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A Review on Soil Carbon Sequestration in Ethiopia to Mitigate Land Degradation and Climate Change

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Abstract
Land degradation in Ethiopia leads, *inter alia*, to a decline in soil quality and depletion of soil organic carbon (SOC). Sequestration of SOC, in turn, is a practical option not only to increase the SOC stock and quality, but also to decrease soil degradation, increase productivity, and mitigate climate change. The objective of this review is to show gaps and priorities in research and development related to SOC sequestration in Ethiopia. The review focuses at the SOC pool, distribution, its relation with degradation, progress achieved and future direction in SOC sequestration.
The review shows that land degradation in Ethiopia also implies a historic loss of the SOC pool. A preliminary estimate in this study shows that the SOC pool in Ethiopia is 14 billion tons of C. Reviewed figures (from plot to large scale study) implied erosion-induced SOC depletion values from 0.02 to 0.97 tonnes/ha/yr. Accelerated carbon depletion (in both biomass and soils) occurs on an estimated 0.2 million ha of forest land and on 8 million ha of croplands in two cropping seasons. Review of eight year Ministry of Agriculture report shows that the current national estimate of SOC building practices, sustainable land management, is covering about 2 million ha per year, with an investment of 150 million USD/yr. In spite of such development efforts in natural resources management since the mid-1970s, still about 50 million ha of land has depleted SOC. Based on the review, the paper outlines research and development priorities and recommends establishing carbon network and linking SOC financing with efforts to mitigate land degradation and climate change.
Key words: Climate Change, Ethiopia, Soil, Carbon Sequestration.

1. Introduction

Ethiopia is located at 2°54'N-15°18' N latitude and 32°42'E -48°18' E longitude. It is a land-locked country with a land area of 1.12 million km^2 occupying a significant portion of the Horn of Africa. The country has diverse climate, geology and topography resulting in a heterogeneity of soil types (Hurni *et al*, 2007; Mesfin, 1998). The Ethiopian highland is believed to have been very fertile prior to human settlement a few thousand years ago. Today, however, one of the major challenges facing the nation is the degradation of land. Land degradation in the Ethiopian highlands is well-documented (e.g., Hurni *et al* 2007, Demel 2001, SIDA 2003, FAO 1984, Hawando 1997, Taddese 2001). Land degradation in Ethiopia has contributed to the decline in agricultural productivity, persistent food insecurity, and rural poverty (World Bank, 2008). Soil loss, nutrient depletion and decline in soil quality are some of the manifestations of land degradation. The drastic effect of soil erosion on soil quality and soil organic carbon (SOC) is described in Kimble *et al.* (1999) and Lal (2004) as the effect of high SOC concentration in the top soil. Thus, the degradation of land in Ethiopia has resulted in the depletion of the carbon stock not only in biomass, but also in soils.
Coupled with land degradation, climate change is exacerbating environmental problems in Ethiopia (NMSA 2001, Niles, *et. al* 2010). The first national greenhouse gas (GHG) inventory was conducted in 1994. The study shows that the sink capacity in the agriculture, forestry and land use sectors were decreasing rapidly while there has been an increasing trend in GHG emissions in Ethiopia (NMSA 2001). Carbon sequestration is one of the mitigation measures to offset one of the GHG emission, namely CO_2.
Carbon sequestration can store carbon in the long term in oceans, soils, vegetation (especially forests) and in geologic formations. The term "sequestration" as used in the Kyoto Protocol is equivalent to the term "storage" (FAO, 2001b). Carbon sequestration is a term describing the process that removes carbon from the atmosphere either through natural and artificial processes. Natural carbon sequestration considers soils as a biogeochemical interface between atmosphere, biosphere and hydrosphere, playing an active and significant in global emissions

and sequestration. Sequestration could be in organic or inorganic forms, and places where carbon is stored are called carbon sinks (Jones 2007).
Bass *et al. (*2000) reviewed two carbon management strategies as being (1) carbon sequestration and (2) carbon conservation. Sequestration is increasing the rate of carbon accumulation into a sink, while conservation is reducing or minimizing the already fixed carbon in a sink. For this paper, soil organic carbon (SOC) sequestration has been defined as the accumulation of carbon through sustainable land management practices. In determination of SOC sequestration, the resistant forms of soil organic carbon, such as charcoal, are not taken into account (Batjes 1996); however, sequestration focuses on resistant forms of soil carbon. A soil carbon pool comprises both of the soil organic carbon (SOC) and the soil inorganic carbon (SIC),cf. Lal (2004). Soil has the potential to store carbon and contribute to mitigating global climate change. The soil is the largest terrestrial pool of organic carbon (Batjes 1996, Lal 2004). In total, soil contains about 3 times more carbon than the atmosphere, and 4.5 times more carbon than in living beings. Hence, a relatively small increase in the proportion of soil carbon could make a significant contribution to reducing atmospheric carbon (Walcott *et al*. 2009, Lal 2004).
A review on soil carbon sequestration in Ethiopia is required to identify key gaps and know major priorities in research and development to increase soil carbon stocks while increasing agricultural productivity. In the past, the most visible problem, land degradation, has taken attention of the government and its development partners. There are several research projects focusing on the visible problem of soils and associated issues, yet no attention was given to the invisible problem, depletion of the soil organic pool. This difference in focus has necessitated review on soil carbon sequestration in order to direct research and development projects focusing on soils in a bid to mitigate land degradation and climate change.

2. Soil carbon pool and distribution in Ethiopia

The great variability in topography, geology, organic material and climatic factors have resulted in high variability of the different soil types in Ethiopia (Hurni *et al.*, 2007; Haileslassie *et. al*, 2005; Mesfin, 1998). FAO's soil map provides the description and regional distribution of soil types in Ethiopia (Hurni *et al*, 2007). In spite of the existence of the 19 FAO soils units and its variability, six units cover half of the land mass (Haileslassie *et al.*,;2005) (Table 1).
Although there are case studies on soil carbon pools for selected parts of Ethiopia (Girmay *et al.*,2008) estimate on national soil carbon pools is missing. In spite of the limited knowledge of soils, data, variability and various forms of soil carbon and factor influencing the pools, attempt was done to estimate soil carbon pool in Ethiopia (Table 1). The estimate was based on bulk density figures from African Highland Initiative (AHI 1997) and Mesfin (1998). Soil profile data were used from UNDP/FAO (1984) and estimates from Batjes (1996). Soil carbon stocks (tonnes C/ha) was calculated based on carbon concentration (%) and bulk density (BD) for each mean depth in the soil unit as described in Jones (2007). In this review, soil organic carbon (SOC) and soil organic matter (SOC) are used interchangeably, with the understanding that SOC is only about 58% of SOM (Lal 2004, Batjes 1996, Jones 2007).
Looking at the major landforms and altitudinal variations, the soils of Ethiopia can be grouped as highland soils and lowlands soils (AHI 1997, Hurni *et al.* 2007). Divided by the Ethiopian Rift Valley, the highlands have plateaus and mountain landforms with adequate rainfall, moderate to cool temperatures and a dense human population. According to Hawando (1997), the highland areas represent areas above 1500 m asl.
According to Mesfin (1988), the predominant soil types in the highlands are Nitosols, Ferralsols and Vertisols. Nitosols are often associated with Ferralsols and Acrisols (FAO 2001a; Hurni *et al.* 2007). Large amounts of soil organic carbon lie above 100 cm in depth, as less dynamic soil carbon in the deep soils of tropics and subtropics, such as Acrisols, Ferralsols and Nitosols and alluvial soils (Batjes, 1996)**.** Vast area of Vertisols exist in Ethiopia (FAO, 2001,a; Mesfin, 1988). Most surface horizons of Vertisols in Ethiopia contain 3-10% organic matter and generally increasing with higher clay contents (Jutzi *et al.* 1988). Cambisols occur in both the highlands and the lowlands on slopes where erosion is common. These are youngish soils with a humus surface layer, and used intensively leading to lower soil organic content in the highlands of Ethiopia.
The lowlands of Ethiopia are in the Rift Valley of the Somalia, Afar and Borena lowlands. The lowlands have scarce vegetation, inadequate rainfall and high temperature. Some of the lowland soils are shallower than 50 cm (Hawando 1997). The dry conditions in the lowlands restrict soil development (Hurni *et al* 2007). Soils formed under dry and low land condition have shallow depth and low organic carbon (FAO, 2001a). According to Jones (2007) "soil carbon accumulation is positively correlated with rainfall and negatively correlated with temperature". A good soil inorganic carbon (SIC) pool is important in arid region soils (Lal 2004). Except for Fluvisols and Andosols, which have high organic carbon similar to the Rift Valley (FAO, 2001a), the lowland soils like Xerosols, Yermosols, Arenosols have very low organic carbon (Hawando 1997; Hurni *et al.* 2007). Inorganic soil carbon (ISC), occurs largely as carbonate minerals, are common for low land soils formed over calcareous parent material. Globally, small amounts of organic carbon are encountered in Xerosols (4.2-6.2 Kg

C/m^2) Yermosols (3.1-3.4 Kg C/m^2) (Batjes, 1996). The SOC pool is low in arid regions and is high in cool and moist regions (Lal 2004). In the Ethiopian context, relative to the lowland soils, the highland soils have high organic matter content (except for areas with high degradation due to anthropogenic effect), because the soils are deep with high vegetation and cool temperature.

