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Assessment of Grain Legumes Adaptation to Climate Change in Bugesera District, Rwanda

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Abstract

The aim of this study was to assess the adaptability to climate change of selected grain legumes (including beans, peas and soybeans) in Bugesera district in Rwanda. Climate change was analysed by considering significant changes in mean, minimum and maximum temperature and the mean annual rainfall from 1970 until 2014, the year during which data for this study were collected. The sampling strategy followed a cluster area sampling and random sampling approach, which led to the sample size of 99 households surveyed using a structured questionnaire. MAKESENS model and Analysis of Variances (ANOVA) were applied to analyze climate data and information from the household survey. This study revealed significant increase of mean temperature (0.39^0C and 0.46^0C per decade for rainy seasons A and B respectively) and irregularity of rainfalls during both rainy seasons. The Diurnal Temperature Range (DTR) has been decreasing considerably, impacting the crops development traits such as internode length. The farmers' responses indicated low adaptation capacity to the climate change, leading to a high sensitivity of the grain legumes. For an improved mitigation of climate change impacts, the following strategies were proposed: land consolidation and creation of grain legumes farmers' cooperatives, improved economic capacity of the farmers, use of climate-resilient selected seeds, creation of the off-farm activities, improved climate information reliability and dissemination.

Keywords: climate adaptive capacity, climate change, climate vulnerability, grain legumes.

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1. Introduction

Climate change is an eminent threat across the globe. Agriculture is among the most threatened economic sectors. Climate projections indicate that by the end of the 21st century, climate change will have significant impacts on the agricultural production (Slater, et. al., 2007). To exemplify, observations indicate that the African climates were about 0.50C warmer in 2000 compared to the year 1900. Many areas in Africa are recognized as having climates that are among the most variable in the world on seasonal and decadal time scales, and impacts such as floods and droughts can be observed several times in a year over the same area (Slater, et. al., 2007). Different factors contribute to the impacts of current climate change in Africa and will continue to have negative effects on the continent’s ability to cope with climate change (Morton, 2007). These factors include, among others, poverty, high illiteracy rate, weak institutional arrangement and capacity, limited infrastructure, lack of adequate technology and regular information, low levels of primary education and health care, poor access to resources, low management capabilities and armed conflicts (UNDP, 2006).

Previous studies showed that Africa will continue to face increasing water scarcity and stress with a subsequent potential increase of water conflicts, as almost all of the 50 river basins in Africa are transboundary (Ashton, 2002). Agricultural production which heavily relies on these water resources and rainfall for irrigation, is expected to be strongly compromised in different African countries, particularly for subsistence farmers and in sub-Saharan Africa, where Rwanda is located (De Wit & Jacek 2006). Moreover, the southern and East African regions will experience hotter and drier climatic conditions in the medium to long term (Kinuthia, 1997), leading to a serious compromise of African agricultural production and access to food. Consequently, in some countries, yields from rain-fed crops could be halved by 2020 (Oxfam, 2007). Sub-Saharan African region will be hit hardest because of a very high poverty rates, very slow technological improvements, strongly agriculture-dependent domestic economies (Mendelson, et al, 2000 & Morton, 2007).

Rwanda is among the Sub-Saharan African countries with a large number of population depending on subsistence agriculture, although the sector is under threat. Agriculture grows at a rate of 5.8% per year, employs about 70% of Rwandan population, and contributes to about 26% of the national GDP (NISR, 2020). Nevertheless, the agriculture sector faces hindrances, especially from climate change. Moreover, with a rapid population growth with 2.6% (NISR, 2014), there is a high pressure on land resources, making it more scarce and over-exploited. Also, Rwanda is located in a region which is experiencing an increase in temperature by 0.3°C to 0.7°C per decade during the second half of the last century (Siri, et al., 2008), which will continue to threaten the crops, among other effects. Another threat to the agricultural sector in Rwanda is soil fertility. A high proportion of the Rwandan soils have significant acidity: 75% of the land is “highly degraded,” and overall Rwanda has one of the highest negative nutrient balances in sub-Saharan Africa (REMA, 2007). One of the strategies to cope with the acidity issue is the use of lime. However, this strategy is expensive and therefore, not affordable to many farmers in Rwanda. Bugesera district is one of the Rwandan districts with serious impact from both the climate change and the soil acidity. In addition, Bugesera district has experienced prolonged and repeated droughts since 1998, resulting in food insecurity and massive population movements (REMA, 2007), and has often recorded frequent famines due to poor harvest in the wake of drought and inadequate water control (Siri, et.al. 2008).

Although Bugesera district is under serious threat by the climate change, there is a limited knowledge on the level of sensitivity and adaptation to climate change for specific staple crops among the farmers, which would lead to proposing and implementing effective climate mitigation and adaptation strategies, for climate-resilient agriculture. In this regard, this study aims at analyzing the relationships between exposure and sensitivity to climate change, as well as the potential of adaptive capacity and coping strategies among grain legumes farmers in Bugesera district This was achieved through responding the following research questions: 1) what are the climate change trends in Bugesera district from 1970s up to 2014? 2) what is the frequency and significance of climate variables’ (temperature and rainfall) thresholds in Bugesera district? 3) how grain legumes have been impacted by the climate change in Bugesera district?

