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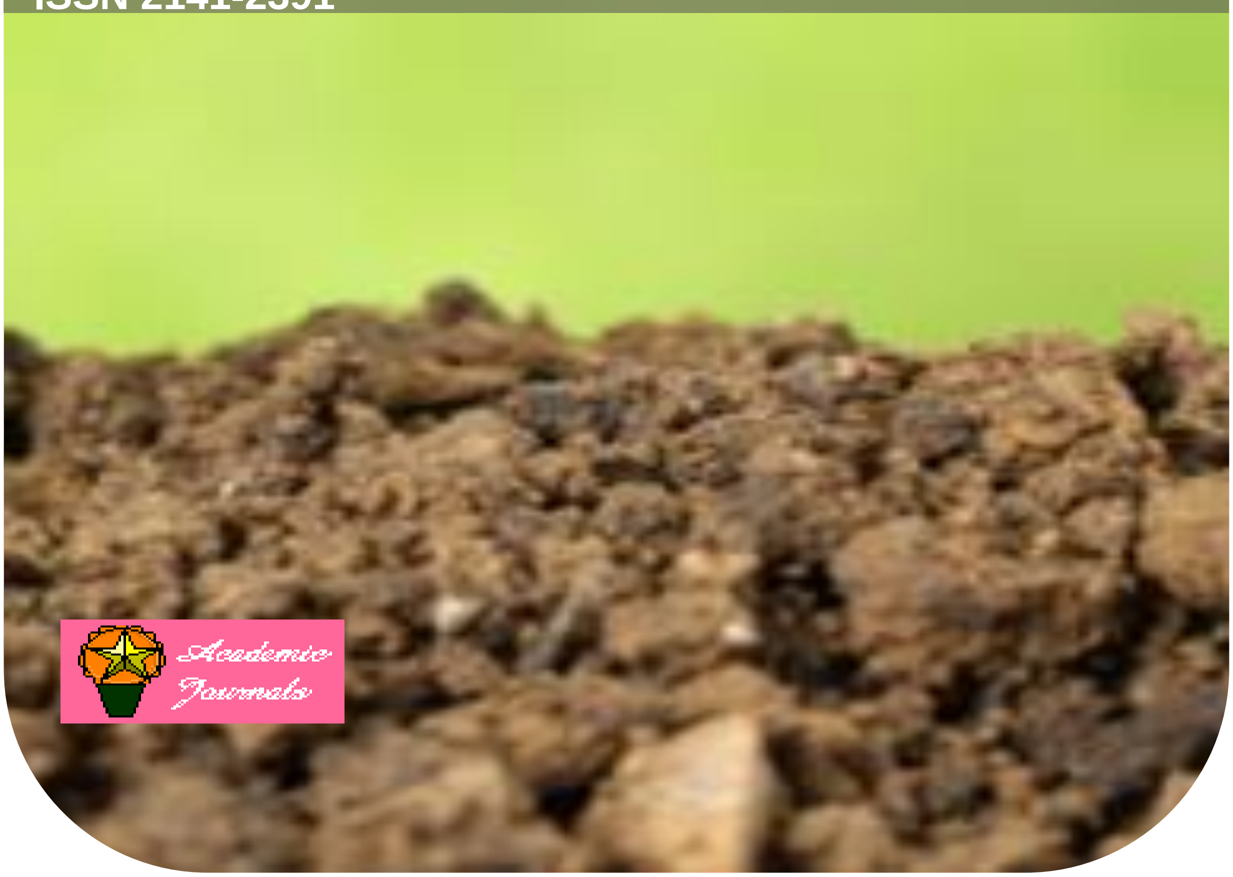

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Journal of Soil Science and Environmental Management

Full Length Research Paper

Community's perception on soil erosion and their participation in soil conservation practices: A case study of Alaltu watershed of Najo District, Ethiopia

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Community's perception of land degradation by erosion is a key social factor that is important in deciding options for controlling soil losses. Therefore, understanding Community's knowledge and their perception and factors that influence their land management practices are of paramount importance for promoting sustainable land use in the study area. Community of the study area have good perception of soil erosion in general and its causes, indicators and the area of their plot of land vulnerable to soil erosion in particular. Moreover, they have good traditional and modern measure of soil conservation methods. However, various hindering factors such as lack of capital, poverty, small size of their land and other socio-economic and physical factors were observed which obstacle to apply the SWC technologies. In addition, Community's perception of importance of modern SWC technologies was very high. However, the way of their perception seems wrong. Because, they perceive that modern SWC is government strategy to rehabilitate highly degraded area through campaigns rather than method of soil conservation on the agricultural land. They consider that the structure occupy large area that it hinder them to fully utilize their highly fragemented farmland due to high dependency on agriculture. Therefore, it is recommended that good policy and strategies by the government, corrective intervention from any concerned organizations aimed at this issue as well as the community's participation on encouraging farmers' participation in soil conservation practices are very important to solve current soil erosion devastations and environmental deterioration of the study area.

Key words: Participation, perception, soil erosion.

INTRODUCTION

Soil erosion studies have gained great prominence because of the potentail threat it has to land resource and crop productivity. Globally, about 80% of the current degradation of agricultural land is caused by soil erosion (Angima et al., 2003). Soil erosion in association with inappropriate land management practices is one of the main factors causing degradation. Poor land management practices and lack of effective planning and implementation for soil conservation are responsible for accelerating degradation on agricultural land (Hurni, 2005).

Intense land cultivation, uncontrolled grazing, and

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deforestation were commonly observed which has been exacerbate soil erosion in the study area. These factors undermine agricultural productivity and frustrate economic development efforts, especially heavy land dependence in low external-input farming systems in the study area similar to other parts of Ethiopian highlands. Community's perception of land degradation is crucially affected by social, economical, environmental and political factors. Factors such as land size, method of land preparation, land tenure arrangement, distance between farm plot and home, education and wealth status of farmers aggravate soil fertility depletion.

Earlier studies have clearly demonstrated that farmers are decisive in social part in achieving sustainable land use in general and SWC in particular through control of soil erosion. However, these studies were conducted under different conditions and none of these studies address communities' perception of soil erosion and the degree at which they are participating in soil conservation to overcome socio-economic and environmental impact of soil erosion in the study area. For successful soil conservation planning, it is however, necessary to identify communities' knowledge and perception of soil erosion and their contribution in soil conservation. The general objective of this research is to assess the communities' perception of soil erosion and their participation in soil conservation practices. Specifically: 1) To identify the current communities' perception and awareness of soil erosion ; 2) To evaluate the local communities' acceptance and adoption of soil conservation technologies; 3) To identify factors affecting their soil conservation decision.

RESEARCH METHODOLOGY

Description of the study area

The study was conducted in Alaltu watershed located in Najjo Woreda of West Wollega zone, Ethiopia. Astronomically, the district is between 9°37'- 9°44' North latitude and 35°14'- 35°40' East longitude. The study area is composed of various land forms such as dissected plateaus, hills, plains and valleys. The district totally lies with in sub-tropical agro-climatic condition. The annual temperature ranges from 18 to 28°C while rainfall amount ranges from 1350 to 1600 mm. The study area is characterized by rapid population growth similar with other parts of Ethiopia; with annual growth rate of 2.9%. About 82% of the total land was used for agricultural activities including forest land which has been supporting 85% of total population. Averagely,72% of an individual income in the woreda rely on crop production and 22% from livestock production, were as crop production and livestock production which are not separated activities in the district.

In general, the following are some economic, social and environmental problems common in the district:- shortage of farmland and grazing dueto poor soil and water conservation techniques, termite infestation, low utilization of modern agricltural inputs, weak credit and extension services, high prevalence of malaria and some diseases and shortage of medicines and medical equipments and general services rendered by health institution, shortage of school, teachers of better quality,teaching materials, poor transportation and communication networks and gradual rising of rate of unemployment. Three kebeles/villages were selected based on the degree of soil erosion, topographic variation and other socio-economic factors affecting soil erosion. Accordingly, Dongoro Buna is the village which is located relatively at steepy slope and affecting by frequent running water during rainy season in the region while relief structure become gentler along Kiltu Mako and Waltate Agar, respectively.

Research design

The study was designed to use descriptive methods. This method was chosen with strong assumption that it is convenient to collect several kinds of data regarding community's perception on soil erosion, opinion on prevailing problems of soil conservation practices and the action they are taking to overcome the problems.

Source of data

The study has used both primary and secondary data .The primary data were obtained through questionnaire, interview and focused group discussion; while secondary data were obtained from books , journals and different reports on human population, agro-ecology, and land use pattern, topography, soil type, and climate are gathered from Zonal and district Agriculture and Rural Development offices.

Sampling techniques and procedures

Discussions were held with the experts in the zonal and district natural resource offices on the condition of soil resource of the study area and present condition of soil erosion in the district. The study site was selected based on the degree of soil erosion, topographic variation and other factors affecting soil erosion; accordingly, three kebeles were selected purposively for the study. Then household's heads selected from each randomly, through discussion with key informants in the village and secondary information. The total households heads in the selected kebeles were 1197. Out of these 10% were selected as respondent which was 120 household heads believing that they can reperesent the entire population due to the homogeneous characteristics of the population.

Data collection instruments

Primary data was collected through observation, structured questionnaire, semi-structured interview and FGD. Transect walks were held in all selected village, guided by the respective key informants, who we also asked to give their opinions regarding soil erosion issues and land-management activities in the area. The checklist of issues that guided our discussions was:

1. Observable erosion indicators (rills, gullies, stoniness, sedimentation, etc.).
2. Existing SWC structures.
3. Slope gradients and land-use patterns (dominant slopes and niches of crops and trees, etc.).
4. General land-husbandry practices (up–down and across slope tillage patterns, pure and mixed cropping systems, etc.).

During the second survey, 120 farm households were interviewed using semi-structured questionnaires. Prior to conducting the interviews, the researcher trained the enumerators on how to conduct the survey and how to interpret and translate the

Table 1. House hold heads sex and age structure, family size and educational level (Respondents=120).

S/N	Kebeles	Total No. HH heads			Age structure of the family			Educational levels of HH heads			
		Male	Female	Total	0-14	15-64	>65	01	02	03	04
1	Dongoro Buna	34	5	39	220	153	11	3	31	5	0
2	Waligalte Agar	37	4	41	229	126	7	5	26	10	0
3	Kiltu Mako	38	2	40	254	50	2	7	22	9	0
	Total	109	11	120	703	329	20	15	79	24	0
	Percentage	90.83	9.17	100	66.7	31.3	2	12.5	65.8	21.7	0

questions. The questionnaire was pre-tested before administration and some re-arrangement, reframing and correction in accordance with respondent level of understanding were done. The issue of community's awareness as soil erosion is taking place on their land, how they identify level of soil loss among different slope position, causes of soil erosion, their perception of consequences of soil erosion, level of awareness and adoption of soil conservation measures, their practices of soil conservation methods, the constraints that hindered soil conservation were collected by this technique. The DA's and Soil conservation experts of the district were interviewed on their status to uphold farmers skills and capacity to participate on SWC technologies. Focused group discussions were held with elderly farmers, village leaders, and socially respected farmers who were known to have better knowledge on the present and past environmental, social and economic status of the study areas, to substantiate the information collected through individual farmer interview.

Methods of data analysis

In this study, descriptive statistics mainly percentage was used to analyze data. Moreover, qualitative method was used to describe the community's attitude toward soil erosion and the elder farmers' critical view of past and present situation of soil erosion problems in relation to socio-economic and political situations of the study area, by using information collected through interview and focused group discussion. Moreover, likert scale method was used in questionnaire part in order to measure attitude of the respondents on indicators of soil erosion and farmers' perception on trends of soil erosion over time.

RESULTS AND DISCUSSION

General background

The socio-economic and demographic condition of the respondents is described in Table 1. Accordingly, 66.7% were below 15 years of age and 2% above 64 years.This indicate, that the study area is characterized by high dependency ratio mainly with young age dependence. The sex structure of the sampled house hold composition is nearly equal (101.2). The average family size was 6.2 persons. Of the total respondents, over half of the respondents (65.8%) have basic primary education while 12.5% were illiterate, and 21.7% completed secondary school and no higher education level among the respondent. Almost all of the interviewed respondents owned land (97.2%) and only 2.8% of the respondent depends on the contract land and non-agricultural activities (mainly natural resources based activities such as charcoal production from wild forests, timber production and other natural resource based economic activities) with only land consisting of roof in their houses.