3. Soil carbon depletion and sequestration in Ethiopia.

The degradation of Ethiopian soil, especially in the highlands, implies depletion of soil carbon on the one hand. On the other hand, the massive land rehabilitation and conservation response by Ethiopian government and its partners since the mid 1970s (Osman and Sauerborn, 2001) also imply possibilities for sequestration of carbon.

The causes of land degradation in Ethiopia are complex and diverse but it has implication for soil carbon. Several natural, social and institutional factors are discussed (World Bank, 2008; Taddese, 2001; Hurni, et al 2007, Demel 2001; Alemayehu 2009; SIDA 2003; Hawando 1997; Berry 2003), the major five reasons are: first, the heavy reliance of Ethiopia's rapidly growing population on subsistence agriculture. Second, Ethiopia's rugged geomorphic features, steep slopes, highly erosive rainfall and scarce land cover. Third, widespread poor farming (over-cultivation, deforestation, crop residue and dung use for energy, monoculture, slope cultivation, imbalance between crop-livestock /over grazing/) methods. Fourth, land tenure insecurity discouraged long-term land improvement measures. Fifth, inadequate agricultural knowledge and poor soil extension service, weak network in coordination and mobilization of human and financial resources.

There are several case studies conducted to portray loss of forest, soil, nutrients, vegetation and water resources (Table 2). The studies imply the resulting depletion of soil carbon stock in the nation. The huge loss of fertile top soil is also a loss of SOC. The burning of crop residues and use of dung for fuel leads to the depletion of soil carbon. A global study of soil carbon shows that the first 30 cm of mineral soil holds 39-70% of total organic carbon and the first 50cm accounts for 58-81% of the total organic carbon (Batjes, 1996). This reflects the potential loss of SOC when soil is mis-managed especially in context of tropical soils. Progressive national forest declined from the original cover of 65% to 16% in the 1950s, 2.7% in 1990 and 2.2% in 2002 (Berry, 2003). In spite of the inconsistency of data on trends of land use change over the years, there is an increasing trend in expansion of arable land and a reduction of forestland (Girmay *et al.*, 2008; EPAE, 2004), which again leads to biomass and soil carbon depletion.

It is worth to notice the importance of soil organic carbon and the danger associated to it in the past Ethiopian history. The collapse of the Aksumite Kingdoms and shift of power to the southern kingdoms is also associated with relative overpopulation, deforestation, over cultivation of the once fertile land (Hurni *et al*, 2007). The cost estimates vary as estimates on the severity of land degradation varies (Berry, 2003). If left unchecked, deforestation, soil degradation and declining fertility are predicted to lead to as much as a 30 per cent drop in average per capita income by 2015 (Bekalo and Bangay, 2002). Minimum estimated annual national direct costs of land degradation range from 2 to 3 % GDP (World Bank, 2008; Berry, 2003). The effect of soil loss on annual cropland productivity decline is 0.02-0.03 % in the highlands (Hurni, 1993). The loss of agriculture value from 2000 to 2010 due to land degradation is 7 billion USD (Berry, 2003).

On the bases of the above review, out of the total land mass of 112 million ha (CSA, 2010), about 50 million ha has depleted soil carbon. This figure takes in to account the extent of current degradation, rehabilitations effort and the low soil input on agricultural land (Table 2). The estimated annual deforestation rate implies accelerated biomass and soil carbon depletion over 0.2 million ha of land in Ethiopia. The various soil loss studies (Table 2) reflect an estimated erosion induced soil carbon depletion rate of 0.02 to 0.97 tons/ha/yr. Based on EPAE 2001 and 2004 data, the annual estimates of soil carbon building practices (sustainable land management) cover an area of 2 million ha in Ethiopia (Table 2). Sustainable land management practices, which result in an increase in soil carbon content, are described here as soil carbon building practices. Some of the efforts in rehabilitation and conservation effort since the mid-1970s in the nation have been summarized in Annex 1.

4. Efforts in SOC sequestration in Ethiopia

Realizing the visible problem of land degradation and the degradation-induced depletion of the soil organic pool, efforts to avert the problem started already in the 1970s. Examining government policy, partnership and existence of fora reflect the efforts in overcoming soil carbon depletion. Review of existing national policies and programs (action plans) shows that the problem of soil degradation as part of environmental problem is fully recognized, and soil-related problems are addressed as a top priority for intervention. Ethiopia has been implementing a 10-year Plan for Accelerated Sustainable Development to End Poverty (PASDEP) until 2010 (MoFED, 2006) which was followed by the GTP (Growth and Transformation Plan).

The government of Ethiopia has focused on agricultural intensification to increase agricultural productivity focusing on technology packages (World Bank, 2006) including the use of fertilizers and better management of land. Based on data from the Central Statistics Abstracts (CSA) (CSA, 2010) there is a progressive trend in fertilizer use; however, at national level, 30 % of current cropland is still without fertilizer (Figure 1). This partly explains the World Bank (2006) description of the low input agricultural system in Ethiopia. According to CSA (2010), there is a total 13.2 million ha of cropland from both private and commercial holdings and in up to two cropping seasons per year. From the total cropland, 4 million ha are smallholder cropland that lack organic inputs, while a further 4 million ha of cropland has inadequate inputs (low application rate). There is a high removal of organic carbon as biomass for various purposes from all cropland. Thus, the estimated area of cropland (in two seasons) with soil carbon depletion is about 8 million ha. This gap shows the existence of high potential for soil carbon sequestration with the use of sustainable land management (SLM) at national level.

There are well formulated national polices, strategies, programs (action plans) and enacted proclamations (laws), which contribute to soil carbon sequestration. The constitution of the Federal Democratic Republic of Ethiopia recognizes right to a clean and healthy environment. Existing environmental agreements also encourage and contribute to soil carbon sequestration. The most relevant national policy and strategy, which directly addresses soil degradation, includes an environmental policy, a conservation strategy for Ethiopia, and a national fertilizer policy. These policies adopt a holistic view of natural, human-made and cultural resources to be used to address environmental problems (EPAE, 2004; SIDA, 2003; NMSA, 2001; EPAE, 1989). The proclamation on the establishment of government agencies (e.g., the Environmental Protection Authority, EPA) shows the ratification of these polices (NMSA, 2001). There are various programs and action plans launched (e.g., sustainable land management program) in response to the concern on soil degradation in Ethiopia (MoFED, 2006).

In natural resource development, two major milestones, which took the attention of government and international development agencies, are the 1974 Land Reform Proclamation and the 1972/73 drought. These milestones initiated the rehabilitation of degraded lands, and induced massive soil and water conservation efforts as of the mid-1970s. A review on conservation activities in Ethiopia shows that these efforts had been very localized and insignificant before the mid-seventies (Osman and Sauerborn, 2001).

To avert land degradation and address agricultural development, the government of Ethiopia has allocated budget progressively. For instance, from 1990-2001, out of the total annual budget of 4.4 billon ETB (510 million USD), 15 million USD (136.50 million ETB) was used for activities related to agriculture and natural resources conservation (EPAE, 2004).

