et al.*, 2012). For instance, it has been reported that rainfall variability affects the production of traditional crops, increase crop disease incidents and cause drastic reduction in soil fertility (Ray *et al.*, 2015).

Various researchers in different areas have assessed the impact of rainfall on crop production differently. Piao *et al.* (2010) analyzed the impact of intra-seasonal, inter-seasonal and annual rainfall variability on crop production. Webber *et al.* (2014) Used statistical models to highlight the importance of intra-seasonal changes in temperature and precipitation on crop production in Rwanda. They showed that, although precipitation and temperature variability might have a negative impact on crop yield, the net crop yield in the future would be higher due to the lengthening of the growing season. Webber *et al.* (2014) Worked on inter-annual variability methods to monitor rainfall patterns in rainy season of the sub humid regions to assess the potential threat of rainfall variability to food security. Although, the number of years of rainfall record that was necessary to detect any significant trends in rainfall in arid and semiarid region is quite debatable. In a study conducted in the east African region by (Cheng, Tsubo et al. 2011) it was recommended to more invest more in improving the climate records to enhance the understanding of relationship between climate variability and extreme events on their crop production/yield. Historical climate data provides an opportunity to better understand the nature of climate variability and its impact on outcomes of importance to society such as agriculture (Vermeulen *et al.*, 2012). It can also be used to help understand climate trends and changes in the frequency of extreme events by placing current observations and predicted changes in historical context (Vermeulen *et al.*, 2012).

Recent work by Dinku *et al.* (2018) helped Rwanda to have a complete high resolution (4x4km) of climatology dataset of more than 35years. This is a result of fill data gaps by merging quality-controlled observations from meteorological stations with proxy data from satellites or climate model reanalysis (Dinku *et al.*, 2018). The resulting high-resolution gridded data, going back more than three decades, served as a foundation for a suite of online climate information tools and products.

Tapping into this vast climatology dataset, this study, attempts to identify factors determining the crop yields of maize and beans under different management. More specifically, the cause of low yield of maize and beans will be determined through a thorough analysis of rainfall intra-seasonal variability.

2. Methods and materials

2.1. Description of Rwanda

Rwanda is a landlocked country located in East Africa and because of its relief composed of hills and mountains; Rwanda is often called a country of thousand hills (Zeekaf 2014). It covers an estimated surface area of 26,338km^2 (Hanif, 2018).

It is located between 1^{o}4$'$and 2^{0}51’ latitude South and longitudes 28^{0}53’ and 30^{0}53’ East (Sumbiri, Afullo et al. 2016). The neighbors of Rwanda are Uganda in the Northern, Tanzania to the East, Burundi on the border of South and the Democratic Republic of Congo to the West border (Hanif, 2018). The Eastern province is a relatively lowland with a dry and warmer climate, and is known for its fertile land and pastoral area (Nahayo *et al.*, 2018). However, the province is recognized by its water shortage mainly due to low rainfall frequency and intensity compared to other provinces of Rwanda (Nahayo *et al.*, 2018).

This study will be conducted in NYAGATARE and RUSIZI respectively located in the eastern and west province.

2.2 Study area

Nyagatare District is located in the Eastern Province, in the north-eastern part of Rwanda (latitude: -1°18'S; longitude: 30°19'E) (Iraguha *et al.*, 2015). It is 158 km from Kigali, the capital city of Rwanda, and about 35 km from the Ugandan border (Kagitumba). It is the largest dairy district in Rwanda and has eight active milk collection centres (MCCs)(Iraguha *et al.*, 2015).Nyagatare District is characterized by two main seasons: one long, dry season that lasts for 3-5 months and a short rainy season that lasts 2-3 months and a second rainy season of 4-6 months (Mudatenguha *et al.*, 2014). It has an annual average temperature varying between 25.3 °C and 27.7 °C and receives an annual rainfall of 827 mm (Mudatenguha *et al.*, 2014)The altitude is 1513 m above sea level (Mudatenguha *et al.*, 2014). The District of Nyagatare consists of gently sloping hills separated by low granite valleys. The vegetation type is largely savannah vegetation and some gallery forestry (Mushonga *et al.*, 2017). The major soil type is vertisols, which are rich in nutrient mineral elements but lack organic matter (Mushonga *et al.*, 2017).Rusizi is a district in Western Province, Rwanda. Its capital is Cyangugu, the major city of the Rwandan south-west and the district contains large parts of the former Cyangugu Province (Uwizeyimana *et al.*, 2018). Figure depicts the location of the study area as adapted from.

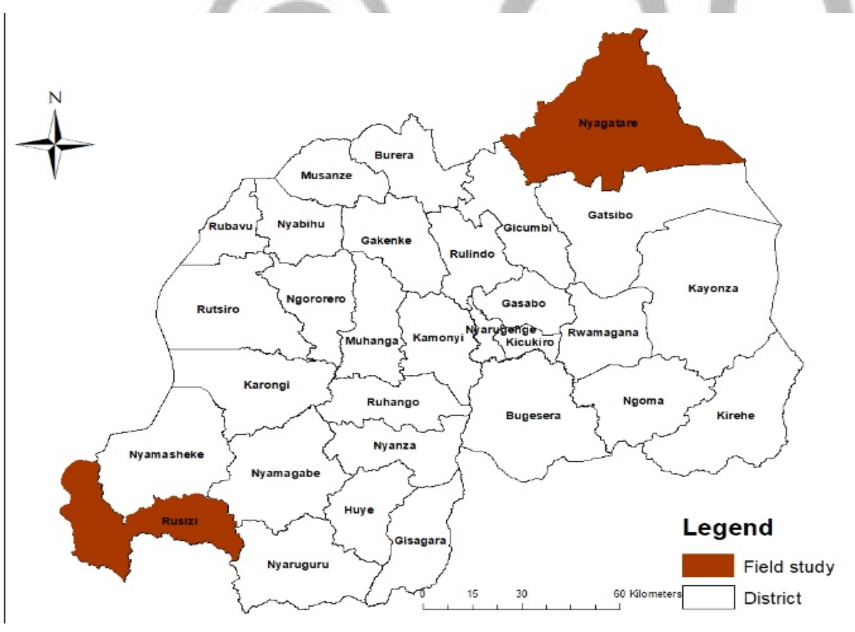

Fig1: map of Rwanda showing location of station used in this study

Rainfall data will be collected from observed ground stations as well as from the Rwanda meteorological Agency (MeteoRwanda) data library. This climate dataset is hosted by Rwanda Meteorological Agency (Dinku, 2017) and the dataset was developed through the ENACTS that has an spatial resolution of 4 km (Dinku, 2017). The dataset is the outcome of the merger of satellite data and ground station observation (Dinku, 2017). The dataset includes both rainfall and temperature.

2.3 Data collection

To evaluate factors influencing main crop production at Nyagatare and Rusizi, we consider the seasonal maize and beans a cropland and production of the SOND seasons and MAM season and monthly maximum rainfall, daily rainfall, total rainfall, average rain daily, maximum and minimum temperature and its corresponding growing degree days of the years 1998 and 2019, respectively. The rainfall data considered by this study collected by meteorological stations located within these districts. The rainfall data analyze in comparison with the maize and beans production. The primary data on the seasonal maize and beans production, planted and harvested area (agricultural season A and B of 1998 and 2019) collected from Rwanda Agriculture Board (RAB) and National Institute Statistics of Rwanda (NISR).

2.4 Method of data analysis

We used the build in linear model of R-Instant to compute climate data (rainfall and temperature). One of the particularities of R-Instant is that it contains a database gathered from different African country Meteo services. Fortunately, the data we need for this study is available in the R-Instant database and was provided by Meteo Rwanda. Since the goal this project is to evaluate the factors affecting crop yields (maize and beans) in Rwanda, to find exemplary graphs and tables that help farmers to make decisions depending on the rainfall patterns, it is imperative to develop the best tools which can produce accurate and understandable graphics.

We used python to generate different models of maize and beans yield for both SOND season and MAM season at Rusizi and Nyagatare, it is help us to describe the data we have and also computing the correlation coefficient in another to know more the relationship between individuals climate variability and yields.

