Gebeyehu and Soromessa *Agric & Food Secur (2018) 7:9*
https://doi.org/10.1186/s40066-018-0162-8

Agriculture & Food Security

RESEARCH

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Status of soil organic carbon and nitrogen stocks in Koga Watershed Area, Northwest Ethiopia

Getaneh Gebeyehu* and Teshome Soromessa

Abstract

Background: Soil organic carbon and nitrogen are key indicators to evaluate farmland management. Many studies of soil organic carbon (SOC) and total nitrogen (TN) in Ethiopia had focused on either rainfed or irrigated farming. A comparative study was meager and less understood on the variation of SOC and TN between farming systems. Thus, the objective of the study was to carry out comparative analysis on the status of SOC and TN stocks between farming systems. Thirty-six composited and cumulative soil samples had been collected from 25 m^2 plot designed at discrete intervals as 0–15 and 15–30 cm in both farming systems. Soil organic carbon and nitrogen were analyzed using Walkley and Black, and Kjeldahl method, respectively, and performed in Environmental Protection Authority (EPA) in Addis Ababa.

Results: The result showed that mean SOC stock increased by 2.85 t C ha^{-1} (3.44%) and total nitrogen stock by 0.12 t N ha^{-1} (1.99%) in irrigated compared to rainfed farming up to 30 cm soil layer. Similarly, soils of irrigation farming had sequestered at the rate of 0.41 t CO_2 ha^{-1} $year^{-1}$. One-way analysis of variance (ANOVA) revealed that SOC and nitrogen stocks did not show the significant difference between farming systems ($p < 0.05$) because of slow turnover of organic matter. However, SOC and TN stocks had shown significant variation along depth ($p < 0.05$). Problems of soil acidity were found in both farming systems, but 9.3% mean pH value of soils of irrigation showed lower acidity than rainfed farming.

Conclusion: The present study revealed that farming systems and soil depth had shown the variation in the spatial and vertical distribution of organic carbon and nitrogen stocks. Soils in irrigation farming system sequestered higher carbon and nitrogen and promise climate mitigation than the rainfed farming system.

Keywords: Land use, Organic carbon, Total nitrogen, Soil depth, Watershed

Background

Soils represent the largest active organic components including carbon and nitrogen in agricultural lands. A global study highlighted that 39–70 and 58–81% of the total organic carbon stored on 30 and 50 cm soil layer, respectively [1]. However, the presence of large soil carbon and nitrogen stocks and their sensitivity to land management practices correspond to a threat and an opportunity [2]. Management of soil carbon and nitrogen in agricultural lands such as crop residuals, conservation tillage, crop rotations, integrated nutrient management and efficient irrigation in proper ways play positive roles for soil fertility, maintaining soil and environmental quality [3]. This gives an opportunity to reduce erosion and increase organic matter in the soil surface and thus for climate change mitigation [4]. Carbon storage in agricultural land has produced worldwide interest because it provides potential benefits for improving agricultural soil fertility while concurrently addressing climate change mitigation and adaptation [4].

Many studies provided convincing evidence that large amounts of carbon and nitrogen have been lost in agricultural ecosystems through erosion on sloping lands,

*Correspondence: getanehgebeyehu@yahoo.com
Center for Environmental Science, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia

floods and accelerated soil respiration during tillage operation [5, 6]. These farming on slope lands, tillage operation, soil disturbances and removing of crop residuals can increase soil CO_2 emission and reduce soil organic carbon and nitrogen storage and consequently threats to crop productivity and environmental quality. Management practices through retention of crop residuals in the field, shift to zero tillage, crop rotations, integrated nutrient management and efficient irrigation improve soil organic carbon and nitrogen storage in agricultural lands [3].

Ethiopia has estimated 12 million hectares of farmlands where potential irrigation area corresponds to approximately 25% of farmland mass. However, Agricultural Transformation Agency (ATA) [7] reported that most agroecosystems had lost their organic carbon and nitrogen in the soils. Efforts to overcome land degradation have now shifted from simple reducing degradation to the promotion of sustainable land management. This suggests that studies should assess the two key factors such as soil erosion and soil organic carbon (SOC) distribution and loss at the field [8] or watershed level to evaluate existing management practices in the area.

Watershed is a topographically defined area delivered by a system of water bodies, which become necessary to examine the sustainable development of local communities surrounding in the area [6]. A number of environmental factors and land use processes operating within agricultural activities influence carbon pools and fluxes in the watershed area. However, the most significant can be land uses, land use changes, soil erosion and deforestation [9, 10]. In the contrast, agricultural management practices through irrigation system can increase both crop growth and productivity. Soil carbon sequestration as a CO_2 mitigation option requires the reliable carbon quantification held in soil organic matter (SOM) at field or watershed level. This assessment of amounts and quality of SOM in agricultural lands has received great attention in recent years assuming that SOC is one of the main indicators of soil quality [11]. Soil degradation can occur at multiple scales in the farm field, farm community and landscape that might affect SOC storage in each scale [12]. Determination of soil organic carbon (SOC) and nitrogen provides simplest ways for measuring of soil degradation.