Government rehabilitation activities in the nation included various physical conservation measures, seedling raising and plantation (EPAE, 2004). Based on data from EPAE (2001) and EPAE (2004), the annual estimate of the national land rehabilitation efforts covers 2 million ha of land. According to Hurni *et al* (2007), 16.4 % of the total land in Ethiopia is protected as nature reserves and national parks. Bass *et al.*(2000) identify and describe protected areas as carbon conserving projects contributing to carbon sequestration.

There are various associations, partnership and fora established to contribute indirectly to soil carbon sequestration because of favorable policy in Ethiopia. The partnership and fora are between Government Organizations (GO) and Non-Governmental Organizations (NGO), Community-Based Organizations (CBO) on various environmental issues. Different fora like the Sustainable Land Use Forum (SLUF), the Forum for Environment (FfE), the Environmental Economics Policy Forum and scholarly societies engaged in natural resources protection and Sustainable Land Management (SLM) contributing to efforts of soil carbon sequestration. Partnerships exist on land rehabilitation, organic farming, desertification, reforestation and adaptation to climate change. For example, there exists a partnership of 76 NGOs with GO on desertification (EPAE, 2004), and there are various associations contributing to soil carbon sequestration. The Ethiopian Association of Organic Agriculture (EAOA) plays a significant role as umbrella organization for the organic movement in Ethiopia (Alemayehu, 2009). Other relevant organizations are the Sustainable Natural Resources Management Association (SUNARMA), the Ecotourism Association of Ethiopia, the Green Development Society of Ethiopia, the Ethio-Wetlands and the Natural Resource Association (EWRNA), the Selam Environmental Development Association (SEDA), the Ethiopian Environmental NGO (EENGO), the Environmental Protection and Assistance Organization (EnPrAO) (DDO,2006). In spite of the existence of various associations, partnerships and fora in the nation, the networking and coordination is weak.

To examine the extent of investment of GO, NGOS, and CBOs, 79 programs/projects that are believed to have contributed to soil carbon sequestration were reviewed (Annex 1). Over 40 webpage sites were browsed to understand projects implemented since the 1970s in Ethiopia. An estimate on national investments in soil carbon sequestration based on environment and conservation effort amounts to 150 million USD/year (based on project budgets in Annex 1). Five major donors account for 75 % of the investments in agricultural capacity building, rehabilitation and management of natural resources. In a decreasing ranking of donors, the USAID is followed by NEPAD, the World Bank Group, various UN programs and funds (WFP, UNDP, UNEP and UNCCF), and GIZ. Nationwide implementation of conservation programs and development in natural resource involve over 100 organizations. The review shows that only 4% of the projects contribute to a carbon-off set that agrees with the Bass *et al.* (2000) definition. The projects are: the national bio-carbon fund project in Sodo and Humbo communities implemented by World Vision Ethiopia (World Bank, 2006), the Save the children UK/USA Carbon Finance in Ethiopian Rangelands (Niles, *et. al*, 2010), the UNFCCC Rift Valley acacias carbon project (EPAE, 2004). There are recent efforts by FARM Africa focusing on biomass carbon sequestration. Most of the reviewed projects focused on reforestation, climate change and conservation that indirectly contribute to carbon sequestration.

The three conclusions from the review of development projects are, first, that programs and projects are scattered, often running with multiple objectives and overshadowing the direct role on carbon sequestration. Second, except for projects and programs with one or two phases, 86 % of the projects' lifetime is less than 5 years (FAO, 2001,b). However, soil conservation only pays after a period of about 30 years, i.e way beyond the planning perspective of farmers and the administration (SCRP, 2000). This implies that natural resource development projects with a short period often cannot lead to a realized benefit for the community. This might be a factor, which has reduced the success of conservation efforts in Ethiopia. It is worth to see the importance of the project period as carbon sequestration demands at least five years. Third, the existence of different coordinators for various fora and partnerships is a problem. For example, there are various national institutes involved in the generation, storage and dissemination of data on natural resources and environment (EPAE, 2004). These efforts need networking and coordination at the national level.

5. Soil education in Ethiopia

There has not been any systematic review conducted on soil science education in Ethiopia, both in the informal and the formal sectors from first cycle to tertiary level. This section thus reviews environmental education as the field of study nearest to soil science and soil organic carbon. The Ministry of Education (MoE) has made efforts to introduce Environmental Education (EE) in school curricula at various levels. Science, environmental science, geography, and biology modules at all levels address topics related to climate, land resources and soils. The importance of creating public awareness on environmental problems is well recognized in school curriculums. Environmental Education (EE) was introduced to the lower primary education in the mid-1980s, but the curriculum has been too theoretical. In Ethiopia, 24% of adult education completed primary education (Saint, 2004), which reflects the low level of awareness on soil degradation, including soil carbon depletion.

The new structure of Ethiopia's education system has primary, secondary and tertiary education. The formal education system has serious challenges to address environmental education because it oversimplifies the anthropogenic causes of environmental problem (Bekalo and Bangay, 2002).

There is successful progress in human resources development associated with Agricultural Technical and Vocational Education and Training (ATVET), Colleges and Farmers Training Centers (FTC) according to NEPAD/CAADP (2005). There are various programs leading now to specialization in soil sciences (e.g soil and water conservation, soil analysis)in ATVET (MoE, 2010). The progress at ATVET includes the development of curriculums on natural resources especially in agriculture and related faculties. The NEPAD and MoA plan addressed the establishing of agronomy, soil laboratory and green house units in the regions and academic institutes.

There is an increase in the share of the public education budget from the total government expenditure (MoFED, 2006). Public investment in education spending is 4.5 % of the GDP (Saint, 2004; CREST and IRD, 2007), which is higher than the 3.9% registered for Sub-Saharan Africa. With its current expansion, the budget share of higher education has increased to 23% (Saint, 2004).

At tertiary level, the history of agricultural education in Ethiopia coincides with the establishment of the Ambo and Jima Junior Colleges of Agriculture in 1974 and the Imperial College of Agriculture and Mechanical Arts in 1953, now Haromaya University. Afterwards, Awassa College of Agriculture was established in 1977, Wondo Genet College of Forestry in 1978, the Faculty of Veterinary Medicine in 1979 and Mekelle University College in 1994 (WANA NARS Study, 1999). The establishments of these academic institutes have contributed to the development of work force in soil science.

According to data of CSA (2010), in 2009 the number of graduates in both private and government colleges and universities has grown exponentially to 135,800 (28 % females). However, the disciplinary distribution shows a higher enrolment share in social sciences at the expense of agriculture and natural sciences. Saint (2004) had pointed out this imbalance in disciplinary distribution. Institutes of agricultural higher education (AHE) were also conducting education in soils, soil conservation, forestry and related fields, which will address the issue of soil carbon sequestration.

According to the directory of World University (retrieved in June 2010) and MoE (2010), there are relevant research and academic programs in soil science at BSc, MSc, PhD levels. A soil specific program exists at Adama University (soil conservation and irrigation), Haromaya and Jijiga University (soil and water engineering and management), Hawassa University (soil resource and water management, post-graduate in soil science, agroforestry and soil management), Wollega University (soil resources and watershed management). Wollo

University (soil and water), and a postgraduate program in agronomy at Bahir Dar and Mekelle Universities. General programs related to soils as part of land science exist at Mekelle, Jijiga, BahirDar and Dilla and Addis Ababa Universities. Until recently, the focus of private colleges has not addressed soil science except for new efforts to provide education in the field of natural resources and rural development. With the current expansion of 21 public universities, the graduate schools in soil and related sciences will address the work force development needed to undertake research and development focused on soil carbon sequestration.

6. Soil research and findings on Organic Carbon

Soil science research in Ethiopia coincides with the establishment of the Agricultural Technical School and Colleges in the 1950s and 1960s (AHI, 1997). The inception of the Institute of Agricultural Research (IAR) in 1996 also marks the beginning of natural resources research in Ethiopia (WANA NARS Study, 1999). Although agricultural research in Ethiopia started more than fifty years ago, little attention was given to research in organic matter, or more specifically, in carbon sequestration.

