International Journal of Plant & Soil Science

27(1): 1-12, 2019; Article no.IJPSS.47162
ISSN: 2320-7035

Evaluation of Carbon, Nitrogen and Phosphorus in Disturbed and Intact Tropical Coastal Forest Sites in Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author EJL designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author CC managed the analyses of the study. Authors EJL and CC managed the literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2019/v27i130065
Editor(s):
(1) Dr. Hon H. Ho, Biology, State University of New York, New York, USA.
(2) Dr. Yong In Kuk, Professor, Department of Development in Oriental Medicine Resources, Sunchon National University, South Korea.
Reviewers:
(1) Nyong Princely Awazi, University of Dschang, Cameroon.
(2) Dale Loussaert, DuPont-Pioneer Hybrid, USA.
(3) Florin Sala, Banat University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, Romania.
(4) Nkwoada Amarachi Udoka, Federal University of Technology Owerri, Nigeria.
Complete Peer review History: http://www.sdiarticle3.com/review-history/47162

Original Research Article

Received 30 November 2018
Accepted 04 March 2019
Published 18 March 2019

ABSTRACT

This study investigated and established the variation of soil nitrogen, total carbon and phosphorus across closed forest; crop-agriculture and livestock disturbed sites. The study provides useful information for local management strategies. It sets initial basic data on the soil status of Uzigua Forest Reserve after 50 years of crop-agriculture and livestock grazing pressure. Forty-seven (50 m × 50 m) quadrats were established on each land uses for soil samples collection. Total nitrogen was analyzed by Kjeldahl acid-digestion, total carbon by the Walkley-Black procedures and phosphorus by Bray-II method. The mean values (percentage) were nitrogen = 16.07 ± 0.34, 1.75 ± 0.25, 6.5 ± 0.20; carbon =14.48 ± 0.23, 11.81 ± 0.13, 12.24 ± 0.30; phosphorus =14.12 ± 6.57, 17.74 ± 3.96, and 13.31± 2.86 for closed forest; agriculture disturbed and grazed sites respectively. There was a slightly lower amount of total carbon on crop agriculture disturbed sites than on the

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livestock grazed land uses. Carbon-nitrogen ratio was higher in closed forests than in the disturbed sites. The relationship between forest degradation and soil nutrient status is an indication that the below-ground nutrient pools are mainly determined by activities, which disturb the above-ground components mainly vegetation. To restore soil fertility status, it is important to establish the management of the disturbed sites through restoration of vegetation and minimization of disturbances.

Keywords: Coastal-forests; agriculture; grazing; disturbances.

1. INTRODUCTION

The dependence of human life on forest ecosystems is evident [1,2]. This dependence is based on the fact that forests play important roles, ranging from ecological functions (regulating the climate and water sources and by serving as habitats for plants and animals). Indeed, forests provide goods (wood, food, fodder and medicines), recreation, spiritual values and other services [3,4,5,6].

Although forest ecosystems are important in providing all these services, these ecosystems are under pressure of deforestation from increasing demand of land use-based products and services [7]. The human based forest disturbances are brought mainly by harvesting of forest resources, crop-farming, livestock grazing, and damage by fire [1,2]. In Tanzania, crop-agriculture and livestock grazing are the major activities for deforestation and disturbances. These activities cause massive loss of forest and forestry resources [6,8,9]. For example, deforestation has caused loss of forest area from 55 920 in 1990 to 46 060 million ha in 2015 [2]. The current operations on crop-agriculture and livestock grazing cause forest ecosystem disturbances particularly along the coastal zone. This zone is located within 100 kilometers of the Indian Ocean, where by about 800 km^2 of forest ecosystems are located [9,10]. Forest disturbance is highly pronounced along this zone because human activities are accelerated by climate change impacts. Certainly, climate change forces the crop growers to expand farming activities by encroaching forest ecosystems broadly. Similarly, forest disturbances are acerbated by the increasing number of livestock along Tanzania coastal zone just like many other coastal zones globally [5].

