Global Scientific JOURNALS

GSJ: Volume 9, Issue 8, August 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

Contribution of Agroforestry and Terraces in Increasing Maize Production in Rwanda

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Abstract: In Rwanda, more than 70 percent of livelihoods rely on subsistence rain-fed agriculture while land and water resources are seriously overused and/or threatened by rapidly growing population and inappropriate land management practices. Sustainable and relevant management of these resources is of paramount importance. This study aimed to analyze the contribution of land management practices (agroforestry and terraces) to maize production from 2014 to 2020 at Akanyaru watershed located in Gisagara District, Southern Rwanda. Secondary data on cultivated land, agroforestry, radical and progressive terraces, organic and inorganic fertilizers, maize production were employed. These data were collected from National Institute of Statistics of Rwanda (NISR), Rwanda Green Fund (FONERWA), Rwanda Agricultural and Animal Resources Development Board (RAB), Rwanda Water Board (RWB) and Gisagara District reports. The Statistical Data (STATA) presented annual changes of each type of data whereas the linear regression analysis in STATA facilitated to analyze the relationship between agroforestry and terraces and maize production at Akanyaru Watershed. The results showed that the land under progressive terraces increased up to 4,000 acres in 2020 compared to that of progressive terraces which is 1,000 acres. The number of agroforestry trees increased from 1,151 to 4,861 in 2014 and 2020, respectively. It was noted that the production increased from 10,920 tons to 15,960 tons in 2014 and 2020, respectively. Regarding the contribution of land management practices to maize production, a linear relationship of R^2=0.97 was noticed. Therefore, as long as the value of R2 obtained is greater than 0.5, it was concluded that agroforestry and terraces practices significantly contributed to maize production at Akanyaru watershed. The results of this study can clearly indicate how adopting agroforestry and terraces practices contributes to the increase of maize production.

Keywords: Land management practices, Watershed, Agroforestry, Terraces, Ecosystem, Gisagara district, Rwanda

1. Introduction

The need for fertile soils is increasing due to the growing global demand for renewable raw materials and meat, and persistent population growth. At the same time, we are seeing a loss of fertile, healthy soils as a result of degradation processes such as erosion, salinization and contamination. It is estimated that as much as 20-25% of global soil resources is degraded, i.e. has a reduced functional capacity (UNCCD, 2014). Soil degradation is an ongoing process which affects an additional 5-10 million hectares each year (for comparison, Austria has an area of 8.4 million hectares). Soil degradation across the world will therefore jeopardize global food security in the long run and deprive rural regions in particular of one of their main sources of income and economic development (umwelt bundesamt, 2015).

Land degradation is a global problem affecting an estimated 1.5 billion people and a quarter of land area in all agro–ecological zones around the world (Lal et al, 2012). Soil degradation is a global phenomenon. That is why the elusiveness of the concept in combination with the difficulties of measuring and monitoring land degradation at global and regional scales by extrapolation and aggregation of empirical studies at local scales, such as the Global Assessment of Soil Degradation database (GLASOD) (Sonneveld and Dent, 2009) contributed to conflicting views. The conflicting views were not confined to science only, but also caused tension between the scientific understanding of land degradation and policy (Anderson et al, 2011; Behnke and Mortimore, 2016; Grainger, 2009) Another weakness of many land degradation studies is the exclusion of the views and experiences of the land users, whether farmers or forest-dependent communities (Blaikie and Brookfield, 1987; Fairhead and Scoones, 2005; Warren, 2002).

Soil erosion in Sub-Saharan Africa is considered one of the root causes of stagnating or declining agricultural productivity and the provision of further ecosystem services, Sub-Saharan Africa is the only region in the world where average cereals yield have not significantly increased and per capita food production declined since the 1980s (Muchena et al, 2005). Other related problems that reduce agricultural land productivity include soil organic matter depletion, soil nutrient depletion and loss of soil biodiversity. Soil fertility depletion and nutrient imbalances on smallholder farms is due to more nutrients being removed from the soil than replenished (FAO, 2016). Although Africa has 13% of the world's arable land and contains 12% of the world's population, unless these problems are addressed, many parts of the continent will suffer increasingly from food insecurity. Other key factors that contribute to soil fertility challenges include the removal of input subsidy, high cost of moving fertilizers from ports to the farm, untimely availability and low quality of fertilizers, poor cultural practices, inadequate supplies of organic and inorganic fertilizers, deteriorating soil science capacity and weak agricultural extension services, lack of soil fertility maintenance plans, nutrient mining and low nutrient use efficiency, inappropriate fertilizer recommendations, differences in crop response to fertilizers, and nutrient deficiency and climate change. (Morris et al, 2007)

In Rwanda the national average of soil losses is about 94t/ha/year and 15 billion tons per year, which can contribute to survival of 40,000 persons per year (*www.devpartners.gov.rw*).

