IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 14, Issue 1 Ser. I (January 2021), PP 07-13
www.iosrjournals.org

Landscape-based assessment of risk for soil acidification in Rwanda

C. Ngendo[1]; H.C Tuyishime[1]; J.D.D. Iyakare[2] and J. Uwihirwe[3]
[1]*Department of Agriculture Engineering, Rwanda Polytechnic-IPRC Musanze, Rwanda*
[2]*Department of Civil Engineering, Rwanda Polytechnic-IPRC Kigali, Rwanda*
[3]*School of Agriculture Engineering, College of Agriculture, Veterinary Medicine and Animal Resources, University of Rwanda*

***Abstract**: The aim of this study was the identification of acidification risk areas and hotspots, and gaining insight in the acidification process, its causes and consequences.*
Soil acidification, an important type of land degradation in Rwanda, and more specifically in the central plateau, is challenging the sustainable use of cropping systems.
The soil profile database has proved to be a useful tool to this study because indicators of both soil acidity and risk for acidification were contained. All these indicators allowed us to assess the relationship between acidity parameters and other soil/landscape parameters.
We checked the correlations between acidity parameters themselves and they were found strong (r>0.8) to moderate strong (0.6<r<0.8) except for exchangeable acidity.
For the correlations between acidity parameters and other soil properties, they were very weak (r<0.4), thus less important to consider. All these statistical analyses were carried out using SPSS.
***Key words**: Topsoil pH, clay and organic matter content, acidification, pH buffer capacity*

Date of Submission: 20-12-2020 Date of Acceptance: 03-01-2021

I. Introduction

Rwanda is a landlocked country in Central Africa. It is one the most densely populated countries in sub-Saharan Africa (more than 270 persons per km^2). It is endowed with a diversity of ecosystems, ranging from moist steep mountains to dry plains. Almost all valleys are wet and their natural sources of water and soils have continued to support at least two growing seasons of food and cash crops annually. Food crops of Rwanda include plantains, sweet potatoes, cassava, potatoes, sorghum, beans and maize. The main export crops are tea and coffee (Bidogeza et al., 2012).

It is estimated that acid soils comprise two-thirds of the cultivated soils of Rwanda, and serious problems occur on about half of these soils having lowest pH (Musahara and Herman, 2001).

Soil acidification thus is the most important type of soil degradation in Rwanda, and has become a major challenge for agricultural management. Land use and management, especially inappropriate tillage (ploughing up and down the slope) and unsustainable soil fertility management practices (low input and no restitution of exported biomass during the harvesting period), may rapidly acidify the soil. The main agent causing this acidification is thus expected to be human activity.

In order to design and implement a sustainable agricultural sector strategy that aims at increasing rural incomes, enhancing food security, and converting agriculture into a viable sector by moving away from subsistence to market-based activities, an assessment of processes leading to soil degradation in general and soil acidification in particular is of great importance.