Many studies of soil organic carbon and nitrogen in Ethiopia had focused on either rainfed or irrigation farmland separately, but the comparative study was meager and less understood on the variation of SOC and nitrogen stocks in agricultural land. Few previous studies have focused on effects of the plantation on soil physical and chemical properties [13], land use and land cover changes [14] and role of biochar for acid soil reclamation [15] in the study area. Farmers commonly practice small-scale traditional irrigation throughout the highlands. However, significant soil degradation occurs in the highlands of the study area for decades. Therefore, Koga watershed was established for modern irrigation system in recent time to increase crop production and improve the livelihood of communities by reducing soil degradation. The watershed area gives services for crop production during the rainy season for the rainfed and dry season for irrigation systems. Therefore, the objective of the present study was to carry out comparative analysis on the status of SOC and TN stocks between rainfed and irrigation farming in the watershed area, Northwest Ethiopia.

Methods

Description of the study area

Koga watershed area is located in 'Mecha' district in West Gojam Zone, Northwest Ethiopia (Fig. 1). The Koga watershed covers about 7000 ha of potential irrigable command area [22]. It lies on geographical coordinates at latitudes of 11°9.7′ and 11°30′N and longitudes of 37°02′ and 37°18′E. Specifically, the altitude of Koga watershed ranges from 2028 to 2193 m, which encompasses small variation. Therefore, topographic feature in the watershed area lies in flat sloping (< 5%).

The climatic condition in the study falls within cool semi-humid agroecosystem that attributes distinct dry and wet seasons. Unimodal rainfall pattern characterizes the dry seasons to occur between November and April and the wet season between May and October. Small rains occur irregularly during April and May. According to meteorological station rainfall and temperatures recorded in Merawi center [16], weather condition shows that the annual rainfall is 1703 mm, the mean daily temperature is 18.25 °C, and the monthly mean maximum temperature varies from 23.7 °C in August to 30.0 °C in March. The monthly mean minimum temperature varies from 5.4 °C in December to 13.1 °C in May and June.

Land use management in the watershed

Land uses in the watershed area are characterized by cultivated land, Eucalyptus plantation and grazing lands. Farmlands are areas where local communities practice continuously for crop production. Cultivated land in the watershed can be classified into two distinct types, namely rainfed and irrigation land [17, 18]. These were the initial methods for land use classification in the present study.

The irrigation system extends the growing period and allows two or more crops to be grown each year on the same piece of land. The rainfed area is a farming system where it can provide crop production once in each