2.4.1 Crop data

In Rwanda, Beans are pivotal to the Rwandan household (Oparinde, Murekezi et al. 2019). Eaten twice daily with pods, green seeds, leaves and grains all variously thrown into the cooking pot beans provide 65% of the protein and 32% of the caloric intake (Oparinde, Murekezi et al. 2019). Beans are the 'meat' and to some extent the 'bread' of the Rwandan countryside(Oparinde, Murekezi et al. 2019). Another important crop in Rwanda is maize, maize was introduced in 1960 and has been identified as a priority stable crop by the government of Rwanda within the context of the national crop intensification program also the maize has the potential for export (Kagabo, Stroosnijder et al. 2013). The maize grows all over the country but the most producing districts in Rwanda include Gicumbi, Nyagatare, Gisagara, Nyaruguru, Rukomo Site, Musanze, Ngoma and Rutsiro(Kagabo, Stroosnijder et al. 2013). The Government of Rwanda has increased area of maize plantation and different hybrid varieties were introduced in order to reduce poverty and ensuring food security (Smale, Byerlee et al. 2011).Among all cereals grown in the country, Maize has the highest average yield productivity per hectare. Maize contribute 4.88% of the value-added crops which hold 64.6% of all major crops which is the third highest share after wheat and rice, Maize accounts for 4.8% of the total cropped area and 3.5% of the value of agricultural output (Kagabo, Stroosnijder et al. 2013). In this study, we analyzed the relationship between crop yields and climate for two crop which are widely planted across Rwanda: maize and beans. Rainfall data in (mm) and production (MT) for these two crops were acquired from Rwanda ministries of Agriculture. The data covers the two regions of Rwanda and represent the period from 1998 up 2019. These data were then converted to yields (kg/ha). Obvious outlier related to poor data quality and typographical errors were removed.

2.4.1.1. **Crop Adaptation**

There are many factors that contribute to agricultural productivity. Those include: sunshine, relative humidity, latitude and longitude, wind movement, topography soil factors and many others (Chand, Kumar et al. 2011). However, the imperative ones which affect agricultural production is temperature and precipitation (Chand, Kumar et al. 2011).

Crops	Growing days	Qt of water	Exd Prob.of days	Exd. Prob.of water
Barley/Oat/Wheat	$120-150$	$450-650mm$	$0.47-0.25$	$0.8-0.23$
Bean	$75-90$	$300-500mm$	0.95	$0.9-0.45$
Maize	$125-180$	$500-800mm$	$0.45-0.2$	$0.45-0.1$
Cabbage	$120-140$	$350-500mm$	$0.47-0.30$	$0.89-0.45$
Melon	$120-160$	$400-600mm$	$0.46-0.15$	$0.84-0.25$
Onion	$70-95$	$350-550mm$	0.97	$0.89-0.42$
Peanuts	$130-140$	$500-700mm$	$0.32-0.3$	$0.45-0.2$
Pea	$90-100$	$350-500mm$	$0.94-0.625$	$0.89-0.45$
Pepper	$120-210$	$600-900mm$	$0.47-0$	$0.25-0$
Potato	$105-145$	$500-700mm$	$0.5-0.31$	$0.45-0.2$
Rice (Paddy)	$90-150$	$540-700mm$	$0.15-0$	$0.4-0.2$
Sorghum	$120-130$	$450-650mm$	$0.47-0.32$	$0.8-0.12$
Soybean	$135-150$	$450-700mm$	$0.28-0.27$	$0.8-0.2$
Sugar beet	$160-230$	$450-750mm$	$15-0$	$0.8-0.18$
Sugarcane	$270-365$	$1500-2500mm$	0	0
Sunflower	$125-130$	$600-1000mm$	$0.34-0.32$	$0.25--0$
Tomato.	$135-180$	$400-800mm$	$0.28-0.1$	$0.84-0.06$

Table 1:Crop adaptation information in NYAGATARE (Byiringiro, Birungi et al. 2017).

There are crop whose conditions meet the available rainfall and length of the season (Zingiro, Okello et al. 2014). These include beans whose 0.95 probability to have enough days and 0.9−0.45 probabilities for adequate water (Zingiro, Okello et al. 2014). The result is conducive to onion, pea, maize, soybean, sugar beet, tomato, melon, cabbage, since their conditions meet climatic information currently available. Others can struggle since they have low probability to have enough rainfall (Mutimura and Everson 2012). As we see, this table shows that, sugarcane has zero probability, this is because, we considered six months, while they take more than six months to mature. Other crops, if we can apply other means to increase the quantity of rainfall like irrigation, their probabilities can be boosted since they are not very bad. From this information, it is risky to plant crops which require amount of rainfall ranging from 600 and above, since in the previous years, this amount did not occur in many years, since we are not sure that it will occur in next few years. But those whose rainfall requirement is below this value, can be grown with no problem unless irrigation is applied.

Crops	Growing days	Qt of water	Exd Prob.of days	Exd. Prob.of water
Barley/Oat/Wheat	$120-150$	$450-650mm$	$0.95-0.75$	$1-0.8$
Bean	$75-90$	$300-500mm$	1	$1-0.95$
Maize	$125-180$	$500-800mm$	$0.95-0.75$	$0.95-0.25$
Cabbage	$120-140$	$350-500mm$	$0.95-0.75$	$1-0.95$
Melon	$120-160$	$400-600mm$	$0.95-0.73$	$1-0.94$
Onion	$70-95$	$350-550mm$	1	$1-0.95$
Peanuts	$130-140$	$500-700mm$	$0.95-0.75$	$0.95-0.65$
Pea	$90-100$	$350-500mm$	$1-0.95$	$1-0.95$
Pepper	$120-210$	$600-900mm$	0.95	$1-0.9$
Potato	$105-145$	$500-700mm$	0	$0.95-0.65$
Rice (Paddy)	$90-150$	$540-700mm$	$1-0.96$	$0.94-0.75$
Sorghum	$120-130$	$450-650mm$	0.95	$1-0.95$
Soybean	$135-150$	$450-700mm$	$0.85-0.75$	$0.81-0.65$
Sugar beet	$160-230$	$450-750mm$	$0.73-0$	$1-0.6$
Sugarcane	$270-365$	$1500-2500mm$	0	0
Sunflower	$125-130$	$600-1000mm$	$0.85-0.95$	$0.94-0$
Tomato.	$135-180$	$400-800mm$	$0.95-0.25$	$1-0.26$

Table 2: Crop adaptation information at Kamembe (Mukashema, Veldkamp et al. 2014).

The following (table2) shows types of crops whose conditions conducive with the area. The quantity of rainfall and the length of the season in Kamembe is very good for the crops shown in the table 5.2. Since the amount of rainfall needed by these crops is likely to occur every year as the probability of exceeding graph for precipitation depict. Sufficient rainfall for these crops have occurred for previous which will continue to happen in the next years and also time to grow these crops is available since the length of the season is long enough.

Vegetative phases	Reproductive phases
Emergence is represented by **VE**	Silking is represented by **R1**
Appearance of the first leaf: **V1**	Blister is represented by **R2**
Appearance of the second leaf: **V2**	Milk is represented by **R3**
Appearance of the third leaf: **V3**	Dough is represented by **R4**
The n^{th} leaf is represented by **V(n)**	Dent is represented by **R5**

Table 3: VEGETATIVE AND REPRODUCTIVE FOR MAIZE*(Ciampitti and Vyn 2011).*

Growth stage	**Approximate time following seedling emergence (days)**	**Environmental impact**
V3	From 8 to 10 days	The leaves and ear shoots are determined. At this stage maize plant can be destroyed by the persistence of flooding.
V6-V8	From 21 to 36 days	Maize is developing above the soil. Corn is at risks of wind and hail. The plant requires adequate moisture and nutrients.
V12-V17	From 36 to 60 days	Number per ear and rows' size are determined at this stage and. The stress in kernel at this stage is due to moisture and nutrients.
VT-R1	From 54 to 62days	This stage is represented by the visibility of tassel and Ears shoots. Final yield is affected by water stress.
R2	From 66 to 74 days	This stage is known as swelling phase. Kernels contain almost 85% of moisture.
R3	From 76 to 86 days	This is the milking stage. Moisture stress is the main cause to reduce yield. The Kernel contains 80% of moisture.
R4	From 84 to 88 days	This is the Dough stage. Dry weight is formed and kernel contain 70% of moisture.
R5	From 90 to 100 days	This is the Dent stage. Moisture stress can reduce the kernel weight and 55% of moisture is in the Kernel
R6	Between 105days and 120 days	The kernel is fully developed. Dry weight accumulation is at the maximum. This stage is known as Physiological maturity.

Table 4:maize growths stages and their approximate days after emergence (Niu, Peng et al. 2010).

