

Research Article

***Acacia Melanoxylon* and *Alnus Accuminata* Effect on Some Acidic Soil Content: A Case Study of Southern Rwanda**

Nsabimana Leonard^{1,*} , Rukangantambara Hamudu², Marguerite Mukangango², Francois Xavier Naramabuye², Khan Humayun¹ 

¹Department of Agricultural promotion (Specialization in Rural and Regional Development), Zhejiang Ocean University, Lincheng city, China

²Soil and Environment Management, University of Rwanda, Huye City, Rwanda

Abstract

Background: Soil chemical content can be usually influenced by tree species positively or negatively. It is necessary to study the effect of *Acacia Melanoxylon* and *Alnus Accuminata* tree species on some acidic soil content. The research was conducted in Rwanda forestry Authority (RFA)/ Ruhande Arboretum to assess the effect of *Acacia melanoxylon* and *Alnus accuminata* on nitrogen, soil organic matter, and soil acidity content in acidic soil. A Randomized Complete Block Design (RCBD) with three replications and three treatments were used. Soil sampling was done following the zigzag method per each treatment and each replication at two depths (0-15 and 15-30 cm). In each plot and each depth, ten soil samples were put together to make one composite sample. **Results:** The results indicated that the alter of soil chemical content can be influenced by tree species together with soil depths. The laboratory analyses indicated significant influence of tree species on Soil pH, Organic Carbon, Organic Matter, Total Nitrogen, and Carbon to Nitrogen Ratio. The high values were observed under these two tree species and the low under fallow as a control for all parameters undertaken. The main factors should be the higher biomass and soil nutrients production under *Alnus accuminata* comparatively to *Acacia melanoxylon* and fallow as control. **Conclusion:** The study indicated that tree species influence soil chemical content. Therefore, the establishment of *Acacia melanoxylon* and *Alnus accuminata* tree species in farming systems like forestry and agroforestry under acidic soil is recommended and much should be done by Rwanda Ministry of Agriculture and Animal Resources (MINAGRI), Rwanda Forestry Authority (RFA) and Rwanda Environment Management Authority (REMA) to use these miracle tree species especially *Alnus accuminata* in farming systems where are suitable across the whole Country.

Keywords

Soil Acidity, Soil Fertility, Agroforestry, Soil Nutrients Improvement, *Acacia Melanoxylon*, and *Alnus Accuminata*

1. Introduction

The widespread decline in land productivity in sub-Saharan Africa is reported to be caused by soil fertility depletion [29].

Total NPK deficit on a global scale in 2000 of 20 Tg (1012 g), of which 75% was in developing countries as estimated [33].

*Corresponding author: nsabileo5@gmail.com (Nsabimana Leonard)

Received: 28 June 2025; **Accepted:** 19 July 2025; **Published:** 31 December 2025



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Soil erosion, nutrient leaching, removal of crop residues, and continuous cultivation are major factors responsible for soil fertility depletion [32].

As other tropical soils, Rwandan soils are facing high degradation problems due to high level of leaching and intense erosion, which result to soil acidity with low fertility [34], low cation exchange capacity, small amounts of other clay minerals and organic matter, high aluminium toxicity on its mostly dominant Oxisols soils [26].