Forest disturbances have impacts on soil properties [11]. Previous studies show that deforestation results into soil degradation and loss of total nitrogen, organic carbon and phosphorus in the tropics [11]. Forest disturbances affect the properties of soils by causing loss of soil organic matter due to imbalance between materials entering and those leaving the ecosystem [12]. Disturbances affect the interplay between inputs to soil organic matter by increasing or lowering decomposition of above-and belowground plant litter and animal excreta [13]. Indeed, disturbance affects outputs from soil organic matter pools by accelerating mineralization and leaching of nutrients [13]. However, research to establish the status of the coastal soil nutrient in Tanzania is lacking like in many tropical countries [1,2]. Specifically, there is deficit on the comparative research about the status and variations of soil nutrients across crop-agriculture, livestock grazing and intact forest sites along the coastal forest ecosystems. Hence, we conducted this study to address this deficit by establishing baseline information, which is crucial in the management of coastal forests [14]. Therefore, addressing the interplays between soil nutrients and vegetation in the disturbed and intact sites of coastal forests is important in forest small sub-sector. The information on the status of soil health under crop-agriculture and livestock grazing disturbances is important on the management of tropical coastal forests. We conducted this study to test the following two hypotheses. (i) Closed forest sites have higher content of carbon, total nitrogen and phosphorus than crop-agriculture and livestock disturbed sites at 5% level of significance. The following question guided this research. How do total carbon, total nitrogen and phosphorus differ in closed forest sites from agriculture and livestock disturbed sites?

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study was conducted at Uzigua Forest Reserve (UFR), which is found in Mbwewe Ward in Bagamoyo District, in Pwani Region in the coast of Tanzania mainland (Fig. 1). The forest covers an area of about 24,730 ha [6]. This forest is within 100 km of the coast of Indian Ocean and thus is considered a coastal forest [15]. The Uzigua forest is supposed to be completely restricted from human use, serving for catchment and biodiversity conservation [6]. Unfortunately, this forest is overexploited by anthropogenic activities such as collection of fuel-woods, fodder, grazing pressure and encroachments for agriculture. These activities put UFR into among a few remaining coastal forests of Tanzania that are in danger of being highly exploited.

The UFR is located in the tropical and sub humid area with 700 mm to 1000 mm rainfall, with the temperature fluctuating within the annual mean of 24.3°C. The soils are well-drained, red, sand clay, loamy with brown friable top soils covered by more or less decomposed litter. The area is progressing with continuous hills ranging between 300 to 600 meters above the sea level. This altitudinal range crated a wide range for coastal forests to harbor high diversity of forest trees species [16]. However, the current climate change and human activities along the coast have greatly influenced temperature, rainfall, and the distribution pattern of plant species and their composition at large [17].

2.2 Sampling Design

A systematic sampling design was used in this study. To cover a representative sample of forested blocks and disturbed sites in UFR, the stratification approach was adopted from [6,18]. A comparison between impacts of disturbances on soils was studied under each site subjected to different land uses (LU). For comparing impacts of disturbance on soils chemistry, 47 random plots were established in the three major LU (i.e., closed forests (CFS) crop-agriculture (ADS) and livestock disturbed sites (DGS).