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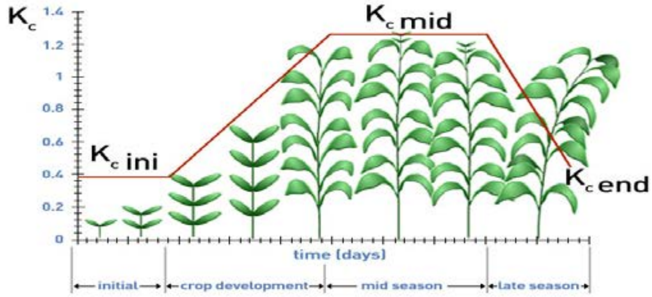


Stages of Development						Plant date	Region
Crop characteristic	Initial	Crop Development	Mid-season	Late	Total		
Stage length, days	30	50	60	40	180	April	East Africa (alt.)
	25	40	45	30	140	Dec/Jan	Arid Climate
	20	35	40	30	125	June	(alt.)

Figure2:Beans growths stages and their approximate days after emergence (Niu, Peng et al. 2010).

2.4.2 Climatic Data

Rainfall and temperature were analyzed to determine trends and patterns. The different weather stations that supplied climate data were (Kamembe from Rusizi and Nyagatare). Monthly value of precipitation, daily mean precipitation, total precipitation and mean temperature were available in different stations from 1998 to 2019 covering the district (fig.1) across Rwanda. In order to relate the climate data to the regional agriculture production, Seasonal and annual patterns were computed from daily rainfall data. We disaggregated the rainfall data into two growing season March-April-May (MAM) and September, October, November and December (SOND). The main growing season is SOND while the second growing season is MAM. We also established the spatial average daily rainfall, start of rain, end of rain, dry spell, total rainfall for MAM season and SOND season, average temperature these are other factors that influence crop yields of maize and beans at Rusizi and Nyagatare. The start of rain (Onset) and end of rain (Cessation) was determined by use of the number of rainy days, where the start of rain was defined as the first day after September 1st or after March 1st when the rainfall accumulated in at least three days was at least 20mm and was not followed by dry spell of 7 consecutive dry days in the following 30 days (Moron, Robertson et al. 2010). Seasonal and annually trends of maximum and minimum temperature were computed from daily data and trend and patterns determined by means of graph and trends line.

2.5 Regression Analysis

Association between maize yields, beans yields and climate were explored by use regression techniques. In order to find the effects of climate change on agricultural yields and to exploit the cross sectional and temporal attributes of our dataset, we develop linear mixed models for each of the main crop such as maize and beans as an example of main crops. This method is appropriate for longitudinal data where observations within a group are often more similar than would be predicted on a pooled data basis. In this case, a simple linear regression ignores grouping effects and violates the assumption of independence of observations. The peason correlation coefficient is including in the models to capture the linear relationship between yields and climate trends related to non-climatic factors and other technological progress.

We ran multilinear regression model to find the model of maize and beans at Rusizi and Nyagatare that corresponding to MAM season and SOND season and also to establish the most important factors influencing maize and beans for both seasons. We computed correlation matrix to obtain redundancy of the data. Maize yield was plotted against time to establish the trends and beans yield was plotted against time to establish the trend. Detrended maize yield and beans yield were plotted against each variable from Ordinary least square method (OLS) to determine the strength of correlation.

The multilinear model also used to evaluate factors that has highest impact on crop yield of maize and beans at Rusizi and Nyagatare. The full model includes a fixed part comprised of X and Y, where Xi are explanatory variables and Yi are dependent variables (predictant).

$$Y_i=\beta_0+\beta_1X_1+\beta_2 X_2+\beta_3 X_3+\beta_4X_4+\ldots\ldots\ldots\ldots\beta_n X_n+ \varepsilon$$

Where Y is the yield, $\beta_{1,}$ $\beta_{2,}$ $\beta_{3\ldots\ldots}$ B_n represents regression coefficients independent of climatic characteristics (rainfall, maximum temperature and minimum temperature) and ε is the error term.

We used R-squared (R^2) to measure how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression(Recchia 2010). We used R-squared for measuring the strength of the relationship between model and the dependent variable on a convenient 0 – 100% scale.

2.6 Results and Discussion

2.6.1 Trend analysis of Rainfall variability at Nyagatare during MAM and SOND season.

Fig.3 highlight the trend of onset, cessation, and length of season, rain days, and total rainfall in Nyagatare during MAM and SOND seasons. It can be observed that fig.3 (a) the rainfall data revealed that the mean rainfall onset dates were to be on the day of 295 on fourth of November during SOND season by considering linear line of SOND. While linear regression line of MAM shows that the rainfall data revealed that the mean rainfall onset dates during the MAM season were to be on the day of 61 on second of March during MAM season. The fig.3 (b) shows the rainfall data revealed that the mean rainfall cessation date were to be on the day of 343 on fourth December while linear MAM on fig.3 (b) shows the rainfall data revealed that the mean cessation date were to be on the day of 130 on tenth May during MAM season. By considering fig.3 (d) linear regression line of SOND shows the number of daily rainfall in each year decreased from days of 38 to 30 days similar to regression line of MAM where number of daily rainfall decreased from days of to 25 days this also implies total rainfall to be decreased from 1981 to 2019.

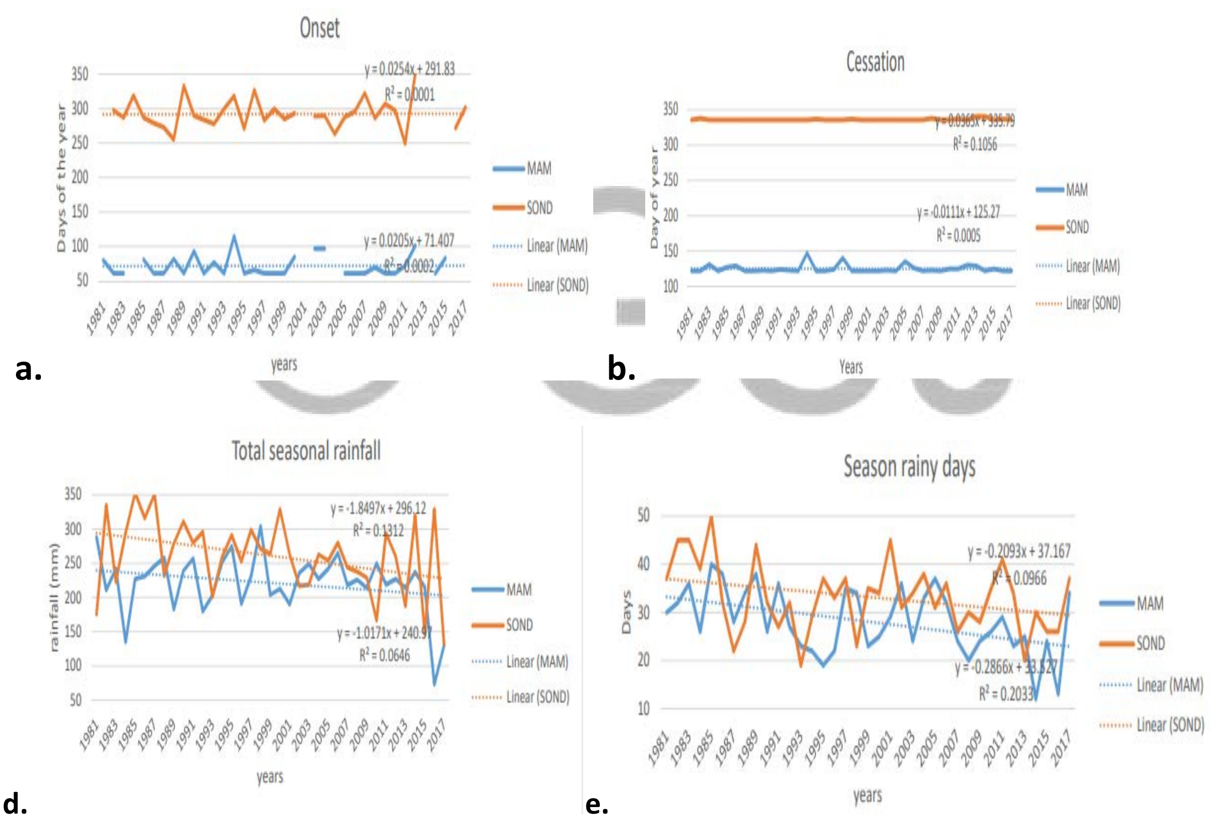


*Figure 3: trends analysis of seasonal rainfall characteristics (**a**) onset, (**b**) cessation, (**c**) length of season, (**d**) rain days, and (**e**)total rainfall) at nyagatare from 1981 up 2019.*

2.6.2 Trend analysis of Rainfall variability at Rusizi during MAM and SOND season.

Fig.4 highlight the trend of onset, cessation, and length of season, rain days, and total rainfall in Rusizi during MAM and SOND seasons. observed fig.4 (a) that the rainfall data revealed that the mean rainfall onset dates were to be on the day of 255 on first of November during SOND season while linear regression line of MAM shows the rainfall data revealed that the mean rainfall onset dates during the MAM season were to be on the day of 60 on first of march during MAM season. The fig.4 (b) shows the rainfall data revealed that the mean rainfall cessation date were to be on the day of 120 first of May while linear regression SOND on fig.4 (b) shows the rainfall data revealed that the mean cessation date were to be on the day of 350 on seventh of September during SOND season. Considering fig.4 (e) linear regression line of SOND shows the number of daily rainfall in each year increased at Rusizi from days of 70 to 78 days similar to regression line of MAM where number of daily rainfall increased from days 49 to 50 days while fig.4 (d) total rainfall decreased from 1981 to 2019.

a.

b.

c.