2. Materials and methods

2.1. Study Area

Bugesera district is located in the South West of Eastern Province, Rwanda (Figure 1). It is bordered in the south by Burundi, Ngoma district to the East, Kigali City and Rwamagana district to the North. Its relief has a succession of undulating hills, dry valleys

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and some marshes due to tectonic collapse. The area is prone to droughts, and has a higher average daytime temperature than the Rwandan average, and lower precipitation (CSEA, 2014). Since late 1990, the district has experienced long periods of drought and low levels of rainfall. The district had total population of 363,339 by end of 2012, and is dominated by rural areas, with subsistence agriculture being the backbone of livelihood (UNEP, 2011). Like the rest of Rwanda, Bugesera district is characterised by a bimodal climate, with the long rains falling between February and May (Season B of agriculture), and the short rains falling between September and December (Season A of agriculture). However, one out of every two years, the rainfall of the first rainy season is insufficient for healthy crops, resulting in deficit crop production (CSEA, 2014). Mixed farming is also the most common farming system, with traditional way of farming: reliance on family labor, use of hoes and machetes as the main cultivation equipment, and practice of intercropping, crop rotation and minor soil and water conservation techniques. The main food crops grown in Bugesera are sorghum, maize, groundnuts, cassava, soybean, sweet potatoes, beans, peas, and rice (UNDP, 2007).

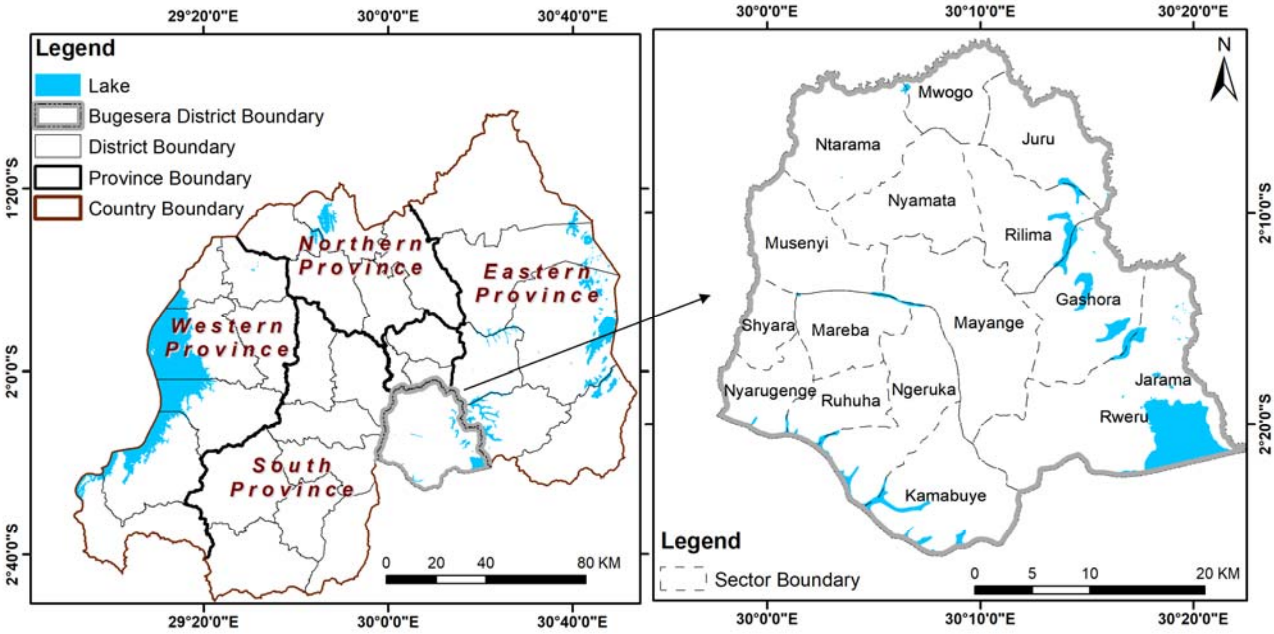

Figure 1: Location of the Bugesera District in Rwanda

2.2. Data

Different types of datasets were used to achieve the aim of this study. Those data were collected in 2015, based on the extensive research work which was undertaken in Bugesera District during that period. This research relied on four categories of data. First, the review of the existing literature has contributed to the deep and specific understanding of the climate change situation and related impacts in Bugesera district. Second, climate data (mean, minimum and maximum daily temperature, as well as daily rainfall) were used to analyse the historical change of the climate in Bugesera district. Third, administrative shapefiles were used to delineate study area and plan for field data collection (the sampling framework design). Finally, household (HH) survey and interview with key informants were held to analyse the climate adaptive capacity among the grain legumes in Bugesera district.

