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Soil Organic Carbon (SOC) Dynamics in Relation to Human Induced Land Use Practices in Lenca Forest, Toke Kutaye District, West Showa, Ethiopia

P. Sekhar
Associate Professor, Environmental science division, Biology Department, College of Natural & computational sciences, Ambo University

Abstract: Soil organic potential and its dynamics in relation to anthropogenic activities were studied in Lenca forest, Toke kutaye district, West showa, Ethiopia and results have shown a direct relation between these two parameters. From ***the results, it was observed that carbon sequestration potential varied among different soils. Highest proportion of carbon sequestration was found in forest soils (612.89 t CO2/ha) followed by soils of tef crop (482.89 t CO2/ha). The results have indicated that soil organic carbon has increased with increasing depth irrespective of land use type but with regard to bulk density, there is no much significant variation with increasing depth in case of forest and open lands. From the results it was clear that a strong positive correlation was observed between soil organic carbon, cation exchange capacity, pH, soil moisture and nitrogen. A negative correlation was observed between bulk density, and other soil parameters of interest. The carbon stock in the present study was found to be forest soils (167.04-349.04 tonnes C/ha) followed by soils of tef crop to an extent of 131.58-375.84 tonnes C/ha. Open land carbon stock was observed to be between 111.36 to 306.93 tonnes C/ha.***

Keywords: Carbon sequestration, Carbon sequestration, Carbon stock, Lenca forest

I. INTRODCUTION

Soil is also the major terrestrial pool of soil organic carbon (SOC) due to its carbon storage potential which is generally greater than that of vegetation (Post and Kwon, 2000). SOC content plays a crucial role in sustaining soil quality, crop production, and environmental quality due to their effects on soil physical, chemical, and biological properties. The type of land use system is an important factor that controls SOC levels. Changes of land use and management practices influence the amount and rate of soil organic carbon losses (Guggenberger et al., 1995). Many research results have confirmed that soil organic carbon associated with different land uses varies dramatically at the regional or catchment scale (Jaiarree et al., 2011). Land use can reflect differences in regional scale SOC spatial distribution, expressing its dominant influence at the hillside and catchment level. Restoration of soil quality through soil organic carbon (SOC) management has remained the major concern for tropical soils. To make this programme successful, the comprehensive knowledge on SOC stocks forms an essential prerequisite in future land resource management programmed.

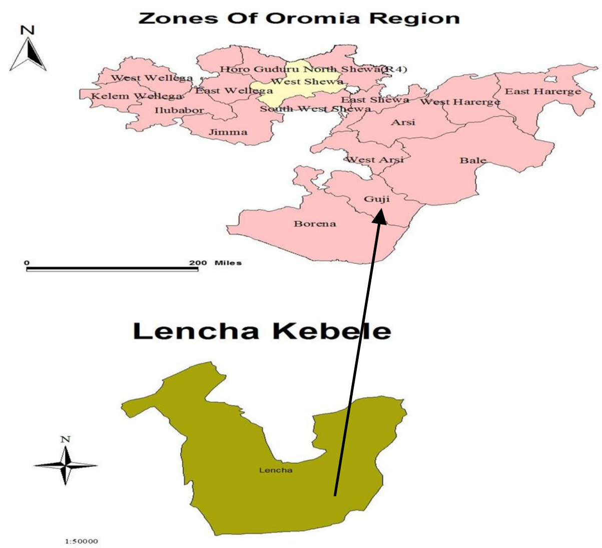
Land degradation in Ethiopia has contributed to the decline in agricultural productivity, persistent food insecurity, and rural poverty (World Bank, 2008). Soil loss, nutrient depletion and decline in soil quality are some of the manifestations of land degradation. The drastic effect of soil erosion on soil quality and soil organic carbon (SOC) is described by Lal (2004) as the effect of high SOC concentration in the top soil. Thus, the degradation of land in Ethiopia has resulted in the depletion of the carbon stock not only in biomass, but also in soils. With the intense focus on the increasing levels of atmospheric CO2 and the potential for global climate change, there is an urgent need to assess the feasibility of managing ecosystems to sequester and store more carbon.. Unlike in the developed countries, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Only small efforts have been made so far to assess the biomass and soil carbon sequestration potential at small scale level. Furthermore, the studies on the effects of environmental factors on the carbon stocks of forests are still lacking.

In Lenca forest toke Kutaye,West Showa, Ethiopia, there is a scarcity of studies addressing land use change dynamics and its effect on carbon pool. So this study assumes importance as the result of this study expected to add value to the up-to-date scientific documentation of the status of soil fertility and soil quality of different land uses of the study area and other similar agroecological environments in the country. And also this knowledge will help in formulation of strategies that will conserve SOC regional level and sustainably maintain the productivity of the study area.

II. MATERIALS AND METHODS

A. Study Site

The present study was carried out in Toke Kutaye wereda lenca forest area which covers 202 km^2. It is located about 136 km west of Addis Ababa, in West Showa zone lies between 8°16' – 9° 56' N latitude and 37 º 01' 38 º.



B. Site Selection

Sample sites were selected based on different land use practices being practiced in the study region. A total 5 types of land use practices such as natural forest land, agricultural with bean, wheat and tef crops and open/grazing land were selected for the present study for estimation of soil organic carbon and other parameters like bulk density, soil moisture content, pH ,soil texture, soil cation exchange capacity, and soil organic nitrogen.

C. Sample Collection

In order to investigate soil fertility status through the analysis of some physical soil properties, Representative, intact soil samples were collected with a manual core sampler of known volume and weight, from each land-use practice unit plot in X design in five replicates from three blocks. Thus, samples were collected from four corners of a square of 20 x 20 plots, with one from the center. The samples were separated into 0–10cm, 10–20cm and 20 - 30cm horizons. To determine the effect of different land uses on soil chemical properties, a total of 45 (5 land uses*3 soil depths*3 replicates) soil samples were taken. Then, the soil sample was taken from the pits by scuffing the wall of the soil profile for respective depth; the lowest first and the top soil at last to avoid contamination between the two layers. For each land use types and a soil samples, about 1kg of soil samples was taken. Then, the soil samples from each pit was bulked together to obtain composite soil samples for each replicates (the three blocks) in three depth interval and land use types. Soil clods in each composite sample was thoroughly broken to make a uniform mix, and then divided into four equal parts from which two diagonal parts was retained and the other two parts removed. This process was continued several times until the successive quartering reduced the weight of a composite sample to about 0.5 kg. Samples were air dried ground and passed through 2 mm sieve for analysis.