In fact, in recent years, rainfall has become more erratic and less predictable because of the climate change and that leads to more floods, landslides and erosion. Because of these problems, reducing vulnerability to climate change has become a national priority in EDPRS 2 and Environment and Natural Resources Sector Strategy (2013-2018). There are soil erosion due to lack of sufficient infrastructure for soil erosion control, along Akanyaru river, Mamba, Gikonko, Gishubi, Kigembe, Muganza, Mugombwa, Mukindo, Kansi and Nyanza are sectors that slopes directly fall in the Akanyaru river.

Soil erosion at the Akanyaru river watershed is increased by the sloppy watershed lacking vegetation and erosion control techniques such as radical and progressive terraces and trees. The field's topsoil is eroded and sediments are transported into the river, runoff water and raindrop splash removes nutrients and soil organic matter and affect soil productivity. Soil erosion is exacerbated by deforestation, as the trees are utilized by local people for construction and firewood (FONERWA, 2020)

2. Methods and Materials

2.1 Description of Study Area

This study was conducted in Gisagara District one of the eight districts forming the southern Province of Rwanda. The Gisagara District stretches over an area of 680 Km^2; it has an altitude varying between 1,600 to 1,800 meters. The district of Gisagara possesses 13 sectors, 59 cells and 524 villages. In the 8 sectors touching on the Akanyaru river, there are 196,655 people whose 91,786 are men and 104,869 are women. The area has 437 km^2 with density of 458%. Among these population, 66,280 (33%) are in extreme poverty ((EICV 3 District profile Gisagara, June 2017).

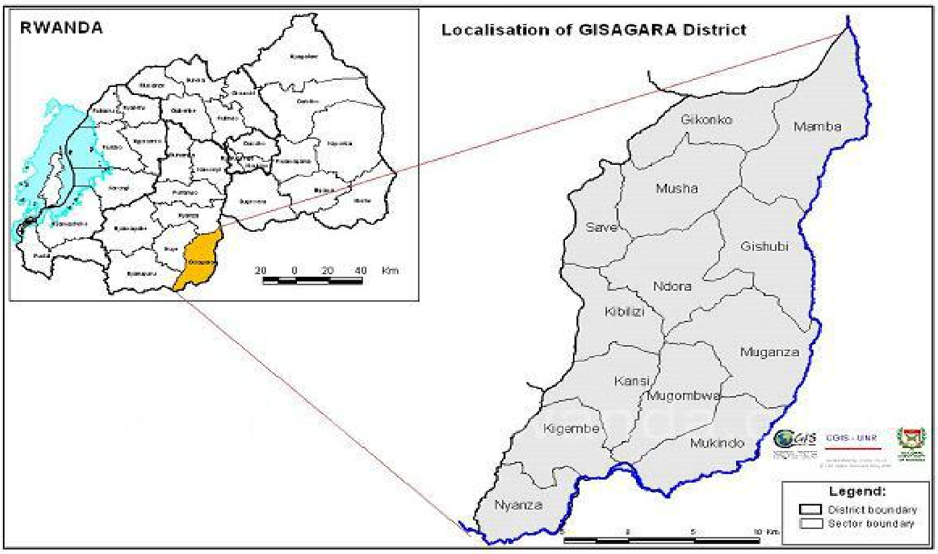

Figure 1: Map indicating the location of Gisagara district in Rwanda

In Gisagara district, the majority of the population is young with 53% aged less than 19 years and 81% under 40; people of 65 years old and above are 2%. Females are 52% in the district. Most of the people of Gisagara District depend on rain-fed subsistence agriculture (85%). (EICV 3 District profile Gisagara, June 2017).

Data Collection and Analysis

For the study, the authors employed secondary data which led to obtaining the analyzed and presented results. These data were related to total land size under maize cultivation, trees of agroforestry planted, land under radical and progressive terraces practices, applied organic and inorganic. The authors judged it necessary to consider data ranging from 2014 to 2020 in order to better indicate changes on land management practices and their contribution to maize production at Akanyaru watershed.

The above secondary data employed by this research were mainly collected from National Institute of Statistics of Rwanda (NISR), Rwanda Green Fund (FONERWA), Rwanda Agricultural and Animal Resources Development Board (RAB), Rwanda Water Board (RWB), Ministry of Agriculture and Animal Resources, and Gisagara district reports

After the collection of the above data considered from 2014 to 2020, the authors proceeded with their analysis which was facilitated by the Statistical Data (STATA). Details of the methodological steps undertaken by this study for its completion are presented in Figure 2.