Research on soil organic carbon (matter) is part of research on soil chemical, biological and physical property in Ethiopia (AHI, 1997). A soil analytical service is available in five Ethiopian Institutes of Agricultural Research (EIAR) centers, including the national Ethiopian Soils Laboratory (EST, 2005). The national soil laboratory was established in 1989 (WANA NARS Study, 1999). Analytical services are now provided by Haromaya, Jimma, Ambo, Mekelle, Hawassa Universities and by 17 regional soil laboratories under the bureaus of agriculture or regional research centers. These infrastructures contributed a lot to soil research in Ethiopia.

In 1998, the Ethiopian Agricultural Research system (agricultural university, college and research institute) had 728 scientific and technical staff (114 PhD, 365 MSc , 249 BSc holders) (WANA NARS Study, 1999). In 2004, EIAR and research organizations with agriculture centers had 1811 staff (141 PhD, 443 MSc/MvSc, 615 BSc/BA/DVM and 612 technicians (EST, 2005). This excludes staff working at Agricultural Universities and Colleges. At the Ethiopian agricultural research institutes, only 9 % of the researchers worked on natural resources (WANA NARS Study, 1999; Beintema and Solomon, 2003).

There is a lack of data at the level of expenditures in research and development in Ethiopia (CREST and IRD, 2007). The government annually allocates up to 1.5 % of Agriculture Gross Domestic Product (A.G.D.P) for science and technology activities in the country (CREST and IRD, 2007; WANA NARS Study, 1999). Since the early 1990s, total investments and number of researchers in agricultural research and development doubled (Beintema and Solomon, 2003). In the Ethiopian Agriculture Research Institute (EARI), the lion share of funds allocated went to crop-related research (WANA NARS Study, 1999). The EARI and Regional Agricultural Research Centers have a directorate dedicated to research in soil and water addressing conservation, land degradation and soil-related problems.

Crop cultivation in Ethiopia has a long history of at least 5000 years (Edwards, *et al.*, 2007) and traditional soil organic matter management is an age-old practice. However, promotion of organic agriculture is very recent (Alemayehu, 2009) as reveled by the first baseline survey on organic agriculture and CSA data. The extent of organic fertilizer use in Ethiopia is reflected in CSA data showing that 35% of cropland has organic fertilizer (CSA, 2010). Ethiopia ranks 30th in the world and has 137,822 ha certified organic land (Alemayehu, 2009). Past research has not focused on drawing lessons from indigenous soil conservation (Osman and Sauerborn, 2001). The first survey on indigenous soil and water was carried out in Ethiopia in 1983 (SCRP, 2000). There are case studies on indigenous practices and management of organic matter in Ethiopia (Haileselaee *et al* , 2006; Amede *et al* , 2001; GebreMichael and Kifle, 2009; EPAE, 2004).

Past efforts to map soil carbon in Ethiopia at the national level includes the above and below ground biomass carbon map by Niles *et.al* (2010) and organic carbon map of highland soils by AHI (1997). The importance of organic matter in agriculture has taken attention of past researchers on soil carbon by focusing on land degradation and conservation, land use change, biodiversity, nutrient recycling, integration of crop-livestock and other elements of the ecosystem (Table 3). Past research in Ethiopia focused on soil organic matter or carbon from a plant nutrition point of view, while studies on carbon sequestration *per se* started only recently, after 2005.

Except for the inventory on carbon sink and emission (NMSA, 2001) and the soil carbon map (AHI, 1997; Niles *et.al*, 2010), past research was conducted at the local level and mainly in the highlands. Most of the studies were conducted for academic purposes. The sequestration of soil carbon in forest land, enclosures and with different types of management is well documented (Lemma *et al* , 2006; Lemenih *et al* ,2005; Girmay *et al.* ,2008).

7. Recommendations for soil carbon sequestration in Ethiopia

Based on identified key gaps in soil carbon research and development, priorities are indicated to mitigate climate change in Ethiopia. Most research in soil carbon in the past examined more the degradation than the rehabilitation or restoration aspects. Moreover, the research concentrated more on the highlands than the lowlands, focused more at the local than the macro level. Research priorities should focus on multiple scales, in the lowlands and on long-term basis. Research has also not paid attention to the socio-economic (costs and efficiency of sequestration), institutional, cultural issues associated with soil carbon sequestration. Research should focus on use of soil carbon models, dynamics, diversifying inputs for the carbon pools, making use of indigenous knowledge and promoting sequestration practices. Research focused on drawing lessons based on the past 35 years' of development experience and on traditional soil organic management, which is missing. A major knowledge gap noted in research is the lack of a national database on soils. Immediate and most important research needs should focus on how to guide carbon credit programs or pave a way for soil carbon market (e.g., payment rates with sequestration amount, assessment of carbon gains and various payment schemes in sustainable land management).

The review of Environment Education (EE) shows that there is a low awareness level among the community members to address land degradation and climate change problems. Looking at the urgency of the problem, environmental education (both formal and informal) should thus foster awareness on the depletion of soil resources and in particular on its economic, social and ecological consequences. Except for recent graduate and post-graduate programs in forestry, natural resources, environment and soils, the enrolment in agriculture at tertiary level was too small to address existing problems in the past. Immediate recommendation in EE is to increase public awareness and assess current curriculums at all levels in both the public and private sectors. It is also worth focusing on the anthropogenic causes of environment problems, provide practical oriented EE, and provide lessons on importance of soil organic carbon.

Examining 79 development programs/projects in Ethiopia (Annex 1), shows that 96% of the projects on natural resources do not focus on carbon sequestration. Although the current funding is limited to biomass carbon sequestration (Niles *et.al*, 2010), special efforts are needed to promote soil carbon sequestration and design long-term land rehabilitation projects focusing on carbon sequestration. Only 4% of the reviewed projects had an adequate project lifetime to allow observing changes in soil carbon sequestration. The priority focus is thus to design long-term projects and promote soil carbon financing or ecosystem service payments (ESP) to benefit smallholder farmers. The high potential for soil carbon sequestration calls for a large-scale and diversified use of fertilizer (organic and inorganic) on cropland along with a number of potential mitigation measure to sequester soil carbon on different types of land uses. The existence of partnerships, fora on various environmental issues in the nation is an opportunity, yet a national level coordinator and developing guideline on soil carbon sequestration are also needed.

8. Conclusions

The past degradation of soils in Ethiopia implies a historic loss of SOC pool. The national inventory of GHG emission shows a decrease in sink capacity of the agriculture, forestry and land use change sectors. Out of the total land mass of 112 million ha, 50 million ha of land has depleted soil carbon. Studies imply that the erosion-induced soil-carbon depletion rate is 0.02 to 0.97 tonnes/ha/yr. Based on existing estimates of the deforestation rate, the accelerated forest land biomass and soil carbon depletion rate occurs on 200,000 ha/yr. Based on CSA data (Figure 1) and the 13.2 million crop land without soil fertilizers (in two cropping seasons), the accelerated rate of soil carbon depletion occurs on 8 million ha /yr. Current national estimates of soil-carbon building practices cover 2 million ha of land/yr. The overall effort in natural resources management associated with soil-carbon building activities has been summarized in Annex 1.

Although the soils of Ethiopia have a great variability in soil organic carbon content, soils in the highland have better organic carbon compared with the lowlands, except for degraded areas due to anthropogenic causes. A preliminary estimate of national soil organic pool (Table 1) shows that Ethiopia has 14 billion tons of SOC.

The review of national strategy, policy and enacted proclamations reflects that the government programs take into account soil degradation as a problem and contribute positively to soil carbon sequestration. The various associations, multiple partnerships and fora on different environmental issues also reflect the existence of a favorable environment. The existence of the huge potential to increase the SOC pool in Ethiopia lies on two reasons. First, there is 50 million ha of degraded land with depleted soil carbon. Even without looking at the low fertilizer application rates, 30 % of the current cropland is without fertilizer. Second, there are over 100 organizations investing in environment rehabilitation and conservation focusing on soil, with an estimated budget of 150 million USD/year (Annex 1). The review of 79 programs/projects shows that five major donors account for 75 % of the investments, but only 4% of the projects focus on soil carbon sequestration. Among other things, the success of the past conservation and development efforts was reduced because projects were scattered, run with multiple objectives that overshadowed the problem of soil carbon sequestration. Development projects focused on natural resources with less than 5-year life span can neither ensure sustained benefits for the community nor provide adequate time to see changes in soil carbon.