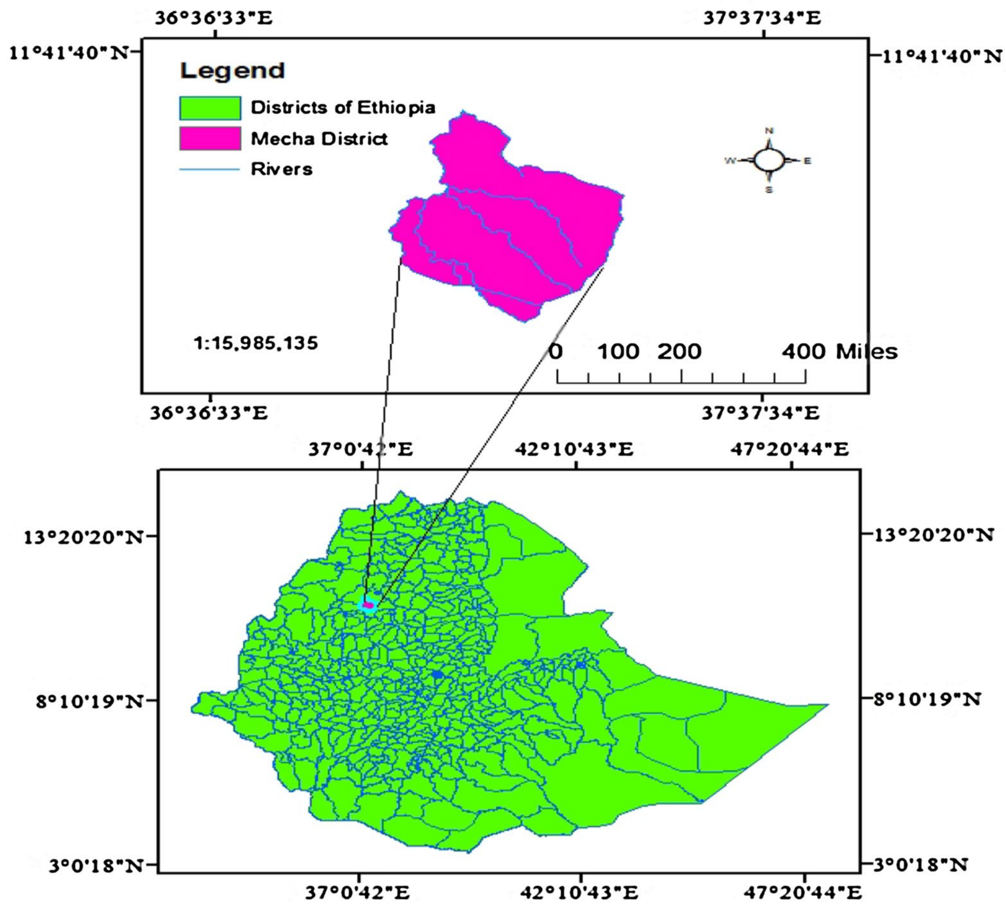

Fig. 1 Map of the study area

year on the same pieces of land [20]. The system forms a matrix and provides services during the rainy season. The main conservation agriculture practices had taken place in the study area including retention partial crop residuals, crop rotations and soil and water conservation measures. There sometimes takes place reduce or zero tillage operations in some farmlands.

Soil types and distribution

Koga watershed is located in the lower catchment based on slope gradient. The lower catchment consists of three major soil groups. The reddish brown and yellowish brown Haplic Alfisols found in the well-drained and moderately well-drained upland areas. Eutric soil types distributed in poorly drained plains while Eutric Gleysols soil types are features of floodplains of tributaries. Among major soil types, soils in the watershed classified as Alfisols (Nitosols), which attributed to clay textural class [13, 19]. Nitosols occur from sub-moist to humid agroecological zones in the country.

Agricultural inputs in farming systems

Local communities in the study area primarily depend on a mixed farming system that involves crop production and animal husbandry. Mixed farming systems consist of both seed farming and livestock rearing which support the livelihoods of local communities [20]. The seed-farming complex focuses on grain production, particularly cereals, but also pulses and oilseeds. The most common cereals grown in the study area are teff (*Eragrostis tef*), maize, wheat and Finger millet. To improve crop production, artificial fertilizers such as Urea and DAP are frequently used agricultural inputs. The rainfed system provides crop rotation patterns. The land management systems for cultivation of such crops in the watershed include terracing, repeated contour plowing, application of chemical fertilizers, application of 2, 4-D chemicals to reducing weed competition with crops in addition to hand weeding [16]. However, no fallow practice in the watershed area occurs due scarcity of farmland for satisfying high population densities.

Sampling design and data collection in the field

The study employed stratified random sampling pattern to obtain appropriate sample locations because pure randomization in the large and remote area may not become feasible. Out of twelve blocks, soil samples were collected from three core areas (block 1 = 373 ha, block 3 = 812 ha and block 5 = 803 ha with a total of 1988 ha) where 492.26 ha of rainfed farming is located in the watershed command area. Quadrats were demarcated using 5 m × 5m big plot design in each farmland position, and subplots were far apart in 120 degrees [11]. The transect lines, 200 m apart from each other, were established among quadrats. Soil samples were collected during December 2015 to January 2016 after crop harvest. To obtain comparative soil organic carbon distribution and minimize internal soil variability between rainfed and irrigation area, soil samples were collected from the farmlands having similar treatments. Thirty-six (3 replications × 3 blocks × 2 land uses × 2 soil depths) composite soil samples were collected in the field before tillage operations. Soil samples were collected from three points (three replications) and composited for chemical analysis. Bulk soils were collected using core sampler on the center plot only. Soil samples were collected at discrete intervals as 0–15 and 15–30 cm depth to understand land management effects on soils. About 200 g of fresh soil samples were gathered in each depth, kept in double polyethylene plastic bag, leveled separately, prepared and transported to the laboratory for further processes.

Laboratory analysis

Four soil parameters (SOC, TN, Bulk density and Soil pH) were determined in the laboratory of Environmental Protection Authority (EPA), Addis Ababa. The soil bulk density (Bd) was determined as the mass of oven-dried soil at 105 °C divided by its volume as BD (g cm^{-3}) = Ms/Vb, where BD = soil bulk density (g cm^{-3}), Ms = mass of soil after oven dry (g), Vb = bulk volume of the soil (cm^{-3}). Soil pH was prepared in 1:2.5 soil–water solutions and measured with the help of digital pH meter. Walkley–Black and Kjeldahl method [23] was employed for carbon and total soil nitrogen analysis, respectively.

Data analyses

Data were analyzed where a summary of statistics (mean, standard deviation, analysis of variance) was obtained. Simple one-way analysis of variance (ANOVA) employed to test significance variation of SOC between distinct farmlands (rainfed and irrigation) and along the depth. Ellert and Bettany [24] method adopted for soil organic carbon and nitrogen stocks (t ha^{-1}) determination as follows: SOC (or TN) Stock = Con. C or N (%) * BD (g cm^{-3}) * soil depth, d (cm) * (1-Si), where SOC (or TN) Stock = Soil organic carbon or nitrogen stock (t ha^{-1}), Conc. = Soil organic carbon (%), BD = bulk density (g cm^{-3}) and d = depth or soil layer (cm), and Si is volume of fraction of coarse fragments > 2 mm. However, most of the fraction of fragments was below 2 mm, which were fine particles and excluded in the calculation. Carbon sequestration was calculated by conversion factors of 3.67 as Carbon sequestration = SOC stock × 3.67 [24]. Pearson method was employed to show the correlation among four measured soil variables.