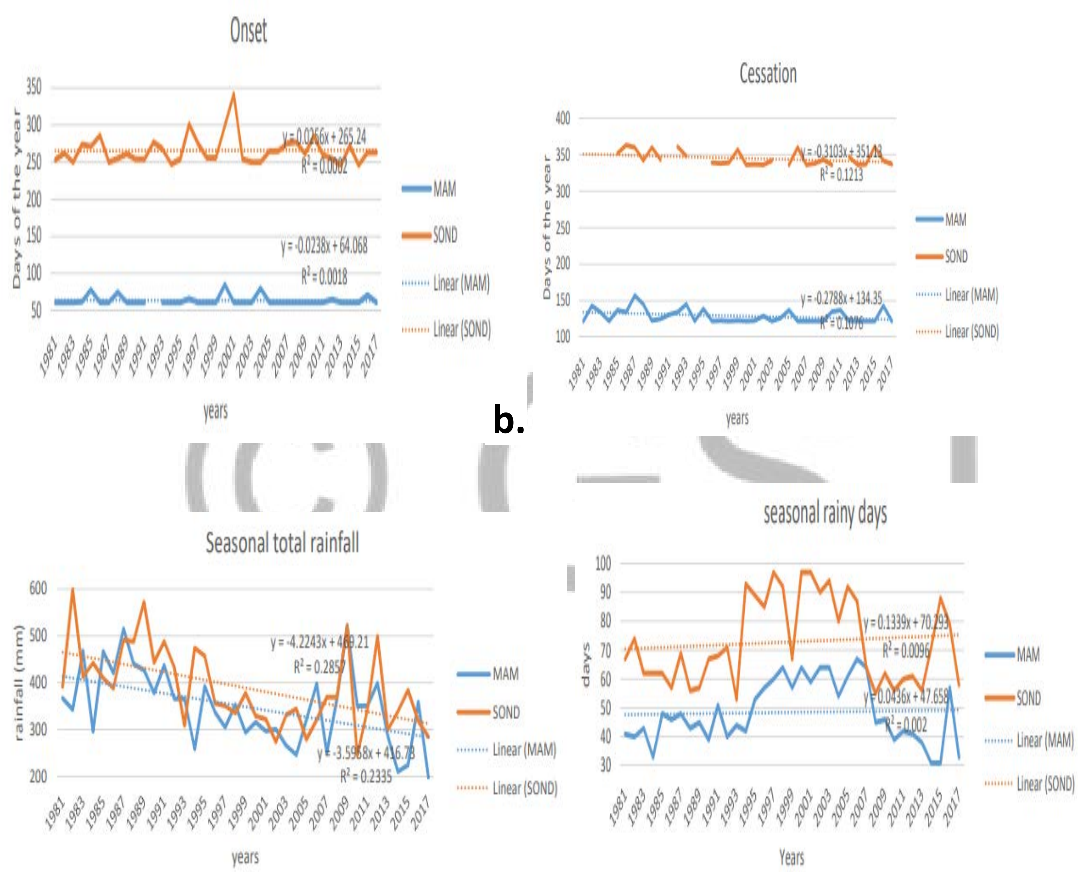
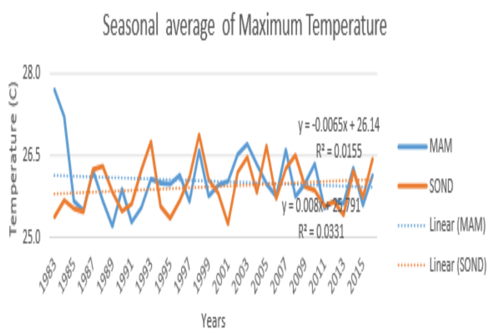


*Figure 4: trends analysis of seasonal rainfall characteristics (**a**) onset, (**b**) cessation, (**c**) length of season, (**d**) rain days, and (**e**)total rainfall) at nyagatare from 1981 up 2019.*

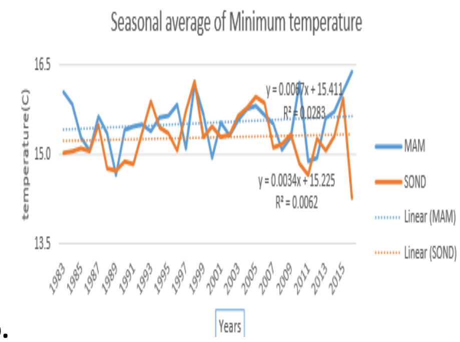
After the above analysis we can say that the onset started early at Rusizi and onset in Nyagatare started late and also the cessation started late at Rusizi while in Nyagatare it started early.

2.6.3 Temperature characteristics at Rusizi

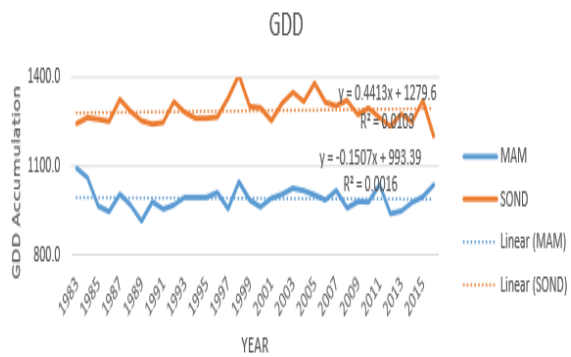
Fig.5 highlight seasonal average of maximum temperature, seasonal average of minimum temperature, growing degree days in Rusizi, (fig.5a) we observed that seasonal average maximum temperature is more slightly decrease in maximum temperature during MAM while during SOND season, it is more slightly increase in maximum temperature. (Fig.5b) we observed that seasonal average of minimum temperature shows more slight trends of minimum temperature during MAM season and during SOND season. These linear regression line shows that there is more slightly an increase of seasonal average of minimum temperature during MAM and SOND season. (Fig.5c) shows a constant trend of growing degree days at Rusizi during MAM and SOND season which means that there are no variation of seasonal average maximum temperature and seasonal average of minimum temperature at Rusizi , the tends of growing degree days are very small.



a.



b.



c.

Figure 5: trends analysis of ***(a)*** *maximum temperature,* ***(b)*** *minimum temperature and* ***(c)*** *growing degree days at kamembe from 1981 up 2019.*

2.6.4 Temperature characteristics at Nyagatare.

Fig.6 highlight seasonal average of maximum temperature, seasonal average of minimum temperature, growing degree days in Nyagatare, (fig.6a) we observed that seasonal average maximum temperature is more slightly decrease in maximum temperature during SOND while during MAM season, it is more slightly increase in maximum temperature. (Fig.6b) we observed that seasonal average of minimum temperature shows trends of minimum temperature during MAM season and also trend of minimum temperature during SOND season. These linear regression line shows that there is an increase of seasonal average of minimum temperature during MAM and SOND season. (Fig.6c) shows that there more slightly trend of growing degree days at Rusizi during MAM and SOND season.

*Figure 6: trends analysis of **(a)** maximum temperature, **(b)** minimum temperature and **(c)** growing degree days at Nyagatare from 1981 up 2019.*

The result from Fig.5 and fig.6 shows that Nyagatare had the highest maximum temperatures.In both seasons the recorded highest temperature was 27^{0}C for MAM season and 27.6 for SOND season. As it can be seen from the results Fig.9a,SOND season is hotter than MAM season, where the temperature range is between 27.65^{0}C and 27.5^{0}C for SOND compare to MAM season which is ranging from 26.5^{0}C to 27.0^{0}C .The result from fig.8a,MAM season is hotter than SOND season, where temperature range is between 26.14^{0}C and 25.79^{0}C for MAM compare to SOND season which is ranging from 25.79^{0}C to 26.14^{0}C. The eastern part and central part of Rwanda were drier compare to the other part of Rwanda including North,South and West province (Zhou, Yang et al. 2010).