2.3. Data Collection

Data collected include both primary and secondary datasets. Primary datasets include the household survey, and the interview with the key informants from the Bugesera district administration (i.e., sector agronomist officers, and socio-economic development officers (SEDO) at cell level). The household surveys consisted of collecting different information including trends of crop yields from last 10 years, seeds suitability to plots, household financial capacity, agriculture dependency (main source of income), physical resources, demographic characteristics, and awareness and information about climate change and its adaptation. The above-mentioned data were collected in all cells of Mareba sector, Bugesera district (Figure 1). The sector was selected to represent the district based on critical vulnerability of grain legumes to climate vulnerability, as per the local expert knowledge and the district's agronomist officer. Cluster area sampling technique was applied to determine the sample size, clusters being the cells of Mareba sector. The sample size was determined using the formulae in Equation 1 (Yamane, 1967):

$$n = N/ (1+N (e)^2) \qquad \text{(Eq. 1)}$$

Where n is sample size, N is population size, and e is the level of precision estimated to be 10% or 0.1 and confidential level of 90%.

The sample size in Mareba sector was: $n = \frac{5767}{1+5767\,(0.10)^2} = 98.24 \sim 99$

Therefore, this study has used 99 households as sample size, and which were selected from the 5 cells of Mareba district using a proportionate approach: 25 households in Bushenyi cell, 16 in Gakomeye cell, 14 in Nyamigina cell, 28 in Rango cell, and 16 households in Rugarama cell. More information was collected from the key informants: Mareba sector agronomist officer, and socio-economic development officers of the cells in Mareba sector. Their responses focused on more awareness, plans, projects, initiatives and priorities towards improving food security in the sector, increasing agriculture productivity, and reducing impacts of climate change on the grain legumes in the area.

2.4. Data Analysis

The first step of data analyses has been data entry and questionnaire coding for the household surveys, upon which Analysis of Variances (ANOVA) was applied later, using SPSS software package. Regarding climate data, the analysis was performed using the Excel-based tool 'MAKESENS' (Salmi et al., 2002). The software combines two tests; the first is a nonparametric Sen's method for identifying the magnitude of any trend and the second is a non-parametric Mann-Kendall test to identify the significance of any trend (Sen, 1968). Then, trends in different variables are described with reference to their 'significance': a statistical term that indicates the likelihood of that trend occurring by chance. Where a trend is described as significant it will be followed in brackets by the level of significance (either 0.1, 0.05, 0.01 or 0.001; i.e. the chance of that trend occurring by coincidence would be 10%, 5%, 1% or 0.1% respectively). Where a trend is not significant, it has a better than 10% chance of occurring by coincidence and therefore it cannot be ruled out that it happened by fluke. Furthermore, the software detects trends in annual values, therefore, monthly values were either summed or averaged to give an annual value. Where seasons are assessed, monthly data were summed or averaged into two rainy seasons for the analysis: March-April-May (MAM - Season B of agriculture) and October-November-December (OND - season A of agriculture). Three months per season are in accordance with grain legumes (i.e. beans, peas and soybeans) have their maturity after 120 days. All the data were analysed as "monthly" instead of "daily" given that it was not possible to ascertain information on changes in heavy rainfall events or the specific timing of the start and end of the rainy seasons.

3. Results and Discussion

3.1. Exposure of grain legumes to climate change in Bugesera

3.1.1. Temperature and Rainfall Trends in Rwanda

The national reports on climate indicate that the temperature would increase by 1.4 ºC in Rwanda, between 1970s and 2050 (REMA, 2017). Similarly, rainfall has also been described as with a high variability, with potential increase of 5% to 10% between 1970 and 2030 (GoR, 2015). This changing climate will result in a high exposure of the country to effects such as seasonal irregularities, high frequency of floods, landslides, crops losses, damage top infrastructure, among many others. The IPCC global climate models also predict similar changes in the climate. The first model is the Representative Concentration Pathways (RCPs) 8.5, corresponding to business-as-usual scenario: a pathway with the highest greenhouse gas emissions and related consequences on both ecosystem services, food production and the livelihoods of the population (Livingston, Lövbrand & Alkan Olsson, 2018). The model predicts an increase of 3ºC between 1970 and 2050 in Rwanda’s temperature (Figure 2). The same model predicts an increase of about 350 mm in the annual mean rainfall within the same period, which would be 230 mm of decrease with pronounced variability by 2100 (IPCC, 2014).