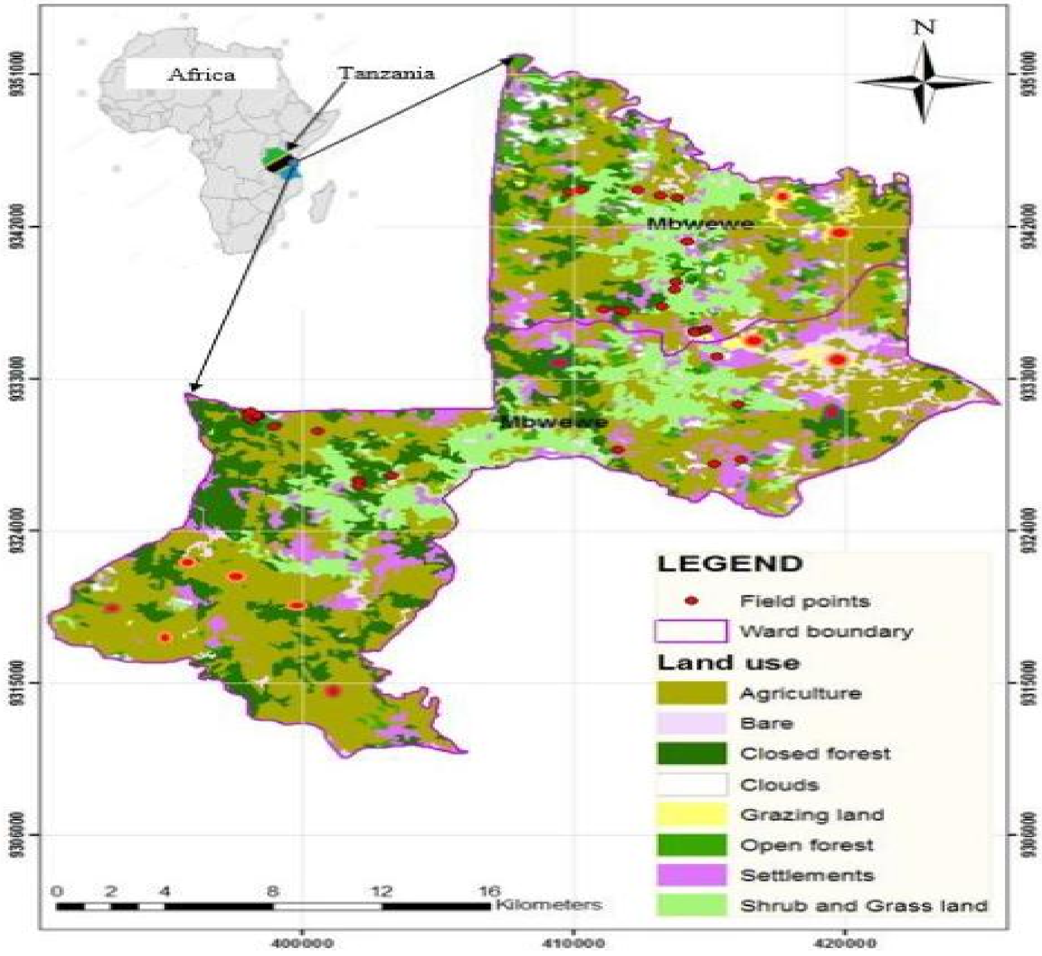


Fig. 1. A map of study area [19]

2.3 Sample Collection

Prior to intensive field data collection, reconnaissance surveys were conducted to get geographical coordinates, which were used to produce stratified different LU. We used satellite image interpretation to identify areas for ground study [20]. The LU classes were identified and developed by checking on the images and corresponding mean layer values, and normalized difference vegetation index (NDVI). The NDVI was used in LU classification together with a support of vector machine classifier for processing images. The closed forest, agriculture and grazing lands were classified from mean layers. Site selection was conducted based on patterns of human activities (crop-agriculture and grazing) as supported by the maps. Conspicuous land-cover changes because of deforestation, agriculture and grazing were considered as the main criteria to obtain ADS and DGS for collection of soil samples [21].

2.4 Soil Sampling

Soil survey and sampling were conducted from May to August 2016 at UFR sites. The soil sampling sites were based on the classified land use and management characteristics (i.e., closed sites, disturbed by crop-agriculture and livestock grazing sites). From each of the three strata (CFS, ADS, DGS), soil samples were collected using an Edelman auger at 1-30 cm (topsoil) [22,23,24]. The soil samples in each quadrat were then mixed together to make one composite sample to eliminate variability. One hundred and forty one (141) soil samples were collected (47 soil samples at each LU) drawn at 50 m × 50 m sampling plots, which were stratified and purposively selected. Representative samples put into tightened double plastic bags, labeled and stored at 4°C to reduce further microbial degradation. Fresh air dry and oven dry weights were determined before subjecting soil samples to further laboratory analysis.