Due to soil degradation which leads to soil acidity and depletion of nutrient elements to plant, Rwanda is undergoing a gradual decline in food production which has led to severe food shortages in recent years [25]. Furthermore, the increased pressure on land by over-cultivation without fallowing, low supply of fertilizers, and low-level use of agroforestry tree species result in the decline in soil nutrients. Farmers need to readapt their agricultural system to this degradation of the physical environment, forming a loop of people-environment interaction [11]. Moreover, enhancing agricultural productivity and preventing food insecurity in Rwanda will rely on incorporating environmental sustainability interventions into the planning process to ensure that investments are adequately allocated to address environmental priorities within the relevant sectors. The recent Crop Intensification Program (CIP) policy in Rwanda is aimed to boost agricultural productivity through the improvement of agricultural inputs use irrigation coverage, and soil quality [17]. Agroforestry has been considered as one of the agronomic measures that provide sustainable management of soil nutrients by the production of biomass and mulching materials [12]. Furthermore, various exotic agroforestry trees and shrubs species have been evaluated and established in many family farming systems to ensure sustainable management of soil fertility, and thus improve family's livelihood by increasing the overall food production in Rwanda [27]. Thus, effective adoption of using *Acacia melanoxylon* and *Alnus accuminata* species can restore the depleted soil nutrients to overcome this situation as they increase the total biomass per unit land area and are one of N₂-fixing tree species that contribute to soil fertility improvement [20]. The objective of this study was to evaluate the effect of *A. melanoxylon* and *A. accuminata* on soil nutrients content when grown on acidic soil.

2. Materials and Methods

2.1. Site Characterization

The study was conducted in Ruhande arboretum forest located near the University of Rwanda-Huye Campus in Southern Province of Rwanda, Huye district, and Ngoma sector at a location of 29°46' East and 2°33' South. The latitude and the altitude comprises between 1,638 to 1,728m [30]. The climate in this region is tropical humid with an average annual temperature of 19.6 °C, and the mean annual precipitation is 1232mm [4]. The rainfall has a bimodal pattern: the heavy rainy season extending from March to May and the

mid-season rain from September to December. The two rainfall seasons alternate with two dry seasons, one from January to February and the other from June to September. We selected this area in our study because it maintains a land-use history. The total forest area covers 200 ha. Before forest plantation, the area had been used for human settlement and multiple croplands until 1933 when the population was displaced, and the tree plantation was established [8]. The Arboretum of Ruhande which is currently managed by the Rwanda Forestry Authority (RFA) is considered as a center to produce ecologically adapted silvicultural species and provide tree seeds at the national level as well as the uses the forest resources mainly for research purpose and biodiversity conservation. It has over 207 native and exotic trees, including 143 hardwoods among them *Acacia melanoxylon* and *Alnus accuminata* and 69 eucalyptus species, 57 soft kinds of wood, and 3 Bamboo species. Most species were replicated in different plots intercalated by alleys of about 6m wide, which offers an opportunity to examine the effect of *Acacia melanoxylon* and *Alnus accuminata* and other species on soil properties under tree plantation. The forest is composed of 529 plots of 50m×50m in which 459 are planted with tree species.

The soil in Arboretum is classified as a Ferralsols [6] formed from the parent material of schist and granites mixed with mica schist and quartzite [31, 35]. with a deep sombric horizon. They are infertile soils formed in hot wet tropics that require fertilizers and lime for a good yield of cultivated crops [5].

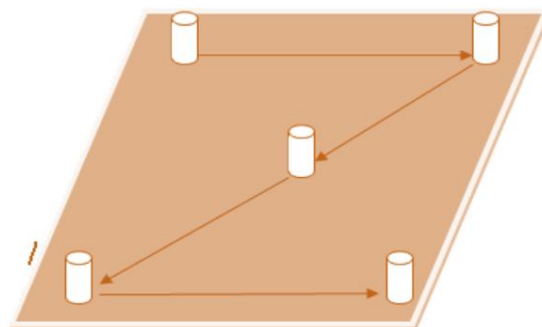


Figure 1. Soil sampling method.

2.2. Field Experimental Design and Sampling

A Randomized Complete Block Design (RCBD) with three replications treatments were: T1: fallow as control; T2: *Acacia melanoxylon* and T3: *Alnus accuminata*. *Acacia melanoxylon* was planted in 1983 whereas *A. accuminata* planted in 1986 in the same size. At the time of research, both *A. melanoxylon* and *A. accuminata* were not pruned since they have been planted and their respective heights were 13.82m and 10.21m. The natural fallow used as control treatment was dominated by *Polyscias Fulva* and *Ricinus Communis* plants

which were also not pruned during the time of the study.