D. Soil Sample Preparation for Analysis

The collected soil samples were homogeneously mixed and left to attain equilibrium with air for 2 hours in the trays. For already dried soil samples, samples were directly used without keeping in the oven. For wet samples, samples were initially dried in the oven at 25^{o}C for 2 hours. After drying the soil, clods were crushed gently and grounded with the help of wooden pestle and mortar. Gravel, soft chalk, limestone, stones and concretions were removed from the samples. Then soils were passed through 2.0mm stainless steel sieve. The sufficient quantity of sieved soil sample was kept in plastic bag labeled with permanent ink marker for further analysis.

E. Determination Of Soil Parameters

1) Determination Of Organic Matter In Soil By Ash Method: Procedure

Mass of an empty, clean, and dry porcelain dish was measured and recorded (MP). Entire oven-dried test specimen from the moisture content experiment was placed in the porcelain dish and determined and recorded the mass of the dish and soil specimen (MPDS) and placed in muffle furnace. Gradually the temperature in the furnace increased to 440^{o}C and left the specimen in the furnace for overnight. After overnight, dish was removed carefully and allowed to cool to room temperature. The mass of the dish containing the ash (burned soil) was determined and recorded (MPA).

% Organic matter = % organic carbon x 1.724

%Total organic carbon = % organic carbon x 1.3 (Metson AT. 1961)

Determination of soil nitrogen (Wairiu and Lal, 2003)

Soil organic nitrogen was calculated using following equation:

Organic Nitrogen (%) = 0.0862 x % organic carbon

2) Estimation Of Soil Organic Carbon Stock (SOCS) And Total Nitrogen Stock (STN): Soil organic carbon and STN were converted to a mass basis per unit area following the formulae proposed by Wairiu and Lal (2003)

SOC (t ha-1) = soil organic carbon (%) x bulk density (g/cm-3) x depth of soil taken (cm)

STN (t ha-1) = N (%) x bulk density (g/cm-3) x depth of soil taken (cm)

3) Estimation Of Carbon Sequestration

Carbon sequestration was calculated by conversion factors of 3.67

Carbon sequestration = SOC stock × 3.67 (Ellert BH, et al. 1995)

Bulk density, soil moisture content and cation exchange capacity were determined by core sampler method, gravimetric method and ammonium acetate method respectively.

III. RESULTS AND DISCUSSIONS

Land use change and changes in soil fertility management often occur together resulting changes in soil quality including the activities of soil micro-organism (Halvorson et al., 2000). As a consequence, one would expect close relationships between land use change and soil nutrient contents (Kennedy et al., 1995).

TABLE I: Table showing soil texture types of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	SAND (%)	SILT (%)	CLAY (%)	SILT TO CLAY RATIO	TEXTURAL CLASS
1	NF	0-10	28.2	11.8	60	0.19	Clay
2	NF	10-20	18.2	24.05	57.75	0.41	Clay
3	NF	20-30	11.6	15	63.4	0.23	Clay
4	OL	0-10	18.2	22.7	59.1	0.38	Clay
5	OL	10-20	37.9	25.05	37.05	0.67	Clay loam
6	OL	20-30	15	22	63	0.34	Clay
7	AGR_{Bean}	0-10	7.5	20	72.5	0.27	Clay
8	AGR_{Bean}	10-20	12.5	22.5	65	0.34	Clay
9	AGR_{Bean}	20-30	14.1	23.4	62.5	0.37	Clay
10	AGR_{Wheat}	0-10	27.5	13	59.5	0.21	Clay
11	AGR_{Wheat}	10-20	30	26.6	43.4	0.61	Clay
12	AGR_{Wheat}	20-30	24.1	16.6	59.3	0.27	Clay
13	AGR_{Tef}	0-10	7.5	20	72.5	0.27	Clay
14	AGR_{Tef}	10-20	7.5	22.5	70	0.32	Clay
15	AGR_{Tef}	20-30	7.5	20	72.5	0.27	Clay

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

Texture of soils in the study site were depicted in table I and it indicated that all most all soils are dominated by clay type of soils irrespective of depth. In the present study, it was observed that the soils on which tef and bean are being cultivated registered high amount of clay at the tune of 70-72.5% and 62.5-72.5% respectively. Percent clay content in soils of forest (57.75-63.40%) and open lands (37.05-63.0%) was significantly higher than that of silt and sand contents. Percent clay content was significantly higher in soil collected from forest land (57.75-63.40%) than from open lands (37.05-63.0%). The percent clay content in the soils of bean crop was found to be in the range of 62.5-72.5%, in the soils of wheat crop it was found to be in the range of 43.4-59.5% whereas in the soils of tef crop the percent of clay content was found to be in the range of 70-72.5%. In the present study, it was observed that the soils on which tef and bean are being cultivated registered high amount of clay at the tune of 70-72.5% and 62.5-72.5% respectively when compared to forest land (57.75-63.4%) which is in excellent agreement with Achalu (2012) who reported higher clay content in cultivated land than the adjacent soils under grazing land and natural forest. Higher mean clay fraction recorded in the cultivated land attributed to the impacts of deforestation and farming practices (Chikezie *et al.*, 2009). Silt to clay ratio in the 0-10 cm depth for agricultural lands varied from 0.27, 0.21 and 0.27 for bean, wheat and tef crops respectively. While, Silt to clay ratio in the 10-20 cm depth was high in all types of land uses except for bean crops soils and varied from 0.41, 0.67 for soils of forest and open/grazing lands respectively. Whereas silt to clay ratio in the 10-20 cm depth for agricultural lands varied from 0.34, 0.61 and 0.32 for bean, wheat and tef crops respectively. Above findings are in good agreement with previous studies carried out by Lechisa Takele et al., (2014) in Gindeberet district, west showa zone, Ethiopia. High silt-clay ratio observed in the 10-20 cm soil depth of forest land (0.41) may be attributed to the deposition of plant materials (litter) which are still undergoing decomposition.