The Environment education (EE) review shows that public awareness among the adult population is low. The EE curriculum is too theoretical and gives less emphasis on anthropogenic causes of land degradation. With current expansion of higher education, relevant research, academic programs and courses focusing on soil carbon are emerging at both the graduate and undergraduate levels. Until 2010, the expansion of higher education was at the expense of natural sciences and agriculture. Although recent human resource development in agricultural extension through Agricultural Technical and Vocational Education and Training (ATVET) colleges had positive effect, the current work force at tertiary level in soil science is still inadequate.

Although agricultural research in Ethiopia started more than forty years ago, little attention was paid to research on organic carbon. In spite of the long history in traditional uses of soil organic inputs, attention was not given to the promotion of these diversified and extensive uses of soil organic inputs. This review shows inadequate work force and budget allocated for research on soil in general and organic carbon in particular. Studies focusing on soil carbon sequestration have started since 2005. Past research on soil carbon has shown three major points. First, land degradation reflects the historic loss of SOC pool, which contributed to the reduced sink capacity of agriculture, land use change and forestry sectors. Second, the depletion of soil organic carbon threatened the sustainability of the smallholder farming system. Third, there is huge potential for soil carbon sequestration in Ethiopia with the adoption of sustainable land management practices. The study recommends promotion and use of soil carbon building practices by ministry of agriculture and partners at all level. For better alignment and harmonization between existing partners, associations and fora, there is a need to establish a soil carbon network (with a national coordinator) and a meta-data base on soils.

References

Alemayehu A(2009) Ethiopian Organic Forum: Public Private Partnership. Forum Organized by Ministry of Rural and Agriculture Development and Ethiopian Association of Organic Agriculture (EAOA) at UN ECA in Addis Ababa on July 8, 2009.

AHI (1997) An inventory of spatial and non-spatial survey and research data on natural resources and the land productivity in the highlands of Ethiopia, Kenya, Madagascar and Uganda. (eds., Braun.A.R, Smaling,E., Muchung, E, Shepherd,K.D and Corbett,J.D) African Highland Initiatives (AHI) Technical report serious No. 6; 126 pp

Amede T, Belachew T and Geta E (2001) Reversing the degradation of arable land in the Ethiopian Highlands, *Manaing Africa's Soil No 23*

Bass, S.,Dubois, O.,Moura Costa,P.,Pinard, M.,Tipper,R. and Wilson, C.,(2000) Rural Livelihoods and carbon Management, IIED Natural Resource Issue Paper No 1. International Institute for Environment and Development, London. Available at < pubs.iied.org/pubs/pdfs/7558IIED.pdf>

Batjes, N.H (1996) Total carbon and nitrogen in the soil of the world. *European Journal of soil sciences*, 47: 151-163.DOI: 10.1111/ j.1365-2389.1996.tb01386.x

Beintema, N.B and Solomon M (2003) Agricultural Science and Technology Indicators: Ethiopia, ASTI Country Brief No 9, IFPRI, ISNAR and EARO, 10 pp. Available at<www.asti.cgiar.org/pdf/Ethiopia_CB9.pdf>

Berry, L (2003) Land Degradation in Ethiopia: Its Extent and Impact, Report submitted to Global Mechanism with support from World Bank. pp. 26 Available at<home.agrarian.org:8080/Ethipoia/ethiopian%20%20soils/LAND3.pdf>

MoE (2010) Education Statistics, Annual Abstract, Ministry of Education(MoE) (2010/11), Addis Ababa, Ethiopia, Available at <http://info.moe.gov.et/emdocs/esaa03.pdf>

MoFED (2006) Ethiopia: Building on Progress, Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (2005/6-2009/10) Volume I, Main Text, Ministry of Finance and Economic Development (MoFED), Addis Ababa, Ethiopia, 278 pp.

Bekalo, S and Bangay C (2002) Towards Effective Environmental Education in Ethiopia: problems and prospects in responding to the environment-poverty challenge, *International Journal of Educational Development*, No. 22, p35-46. DOI:10.1016/S0738-0593(00)00076-6

Chibsa, T. and Ta' A.A (2009) Assessment of Soil Organic Matter Under Four Land Use Systems in Major Soils of Bale Highlands, South East Ethiopia (b) factors affecting soil organic matter distribution, *World Applied Sciences* Journal 6 (11): 1506-1512. idosi.org/wasj/wasj6(11)/8.pdf

CSA (2010) National Statistics Abstract (Document # 3, Agriculture-2010), Central Statistical Agency (CSA) http://www.csa.gov.et/documents/2010 National Statistics (Abstract).

CREST and IRD(2007) Science and Technology System of Ethiopia, Mapping Research Systems in Developing Countries, Center for Science and Technology Center (CREST, South Africa) and Institute for Research and Development (IRD, France) synthesis report, UNESCO, France, 34 pp. Available at< academic.sun.ac.za/crest/unesco/data/Synthesis%20report.pdf>

Demel, T.(2001) Deforestation, Wood Famine and Environmental Degradation in Ethiopia's Highland Ecosystems: Urgent Need for Action. *Northeast African Studies* –Volume 8, Number 1(New series) pp 53-76.

DOI: 10.1353/nas.2005.0020

DDO (2006) Directory of Development Organizations 2006, Volume I.A/Africa, http://www.devdir.org

Edwards, S. (2007) Role of Organic Agriculture in Preventing and Reversing Land Degradation, pp 523-536, In Climate and Land Degradation (Sivakumar M.V.K, Sivakumar,V.K and Ndiang'ui, N.(eds), Springer, Berlin, Germany, pp 623.

EPAE (1989) The conservation strategy of Ethiopia (CSE), Environmental Protection Authority of Ethiopia. Addis Ababa, Ethiopia. http://www.tcdc.undp.org/sie/experiences/vol3/Conservation%20Ethiopia.pdf

EPAE (2004) The 3rd National Report on the Implementation of the UNCCD/NAP in Ethiopia, The Federal Democratic Republic of Ethiopia Environmental Protection Authority (EPAE). Feb., 2004, Addis Ababa, Ethiopia.

EPAE (2001) National Agenda 21 Implementation Review Report, Environmental Protection Authority of Ethiopia, Addis Ababa, Ethiopia.

EST (2005) Profile of Ethiopian Agricultural Research Institute and Centers, Ethiopian Science and Technology (EST), available at <www.most.gov.et/ethiopia profile of research institutes and centers>

Fantaw Y, Ledin S, Abdu Abdelkadir (2006) Soil organic carbon and total nitrogen stocks as affected by tropical aspects and vegetation in the Bale Mountains, Ethiopia. *Geoderma,* Volume 135, Pages 335-344. DOI:10.1016/j.foreco.2007.01.087 /

FAO (1984) Ethiopian Highlands Reclamation Study (EHRS), Final Reports, Vol 1-2, Food and Agriculture Organization (FAO) Rome, Italy

FAO (2001,a) Lecture Notes on Major Soils of the World, World Soil Resources Reports 94, Food and Agriculture Organization (FAO) Rome, Italy

FAO (2001,b) Soil Carbon Sequestration for Improved Land Management, World Soil Resources Reports 96, Food and Agriculture Organization (FAO) Rome, Italy

FAO/ISRIC (2004) A review of Carbon Sequestration Projects. Rome, Italy. Available at <ftp://ftp.fao.org/agl/agll/docs/misc37e.pdf>

FAO (2007) Impact of Compost Use on Crop Yields in Tigray, Ethiopia, Report by Edwards S, Asmelash A, Araya H and Gebre Egziabher T., to Natural Resources Management and Envt Department, FAO (Food and Agriculture Organization), December 2007, Rome , Italy

Freier., K.P, Glaser B and Zech W (2009) Mathematical modeling of soil carbon turnover in natural *Podocarpus* forest and *Eucalyptus* plantation in Ethiopia using compound specific δ^{13}C analysis, *Global Change Biology*, pp 1487-1502, Vol 16, Issue 5. DOI: 10.1111/j.1365-2486.2009.02096.x

GebreMichael., Y. and Kifle M (2009) Local Innovation in Climate-Change Adaptation by Ethiopian Pastoralists, Final Report submitted to PROLINNOVA-Ethiopia and Pastoralist Forum Ethiopia, Addis Ababa, Ethiopia.