The soil sampling was done following the zigzag method (Figure 1) per each treatment and each replication using a soil auger at two depths (0-15 and 15-30 cm). In each plot and each depth, ten soil samples were put together to make one composite sample. Per each replication, a total of 6 composite samples were collected (2 from the control plot, 2 from *Acacia Melanoxylon* and 2 from *Alnus Accuminata* stand plots) to make 18 composite samples. Soil samples were transported to the Laboratory of Plants and Soil Analysis of the University of Rwanda College of Agriculture, Animal Sciences and Veterinary Medicine, Huye Campus to be analyzed.

2.3. Laboratory Analysis

In Laboratory, soil samples were naturally air-dried, grind, and screened with 2mm and 0.5mm sieves for chemical analysis. Soil pH_{H2O} was measured on 12.5:5 water to soil suspension ratio using the Potentiometric method (pH meter with electrodes). For pH_{KCl}, the procedure is the same except only distilled water was replaced by KCl 1N solution [19] as described in [22]. Total nitrogen was determined using the [14]

method as modified by [1] method and outlined in [22]. Total organic carbon was determined using the [36] method, in modified [18] as described in [22].

2.4. Statistical Analysis

[7] was used to run the statistical analysis. A comparison of means of the two treatments with the natural fallow was examined for differences using “general analysis of variance (ANOVA) in Randomized Blocks”, with least significant differences (LSD) of means calculated at 95% of confidence level ($\lambda=5\%$).

3. Results and Discussion

Soil chemical parameters (pH water, organic carbon, organic matter, total nitrogen, and carbon to nitrogen ratio) were analyzed at different depths. The data were presented as means. Table 1 summarizes the analyzed soil chemical parameters into selected plots.

Table 1. Soil chemical parameters at different depths.

Treatment	Depth (cm)	pH water	TOC (%)	SOM (%)	TN (%)	C/N Ratio (%)
Control	0-15	4.87	2.5	4.31	0.15	16.88
	15-30	4.65	1.99	3.42	0.1	19.12
A. Melanoxylon	0-15	5.31	2.59	4.46	0.43	6.33
	15-30	5.26	2.13	3.67	0.3	7.72
A. Accuminata	0-15	5.4	3.7	6.39	0.62	5.92
	15-30	5.27	3.39	5.84	0.58	5.82
Control		<0.001	<0.001	<0.001	0.001	<0.001
A. Melanoxylon	P. value (5%)	<0.001	<0.001	<0.001	<0.001	0.003
A. Accuminata		<0.001	<0.001	<0.001	<0.001	<0.001
LSD (at 5%)		0.03	0.02	0.04	0.11	3.75
CV (%)		0.2	0.75	8.1	13.4	16.25

TOC: Total Organic carbon;

SOM: Soil Organic Matter;

TN: Total Nitrogen;

C/N ratio: Carbon to Nitrogen ratio;

P. value (5%): Probability value at 5% of confidence level;

LSD (at 5%): Least significant difference; and

CV (%): Coefficient of variation.

3.1. Soil Acidity

The overall analysis of variance (Table 1) showed a sig-

nificant effect of the treatments (Fallow, *Acacia melanoxylon*, and *Alnus accuminata*) on soil pH ($P<0.001$). The soil pH varied from 4.87 to 4.65; 5.31 to 5.26 and 5.40 to 5.27 respectively under control, *Acacia melanoxylon*, and *Alnus ac-*

cuminata. The pH values showed a decreasing trend with soil depth under all treatments. High soil pH value (Figure 2) was observed under *Alnusaccuminata* (5.34); medium under *Acacia*

melanoxylon (5.29) and low under fallow as control (4.76).