II. Materials and Methods

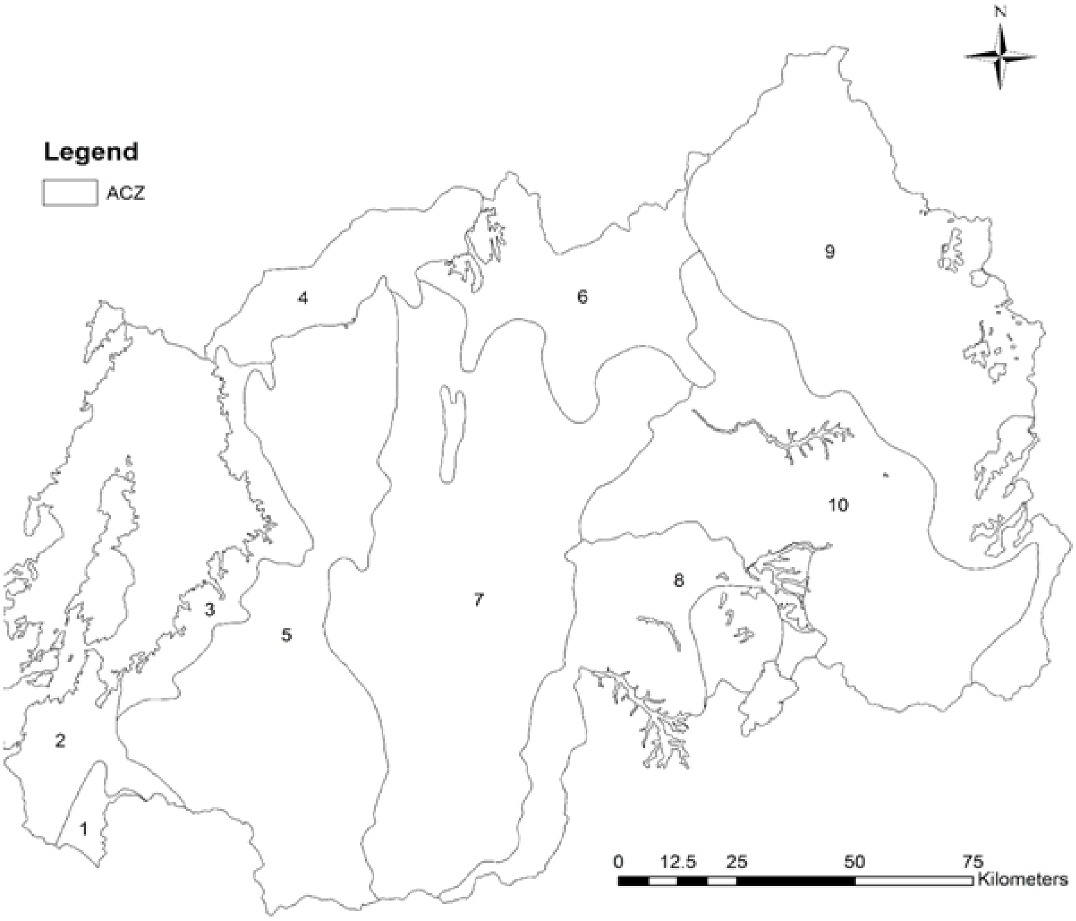
2.1 Study area

Rwanda occupies the eastern shoulder of the Kivu-Tanganyika rift in Africa.

Rwanda can be divided into three altitudinal zones, i.e. the lowlands, middle altitudes, and highlands occupying 38, 32, and 17 % of the territory area respectively (Verdoodt and Van Ranst, 2006), and being confronted with different forms of soil degradation. The western part of Rwanda, dominated by highlands (altitude > 2100 m), is facing a serious problem of soil erosion. The eastern part of the country is dominated by lowlands (altitude < 1600m) facing drought related problems. In the central, middle altitudinal part of the country (between 2100 m and 1600 m); the main problem is soil acidification. The climatic characteristics of the ACZs show that the higher the altitude, the higher the rainfall and the lower the temperature (Table 1).

Table 1: *Characteristics of agro-climatic zones in Rwanda (Verdoodt and Van Ranst, 2006b)*

ACZ	Mean altitude(m)	Mean temperature(°C)	Mean total rainfall (mm/year)
Imbo (1)	<1000	24	1,154
Impara (2)	1,666	19	1,710
Kivu Lake borders (3)	1,638	20	1,225
Birunga (4)	1,960	17	1,317
Congo Nile Watershed Divide (5)	2,058	17	1,542
Buberuka Highlands (6)	1,957	17	1,267
Central Plateau (7)	1,749	19	1,298
Mayaga and Peripheral Bugesera (8)	1,403	21	1,101
Eastern Plateau (9)	1,575	20	1,038
Eastern Savanna and Central Bugesera (10)	1,386	21	902