Results and discussion

Spatial and vertical distribution of SOC and Total nitrogen

The present study highlighted that slightly higher mean SOC and nitrogen storage occurred in irrigation than rainfed farming in the watershed and descriptive statistics displayed in Table 1. Soil organic carbon (SOC) and total nitrogen (TN) varied across farm field (plots), depth and farming systems. SOC concentration was increased by 0.16 g kg^{-1} (6.2%) in irrigated compared to rainfed farming up to 30 cm soil layer. Conversion from rainfed to irrigation farmland involves a number of applications like additional fertilizers and short period tillage operation. Studies suggested that additional fertilizers have a weak positive correlation to organic carbon and increasing organic fertilizers might not significantly increase SOC [31]. However, increasing the input of nitrogen fertilizer increased SOC only when crop residues returned to the soil. Retention of crop residuals and mixed in the soils was better in irrigation than rainfed that contributed to slightly higher organic carbon and nitrogen in irrigation farmland.

Appropriate crop residuals management in irrigation farming contributed to reducing soil bulk density, implying improvement of organic carbon and nitrogen. This

Table 1 Analysis of selected physical–chemical properties of soils

Soil properties	Depth (cm)	Land use			
		Irrigation farm		Rainfed farm	
		Mean ± SD	CV	Mean + SD	CV
SOC (%)	0–15	2.73 ± 0.15	0.055	2.67 ± 0.16	0.059
	15–30	2.34 ± 0.20	0.085	2.09 ± 0.18	0.086
BD (g cm^{-3})	0–15	1.06 ± 0.21	0.198	1.07 ± 0.16	0.149
	15–30	1.12 ± 0.08	0.071	1.19 ± 0.17	0.143
TN (%)	0–15	0.20 ± 0.04	0.200	0.18 ± 0.02	0.111
	15–30	0.17 ± 0.03	0.176	0.17 ± 0.03	0.176
pH	0–15	5.4 ± 0.44	0.081	4.9 ± 0.36	0.073
	15–30	4.6 ± 0.28	0.061	4.6 ± 0.19	0.041
C:N	0–30	13.71 ± 0.36	0.026	13.76 ± 0.49	0.035

SOC soil organic carbon, *BD* bulk density, *TN* total nitrogen, *CV* coefficient of variation, *SD* standard error) suggests that irrigation farming has a potential to improve soil physical and chemical properties. Similar studies showed that higher SOC stored in irrigation than rainfed farmland [3, 45]. In the contrast, the low SOC content on topsoil surface of rainfed than irrigation farming probably reflected the presence of continuous cultivation, minimal inputs and removal of crop residuals. Continues cultivation might play redistribution of soil and affect soil structure that facilitates erosion in the rainfed area and consequently reduce organic carbon content. Subsurface soil organic carbon content remained small variations and no significant statistical differences observed between rainfed and irrigation farming. This indicates that land use management influences top fertile soils.

Our result showed that SOC content found in a range of medium level (1.5–3.9). Studies recommended that depending upon SOC, the quality of soil may be graded as low (<1.5), medium (1.5–3.9) and high (>3.9) and the value of SOC in this ranges considered as standard evaluation [26, 27]. Even though SOC occurs in the standard ranges, it approaches in the lower level of carbon content, which indicates appearing of SOC degradation at the watershed level.

Pearson correlation (*r*) showed that the relation among the four variables ranged from − 0.89 to 0.91 value (Table 2). It had shown the existence of a strong relationship between organic carbon and nitrogen. This suggested that the contribution of organic carbon was significantly high for nitrogen improvement. Land management for improvement of organic matter has thus an opportunity to increase soil nitrogen, which plays an important role in crop productivity. SOC and TN varied not only in their mean value of farming systems but across a farm field. This implied that individual crop residuals management played an important role in the storage of SOC and TN on the farm field. Higher SOC concentration in irrigation farming reflected better individual farm management than rainfed farming. In addition, to mean value of SOC, the result showed that soil organic carbon on plot levels was higher in irrigated than rainfed farming (Fig. 2a). This horizontal variation of SOC obtained from the improvement of irrigation farm management. Irrigation farmland provides an opportunity to grow crops two or more season, which contributes to increasing crop biomass on the field. On the other hand, one season crop production (minimum biomass inputs) and removal of residuals in the rainfed area might contribute to the reduction in soil carbon on a plot level. On the contrast, the spatial distribution of SOC on the lower surface (Fig. 2b) has shown slight variation because of the absence of human intervention.