Girmay G, Singh, B.R, Mitiku, H, Borresen T, Lal. R(2008) Carbon Stocks in Ethiopian Soils in relation to land use and soil management, *Journal of Land degradation and Development*, Vol 19 Issue 4, pp 351- 367. DIO: 10.1002/ldr.844

Jutzi., S C, Haque I, McIntire J and Stares J E S (eds) (1988) Management of Vertisols in Sub-Saharan Africa. Proceedings of a conference held at ILCA, Addis Ababa, Ethiopia, 31 August-4 September 1987. ILCA, Addis Ababa.

Lemma, B, Kleja D. B, Olsson M, Nilsson, I (2007) Factors controlling soil organic carbon sequestration under exotic tree plantations: A case study using the CO2 Fix model in southwester Ethiopia. *Forest Ecology and Management*, Volume 252, Issues 1-3, Pages 124-131. DOI:10.1016/j.foreco.2007.06.029

http://www.sluf.org.et/ (Sustainable Land Use Forum)

http://www.undp.org/climatechange/carbon-finance/CDM/ethiopiaOpp.shtml

http://en.wikipedia.org/wiki/Agriculture_in_Ethiopia- Wikipedia, retrieved in Jan 2011.

http://www.university-directory.eu/Ethiopia/Ethiopia-Universities.html retrieved in June 2010

Hawando., T (1997) Desertification in Ethiopian Highlands, *RALA Report No 200*, Norwegian Church AID, Addis Ababa. Available at <www.rala.is/rade/ralareport/Hawando.pdf >

Haileslassie A, Priess J, Veldkamp E, Teketay D, Lesschen J.P (2005) Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances, *Agriculture Ecosystems and Environment*, 108 pp 1-16. DOI:10.1016/j.agee.2004.12.010

Hurni H, Amare Bantider, Herweg K, Portner,B and H. Veit (2007) Landscape Transformation and Sustainable Development in Ethiopia. Background Information for a study tour through Ethiopia, September 4-20, 2006, CDE (Center for Development and Environment) University of Bern , Bern , 321pp

Hurni H, (1993) Land Degradation, Famines and Resources Scenarios in the Ethiopia. pp 27-62, In Pimental, D (ed.) World Soil Erosion and Conservation, Cambridge University Press, UK.

Hurni H, (1998) Degradation and conservation of the resources in the Ethiopian highlands, *Mountain Research*

and Development, 8 (2/3)
Jones, C.,(2007) Australian Soil Carbon Accreditation Scheme, Presentation for “Managing The Carbon Cycle” Katanning Workshop, 21-22 March 2007, Carbon For Life Inc. Australia.
Kimble, J.M., Lal, R and Mausbach (1999) Erosion Effects on Soil Organic Carbon Pool in Soils of Iowa, In Stott et. al (eds.) Sustaining the Global Farm, pp 472-475. Available at < http://www.tucson..ag.gov/isco/.../SustainingTheGlobalFarm/P241-Kimble.pdf>
Lal, R.,(2004) Soil Carbon Sequestration to mitigate climate change, *Geoderma* 123, pp 1-22. DOI:10.1016/j.geoderma.2004.01.032
Lemma B, Kleja D.B, Nilsson I, Olsson M (2006) Soil carbon sequestration under different exotic tree species in the southern western highlands of Ethiopia. *Geoderma*, Volume 136, Issues 3-4, pp. 886-898. DOI:10.1016/j.geoderma.2006.06.008
Lemenih M, Karitun, E and Olsson, M (2005) Soil Organic matter dynamics after deforestation along a farm field chronosequence in Southern Highlands of Ethiopia, *Agriculture, Ecosystem and Environment,* Volume 109, Issues 1-2, pp 9-19. DOI:10.1016/j.agee.2005.02.015.
Mesfin, A., (1988) The Nature and Management of Ethiopian Soils, Alemaya University of Agriculture (AUA), Ethiopia. 272 pp
NEPAD/CAADP(2005) ETHIOPIA: Support to NEPAD(New Partnership for Africa’s Development) – CAADP (Comprehensive Africa Agriculture Development Programme) Bankable Investment Project Profile (BIPP) Volume III “Human Resources Development for Agricultural Extension” (TCP/ETH/2908 (I) NEPAD Ref. 05/08 E)
Niles J O, Cleland E, Gibbs Hand Orcutt B (2010) Carbon Finance in Ethiopian Rangelands: Opportunities for Save the Children Leadership, Final TFG Report submitted to save the children, Addis Ababa, Ethiopia.
NMSA (2001) Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC), National Meteorological Services Agency (NMSA), Addis Ababa, Ethiopia.
Osman, M. and Sauerborn., P., (2001) Soil and Water Conservation in Ethiopia: Experiences and Lessons, *Journal of soils and sediments* 1 (2), pp 117-123.
Omiti J.M, Parton K.A, Sinden J.A and Ehui S.K (1999) Monitoring changes in land-use practices following agrarian de-collectivization in Ethiopia, *Agriculture, Ecosystems & Environment*, Volume 72, Issue 2, 4 , Pages 111-118. DOI: 10.1016/S0167-8809(98)00162-5
Saint, W (2004) Higher Education in Ethiopia: The Vision and Its Challenges. *Journal of Higher Education in Africa*, JHEA/RESA. Vol 2 , No 3, 2004 pp 83-113.
SIDA(2003) Ethiopia: Strategic Environmental Analysis, Country Strategic 2003-2007, Swedish International Development Cooperation Agency(SIDA), Addis Ababa, Ethiopia.
Solomon D, Fritzsche F., Tekalign M, Lehmann J and Zech W (2002) Soil Organic Matter Composition in the Sub humid Ethiopian Highlands as Influenced by Deforestation and Agricultural Management. *Soil Science Society of America Journal* 66: pp 68-82. DOI: 10.1111/j.1365-2486.2006.01304.x
SCRP (2000) Concept and Methodology: Long-term Monitoring of the Agricultural Environment in Six Research Stations in Ethiopia. Soil Conservation Research Program (SCRP), Center for Development and Environment (CDE), University of Bern, Bern, Switzerland.
Taddese, G.,(2001) Land Degradation: A Challenge to Ethiopia, *Journal of Environmental Management*, Vol 27, No 5, pp 815-824. DOI: 10.1007/s002670010190
UNDP/FAO (1984) Assistance to land use planning, Ethiopia. Geomorphology and Soils, Field Document 3, Rome, Italy.
UNESCO (2006) Environmental Education, Chapter 23 (Section 5: Curriculum and Learning) Guide Book For Planning Education in Emergency and Reconstruction, International Institute For Education Planning (IIEP), Paris. France.
Walcott J, Bruce S. and Sims J. (2009) Soil Carbon for carbon sequestration and trading: a review of issues for agriculture and forestry, Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Australian Government, Canberra.
WANA NARS Study (1999) The National Agricultural Research System of Ethiopia. Available at <www.icarda.org/NARS/Ethiopia.PDF>
World Bank (2006) Humbo and Soddo Community-Based Natural Regeneration Project, Project Information Document(PID), Ethiopia/Report No 35515, Project I.D P098428, http://www-wds.worldbank.org/external/projects/
World Bank (2008) Sustainable Land Management Project, Project Appraisal Document(PAD), Ethiopia/Report No 42927-ET, Project I.D P107139, http://www-wds.worldbank.org/external/projects/