2.6.5 Yields Trends of maize and beans at Rusizi and Nyagatare

As shown figure below, Season A at Nyagatare, the highest yield production of maize occurs in 2019 and the lowest yield production of maize occurs 2006. At Rusizi the highest yield production of maize occurs in 2014 in season A and the lowest yield production of maize occurs 1998 in Season A. During season B, Nyagatare has the highest yield production of maize in 2015 and the lowest yields production occurs in 2000.while at Rusizi during season B, the highest yield production of maize occurs at 2019 and the lowest yield production of maize occurs 2018.

For Beans, in season A at Nyagatare, the highest yield production of beans occurs in 2012 and the lowest yield of beans occurs 2006 while at Rusizi during season A, the highest yield production of beans occurs in 2006 and the lowest yield production of beans occurs 2000. In season B at Nyagatare, the highest yield production of beans occurs in 2014 and the lowest yield production of beans of 2007.During season B at Rusizi, the highest yield production of beans occurs in 2003 while the lowest yield production occurs in 2018.

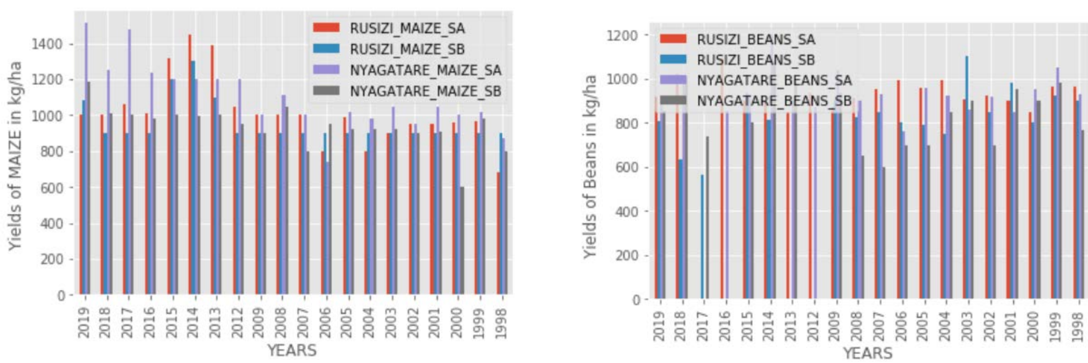


Figure7: THE TEMPORAL TRENDS OF MAIZE YIELDS AND BEANS YIELDS OVER THE 1998-2019.

2.6.6 Model Result of maize in both season A and B at Nyagatare.

table.5 shows that dry spell and total rainfall at Nyagatare have more significant impact on yields of maize during MAM season and SOND season, because the p-value of dry spells during seasons A is 0.001 and 0.004 in season B and p-value for total rainfall is 0.002 for season A, these both p-values of dry spells and total rainfall are less than 0.05 using statistical analysis. This apparition of long dry spell at Nyagatare during the SOND cause the reduction of maize yields in 2006 during season A and reduction of maize yields in 2000 during season B. Other side the total rainfall during the MAM season and SOND season cause the positive impact on yields of maize since 2014 up to 2019. Eastern province and Central region of the country were very dry compared to other locations in the country.Highest temperatures were recorded in Nyagatare (Eastern Province) and Mageragere (Central region) with 27.00C and 26.4 0c respectively (Murenzi 2018).

These positive impact and negative impact of yields of maize at Nyagatare during seasons A and season B,

Multilinear regression model of maize in Nyagatare.				
Dependent variable: Nyagatare_Maize_Season_A	R-squared =0.871			
Model:OLS	Adj.R-squared:0.683			
Method: Least Squares	F-statistics:8.763			
Date:wed,04 Dec,2019	prob(F-statistic):0.000799			
number of obsrevation	19	AIC:230.6		
Df Residuals	13	BIC:236.3		
Df Model:	5			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	2193.9618	529.782	4.141	0.001
ONSET(start_rain_season A)	-1.3251	1.043	-1.27	0.226
Cessation(End_rains_seasonA)	-0.8765	0.968	-0.905	0.382
length of season A	0.4486	0.989	0.454	0.658
dry spells	47.0373	29.677	1.585	0.001
totol rainfall	-0.6785	0.181	-3.759	0.002
average daily rainfall	-25.901	54.265	-0.477	0.641

***TABLE 5*: *MULTILINEAR LINEAR REGRESSION MODEL OF MAIZE AT NYAGATARE DURING SEASON A*.**

Multilinear regression model of maize at Nyagatare during season B				
Dependent variables: Nyagatare_Maize_season B	R_square:0.650			
Model: ordinary Least squares	F-statistics: 3.708			
Method:Least Squares				
Date:Wed,04Dec2019	Prob(F-statistic):0.0255			
number of obseravtion	19	AIC:223.0		
Df Residuals	12	BIC:229.6		
Df model:	6			
Covariance type:	nonrobust			
	coef	std err	t_value	p_value
constant	1578.98	281.987	5.599	0
Onset(start_rain_season A)	-58.25	58.26	-1	0.337
Cessation(end_rain_season A)	54.61	58.926	0.927	0.372
length of season A	-55.6589	57.717	-0.964	0.354
dry spells	-35.7254	12.401	-2.881	0.004
total rainfall	-0.3841	0.251	-1.527	0.153
average_daily_rainfall	44.0474	35.246	1.25	0.235

TABLE 6: MULTILINEAR LINEAR REGRESSION MODEL OF MAIZE AT NYAGATARE DURING SEASON B.

Shows that maize yield production more affected at the mid-season stage of flowering and grain filling during the year 2006 and 2000, where number of times of dry spells occurs in 2006 was four dry spells at flowering stage and five times of dry spells during the yields formation stage of maize and also the total rainfall was 450mm in 2006 during season A and 600mm in2000 during season B. This cause the reduction of maize yields at Nyagatare because Maize crop is very sensitive to water deficit in the critical stages due to its high water requirement in terms of evapotranspiration and high physiological sensitivity when determining its main yield components such as number of ears per plant and number of kernels per ear .we observed that soil moisture condition during the germination at Nyagatare is of higher significant and determines crop performance compare to Rusizi. The agricultural dry spell analysis showed that maize was exposed to at least one dry spell of 10 days or longer in 74–80% of seasons at both sites (Barron, Rockström et al. 2003) compare to beans.

Maize on sandy soil experienced dry spells exceeding 10 days, three–four times more often than maize on clay soil during flowering and grain filling stages (Barron, Rockström et al. 2003). In addition, the water balance analysis indicated substantial water losses by surface runoff and deep percolation as the crop utilized only 36–64% on average of seasonal rainfall(Barron, Rockström et al. 2003). Look at the fig.7 shows that the yields of maize at Nyagatare in season A and season B decreases as the number of dry spells increases similar to total rainfall at Nyagatare. Heavy rainfall occurring in December and January are often not able to support high yield of maize and crop as a result of late planting which is usually carried out during the second and third week of November and first week of December (Oseni and Masarirambi 2011).