Highly significant soil depth effect on SOC concentration was verified in rainfed ($p < 0.01$) than irrigation farming ($p < 0.05$) (Table 3). This vertical variation of SOC might come from continues cultivation for long-term and absence of growing perennial crops in the farmland. Cereals are the most common crops and complete their life cycle annually that might contribute to low inputs. In addition, a relatively high soil disturbance through oxen tillage operation in rainfed farming might be a source of vertical variations. This activity also exposes wind erosion on top fertile soils of farmland in dry condition. The other could be increasing removal of crop residuals for the purposes of fuelwood and animal forage on the rainfed farm. These types of activities played to decline SOC in rainfed than irrigation

Table 2 Pearson correlation (*r*) analysis matrix in selected soil properties

Soil variables	pH	SOC conc.	TN conc.	BD
pH	1			
SOC conc.	0.020	1		
TN conc.	− 0.021	0.911	1	
BD	0.012	− 0.898	− 0.866	1

SOC organic carbon (%), *TN* total nitrogen (%), *BD* bulk density (g cm^{-3})

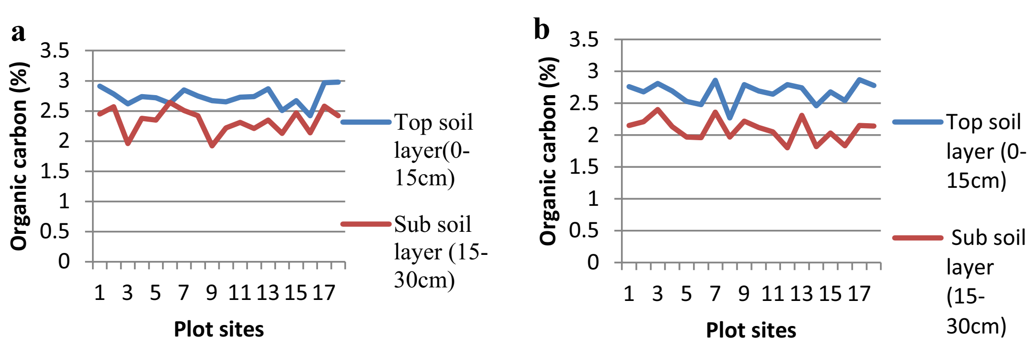

Fig. 2 Variations of organic carbon on plot level. **a** Irrigation farming and **b** rainfed farming

Table 3 Analysis of variance (ANOVA) of SOC concentration along soil layers

Land use	Mean SOC (%) +sd (0–15 cm)	Mean SOC (%) + sd (15–30 cm)	*Pr (> F)*
Irrigation farmland	$2.73^{a} \pm 0.15$	$2.34^{b} \pm 0.20$	0.0196*
Rainfed farmland	$2.67^{c} \pm 0.16$	$2.09^{b} \pm 0.18$	3e−06**
Significant level		'**' 0.01	'*' 0.05

farmland. Therefore, the increase in soil CO_2 emission in the atmosphere lies within rainfed farming (Fig. 4).

Carbon-to-nitrogen ratio

The carbon-to-nitrogen ratio (C/N) becomes an important factor affecting the overall turnover rates of soil organic matter. The higher carbon-to-nitrogen ratio had been found in irrigation and rainfed farming (Table 1). This might contribute to slow rate of organic matter decomposition through microbial performance. Similarly, the studies suggested that soils with C-to-N ratio in the range of 10–12 require an excess of the microbial activities [28] and contribute to slow organic matter decaying [29]. In contrast, some investigations have shown low carbon-to-nitrogen ratio in various sites [30].

Soil pH

Soil pH is the measure of acidity and alkalinity of soils. The result showed that both soils in irrigation and rainfed farming have acidic problems in all soil profile. Comparatively, topsoils in both farmland were moderately acidic than subsoils surface (Table 1). This indicates that parent materials had acidic nature [13] and severe land use effects aggravated soil acidity. If anthropogenic activities influence top soil surfaces continuously, it would expose to high acidic soil properties, which reduce soil fertility and in turn affects crop productivity. Thus, the high acidic soil might affect crop productivity, delays the decomposition of organic matter and consequently affects SOC stocks. Likewise, the previous study explained that soil pH value was significantly higher in the top layer than lower surface [32]. Comparatively, the mean soil pH value in the topsoil surface of irrigation farmland showed lower acidity than rainfed farmland but not statistically significant at 95% of confidence. This spatial trend of acidity linked with better residuals management in irrigation than rainfed farmland.

Soil acidity is one form of chemical degradation of soils. The problems of acid soils are high acidity and low amount of exchangeable cations especially calcium. It is considered to be one of the most important factors that affect the soil chemical fertility. A study showed that the four major causes for soils to become acid are rainfall and leaching, parent material, organic matter decay and harvest of high yielding crops and residues [33]. Therefore, the study found that soil parent material and slow rate of decaying matter contribute to great acidic soil properties.