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Tables and figures

Table -1- Preliminary Estimate of Soil Organic Carbon pool in Ethiopia

Soil Units**	112 mill ha* land area (% cover**)	Soil Organic Carbon (SOC)		+Density (Mg/m^3)	SOC distribution for depth (0-100cm)++ (kg/m^2)
		Density (tons/ha)+++	Pool (Billion tons)		
Nitosols	14.40	143	2.05	1.43	8.4
Cambisols	12.00	136	1.63	1.36	9.6
Vertisols	11.90	150	1.78	1.50	11.1
Luvisols	6.00	154	0.92	1.54	6.5
Fluvisols	6.20	140	0.86	1.40	9.3
Xerosols	5.40	149	0.80	1.49	4.8
Solonchaks	0.22	148	0.03	1.48	4.2
Acrisols	1.80	141	0.25	1.41	9.4
Others	42.08	140	5.89	1.40	13.1

**Hurni *et al* (2007) * Source CSA (2010) + (See also +++) +mean bulk density for profile AHI (1997) & Mesfin (1998)

++ mean distribution along profile (0-100 cm) is 50 cm for shallow soils (supplementary fact) +mean profile depth, organic carbon
was based on AHI (1997), data from UNDP/FAO (1984) and Batjes (1996)

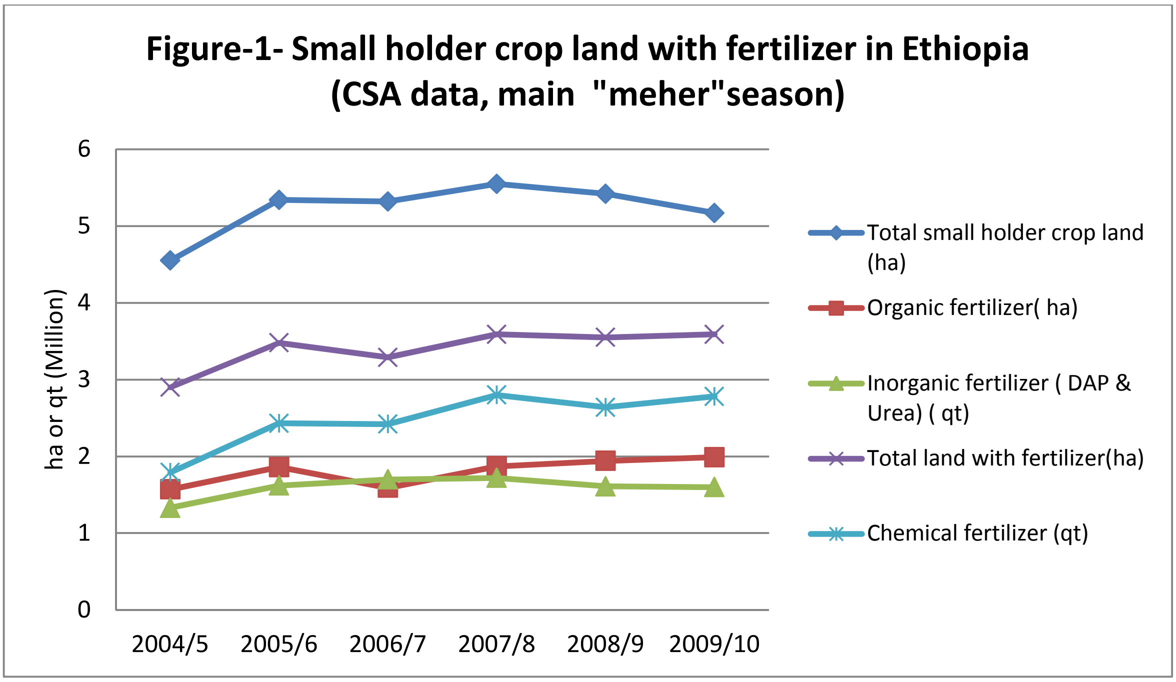
Table - 2 – Land degradation, rehabilitation and carbon in Ethiopia

DEGRADATION & REHABILTATION	CARBON DEPLETION*
Retained 2.7 % of original forest land(World Bank, 2006) 2.2 % in 2002 (Berry, 2003)	Imply loss of 50% biomass carbon from original 30-40% of land mass
Estimated forest loss from 150,000 to 200,000 ha/yr (Hawando, 1997). Recent deforestation rate is 200,000 ha/yr (SIDA,2003). In the 1980s, the deforestation rate was estimated at 163,600 ha/yr. (EPAE ,1989).	Imply 200,000 ha/yr national biomass and soil carbon depletion on forest land.
Maximum soil loss on cultivated land of 400 tons/ha/yr. (EPAE, 1989)	Imply maximum loss of 0.97 tons of soil C/ha/yr in most extreme situations.
Soil erosion rates on cultivated land range from an average 16/tons/ha/yr. to a maximum of 300 tons/ha/yr (Hurni 1988)	Imply estimated loss of 0.04 – 0.74 tons of C/ha.yr.
Soil erosion rate of 10 tons/ha to 200 tons/ha/yr. (SIDA, 2003)	Imply depletion of 0.02 to 0.4 tons of C/ha/yr.
27 million ha is highly degraded, 14 million ha is degraded, and 2 million ha is lost in the highlands (FAO, 1984)	Imply estimated depletion of soil carbon 43 million ha of land in Ethiopia
Negative nutrient balance at national level, loss of 30 kg/ha N and 15-20 kg/ha of P (Haileslassie *et al* 2005; Berry 2003)	Imply loss of soluble organic forms of nutrients and carbon removal.
Average arable land soil loss 42 tons/ha/yr (in the highlands). Average annual crop land production loss is 1-2% (Hurni , 1993)	Imply estimated SOC depletion of 0.08 tons of C/ha/yr (for crop lands).
In 2003, 16.4 % of the total land area of Ethiopia is protected (Hurni *et al*., 2007)	Imply 19 million ha of land has carbon conservation (with reduced anthropogenic effect).

* based on Jones (2007) conversion factors. Soil organic carbon = 0.58 % * OM. For a mineral soil an average of 3% OM, soil density of 1.4g/cm^3 is taken for the first 15 cm depth of top soil .

Table -3- Summary on carbon sequestration research in Ethiopia

Research focus	Research focus	Study site, soil types & depth	Methods	Source
SOC dynamics	SOC depletion, input , translocation and steady state	South Central Ethiopia(Highland) Mollic Andosols, Surface soil (0-20 cm)	Isotope method, chronosequece sampling, land use change	Lemenih *et al* (2005)
SOC sequestration	SOC accumulation and loss rates associated with land use change and tree species	South Western Ethiopia (Highland), Humic Nitisols, Surface and sub-surface soil (0-50 cm)	Soil C analysis, Isotope method, land use change , model	Lemma *et al* (2006)
SOC factors & distribution	SOC amount and change with different land use and major factors affecting it	Bale Highlands (South East Ethiopia), Cambisol & Vertisol , Surface and sub-surface soil (0-60cm)	Land use change , Soil C analysis	Chibsa and Ta' (2009)
SOC and LUC	Change in SOC with land use types and potential for SOC sequestration	Various location & soil orders, Top soil and sub soil (0-60 cm), Land use change	Review Change in land use and SOC change	Girmay *et al* (2008). Fantaw, *et al* (2006)
SOC replenishment	Nutrient balance on farm land with regional difference in land management	National estimate , Regional difference in land management from intensive to less intensive	Partial and full nutrient balance (input and output)	Haileslassie *et al* (2005)
Soil OM loss	Annual loss of Organic matter (OM), depletion rate associated with land use.	Estimate of soil organic carbon depletion for top soil at national level	organic matter loss estimate associated with degradation	Hawando (1997)
SOC dynamics	Change of vegetation type , management on carbon storage and composition	Southern Ethiopia Nitisols Surface and sub-surface (20-30)	Isotope method, Model, mean residence times (MRTs) of SOC compounds	Freier *et al* (2009)
	Depletion and change in chemical composition of SOC with different species	Sub humid highland Ecosystem Surface soil	Soil analysis , land use change	Solomon *et al* (2002)
Role of OM	Impact of compost in doubling crop yield	Northern Ethiopia Comparison of organic and inorganic fertilizer	Yield measurement Soil analysis	Edwards (2007) FAO, 2007