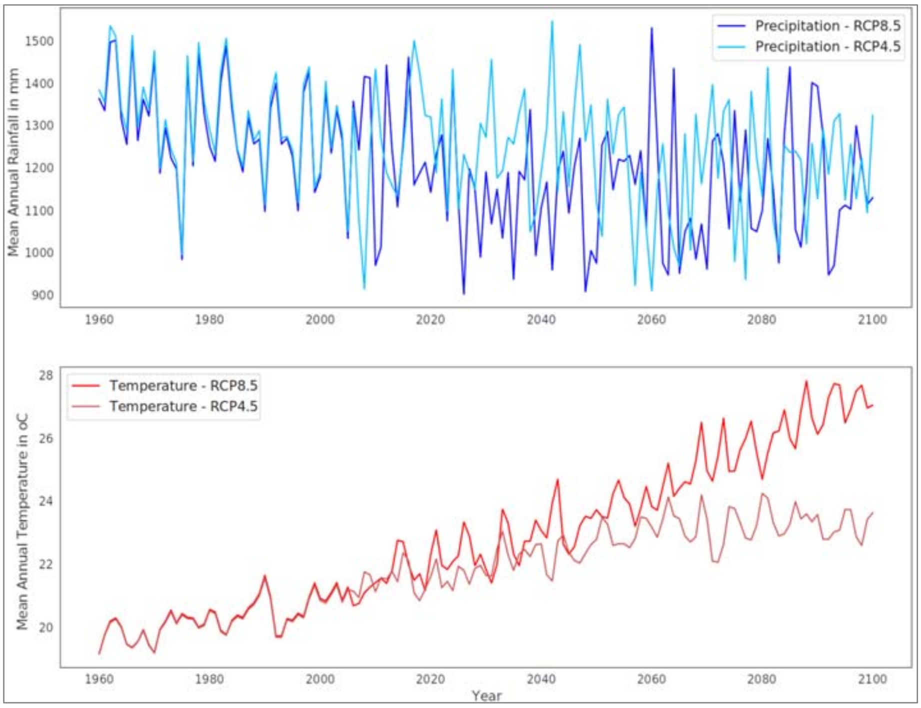

Figure 2: Predictions in Changes of Climate in Rwanda
Data source: Means et al., 2017

The second IPCC model: RCP 4.5 (Minx, Callaghan, Lamb, Garard & Edenhofer, 2017; Pearce, Mahony & Raman, 2018) encourages the use of Clean Development Mechanisms (CDMs) to promote less polluting technologies. Nevertheless, the model also predicts an increase of temperature in Rwanda, by 2ºC between 1970 and 2050, and 3.5ºC by 2100 (IPCC, 2014). Furthermore, the model predicts a decrease of about 30 mm in annual mean rainfall within the same period.

3.1.2. Temperature dynamics in Bugesera district

Figure 3 presents the spatial distribution of the temperature in Rwanda, with highlights on Bugesera district. The figure indicates a clear difference between the western part and eastern part of Rwanda, where the East (where Bugesera district is located) is dryer, making it more exposed to the impacts of climate change.

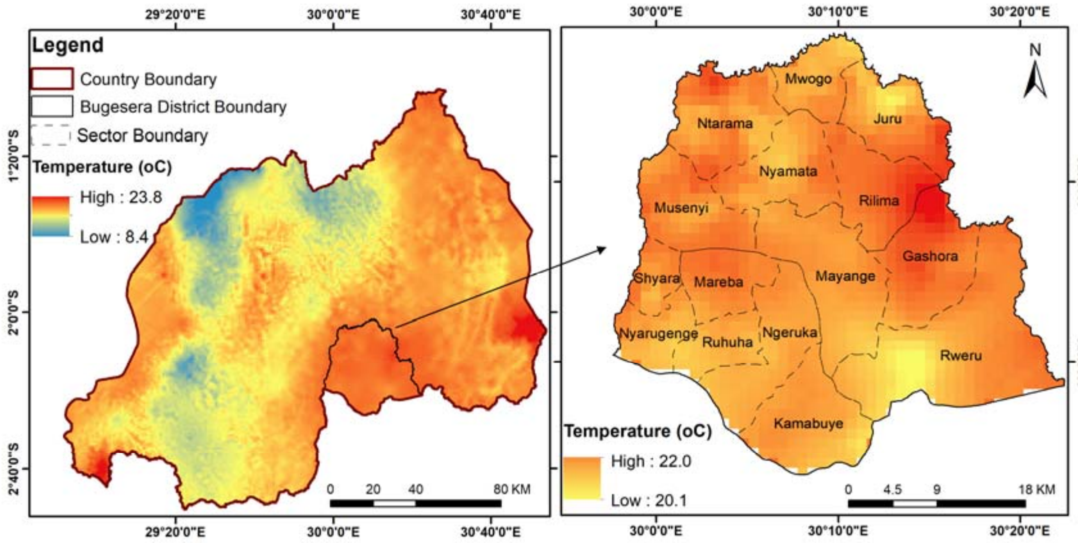

Figure 3: Spatial distribution of temperature in Bugesera district, Rwanda
Data source: Means et al., 2017

The analysis of the climate data indicated that the mean temperature between 1971 and 2014 to both seasons shows a significant increase (p = 0.001) of 0.39°C and 0.46°C per decade for season A and Season B respectively (Figure 4). This trend is more rapid in comparison to the global observed average between 0.19°C and 0.32°C per decade for 1979 - 2005 (Trenberth et al., 2007).