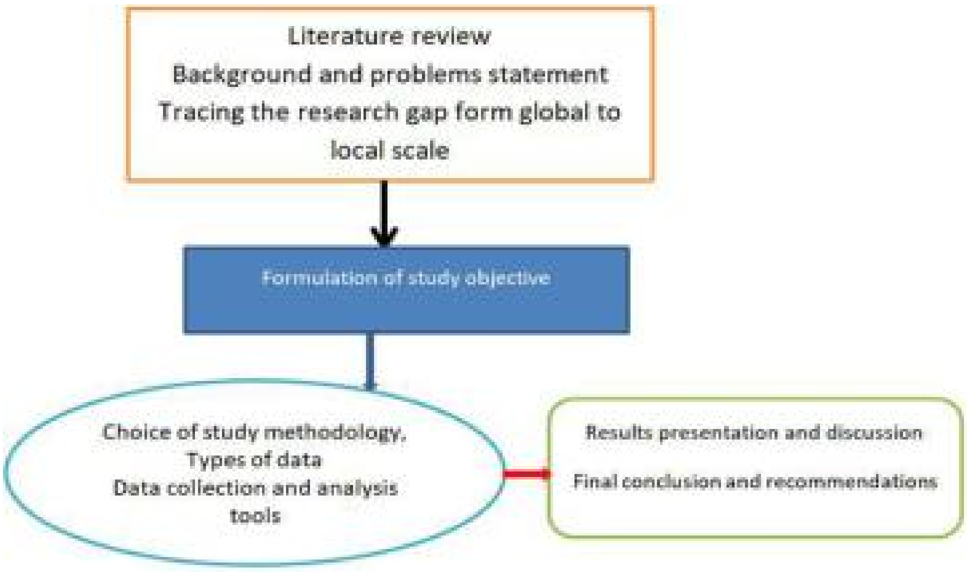

Figure 2. Methodological framework of the study

3. Results

3.1 Agroforestry and terraces practices at Akanyaru watershed

The results in Figure 3 showed that the land under both progressive and radical terraces was 282 acres. This area of progressive terraces has been increasing from 282 up to 4,001 acres in 2020 compared to that of progressive terraces which moved from 282 to 1,208 acres. Thus, it can be mentioned that at Akanyaru watershed, progressive terraces occupy the majority of land at the watershed compared to that under agroforestry practices (Figure 3).

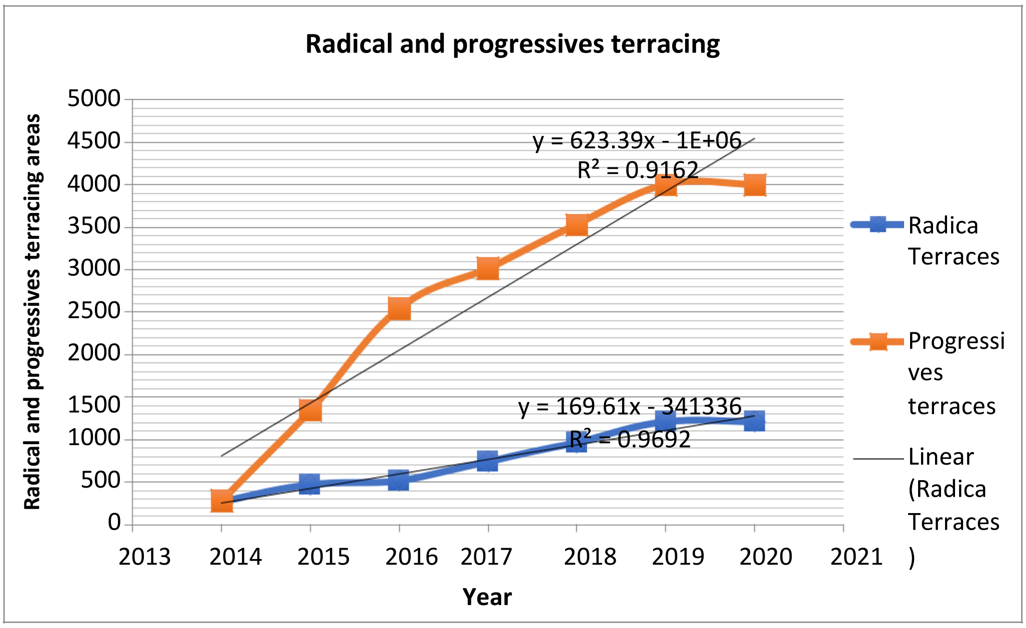

Figure 3: Acres of agroforestry and progressive terraces

Furthermore, the analysis, as revealed in Figure 3, indicated that from 2014 to 2020, the number of trees planted under agroforestry practice at Akanyaru watershed increased. The number of agroforestry trees increased from 1,151 to 4,861 in 2014 and 2020, respectively (Figure 3).