2.5 Soil Sample Analysis

Soil total nitrogen (TN), total carbon (TC) and phosphorus (P) were analyzed by following the standard protocols for soil analysis as follows: (i) Determination of TN was done following the Kjeldahl acid-digestion procedures [25], (ii) Soil TC was analyzed by the Walkley-Black Procedures where by Potassium Dichromate ($K_2Cr_2O_2$) and concentrated Sulphuric acid (H_2SO_4) were used to produce the reaction and products as shown in the following chemical reaction [26].

$$2Cr_2O_7^{2-} + 3C^0 + 16H^+ \rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O \ldots\ldots\ldots \quad (1)$$

In computing the results, a correction factor of 1.33 applied to adjust the organic carbon recovery because of incomplete oxidation in Walkley-Black combustion procedures. (iii) Available phosphorus was determined by the Bray-II method [27]. The Statistical Package for Social Sciences (SPSS) version 20.0 was used together with MS-Excel computer program to run statistical analysis for getting mean and t-values at 5% significance level for TN, TC, and P between and across CFS, ADS and DGS.

3. RESULTS

For comparing the differences between and across closed forests, agriculture and livestock disturbed sites; the following consistence was maintained in the presentation of results. The mean and t-values were kept constant in the order of TN (CFS vs. ADS), TN (CFS vs. DGS), and TN (ADS vs. DGS); TC (CFS vs. ADS), TC (CFS vs. DGS), TC (ADS vs. DGS); P (CFS vs. ADS), P (CFS vs. DGS) and P (ADS vs. DGS) for total nitrogen, carbon and available phosphorus consecutively.

3.1 Variation of Total Nitrogen across Land Uses

The total nitrogen variation between CFS vs. ADS was $t = 11.66$, $p < .001$. There was a significance difference (%) of TN in CFS and ADS from 13.07 ± 0.34 to 11.75 ± 0.25, a difference of 1.32 ± 0.11; TN variation in CFS vs. DGS was: $t = 2.21$, $p < .032$, with a mean difference from 13.07 ± 0.34 to 12.57 ± 0.20, a variation of 0.50 ± 0.23; TN in ADS and DGS showed a variation of $t = 5.34$, $p < .001$, with mean difference from 11.75 ± 0.25 to 12.57 ± 0.20, i.e. 0.82 ± 0.15. TN-variation between ADS and DGS showed that TN in DGS is higher than in ADS.

3.2 Variation of Total Carbon across Land Uses

The total carbon difference between CFS vs. ADS was: $t = 11.80$, $p < .001$. There was significant difference (%) of TC from CFS to ADS (i.e. 14.48 ± 0.23 to 11.81 ± 0.13), a difference of 2.67 ± 0.23; the difference of TC between CFS vs. DGS was: t = 7.66, p < .001 with the mean values differing from 14.48 ± 0.23 to 12.24 ± 0.30, a significant difference of 2.24 ± 0.29, and TC in ADS vs. DGS was: t = 2.18, p < .035 and the mean difference was 11.81 ± 0.13 to 12.24 ± 0.30, showing a variation of 0.43 ± 0.19. This variation shows that there was less TC in ADS than in DGS.

3.3 Variation of Available Phosphorus across Land Uses

The available phosphorus variation between CFS vs. ADS was: t = 24.78, p <.001. There was a significant difference of the available phosphorus between these two LU from 13.12 ± 6.57 to 11.97 ± 6.96, a variation of 1.15 ± 0.93; variation of the available P between CFS vs. DGS was: t = 4.04, p < .001, with the mean difference from 13.12 ± 6.57 to 10.12 ± 2.86, a difference of 3.00 ± 1.56 and variation in the available phosphorus between ADS vs. DGS was: t = 1.54, p < .131, with a mean difference from 11.97 ± 6.96 to 10.12 ± 2.86, and a difference of 1.85 ± 01.10.

3.4 Carbon-Nitrogen Ratio across Land Uses

Carbon-nitrogen ratio variation between CFS vs. ADS was: t = 3.97, p < .001. There was a significant difference of CN ratio between these two LU i.e. from 8.62 ± 2.84 to 9.88 ± 2.91, a difference of 1.26 ± 2.77; variation of CN ratio between CFS vs. DGS was: t = 2.33, p < 0.02, with the mean difference from 8.62 ± 2.84 to 6.53 ± 2.06, a difference of 2.09 ± 0.57, and variation in CN ratio between ADS vs. DGS was: t = 2.94, p < .001, with a mean difference from 9.88 ± 2.91 to 6.53 ± 2.06, a difference of 3.35 ± 1.39.