Map 1 : Agro-climatic zones in Rwanda

2.2 Rwanda Soil Information System

The Rwanda Soil Information System, whose the structure is shown in Figure 1, comprises a soil profile database containing records for 1833 geo-referenced soil profiles, 43 semi detailed soil map sheets covering the national territory, at a scale of 1: 50,000 and the corresponding explanatory notes

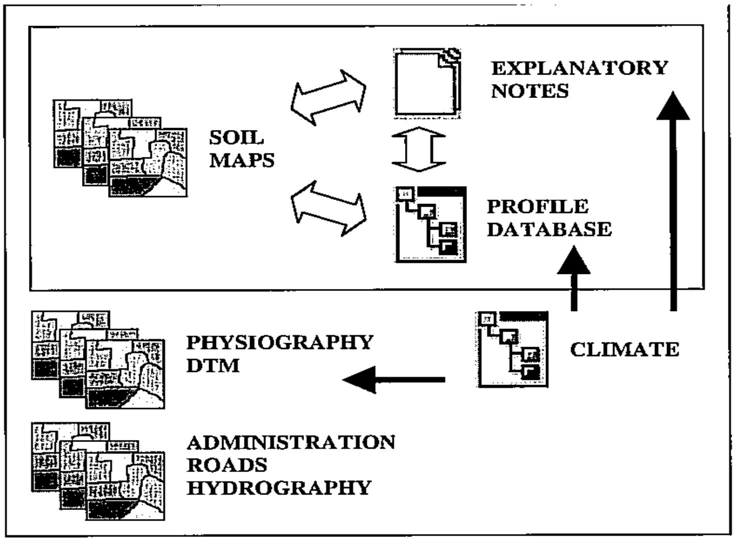


Figure 1 : *Structure of the Rwandan soil information system (Verdoodt and Van Ranst, 2006b)*

Table 2 gives an overview of all physico-chemical parameters that were selected from the soil profile database for further analysis, as well as the analytical or arithmetic procedures used to determine them. Based on deemed relevance to this study, weighted average parameter values characterizing the mineral topsoil (0-30 cm) were calculated for the selected physico-chemical soil properties.

Table 2 : *Selected soil characteristics and the analytical methods used for their determination*

Parameters	Unit	Method
Clay	%	By sedimentation
BD	g/cm^3	Volumetric ring method
OC	%	Walkley & Black
N	%	Kjeldahl
P	Ppm	Truog
pH-H2O	-	Ratio soil/H_2O=1/10
pH –KCl	-	Ratio soil/KCl (1N)=1/10
Ca	cmol(+)kg^{-1} soil	NH_4OAc 1N, pH 7
Mg	cmol(+) kg^{-1} soil	NH_4OAc 1N, pH 7
K	cmol(+) kg^{-1} soil	NH_4OAc 1N, pH 7
Na	cmol(+) kg^{-1} soil	NH_4OAc 1N, pH 7
Soil CEC	cmol(+) kg^{-1} soil	NH_4OAc 1N, pH 7
Exchangeable acidity	cmol(+) kg^{-1} soil	Extraction with KCl 1N
Base saturation	%	(CEC/(Ca+Mg+Na+K))x100
Al saturation	%	(Al/CEC)x 100
SBC	cmol(+) kg^{-1} soil	Ca+Mg+K+Na

2.3. Assessing soil acidity status and acidification risk

2.3.1 Descriptive statistics

Descriptive statistics (mean, standard deviation, minimum and maximum) of all acidity status indicators measured in the soil profile database were calculated using SPSS software. Correlations among acidity indicators; and between these indicators and other numerical soil /environmental variables, were evaluated. The following guideline was used to classify the correlation strength (1) 0 - 0.2: very weak, (2)0.2-0.4: weak, (3)0.4-0.7: moderate, (4)0.7-0.9: strong and (5)0.9-1: very strong.

2.3.2 Assessing soil acidification risk

This research focused on estimates of the initial pH and the vulnerability of the soil to pH change, reflected in its pHBC. As such, it reflects a potential soil acidification risk.