TABLE II: Table showing soil cation exchange capacity (CEC) of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	CEC (meq/100g soil)	REMARK
1	NF	0-10	65.92	Very high
2	NF	10-20	58.47	Very high
3	NF	20-30	51.98	Very high
4	OL	0-10	49.83	Very high
5	OL	10-20	47.85	Very high
6	OL	20-30	49.59	Very high
7	AGR_{Bean}	0-10	38.68	High
8	AGR_{Bean}	10-20	36.6	High
9	AGR_{Bean}	20-30	38.22	High
10	AGR_{Wheat}	0-10	38.85	High
11	AGR_{Wheat}	10-20	36.31	High
12	AGR_{Wheat}	20-30	35.72	High
13	AGR_{Tef}	0-10	41.82	High
14	AGR_{Tef}	10-20	38.08	High
15	AGR_{Tef}	20-30	25.08	High

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

In table II, cation exchange capacity of soils were represented, and highest cation exchange capacity was associated with forest soils (51.98 – 65.92 meq/100g soil) followed by open land soils (47.85-49.83 meq/100g soil). With respect to agricultural lands, the soils with bean crop, wheat crop and tef crop registered CEC values of 36.6-38.68 meq/100g soil, 35.72- 8.85, 25.08-41.82 meq/100g soil respectively. Cation exchange capacity was found to decreased with increasing depth irrespective the land use types. The change in CEC with increasing depth was more pronounced in natural forest, wheat and tef crop soils as evident from the above table. The variation in CEC along the depth gradient was very much insignificant in the soils of open land, bean crop. Above results are in excellent agreement with the findings by Gebeyaw (2007) who reported that mean value of CEC in soil of the three land cover types were 48.08, 37.87 and 31.48 (meq/100gm) for forest, grazing and deforested land, respectively. The relatively high CEC values was recorded, in forest land may attributed to the fact that soil in forest land accumulate high percent OC and has greater capacity to hold cations thereby resulted greater potential fertility in the soil.

TABLE III: Table showing soil bulk density of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	BULK DENSITY (gm/cm3)
1	NF	0-10	1.2
2	NF	10-20	1.2
3	NF	20-30	1.18
4	OL	0-10	1.2
5	OL	10-20	1.2
6	OL	20-30	1.26
7	AGR_{Bean}	0-10	1.29
8	AGR_{Bean}	10-20	1.278
9	AGR_{Bean}	20-30	1.26
10	AGR_{Wheat}	0-10	1.28
11	AGR_{Wheat}	10-20	1.3
12	AGR_{Wheat}	20-30	1.37
13	AGR_{Tef}	0-10	1.29
14	AGR_{Tef}	10-20	1.25
15	AGR_{Tef}	20-30	1.447

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

The results of bulk density of soils of study sites were given in table III. The bulk density of forest and open land was found to be in the range of 1.18-1.2 gm/cm3 and classified as clay type soils whereas the bulk density of agricultural soils was found to be in the range of 1.25 to 1.37 gm/cm3 and classified as silt loam type of soils. It was observed that, bulk density increased with increasing depth in case of agricultural soils like tef and wheat but decreased in the soils of bean crop. In the soils of tef crop, bulk density at 0-10 cm was found to be 1.29 g•cm−3 and it increased to 1.44 g•cm−3 at 20-30 cm depth. Similarly, the bulk density in wheat crop soils at 0-10 cm depth was found to 1.28 g•cm−3 whereas it was increased to 1.37 g•cm−3 at 2-30 cm depth. But in forest and open lands, the change in bulk density with depth was very much insignificant. The mean bulk density values at all depths were higher under agricultural lands like AGR_{Bean} (1.27 g•cm−3), AGR_{Wheat} (1.31 g•cm−3) and AGR_{Tef} (1.32 g•cm−3) than at the corresponding depths under forest land (1.18-1.2 g•cm−3), and open land (1.2-1.26 g•cm−3). In line with the present finding, Islam et al. (2007) reported lowest bulk density for soils taken from natural forest compared to other land uses like cultivated land and grazing land. This is possibly due to low organic matter inputs and moderate soil compaction under agricultural lands due to tillage (ploughing and puddling) and livestock trampling.

TABLE IV: Table showing soil moisture content of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	SOIL MOISTURE (%)
1	NF	0-10	26.74
2	NF	10-20	22.84
3	NF	20-30	16.05
4	OL	0-10	22.98
5	OL	10-20	21.7
6	OL	20-30	14.39
7	AGR_{Bean}	0-10	23.16
8	AGR_{Bean}	10-20	13.46
9	AGR_{Bean}	20-30	6.72
10	AGR_{Wheat}	0-10	16.54
11	AGR_{Wheat}	10-20	13.75
12	AGR_{Wheat}	20-30	6.12
13	AGR_{Tef}	0-10	11.63
14	AGR_{Tef}	10-20	9.39
15	AGR_{Tef}	20-30	3.2

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

Soil moisture content plays an important role in soil organic carbon levels and results of soil moisture of study sites were shown in table IV. It was clearly observed that the forest soils hold highest soil moisture (16.053-26.74%) content when compared to other types of soils. Open lands also registered appreciable amounts of soil moisture content (14.93-22.98%) but less than forest soils but greater than agricultural soils. Among agricultural soils, least moisture holding capacity was observed with tef crops (3.2-11.63%) and high moisture content was recorded in case of bean crop (6.72-23.16%). In general, there observed a decreasing soil moisture with increasing depth in all types of soils. From the results it was observed that the change in soil moisture content across the depths is very much significant. In natural forest lands, the soil moisture content at 0-10 cm depth was 26.74% and it was drastically decreased to 16.05% at 20-30 cm depth. In open land soils, the soil moisture content at 0-10 cm depth was 22.98% and it was decreased to 14.39% at 20-30 cm depth. In case of agricultural soils, the soil moisture content in bean, wheat and tef crops at 0-10 cm depth was found to be 23.16%, 16.54% and 11.63% respectively and at 20-30 cm depth, the moisture content was found to be decreased at the tune of 6.72%, 6.12% and 3.2% in bean, wheat and tef crops respectively. The soil of forest land with highest moisture content might be due to accumulation of absorbent humus on the soil surface, the water infiltration capacity of undisturbed forest soils due to significantly reduction of volume, velocity, and erosive and leaching capacity of surface run-off by leaves and roots of trees.

