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Research Article

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

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Abstract

Background: Soil chemical content can be usually influenced by tree speciespositively or negatively. It is necessary to study the effect of *Acacia Melanoxylon* and *AlnusAccuminata* 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 *Alnusaccuminata*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 oftree specieson Soil pH, Organic Carbon, Organic Matter, Total Nitrogen, and Carbon to Nitrogen Ratio. The high values were observed under these two tree speciesand the low under fallow as a control for all parameters undertaken. The main factors should be the higher biomass and soil nutrients production under *Alnusaccuminata* 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 *Alnusaccuminata* tree species in farming systems like forestry and agroforestry under acidic soil is recommended andmuch 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 miracles 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 *AlnusAccuminata*

1. Introduction

The widespread decline in land productivity in sub-Saharan Africa is reported to be caused by soil fertility depletion [29]. [33] estimated a total NPK deficit ona global scale in 2000 of 20 Tg (1012 g), of which 75% was in developing countries. 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 levelof leaching and intense erosion, which result to soil acidity with low fertility [31], low cation exchange capacity, small amounts of other clay minerals and organic matter, high aluminiumtoxicity on its mostly dominant Oxisols soils [23].

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 [22]. 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. Famers needto 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 [15]. 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 [24]. Thus, effective adoption of using Acacia melanoxylon and Alnusaccuminata 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 [18]. The objective of this study was to evaluate the effect of A. melanoxylon and A. acumnata on soil nutrients content when grown on acidic soil.

2. Materials and Methods

2.1 Site Characterization

The study wasconducted in Ruhande arboretum forestlocated near the University of Rwanda-Huye Campus in Southern Province of Rwanda, Huye district, and Ngoma sector at a location of 29o46' East and 2o33'South. The latitudeand the altitude comprises between 1, 638 to 1, 728m [27]. The climate in this region is tropical humid with an average annual temperature of 19. 6 oC, 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 becauseitmaintains 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 thetree 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 levelas 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 AcaciaMelanoxylon and AlnusAccuminataand 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 AlnusAccuminata 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].

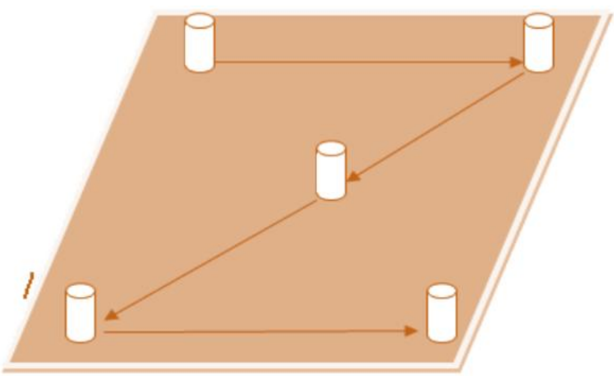


Figure 1. Soil sampling method

2.2 Field Experimental Design and Sampling

A Randomized Complete Block Design (RCBD) with three replications treatments were: T1: fallow as control; T2: Acacia melanoxylonand T3: Alnusaccuminata. Acacia melanoxylonwas planted in 1983 whereas A. accuminata planted in 1986in the same size. At the time of research, both A. melanoxylon and A. accuminatawere not pruned since they have been planted and their respective heightswere 13. 82m and 10. 21m. The natural fallow used as controltreatment was dominated byPolysciasFulva and RicinusCommunis 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 treatmentand each replication using a soil auger at two depths (0-15 and 15-30 cm). In each plot and each depth, tensoil 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 fromAcacia Melanoxylon and 2 from AlnusAccuminata stand plots) to make 18 composite samples. Soil samples were transported to the Laboratory of Plants and Soil Analysis of the University of RwandaCollege 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 pHH20 was measured on 12. 5: 5 water to soil suspension ratio using the Potentiometric method (pHmeter with electrodes). For pHKCl, 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 (λ=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 depts. 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	P. value (5%)	<0.001	<0.001	<0.001	0.001	<0.001
A. Melanoxylon		<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 (table1) showed a significant effect of the treatments (Fallow, Acacia melanoxylon, and Alnusaccuminata) 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, andAlnusaccuminata. 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 underAcacia melanoxylon (5. 29) and low under fallow as control (4. 76).