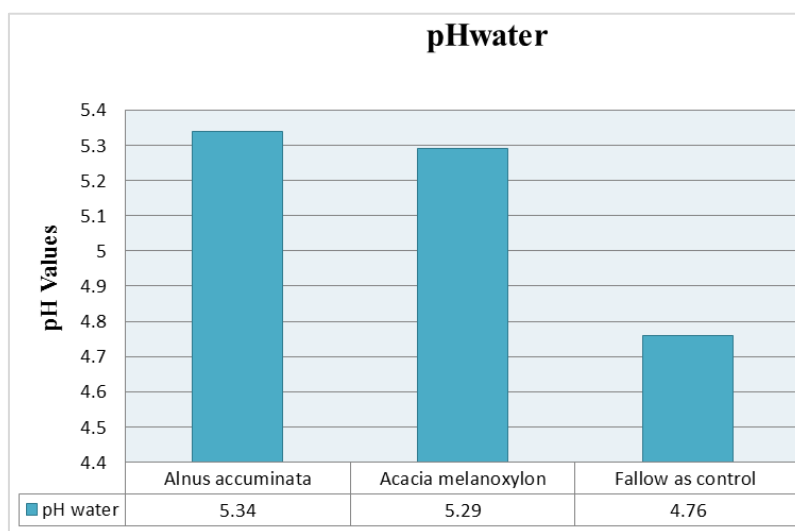


Figure 2. Soil pH water mean values under *Alnusaccuminata*, *Acacia melanoxylon*, and Controlat Ruhande Arboretum at 0-30 cm depth.

The soil pH value (Figure 2) increased from strongly acid to slightly acid under *Acacia melanoxylon* and *Alnusaccuminata* treatments (5.2 - 6.2) whereas it was strongly acid under control fallow (4.2 - 5.2) according to the pH norms established by [9]. Soil pH has a great influence on the soil solubility soil minerals and nutrients and a useful indicator of the availability of exchangeable cations (Ca, Mg, K) [23]. The difference in soil pH under *Acacia melanoxylon* and *Alnusaccuminata* plantation treatment compared to control treatment should be related to differences in the accumulation and dynamic of soil organic matter from litterfall of the tree species composition. Tropical soil conditions such as high temperature and humidity are conducive to the decomposition of organic matter, so that there is not only the release of nutrients but also the formation of negatively charged particles, which help to retain cations such as K, Ca, and Mg and maintain them in constant interface with the soil solution, where they can be absorbed by plants [24].

Furthermore, the low pH under control may be favored by low organic matter content probably due to the low decomposition rate of its vegetation component. In addition to that, the leaching of basic cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+) due to high rainfall and replacement of many of them by H^+ from carbonic acid formed from water and dissolved carbon dioxide [15]. There is a reduction of primary macronutrient elements (N, P, K, Ca, Mg, S) in a strongly acid (< 5.2 pH) according to [2]. This is followed by various harmful effects to plant growth like reduction in nitrogen, soil phosphorus deficiency, aluminum and manganese toxicities, and the greater availability

of heavy metals. In such a situation, there exists very little chemical and biological reactions in the soil. The soil pH behavior of Arboretum soil is common for most of the tropical soils (Ferralisol&ultisol) characterized mainly by leaching of basic elements due to high rainfall, accumulation of acidic ions (H^+ , Fe^{2+} , and Al^{3+}) and inactivation of soil microorganisms especially nitrogen-fixing bacteria due to high acidity. Therefore, Arboretum soil is not suitable for crop production. Liming and fertilizer application should be applied to increase crop productivity. Otherwise, planting acid-tolerant crops should be advised in areas characterized by such soils in Rwanda.