TABLE V: Table showing soil pH of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	PH	REMARK
1	NF	0-10	6.1	slightly acidic
2	NF	10-20	6.2	slightly acidic
3	NF	20-30	6.1	slightly acidic
4	OL	0-10	5.2	strongly acidic
5	OL	10-20	5.3	moderately acidic
6	OL	20-30	5.3	moderately acidic
7	AGR_{Bean}	0-10	4.9	strongly acidic
8	AGR_{Bean}	10-20	5.1	strongly acidic
9	AGR_{Bean}	20-30	5.2	strongly acidic
10	AGR_{Wheat}	0-10	4.8	strongly acidic
11	AGR_{Wheat}	10-20	4.9	strongly acidic
12	AGR_{Wheat}	20-30	4.9	strongly acidic
13	AGR_{Tef}	0-10	5.3	moderately acidic
14	AGR_{Tef}	10-20	5.4	moderately acidic
15	AGR_{Tef}	20-30	5.4	moderately acidic

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

pH of soils in the study sites were given in table V and the forest soils were designated as slightly acidic in nature with pH values ranging from 6.1 to 6.2 across the depths. The soils with agricultural crops like bean and wheat were considered as strongly acidic in nature (4.8- .1) whereas the soils of open land and tef crop were found to be moderately acidic in nature (5.3-5.4). From the results it was observed that the change in pH along the depths is very minute. In all agricultural soils, pH was found to be increased with increasing depth. The lowest value of pH recorded in soils of cultivated lands might be due to the low organic carbon content and drainage of cations to streams by run-off. This result is in agreement with the study reported by Gebeyaw (2007) that the highest pH recorded in forest land than cultivated lands is due to cation drainage to streams in run- off generated from accelerated erosion. In another study conducted by (Lechisa Takele et al., (2014) shows that the pH value under forest land was found to be the highest followed by grazing land and cultivated land respectively which is in good agreement with the findings of the present study.

TABLE VI: Table showing soil organic matter of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	SOIL ORGANIC MATTER (%)	REMARK
1	NF	0-10	24	Very high
2	NF	10-20	17.6	Very high
3	NF	20-30	17	Very high
4	OL	0-10	16	Very high
5	OL	10-20	14.3	Very high
6	OL	20-30	14	Very high
7	AGR_{Bean}	0-10	12.6	Very high
8	AGR_{Bean}	10-20	12.6	Very high
9	AGR_{Bean}	20-30	12	Very high
10	AGR_{Wheat}	0-10	15	Very high
11	AGR_{Wheat}	10-20	15	Very high
12	AGR_{Wheat}	20-30	12.6	Very high
13	AGR_{Tef}	0-10	17.6	Very high
14	AGR_{Tef}	10-20	16.3	Very high
15	AGR_{Tef}	20-30	15	Very high

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

The results of soil organic matter content in different soils were represented in table VI. The results indicated that soil organic matter was highest in forest soils when compared to other soils. In forest soils, organic matter content at 0-10 cm depth was found to be 24%, while at 10-20cm and 20-30 cm it was found to be 17.6% and 17% respectively. The relatively large SOM density under forests lands could be due to high OC inputs, slow decomposition and deep rooting depth compared to open lands and agricultural lands. In open land soils, organic matter content was found to be 16%, 14.3% and 14% respectively. Among agricultural soils, highest organic matter content was found in tef crop soils at the tune of 17.6%, 16.3% and 15% at 0-10, 10-20, 20-30cm depths respectively. The organic matter content in wheat crop soils was 15%, 15%, 12.6% at 0-10, 10-20, 20-30cm depths respectively. In general, the organic matter content was found to be in decreasing order with increasing depth irrespective of land use types. The decreasing trend of SOM with an increase in soil depth was also reported by Abebe *et al.* (2006) in Borana rangeland and Abule *et al.* (2007) in the Middle Awash Valley of Ethiopia.

TABLE VII: Table showing quantitative composition of various soil organic components of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	% OF ORGANIC CARBON (SOC)	% OF TOTAL ORGANIC CARBON (TOC)	% OF ORGANIC MATTER (SOM)	REMARK
1	NF	0-10	13.92	31.2	24	Very High
2	NF	10-20	10.20	22.88	17.6	Very High
3	NF	20-30	9.86	22.1	17	Very High
4	OL	0-10	9.28	20.8	16	Very High
5	OL	10-20	8.29	18.59	14.3	Very High
6	OL	20-30	8.12	18.2	14	Very High
7	AGR_{Bean}	0-10	7.30	16.38	12.6	Very High
8	AGR_{Bean}	10-20	7.30	16.38	12.6	Very High
9	AGR_{Bean}	20-30	6.96	15.6	12	Very High
10	AGR_{Wheat}	0-10	8.70	19.5	15	Very High
11	AGR_{Wheat}	10-20	8.70	19.5	15	Very High
12	AGR_{Wheat}	20-30	7.30	16.38	12.6	Very High
13	AGR_{Tef}	0-10	10.20	22.88	17.6	Very High
14	AGR_{Tef}	10-20	9.45	21.19	16.3	Very High
15	AGR_{Tef}	20-30	8.70	19.5	15	Very High

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

Table VII represents various soil organic components of study sites. Based on the soil organic matter values, soil organic carbon values were obtained by dividing organic matter content by a factor of 1.724. Total organic carbon values were derived by multiplying organic carbon content by a factor of 1.3. From the above table it was evident that soils of present study sites are very rich in organic matter as all the sites were designated as 'Very high'. Total organic carbon in forest soils was found to be 31.2, 22.88 and 22.1% at 0-10, 10-20 and 20-30 cm depths respectively. Open land soils registered 20.8, 18.59 and 18.2% of total organic carbon at 0-10, 10-20 and 20-30 cm depths respectively. Mean total organic carbon in cultivated soils was found to be 15.99%, 18.46% and 21.19% in bean, wheat and tef crops respectively across all depths. Mean organic carbon across all depths in forest, open land, bean, wheat and tef soils was found to be 11.32%, 8.56%, 7.18%, 8.23% and 9.45% respectively.