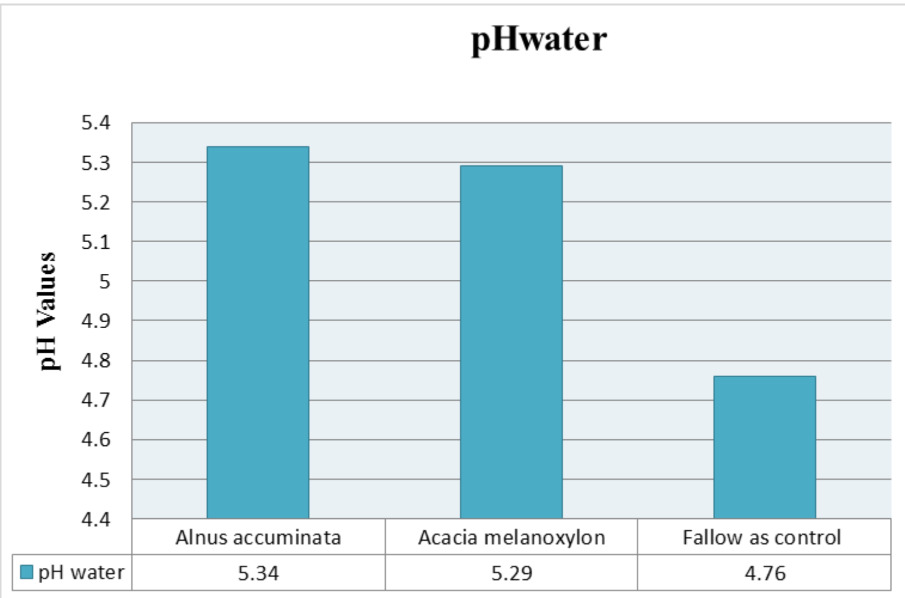


Figure 2. Soil pH water mean values under Alnusaccuminata, Acacia melanoxylon, and Controlat Ruhande Arboretum at 0-30 cm depth

According to the pH norms established by [9], the soil pH value (Figure 2) increased from strongly acid to slightly acid under Acacia melanoxylonand Alnusacuminatatreatments (5. 2 -6. 2) whereas it was strongly acid under control fallow (4. 2 -5. 2). 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 Alnusaccuminataplantation treatment compared to control treatment should be related to differences in the accumulationand 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 (Ca2+, Mg2+, 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]. According to [2] the availability, there is a reduction of primary macronutrient elements (N, P, K, Ca, Mg, S) in a strongly acid (< 5. 2 pH). 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+, Fe2+, and Al3+) 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. 43to 0. 30% and 0. 15to 0. 10% respectively under Alnusaccuminata; Acacia melanoxylonand control. For each treatment, the results revealed that total nitrogen decreased with soil depth. The higher nitrogen content value (figure 3) was observed underAlnusaccuminata (0. 51%) compared toAcacia melanoxylon (0. 37%) and fallow as control (0. 12%).

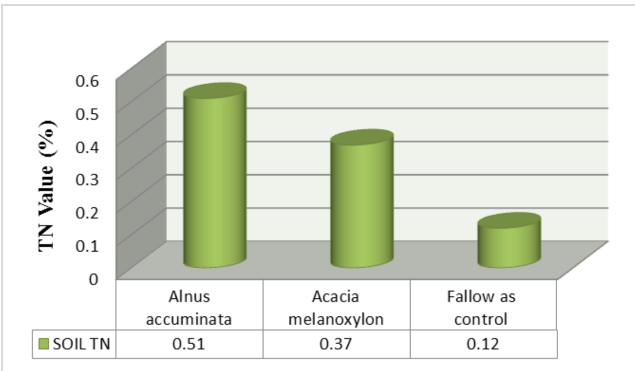


Figure 3. Total Nitrogen mean values of soil under Acacia melanoxylon and Alnusaccuminata tree species at Ruhande Arboretum/Rwanda

According to [9]. and [16]., the total nitrogen value (Figure 3) was high under treatments with Acacia melanoxylon and Alnusaccuminatastands (>0. 25%) and medium under control (0. 05-0. 12%).

The higher content in TN found under Alnusaccuminata and acacia melanoxylonplantations 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 thelow C/N ratio [28]. In addition to that, higher biomass produced by these tree species in particularly Alnusaccuminataadds 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 studyarea 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%).