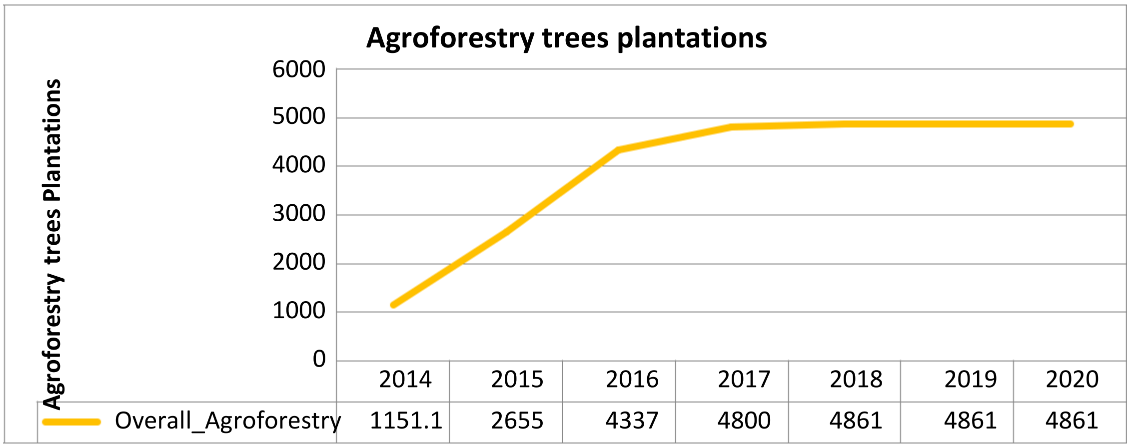

Figure 4: Trees planted under agroforestry practice

Apart from agroforestry and progressive terraces, the authors considered the maize seeds which have been used within the considered period (2014- 2020). As shown in Figure 4, it was realized that the years of 2017 and 2020 recorded high quantity of the employed improved seeds at Akanyaru watershed.

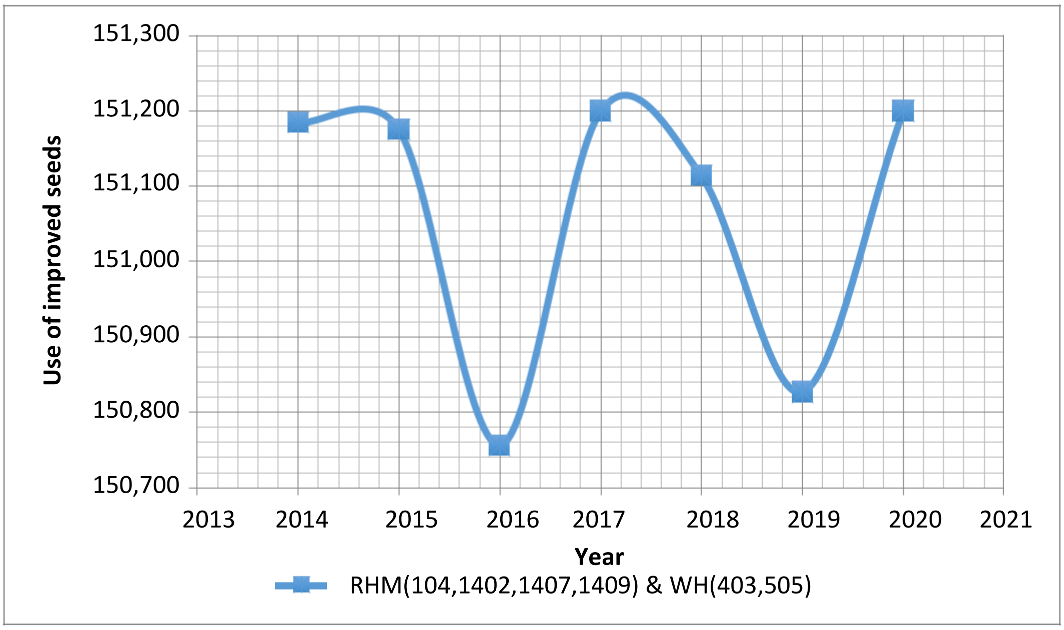

Figure 5: Improved seeds used at Akanyaru watershed

As long as the intention of practicing agroforestry and terraces at Akanyaru watershed as to improve crop production, the authors considered the fact that fertilizers (both organic and inorganic) were associated with both practices and then assessed their application.

Therefore, the result on fertilizers, as illustrated in Figure 5, it was revealed that the application of inorganic fertilizers varied slightly. For the organic manure, there was a variation as in the first 3 years; organic manure was applied at 60% of the total agricultural area after stabilization of terraces the organic manure was applied at the 40% of agricultural area at Akanyaru watershed.