3.2. Soil Total Nitrogen

The overall analysis of variance (Table 1) showed a significant difference in total nitrogen content under control, *Alnusaccuminata*, and *Acacia melanoxylon* plantations ($P=0.001$ and $p< 0.001$). The results showed that the total nitrogen change was affected by depth and treatment. From low depth (0-15 cm) to high depth (15-30 cm), the total nitrogen changed respectively from 0.62 to 0.58%; 0.43 to 0.30% and 0.15 to 0.10% respectively under *Alnusaccuminata*; *Acacia melanoxylon* and control. For each treatment, the results revealed that total nitrogen decreased with soil depth. The higher nitrogen content value (Figure 3) was observed under *Alnusaccuminata* (0.51%) compared to *Acacia melanoxylon* (0.37%) and fallow as control (0.12%).

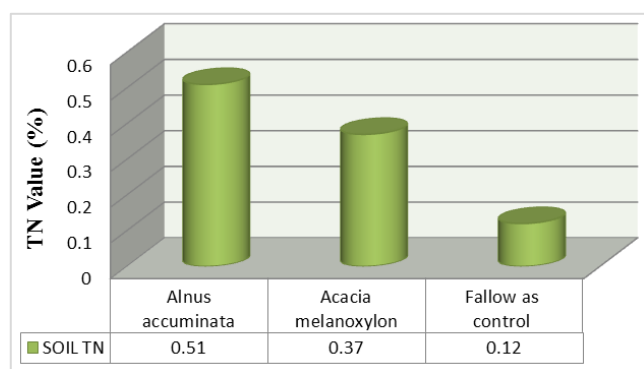


Figure 3. Total Nitrogen mean values of soil under *Acacia melanoxylon* and *Alnusaccuminata* tree species at Ruhande Arboretum/Rwanda.

The total nitrogen value (Figure 3) was high under treatments with *Acacia melanoxylon* and *Alnusaccuminata* stands (>0.25%) and medium under control (0.05-0.12%).

The higher content in TN found under *Alnusaccuminata* and *acacia melanoxylon* plantations are explained by the fact that the above tree species have the nitrogen-fixing ability and in addition to that the accumulation of organic material through litterfall, followed by fast mineralization to nitrogen as it can be explained in both species by the low C/N ratio [28]. In addition to that, higher biomass produced by these tree species in particularly *Alnusaccuminata* adds nutrients to the soil including nitrogen. Furthermore; the lower nitrogen content under control may be due to lower quality biomass production of present species in the fallow control plot which provides little production of organic matter [10] and the fact that those species are not nitrogen-fixing. Thus, the soil in the study area is not suitable to grow crops and its use for the agricultural purpose would require nitrogen fertilizer content application.

3.3. Total Organic Carbon

The overall analysis of variance (Table 1) showed significant difference in total organic carbon (TOC) under *Acacia melanoxylon* and *Alnusaccuminata* ($P < 0.001$). The TOC values decreased with soil depth varied from 3.70 to 3.39%; 2.59 to 2.13% and 2.5 to 1.99 respectively under *Alnusaccuminata*, *Acacia melanoxylon*, and control. High TOC (Figure 4) was found under *Alnusaccuminata* (3.83%); moderate under *Acacia Melanoxylon* (2.36%) and lower in control (2.25%).

The higher total organic carbon value (Figure 4) was found under *Alnusaccuminata*, (> 3.0%) compared to *Acacia melanoxylon* and control according to the norms of interpretation of [9] and [16]. The high organic carbon content under those species could be attributed to several factors such as the contribution of litterfall, root biomass, root exudates, and the recycling of above-ground plant parts through a natural process [3]. The lower values of TOC under control could be a result of little accumulation of organic material from the vegetation species in fallow and their limited mineralization

as it has been shown by a higher C/N ratio [13] compared to *Acacia* species used in the study. A decreased value in soil organic carbon recorded with soil depths in all the treatments across surface soil to subsurface soil may be attributed to the contribution made by the litterfall that increases biomass at the soil surface.