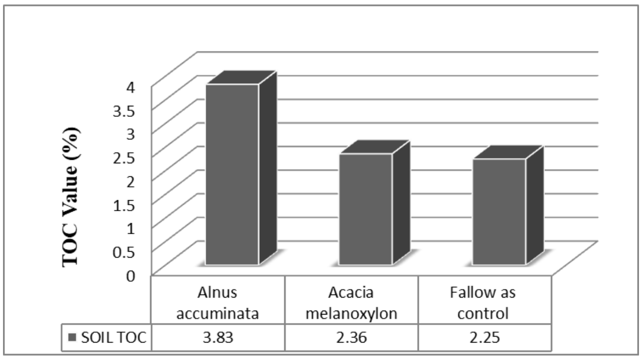


Figure 4. Total Organic Carbon (TOC) mean values of soil under Acacia melanoxylon and Alnusaccuminata tree species at Ruhande Arboretum/Rwanda

According to the norms of interpretation of [9] and [16], the higher total organic carbon value (Figure 4) was found under Alnusaccuminata, (> 3. 0%) compared to Acacia melanoxylonand control. The high organic carbon content under those speciescould 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 hasbeen shownby 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.

3.4 Carbon-Nitrogen Ratio

The overall analysis of variance (Table1) 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 melanoxylonand Alnusaccuminata.

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) andinterpretation norms of C/N Ratio (Table 3), the biomass produced in control showed a higher C/N ratio (18. 00: 1) than Acacia species used in the study (7. 03: 1).

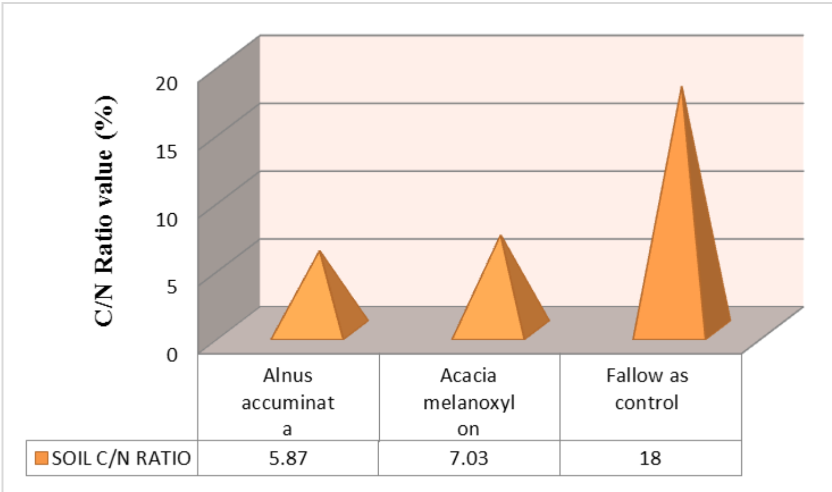
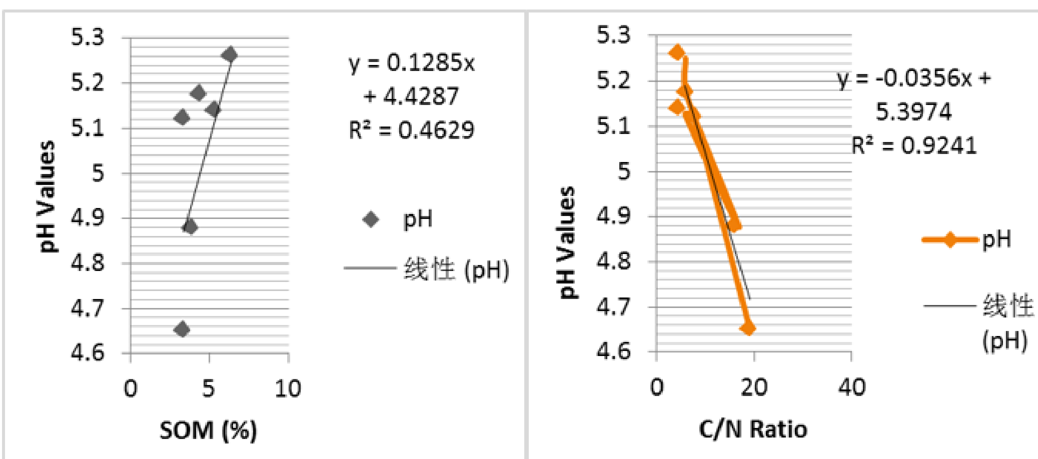


Figure 5. C/N ratio mean values of soil under Alnusaccuminata, Acacia melanoxylon, and control at Ruhande Arboretum /Rwanda

[21] defined 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. 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 (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 melanoxylonandAlnusaccuminata plantations is attributed to the higher content in organic carbon and total nitrogen.

4. Correlation Analysis Between Parameters



(a) (b)

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

The effect of soil pH don SOM referred tothe 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).