The mean land holding size of sample household was about 1.1 ha which is closer to the average land holding size of the woreda (1.4 ha). Taking the average household size and average land holdings of the sample households, the per capita land holding was 0.2 ha. Source: Field Survey, 2014 HH-House Hold 1)No education 2)Primary school 3)High school 4)Higher education

Most of the farmers' practices mixed farming system (88%) and only 12% depend on cropping only, while livestock production is not practiced as an independent agricultural activity in watershed. Livestocks are not only used as a means of cultivating land (oxen for ploughing), to produce meat and milk, manure for fertility, but are used as a store of wealth, as a saving method.

Off-farm activities are important economic base of some farmers in the study area which account to 8%. The common types of off-farm employment in the watershed is mostly exploiting natural resource (wood works, charcoal production for market and selling fire wood) Therefore, they don't give due emphases for soil conservation since their livelihood partially achieved through non-agricultural activities. These activities (mainly charcoal production for market) are practiced by people who own very small plot of land. According to the respondents, poverty is very likely to contribute to soil erosion for many reasons. When people lack access to alternative sources of livelihood, there is a tendency to exert more pressure on the few resources that are available to them.

The farmers were asked how livelihood diversification can be coping mechanism for preventing the socio-economic and environmental impact of soil erosion. However, most of them were criticized by those non-agricultural economy because of different reasons. They argued that the common type of non-agricultural economy in the area are natural resource based such as charcoal production which was resulting to the destruction of natural vegetations. Farmers have

Table 2. Community's perception on causes of soil erosion (Physical Factors) (n=120).

Causes		Percentage		
		Dongoro buna	Waltate agar	Kiltu mako
1	Lack of vegetation cover	22.2	37	23.1
2	Runoff	11.1	14.8	26.9
3	Expansion of grazing land	7.4	3.7	0
4	Heavy rainfall	25.9	29.7	34.6
5	Steep slopes	33.4	14.8	15.4

Source: Survey, 2014.

planting trees, non-agricultural people use the natural vegetation by cutting for different purposes. Furthermore, the farmers of dual income system are not active in community based natural resource conservation in general and soil conservation practices in particular.

Community's perception on soil erosion

Community's perception on causes of soil erosion

Almost all interviewed respondents (96.7%) perceived soil erosion as a problem constraining crop production on their farm land. Both physical and socio-economic causes of soil erosion were presented for respondents separately (Tables 2 and 3 respectively). They perceived all estimated factors as the causes of soil erosion; even if the degree of perception toward the variables vary among the respondents within and different kebeles. This may probably be due to variation in method of soil cultivation, gradient of plot of land, land holding system and land size and other socio-economic variation among the house hold. As indicated on the Table 2, in Dongoro Buna , most of the farmers perceive steep slope of their land as the determinant physical causes of soil erosion (33.4%) while the perception on expansion of grazing land as cause for soil erosion was (7.4%) and runoff (11.1%), lack of vegetation covers (22.2%), more rain (25.9%). This may probably due to relief structure of the area which is relatively steep than Kiltu mako and Waltate Agar. Many conservation structures such as cut-off drain, terraces (both level and graded bunds) were observed in this kebele.

Slopes affects peoples awareness and perception of soil erosion. This is in line with what were observed in the field, the erosion features such as rills and gullies were denser in Dongoro Buna than Waltate Agar and Kiltu Mako and farmers awareness were high. In general, according to the findings, communities awareness and perception on causes of soil erosion are mixed and highly influenced by their real physical and socio-economic condition. According to DA's, different people and thier livilihoods depends on different activities and are living in the study area, and they behave differently. Farmers those their livilihoods are directly related with soil condition, have good perception on cause and effects of soil erosion. They relate soil erosion with different factors such as slope of land , topography, vegetation covers etc. However, non-agrarian have wrong perception on cause and effects of soil erosion and how their activity affect the environment in general and soil condition in particular (how forest deplation exarbate soil erosion). This was realized by FGD discussion that they have no intention to conserve the vegetation; rather they need to shift their settlement to where these resources are available.

Among socio-economic causes of soil erosion, rapid population growth were the most peceived factor. It ranked first (35%) followed by lack of fertilizers (31%). According to the farmers, population growth increases the demand for land and contributes to farming on steep and fragile soils, and land fragmentation which resulted to erosion problems. On the other hand, limited access to knowledge of viable soil management options, is the lack of capacity to invest in soils especially in fertilizers, and having less ability to bear risk constrained by farmers attempt to improve soil.

Community's perception on indicators and severity of soil erosion on their farm land

Even if all respondents perceive problem of soil erosion on their land, their attitude toward its severity shows remarkable differences among the surveyed three kebeles. In Dongoro Buna, most of the farmers reported the severity of soil erosion on their land as severe (86.3%) and only 13.7% said moderate while no respondent says low and undecided. In Kiltu Mako, 56.3% said severe, 18.7% moderate and 15% said undecided and 10% said low. In Waltate Agar, only 37.5% of the respondents said severe and more than half of the respondents (50%) describe the severity as moderate, 12.5% says low. This indicate that topography influence farmers' perception of severity of soil erosion. However, regardless of their gentle slope of land, farmers of Waltate Agar have good perception of severity of soil

Table 3. Communities' Perception of Causes of Soil Erosion (Socio-Economic Factors).

S/N	Expected socio-economic causes of soil erosion	Rank in percentage				
		1st	2nd	3rd	4th	5th
1	Proximity to farmland	8	10	9	38	35
2	Land tenure system	15	22	7	26	30
3	Lack of organic fertilizer	31	28	29	8	4
4	Lack of education /awareness	11	9	22	27	31
5	Increased cultivated area due to rapid population increase	35	31	33	1	0

Source: Field Survey, 2014.

erosion. Because, no respondent said the severity is undecided.

Farmers' perception on indicators of soil erosion on their land were described. Accordingly, 65% of the respondents strongly agreed that reduction in crop yield indicate existence of soil erosion on their agricultural land while 7.5% perceived as undecided. Among the respondents, no one disagree with the effect of soil erosion on crop production. Soil color change as indicator of soil erosion strongly agreed by 36.3% of the respondent while 55% agreed, 2.5% say undecided, and 6.2% disagreed with the soil color change as the indicators of soil erosion. Most of the farmers were strongly agreed with formation of small depression (rills) as an indicator of existence of soil erosion (63.8%) and 22.5% agree with the indicator while only 13.7% were disagreed. 71.2% strongly agreed that gullies development is the indicator of existence of soil erosion on their lands. Presence and absence of weed is one of the indicators of soil erosion. However, most of the respondent undecided (76.3%). They attached existence or absence of weed with another factors rather than the effect of soil erosion. In general, farmers have good perception on indicators of soil erosion as a problem that limits soil productivity.

Community's perception on trends of soil erosion and its effects on their living conditions

Most of the respondents (89.7%) perceive that the rate of erosion is too much increasing over time. They identified shortage of cultivable and grazing lands as matter. Farmland have been highly fragmented in to insignificant size of plot for newly emerging house hold heads through inheritance of land for children. Finding of new land is impossible since all land available for cultivation is occupied, even the land along the steep slope are taken for the settlements they said. Therefore, intensive cultivation exposed their land for erosion. According to them, if the land cultivated again and again without fallowing, it has a probability of been easly affected by soil erosion. Almost all respondent (94.1%) reported that crop yield has been too much decreasing from time to time. No respondent perceive that their production is either increasing or remain constant throughout 20 years. They indicate as their living condition is deteriorating from time to time due to decrease in production resulting from soil erosion.

Previously, crop production mainly coffee, sesame, maize, teff, wheat and barley were the source of income in addition to home consumption. But now, except coffee which seasonally flactuate in productivity based on general climatic condition,other crops are not sufficient to feed their children.

Soil conservation practices in the study area

Situation of soil conservation practices in the study area

There were different conservation structures constructed on the individual farmers land and outside the farm lands. Commonly observed conservation structures were both traditional and modern methods. Modern conservation structures were mainly constructed on the fragile lands outside of cultivated and grazing lands. They believed that the construction of modern soil conservation measure locally known as '*dega'* took place by the government through campaign. According to woreda's Agriculture and Rural Development, the farmers are resistant of adopting SWC technologies; because it consume large areas of their farm lands. Mainly, the farmers of steep slope area highly resist the design of terraces constructions. Because as the steepness of the slope increase, the gap between the structures are expected to close to one another which result in the occupying of their land by the structures. Sustainable Land Resource Management Programs (SLMP) is an important organization work under woreda's Agriculture and Rural Development office organized and funded by CIDA in ten micro-watershad of Najjo Woreda (2012). The activities of the program include:

1. Organizing training and workshops on land resource conservation and management activities.

2. Hill-side degraded area closure activies through Community mobilization and financial support to the farmers. Both physical (cut-off drain,bund stabilization and micro-basin development) and biological (afforestation, reforestation, agroforestry, grassed water-way) structures are constructing in ten micro-watershed of the woreda.
3. Establishment of user group inline with conservation activities-*“integrated economic and ecological development”*. Mainly they use biological conservation methods for dual purposes. For example, the grassed water-way uses as conservation methods and fattening of bull while afforestation, reforestation, agroforestry done by flowering plants used for beekeeping and other activities (multi-purpose tree seedling).

Communities’ participation on soil conservation practices

Most of the farmers in the study area (87%) believe that erosion can be controlled were only 23% reported as impossible. The same number of respondent were also asked wether they are preventing their land from soil erosion devastation and only 56% reported as they are practicing the conservation methods. These indicate that significant percentage of the farmers (44%) is not conserving their land. The most important method of soil conservation in the study area was cultivating along the contour (30%) followed by terracing (38.75%) which is commoly observed. According to DA’s, there are two types of terracing practicing in the study area through community mobilization. First, level-bund which is used to retain water in relatively dry areas. The second is graded band which is commonly practiced in areas of excess run-off and accessibility of river outlate. The DA’s realized that the farmers clearly know where to establish which structure based on the condition of their farmland.

Contour ploughing is used separately or in combination with other conservation structures such as plantation of trees and cut- off drains. In the study area, a contour ploughing has been carried out using the ox-drawn plough. Hence, it is part of the normal farming activity; it needs no extra labor and time for construction and unlike other methods such as cut-off drain and terracing, it doesn’t take large areas. Probably, it is the reason why the largest percentage of farmers uses the method since it does not require resource and time in addition to cultivating land. Most of the interviewed people know the fallowing method; even most of them believe that it is an indigenous soil conservation method. However, only 2.5% of the respondents were practices due to shortage of land. Leaving crop residues on the field after harvest is another traditional practice used by the farmers in the area. However, this method is no longer applied because the importance of crop residues is increasing from time to time due to shrinking in size of grazing land and shortage of fuel wood. Thus, farmers are intended to use the residues for fodder of livestock and source of energy.

Highest percentage of the farmers in the study area (32.5%) agreed that the reason for the inability to conserve their land was lack of capital followed by poverty 28.3%. Similarly, 12.5% of the respondents said policy related problems, only 11.2% attached the problem with physical feature of their land, 9.2 % said climatic conditions, 5.8% related with effectiveness of off-farm activities (those preferring non-agriculture activities). However, the factors are perceived by all farmers differently which can be concluded from fair distribution of the percentage throughout the factors. These indicate that farmers are aware of their low level of soil conservation and factors hindering them to practice.

Acceptance and adoption of soil conservation technologies

According to interviewed DA’s, awareness creation have been taking place by the experts to implement newly introduced soil conservation technologies on their lands. This is done before community mobilization to participate on soil conservation campaign. The campaign has two types of committee organized from the farmers (technical committee and auditing committee). Then, the farmers who implement the structure accordingly on their farmland during awareness creation and without enforcement are considerd as the models and selected to be the member of committees. The duties of technical committee is to identify and select the site where to establish which structure and when according to the training given for them by the woreda’s soil conservation experts. From this, it is possible to conclude that the committee selection is not by the consent of the community which makes the approach top-down.

Moreover, the training for preselected farmers based on their execution of the technology is not enough and it may result biase and disregard the role of others. The farmer who implement first may not be knowledgeable and those unable to implement may not floosh rather they are affected by other economic and no-economic factors. As newly introduced, all of the farmers know about SWC technologies which they defined as the government strategies in order to rehabilitate the degraded land. Most of the farmers describe the technologies as very important (94%). However, only 2% of the respondents ever participated on SWC technology demonstration, field days and workshops before. This 2% were probably those selected from the community as technical committee to be trained and design areas to establish the conservation structures.