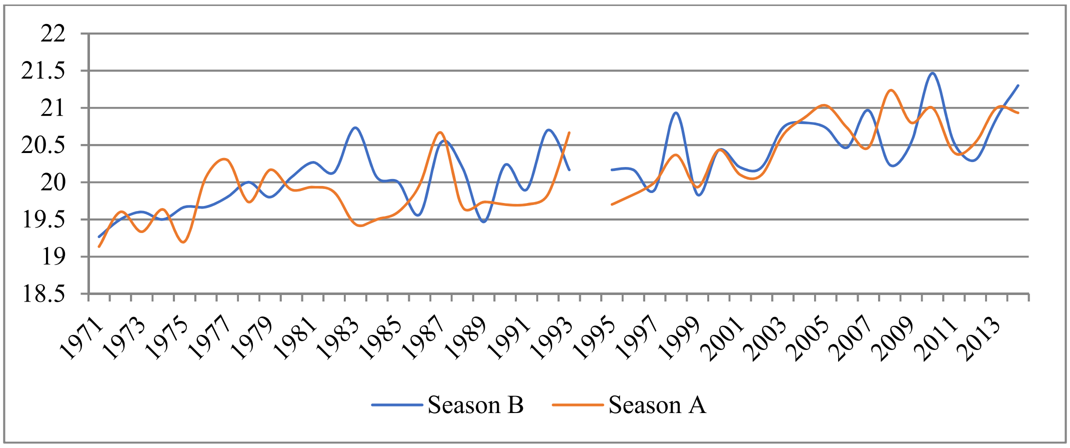

Figure 4: Average temperature for Kigali Airport station (1971-2014) - Season A and B
Data source: RMC, 2014

Like the Figure 4, records for maximum and minimum temperature showed a significant increase (p=0.001) of around 0.5ºC per decade. The season A has experienced the increase of 0.41°C and 0.50°C for maximum and minimum temperatures respectively while the increase of minimum and maximum temperatures for season B was 0.48°C and 0.46°C respectively (Figure 4). Similar to the observations made by the Rwanda Environment Management Authority (REMA, 2011), this study has noted that minimum temperatures are strongly increasing than maximum temperatures, resulting in reduction in Diurnal Temperature Range (DTR). The national trend over 1971-2010 for minimum temperature also was larger than that of maximum temperature (0.52°C and 0.45°C respectively), with a corresponding reduction in DTR (McSweeney, 2010). This reduction of DTR negatively impact plant development, specifically, the decrease in internode length, decrease in height, stem thickness and leaf area, leading to a significant decrease in photosynthetic area (Phommy, et al., 2014).

3.1.3. Rainfall dynamics in Bugesera district

Spatial distribution of rainfall in Rwanda indicates that Bugesera district is located in areas with less than 1000 mm of mean annual rainfall (Figure 5).

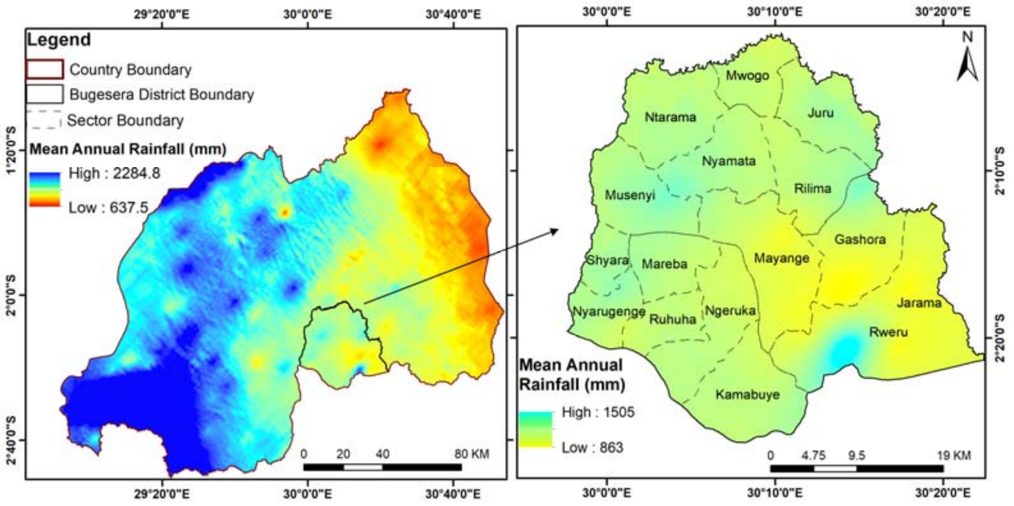

Figure 5: Spatial distribution of mean annual rainfall in Bugesera district, Rwanda
Data source: Means et al., 2017

The climate data analysis indicated slight decrease in rainfall over the period of 1971 - 2014, which is not significant (p=0.0001), though there are years with unusually low and high amount of rainfall (figure 6). The rainfall has decreased by 4.4 mm and 2 mm per decade for Season B and Season A respectively.