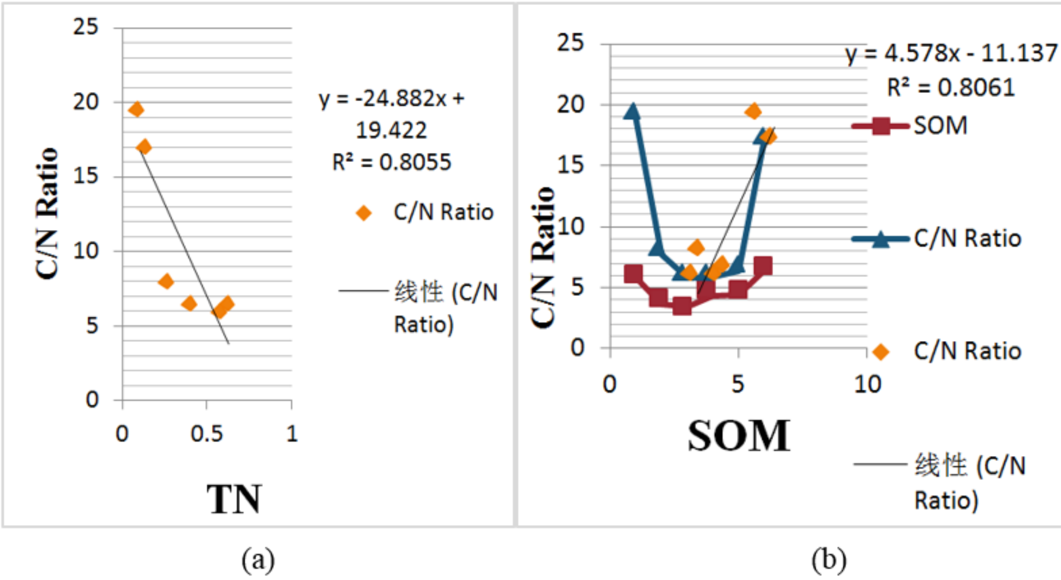


Figure 7. Relationship between C/N ratio and soil organic matter (a), and total N (b)

The high correlation coefficients (0. 805 & 0. 806) showed thatthe C/N ratio increased with a declinein 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 andit 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 Alnusaccuminata 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

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References

[1] Anderson J. M. and Ingram J. S. I. (1993). *Tropical Soil Biology and Fertility*. A handbook of methods second edition. C. A. B International Wallingford Oxon OX 10 8DE UK.

[2] Brady, N. C. (1984). *The Nature and Properties of soils 9thEdition*. Macmillan Publishing Company, New York. Collier Macmillan Publishers, London.

[3] Cervantes & Rodríguez Barrueco (1992). *Relationships between the Mycorrhizal and Actinorhizal Symbioses in Non-legumes.* IRNA-CSIC, Apartado 257, 37071 Salamanca, Spain.

[4] Climate-Data. org. (2019). *Africa: Climate classification*.

[5] Donahue. R. L., Miller, R. W., and Shickluna, J. C. (1983). Soils, An introduction to soils and plant growth.5th ed. Prentice-Hall, Englewood Cliffs, NJ.667 pp.

[6] FAO. (2006). *Guidelines for soil description.4th edition*. Rome.

[7] Genstat version 4. (2012). Genstat Discovery Edition for everyday use. ICRAF Nairobi, Kenya, 114 pp.

[8] Habumugisha Vincent, Khaldoon A. Mourad, and Hashakimana Léonidas. (2019). *The Effects of Trees on Soil Chemistry*. Current Environmental Engineering, 2019, 6, 35-44.

[9] Hazelton, P., and Murphy, B. (2007). *Interpreting Soil Test Results – What do all the Numbers. Mean?* CSIRO Publication, Collingwood, VIC.

[10] Henry D. Forth (1978). *Fondamentals of Soil Sciences 8th Edition (1991),* Michigan State University, United States of Amerca.

[11] Jennifer Olson, L. Berry (2004). *Land Degradation in Rwanda: Its Extent and Impact*. https://www.researchgate.net/publication/257776503

[12] Kuyah, S., Whitney. C. W., Jonsson, M., et al. (2019). *Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa*. A meta-analysis, Agron, Sustain. Dev.39.47. https://doi.org/10.1007/s13593-019-0589-8

[13] Khalil et al. (2005). *Carbon and nitrogen mineralization in different upland soils of the subtropics treated with organic materials. Soil Biology & Biochemistry* 37 (2005) 1507–1518 Freising, Germany. p12. Available at http: www.elsevier.com/locate/soilbio

[14] Kjeldahl, Johan Z. (1883). *A new method for the determination of nitrogen in organic bodies.* Analytical Chemistry 22(1883): 366.