Half of the respondents (52.5%) reported that the technologies were effective in arresting soil erosion. Similarly, 57.5% believed that the new SWC technologies had the potential to improve land productivity. Nevertheless, acceptance of the technologies as effective measures for controlling soil loss and as having potential to improve land productivity cannot warrant its adoption on the farm. While acceptance depends more on the design characteristics of the technologies as related specifically to effectiveness, farm level adoption of the measures depends also on several socio-economic and institutional factors. Therefore, the farmers who implemented some conservation measures in their plots were interviewed how they measure the effectiveness of SWC technologies. They described as they observed a better growth and development of crops mainly along the structures where fertile sediments were trapped. They also evaluated that the amount of sediment trapped by the structure was very high which would be taken away out of the field if that conservation structure were not built.

Almost all farmers of the study area (92%) expressed their interest to continue maintaining the established structures. They have interst to apply the SWC technologies in the rest of their farm fields (plots that were not treated by that time), but only 42.5% of the respondents expressed that they had plan to implement the SWC technologies. The condition of traditional indigenous soil conservation methods and its effectiveness when compared with newly introduced soil and water conservation (SWC) technologies were the point presented during focused group discussion. They argued that both have their own place of effectiveness. The traditional methods particularly contour ploughing in combination with cut-off drain were effective on the farm lands while they are practicing the newly introduced technologies (construction of terracing along steep mountainous area and communal grazing land) through campaign on designed areas by the experts. They express the construction of the terracing as the government method for rehabilitation of degraded land rather than the soil conservation practices. This was realized by most observed structures were constructed on the isolated rugged areas. These indicate that farmers misunderstood the importance of newly introduced SWC, and they were not willing to construct on their farm land but only on the highly degraded areas as the means of rehabilitation.

Factors affecting communities'acceptance and adoption of soil conservation technologies

Farmers' acceptance and adoption of soil conservation technologies in Alaltu watershed of Najjo woreda was affected by various factors. The most important perceived factor was small size of the agricultural land (47.5%), the new technologies require too much labor to implement (15%) and 6.3% identified other factors which are not included in the list. These include lack of time to implement; that they focus on day to day activities rather than sustainability of their land, lack of financial and material support, disappointments with local leaders and committee that they enforce to construct and maintain only on their own degraded land, and their clan rather than where problems are abundant. Only 5% and 8.7% of the respondents believe that land tenure insecurity and lack of knowledge are hindering them not to implement conservation practices, respectively. The most important reason is a small size of their land which they believe that establishing conservation methods on small land is not advisable.

They noted that constructing terraces or bunds on small size farmland is believed as adding another problem greater than erosion problems. Farmers do not recommend constructing physical structures on very small croplands. Farm experiance was another factor affecting acceptance and adoption of the technology. However, 95% of those selected farm experiences explained it negatively on their comments. Accordingly, experienced farmers are resistant to accept and adopt newly introduced SWC. Moreover, they commented that, farmers of severe erosion area are active to accept and adopt newly introduced SWC technologies than the farmers found in the less affected area by soil erosion. Farm size also affects the acceptance and adoption in such way that the farmers of small plot of land do not have willingness to practice the conservation measures.

Conclusion

The current trend of land degradation by soil erosion is a threat to food security, and Alaltu watershed is not an exception. Community of the study area were characterized by poor socio-economic conditions. The farmers on the watershed suffer from severe erosion. Different features of soil erosion indicators mainly rills and gullies were dominated. Basic natural resources like soil, water and vegetation cover in the watershed are highly deteriorating. The community has good perception of problems of soil erosion as a problem constraining production on their farm land. They were able to identify the physical and socio-economic causes of soil erosion. However, their perceptions of causes were varying among surveyed kebeles. The most perceived causes are the steep slope, deforestation and run-off in Dongoro Buna, Waltate Agar and Kiltu Mako, respectively. The trends of soil erosion devastations has an alarming increase on their farm land. As a result , their production is decreasing from time to time which reduce their production at subsistence level, enforces them to change their livelihood to non-agricultural activities basically to forest utilizations.

Most of farmer believed that erosion can be controlled.

However, the significant percentage (44%) are not practicing in any soil conservation activities due to lack of capital, poverty, policy related problems , physical features of the land etc. SWC technologies were well-accepted by the farmers as effective ways of arresting soil erosion, and as it has the potential to improve land productivity. However, the way of acceptance seems wrong; because, they perceived the government strategies to rehabilitate the degraded non-agricultural land rather than farm land. The important factors affecting communities' acceptance and adoption of SWC technologies include the small size of agricultural land, the technologies require too much labor to implement, lack of time, lack of financial and material disappointments with local leaders.

RECOMMENDATIONS

Even if farmers have good perception of prevalence of soil erosion in their farm land, they attached its existence mainly with what they can observe physically such as rills and gully formations. Therefore, it is important to enhance farmers' awareness of other indicators of soil erosion in addition to physical conditions of their land. Farmers have good perception on trends of soil erosion over time and its causes. However, they have no intention for livelihood diversification and other methods of coup upping with the problems of land fragmentations. Therefore, any concerned body should intervene to encourage farmers in reversing the problems and adopt alternative livelihood so as to reduce pressure on land resources.

So far, farmers hardly undertake action to reduce erosion. Therefore, if corrective measures are not taken to tackle the existing situation, more land will become unsuitable for crop production and put even more strain on the existing resources. Farmers should be motivated to adopt the newly introduced SWC technologies. The approaches to expansion of SWC technologies should not be top-down coercively. It should be participatory and depend on the indigenous knowledge of the farmers. In general, any policy and program aimed at land resource management in general and soil conservation in particular has to give due attention and priority in mobilizing farmers to manage and use the land resource in a sustainable way.

Conflict of Interests

The authors has not declared any conflict of interests.

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Spatial distribution of organic carbon and nitrogen in soils related to flood recurrence intervals and land use changes in Southern Québec, Canada

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Several hydromorphological and soil factors may be the cause of variations in the total organic carbon (TOC%) and total nitrogen (TN%) content of riparian soils. Despite the importance of these two essential components in soil-forming processes, few studies have focused on the variability of carbon and nitrogen content for soils subjected to frequent flooding. Successive floods may in fact result in soil depletion. Measurements of TOC% and TN% content as well as of other physico-chemical soil properties (e.g. litter thickness, texture, pH, Fe and Al concentrations, C/N ratio, bulk density, colour) were performed in various flood zones (recurrence intervals of 0-20 and 20-100 years) and in no-flood zones (outside of floodplains). To do so, soil samples were systematically collected along transects perpendicular to the riverbank which cross through the various flood zones. The results show that TOC% and TN% content varies significantly from one zone to another. The concentrations of these two components are significantly lower in the flood zone with a recurrence interval of 0-20 years (29% ±0.80 TOC and 0.17% ±0.05 TN) compared to the other two zones, name 3.45% ±1.56 TOC and 0.26% ±0.10 TN (recurrence interval of 20-100 years), and 3.52% ±1.57 TOC and 0.27% ±0.11 TN (no-flood zone). There is often no soil biomass (litter) in flood zones with a flood recurrence interval of 0-20 years (72% of sites without litter), whereas litter is almost always present in the flood zone with a recurrence interval of 20-100 years and in the no-flood zone, with average thicknesses of 2.84 and 3.65 cm, respectively. The absence or virtual absence of litter in the frequent-flood zones progressively results in soil depletion in terms of CO and N, which over time could adversely affect forest stand regeneration and deeply alter current river ecosystems.

Key words: Alluvial soils, total organic carbon (TOC), total nitrogen (TN), soil biomass, floodplain, flood, recurrence intervals.

INTRODUCTION

Organic carbon and nitrogen are important indicators of soil fertility and quality. These two components also have a direct impact on soil biochemistry, in addition to contributing to the vitality of plants and forest stands (Myster, 2015; Yang et al., 2016). The organic carbon and nitrogen content in soil varies temporally and spatially based on numerous soil, hydroclimatic and morphological factors as well as soil use (Bedison et al., 2013; Häring et al., 2013). Soil biomass (litter), the main source of organic matter, is also a key element for measuring soil fertility and nutrient content. It is also known that the distribution of organic carbon and nitrogen can vary based on the depth of the soil profile (Don et al., 2007; Schilling et al., 2009) and that these two components are especially concentrated in surface horizons, frequently referred to as the "rhizosphere", the first 20 cm of soil profile and that this percentage decreases with soil depth (0-100 cm). It is also known that organic carbon and nitrogen concentrations can vary based on soil use (Wiesmeier et al., 2013). Farmed soils, for instance, can contain fewer nutrients than grassland and forest soils. Mechanical tillage of the soil and especially small amounts of crop residue may result in progressive soil depletion.

Lastly, certain physical soil properties such as bulk density (Don et al., 2007), texture (Bedison et al., 2013), water saturation and leaching (Wiesmeier et al., 2013) can also affect the organic carbon and nitrogen contents in soils.

In riparian areas, soil-forming processes are significantly affected by river dynamics (Bayley and Guimond, 2011; Myster, 2015). For instance, the soil organic carbon and nitrogen content can vary considerably based on river flows and the flood regime. Cierjacks et al. (2010) have shown that soil organic content in riparian areas increases further away from the main channel. Also, the phenomenon of vertical aggradation (that is, accumulation of flood sediment) maintains the soil in an immature state and inhibits the mineralization and humification processes essential to biogeochemical cycles (Bayley and Guimond, 2011; Gervais-Beaulac et al., 2013). It was also found that overly frequent floods contribute to leaching of the nutrients contained in the soil organic matter and that the stripping of surface litter progressively leads to soil depletion (Bayley and Guimond, 2011; Bedison et al., 2013; Gervais-Beaulac et al., 2013). Bedison et al. (2013) showed that about 70% of the forest sites that were studied in flood zones had no organic horizons and that the mineral matrix had low organic carbon and nitrogen contents. Although numerous studies have been done on the relationship between soil use and soil organic carbon and nitrogen (Don et al., 2007; Li et al., 2013; Schilling et al., 2009), there are few detailed studies on the effects of successive floods on CO and N content in alluvial soils (Bayley and Guimond, 2009; Bedison et al., 2013; Cierjacks et al., 2010). Recent works (Gervais-Beaulac et al., 2013, Saint-Laurent et al., 2014) have led to the determination that frequent floods can result in soil depletion and that organic carbon and nitrogen contents are significantly lower in frequent-flood zones than in areas prone to less flooding. This is attributed to the absence or virtual absence of litter that cannot accumulate on the surface of the soil due to very frequent floods (every 2 to 3 years, for instance), and the absence of litter prevents a major contribution of organic matter for the soil and progressively contributes to its depletion and lack of fertility. Given the importance of components such as organic carbon and nitrogen in soil biogeochemical processes, it seems critical to fully understand their distribution and variability in dynamic environments such as river systems. The main aim of this study is therefore to examine the spatial distribution of organic carbon and nitrogen for soils subjected to variable flood recurrence intervals (0-20 and 20-100 years). Sites located in no-flood zones but near riverbanks will also be studied for comparative purposes. Other key soil properties were analyzed, including pH, texture, bulk density and Fe and Al content. The study area covers a large floodplain (Richmond area) located on the left bank of the Saint-François River, a major watercourse in southern Québec (Canada). This large plain is characterized by periodic floods that affect the surface soil through erosion and sedimentation. At the same time, a diachronic analysis of the site using different series of aerial photographs (from 1945 to 2007) was done to track changes in soil use and to determine the possible effects of these changes on soil properties based on the various areas being studied.

MATERIALS AND METHODS

Study area

The study area is located in the Saint-François River catchment (Figure 1), which occupies roughly 10.228 km², 15% of which is found in the State of Vermont in the United States. This watershed is generally characterized by woodlands, which occupy about 65.7% of the area, followed by farmland (22.9%), with the remainder consisting of urban areas, watercourses, and wetlands (11.4%). The river landscape I characterized by ancient or recent alluvial sediments, while till deposits, glaciolacustrine sediments and rocky outcrops are mainly found along the riverbank and on higher ground (MEMR, 1989). The floodplain soils are part of the Cumulic Regosol (CU.R) and Gleyed Cumulic Regosol (GLCU.R) subgroups in the Canadian System of Soil Classification, while the no-flood zones are mainly characterized by brunisolic and podzolic soils (Gervais-Beaulac, 2013). This region is known for having a humid continental climate with average annual temperatures of 5.6°C (1981-2010) and average annual precipitation of 1185 mm (Richmond Weather Station, 7026465; MDDELCC, 2015b).

The mean annual flow of the Saint-François River measured downstream of the study area is 190 m³/s (Chute-Hemming/Drummondville; Cogesaf, 2006), and the mean annual flow measured at the Sherbrooke Station (030208), located 40 k upstream of the study area, is 162 m³/s.