TABLE VIII: Table showing organic nitrogen and C/N ratio of study sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	% OF ORGANIC CARBON (SOC)	% OF ORGANIC NITROGEN (N)	C/N RATIO
1	NF	0-10	13.92	1.19	11.69
2	NF	10-20	10.20	0.87	11.72
3	NF	20-30	9.86	0.84	11.73
4	OL	0-10	9.28	0.79	11.74
5	OL	10-20	8.29	0.71	11.67
6	OL	20-30	8.12	0.69	11.76
7	AGR_{Bean}	0-10	7.30	0.62	11.77
8	AGR_{Bean}	10-20	7.30	0.62	11.77
9	AGR_{Bean}	20-30	6.96	0.59	11.79
10	AGR_{Wheat}	0-10	8.70	0.74	11.75
11	AGR_{Wheat}	10-20	8.70	0.74	11.75
12	AGR_{Wheat}	20-30	7.30	0.62	11.77
13	AGR_{Tef}	0-10	10.20	0.87	11.72
14	AGR_{Tef}	10-20	9.45	0.81	11.66
15	AGR_{Tef}	20-30	8.70	0.74	11.75

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

The organic nitrogen content and C/N ratio in different soils were presented in the table VIII and organic nitrogen was considerably influenced by different land use types. The mean values of organic nitrogen at all three depths were 0.96%, 0.73% for soils of forest, open/grazing lands, respectively. The mean organic nitrogen at all three depths in cultivated lands like bean, wheat and tef were found to be 0.61%, 0.70% and 0.80% respectively. It was observed that the organic nitrogen content was decreased with increasing depth with all land use types. Data presented in table VII revealed that the organic nitrogen content of soils obtained from forest land (0.96%) was significantly higher than the organic nitrogen content in soils taken from cultivated (0.61%, 0.70% and 0.80%) and open/grazing lands (0.73%). The organic nitrogen content in open/grazing land (0.73%) was in turn significantly higher than that of cultivated lands like bean (0.61%) and wheat (0.70%) but found to be less compared to soils of tef crop (0.80%). In the present study, it was observed that all the soils were found to be fall under "High" category with respect to their nitrogen content according to IRD (2009). A study conducted by Gebeyehu at al., (2018) in koga watershed, C/N ratio of the soils ranges from 12.74 to 9.62 in grazing and forest lands respectively which can be due to the rapid loss of N in the former. In contrast to the above findings, C/N ratio in the present study did not show much variations at different sites. The present finding was in line with (Yihenew et al., 2013) who reported highest values of C/N contents under grazing land use in northwestern Ethiopian soils.

TABLE XI: Table showing soil organic carbon stocks of sample sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	% OF ORGANIC CARBON (SOC)	BULK DENSITY (gm/ cm3)	SOIL ORGANIC CARBON STOCK (T/ha)
1	NF	0-10	13.92	1.2	167.04
2	OL	0-10	9.28	1.2	111.36
3	AGR_{Bean}	0-10	7.30	1.29	87.6
4	AGR_{Wheat}	0-10	8.70	1.28	113.1
5	AGR_{Tef}	0-10	10.20	1.29	131.58
Mean organic carbon stock					122.13

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

Table IX shows soil organic stocks of study sites at 0-10 cm depth. For estimation of soils organic carbon stocks, percent soil organic carbon, bulk density and depth of soils at each depth were taken into consideration. As indicated in the table, the highest carbon stock was present in the forest soils (167.04 tonnes C/ha) followed by soils of tef crop to an extent of 131.58 tonnes C/ha. Open land carbon stock was observed to be between 111.36 tonnes C/ha whereas in bean and wheat crop soils the carbon stock was found to be in the range of 87.6 tonnes/ha and 113.1 tonnes C /ha respectively. The mean organic carbon stock in different land use soils was found to be 122.12 tonnes C /ha. The mean carbon stock in study area was found to be 122.13 t ha-1, which is comparable to reports from Menagasha Suba State Forest (133 and 26.99 t ha-1, respectively) (FAO, 2001) and selected church forests in Addis Ababa (122.85 and 25.97 t ha-1, respectively) (Lal R. 2007). However, the mean carbon stock value obtained in the present study was much higher than those reported for the global above ground carbon stock in tropical dry and wet forests ranged between 13.5-122.85 t ha-1 and 95-527.85 t ha- 1, respectively (MWR, 2008). Thus, the higher mean SOC stock is may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock and thus sequestered large amount of CO_2 contributing to the mitigation of global climate change.

TABLE X: Table showing soil organic nitrogen stock of sample sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	% OF NITROGEN	BULK DENSITY (gm/ cm3)	TOTAL NITROGEN STOCK (T/ha)
1	NF	0-10	1.19	1.2	14.28
2	OL	0-10	0.79	1.2	9.48
3	AGR_{Bean}	0-10	0.62	1.29	7.99
4	AGR_{Wheat}	0-10	0.74	1.28	9.47
5	AGR_{Tef}	0-10	0.87	1.29	11.22
	Mean organic nitrogen stock				10.48

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

Total organic nitrogen stock at 0-10 cm depth in study soils were presented in table X and results showed that total nitrogen stock in forest soils was found to be 14.28 T/ha. It was observed that total nitrogen stock in the soils of tef, wheat and bean were found to be 11.22, 9.47 and 7.99 T/ha respectively. Generally, the total nitrogen stock (TNS) followed the pattern of soil organic carbon (SOC) distribution in all the soils studied.