3.5 Variation of TN, TC and P against Elevation

Between 300-390 m elevations, differences in each nutrient (percentage) were TN in ADS > CFS >DGS; TC was in the order of CFS > DGS > ADS, while P was in the order of CFS > ADS > DGS. Between 391 to 447 m, TN was in DGS > ADS >CFS; TC was recorded in CFS > DGS > ADS; while P was in CFS > ADS > DGS orderly. At the elevation of 448-500 m, TN was DGS > ADS > CFS; TC order was TFS > ADS > DGS; P was DGS > CFS > ADS. The results showed that, with the increase in elevation there is unit loss of nutrients (Fig. 2-1: a, b, c, d, e, f, g, h and i).

3.6 Correlation (R^2) of TN, TC and P within Land Uses

The correlation (p = .05) between TN, TC and P within LU were: (i) positive correlation between TN & TC in ADS (R^2 = 0.59); TN & TC in DGS (R^2 = 0.84); (ii) weak positive correlation between TN & TC in CFS (R^2 = 0.18); TN & P in CFS (R^2 = 0.14); TN & P in ADS (R^2 = 0.01); TN & P in DGS (R^2 = 0.12); TC & P in DGS (R^2 = 0.11; (iii) negative correlation between TC & P in CFS (R^2 = 0.07) and TC & P in ADS (R^2 = 0.17).

3.7 Correlation of TN, TC and P across Land Use

The correlation (p = .05) between TN, TC and P between LU showed both positive and negative relationships as follows: (i) strong positive correlation between TN in CFS and ADS (R^2 = 0.62), TN in CFS and DGS (R^2 = 0.96), TN in ADS and DGS (R^2 = 0.61), TC in ADS and DGS (R^2 = 0.97), P in CFS and ADS (R^2 = 0.98), (ii) weak positive correlation between TC in CFS and DGS (R^2 = 0.09), TC in CFS and DGS (R^2 = 0.15), (iii) weak negative correlation between P in CFS and ADS (R^2 = 0.14) and P in ADS and DGS (R^2 = 0.18).

4. DISCUSSION

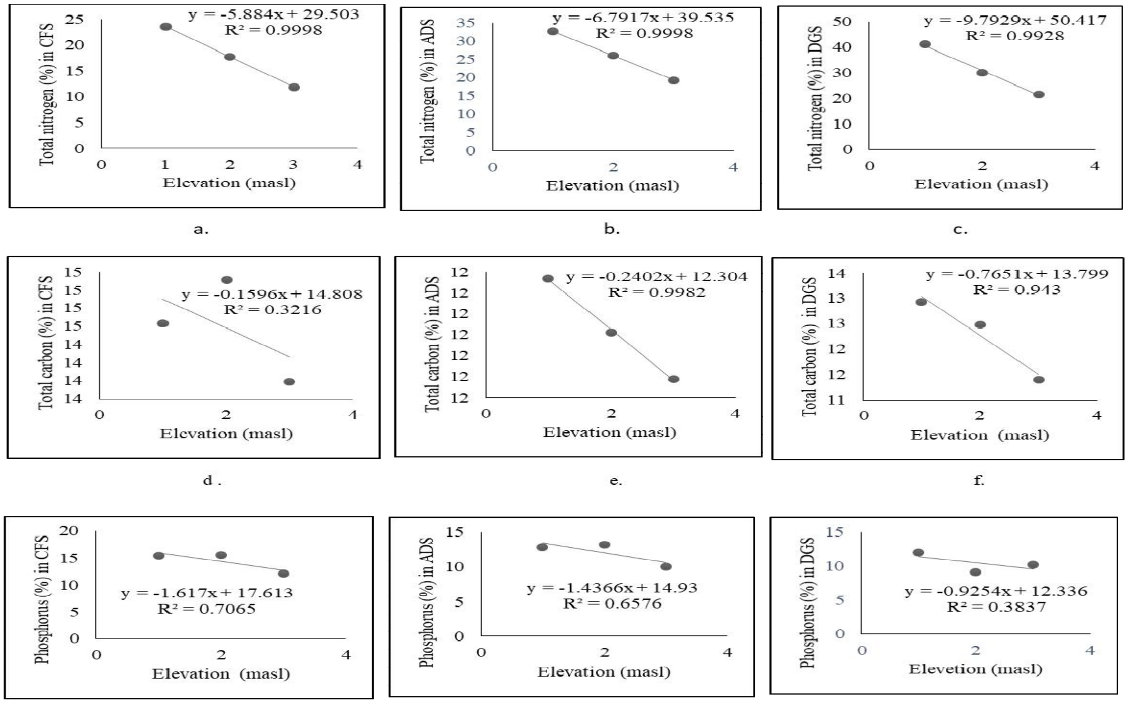
This discussion is presented on the basis that this work had some challenges emanating on the lack of baseline data about TN, TC and P status along the coastal zone of Tanzania. Hence, the discussion mainly focuses on the existing differences of soil nutrients and identifying the possible causes of variation under the hypothesis that disturbance type and the associated cumulative severity affect the distribution and structure of forest vegetation and soil properties [28]. To establish the variation, we based our discussion on closed forest sites as our control for comparison with the disturbed sites. Indeed, our findings suggest that disturbances cause impacts on above-ground and under-ground forest ecosystems hence resulting in differences in nutrients across different land uses [6,29].