2.3.2.1 Impact of soil pH

Assessment of soil acidification risk was thus made possible considering the nature and efficiency of the most active buffer reaction (table 3) in each pH range (Blaser et al., 2008).

Table 3 : *Classification of acidification risk in relation to soil pH range and respective buffer reactions*

pH range	Buffer capacity reaction	Acidification risk
>7	Carbonate buffer range	Very low
4.8<pH<7	Silicate weathering and protonation of acid functional groups buffer range	High
3.8<pH<4.8	Aluminium buffer range	Low
<3.8	Iron buffer range	Very low

2.3.2.2 Impact of soil pH buffering capacity

Given the range of topsoil pH values observed in Rwanda, we decided to use the equation of Helyar et al. (1990) developed for soils in the tropics to estimate pHBC

pHBC = 4.2*OM+2.0*Clay (1)

With pHBC as pH buffer capacity in kmol (+)(ha) $^{-1}$pH $^{-1}$, OM as Organic matter content in % and clay as clay content in %.

Table 4 provides a qualitative classification of potential acidification risk based on pH buffering capacity (Singh et al., 2003).

Table 4: *Classification of acidification risk according to pHBC range*

pHBC range (kmol H^+/(ha).pH)	Acidification risk
0-40	Very high
40-60	High
60-100	Low
>100	Very low

III. Results

3.1 Topsoil acidity status

3.1.1. Descriptive statistics of selected acidity indicators

Table 5 provides, among others, an overview of the descriptive statistics of the main acidity indicators in Rwanda while table illustrates the specific case of Central Plateau.

Table 5: *Ranges of a selected set of mineral topsoil (0-30 cm) physical and chemical soil properties comprised by the Rwandan soil profile database*

Soil properties	Unit	N° of profiles	Mean	Std. Dev.	Minimum	Maximum
Acidity indicators						
pH-Water	-	1429	5.1	0.9	2.8	11.2
pH-KCl	-	1397	4.2	0.8	2.3	10.3
Exch. Acidity	cmol(+)kg^{-1} soil	1429	2.3	3.7	0.0	61.1
Al saturation	%	1329	13	13	0	64
Base saturation	%	1329	37	33	0.06	254
Other soil properties						
Clay	%	1405	36	15.1	2	85
Bulk density	Mg m^{-3}	150	1.1	0.2	0.4	1.7
OC	%	1426	2.8	2.6	0.3	32.8
Total N	%	1323	0.2	0.1	0.0	2.4
Available P	ppm	363	19.2	43.3	0.0	372.0
CEC	cmol(+)kg^{-1} soil	1329	17.74	13.4	1.6	200.3

Topsoil acidity in the Central Plateau

During the soil survey, 286 soil profiles have been analyzed and this represents 20% of all soil profiles countrywide. Table 6 gives an overview of data on the Central Plateau. While the mean clay and OC content for the whole country is 36% and 2.8% respectively, it is 33% and 1.46% respectively for the Central Plateau. Here we have to remind that these two soil properties are very important and have been used to estimate the Phbc

Table 6 : *Ranges of a selected set of mineral topsoil (0-30 cm) physical and chemical soil properties of Central Plateau of Rwanda*

Soil properties	N	Mean	Std. Deviation	Minimum	Maximum
PHH2O	242	.,2	.7	2.7	7.1
PHKCL	242	4.2	.6	2.4	6.1
OC	241	1.4	.7	.3	7.3
BD	17	1.3	.1	1.1	1.6
N	229	.1	.0	.0	.4
P	69	15.6	24.2	.0	128.0
CEC	233	10.0	4.3	2.2	26.8

Clay	239	33.1	15.2	4.6	74

The frequency distribution of pH as shown in figure 2 reveals that an important number of the Rwandan topsoil exhibits soil pH value within the range between 4 and 5.5 and this has been confirmed by the statistical analyses which showed that 58%(832 out of 1429 profiles) of soil profiles are within this range.