3.2 Maize production progress at Akanyaru watershed

The results in Figure 6 revealed that on a fixed land size of 4,200 hectares, the production has been increasing over years. The production increased from 10,920 tons to 15,960 tons in 2014 and 2020, respectively (Figure 6).

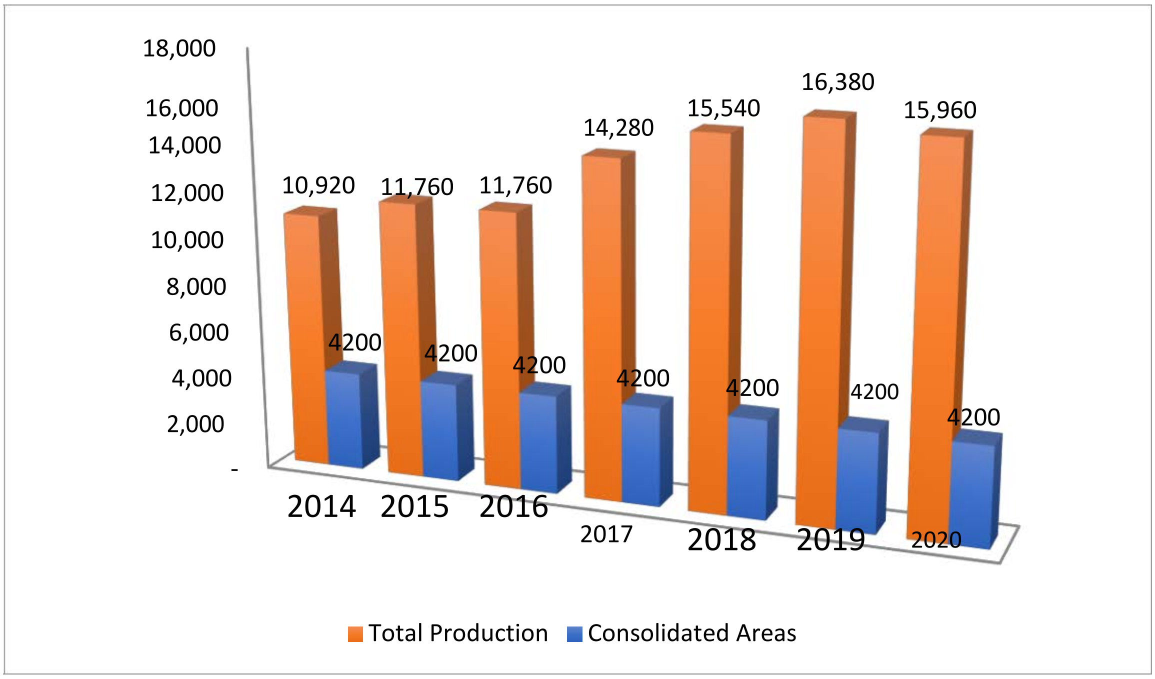

Figure 6: Maize production at Akanyaru watershed

Furthermore, in order to better indicate the recorded changes on maize production, the researcher analyzed the annual yield (T/Ha) with reference to each land us management practices applied at Akanyaru watershed. The results in Table 1 showed that on a fixed maize consolidated land size of 4,200 hectares, the production has been increasing over years. The production increased from 10,920 tons to 15,960 tons in 2014 and 2020, respectively

Table 1: Annual increase rate of Maize production

Year	Radica Terraces	Progressive s terraces	Agroforestry trees	Total Production	Yield (T/Ha)	Increase rate (Total Production)	Increase rate (Yield)
2014	269	282	1151,1	10 920	2,6	0,00	0
2015	470	1343,97	2655	11 760	2,8	840,00	0,2
2016	514,11	2545,7	4337	11 760	2,8	0,00	0
2017	738,4	3016,58	4800	14 280	3,4	2520,00	0,6
2018	966,7	3527,58	4861	15 540	3,7	1260,00	0,3
2019	1208,7	4001,38	4861	16 380	3,9	840,00	0,2
2020	1208,7	4001,38	4861	15 960	3,8	-420,00	-0,1

3.3 Contribution of agroforestry and terraces to maize production

In order to measure to which extent agroforestry and terraces as land management practices contributed to maize production at Akanyaru watershed. The linear regression was applied on organic manure and inorganic fertilizers and on agroforestry trees and terraces as land management practices.

Linear regression analysis is discussed as a technique that is used to analyze the response of variable Y, which changes, with the value of intervention variable x (V.Sellam, et al., 2016). An approach of predicting the value of a response variable from a given value of explanatory variable is Multiple Linear Regression used to analyze the contribution of agroforestry trees and terraces as land management practices on maize production in Akanyaru watershed since 2014 up 2020.