Soil pH is one of the important chemical indicators, which influence some of the soil functions. If inappropriate irrigation management system continues, it will change soil health in terms of soil acidification. Similar studies have reported that soil acidity affects the process of other nutrient transformations, solubility or availability of many plant essential nutrients [34].

In Ethiopia, 40.9% of the soil is acidic of which 27.7% is moderate to weakly acidic (pH of 5.5–6.7) and 13.2% is strong to moderately acidic (pH $<$ 5.5) [33]. Soil pH influences soil nutrient availability and biological activity. Fertile soils usually found in the range of pH 6.0–7.0 and below this range, soils become either low or medium fertility. Therefore, study suggests that soil management strategies such as the application of mineral fertilizers, lime, compost and manure have a potential to ameliorate soil acidity [33]. Soil liming can increase soil pH, supply essential plant nutrients and make other essential nutrients [35]. Soil pH is one of the attributes sensitive to changes in natural environment and soil management processes because of human activity.

Soil bulk density and its relation to organic carbon

The analysis showed that a strong negative relation exists between soil bulk density and organic carbon on both farmlands. The relation shows as bulk density decreases, organic carbon increases (Fig. 3). Bulk density was the key factor that determines organic carbon change in the study area. The result showed that mean soil bulk density of 1.09 g cm^{-3} in soils of irrigation and 1.13 g cm^{-3} in rainfed farmland accounted for up to 30 cm depth. Earlier studies explained that average bulk densities need to be below 1.4 g cm^{-3} for clays soils [36] and lower bulk density better than higher value for good plant growth [37] and to increase organic matter [38]. Below average range of soil bulk density partly attributed to the increase in SOC content. It varies over a wide range, particularly in Nitosols ranges from 1.0 to 1.8 g cm^{-3} and average density for soils estimated to be 1.4 g cm^{-3} [36]. In general, bulk densities showed variation along plot level and soil depth due to land management differences among farmers.

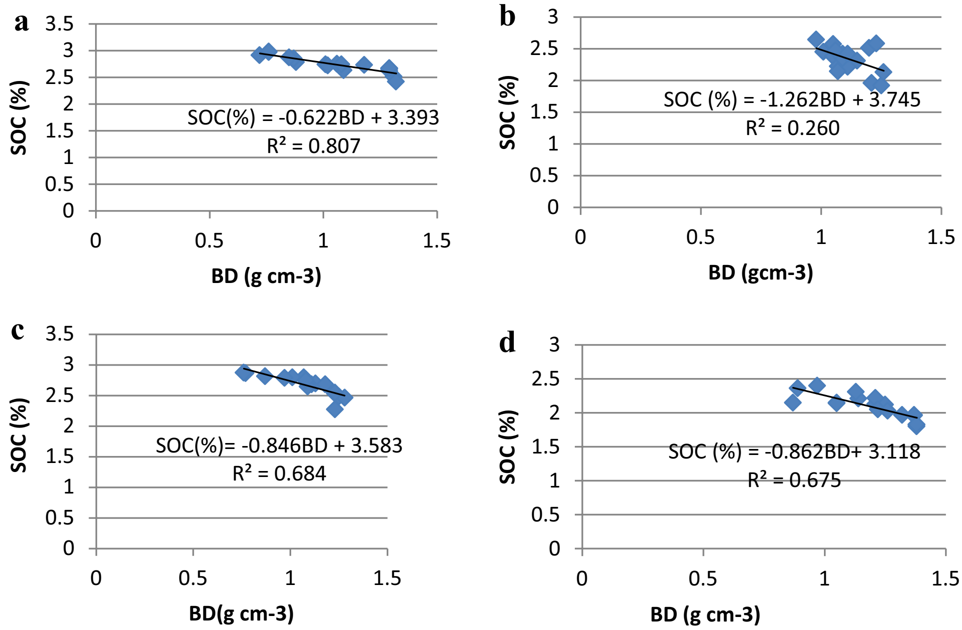

Fig. 3 Relation between soil bulk density (BD) and organic carbon concentration. **a** Top soil layer (0–15 cm) of irrigation, **b** sub soil layer (15–30 cm) of irrigation, **c** top soil layer (0–15 cm) of rainfed, **d** subsoil layer (15–30 cm) of rainfed

The analysis revealed that soil bulk density did not show significant differences between soil treatments. The similar finding showed that no significant difference found between rainfed (1.57 g cm^{-3}) and irrigation cropland (1.57 g cm^{-3}) [25] and soil under cultivation has frequently higher bulk density (1.3 g cm^{-3}) [39]. In the contrast, the study [40] explained that significant difference in soil bulk density occurred along depth wise. Therefore, cropping patterns, soil types and management practices might contribute variations along spatial and vertical layers.