4.1 Variation of Total Nitrogen across Land Uses

Forests subjected to crop-agriculture and livestock grazing have different TN status. Closed forest sites contain a higher amount of TN than that found in ADS or DGS. It is explained that both crop-agriculture and livestock grazing contribute in making the soil susceptible to erosion and hence loss of nutrients [13]. Indeed, the impacts are not the same between agriculture and livestock disturbed sites [13,30,31]. That is why, DGS had the lowest amount of TN across all the three LU as supported by [30,31].

The findings suggest that disturbance reduces nitrogen mineralization, a process occurring in DGS and ADS than CFS because there is low moisture content following the fact that disturbances affect vegetation and thus the land is exposed to solar radiation [32]. These findings agree with other research works that low TN content in DGS (for example), is because livestock grazing decreases the input of organic matter and exposes litter to photo-degradation [32,33,34]. Therefore, we establish that photo-degradation causes excessive loss of N from DGS than in ADS (Golluscio et al. 2009). However, this low content of TN in DGS is contrary to findings by Britton, Pearce and Jones [35,36]. This controversial observation is that, we expected DGS to contain higher amount of TN because of inputs from livestock excreta mainly urine [37] but now in this current study it has been reflected to be differently.

From our results, it seems that a small amount of N inputs from excreta does not make up for the amount lost because of disturbed biomass. Low return of N from grazing animals is explained in part by the fact that that livestock grazing in these forest sites is mainly a free-range system, under which animals are randomly grazed. As a result, there is no guarantee of the return of nutrients from excreta in a particular piece of grazed land. The low amount of TN in DGS as compared to that in ADS is explained by the fact that, while grazing sites are left bare, cultivated farms have the advantage of harboring plant species (crops and weeds) that check soil erosion and photo-degradation. In addition, there is partial recycling of nutrients from crop residues and weed decomposition. Therefore, it is reasonable for DGS to contain relatively low amount of TN as compared to ADS and CFS [31].



a. b. c.

d . e. f.

g. h. i

Fig. 2. Correlation between nutrients levels (%) and elevation (masl×10^2) (a = TN in CFS vs. elevation, b = TN in ADS vs. Elevation, c = TN in DGS vs. Elevation, d = TC in CFS vs. Elevation, e = TC in ADS vs. Elevation, f = TC in DGS vs. Elevation, g = P in CFS vs. Elevation, h = P in ADS vs. Elevation and i = P in DGS vs. Elevation

4.2 Variation of Total Carbon across Land Uses

Grazing within coastal forest ecosystems is randomly done, so the current grazing system does not provide redistribution of carbon and rapid increase in soil TC is also reported in [38]. The low amount of TC in ADS and DGS proves that most degraded and depleted soils of agro-ecosystems contain lower soil organic carbon pool than those under natural ecosystems, as is supported by Lal [39]. The low amount of TC in ADS as compared to that in any of the other LU sites indicates that farming activities are responsible for soil carbon reduction which is supported by Syswerda et al. [40] and Kane [38]. In this view, farming accelerates soil heterotrophic activity and typically leads to carbon loss [40]. Indeed it is possible that low amount of carbon in ADS and DGS is limited by nutrients, predominantly nitrogen and phosphorus in addition to other environmental constraints [41].