In this study, it was assumed that if the value of R2 obtained is greater than 0.5 then the relation between the dependent variable and the explanatory variable is quite high. The regression analysis printed out higher and strong correlation coefficients of Agroforestry trees and terraces construction as land management practices on maize production in Akanyaru watershed through the using the improved Agriculture practices.

The results from regression analysis of maize production within the use of agriculture improved inputs in Akanyaru watersheds (Table 2) provided a linear relationship between maize production with the use of organic manures, and inorganic fertilizers. It have been found that the maize production in Akanyaru watershed were depending on the use of Organic manure and improved inputs with the higher R-Squared with R2=0.92 with a significance at 5% of Prob>F=0.0341.

Table 2: Regression analysis on fertilizers and maize production

Source	**SS**	**df**		**MS**	**Number of obs**	**7**
					F (3, 3)	= 12.34
Model	1.63598892	3		0.54532964	Prob > F	= 0.0341
Residual	.132582509	3		0.04419417	R-squared	= 0.9250
					Adj R-squared	= 0.8501
Total	1.76857143	6		0.294761905	Root MSE	= .21022
Yield (t/ha)	**Coef.**	**Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
Manure Tones	5.0011436	.0002273	-5.03	0.0015	4.0018671	5.00342
DAP Tones	4.0000418	.0000486	0.86	0.0045	4.000113	4.000796
NPK Tones	2.5000763	.0000755	-1.01	0.0038	2.0003166	2.000964
_cons	10.1794	7.532315	1.35	0.0026	-13.79179	34.15059

Maize Yield=$10.1794+5x_1+4x_2+9x_3$+Error **Source: Secondary data, 2014-2020**

The linear regression of maize production within organic manure and inorganic fertilizers was Y=10.1794+5x1+4x2+9x3+ εo. This equation implied that, if the farmers who produced the maize in Akanyaru watershed did not use the organic manure and inorganic fertilizers, but with the existence with others unspecified factors, the maize production will increase with 10kg/ acre on total seasonal maize yield with P-Value of 0.0015<0.005. The increase of 1kg of organic manure will lead at back with an increase of 5kg of maize production, an increase of 1kg of DAP will increase the 4kg of maize production with P-Value of 0.000<0.005; while an increase of 1kg of DAP will increase at back of 2.5kg of maize production with P-Value of 0.000<0.005. The regression analysis results (Table 3) of maize production analysis with the agriculture practices provided the higher contribution of radical and progressives' terraces, and agroforestry trees within maize production in Akanyaru watershed. It have been found that the maize production in Akanyaru watershed were depending much more on the environmental protection, especially through radical and progressives terraces construction and the plantation of the Agroforestry trees with the higher R-Squared with R2=0.97 and this model was spastically significance at 5% of Prob>F=0.0084.

Table 2: Regression analysis on agroforestry trees and terraces with maize production

Source	**SS**	**df**	**MS**	**Number of obs**	**= 7**
				F (3, 3)	= 33.18
Model	1.71682179	3	0.57227393	Prob > F	= 0.0084
Residual	.05174964	3	0.01724988	R-squared	= 0.9707
				Adj R-squared	= 0.9415
Total	1.76857143	6	.294761905	Root MSE	= .13134

Yield (t/ha)	**Coef.**	**Std. Err.**	**T**	**P>t**	**[95% Conf.**	**Interval]**
Radical Terraces	2.0028977	.0014118	2.05	0.0013	2.0015952	2.0073906
Progressives terraces	1.0008544	.0007746	- 1.10	0.0035	1.0033196	1.0016109
AgroforestryTrees plantations	.500492	.0004325	1.14	0.0033	-.0008843	.0018683
_cons	1.410339	.6961667	2.03	0.0013	-.8051746	3.625852

Maize Yield=1.410339+2.003x_1+1x_2+0.5x_3+Error **Source: Secondary data, 2014-2020**

The linear regression equation of maize production within the environmental protection practices was Y=1.410339+2.003x1+1x2+0.5x3+ εo. This equation implied that, in times farmers produced the maize in Akanyaru watershed without the presence of environmental protection, especially radical and progressives' terraces, and agroforestry trees but within the use of others unspecified factors like use of improved inputs and others associated agriculture practice, the maize production increased within little proportion of 1.41kg/acre on total seasonal maize yield with P-Value of 0.0013<0.005.