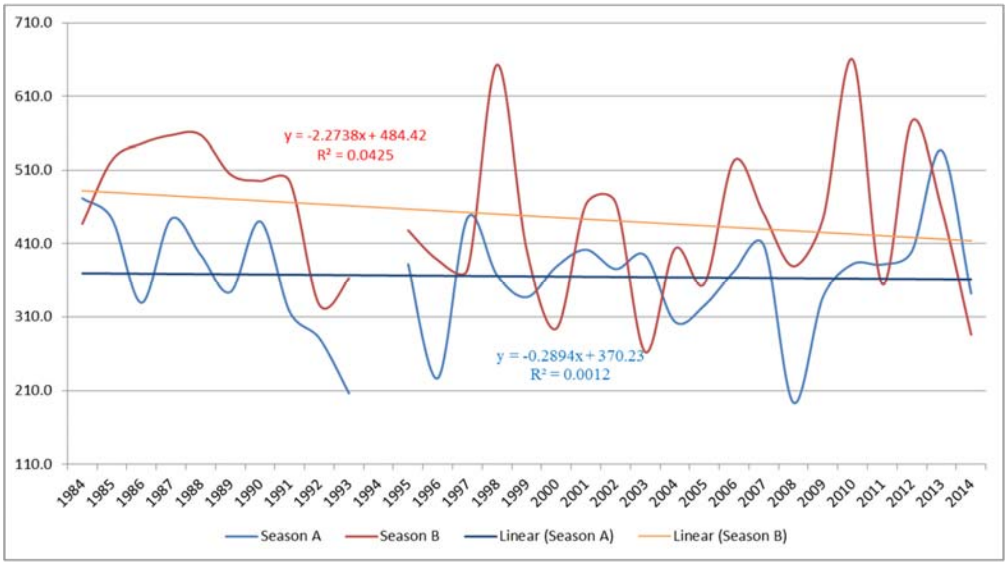

Figure 6: Total annual trend in rainfall on Kigali Airport station (1971-2014) - Season A and B

Data source: RMC, 2014

REMA (2011) has revealed that annual average total number of rain days has reduced from 148 days in 1971 to 124 days in 2009, indicating not only reduction rainy season period, but also increasingly poor distribution and reliability of rainfall with negative impact on agricultural productivity.

3.2. Exposure of Grain legumes to climate change

To analyse the exposure of grain legumes to climate change, reference was made to OSA, 2007; Myres et.al., 2014; Franklin, 1998; Chad, 2012; Franklin, 1998. The studies have defined threshold of the optimum climate conditions for the development of grain legumes, especially beans, peas, and soybeans.

3.2.1. Exposure of grain legumes to temperature variability

The literature indicates that during an agricultural season, peas grow reasonably well between 10°C and 30°C with an optimum of 20°C (OSA, 2007). Common beans grow within a range of temperature of 21°C -27°C (Myres et al., 2014), while for soybeans, temperature below 21°C and above 32°C can reduce flowering and pod set (Franklin, 1998). This study found that so far temperature is favorable for beans development, however, unfavorable for peas and soybeans in both seasons A and B (table 1).

Table 1: Temperature dynamics per decade for season B (OND) and season A (OND) from 1970s

Decade	**Av. min temp Season B (ºC)**	**Av. max temp Season B (ºC)**	**Mean (ºC)**	**Crop's resistance status**		
				Beans	**Peas**	**Soybeans**
Season B (March, April & May)						
1970s	15.0	25.9	19.7	🟩	🟩	🟥
1980s	15.6	26.0	20.1	🟩	🟥	🟥
1990s	15.8	26.7	20.2	🟩	🟥	🟥
2000s	16.4	27.2	20.7	🟩	🟥	🟥
2010s	16.5	27.1	20.8	🟩	🟥	🟥
Season A (October, November & December)						
1970s	14.8	26.4	19.9	🟩	🟩	🟥
1980s	15.3	26.3	20.1	🟩	🟥	🟥
1990s	15.8	27.2	20.4	🟩	🟥	🟥
2000s	16.4	27.5	21.0	🟩	🟥	🟩
2010s	16.5	27.2	20.3	🟩	🟥	🟥
				🟩 Suitable		🟥 Unsuitable

3.2.2. Exposure of grain legumes to rainfall variability

The literature indicates that minimum of 400 to 500 mm rainfall per cropping season is required for growing peas and soybean without supplementary irrigation (Chad, 2012 and Franklin, 1998). Beans require a moderate well-distributed rainfall (300-400 mm per crop cycle) but dry weather during harvest is essential (OSA, 2007). Table 2 indicates that, the rainfall has become insufficient from 2000s in study area, therefore, the grain legumes have been exposed to droughts.

Table 2: Rainfall dynamics per decade for season B (OND) and season A (OND) from 1970s

Decade	Precipitations (mm)	**Crop's resistance status**		
		Beans	**Peas**	**Soybeans**
Season B (March, April & May)				
1970s	313.5	🟩	🟥	🟥
1980s	332.1	🟩	🟥	🟥
1990s	302.8	🟩	🟥	🟥
2000s	287.7	🟥	🟥	🟥
2010s	433.4	🟥	🟩	🟩
Season A (October, November & December)				
1970s	381.3	🟩	🟥	🟥
1980s	404.3	🟥	🟩	🟩
1990s	302.8	🟩	🟥	🟥
2000s	287.7	🟥	🟥	🟥
2010s	400.9	🟥	🟩	🟩
		🟩 Suitable		🟥 Unsuitable

As presented in table 2, rainfall has become insufficient to satisfy the development of grain legumes, i.e., beans, peas, and soybeans, which could eventually lead to a negative impact on the grain legumes productivity. Also, it has been noted that peas and soybeans are more seriously threatened by the changing climate.