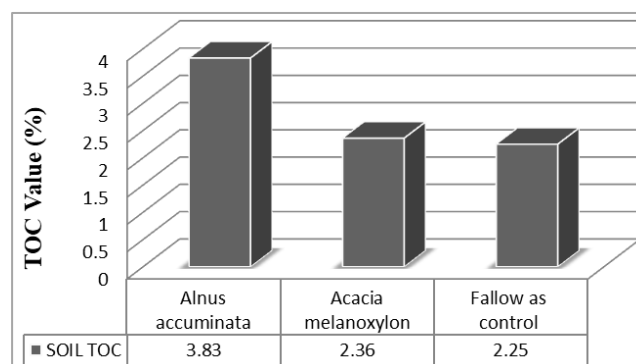


Figure 4. Total Organic Carbon (TOC) mean values of soil under *Acacia melanoxylon* and *Alnusaccuminata* tree species at Ruhande Arboretum/Rwanda.

3.4. Carbon-Nitrogen Ratio

The overall analysis of variance (Table 1) showed a significant difference in the C/N ratio between *Acacia melanoxylon*, *Alnusaccuminata* plantations, and control ($P < 0.001$ and $P = 0.003$). The C/N ratio changed from 16.88:1 to 19.12:1; 6.33:1 to 7.72:1 and 5.92:1 to 5.82:1, respectively to control, *Acacia melanoxylon* and *Alnus accuminata*.

Table 2. Interpretation norms of C/N Ratio.

C/N ratio	Mineralization
< or =9	Very rapid
9-12	Rapid
12-17	Normal
17-25	Slow
>Or=25	Very slow

Source: Landon, 1991

The carbon-nitrogen ratio tended to increase with soil depth under control and *Acacia melanoxylon* treatment and decrease under *Alnusaccuminata* treatment. Based on mean values (Figure 5) and interpretation norms of C/N Ratio (Table 2), the biomass produced in control showed a higher C/N ratio (18.00:1) than *Acacia* species used in the study (7.03:1).

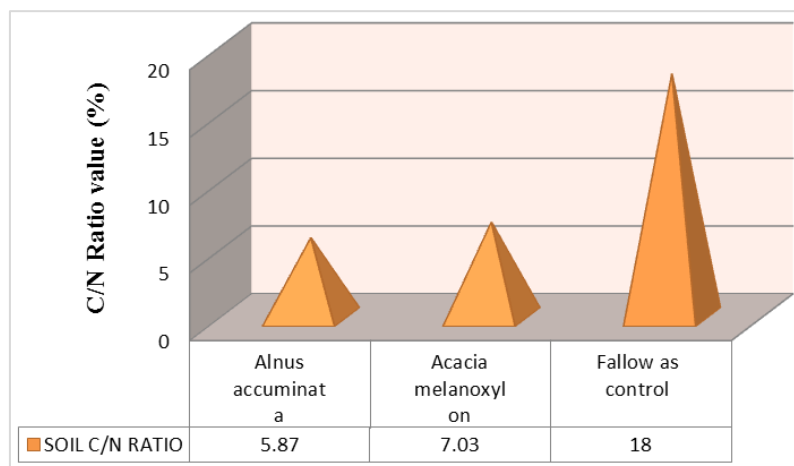


Figure 5. C/N ratio mean values of soil under *Alnus accuminata*, *Acacia melanoxylon*, and control at Ruhunde Arboretum /Rwanda.

C/N Ratio is the relationship existing between the organic matter and nitrogen contents of soil which is an important factor for the decomposition of organic material (mineralization) and microbial activity as defined by [21]. High C/N ratio in the control plot is attributed to low organic matter content and low availability of Nitrogen element in biomass produced.

The chemical properties of oxisols soil under control ($\text{pH} < 5.2$) that limit the mineralization process of organic carbon through the accumulation of aluminum and iron oxides [5]. The low value of the C/N ratio under *Acacia melanoxylon* and *Alnus accuminata* plantations is attributed to the higher content in organic carbon and total nitrogen.