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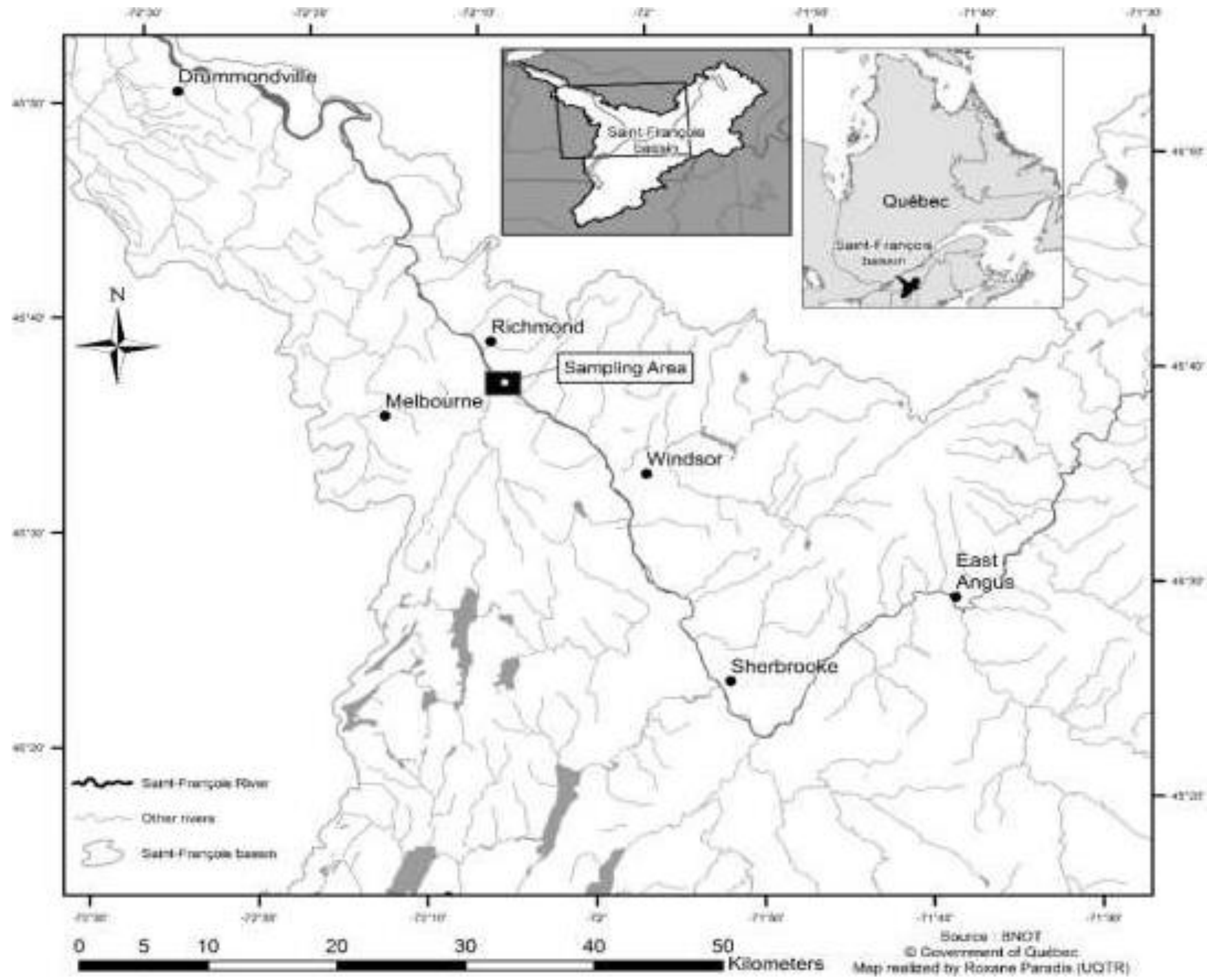

Figure 1. Location of sampling sites along the Saint-François River in the Richmond area (Southern Québec, Canada).

The river section between the towns of Drummondville and Sherbrooke is subject to frequent floods, especially since 1970s (Saint-Laurent et al., 2010). Richmond-Windsor is one of the municipalities that is most affected by the floods in the Saint-François River catchment, and it is estimated that over 55 floods (mainly in the spring) have occurred between 1900 and 2015 (Saint-Laurent et al., 2010).

In this area, the riparian forests and woodlands are most often found on the low terraces (1-2 m in height) and the tree stands are mainly characterized by red ash (*Fraxinus pennsylvanica* Marsh.), silver maple (*Acer saccharinum* L.), sugar maple (*Acer saccharum* L.) and balsam fir (*Abies balsamea* L.), while slopping terrain is characterized by hemlock (*Tsuga canadensis* L.), white pine (*Pinus strobus* L.), fir (*Abies balsamea* L.) and yellow birch (*Betula alleghaniensis* Britton) (Berthelot et al., 2014). Despite some diversity of forest stands in the frequently flood zone, there is less dense vegetation cover and especially a lack or thin layer of soil litter on the ground.

Sampling sites

The soil sampling sites were located along transects perpendicular to the riverbank within the floodplain that cuts across wooded areas. The layout of the transects inside the site took into account the site topography and the cartographic boundaries of the various flood recurrence zones determined with official flood risk maps (scale of 1:10 000) produced by Environment Canada and the Ministère de l'Environnement du Québec (EC-MENV, 1982). These boundaries consist of two flood-risk zones, including the zone with a flood recurrence interval of 0-20 years (FFZ: frequent flood zone) and the zone with a flood recurrence interval of 20-100 years (MFZ: moderate flood zone). The transects also extend beyond the flood zone boundaries, thus cutting across an area outside the floodplains (NFZ: No-flood zone). The soil samples were collected along the transects from the river bank and extend past the floodplain's outer boundaries. The samples were collected every 50m using an Eijkelkamp hand auger at predetermined depths

(0-20, 20-40, 40-60, 60-80 and 80-100 cm). Additional samples were collected on the soil surface (0-20 cm) every 25 m along the transects, for a total of 155 soil samples. Hence, there are 26 sites in the FFZ, 27 in the MFZ and 33 in the NFZ.

A characterization of the soil litter along with a description of the dominant plant species were noted at each sampling station, as well as measurements of the bulk density of the soil surface horizons (0-20 m), the microtopography, the presence/absence of groundwater, and the surface drainage based on the criteria outlined in the Canadian System of Soil Classification (CSSC, 1998) and the Manual on Soil.

Sampling and methods of analysis

The sampling period was from August to November 2014, and the position of the sampling points along the transects was determined using a GPS (Garmin 60CSx) after which the data were exported into mapping software (ArcGis® 10.2).

Physical and chemical analysis of soils

The soil samples were analyzed to characterize their main physical and chemical properties, mainly consisting of total organic carbon content (TOC%), total nitrogen (TN%), acidity, bulk density, Fe and Al (%), soil colors (Munsell Chart), and texture (CSSC, 1998). The samples were dried on aluminum plates (2-3 weeks) and then sieved through a wire sieve (<2 mm). For the analysis of bulk density (BD), the samples were weighed while wet and then when dry. The ratio between the weight of the sample (g) and the volume of the cylinder (ml) allowed the BD values to be determined for all the surface horizons that were sampled (0-20 cm). To determine the proportion of the particle sizes (sand, silt and clay), the samples were analyzed using a laser particle sizer (Fritsch "Analysette 22" MicroTec Plus), based on an interval class ranging from 0.08 to 2,000 microns. The texture classes are those found in the Canadian System of Soil Classification (CSSC, 1998) and roughly correspond to those of the FAO-USDA international system (FAO, 2015). The method used to measure the pH was taken from Soil Sampling and Methods of Analysis (Carter and Gregorich, 2008), which uses a $CaCl_2$ solution (0.01 M) at a ratio of 1:2. The total organic carbon content (TOC%) was determined using the method developed by Yeomans and Bremner (1988).

The Kjeldahl method was used for total nitrogen (Quikchem Method, 1996). Lastly, the iron and aluminum contents were measured using the method developed by Ross and Wang (1993) which uses sodium pyrophosphate as reagent. All the chemical analyses were carried out at the Université Laval soil laboratory (forestry, geography and geomatics Department).

Finally, to evaluate the C stocks in soils for different flood and no-flood zones, we used the method of Tremblay et al. (1995:5) which is comparable to that defined by Wiesmeier et al. (2015:3839). The equation is:

$$Q = C \times Bh \times Th \qquad (1)$$

Where, Q = Quantity of organic C of the horizon ($t.ha^{-1}$); C = Concentration of organic C of the horizon (%); Bh = Bulk density of the horizon ($g.cm^{3}$); Th = Thickness of the horizon (20 cm), excluding coarse particles > 2 mm

Diachronic analysis

To analyze the changes and developments in land use in the study area, a diachronic analysis was done using different series of available aerial photographs (1945, 1960, 1966, 1979, 1988, 1998 and 2007) (MRNF, 2012). These panchromatic photographs were scanned and georeferenced in order to analyze the main changes that occurred over the period involved (1945-2007). Orthophotographs were also used to determine the changes that may have occurred between 2007 and 2010 (MRNF, 2012).

The various land use surfaces (farmland versus woodlands) were traced in the form of polygons, and polygonal surfaces were calculated precisely to measure the respective surface areas. The ArcGis (version 10.2) and PCI Geomatica (Version 2013 SP2) software programs were used for the various steps involved in converting standard aerial photographs into scanned and georeferenced images. The years selected to represent the main changes in land use in the study area are 1945, 1966, 1998 and 2007.

Statistical analysis

The soil properties (total organic carbon content (TOC%), total nitrogen (TN%), pH, Fe and Al (%), textural classes and soil bulk density), and soil litter measurements were compiled in Excel files for the processing of statistical analyzes. An analysis of variance (ANOVA) and the Tukey's test were used to check the values of the resulting averages and the statistically significant thresholds (p-value) compared to different variables and groups that were analyzed based on the various flood recurrence zones (FFZ and MFZ) and no-flood zone (NFZ). Correlation analyses (Pearson test) of the various soil properties and litter thickness were also done. A confidence interval of 95% ($p = 0.05$) was used for the statistical processing using R statistical software (version 3.1.2).

RESULTS

Soil properties

Table 1 summarizes the main soil properties that were analyzed for the surface horizons (0-20 cm) based on the various study areas (FFZ, MFZ and NFZ). The average pH measured in the frequent flood zone (FFZ) was 4.94 ±0.74, compared to 4.70 ±1.33 for the moderate flood zone (MFZ) and 4.34 ±0.82 for the no-flood zone (NFZ). Bulk density (BD) was equivalent for all three zones. The average densities were 1.00, 0.99 and 1.10 g/cm^3, respectively.

Regarding soil texture, the values are comparable among the two flood zones, in particular with respect to the proportions of sand and silt. The averages are respectively 44 and 46% for sand and 54 and 52% for silt. The average values obtained for the no-flood zones (NFZ) are 52% for sand and 46% for silt.

The proportion of clay, for its part, is relatively similar for the soils in all three zones, rarely exceeding 3% on average. Lastly, with respect to Fe and Al concentrations, notable differences are found in the floodplain zones and in the no-flood zones. The non-alluvial soils (NFZ) have higher concentrations than in the two other zones (FFZ and MFZ), which is likely due to more marked leaching of these elements (Fe and Al) toward the subsurface horizons (0-20 cm). The average concentrations range from 0.40 ±0.22% (FFZ), 0.67 ±0.40% (MFZ) and 0.98 ±0.57% (NFZ) for each respective zone. For the soils in

Table 1. Physical and chemical soil properties of surface layer (0-20 cm) in the different zones (FFZ, MFZ and NFZ) in Richmond sector (Southern Québec, Canada).