3.2.3. Sensitivity of grain legumes to climate variability

The collected datasets indicate changes in yields of all the three grain legumes, i.e., beans, peas and soybeans, for all the two agricultural seasons ($R^2 > 70\%$), as detailed in the following table 3, with the ANOVA results. From the available data, linear regression models were built to relate the yield and climate variables (temperature and rainfall), in order to enable predictions of yield under the changing climates conditions.

Table 3: Yield characteristics of the grain legumes

Season	**Crop**	**R^2**	**Model Significance**	**Significance coefficients (p)**		**Equation**
				Temperature	**Rainfall**	
Season A	Beans	95.2%	0.001	0.001	0.008	Yield = 18333.3 – 789.35 x Temperature – 0.2 x Rainfall
	Peas	86.7%	0.002	0.007	0.008	Yield=22806.9-1011.6 x Temperature – 0.3 rainfall
	Soybeans	76.7%	0.03	0.04	0.01	1765.74+1.35emperature-74.149 rainfall
Season B	Beans	83.7%	0.004	0.001	0.008	Yield=5879.43-228 temperature -0.5rainfall
	Peas	73.5%	0.003	0.01	0.03	Yield=12177-521.9 temperature – 0.63 rainfall
	Soybeans	73.1%	0.002	0.008	0.0017	Yield = 8130-338 Temperature-0.69 rainfall

As presented in the table 3, rainfall and temperature values have negative influence on yield of grain legumes, implying a decrease in the yield of beans, peas, and soybeans from 2005 up to 2014 in both agricultural seasons. This is in accordance with farmers' responses, where 91% confirmed a decrease in grain legumes production during this period.

3.2.4. Adaptive capacity to the climate change

The study has revealed that the awareness of climate change and its impacts by the local farmers is still low. Most of respondents (68.7%) doubt the quality/credibility of the available climate information. The sources of information on climate mentioned by the respondents include radio (68.7%), local authorities (30.2%), local meetings (20.8%), climate awareness campaigns (2%), and friends (1%). Morever, 28.4% of the interviews mentioned that they do not know any climate-resilient agricultural practice, and 20% responded that nothing could be done to adapt to or offset the impacts of climate change, while only 2.1% have suggested terracing their lands as one of the effective mechanisms to prevent oil nutrients to be washed away, thus, practice climate-smart agriculture, together with the 47% who mentioned hillside irrigation as another strategy.

The implementation of those strategies requires an increased consideration of various factors, including those related to soil properties and climate conditions. The combination of edaphic and climate conditions show that some areas are suitable for the production of the three grain legumes as follows:

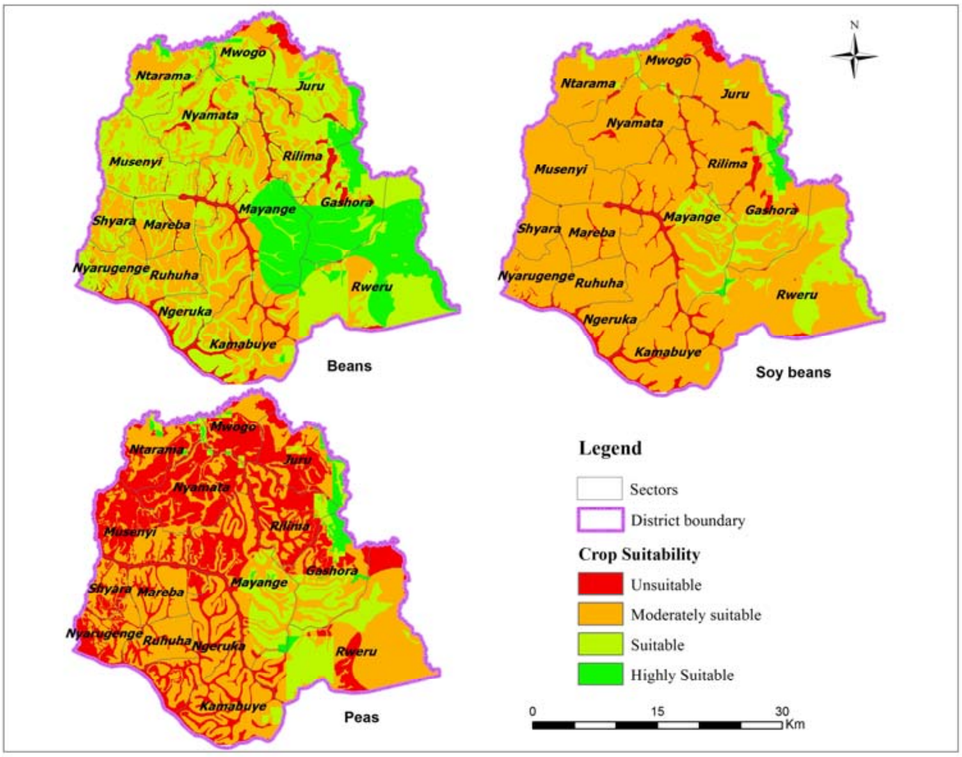

Figure 7: Suitable areas for farming of grain legumes in Bugesera District.