TABLE XI: Table showing soil properties of sample sites

S.NO.	SAMPLE SITE	DEPTH OF SOIL (cm)	% (SOC)	% (N)	CEC (meq/100g)	BD (gm/cm3)	PH	SMC (%)
1	NF	0-10	13.92	1.19	65.92	1.2	6.1	26.74
2	NF	10-20	10.20	0.87	58.47	1.2	6.2	22.84
3	NF	20-30	9.86	0.84	51.98	1.18	6.1	16.05
4	OL	0-10	9.28	0.79	49.83	1.2	5.2	22.98
5	OL	10-20	8.29	0.71	47.85	1.2	5.3	21.7
6	OL	20-30	8.12	0.69	49.59	1.26	5.3	14.39
7	AGR_{Bean}	0-10	7.30	0.62	38.68	1.29	4.9	23.16
8	AGR_{Bean}	10-20	7.30	0.62	36.6	1.278	5.1	13.46
9	AGR_{Bean}	20-30	6.96	0.59	38.22	1.26	5.2	6.72
10	AGR_{Wheat}	0-10	8.70	0.74	38.85	1.28	4.8	16.54
11	AGR_{Wheat}	10-20	8.70	0.74	36.31	1.3	4.9	13.75
12	AGR_{Wheat}	20-30	7.30	0.62	35.72	1.37	4.9	6.12
13	AGR_{Tef}	0-10	10.20	0.87	41.82	1.29	5.3	11.63
14	AGR_{Tef}	10-20	9.45	0.81	38.08	1.25	5.4	9.39
15	AGR_{Tef}	20-30	8.70	0.74	25.08	1.447	5.4	3.2

NF = Natural Forest., OL = Open land., AGRBe = Bean crop., AGRWh = Wheat crop., AGRTe = Tef crop

TABLE XII: Table showing descriptive statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
CEC	15	25.08	65.92	43.5333	10.34682
BD	15	1.18	1.44	1.2660	.07008
SMC	15	.00	26.74	13.7220	7.79536
PH	15	4.80	6.20	5.3400	.45324
N	15	.59	1.19	.7627	.15002
SOC	15	6.96	13.92	8.9520	1.74135
Valid N (listwise)	15				

Table XI & XII shows overall soil properties of study sites and results of analysis of descriptive statistics. The minimum and maximum values of soil organic carbon found to be 6.96 and 13.92% respectively with a mean value of 8.95%. Mean values of cation exchange capacity (CEC) of soils was found to be 43.53 with minimum and maximum values of 25.08 and 65.92 meq/100g soil respectively. In case of bulk density of study sites, lower end and higher end values found to be 1.18 and 1.45 g/cm3 respectively with a mean of 1.26 g/cm3. With regard to soil moisture content, there observed a significant difference between minimum and maximum values ranging from 3.20 to 26.74 %. Nitrogen values in the study sites registered a minimum value of 0.59 and a maximum value of 1.19% with a mean value of 0.762%. Maximum pH value was found in forest soils (6.2) whereas minimum soil pH was found in soils with wheat crop (4.80).

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TABLE XIII: Table showing analysis of correlation matrix

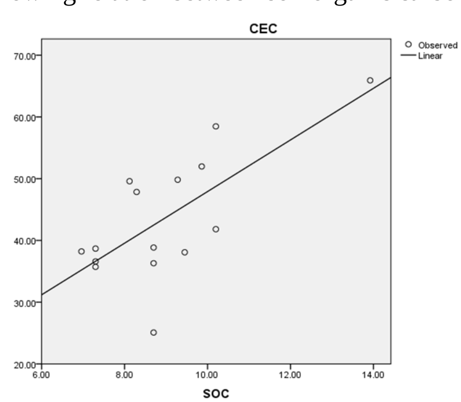
		CEC	BD	SMC	PH	N	SOC
CEC	Pearson Correlation	1	-.820**	.410	.721**	.703**	.704**
	Sig. (2-tailed)		.000	.129	.002	.003	.003
	N	15	15	15	15	15	15
BD	Pearson Correlation	-.820**	1	-.469	-.519*	-.413	-.411
	Sig. (2-tailed)	.000		.078	.048	.126	.129
	N	15	15	15	15	15	15
SMC	Pearson Correlation	.410	-.469	1	-.079	.292	.291
	Sig. (2-tailed)	.129	.078		.781	.291	.292
	N	15	15	15	15	15	15
PH	Pearson Correlation	.721**	-.519*	-.079	1	.715**	.714**
	Sig. (2-tailed)	.002	.048	.781		.003	.003
	N	15	15	15	15	15	15
N	Pearson Correlation	.703**	-.413	.292	.715**	1	1.000**
	Sig. (2-tailed)	.003	.126	.291	.003		.000
	N	15	15	15	15	15	15
SOC	Pearson Correlation	.704**	-.411	.291	.714**	1.000**	1
	Sig. (2-tailed)	.003	.129	.292	.003	.000	
	N	15	15	15	15	15	15

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

Table XIII represents analysis of correlation matrix and based on the analysis there observed a definite correlation among different soil parameters of interest. With regard to relation between soil organic carbon and cation exchange capacity of soils, there observed a strong positive correlation (0.704) and found to be highly significant (0.003) at 0.01 level (<0.01). The relation between soil organic carbon and nitrogen was found to highly significant (0.000 at 0.01 level) as indicated by pearson correlation (1.000) in the table. Cation exchange capacity and organic nitrogen values also showed a strong positive correlation (0.703) with high significance (0.003) at 0.01 level. Soil moisture registered a significant correlation with soil organic carbon (0.483) and CEC (0.780) at 0.05 and 0.01 levels respectively. From the above table it was clear that a strong positive correlation was observed between soil organic carbon, cation exchange capacity, pH, soil moisture and nitrogen. A negative correlation was observed between bulk density, and other soil parameters of interest. A negative correlation (-0.820) between bulk density and cation exchange capacity was found to be very significant (0.000) at 0.01 level. pH exhibited a strong positive correlation with CEC (0.721), Nitrogen (0.715) and organic carbon (0.714) with high levels of significance at 0.01 level.