Frequent flood zone (FFZ) (*n* = 26)	**pH ($CaCl_2$)**	**TOC (%)**	**TN (%)**	**C/N**	**Fe + Al (%)**	**Bulk density (g/cm³)**	**C stock (t.ha^{-1})**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Textural Class[a]**	**Colour[b] (Munsell Chart)**
Mean	4.94	2.09	0.17	12.23	0.40	1.00	41.8	2	54	44	2	10YR 4/2
S.D.	(±0.74)	(±0.80)	(±0.05)	(±1.90)	(±0.22)	(±0.17)		(±2)	(±12)	(±13)	(±2)	10YR 5/2
Maximum	5.76	4.60	0.30	16.76	1.17	1.40	128.8	13	83	74	13	
Minimum	2.88	0.39	0.06	6.96	0.18	0.60	4.68	1	25	5	1	
Median	5.30	1.20	0.16	12.12	0.32	1.03	24.72	2	55	43	2	
Moderate flood zone (MFZ) (*n* = 27)												
Mean	4.70	3.45	0.26	12.88	0.67	0.99	68.31	2	52	45	2	10YR 4/2
S.D.	(±1.33)	(±1.56)	(±0.10)	(±2.79)	(±0.40)	(±0.25)		(± 2)	(±13)	(±14)	(± 2)	2.5Y 5/3
Maximum	7.19	8.34	0.59	20.33	1.30	1.57	261.88	12	75	73	12	
Minimum	2.88	1.21	0.14	7.81	0.10	0.63	15.25	1	26	13	1	
Median	4.16	2.97	0.26	12.69	0.64	0.96	57.02	2	56	41	2	
No-flood zone (NFZ) (*n* = 33)												
Mean	4.34	3.52	0.27	13.25	0.98	1.10	77.44	2	46	52	2	10YR 4/2
S.D.	(±0.82)	(±1.57)	(±0.11)	(±2.62)	(±0.57)	(±0.20)		(±2)	(±11)	(±13)	(±2)	10YR 3/2
Maximum	6.98	7.11	0.59	19.37	2.20	1.54	218.98	12	80	70	12	
Minimum	3.08	1.03	0.07	8.84	0.07	0.84	17.30	1	28	8	1	
Median	4.10	3.43	0.24	13.24	0.86	1.08	57.62	2	44	54	2	

[a]Textural classes (CSSC, 1998) and frequency (%). Dry colour.

the no-flood zone, the average concentrations are more than double compared to the values of alluvial soils (FFZ).

Soil biomass

Litter thickness varies significantly depending on the zone (Table 2). There is less litter in the FFZ zone than in the MFZ and NFZ zones. In general, FFZ soil is characterized by a small amount of litter (that is, no litter in 72% of the sites), while litter is present in all the sites for the MFZ and NFZ zones. The average litter thickness is 0.80 cm (FFZ), 2.84 cm (MFZ) and 3.65 cm (NFZ). Although the average litter thickness is relatively comparable among the MFZ and NFZ zones, some differences are found with respect to the composition and type of organic material (Table 2). There is generally less diversity of organic material for the MFZ versus the NFZ zone.

In addition, NFZ soils are usually completely covered with litter, while litter cover in MFZ zones can at times be discontinuous. The differences observed in litter thickness for the three study zones is confirmed by statistical analyses, which provide significant values between the FFZ and the MFZ zones and between the FFZ and NFZ zones (Table 3).

TOC% and TN% concentrations

Total organic carbon (TOC%) and total nitrogen (TN%) concentrations vary significantly based on the different zones under study.

Table 2. Soil biomass (litter) in the different zones (FFZ, MFZ and NFZ) in the study area (Richmond, Southern Québec).

Frequent flood zone (FFZ) (*n* = 26)	**Moderate flood zone (MFZ) (*n* = 27)**	**No-flood zone (NFZ) (*n* = 33)**
Characteristics and nature of organic debris at the top of soil surface (litter)		
Top of the soil surface: The vegetation cover is dominated by hardwood; low recovery of the canopy; dominant tree species: *Fraxinus pennsylvanica*, *Acer negundo* and *Acer saccharinum*; undergrowth dominated by ferns (*Matteucia Struthiopteris*), nettles (*Laportea canadensis*) and goldenrod (*Solidago canadensis*); litter are absent orrarely present and the ground surface is often stripped. (Photo A)	Top of the soil surface: The vegetation cover is dominated by hardwood and shrubs; low to moderate recovery of the canopy; dominant tree species: *Fraxinus nigra*, *Prunus serotina*; underground dominated by herbaceas (gramineae sp.); litter present in all sites; litter cover partially discontinuous; litter composed mainly by twigs, foams and some leaves; mull or moder plant litter dominated. The horizons in subsoil are more visibles in the profile. (Photo B)	Top of the soil surface: The vegetation cover is dominated by hardwood and conifers; moderate to high recovery of the canopy; dominant tree species: *Acer rubrum*, *Abies balsamea*; underground dominated by herbaceas and young trees; litter present in all sites; litter cover generally continuous; litter composed mainly by twigs, foams, leaves, herbaceous, mosses, and conifer needles. Mor or moder plant litter dominated. (Photo C)
	Average of litter thickness (cm)	
0.80 ± 1.66	**2.84 ± 2.80**	**3.65 ± 2.95**
		

The NFZ surface horizon contains 3.52 ±1.57% of organic carbon on average, while the average value is significantly lower for the FFZ, that is, 2.09 ±0.80%. The results of statistical tests (Tukey test) confirm that the values are significantly different between the FFZ zone and the other two zones (MFZ and NFZ). Values below 0.05 are obtained between the FFZ and MFZ zones and the FFZ and NFZ zones (Table 3).

The proportion of C stocks calculated in the three zones is comparable to the SOC concentrations measured in surface soil (0-20 cm) with average values of 41.8, 68.31 and 77.44 $t.ha^{-1}$, respectively.

The SOC values in the no-flood zone are almost double that estimated in the frequent flood soils (FFZ). With respect to total nitrogen (TN%), the lowest average concentrations were measured in the frequent flood zones (FFZ), with average value of 0.17±0.05%, compared to 0.27 ±0.11% for the NFZ. The statistical analysis shows that TN% concentrations in the no-flood zone differ significantly from the other values obtained for the floodplain soils (Table 3). Lastly, the C/N ratio for the data obtained between these two variables does not show a marked difference among the three zones. The average values are 12.23 ±1.90 (FFZ), 12.88±2.79 (MFZ) and 13.25±2.62 (NFZ), respectively.

Table 3. Tukey test in the comparison of mean values of TOC%, TN% and soil biomass between the different zones (FFZ, MFZ, NFZ) in Richmond area (Southern Québec).

Parameter	Group B	Group B	Group B
	FFZ and MFZ	FFZ and NFZ	MFZ and NFZ
Soil Biomass	0.012*	0.000*	0.445
TOC%	0.002*	0.000*	0.980
TN%	0.001*	0.000*	0.997

*Significant at P <0.05 (95%).

With respect to the vertical distribution of TOC% and TN% in the soil profile, concentrations are generally lower deeper in the soil than on the soil surface (Figure 2). Furthermore, variations in the average concentrations of organic carbon between the surface horizons (0-20 cm) and the deeper horizons (80-100 cm) are significantly more marked in the NFZ zone than the other two zones (FFZ and MFZ). The difference between the surface horizons (0-20 cm) and deeper horizons (80-100 cm) is 3.24% in soils of NFZ, 2.69% (MFZ) and 1.60% (FFZ) in alluvial soils respectively. The vertical distribution of TN% in the profiles is similar to that observed for organic carbon, namely, higher concentrations in the surface horizon than in the deeper horizons. The average values for the surface horizons are 0.17% (FFZ), 0.26% (MFZ) and 0.27% (NFZ). The average concentrations obtained at the base of the profile range from 0.02 to 0.05%, which are comparable for the three zones under study. A photography A (Table 2) shows an example of a soil profiles in FFZ which is characterized by a weak differentiation of horizons and no litter layer at the surface.

Table 4 shows the results of Pearson correlation tests obtained for organic carbon and nitrogen, as well as other soil properties measured on the soil surface (0-20 cm). The results show a highly significant correlation (r = 0.92) between TOC% and TN% concentrations. The presence of nitrogen in the soil is therefore closely linked to the presence of carbon, the main source of which is the breakdown of organic matter. Clay and silt are also positively correlated (r = 0.61). Lastly, there is a high negative correlation between sand and clay (r = -0.70) as well as between sand and silt (r = -0.99), which is easily explained by the contrasting differences between the respective proportions of each particle size.

Land-use changes

The diachronic analysis performed using the various series of aerial photographs (from 1945 to 2007) allowed researchers to monitor changes in land use in the study area as well as determine whether the changes that occurred during this period may have had a measurable impact on soil properties, including TOC% and NT% levels. The analysis revealed that the main changes consist of a densification and an extension of wooded areas at the expense of farmland, especially after the 1970s (Figures 3B and 3C). All the sampled sites were previously found on farmland (open fields), and this land progressively turned back into forest. In the areas next to Richmond and Windsor, especially along the riverbanks, this same phenomenon was also noted, which resulted in the farmland being abandoned in favour of wooded areas (Castonguay and Saint-Laurent, 2009).

If we more closely examine the changes that occurred between 1945 and 2007, the study area still constitutes an extensive agricultural area in 1945 (pasture land and forage fields), delimited by wooded areas (Figure 3A). Woody fringes can also be seen along the river banks. The photograph from 1966 shows an expansion and densification of wooded areas, in particular along the river banks and across the island (Figure 3B). Crop lands (especially forage plants) were abandoned in part in favour of forest areas (natural regeneration).

On the photograph from 1998, a large portion of the farmland is now covered with forest stands (Figure 3C). On the photograph from 2008, virtually the entire study area is under forest cover, with open or sparsely vegetated areas along the riverbank (Figure 3D).

These wooded areas were reconstituted naturally, except for a few patches resulting from planting activities. With the calculation of the surface areas measured on the georeferenced aerial photographs (Table 5), wooded areas have increased by 152.1% from 1945 to 2007, including close to 41.7% between 1998 and 2007, which constitutes the most rapid change on the temporal scale being studied.

The farmland was progressively abandoned and a woody fringe was reconstituted on its own, now primarily characterized by maple (*Acer rubrum* and *A. saccharum*) and red ash (*Fraxinus pennsylvanica* and *F. nigra*), species typical of the wetlands in this area (Berthelot et al., 2014).

Finally, an examination of the aerial photographs reveals that the expansion of woodland to the expense of farmland occurred progressively, and the forest cover was relatively similar in all three zones. Major differences

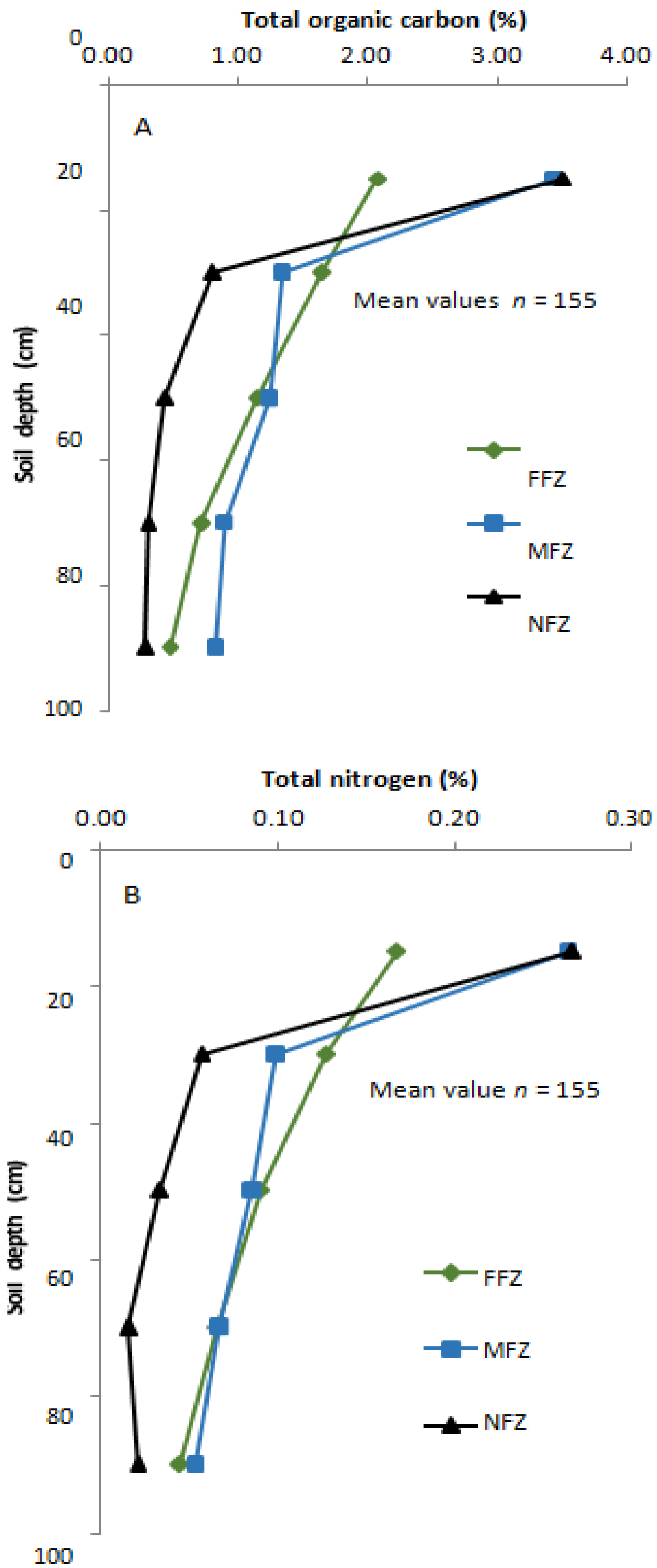

Figure 2. A. Decrease in total organic carbon concentration (TOC%) in the soil profiles (0-100 cm) of the three zones studied (FFZ, MFZ and NFZ); B. Decrease of total nitrogen concentration (TN%) in the soil profiles (0-100 cm) of the three zones studied (FFZ, MFZ and NFZ) (Richmond sector).