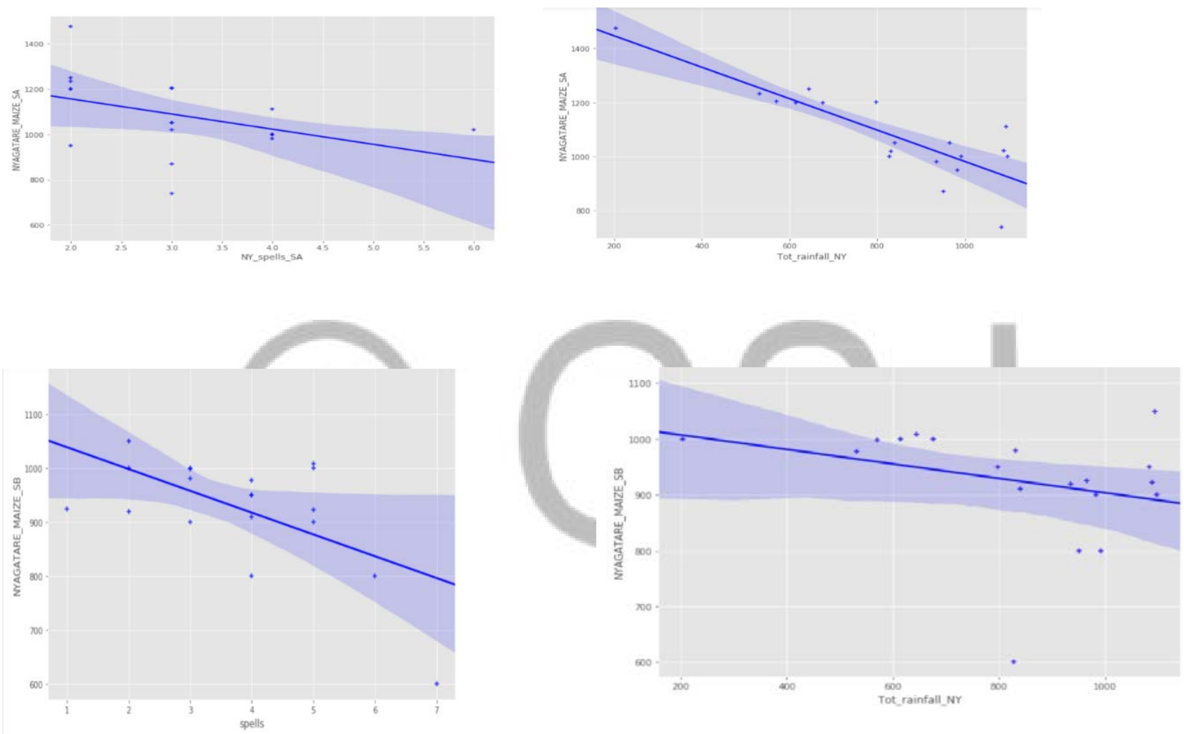


Figure 8: SCART plot of maize for season A and b at nyagatare.

During the year 2015 in season B up to 2019 season A, the yields of maize was increase due to the facts that the number of times of dry spells occurs at Nyagatare in 2015 during MAM season was five at maturity stage of maize and three times of dry spells in 2019 at Nyagatare during SOND season, this shows that there is no impact of dry spells on maize yields production during these years because at the maturity stage of crop and also the total rainfall was 550mm for both season. Dry spells may affect crop growth without significant reductions in seasonal rainfall totals as compared to average totals, meteorological droughts occur when cumulative rainfall generally aim to detect (inter) annual drought cycles and/or to identify possible climatic change, usually with regard to rainfall (Murenzi 2018).Water has long been considered to be the main limiting resource for crop growth in semi-arid sub-Saharan Africa (SSA). Although water is limiting, it is often the distribution of water rather than lack of total seasonal amounts that is affecting crop growth and final yields *(Niu, Peng et al. 2010)*. Rainfall variability worsened by prolonged dry spell occurrence within seasons at Nyagatare and years of agricultural production therefore has serious repercussion to small scale farmers in food crop production. Evaluating crop response to the changing annual rainfall amounts received in a given area can hence inform the best mitigation strategies to reduce the impact of the prolonged dry spells and improve crop yields *(Niu, Peng et al. 2010)*.

2.6.8 Model results of Maize in both season A and B at Rusizi

Table.7 shows at Rusizi, Total rainfall during the SOND season and start of rain season B (Onset), end of rain season B (Cessation) and average daily rainfall have more significant impact on yield of Maize at RUSIZI. Because p-values of total rainfall is 0.002 where P-value of start of rain season B is 0.001 and the p-value of end of rain season B is 0.002. Which means that these p-value are less than 0.05 using statistical analysis that why they have more Significant impact on yields of maize at RUSIZI. This apparition of total rainfall during the SOND, onset and cessation during the MAM season at Rusizi because positive and negative impact of maize yields at Rusizi.

Multilinear regression model of maize in Rusizi.				
Dependent variable:Rusizi_Maize_Season_A	R-squared =0.778			
Model:OLS	Adj.R-squared:0.656			
Method: Least Squares	F-statistics:2.010			
Date:wed,04 Dec,2019	prob(F-statistic):0.000468			
number of obsrevation	18	AIC:168		
Df Residuals	11	BIC:184.5		
Df Model:	3			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	1975	357.932	5.519	0
ONSET(start_rain_season A)	0.8912	2.025	0.44	0.001
Cessation(End_rains_seasonA)	0.8982	2.537	0.354	0.002
length of season A	0.0069	1.852	0.004	0.997
dry spells	74.635	17.136	4.353	0.0002
totol rainfall	-0.0634	0.261	-0.243	0.002
average daily rainfall	-0.0634	0.261	-0.243	0.003

TABLE 7: ***MULTILINEAR LINEAR REGRESSION MODEL OF MAIZE AT RUSIZI DURING SEASON A.***

Multilinear regression model of maize in Rusizi.				
Dependent variable: Rusizi_Maize_Season_B	R-squared =0.932			
Model:OLS	Adj.R-squared:0.356			
Method: Least Squares	F-statistics:3.010			
Date:wed,04 Dec,2019	prob(F-statistic):0.0717			
number of obsrevation	15	AIC:181.0		
Df Residuals	10	BIC:184.5		
Df Model:	4			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	1975	357.932	5.519	0
ONSET(start_rain_season B)	0.8912	2.025	0.44	0.001
Cessation(End_rains_seasonB)	0.8982	2.537	0.354	0.002
length of season B	0.0069	1.852	0.004	0.997
dry spells	74.635	17.136	4.353	0.0002
totol rainfall	-0.0634	0.261	-0.243	0.002
average daily rainfall	-0.0634	0.261	-0.243	0.003

TABLE 8: ***MULTILINEAR LINEAR REGRESSION MODEL OF MAIZE AT RUSIZI DURING SEASON B.***

Heavy rainfall occurring in September, October and December at Rusizi are often not able to support high yield of maize crop in 1998 and 2019 for SOND, the rainfall occurred in 1998 was 800 mm where in 2019 was 756 mm, this precipitation affected yields of maize to the highest level because, it occurs at germination stage of maize where the rainfall affected the roots of maize in that time. During MAM season, as a result from table.8 shows that the onset and cessation at Rusizi have positive impact on yields of maize. The yields of maize at Rusizi in 2014 during SOND was high and also in 2019 the yield of maize was high during MAM due to the fact that the planting date in 2014 happened on the day of 363. To mean that, 363 was planting date, the household farmers who planted within window at Rusizi their crop production decreases other side increase .the results shows that those who planted within window their crop yield of maize decreases as show in (fig .9) because the season took a long time without dry spell occurs at Rusizi during MAM, this cause the yield maize to be reduced. We saw that in 2019 the planting date happened on the day of 263. The household farmers who plant after 263 their crop yields decreased. To get crop yield of maize, it took four to five months to the maturity stage as shown (table.4) therefore if the season ended before maturity of maize crop, while maize needed full season to be mature, this tends to the reduction of maize yields at Rusizi. Fig9 shows that as dry spells increase at Rusizi as yields of maize also increase because dry spells at Rusizi is mostly occurs few times compare to Nyagatare.

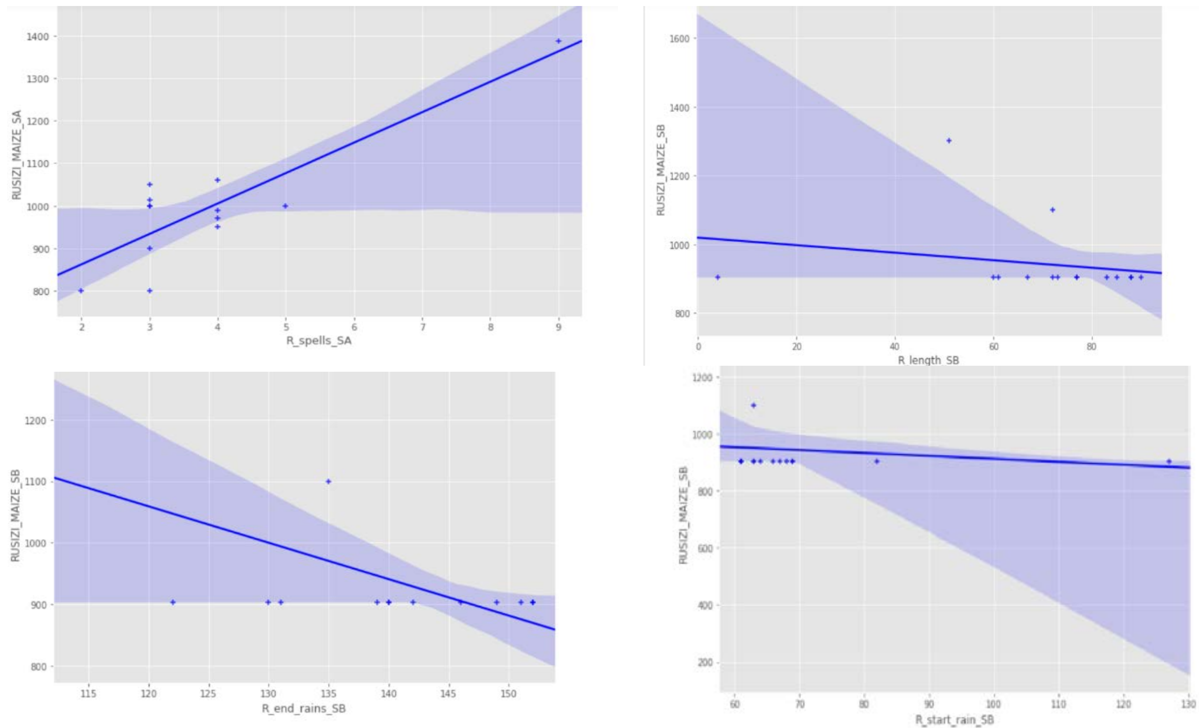


Figure 9: scart plot that shows the impact of dry spells on yields of maize for season A and impact of length of season Start of rain, end of rain for season B on yields of Maize at RUSIZI.