IV. RELATIONSHIP BETWEEN SOIL ORGANIC CARBON AND OTHER SOIL PARAMETERS

Fig 1a : Linear regression plot showing relation between soil organic carbon and cation exchange capacity (CEC)



Model Summary and Parameter Estimates

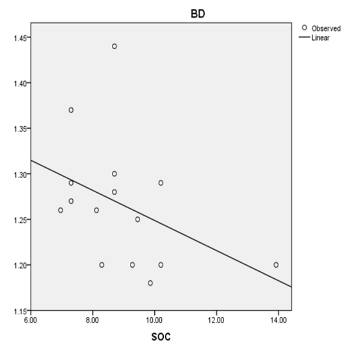
Dependent Variable: CEC

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.495	12.739	1	13	.003	6.113	4.180

The independent variable is SOC.

The relation between soil organic carbon (SOC) and cation exchange capacity (CEC) in the study sites was presented in Fig I, Fig Ia & Table Ia and there observed a marked correlation between these two parameters with respect to depth. It was observed that both soil organic carbon and cation exchange capacity decreased with increasing depth. Both of these parameters were found to be high in forest land and open land compared to cultivated lands. A strong positive relation was noticed between these two soil parameters (R square= 0.495; F=12.739; Significant = 0.003).

Fig IIa : Linear regression plot showing relation between soil organic carbon and cation exchange capacity



Model Summary and Parameter Estimates

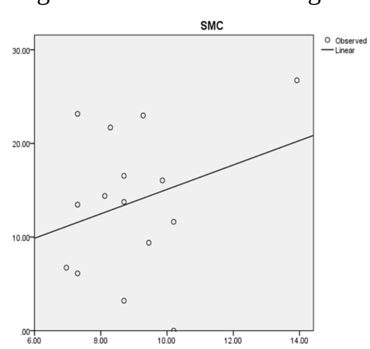
Dependent Variable: BD

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.169	2.635	1	13	.129	1.414	-.017

The independent variable is SOC.

Fig II, IIa & Table IIa shows the relation between soil organic carbon and bulk density. The results have indicated that soil organic carbon has increased with increasing depth irrespective of land use type but with regard to bulk density, there is no much significant variation with increasing depth in case of forest and open lands. From the regression analysis it was found that, there observed an inverse relation between these two parameters with less significance as indicated in the above table (R square=0.169; F=2.635; Significant= 0.129).

Fig IIIa : Linear regression plot showing relation between soil organic carbon and soil moisture content (SMC)



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Model Summary and Parameter Estimates

Dependent Variable: SMC

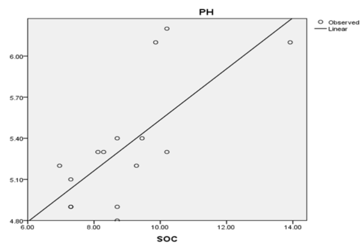
Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.085	1.206	1	13	.292	2.045	1.304

The independent variable is SOC.

Table IIIa : Table showing relation between soil organic carbon and soil moisture content (SMC)

The relation between soil organic carbon with that of soil moisture in different depths among different land use types in the study sites was depicted in Fig III, IIIa & IIIa. There observed a positive relation exits between soil organic carbon and soil moisture across various depths. Soil moisture was found to be decreased with increasing depth along with soil organic carbon. It is interesting to note that both soil organic carbon and soil moisture were high in forest land compared to cultivated lands. From the regression analysis it was observed that the relationship between soil organic carbon and soil moisture was not that much significant (R square= 0.085; F= 1.206; Significant= 0.292)

Fig IVa : Linear regression plot showing relation between soil organic carbon and pH



Model Summary and Parameter Estimates

Dependent Variable: PH

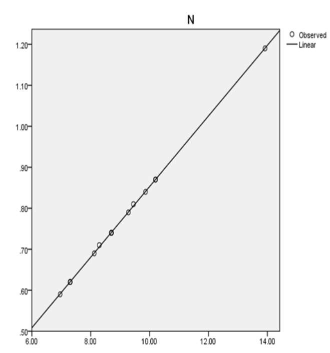
Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.510	13.550	1	13	.003	3.675	.186

The independent variable is SOC.

Table IVa : Table showing relation between soil organic carbon and soil pH

Fig IV, IVa & IVa represents relationship between soil organic carbon and pH in the study sites and it was noted that higher pH values were recorded with high soil organic carbon of forest soils and lower pH values were associated with cultivated lands whose organic carbon content is less when compared to forest soils. Based on the linear regression analysis, it was observed that there exists a significant positive relation between organic carbon and pH (R square= 0.510; F= 13.550; Significant= 0.003)

Fig Va : Linear regression plot showing relation between soil organic carbon and organic nitrogen



Model Summary and Parameter Estimates

Dependent Variable: N

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	1.000	88974.915	1	13	.000	-.009	.086

The independent variable is SOC.

Table Va: Table showing relation between soil organic carbon and soil organic nitrogen

Relationship between organic nitrogen and soil organic carbon was evaluated using linear regression plot and represented in Fig V, Va & Table Va and it was observed that there exists a strong positive relation between them. Along with soil organic carbon, nitrogen also found to be decreased with increasing depth in all study sites. From the regression analysis, there observed a very strong significant relation between organic carbon and nitrogen (R square= 1.000; F= 88974.915; Significant= 0.000).