Table 4. Correlation between different soil properties (depth of 0-20 cm) in the three zones (FFZ, MFZ, NFZ) in Richmond sector (Southern Québec).

	pH	TOC	TN	Clay	Silt	Sand
pH	1					
TOC (%)	-0.49	1				
TN (%)	-0.40	0.92*	1			
Clay	0.33	-0.30	-0.34	1		
Silt	0.06	-0.33	-0.34	0.61*	1	
Sand	-0.01	0.34	0.36	-0.70*	-0.99*	1

* Correlation is significant at the 0.05 level.

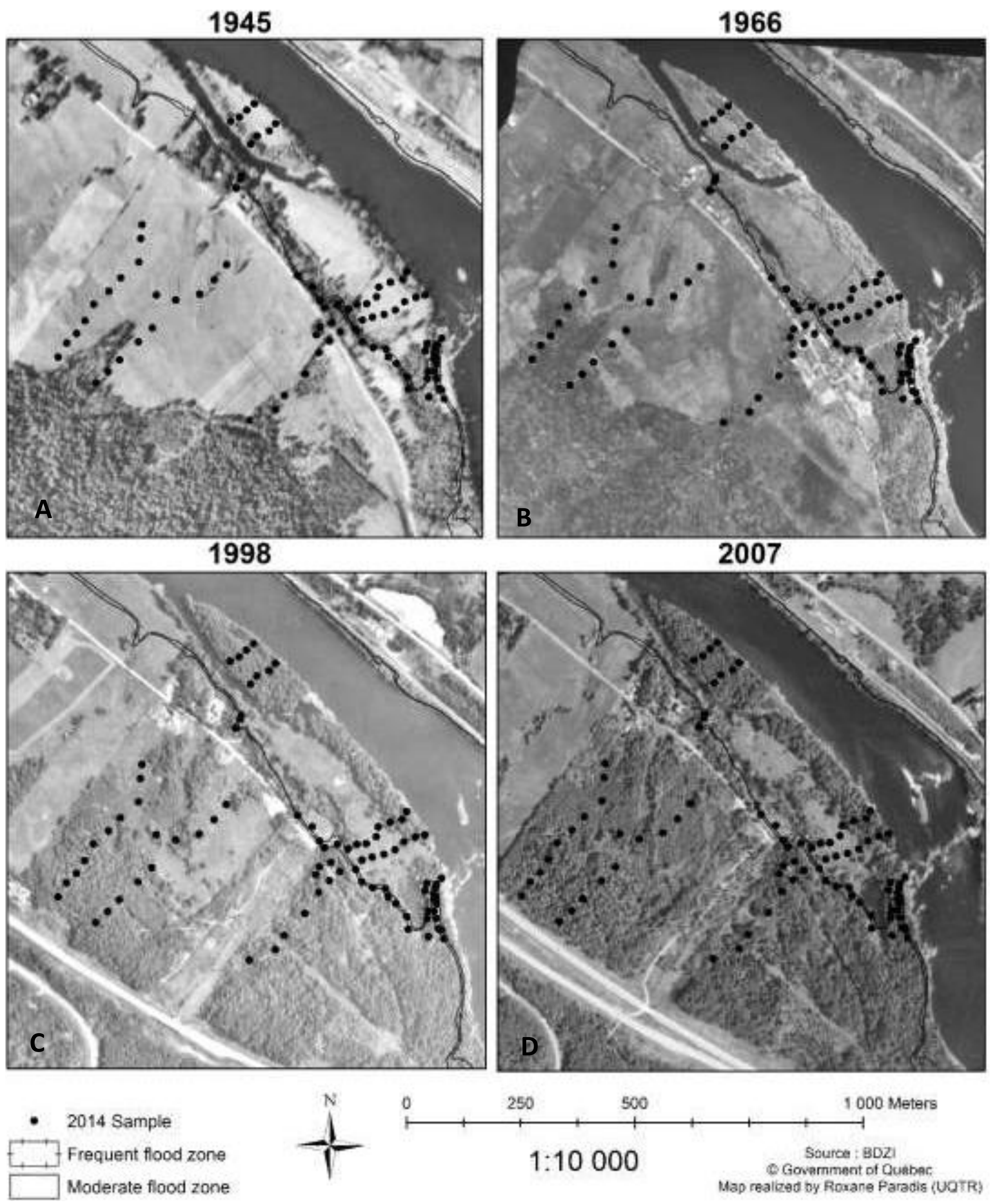

Figure 3. Diachronic analysis of aerial photographs (1945-2007) of the study area in the Richmond sector (left bank of the Saint-François River in southern Québec). A: 1945; B: 1966; C: 1988; D: 2007.

Table 5. Woodland gains in study area between 1945 and 2007 (Richmond sector, southern Québec).

Zone/ year	Woodland areas (m^2)							
	1945	1960	1966	1979	1985	1988	1998	2007
FFz	55.582.41	57.600.45	61.897.26	74.228.43	61.488.83	65.943.39	74.232.86	94.512.79
MFZ	6.603.60	5.606.45	5.681.17	7.817.87	5.548.55	5.992.30	6.401.03	7.998.20
NFZ	136.815.31	117.121.21	129.791.38	194.094.27	208.864.55	248.922.02	278.284.34	400.198.91
Total	199.001.32	180.328.11	197.369.81	276.140.57	275.901.93	320.857.71	358.918.23	502.709.90

The measures are based on the polygonal surfaces drawn from georeferenced aerial photographs.

can be noted in the density or expansion of forest stands based on the three zones being studied, despite the fact that TOC% and TN% concentrations are higher in the NFZ and MFZ. Although the forest cover was basically constituted during the same period for all the zones being studied, it is likely that changes in land use (farmland versus woodland) had no measurable effect on variations in the TOC% and TN% content of the soils analyzed.

DISCUSSION

Variations in soil acidity, bulk density and texture

Soil properties, including pH, bulk density and texture, vary little based on the various alluvial areas being studied. However, there is generally greater variability for soils in the no-flood zones. With respect to pH, the soils in the NFZ zone are generally more acidic than those from the alluvial zones (Table 1). This different soil pH can be attributed to the type of parental material (that is, till and glaciolacustrine deposits) that make up the soil, but also as a result of the type and quantity of litter, which is more substantial in this zone. The presence of litter can contribute to the acidification of soils, particularly for surface horizons (Curtin and Trolove, 2013; D'Acqui et al., 2015). For instance, an increase of SOM in soil surface was related with high soil acidity, and conversely, a substantial decrease in soil pH (by up to 24% in top 7.5 cm) was associated with a decline in SOM following the conversion of permanent pasture to arable cropping in this case (Curtin and Trolove, 2013).

In the no-flood zone, litter has an average thickness of 3.65 cm, compared to 0.80 cm for the frequent flooding zone (FFZ).

It is known that the breakdown of organic matter causes the release of several acidifying compounds, including fulvic and humic acids, as well as humins. Furthermore, the presence of a larger number of coniferous species in the NFZ zone can also cause a decrease in the pH level, given that the breakdown of resinous debris (e.g. lignin, wax) plays a key role in soil acidification (Brady and Weil, 2007).

With respect to bulk density (BD), the NFZ soils have slightly higher average and median values than the floodplain soils (Table 1). However, the results of the statistical tests do not reveal any significant value between the three areas being studied. The variations observed in the NFZ soils can be attributed to the mineral matrices with different origins (parental material), but also the soil structure (granular or subangular forms), which is more apparent in these soils (Gervais-Beaulac, 2013). Lastly, the dominant texture of the surface soils (0-20 cm) in the flood zones (FFZ and MFZ) is mainly silt loam, while sandy loam is the dominant texture in NFZ soils. These soils can also contain gravel or pebbles, while no coarse materials are found in the floodplain soils (>2 mm) in the uppermost part of the profiles (0-100 cm). Fine to very fine sediment (silt and clay) originating from freshet sediment is frequently found in the alluvial zones. The phenomenon of vertical floodplain aggradation (that is, successive deposits of suspended fine sediment during flooding) often accounts for the dominant presence of fine particulate matter such as silt in alluvial soils. This vertical aggradation process maintains the soil in an immature state and hinders its pedological development (Gervais-Beaulac et al., 2013; Saint-Laurent et al., 2014). The constant inflow of flood sediment in fact generates soil profiles that are young and have little chemical alteration, and this provides some vertical homogeneity to alluvial soils (Saint-Laurent et al., 2014). Soils in the no-flood zones have different textural matrices that must be associated with the bedrock, which is basically made up of more varied materials such as till and glaciolacustrine deposits. In fact, part of the NFZ zone is made up of undifferentiated till (that is, glacial deposit without any particular morphology) and glaciolacustrine deposits with shallow water facies (MEMR, 1989). These two types of deposits are more heterogeneous and likely to contain larger proportions of coarser materials (that is, medium sand, gravel, pebbles).

Variation of soil biomass

The average thickness of the litter is significantly lower in the FFZ zone than in the other two zones being studied. In the sites located in the FFZ, only eight were covered with litter and the measured thicknesses were low, that is, 0.80 cm on average (Table 2). In these frequent-flood zones, the litter that accumulates on the surface of the soil during the growing period is most often carried off by the current during floods, leaving the soil stripped bare in the most affected areas (Figure 3). The Richmond area is particularly affected by successive flooding that can occur equally in the spring and the fall. From 1900 to 2015, over 50 flood events were recorded in the Richmond-Windsor area, a certain number of which in the summer and fall, including increased flooding after the 1970s (Appendix). These successive floods prevent the formation of thick litter, thus limiting the inflow of organic matter. Since the main source of soil organic carbon comes from soil biomass, in particular litter, the transfer of nutrients such as OC and N is often inhibited.

The results obtained for TOC% and TN% concentrations in the surface horizons (0-20 cm) confirm that the inflow of organic matter is minimal in the FFZ zone. Higher levels of OC and N are noted in the MFZ zone, which is due to the presence of litter which, although less thick than the litter in the NFZ zone, still allows a sufficient contribution of organic matter for the soil. The average thickness of the litter for the NFZ zone is significantly higher (3.65 cm ±2.95) than for the frequent-flood zone (FFZ) (0.80 cm ±1.66) and provides a constant inflow of organic matter to the soil. Not affected by floods, soil biomass can accumulate over the years, thus ensuring to some extent a permanent source of organic matter. This naturally favours the transfer of nutrients such as OC and N in the soil surface upper layers. The flood zone with a recurrence interval of 20 to 100 years is very similar to the no-flood zone with respect to the results that were obtained.

Similar results were also observed for the flooded or unflooded soils (Cierjacks et al., 2010; Myster, 2015). These authors find that soils are more fertile in less frequently flooded areas and contain more organic matter. Also, the concentration of organic C in the soil horizons increased significantly with distance to the main channel (Cierjacks et al., 2010). Other results show that increased of floods has an impact on decreased of soil fertility and may have effects on forest diversity (Myster, 2015).

Distribution of TOC% and TN% in alluvial soils

In relation to the absence or virtual absence of litter in the FFZ, TOC% and TN% concentrations in the surface layers (0-20 cm) are reduced compared to the other two zones (MFZ and NFZ), which benefit from an inflow of organic matter through the presence of litter (Tables 1 and 2). OC and N concentrations are directly related to the quantity and quality of litter. Since the soils in the FFZ are virtually stripped of litter, it is not surprising to find significantly lower concentrations of TOC% and TN% in these soils subjected to successive flooding. The quantity of litter is significantly greater in the NFZ soils, and the concentrations of these elements are also significantly higher (Table 1). The correlation analysis performed on the various soil properties in fact reveals a strong positive correlation between these two variables (Table 4), showing a close link between these two soil constituents. In fact, it is known that soils with a certain concentration of organic carbon are also rich in nitrogen (Brady and Weil, 2007). Lastly, although the different textural matrices can play a role in the concentration of these two elements (OC and N) within the soil profile (especially for fine-matrice soils such as clay and silt), the correlation analysis did not reveal any significant values between the textural components and the TOC% and NT% variables.