4. Correlation Analysis Between Parameters

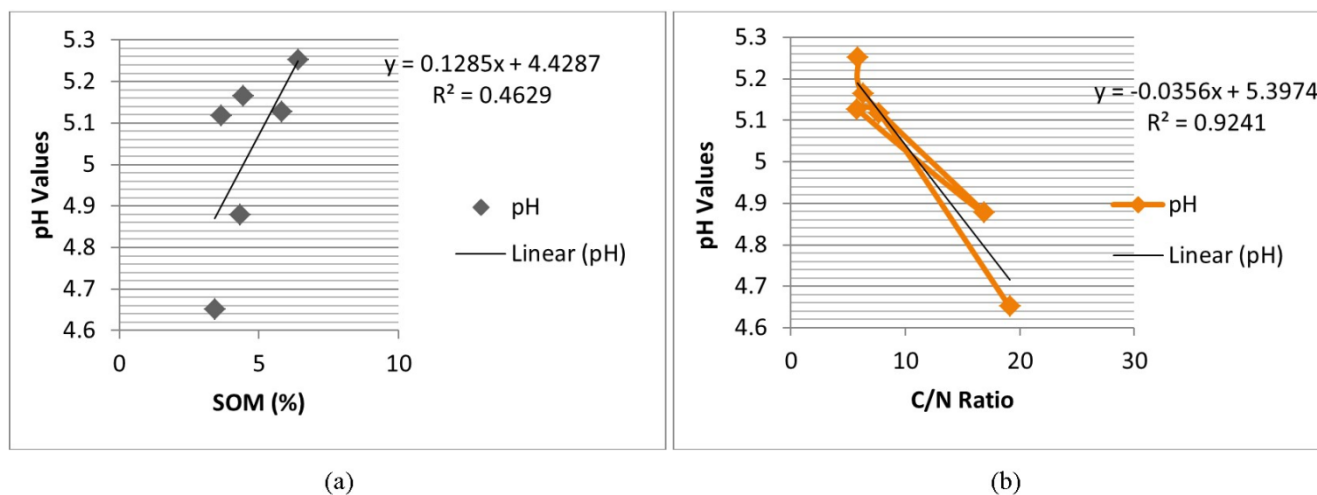


Figure 6. Effect of soil pH on soil organic matter (a) and C/N ratio (b).

The effect of soil pH on SOM referred to the moderate correlation coefficient (0.462) shows that as soil pH increased, SOM increased as well (Figure 6a); and the effect of soil pH

referred to the strong correlation coefficient (0.924) shows that as soil pH increased, C/N ratio decreased significantly (Figure 6b).