Carbon depletion in the degraded coastal forest as represented by the Uzigua ecosystem is contributed by clearing and burning vegetation for farm preparation. It reported that farming in this way has been a common practice for over 50 years since independence in 1960s. During all these years, crop production had been characterized by conversion of forest into agricultural land without addition of mineral fertilizer or manure, so the natural nutrients pool is depleted [39]. Although DGS showed a high amount of TC, yet it is below to that found in CFS. This implies that grazing practices accelerated forest cover loss and hence affected carbon sinks above and below the ground [40]. The effect of livestock grazing in soil TC storage shows that herbivores may facilitate or depress TC deposition rates as compared to crop-agriculture and closed forests [33]. The impacts of livestock grazing in TC show that there is an indirect relationship between animal grazing activities above the ground and underground ecosystems [42]. This relationship is explained by the difference in values of TC between CFS and DGS [13,35,36].

4.3 Variation of Phosphorus across Land Uses

The available phosphorus is among the important nutrients in any ecosystem as it plays roles in driving cellular energy cycles and building the molecules of DNA and RNA in plants [43]. The difference for P across CFS, ADS and DGS implies that ecosystem disturbances cause positive or negative impacts on the availability of this nutrient [44]. The results showed low content of P in ADS and DGS, which is explained by the fact that conversion of forest land into ADS and DGS reduces the amount of P because of the exposure of bare land to processes of soil runoff, erosion and percolation [43]. However, [45,46] and [42] challenge the establishment of P decline in the livestock disturbed sites. This literature shows that livestock grazing supplements P by excretion and egestion processes contrary to our results. Therefore, our findings suggest that coastal forest disturbances affect the above ground biomass and hence lower the amount of P in soils supporting the findings of [36].

4.4 Carbon-Nitrogen Ratio across Land Uses

Carbon-nitrogen ratio, as an important factor for determination of the capability of soil and storage of carbon varied from CFS to ADS and DGS in our study of UFR; this finding is the same to a study by Swangjang [47]. The variation in CN ratio is important in forest ecosystem health because carbon plays an important role in the energy content (carbohydrate) of plant species and production of CO_2 in soil ecosystem, and nitrogen is essential for plant growth [48]. This ratio plays a significant role in regulating soil organic matter mineralization [47]. Thus, this ratio has implications in soil fertility. The findings showed that soil CN ratio in the coastal forest decreased in the order CFS > ADS > DGS, possibly reflecting a higher degree of breakdown of humus stored in ADS and DGS as compared to CFS [49]. However, these results contradict the trend in the CN ratio discovered by Zhang et al. [50]. Our results portray that as breakdown of organic matter proceeds, those easily decomposed materials disappear and nitrogen possibly get immobilized in microbial biomass and decay products supporting some findings in Kennedy et al. [49]. The process of breakdown and immobilization leaves behind more recalcitrant material characterized by slower decomposition rate because only a few microorganism such as fungi can break these materials [50]. These processes lower the CN ratio in ADS and DGS than in CFS. The low CN ratio influences TN dynamics as it causes faster decomposition of organic matter and mineralization of nitrogen by microorganisms [45]. From our findings, it can be understood that the impacts of converting land from native forests to ADS and DGS have contributed to affect microbial activities. As a result, forest disturbances are considered to degrade the rate of organic matter, which is the main source of nutriments in soils [50].