The distribution pattern for TOC% and TN% concentrations is virtually similar at the base of the soil profiles (80-100 cm) for the MFZ and NFZ soils. Since the main sources of organic matter (e.g. leaf litter, rootlets, microorganisms) basically come from the litter and soil surface layers (that is, rhizosphere), it is understandable that higher concentrations are found in the surface horizons (Don et al., 2007). It can be noted, however, that variations between the TOC% and TN% content between the surface horizons and the horizons at the base of the profile are more marked for the MFZ and NFZ soils and have a relatively linear curve for the FFZ soils (Figure 2). The small quantity of litter on these soils in fact hinders the incorporation of organic matter and progressively causes soil depletion.

Conclusion

Marked differences were found with respect to the concentrations of nutrients (organic carbon and nitrogen) in the soils that were analyzed in the various study areas (FFZ, MFZ and NFZ). TOC% and TN% concentrations are significantly lower in the FFZ, while they are higher for the MFZ and especially for the NFZ, as confirmed by the statistical analyses (ANOVA and Tukey test). Litter thickness is also lower in the FFZ than in the other two zones. The stripping of the litter by successive floods in the FFZ creates a direct loss of organic matter, which constitutes one of the main sources of nutrients and has the effect of reducing the quantity of nutrients (that is, TOC% and TN%) in the soil. Since TOC% and TN% are essential elements for soil development and biogeochemical processes, this could have a long-term impact on the vitality of forest stands and their renewal rate. Frequent floods may hinder the establishment of seedlings, which would be vulnerable to the force of the currents, and the seedlings that remain may be burried by flood sediments, thus creating a high risk of mortality for the seedlings.

This study provides a better understanding of the dynamics of alluvial soils of increased flood frequency. If current hydroclimatic changes result in an increase in flood intensity and frequency, a decrease in alluvial soil organic carbon and nitrogen content is to be expected. As a result, the storage of organic carbon in the floodplains is important for maintaining the quality of alluvial soils, quality of alluvial soils, as well as for reducing atmospheric CO_2 and for the vitality of forest stands.

Conflict of Interests

The authors have not declared any conflict of interests.

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Soil organic carbon and total nitrogen stock response to traditional enclosure management in eastern Ethiopia

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Traditional area enclosures are widely used by pastoralists in East Africa. However, the response of basic soil properties to the establishment of traditional enclosure management remains poorly understood. The aim of this study was to investigate the impacts of area enclosure on soil organic carbon and total nitrogen stock in the Bordade rangelands, eastern Ethiopia. The soil samples were collected from twelve area enclosures and openly grazed areas at a depth of 0 to 15 and 15 to 30 cm. The samples were analyzed for soil organic carbon, total nitrogen and bulk density. Establishment of area enclosure had significantly more 27.5% soil organic carbon and 27.5% total nitrogen stock compared with the area outside area enclosure. Soil organic carbon and total nitrogen stock were significantly higher in the top 0 to 15 cm soil layer compared with 15 to 30 cm subsoil. Overall, the study showed that establishment of rangeland enclosures and the short-term resting period followed by dry season grazing at light stocking rate has the potential to improve soil organic carbon and total nitrogen stock, which is an option for realizing positive vegetation changes that support the local pastoral economy in the semiarid rangelands of eastern Ethiopia.

Key words: Carbon sequestration, enclosures, sequestration, total nitrogen stock.

INTRODUCTION

The rangeland biomes of Ethiopia are major feed resources for livestock and wild animals. In the arid to semi-arid environments of the Country, more than 62% of the land is used for livestock grazing (EARO, 2003). However, the majority of these biomes have been subjected to loss of nutrients and biodiversity changes, soil organic matter and land deterioration due to vegetation removal by livestock and/or burning, and climate variability (Du Preez et al., 2011a; Belay, 2015).

In response to different kinds of land deterioration and the scarcity of feed for vulnerable herd classes, pastoralists conducted land restoration through livestock

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grazing management practices (Tache, 2010; Teshome, 2016). Livestock grazing management practices have effects on the magnitude, distribution and cycling of carbon and nitrogen in the rangeland ecosystems (Tessema et al., 2011; Ayana et al., 2012). Improving soil organic carbon storage in the dry land soils through proper management of livestock is one of the techniques advocated to mitigate against and/or adapt to greenhouse gas emission (McSherry and Ritchie, 2013). Despite this fact, the knowledge of the interaction between soil carbon dynamics and livestock grazing in dry lands remains limited, particularly in sub Saharan Africa, where extensive livestock grazing is one of the most common and widespread forms of land uses.

The impacts of livestock grazing management are highly variable and, despite many studies (eg. Reeder, et al., 2004; Li et al., 2011; Tessema et al., 2011), the impact of livestock grazing management on soil organic carbon and total nitrogen stock in rangelands is still unclear. Increasing livestock grazing intensities increases soil carbon (Tessema et al., 2011; Ayana et al., 2012) and nitrogen concentrations (Liu et al., 2011), have no effects (Jafari et al., 2008) or decreases soil carbon (Gill, 2007) and nitrogen levels (Steffens et al., 2008). This variation in carbon and nitrogen stock is a reflection of variation in climate, soil type, landscape position, plant community type and management practices (Reeder and Schuman, 2002; Li et al., 2011; McShery and Ritchie, 2013).

The availability of nitrogen can control both carbon and nitrogen accumulation because it constrains both inputs and outputs of carbon and nitrogen (Piniero et al., 2010). It increases primary productivity, increasing carbon inputs to the soil, and may also decrease soil respiration, decreasing carbon outputs from the soil (Piniero et al., 2010; Cheng et al., 2011). Grazers can alter nitrogen stocks by increasing or decreasing nitrogen inputs and outputs. They may decrease N inputs by decreasing legume biomass or cover as most grasslands experience some level of nitrogen limitation (Lal, 2004). Heavy grazing can negatively influence vegetation by destroying and/or disrupting the soil structure, enhancing organic matter oxidation (Frank and Evans, 1997; Evans et al., 2012), and resulting in the changes of soil organic carbon and total nitrogen storage. Grazing induced change in carbon and nitrogen balance modifies the concentration of other plant nutrients in the soil (Evans et al., 2012; Marriott et al., 2010) and soil compaction (Evans et al., 2012).

Previous studies intensively evaluated the impact of grazing on vegetation in arid and semiarid rangelands of Ethiopia. Only a few studies documented the effects of land management systems on soil properties in the rangelands of Ethiopia. However, the impacts of grazing on carbon and nitrogen stocks and other soil properties have not been studied in rangelands of eastern Ethiopia. In drier and arid ecological regions, there might be trade-offs between managing lands for soil carbon and nitrogen, and animal production. Context-specific information is essential to advocate land management practices that increase carbon sequestration (Derner and Schuman, 2007). Therefore, this study was to assess impacts of traditional rangeland enclosure management on soil organic carbon and total nitrogen stock in eastern Ethiopia.

MATERIALS AND METHODS

Study area

The study was carried out in the Bordade Rangelands of the Oromia Regional State, eastern Ethiopia (40° 12ˈ31.37ˈˈto 40°32ˈ12.32ˈˈ E and 8° 56ˈ38.75ˈˈN to 9°13ˈ58.35ˈˈ N), ~ 268 km east of Addis Ababa (Figure 1). The rainfall in the study areas is bimodal with a short rainy season from March to April, and the main rainy season from July to September. The mean minimum rainfall is ~400 mm and means maximum rainfall ~900 mm. The mean annual temperature is 21°C. The natural vegetation of the study area is characterized as Acacia-wooded grasslands (Le Houérou and Corra, 1980). This study was carried out from September to December 2014, immediately after the main rainy season.

Sampling design

The study was conducted along the livestock grazing gradients representing two sites that were subjected to different grazing intensities (light and heavy) based on the history and intensity of livestock grazing and discussion with local pastoralists and districts pastoral development offices staff, who have extensive knowledge of study areas and visual field observations prior to this study. Heavy grazing sites or open grazing land represents the most common land use system in the Bordade Rangelands and is defined as the communal rangelands that are not privately owned, yet belonging to the communities whose members have equal access rights to the communal resources. Light grazing sites or enclosures in this study means a shrub fenced area of < 1 ha grazing land which is protected from grazing during the wet season, while the adjacent openly grazed rangelands are utilized, although some grazing may occur in the enclosure in the late dry season and in drought years when the forage is extremely scarce (Napier and Desta, 2011).

Twelve replicate of enclosures within the same age group (10 yrs) and 1-2 km apart (aerial distance, measured using Garmin GPS 72 (Garmin International Inc., USA) and adjacent open grazing lands were randomly selected to examine the influence of enclosure establishment across the gradients of woody encroachment. Ten sampling sites in each light and heavy grazing site were selected, using a stratified sampling procedure. The replicates were located on similar lithology, soils, topography and slope.

Soil sampling and analysis

Ten soil samples were taken at a depth of 0 to 15 cm and 16 to 30 using auger in a 1 m x 1 m quadrant, yielding a total of 480 soil samples (2 sites x 12 sampling sites x 2 soil depth x 10 soil samples). The soil samples at each site were pooled to form one composite soil sample per sampling site, yielding a total of 48 soil samples (2 sites x 12 sampling sites x 2 soil depth). Samples of the same depth were mixed thoroughly in a large bucket in order to

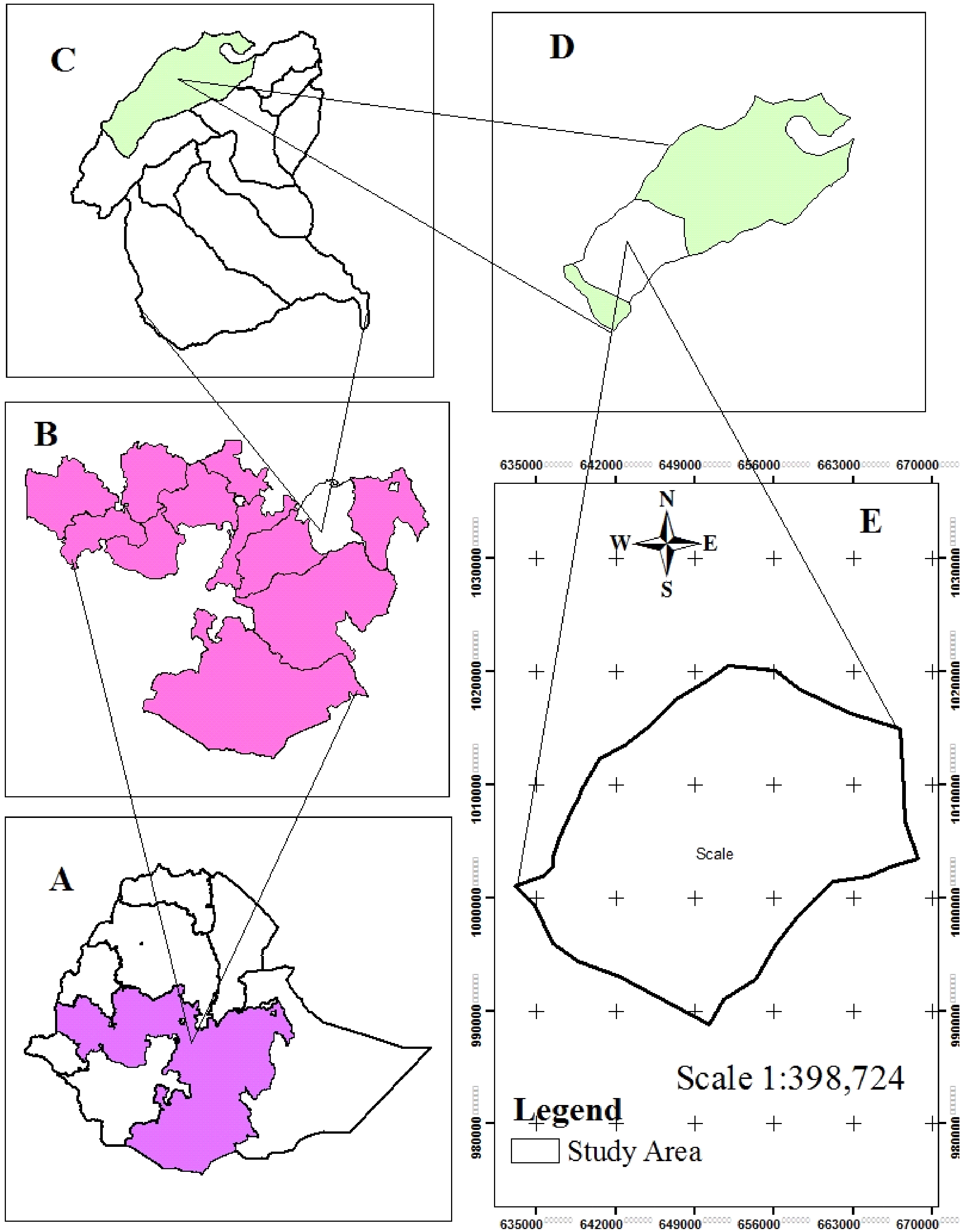

Figure 1. Oromia Region in Ethiopia(A), West Hararghe Zone in Oromia Region (B), Mieso District in West Hararghe Zone (C) Map of study area (D).