Annex -1- Programs /projects related with carbon sequestration in Ethiopia

Name	Description	Source
GEF/SGP	Operates at national scale since 1994 (Global Environment Facility) includes small grant programs (SGP) (69.2 million USD for GEF and ca 1.2 million USD/year for SGP)	http://www.undp.org/sgp http://aida.developmentgatewy.org/
MERIT/LLPPA	Managing Environmental Resources to Improve Food Security (MERIT) operational since 1991 at national scale, implemented by World Food Programme, WFP. Operational for over 30 years. (ca 71.05 million USD for 7 years)	http://www.acdi-cida.gc.ca/CIDAWEB/cpo.nsf/
FAP /Land Tenure project	Forestry and agriculture program funded by SIDA for forestry Education and land rehabilitation since 1992 to 2000(ca 33.4 million USD)	SIDA (2003)
AHI/ AHRM	Operated in east Africa in three phase form 2003 to 2008 funded by IDRC (ca 0.5 million USD for Ethiopian component for 5 years)	www.crdi.ca/uploads/user-S/12039948171Ethiopia_eng_web.pdf
SLM /Reforestation project	GTZ (GIZ)funded Sustainable Land Management (SLM) project at national scale from 2005 to 2015. Reforestation was for 1987. From 1996 to 2001 watershed project operated (ca 93.0 million USD)	http://www.gtz.org/projects/project descriptions/ Sustainable Land Management http://www.odi.org.uk/projects/98-99-tropical-forestry/projects/
SOS SAHEL FM	Forest Management (FM) projects funded by EU /DFID from 1997 to 2006 from 200 to 2005 in Southern Ethiopia and Oromiya (borena) through SOS SAHEL (ca 4.8 million USD)	http://www.odi.org.uk/projects/98-99-tropical-forestry/ EPAE(2004)
CFWCP	Community Forest and wildlife Conservation Project funded by EU from 1993 to 2000 implemented by Farm Africa in South and Oromyia Region. (ca 2 million USD)	http://www.odi.org.uk/projects/98-99-tropical-forestry/
SCRP	SDC funded Soil Conservation Research Program (SCRP) at national scale from 1981 to 2000	SCRP (2000)
PFMP	JICA funded Participatory Forest Management Project (PFMP) from 2003 to 2010 in oromiya region (ca 3.62 million USD)	www.jica.go.jp/ethiopia/english
K and D Devt Program	Koisha (K)and Dalocha (D) programs funded by DFID from 1990 to 1995 (ca 0.7 million USD)	http://www.odi.org.uk/projects /98-99 tropical forestry
World Bank	The Agriculture, Forestry and Environment sectors various projects from 1974 to 2013 focus on development, research , carbon, fertilizer and natural resource management. (200.3 million USD)	http://web.worldbank.org/external/default/main? WORLD BANK (2006)
NCSA	National Capacity Self- Assessment for Global Envt Management to address priority environmental issues funded by UNEP and GEF(0.153 million USD) from 2009 to 2011.	gridnairobi.unep.org/chm/roa/project_profiles/EthiopiaUNEPProjects.pdf
SDP	A sustainable development Project (SDP) funded by UNCDF to address environmental problems in Amhara Region. (8.49 million USD) (Operation year , NA)	SIDA (2003)
Environment Support Project	Implemented through EPAE funded by the Netherlands Govt from 1999-2002(10.0 million USD)	SIDA (2003)
FC	Forest Conservation (FC) in High Priority Areas Implemented through MoARD funded by WWF(1.74 million USD) (Operation year , NA)	SIDA (2003)
Environmental	Implemented through EPAE from 1999-2002 by Finland Government (1.7 million	SIDA (2003)

Name	Description	Source
protection	USD)	
ETHIOCAT	National Data base on Ethiocat supported by World Bank and SDC	http://www.wocat.net/en/network/activities/initiatives/initiative-detail/article/ethiocat.html?
Developing Climate Change Resilience	Assistance to National Meteorological Agency of Ethiopia (NMAE) for climate change initiative since 2009 funded by Rockefeller foundation includes OXFAM (HARITA) project (6 million USD)	http://www.rockefellerfoundation.org/who-we-are/our-focus/climate-environment http://www.oxfamamerica.org/
Envt Protection program	UNCCD Program to combat desertification, support SLM in pastoral , Tigray and South area funded by Norway Govt. through EPAE from 2009 to 2013(2.0 million USD)	http://www.norad.no/en/Tools+and+publications/Publications/
NEPAD/CAADP	Human resource development for extension in nine regional states to upgrades agricultural colleges and Farmers Training Centers (FTCs) form 2001 to 2005. (248.7 million USD)	(NEPAD/CAADP, 2005)
Greening Project	Natural resource development implemented by ORDA from 1998 to 2004 (5 million USD)	EPAE(2004)
Community based SWC project	Govt and FAO funded project on integrated watershed development approach to soil and water conservation (SWC) in 3 regional states from 2004 to 2005(0.67 million USD)	EPAE (2004)
UNFCCC PROJECT	Framework convention on climate change (FCCC) To build capacity , forest carbon trade, nursery establishment and SLM in Ethiopia from 2008 to present (8.0 million USD)	UNFCCC-NAP DATA BASE http://unfccc.int/cooperation_
UNDP/NAP / (CCF-2)	UNDP funded National Action Plan (NAP) for climate change and land degradation in 69 drought prone districts 2003-2006. (4.5 million USD)	EPAE(2004) http://www.undp.org/drylands/docs/what-we-do/IDDP-ANNEXE.doc.
Desertification control -Ethiopia	National Assistance to national capacity building for land degradation assessment and desertification control project from 2003-2005 funded by FAO (0.4 million USD)	EPAE (2004)
USAID program	USAID Ethiopia mission program in economic growth, agriculture and Trade (ATTMID, CAEFS and DAP programs) from 2004 to 2010. (173.3 million USD)	http://www.usaid.gov/locations/sub-saharan_africa/countries/ethiopia/
LCEP	Legahare Catchments Environmental Protection (LCEP) funded by Ethiopian Government from 2004-2005(0.33 million USD)	EPAE(2004)
Environmental Project	Environmental Protection Rehabilitation Project in Harari Regions funded by Government and ESRDF from 2001-2004 (0.5 million USD)	EPAE(2004)
Wondogenet project	Wondogenet Anasei forestry development project (FDP) (2.73 million USD)	EPAE(2004)
Amhara-FDP	Amhara mountain chain forestry development project (FDP) (0.02 million USD)	EPAE(2004)
SE- Project	Selam Environmental (SE)- local NGO Adamitulu project from 2000 to 2005(0.57 million USD)	EPAE(2004)
EEMCY project	EEMCY (Ethiopian Evangelical Mekane Yesus Church) Manasibu project from 2003 to 2006(0.42 million USD)	EPAE(2004)
Merko Project	Today and tomorrow NGO (local) Merko Watershed development from 2001 to 2004(0.39 million USD)	EPAE(2004)
JCCDO project	Jerusalem children and community development organization (JCCDO) Addis Alem community based environmental conservation and development from 2002 to 2004(0.54 million USD)	EPAE(2004)
EENGO projects	Ethiopian Environmental NGO (EENGO) Tokke , Konno and Sellale Development and conservation projects funded by CIDA, PACT and others from 2001 to 2004 (0.28 million USD)	EPAE(2004)
PGE NGO	Rift valley Integrated Natural resources conservation and management for 2 years by Pine for green Ethiopia (PGE) (0.067 million USD)	EPAE(2004)
NCA,REST project	Environmental rehabilitation and Messanu project by Norwegian Church Aid (NCA)/ Relief society of Tigray (REST) from 2000 to 2004(0.66 million USD)	EPAE(2004)
Interchurch development project	Advocating for the Ethiopian Environment funded by Heinrich Boll foundation and Belgian Embassy from 2001 to 2004 (0.14 million USD)	EPAE(2004)
Hope for Horn Project	NOVIB Holistic Natural Resource Management funded by NOVIB from 2003 to 2005. (0.48 million USD)	EPAE(2004)
ISD project	Sustainable development and ecological land management with farmers in Tigray by Institute of sustainable development (ISD, local NGO) funded by Third world Network in 2003(0.02 million USD)	EPAE(2004)
Save USA/UK	Carbon Finance in Ethiopian Rangelands in 2004-by Save the Children USA/UK	www.elmt-relpa.org/.../Final%20TFG%20Report%20_SCUS_Jul09.pdf