Ends of rains season B (Cessation) shows that once season took a long time without ended, the yield of maize also decreases similar to the lengths of season B and also start rain season B (onset). Onset shows that once the season late to start this also affected the yield of maize to be reduced at Rusizi.

2.6.9 Model results of Beans in both season A and B at Nyagatare.

Table.9 shows that dry spell and total rainfall, starts of rains, end of rain, mean daily rainfall at Nyagatare have more significant impact on yields beans during MAM season and SOND season, because the p-value of dry spells is 0.04 for MAM and p-value of mean daily rainfall is 0.012 for MAM, p-value of starts of rains is 0.04 for MAM, end of rains p-value is 0.046 for MAM and 0.040 for SOND and also p-value of total rainfall for both MAM and SOND are 0.02. These p-values of dry spells starts of rains, end of rain and average daily rainfall, total rainfall are less than 0.05 using statistical analysis. Results from (Fig.10) shows the years that have the highest yields and the lowest yields of beans at Nyagatare. In 2012 during SOND, Nyagatare have the highest yield of beans because the number of times that dry spells occurs during this year was two at maturity stage of beans, this dry spells occurred at maturity stage did not have impact on yields of beans as most of dry beans need water during the initial stage and crop development. The amount of total rainfall occurs in this year was 350 mm. The lowest yield of beans occurs in 2006 during SOND, where the number of times that dry spells occurs during this year was five at the initial stage of beans and amount of total precipitation was 400 mm, this dry spells affect yield of beans since it happened at the initial stage where the crop need water another to develop the roots. During the MAM at Nyagatare the highest yield of beans occurred in 2014 where one times of dry spells occurs during the maturity stage of beans and 500mm of total rainfall and lowest yield of beans occurred in 2007 due to four times of dry spells at germination stage of beans and the total rainfall was 550mm.

Multilinear regression model of beans in Nyagatare.				
Dependent variable: Nyagatare_beans_Season_A	R-squared =0.890			
Model:OLS	Adj.R-squared:0.479			
Method: Least Squares	F-statistics:4.121			
Date:wed,04 Dec,2019	prob(F-statistic):0.0207			
number of obsrevation	18	AIC:208.4		
Df Residuals	12	BIC:213.8		
Df Model:	5			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	369.2689	484.52	3.121	0.0009
ONSET(start_rain_season A)	1.69	2.025	0.44	0.934
Cessation(End_rains_seasonA)	0.8322	2.537	0.354	0.445
length of season A	0.8322	1.852	0.004	0.997
dry spells	74.635	17.136	4.353	0.003
totol rainfall	-0.0634	0.261	-0.243	0.0008
average daily rainfall	-0.0634	0.261	-0.243	0.003

TABLE 9: ***MULTILINEAR LINEAR REGRESSION MODEL OF BEANS AT NYAGATARE DURING SEASON A.***

Multilinear regression model of beans in Nyagatare.				
Dependent variable: Nyagatare_beans_Season_B	R-squared =0.548			
Model:OLS	Adj.R-squared:0.276			
Method: Least Squares	F-statistics:2.019			
Date:wed,04 Dec,2019	prob(F-statistic):0.156			
number of obsrevation	17	AIC:216.6		
Df Residuals	10	BIC:222.4		
Df Model:	6			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	1556.2	484.52	3.121	0.0009
ONSET(start_rain_season B)	0.8912	2.025	0.44	0.134
Cessation(End_rains_seasonB)	0.8982	2.537	0.354	0.345
length of season B	0.0069	1.852	0.004	0.997
dry spells	74.635	17.136	4.353	0.004
totol rainfall	-0.0634	0.261	-0.243	0.0007
average daily rainfall	-0.0634	0.261	-0.243	0.003

TABLE 10: ***MULTILINEAR LINEAR REGRESSION MODEL OF BEANS AT NYAGATARE DURING SEASON B.***

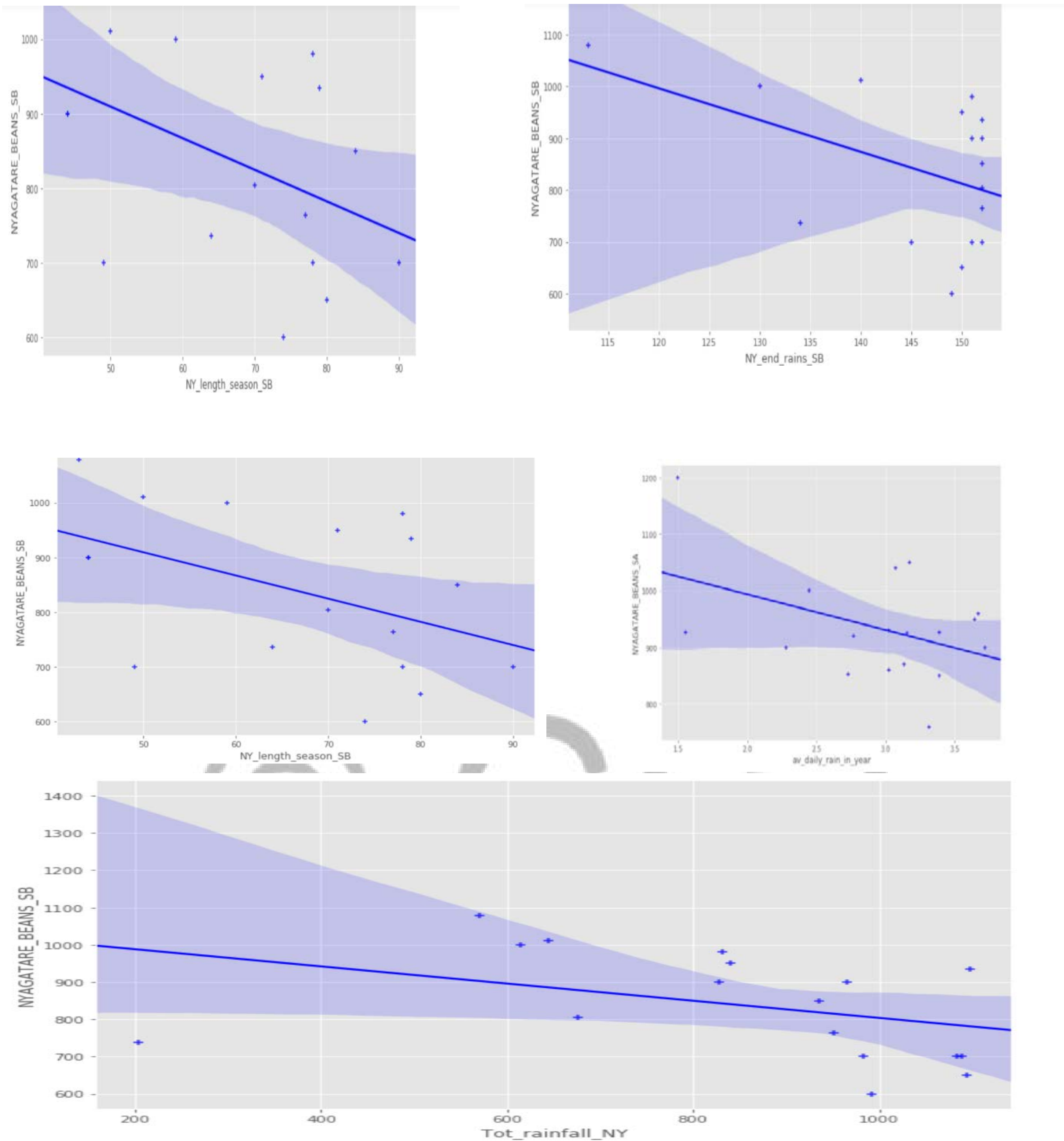


Figure 10: scart plot that shows the impact of length of season, total rainfall, average daily rainfall, Start of rain season and end of rain season at nyagatare.