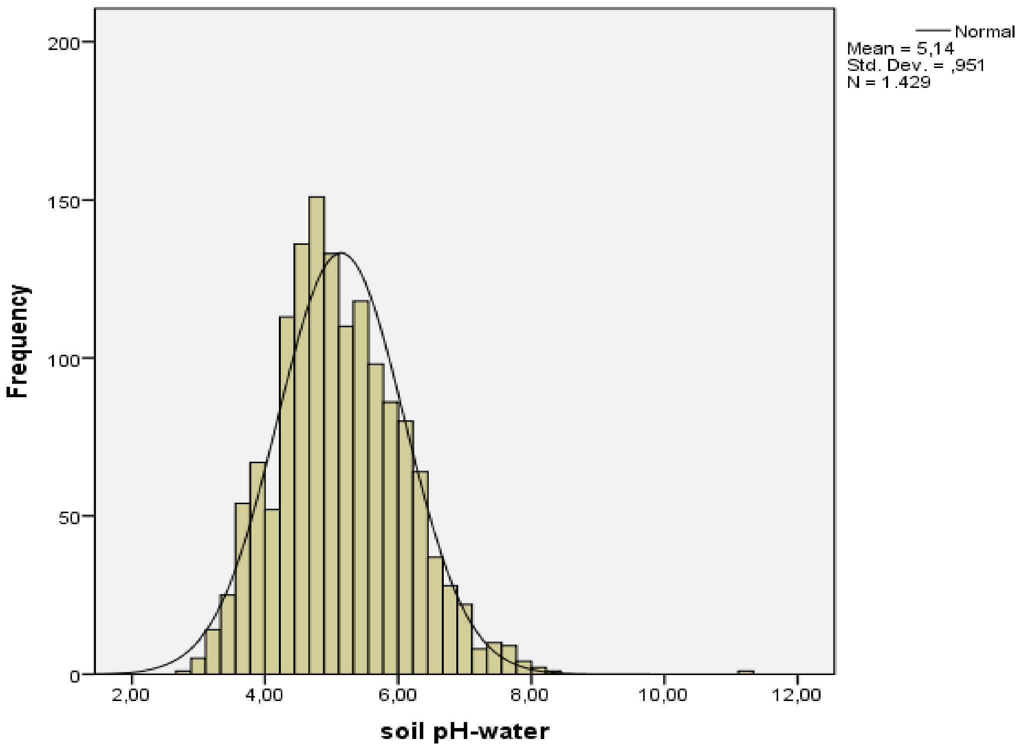


Figure 2: Frequency histogram and normal curve for soil pH in Rwanda

Table 7 shows that all acidity parameters exhibit very significant and very strong to moderate strong correlations among them ($P<0.01$) except the exchangeable acidity whereby the correlation is significant but weak. Al saturation is negatively correlated with both pH-water and pH-KCl.

Table 7: *Pearson correlation coefficients (r) among acidity parameters*

Acidity parameters	pH-H_2O	pH-KCl	Al sat.	Exch.Acidity
pH-H_2O	1	$.92^{**}$	$-.69^{**}$	$-.35^{**}$
pH-KCl	$.92^{**}$	1	$-.64^{**}$	$-.31^{**}$
Al SAT	$-.69^{**}$	$-.64^{**}$	1	$.49^{**}$
Exch.Acidity	$-.35^{**}$	$-.31^{**}$	$.49^{**}$	1

**. Correlation is significant at the 0.01 level (2-tailed).

3.1.2. Correlations with continuous soil and landscape parameters

Table 8 also illustrates the large variation in other soil properties.