4.5 The Variation of TN, TC and P across Land Uses

The differences in soil TN, TC and P across CFS, ADS and P as presented in this study generally indicate that activities such as crop-agriculture and livestock grazing contribute to different alteration of nutrients depending on the differences in LU. Lower amounts of TN and TC were found in ADS and DGS as compared to CFS; this agrees with the findings in Groppo et al [45]. However, the trend of P was contrary to Groppo et al. [45]. In our study, these three nutrients declined from CFS to ADS and DGS. Based on this trend, it is evident that anthropogenic activities have a major contribution in the variation of nutrient pools in forest ecosystems as supported by the findings in Bai et al [36]. Agriculture and livestock grazing activities affect the health status of soils by altering vegetation cover and the physical properties of soil [51].

Lower content of the three nutrients in ADS and DGS across the study sites is an indication that disturbed soils contained little organic matter because of inadequate vegetation life in the past years, which leads to a lack of humus and therefore low nutrient content [52]. The differences in nutrients status between ADS and DGS show that, although all disturbances cause impacts in soil properties, there are some degrees of variation between the category of disturbances and any particular nutrient. For example, across all the nutrient states, DGS has the least amount of any of the nutrients except TC, which was higher than that in ADS. The difference in nutrients status across is used to explain that any conversion of natural forest lands to artificial LU results into loss of nutrients such as TN and TC [50].

4.6 Correlation of TN, TC and P across Land Uses

We found a positive correlation between soil TN and TC in this study. This correlation was significant especially in ADS and DGS than in other land uses. Correlationally, this relationship shows that TN variation goes hand in hand with TC spatially and quantitatively as supported by Groppo et al. [45]. These findings suggest that there are some degrees of TN decline in the same direction of TC in disturbed forest sites. These observations agree with the existing documentations that loss of vegetation because of human activities such agriculture and livestock grazing affects bulk density, hence the decomposition organic matter and mineralization of soils nutrients are effected too [13,36].

In addition, such effects have contributed to the nature of variation of correlations, which were found in ADS and DGS in this study. We observed weak positive correlation between TN and TC in CFS, TN and P in CFS, TN and P in ADS, TN and P in DGS, and TC and P in DGS. These kinds of relationships show that variations existing between these elements in these land uses are partially independent. Weak to negative correlation between either TN and P or TC in CFS and ADS shows that TN or TC do not increase or decrease to the same direction as supported by a study by Bai et al. (2012). However, the weak correlation in variables is contrary with Block et al. [44]. This controversy could emanate on different ecological systems with differing climatic conditions such as temperatures and rainfall, which could affect TN, TC and P mineralization differently [44].

In this article it is established that the variation of nutrients across land uses provides useful information that clearing vegetation for various human activities contributes to physical losses of organic compounds from leaching and other processes that may alter the nutrient content of litter and returns to the soil and plants uptakes [53]. The assumption that the loss of vegetation above the ground influences soil fertility status is also supported by Xuluc-Tolosaa et al. [54] as leaf litter above the ground is the main input of nutrients to the soil. Indeed, the amount of plant available nutrients affects natural and managed ecosystems largely [53]. Therefore, processes that disturb vegetation can also have a significant effect on nutrient cycles and nutrient limitation [41].

5. CONCLUSION

We conclude that the comparison of soil nutrients between closed forests, agriculture and livestock disturbed sites of Uzigua Forest Reserve indicated that there are significant degrees of variations in TN, TC and P content across different forms of land use. However, these differences were not directly defined as caused by human activities; the findings gave useful information to establish the relationships between nutrient status of intact coastal forests from the crop and livestock grazing disturbances. The study suggests that if crop-agriculture and livestock grazing are to be integral part of coastal forest management, further studies are needed to devise crop-agriculture systems and grazing stocking rates that will sustain coastal forests. These activities should take place within limits, for example to take advantage of nutrient cycling between grazed animals, crop residues and forest ecosystems. Nevertheless, the detection of total nitrogen by Kjeldahl method has some limitations acknowledged in this work. By using Kjeldahl, we were unable to detect oximes, nitriles, nitrite or nitrate that might have slightly affected total nitrogen across different land uses. Therefore, we suggest further studies to detect total nitrogen by using an oxygen combustion chamber followed by mass spectroscopy or auto-fluorescence after reaction with O_3.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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