The increase of the existed protection with radical terraces will lead at back with an increase of 2 tones on average yield of maize production with P-Value of 0.0035<0.005, an increase of the existed protection with progressives terraces will lead at back with an increase of 1 tones on average yield of maize production with P-Value of 0.0033<0.005; while an increase of the existed protection with agroforestry trees will lead at back with an increase of 0.5 tones on average yield of maize production with P-Value of 0.0023<0.005. This may be due to the fact that, the maize were produced in different parts of Akanyaru watershed obviously surrounded by the hills, some of them with a remarkable slopes, the erosion protection are very needed in that areas in order to avoid the effects that might be caused by erosion or runoff for the different crops cultivated in that watershed.

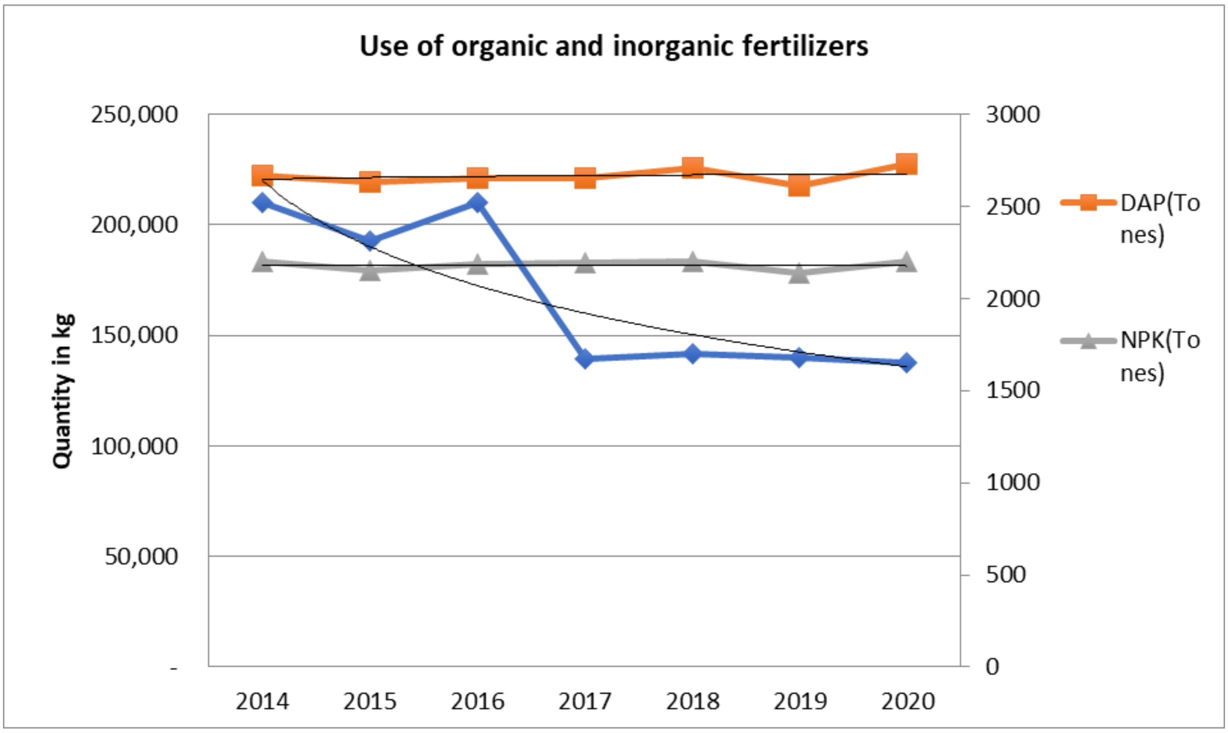

Figure 7: Use of organic and inorganic fertilizers

4. Discussion

In large parts of the sub-Saharan Africa maize is the principal staple crop, covering a total of nearly 27 M ha. Maize accounts for 30 % of the total area under cereal production in this region: 19 % in West Africa, 61 % in Central Africa, 29 % in Eastern Africa and 65 % in Southern Africa (FAO, 2010). In Southern Africa maize is particularly important, accounting for over 30 % of the total calories and protein consumed (FAO, 2010). Despite the importance of maize in sub-Saharan Africa, yields remain low (Shiferaw et al, 2011). While maize yields in the top five maize producing countries in the world (USA, China, Brazil, Mexico and Indonesia) have increased three-fold since 1961 (from 1.84 t ha^{-1} to 6.10 t ha^{-1}), maize yields in SSA have stagnated at less than 2 t ha^{-1}, and less than 1.5 t ha^{-1} in Western and Southern Africa. In SSA maize is predominantly grown in small-holder farming systems under rainfed conditions with limited inputs. Low yields in this region are largely associated with drought stress, low soil fertility, weeds, pests, diseases, low input availability, low input use and inappropriate seeds.

In Rwanda, maize is sold and consumed in both fresh cobs and dried grain. Due to the Crop Intensification Program (CIP), over 65 percent of Rwandan farmers now grow maize, both for household consumption and commercial sale to traders and millers. Rwanda is a net importer of maize grain and a net exporter of maize meal (it is a net importer of processed maize products including maize meal, animal feed, beer, and all of the other types (UNIDO, 2013).