Table 8 : *Pearson correlation between soil acidity parameters and other (soil) properties*

	CLAY	OC	N	P	SM BC	ESP	ECEC	Slope gradient	Altitude
pH-water	.0	$-.2^{**}$	$-.1^{**}$	$.3^{**}$	$.6^{**}$	$.0^{**}$	$.5^{**}$	$-.3^{**}$	$-.2^{**}$
pH-KCl	$.0^{*}$	$-.2^{**}$	$-.0^{**}$	$.3^{**}$	$.6^{**}$	$.1^{**}$	$.5^{**}$	$-.3^{**}$	$-.2^{**}$
AL SAT	-.3	.0	$-.0^{**}$	$-.2^{**}$	$-.5^{**}$	$.0^{*}$	$-.3^{**}$	$.3^{**}$	0.1^{*}
BS	-.0	$-.2^{**}$	$-.1^{**}$	$.3^{**}$	$.7^{**}$	$-.0^{*}$	$.5^{**}$	$-.3^{**}$	$-.2^{**}$
EXCH ACIDITY	$.0^{*}$	$.2^{**}$	$.2^{**}$	$-.2^{**}$	$-.1^{**}$	.0	$.0^{*}$	$.2^{**}$	0.0

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

IV. Discussion

It was interesting to check the correlation between the acidity parameters with other soil/landscape continuous parameters seeing that the soil profile database could provide information about it.

The landscape parameters found in our legacy dataset, slope gradient and altitude, showed a negative strong and very significant correlation with pH. This means that the steeper the slope and the higher the altitude, the lower the pH.

Besides landscape parameters, the other soil properties like sum of basic cations, Nitrogen, available Phosphorous, OC, ESP, ECEC and clay content were assessed as well.

The sum of basic cations and soil pH were strongly and positively correlated and this is because of the higher pKa values of all basic cations. Therefore, where the leaching strength of the climate is higher, the pH will be low because the basic cations are more mobile and will be leached out. This is also confirmed by the strong negative correlation between sum of basic cations and Al saturation which means that when the basic cations are leached out or are less, Aluminium becomes the dominant element, thus leading to soil toxicity for most plant growth. BS is strongly related to the leaching strength of the climate and to the composition of the parent material. In Rwanda, soils are strongly leached as 50% of the profiles have BS less than 20% and only 25% have BS more than 50%.This means that soils which are leached are obviously characterized by high levels of acidic cations. The leaching strength of the climate depends more on rainfall events and as we have divided Rwanda into three altitudinal zones, the soils in highlands are more leached than in lowlands. Continuing with Al saturation, the negative correlation of Al saturation with N, P, CEC and BS is obvious as some of toxic effects of Al are (1) stop OM decomposition, thus preventing the release of N and P, and decreasing CEC provided by OM, (2) present antagonism with basic cations mostly Ca and this reduces base saturation and (3) precipitation of P.

For Nitrogen, the correlation is also negative because as Nitrogen increases in soil, the soil pH decreases. This is mainly due to two important processes: Nitrification and leaching. The gradual buildup of the soil N will support intensive nitrification, provided no other factors limit microbial activity. This microbial oxidation reaction leads to the formation of HNO_3, a strong acid that readily dissociates into one H^+ and one NO_3^- . The impact of the nitrification process on soil chemical properties consequently consists of two components: the acidifying effect from the internal H^+ production, and the acceleration of cation leaching associated with mobile NO_3^-. The extent to which percolating solutions are acidified by this nitrification process depends on the rate of such H^+ release relative to the rate of H^+ neutralization (or pH buffering), which frequently involves cation exchange reactions (Van Miegroet and Cole,1984).

The positive correlation with available phosphorous indicates that the increase in pH leads to an increase in available Phosphorous. The behavior of P in soil is influenced by the solubility of different possible constituents and pH. When the pH is very low (acidic conditions), exchangeable Al and Fe become soluble and together with P form insoluble P compounds thus impeding P to be available for plants.

Another interesting finding is the strong and positive correlation between soil pH and ECEC. This latter is used as a measure of fertility and as CEC decreases, soils loose the capacity to retain cations which now become more prone to leaching. By this latter process, cations such Na^+,K^+,Ca^{2+} and Mg^{2+} move downward at a greater rate than anions , so the pH in the root zone will decrease, because a net increase in H^+ will occur, maintaining electrical neutrality of the soil. This whole process leads to further acidification of the soil. It's now obvious to observe the strong negative correlation of ECEC and Al saturation which now means that the higher the Al saturation the less the capacity.