Figure 7 shows the areas which are potential for the production of beans, soy beans, peas. Large part of the District is suitable for beans production, while the production of peas and peas is restricted to a small area. This means that growing of any of the three crops that within an area should take into account some parameters which are likely to influence the productivity.

3.2.5. Technology applied to produce climate-resilient selected seeds

The study has identified, from the survey, several measures believed to be effective towards climate-resilient agriculture in the study area. These include, practicing the hillside irrigation, agro-forestry, use of climate-resilient selected seeds, practice of water harvesting for irrigation purposes among others (Figure 7), and the planting trees along roads and other features to create wind-breaking effect (Figure 8). Local authorities have also confirmed their support to the local farmers in implementing these strategies, towards effective climate resilient grain legumes agriculture

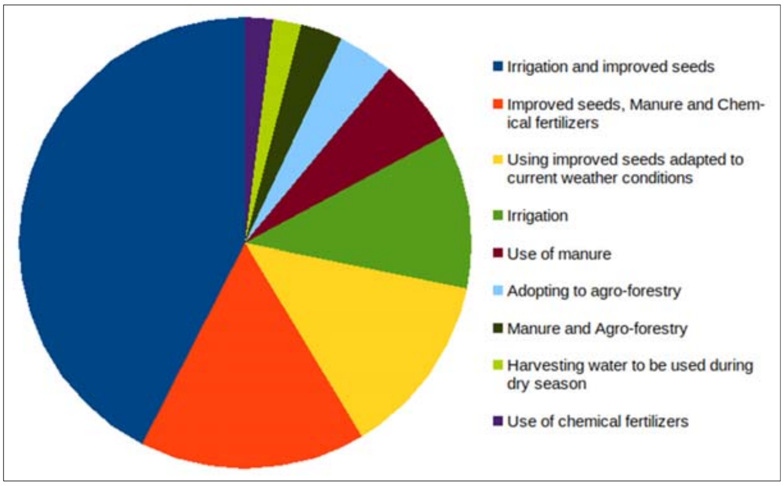

Figure 7: Available and proposed options for climate resilient farming of grain legumes in the study area

Some of the preparations in place to fight the impact of climate change in agriculture in the study area, include 9 agriculture machines for irrigation of leguminous crops, near wetlands, public food stores to motivate farmers to store food which can be used in case if famine, wetland irrigation schemes for rice cultivation.

Figure 8: Wind-breaking trees alongside the road in Mareba sector, Bugesera district

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3.2.6. External response interventions and government intervention

Local authorities have sought an agro-ecological zone- and cultural-specific approach in preparation of offsetting and mitigating climate change and its impacts in agricultural sector. These include reforestation programme implemented in 2005 (GoR, 2008), local access to agricultural inputs and selected seeds, and the construction of silos to store produce which helped to store large amount of the grains during the harvest time, to be used in the famine-like situations.

4. Conclusion

This study aimed at assessing the adaptation to climate change of the selected grain legumes in Bugesera district in Rwanda. This was achieved by evaluating the exposure of the selected grain legumes to climate change in the study area, investigating the sensitivity of grain legumes' yield vis-a-vis climate change in the study area, and analyzing the ability of the local farmers to adapt to the climate change and its impacts. Time series of meteorological datasets (i.e., temperature and rainfall) for the study area was used, and the dataset was analyzed using MS Excel based MAKESENS model. The yield of the selected grain legumes (i.e: beans, peas, and soybeans) was also analyzed of 10-year period (2005 - 2014) using ANOVA. The study has shown that the mean temperature has significantly increased ($p=0.001$) by around 0.4ºC and around 0.5ºC for agricultural season A and B respectively, since 1971 up to 2014. On the other hand, the rainfall changes did not present significant changes. Furthermore, a rapid increase of minimum temperature and minor increase of maximum temperatures which decreases Diurnal Temperature Range (DTR) has been observed. This can can impact the crops development on aspects such as decrease in internode length, decrease in height, stem thickness, and leaf area, therefore, a decrease of photosynthetic area of the crop.

The results showed that the changes in temperature and rainfall will result in significant changes of the grain legumes, with a negative correlation between yield and temperature, and a positive correlation between yield and rainfall. Moreover, it has been noted that the adaptive capacity of the local grain legumes farmers is still low, and therefore, may not be able to cope with the rapidly changing climate and its impacts. Majority of the farmers could not earn at least 1 USD per day, are still dependent on traditional farming

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mechanisms, and are not equipped with regular information and technical capacity to cope with the climate change. Nevertheless, some of climate resilient agricultural practices exist, and if reinforced, it would be an effective way to move forward towards developed a sustainable and climate resilient legumes agriculture in the study area. These include irrigation schemes, used of agricultural inputs, available silos to store harvest which can be used during famine-like situations.

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