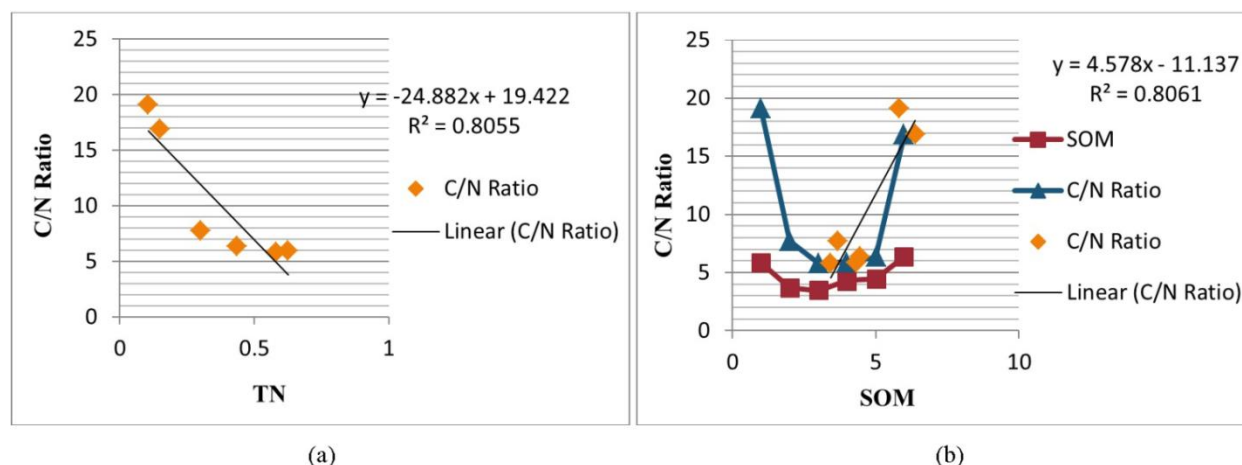


Figure 7. Relationship between C/N ratio and soil organic matter (a), and total N (b).

The high correlation coefficients (0.805 & 0.806) showed that the C/N ratio increased with a decline in nitrogen and soil organic matter content. The adjustment of soil pH to a recommended value can increase the availability of important nutrients. Plants usually grow well at pH values above 5.5. Soil pH of 6.5 is usually considered optimum for nutrients availability. With an increase in soil organic matter, the soil recovers its natural buffer capacity. C/N ratio is the relationship between organic matter and nitrogen content of soils or plants and it controls the decomposition rate in soil. If the C/N ratio is too high (excess Carbon), the decomposition slows down. The same observation is revealed in [2, 37] and [13].

5. Conclusion

This research was undertaken to assess the effect of *Acacia melanoxylon* and *Alnus accuminata* on soil content in acidic soil conditions. *Alnus accuminata* showed great potentiality in soil quality improvement compared to *Acacia melanoxylon*. Based on the results obtained on soil pH, total nitrogen and soil organic carbon in acidic soil of Ruhande Arboretum during this research, we come up with the following recommendations: The use of *Acacia melanoxylon* and *Alnus accuminata* tree species can be recommended to improve soil fertility and overcoming the decayed soil nutrients. The species are very important to disseminate at a national scale as multipurpose agroforestry and forestry trees in farming systems, to optimize soil nutrients management and soil conservation which are the key factors of sustainable crop production and food security in Rwanda. The Ministry of Agriculture and Animal Resources (MINAGRI) through extension agents and all other stakeholders should encourage the farmer to integrate such agroforestry species (*Alnus accuminata* and *Acacia melanoxylon*) under acidic and nutrients depleted soils for soil fertility restoration and erosion control mainly in highlands regions.

Abbreviations

RFA	Rwanda Forestry Authority
RCBD	Randomized Complete Block Design
MINAGRI	Rwanda Ministry of Agriculture and Animal Resources
REMA	Rwanda Environment Management Authority NPK
CIP	Crop Intensification Program
FAO	Food Agricultural Organization
NCR	North Central Regional
KCl	Potassium Chloride
KCl 1N	1 N (one normal) Solution of KCl
ANOVA	Analysis Of Variance
LSD	Least Significant Differences
TOC	Total Organic Carbon;
SOM	Soil Organic Matter;
TN	Total Nitrogen;
C/N ratio	Carbon to Nitrogen Ratio;
P. value (5%)	Probability Value at 5% of Confidence Level
LSD (at 5%)	Least significant Difference; and
CV (%)	Coefficient of Variation

Acknowledgments

Sincerely, Thanks are expressed to the University of Rwanda College of Agriculture, Animal Sciences, and Veterinary Medicine / Huye Campus which provided its Plants and Soil Analysis Laboratory and materials used to complete successfully this study.

Author Contributions

Nsabimana Leonard: Conceptualization; Data curation, Formal analysis, Investigation, Resources; Software, Writing

– original draft

Rukangantambara Hamudu: Supervision, Methodology

Marguerite Mukangango: Validation, Visualization

Francois Xavier Naramabuye: Funding acquisition, Project administration

Khan Humayun: Writing – review & editing

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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