After a general assessment of acidity status and risk for acidification at national level, we can't end this study without giving a general picture of the central plateau now at regional level.

First of all, this ACZ doesn't exhibit any significant difference between acidity parameters with the national data but only the differences were about now the parameters used to assess the acidification risk: clay content and OC content. The values of these latter parameters were very lower than these at national level and this makes this region to be more prone to acidification risk than elsewhere in the country. In fact, the low OC in explained by the fact this area situated in central part of the country has an intermediate climate between warm and cool climate seeing that it's a middle altitudinal zone. This explains why the decomposition rate of OC can be quite high, thus leading to low OC content compared with high altitudinal where cool weather dominates. Talking about the clay content, this ACZ is dominated by granitic parent materials and as reported by Verdoodt and Van Ranst (2006),soils developing on granite or shale intervened by quartzite are loamy and generally have a clay content between 20 and 35 % while seventy percent of the soils of Rwanda are clayey with a clay content varying between 35 and 60 %.This is normally the most striking difference between central plateau and other

ACZ, thus explaining why even currently in Rwanda many liming projects pay too much attention at the Central plateau but this doesn't mean that other areas are not prone too.

Finally, the fragility of this land to acidification combined by overexploitation of the land, caused by the growing demographic pressure, leads to further acidification. Today, in absence of unoccupied lands, farmers cultivate the same holdings year after year and in an increasingly intensive fashion. Land scarcity now has compelled farmers all over the country to depart from their traditional system and convert pastures and woodlots into cropland and cultivate fragile, steep-sloping fields.

V. Conclusion

This study is very important for a country like Rwanda where acidification is one of the most important type of soil degradation on one hand and it allowed us to gain insight about exploiting and mining data from the soil profile database of Rwanda on the other hand.

We conclude that clay content and OC are important soil properties and play a big role to build the capacity of the soil to resist pH changes. This is something important that many projects could consider because in most cases people only base on initial soil pH while they could also check the capacity of the soil to resist pH changes and in that case they will know which areas are really riskier than others.

Reference

[1]. Bidogeza, J., Hoogenboom, G., Berensten, P., De Graaff, J., Oude Lansink, A., 2012. Application of DSSAT crop models to generate alternative production activities under combined use of organic-inorganic nutrients in Rwanda. Journal of Crop Improvement 26, 346-363.

[2]. Blaser, P., Walthert, L., Graf Pannatier, E., 2008. The sensitivity of Swiss forest soils to acidification and the risk of aluminum toxicity. Journal of Plant Nutrition and Soil Science 171, 605-612.

[3]. Helyar, K.R., Porter, W., Robson, A., 1989. Soil acidification, its measurement and the processes involved. Soil acidity and plant growth., 61-101.

[4]. Musahara, H., 2001. Land and Poverty in Rwanda, Landnet Rwanda Chapter Seminar on Land in Rwanda, National University of Rwanda.

[5]. Van Miegroet, H., Cole, D., 1984. The impact of nitrification on soil acidification and cation leaching in a red alder ecosystem. Journal of Environmental Quality 13, 586-590.

[6]. Verdoodt, A., Van Ranst, E., 2006b. The soil information system of Rwanda: A useful tool to identify guidelines towards sustainable land management. Afrika Focus 19, 69-92.

[7]. VerdoodtA, A., BaertB, G., Van RanstA, E., 2010. Baseline organic carbon stocks of Rwandan topsoils, Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010. International Union of Soil Sciences (IUSS), c/o Institut für Bodenforschung, Universität für Bodenkultur, pp. 16-19.

C. Ngendo, et. al. "Landscape-based assessment of risk for soil acidification in Rwanda." *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 14(1), 2021, pp. 07-13.