The findings of the study conducted by (Fashaho, 2020) in which maize growth, Nitrogen uptake and yields were measured, and the residual effect of treatments on soil properties was evaluated. Accordingly, the results of the same study showed significant ($P < 0.05$) changes in certain soil properties after terracing. Terraced lands had higher levels of silt, hydraulic conductivity and populations of bacteria and fungi. Non -terraced lands had higher clay content, water retention capacity and organic carbon. On maize performance, nitrogen fertilizer rates of120 and 180 kg N ha-1combined with phosphorus rates of 80 and 120 kg P_2O_5 ha-1 resulted in significantly ($P < 0.05$) higher grain yields of 6.4 –6.5 t ha-1in the medium altitude site and 6.0 –6.1 t ha-1in the high altitude site.

In addition, another study conducted by (Mukuralinda, 2010), maize grain yields varied from 0.9 to 7.1 t ha-1. Maize grain yields from the control ranged from 0.9 to 1.6 t ha-1. Lime increased maize yield from 1.1 to 3.3 t ha-1. The application of lime resulted in significantly

Throughout the cropping seasons, maize yield from agroforestry green manure and inorganic P, applied independently, did not significantly differ. However, in fourth season T. Agroforestry trees combined with TSP, applied at a rate of 50 kg P ha-1produced similar maize yield as T. Agroforestry trees applied independently at similar rate, but significantly (P\0.05) higher than the remaining treatments.

The above can be similar to the findings of this study which indicated that in Akanyaru watershed, Agroforestry trees and terraces as land management practices are the main contributors to the increase of maize production than application of organic manure and Inorganic fertilizers. This was confirmed by the results in Tables 2 and 3 which demonstrated a linear relationship between agroforestry and terraces as land management practices and maize production with regression R^2=0.97 and also indicated that there is linear relationship between maize production with the application of organic manures, and inorganic fertilizers R^1=0.92. This expresses the need for adopting the Agroforestry trees and terraces as land management countrywide, policymakers should identify major causes of non-adoption of land management practices including plantation of Agroforestry trees and terraces construction as well.

5. Conclusion

This study evaluated the contribution of agroforestry and terraces as land management practices in increasing maize production. The study considered the Akanyaru Watershed within the period ranging from 2014 to 2020. The results showed that if farmers produce maize at Akanyaru watershed without radical and progressives terraces, and agroforestry trees within the use of others unspecified factors, there would be1.41kg/acre on total seasonal maize yield with P-Value of 0.0013<0.005. The use of radical terraces would contribute 2 tones on average yield of maize production with P-Value of 0.0035<0.005, and progressives terraces would generate 1 tones on average yield of maize production with P-Value of

0.0033<0.005. Morever, it was noted that agroforestry could increase the production to 0.5 tones on average yield of maize production with P-Value of 0.0023<0.005. The linear regression analysis showed a relationship between agroforestry trees and terraces and maize production with regression R2=0.97 and a relationship between maize production with organic and inorganic fertilizers R1=0.92 at 5% significance level respectively. The results also implied a positive effect of organic and inorganic fertilizers and agroforestry and terraces on maize production because both calculated regression values are positive, respectively. Finally, in order to ensure high quantity and quality maize production, it is suggested to ensure strong agriculture extension services to the farmers and address all limiting causes for non-adoption of agroforestry trees and terraces as land management for the benefits of both present and future generations.

Contribution/Originality: This paper provided information which is necessary in country like Rwanda or similar regions with high population density looking for food security and development as well. Thus, areas in need of sustainable resources natural management under human pressure can benefit from this study

6. Acknowledgements

Above all, forever and ever, I thank Almighty God for helping me in every area of my life and during my studies. I acknowledge the University of lay Adventists of Kigali (UNILAK) for providing a good learning environment and all facilities for the Msc programme I studied in Environmental Economics and Natural Resources Management.

I would like to express my deepest and special gratitude to my supervisor, Dr. Lamek Nahayo, for his guidance, constructive critiques, scientific and innovative advices throughout the course of this research, thesis writing and publication of this paper.

My special gratitude goes to my dear fiancé Ms. Hyacinthe Benemariya for the support and encouragement and more importantly for comforting me through though periods. My thanks also go to my family for being there for me during my studies.

I would like to thank my colleagues whom we worked at Rwanda Green Fund (FONERWA) and masters students of the environmental studies department of University of lay Adventists of Kigali (UNILAK) for the collaboration and encouragement throughout the whole learning period. Lastly, I wish to thank each and every one who contributed to this work and made it a success.

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