Comparatively, lower mean bulk density value in both treatments occurred on the topsoil surface (0–15 cm) similar to other studies [41, 42]. A relatively, high bulk density in the rainfed farming revealed to have low pore space for crop growth and might play lower crop productivity. This suggested that the increase in bulk density tended to increase soil strength and lower soil porosity. Soil bulk density generally increased with depth under both faring systems similar to other studies [9].

Effects of farming systems on SOC and TN stocks

The result showed that mean value of 82.57 t C ha^{-1} in soils of irrigation and 79.72 t C ha^{-1} in rainfed farming stored up to 30 cm soil layer (Table 4). An increasing of 2.85 t C ha^{-1} (3.44%) in irrigation farming suggests that anthropogenic activities have not only negative impacts on soils but have also positive effect to improve soil fertility. However, organic carbon stocks did not show the significant statistical difference between farming systems (Table 4) because changes in the organic carbon in the soils often take place slowly. An earlier study on soil organic carbon stocks in Nitosols of Ethiopian has recorded to be 143t C ha^{-1}. In relation with other recent

Table 4 ANOVA of soil organic carbon and nitrogen stocks between land uses

Land use	Depth (cm)	Mean SOC stock (t ha^{-1})	Mean N stocks (t ha^{-1})	*(Pr > F)*
Rainfed farm	0–15	42.41*[a]	2.89	0.000172***
	15–30	37.31*[b]	3.03	
Irrigation farm	0–15	43.26[a]	3.18	0.0156*
	15–30	39.31[c]	2.88	

Different letters both vertically and horizontally show significant differences, but the same letter shows no significance

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 studies in similar agroecosystems, SOC stocks were proportional to Guma Selassa (79 t C ha^{-1}) watershed in Ethiopia [18] and Kitabe watershed (75.2 t C ha^{-1}) in another country [43].

The present study result was found in the range of evaluation of the SOC stocks in maize fields to be 80–150 t C ha^{-1} in the 0–30 cm layer [44]. However, the finding showed that organic carbon stock in the soil occurred on the marginal level, which implied in the status of degradation, particularly in rainfed farmland. The study showed the mean value 2.85 t C ha^{-1} increment in irrigation farm up to 30 cm soil depth, rating to 0.41 t C ha^{-1} year^{-1}.

Quantification of SOC stocks had shown higher on the top than lower soil surface in both farmlands. However, nitrogen stocks become reverse along depth wise, particularly in the rainfed farm. This was because higher bulk density occurred in the lower soil surface of the rainfed farm. In farm management, 52.4 and 53.19% of SOC stock in rainfed and irrigation farmland, respectively, were stored in the topsoil layer. This implied that inappropriate land management on the topsoil surface might result in degradation of soil organic carbon. Therefore, conversion of rainfed to irrigation farmland has a potential to increase soil organic carbon and stocks. It also plays vital role to improve soil fertility and crop productivity.

Retention of crop residuals might attribute to increase organic carbon on the topsoil surface of irrigation farmland because of multiple crop production. Human activities had declined in the collection of maize residuals for fuelwood and for forage that attributes to the improvement of organic carbon in the soils. The result showed that slightly higher total nitrogen stocks in irrigation farmland stored than rainfed farmland similar to other findings [25]. However, there are no statistically significant variations between farming systems (Table 4) because improving soil nitrogen on the farmland level occurs in the slow process. The present results on soil nitrogen were found in the range of moderate level similar to other results (0.1–0.2) [27].

Projection of soil carbon sequestration in watershed area

The result showed farming systems improved the projection of mean carbon sequestration from 295.66 t CO_2 ha^{-1} in rainfed to 303.58 t CO_2 ha^{-1} in soils of irrigation up to 30 cm soil layer (Fig. 4) and see detail in Additional file 1: Table S1. Increasing crop biomass production and human intervention on land management played an important role for improvement of soil organic carbon sequestration. The ability of carbon sequestration in farmland dependent on the soil type, crop type and management practices used to grow those crops. Change from rainfed to irrigation farmland involves manipulation of soil properties and additional fertilizers and retention of crop residuals, resulting in an increase in crop biomass that contributes to the improvement of organic matter in the soil. Similar to this, studies suggested that the addition of fertilizers, judicious application of irrigation water in soil could enhance biomass production; increase the amount of aboveground and the root biomass returned to the soil, improve soil biodiversity and improve SOC sequestration [21].

Residues management in the field might play an important role for an increment of soil organic matter. Prevention of residuals from the collection for purpose of fuelwood and animal feed might contribute improvement of organic matter in irrigation farmland. In general, the present result showed soils sequestered carbon following changes from rainfed to irrigation farmland. Conservation of top fertile soils and exclosure of livestock grazing on crop fields might characterize a slight variation of SOC storage and improvement of soil fertility in irrigation area.