FIG VI: Graph showing proportion of carbon sequestration in study sites

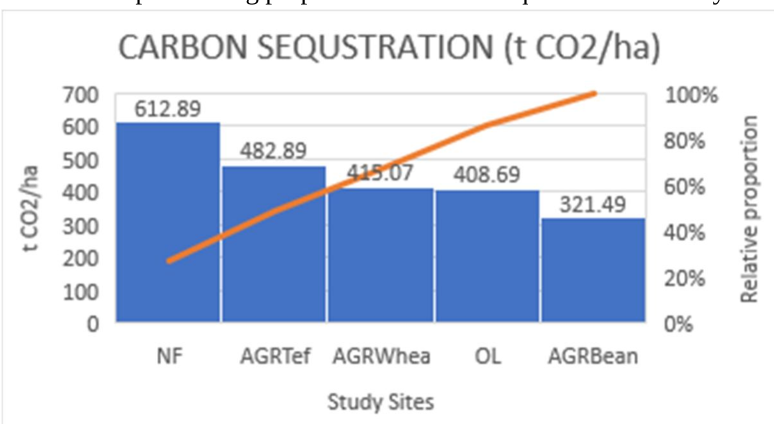


Fig VI shows histogram of carbon sequestration potential of different land use types of the present study. Results indicated that highest carbon sequestration observed in forest lands (612.89 t CO_2/ha) and least carbon sequestration potential was observed in soils with bean crop (321.49 t CO_2/ha). The soils of tef crop, wheat and open land registered carbon sequestration potential of 482.89, 415.07 and 408.69 t CO_2/ha respectively.

V. CONCLUSIONS

Based on above results it was concluded that considerable SOC sequestration potential exists in the study area. The highest potential exists in forest land and least carbon sequestration potential was observed in soils with bean crop. Considerable increases can be achieved by improved management practices in agricultural crops such as bean. Much of the rangelands are in degraded state and considerable SOC sequestration can be achieved for a small rate of sequestration per hectare. In addition, SOC can be sequestered by adopting new land conversion and soil amelioration options including bioenergy crops from perennial vegetation, recycling organics such as biochar, and by ameliorating sodic and acid soils.

The various sink options, opportunities and existing policy drivers and the barriers were discussed in way of recommendations. The promotion of conservation tillage practices (no-tillage) are important to halt further carbon emissions from cropping soils despite the limited potential of these practices to sequester carbon. Many of the management practices that are effective in increasing SOC in agricultural soils also improve productivity and profitability, conserve the resource base and protect the environment.

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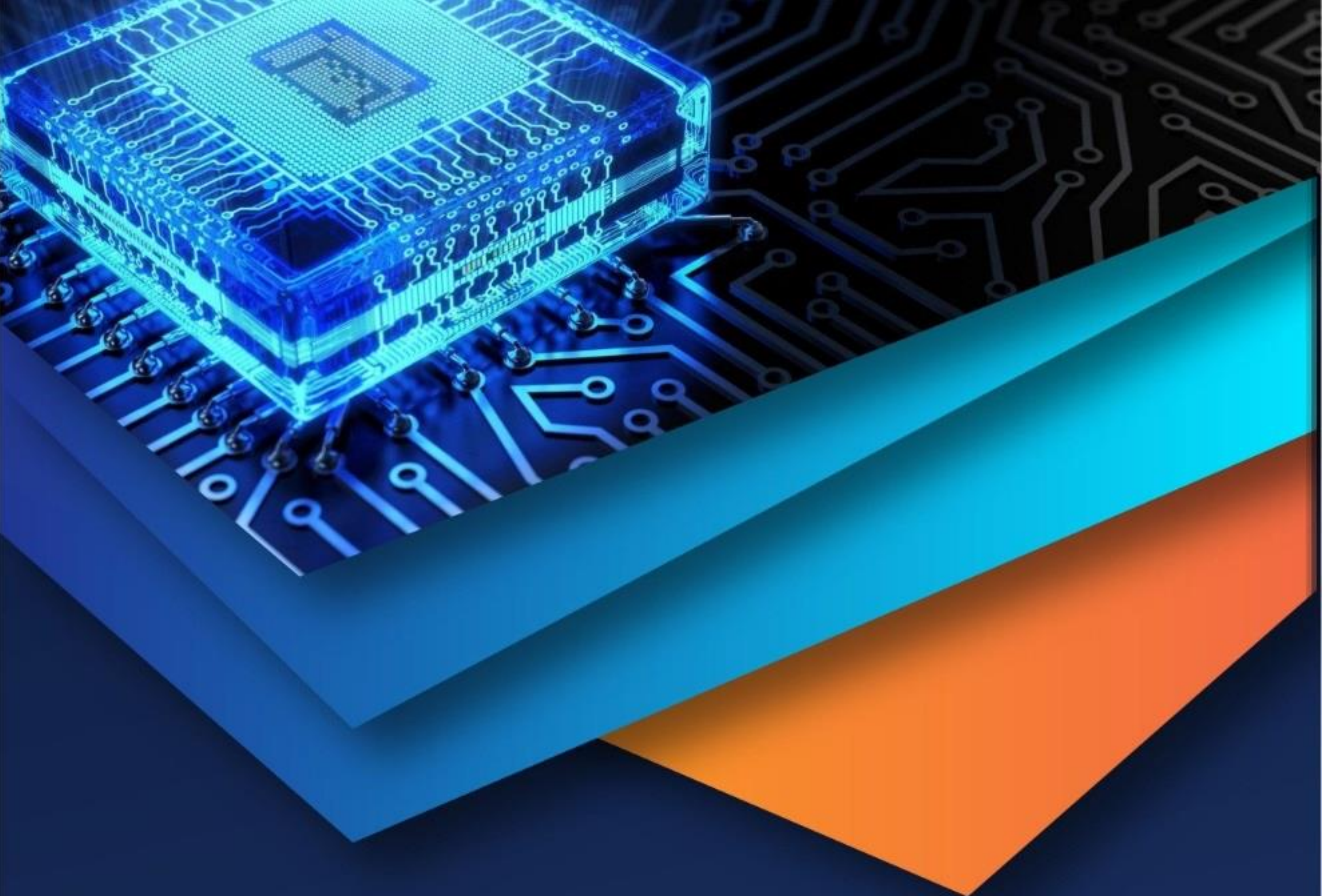

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