Fig .10 shows that as the length of season during the MAM and SOND take long time, the yields of beans decrease because it affect beans crop to the rot of roots. And also more total rainfall increase more the yields of beans decreases, this means that the heavy rainfall destroy the different crop especial beans. If we look at the (fig.10) as the average daily rainfall increase in every year this also affect the yields of maize to decrease.

2.6.10 Model results of Beans in both season A and B at Rusizi

(Fig.12) shows total rainfall, and dry spells at Rusizi have more significant impact on yields beans during MAM season and SOND season, because (fig12) shows the p-value of total rainfall is 0.03 during MAM and SOND and dry spells is 0,001. (Fig.6) shows the year that has the highest yield of beans at Rusizi and the lowest yields of beans at Rusizi during MAM and SOND. Where the highest yields of beans occurs in 2006 during SOND and in 2003 during MAM. The SOND the highest yields of beans occurs due to the fact that the number of time of dry spells was two at maturity stage of beans where total rainfall in the year was 400mm and also the planting date happened on the day 125, those who plant within window the crop production of beans increase during these year. While in 2003, they was no dry spells occurs in this year but the total rainfall was 550mm during MAM, this does not have effect on yields of beans. In 2000 during SOND and 2018 during MAM are the years that have the lowest yields due to the facts that the numbers of times that dry spells occurs in 2018 during MAM was four at initial stage of beans, this has more effect on yields of beans because at this stage, it is where the crop need water to growth that why the yields of beans in this year decreases compare to Nyagatare. As shown in the (fig.13) the more total rainfall increase the more affect yields of beans to decrease as well as dry spells during SOND season.

Multilinear regression model of beans in Rusizi.				
Dependent variable: Rusizi_beans_Season_A	R-squared =0.77			
Model:OLS	Adj.R-squared:0.437			
Method: Least Squares	F-statistics:3.130			
Date:wed,04 Dec,2019	prob(F-statistic):0.0589			
number of obsrevation	12	AIC:140		
Df Residuals	7	BIC:140		
Df Model:	4			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	369.2689	484.52	3.121	0.0009
ONSET(start_rain_season A)	1.69	2.025	0.44	0.0.1
Cessation(End_rains_seasonA)	0.8322	2.537	0.354	0.03
length of season A	0.8322	1.852	0.004	0.01
dry spells	74.635	17.136	4.353	0.63
totol rainfall	-0.0634	0.261	-0.243	0.0008
average daily rainfall	-0.0634	0.261	-0.243	0.03

TABLE 11: ***MULTILINEAR LINEAR REGRESSION MODEL OF BEANS AT RUSIZI DURING SEASON A.***

Multilinear regression model of beans in Rusizi.				
Dependent variable: Rusizi_beans_Season_B	R-squared =0.77			
Model:OLS	Adj.R-squared:0.437			
Method: Least Squares	F-statistics:3.130			
Date:wed,04 Dec,2019	prob(F-statistic):0.0589			
number of obsrevation	12	AIC:140		
Df Residuals	7	BIC:140		
Df Model:	4			
Covariance Type:	nonrubust			
Independent variables	coef	standard error	t_values	p-value>|t|
constant number	369.2689	484.52	3.121	0.0009
ONSET(start_rain_season B)	1.69	2.025	0.44	0.0.1
Cessation(End_rains_seasonB)	0.8322	2.537	0.354	0.03
length of season B	0.8322	1.852	0.004	0.01
dry spells	74.635	17.136	4.353	0.63
totol rainfall	-0.0634	0.261	-0.243	0.0008
average daily rainfall	-0.0634	0.261	-0.243	0.03

TABLE 11: ***MULTILINEAR LINEAR REGRESSION MODEL OF BEANS AT RUSIZI DURING SEASON B.***

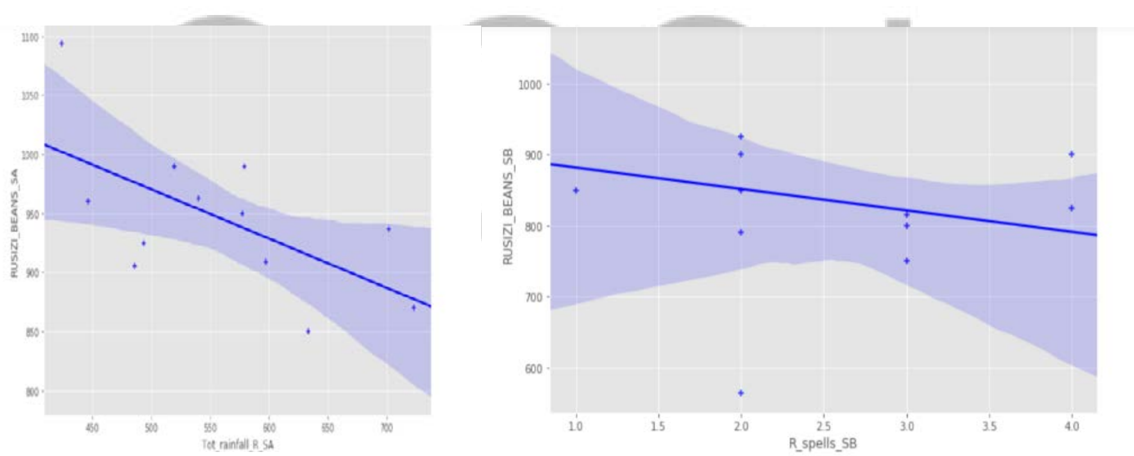


Figure 11: The scart plot that shows the impact of Total rainfall for season A on yields of beans and Dry spells for season B on yields of Beans.

3. Conclusion and Recommendation

Using full climatological dataset of Rwanda, this study has shown that, there is wide variability in dry spells, total rainfall negative trends at Nyagatare that effect yields of maize and beans during SOND and during MAM season. At Nyagatare, maize was ready for harvest during both season more than Rusizi while beans was ready for harvest at Rusizi during SOND season more than Nyagatare during SOND season. At Rusizi the onset, cessation, length of season and also total rainfall have negative impact on yields of maize and beans for MAM season and SOND season compare to Nyagatare, and also the number of rain days and annual rainfall amount have the strongest influence on maize and beans yields per hectare at Rusizi compare to nyagatare. Dry spells has negative impact on yields of maize at Nyagatare compare to Rusizi. Consequently, the variation in climate have enormous impacts on maize even at Rusizi compare to beans. We observed that Temperature characteristics (maximum temperature, minimum temperature, temperature range and Growing Degree Days) negative relationships with maize and positive relationship with beans yield, which implied that an increment in temperature resulted in a reduction in maize yield and a reduction in temperature resulted in increasing maize yields.

Wide variability of correlation coeffients value reflects enormous impact of individuals climate variability on maize and beans with variability in maize and beans yields closely related to Nyagatare and Rusizi September October and December. Relationship between maize and rainfall at Rusizi was positive and negative, beans yields have has significant declined negative at Nyagatare during SOND season compare to beans during SOND season at Rusizi while during MAM beans has significant declined positive compare to beans at Nyagatare during the MAM season. The findings revealed that rainfall variability and dry spells have serious impacts during the germation stage and flowering stage of maize and beans causing massive crop failure at Nyagatare compare to Rusizi. Planting within window at Rusizi is better than planting after window at Rusizi. Those who planted before the window their crop production increase compare to those who plant after window.

Dry spells at Nyagatare had the highest correlation coeffient during SOND season and MAM season implying that the climate impacts were at least on maize rather than beans. While at Rusizi total rainfall had the highest correlation coefficient during SOND and MAM implying that the climate impacts were at least on beans than maize. Because required small period of time to be ready for the harvest.

We recommend, Government of Rwanda should sensitize farmers on climate or weather variability and monitoring of crop climate relationship in the area in the other to achieve improved crop yield.

In view of the high correlation of rain days and rainfall amount with maize yield, the need for appropriate land use management practices that will ensure moisture availability in the area has become crucial for sustainable crop production. To this extent, soil conservation and age old farm practices such as land tillage, mulching, planting cover crops, controlling and checking erosion to help protect the soil from deterioration or degradation should be adopted must be more applicable at Rusizi compare to Nyagatare.

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