Considering rainfed and irrigation area as land use management, estimation of carbon sequestration rate in irrigation farmland of Koga watershed area contributes to

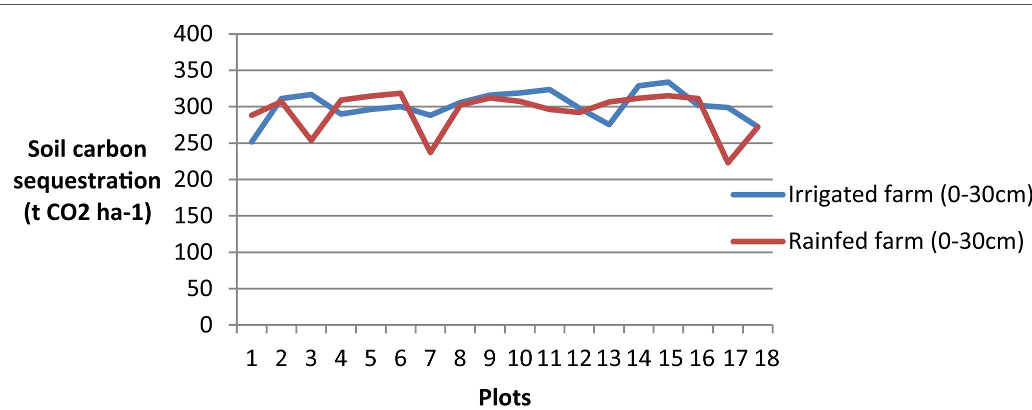

Fig. 4 Soil organic carbon sequestration in farming systems

0.027 t C O_2 ha^{-1} $year^{-1}$. The rate of soil carbon sequestration with improved management in Ethiopia was estimated to be in the range of 0.3–0.5 t C ha^{-1} $year^{-1}$ in irrigation and 0.06–0.2 t C ha^{-1} $year^{-1}$ in rainfed farmland, respectively [18]. This showed that changes land use and management practices affect the land resources that govern carbon sequestration potential.

Conclusions

The present study revealed that farming systems and soil depth had influenced the spatial and vertical distribution of soil organic carbon and nitrogen stocks in the watershed area. Soils in irrigation farming system stored and sequestered higher carbon and nitrogen than the rainfed farming system. This suggested that shifting from rainfed to irrigation farming system might improve soil organic carbon and nitrogen stocks (Additional file 1: Table S1).

Implication of the study

Change in farming systems and management influence the rate of carbon and nitrogen sequestration in the soil or released to the atmosphere. The rate of change in soil organic components also shapes crop growth, productivity and environment. Many questions arise regarding change of soil organic components and associated impacts on crop productivity. However, this study examined by spatial and vertical analysis of soil organic carbon and nitrogen stocks on both rainfed and irrigated farming systems. Comparative evaluation of soil organic carbon and nitrogen stocks showed clues for decision-making and indicating the status of farm management. Hence, finding confirmed improvement of soil organic carbon and nitrogen stocks in irrigated farming. This implied that each organic carbon and nitrogen fraction might contribute to better crop productivity and climate mitigation than rainfed farming. From increasing of crop biomass and retention of crop residuals, prevention from the intrusion of livestock, reduction in soil disturbances and modern irrigation systems supported improvement in irrigation farming. Therefore, it is suggested that local communities should extend irrigation system at least on small scale and policymakers and the government should give attention to extend on large scale for improving agricultural productivity and climate change mitigation. Further studies also suggested on comparative analysis of soil organic carbon and nitrogen in rainfed and irrigated farming using more efficient laboratory analysis methods.

Additional file

Additional file 1: Table S1. Laboratory analysis results on selected soil chemical and physical properties (Key: SOC = Soil organic carbon (%), BD = bulk density (g cm^{-3}), TN = total nitrogen (%), SOC stock = Soil organic carbon stocks (t ha^{-1}) and IR = Irrigation, RF = Rainfed).

Authors' contributions

GG was responsible for conceptualization, designed research method, data collection, analysis, and preparation of draft manuscript while TS gave comments and suggestion for the draft manuscript. Both authors read and approved the final manuscript.

Acknowledgements

We would like to thank Center for Environmental Science in Addis Ababa University for financial support and providing necessary field equipment and Environmental Protection Authority (EPA) for soil laboratory analysis in Addis Ababa. Finally, we would like to appreciate two anonymous reviewers for their valuable comments on an earlier version of the manuscript.

Competing interests

Both authors declare that they have no competing interests.

Availability of data and materials

All data generated during this research work are included in this article.

Consent for publication

There are no images and videos relating to individual participants involved in the research. Therefore, we, both authors approved this manuscript to process for publication.

Consent to participate

This research work did not involve human subject for experimental purpose and informed consent to participate in the study.

Ethical clearance

There are no plants or animals involved for experimental purpose. Therefore, this was not applicable to the research.

Funding

Little financial support obtained from Center for Environmental Science in Addis Ababa University.

Publisher's Note

Received: 7 April 2017 Accepted: 16 January 2018
Published online: 21 April 2018

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