Table 1. Partial ANOVA table showing degrees of freedom (d.f.) and P-values (at α =0.05) for soil organic carbon (SOC), soil total nitrogen (STN), and bulk density (BD) across grazing management (GM) and soil depth (Sd) in the semiarid rangeland, eastern Ethiopia.

Grazing management	d.f.	SOC (%)	STN (%)	SOC (t ha^{-1})	STN(t ha^{-1})	BD (g cm^{-3})
GM	1	<0.001***	<0.001***	<0.001**	<0.01*	< 0.001***
Sd	1	<0.001***	<0.001***	<0.001***	<0.001***	< 0.001***
GM x Sd	1	0.05NS	<0.01*	0.05NS	0.05NS	0.05NS

NS, P ≥0.05, *P <0.05; **P <0.01; ***P <0.001.

Table 2. Percent soil organic carbon (SOC), soil total nitrogen (STN), and bulk density (BD) as affected by grazing management and soil depth (mean±Sd) in the semi arid rangelands, eastern Ethiopia.

Fixed effect	Soil parameter				
	SOC (%)	STN (%)	SOC (t ha^{-1})	STN(t ha^{-1})	BD (g cm^{-3})
Grazing management					
Area enclosure	2.23±0.6	0.21±0.06	43.12±0.72	39.63±0.97	1.32±0.2
Grazed area	1.59±0.5	0.15±0.05	36.85±0.7	33.95±1.04	1.57±0.1
Soil depth(cm)					
0-15	2.41±0.42	0.23±0.04	48.49±0.67	45.3±0.53	1.36±0.2
15-30	1.4±0.37	0.13±0.03	31.47±0.37	28.28±0.59	1.52±0.14

Means followed by different superscript letters in the rows are significantly different at P = 0.05 level, n = 48.

obtain one composite soil sample per depth increment per sampling site (Yusuf et al., 2015). The composite soil samples were divided into three equal parts, out of which one was randomly chosen and stored in plastic bags, labelled, sealed and transported to the Haramaya University (HU) soil laboratory.

Soil samples were analyzed for organic carbon, total nitrogen and bulk density following standard procedures at HU. Prior to analysis, samples were air-dried at room temperature and passed through a 2 mm sieve to remove the coarse mineral fractions, plant leaves, visible roots and other debris. Soil organic carbon was determined following the Walkley and Black (1934) method; total nitrogen by the Kjeldahl method (Bremner and Mulvaney, 1982); and bulk density (g cm^{-3}) using the core method (Blake and Hartage, 1986). SOC and STN were converted to a mass basis per unit area following the formulae proposed by Wairiu and Lal (2003).

$$SOC\ (t\ ha^{-1}) = \rho_b\ (g\ cm^{-3}) \times C\ (\%) \times \text{soil depth (cm)} \times 100 \quad (1)$$

$$STN\ (t\ ha^{-1}) = \rho_b\ (g\ cm^{-3}) \times N\ (\%) \times \text{soil depth (cm)} \times 100 \quad (2)$$

Where ρ_b = bulk density

Data analysis

The data were statistically analyzed by two-way analysis of variance (ANOVA), using the R statistical package (R Development Core Team, 2005) to determine the effect of grazing intensity , soil depth and their interaction on soil carbon sequestration and total nitrogen stock. The values of the probability lower than 0.05 (P < 0.05) were regarded as statistically significant. Averages were calculated per sampling site to avoid pseudo-replication, as sampling sites were assumed to be independent. Data were transformed to meet the assumption of normality and homogeneous variances.

RESULTS

Soil organic carbon stock

The results of this study showed that both grazing management and soil depth influenced both the percent of soil organic carbon and soil organic carbon stock (Table 1). The percentage of soil organic carbon was significantly lower for openly grazed areas compared with enclosure (P < 0.001). As a result, the traditional rangeland enclosure areas attained higher soil organic carbon sock (P<0.01) in comparison to the openly grazed areas. The enclosure had 40.4% more percentage of soil organic carbon and 17% more soil organic carbon stock concentration compared to the openly grazed areas. With regard to soil layers, the soil organic carbon and soil organic carbon stock content varied considerably (Table 2). The uppermost soil layer treatment showed higher (P<0.05) percentage of soil organic carbon and soil organic carbon stock concentration compared to the sub-soil layer.

Soil total nitrogen stock

The results of this study showed that the percentage of soil total nitrogen was significantly influenced by both grazing management and soil depth (Table 1). The percentage of soil total nitrogen was lower for openly grazed areas compared with area enclosures ($P < 0.001$). As a result, the traditional rangeland enclosure significantly attained higher soil total nitrogen stock ($P <0.01$) in comparison to the openly grazed areas. The enclosure had 40.4% more soil total nitrogen and 16.7 % more soil total nitrogen stock concentration compared to the openly grazed areas. With regard to soil layers, the total soil nitrogen and soil total nitrogen stock content varied considerably (Table 2). The uppermost soil layers treatment showed higher ($P <0.05$) percentage soil total soil nitrogen and soil total nitrogen stock concentration compared to the sub-soil layer.

Bulk density

Both grazing management and soil depth influenced bulk density (Table 2). The bulk density of soil at the time of sampling was significantly higher ($P<0.01$) in the open rangeland than that of area enclosures. The mean values of bulk density1.57±0.1 and 1.32 ±0.2 g/cm^3 were recorded for open grazed and enclosure areas respectively. There was also a significant ($P<0.05$) difference in bulk density of soil between uppermost surface soil and sub surface soil, while other grazing management-by-depth combinations had insignificant ($P >0.05$) effects on bulk density (Table 1).

DISCUSSION

Impact of area enclosure on soil organic carbon stock

The results of this study show higher soil organic carbon and soil organic carbon stock in the area enclosures than in the openly grazed areas. The observed higher soil organic carbon and soil organic carbon stocks in area enclosure agrees with findings by Yusuf et al. (2015). The higher soil organic carbon and soil organic carbon stocks could be attributed to the increased vegetation production, litter quality and nutrient cycling (Austin and Vivanko, 2006), and decrease of nitrogen losses via volatilization of ammonia and nitrate through animal urine and dung patches (Pinerio et al., 2010). Higher nitrogen concentration in our enclosures soils might be resulted in enhanced nitrogen availability for soil organic matter formation and storage (Pineiro et al., 2010; Mekuria, 2013).

Heavy grazing outside area enclosure leads to a decrease in soil organic carbon and nitrogen by direct removal of above ground biomass, that is, reduction of potential CO_2 fixation in photosynthetic tissue and reduction in belowground carbon inputs through lower root production and higher root litter turnover (Reeder et al., 2004). Young et al. (2005) in their research evaluated the effect of area enclosure and grazing on soil characteristics in north of China, showed that grazing leads to decrease in plant cover and soil organic carbon. Under heavy grazing, rangelands showed declines in soil organic carbon (Bagheri et al., 2009; He et al., 2011). This can be due to the removal of vegetation by livestock and the deduction of plant cover; and consequently, the decrease of the soil organic carbon. The result of this study is in agreement with Yusuf et al. (2015) who reported lower soil organic carbon and soil organic carbon stock from the areas outside area enclosure in southern Ethiopia. Similarly, studies from Kenya, found a significant decrease of soil organic carbon and soil organic carbon stock due to intensive grazing in semi-arid environments (Stephen et al., 2014).

The finding of this study together with those from previous study in Borana rangeland by Yusuf et al. (2015) and Tigray lowlands by Mekuria (2013) indicated that establishment of area enclosures has altered soil chemical and physical properties and resulted in substantial increases in soil organic carbon stock under area enclosures. This is in agreement with the observed high soil organic carbon due to establishment of area enclosure of this study.

The result of these studies also showed a significant difference in soil organic carbon and soil organic carbon storage between two depths in the study rangelands. The soil organic carbon and soil organic carbon storage were significantly higher in uppermost surface soil than sub soil. Because the aerial organs fall above ground and biological activities are increased. Then, carbon transfers to the root and finally goes to the soil. Yousoufin et al. (2011) and Jafari et al. (2008) in line with the result of this study, they reported decreasing soil organic carbon stock with increasing the depth of the soil. The percentage of soil organic carbon in the first 0 to 15 cm were higher than 15 to 30 cm, therefore the carbon stock in the first depth was greater than the second depth.

The decreasing trend of soil organic carbon with an increase in soil depth was also reported by Abebe et al. (2006) in Borana rangeland and Abule et al. (2005) in the Middle Awash Valley of Ethiopia. Moreover, because most organic residues are incorporated in, or deposited on the surface, organic matter tends to accumulate in the upper layers (Brady and Weil, 1996). Soil organic carbon contents are therefore generally much lower in subsurface horizons than those of the surface soils (Brady and Weil, 1996). According to Yousoufin et al. (2011) and Jafari et al. (2008), soil organic carbon and soil organic carbon stock has indirect relationship with soil depth. This implies that more carbon is sequestered in the top 15 cm of soil.

Impact of area enclosure on soil total nitrogen stock

There was an appreciable increase in soil total nitrogen through establishment of area enclosures (Table 2). The observed increase in soil total nitrogen through establishment of area enclosure might be as a result of increase in organic matter content of soil in area enclosure. Similarly, the higher percentage of nitrogen concentration and total soil nitrogen stocks in enclosures soils might be a result of lower nitrogen losses via volatilization of ammonia and nitrate through animal urine and dung patches (Pineiro et al., 2010). On the other hand, our findings showed that total soil nitrogen was lower the openly grazed rangelands. The possible explanation might be attributed to low nitrate content which are easily lost through soil erosion (Belsky et al., 1989) and higher N losses via volatilization of ammonia and nitrate through animal urine and dung patches (Mekuria, 2013).

Study results by Su et al. (2005) and Pei et al. (2008) from semi-arid environments of Central Asia and Yusuf et al. (2015) from Borana rangelands of southern Ethiopia indicate that establishment of area enclosure have the capacity to improve the percentage of soil organic carbon and soil organic carbon stock. Generally, the soil total nitrogen followed the pattern of soil organic carbon distribution in all the studied soils. This is due to the fact that most nitrogen forms part of the soil organic matter (Ganuza and Almendros, 2003).

Higher soil total nitrogen and soil total nitrogen stock was held in the top soil layer than the lower layers in this experiment, which was consistent with data on arid rangelands of Kenya (Verdoodt et al., 2009). According to Abebe et al. (2006) in Borana rangeland and Abule et al. (2005) in the Middle Awash Valley of Ethiopia, soil depth indirectly related to soil total nitrogen and soil total nitrogen stock and Yousoufin et al. (2011) confirmed this opinion. This may imply the effect of livestock grazing management on soil total nitrogen is more pronounced in the top soil layer.

Conclusions

This study has demonstrated that soil organic carbon and total nitrogen stocks were responded positively to the establishment of area enclosures. There were significantly higher soil organic carbon and total nitrogen stocks inside the area enclosures than in the openly grazed areas. There were also higher soil organic carbon and total nitrogen inside the area enclosures than in the open access grazing areas. The results suggest that establishment of area enclosures in formerly degraded communal grazing lands of semi arid regions is a feasible (conservation-oriented) management option for carbon sequestration and land rehabilitation through an improved plant soil system. However, from perspectives of resource utilization, wet season resting period followed by grazing during dry season at light stocking rate would improve soil organic carbon and total nitrogen, and optimize returns in terms of livestock products, ecosystem services and functions. Further studies are, however, required to investigate the ecological, economic, and social impacts of enclosures before expanding area enclosure for land management as further expansion of enclosures could increase grazing pressure on the remaining communal grazing lands and aggravate degradation in the lowlands of eastern Ethiopia.

Conflict of Interests

The authors have not declared any conflict of interests.

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