[15] Marschner. (1995). *Nutrition of higher plant, Second edition,* School of Agriculture, Food and Wine. The University of Adelaide, Australia.

[16] Murphy. (2014). *Nitrogen balance and use efficiency on twenty-one intensive grass-based dairy farms in the South of Ireland,* Cambridge University Press.

[17] Nicholas and Hay.(1990). *Blackwood (Acacia melanoxylon. R. Br)plantation silviculture: a review*

[18] Nelson, D. W. and Sommers, L. E. (1975). *A rapid and accurate procedure for the estimation of organic carbon in the soil*. Proceedings of Indiana Academy of Science, 84: 456-462.

[19] NCR (2011). *Recommended Chemical Soil Test Procedures for the North Central Region.* North Central Regional Research Publication No. 221(Revised).

[20] Nduwamungu Jean. (2011). *Forest plantation and woodlots in Rwanda*. National University of Rwanda, P. O. Box 117 Butare, RwandaAfrican Forest Forum P. O. Box 30677-00100 Nairobi GPO KENYA.

[21] Nyle, C. B. & R. W. Ray. (1984). *The nature and properties of soils*. Thirteenth edition. PrinticeHall. Upper Saddle River. New Jersey. USA *annual*. Second edition. TSBF-CIAT and SACRED Africa. Nairobi, Kenya.

[22] Okalebo, J. R., K. W. Gathua, and P. L, Woomer. (2002). *Laboratory methods of soil and plant analysis: A working*.

[23] Ololade IA, Ajayi IR, Gbadamosi AE, Mohammed OZ, Sunday AG (2010). *A study on effects of soil physicochemical properties on cocoa production in Ondo state*. Modern Applied Science. 4: 35–43.

[24] Rachel C. Pinho, Robert P. Miller, and Sonia S. Alfaia (2012). *Agroforestry and the Improvement of Soil Fertility: A View from Amazonia. Applied and Environmental Soil Science*. Volume 2012, Article ID 616383, 11 pages. Hindawi Publishing Corporation.

[25] RutungaVenant, Janssen Bert, H. Stephan Mantel, and Marc Janssen (2007), *Soil use and management strategy for raising food and cash output in Rwanda*. Journal of Food, Agriculture & Environment. Vol.5(3&4); 434-441.2007.

[26] Rahman, M. A., Lee, S. H., Ji, H. C., Kabir, A. H., Jones, C. S., & Lee, K. W. (2018). *Importance of Mineral Nutrition for Mitigating Aluminum Toxicity in Plants on Acidic Soils: Current Status and Opportunities.* International Journal of Molecular Sciences. 19(10), 3073, https://doi.org/10.3390/ijms19103073

[27] Roose and Ndayizigiye.(1997). *Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda*.

[28] S. C. Panda.(2008). *Soil Conservation and fertility Management,* Agrobios (India), p. 84- 431.

[29] Sanchez, P. A. &Jama, B. A. (2001). Soil fertility replenishment takes off in East and Southern Africa.

[30] Stanga, S. (1991). *Plan d'aménagement et de Gestion de arboretum de Ruhande, 1991-2000.* Institut des Sciences Agronomique du Rwanda, 1991.

[31] Steiner KG (1988). *Using farmer's knowledge of soils in making research results more relevant to field practice: Experiences from Rwanda*. Agric. Ecos. Environ. 69: 191-200.

[32] Stoorvogel J. J. &Smaling E. M. A. (1988). *Research on soil fertility decline in tropical environments: integration of special scales.* Nutrient Cycling in Agroecosystems Vol. 50, P. 151-158.

[33] Tan, Z., LAL, R. &Wiebe, K. D. (2005). *Global soil nutrient depletion and yield reduction.* Journal of Sustainable Agriculture, 26, 123-146.

[34] Tittonel et al. (2007). *Soil nutrient depletion in the tropic*.

[35] Verdoodt A, Van Ranst E (2003). *Land evaluation for agricultural production in the tropics: A large-scale land suitability classification for Rwanda*. Laboratory of Soil Science, GhentUniversity, Ghent, Belgium. P.175.

[36] Walkley, A. and I. A Black. (1934). *An examination of the Degtjreff method for determining soil organic matter and a proposed modification of the chromic acid titration method.* Soil Sci.37: 39-37.

[37] Weil. (2002). *Soil Organic Matter Management Strategies*. Institut Andre´ Lwoff, 94801 Villejuif Cedex, CNRS-UPR 1983, France.