PROSPECTS OF ENHANCING SOIL ORGANIC CARBON IN UPLAND (*BARI*) FARMS OF MID HILLS NEPAL THROUGH SUSTAINABLE SOIL MANAGEMENT PRACTICES

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The M.Phil. Degree in Environmental Science

By

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DECLARATION

I, Ngamindra Raj Dahal, hereby declare that the work presented herein is genuine work done originally by me and has not been published or submitted elsewhere for the requirement of a degree program. Any literature, data or works done by others and cited within this dissertation has been given due acknowledgement and listed in the reference section.

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CERTIFICATION

This is to certify that the dissertation entitled "***Prospects of Enhancing Soil Organic Carbon in Upland Agriculture Lands (Bari) through Sustainable Soil Management Practices***" by Mr. Ngamindra Raj Dahal, is hereby accepted.

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ABSTRACT

Agricultural land is one of the major sources of carbon dioxide emission (CO_2), which results increase of the CO_2 concentration in the atmosphere. Assessment of SOC concentration can serve to evaluate the soil quality and carbon sequestration potential of agricultural land. In the context where climate change mitigation options are being seriously explored globally, an assessment of soil organic carbon in mountain agriculture lands of Nepal is highly desirable. This is also an effort to appreciate efforts of local farmers who have been practicing sustainable soil management. This study seeks to answer the research question – what are the effects of sustainable soil management practices undertaken in the mid hills districts of Nepal on accumulating soil organic carbon in uplands agriculture lands or *bari* in Nepal?

The present study determined SOC on three types of land uses – farmland with sustainable soil management practices (SSMP), farmland without sustainable management practices (Non-SSMP) and the community managed forest (forest) in four Middle Mountain districts of Nepal, namely Baglung, Dhading, Kavre and Okhaldhunga. The results indicated that the average SOC pools in the SSMP land was in the range of 20 - 44 Mg ha^{-1}, that in non-SSMP agricultural areas ranged from 15 to 48 Mg ha^{-1}, and in the forested land it was in the range of 16 to 23 Mgha^{-1}. In general, the abundance of SOC stocks are in the order of SSM>Non-SSM>Forests. Forests had lower total SOC stocks due to the fact that the soils there were shallow and gravelly being located on steeply sloping areas. The analysis indicates a high potential of SOC sequestration through sustainable soil management.

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CHAPTER 1

INTRODUCTION

Agriculture accounts for about 14% of global greenhouse gases (GHGs) or 6.8 giga tons (Gt) of carbon dioxide equivalent (CO_2e) per year (IPCC 2007). In most countries they are associated with agricultural activities and exceed emissions from all other agricultural sources (FAO, 2009). About 74% of total agricultural emissions originate in developing countries. The technical mitigation potential of agriculture (estimated upper limit if best management practices are widely adopted) has been calculated as 5.5-6 Gt of CO_2 per year by 2030 (IPCC 2007). This potential is extremely large, especially relative to emissions from the sector. About 89% of this potential could be achieved through soil carbon (C) sequestration. Mitigation of methane (CH_4) can provide 9% (through improvements in rice management and livestock/manure management) and mitigation of N_2O can provide 2% (primarily through cropland fertilizer management). The majority of the potential (70%) can be realized in developing countries (Smith et al. 2007).

As soil organic carbon (SOC) has an important role in the global carbon cycle, it generated interest in recent years due to its possible function as a carbon sink. In light of recent concerns over the extent of global warming and the role of SOC as a potential store of atmospheric carbon, there is an increasing pressure and demand to estimate SOC stocks with the greatest possible accuracy (Bell and Worrall 2009). SOC refers to the amount of carbon stored in the soil and is expressed as a weight in percentage and closely related to the amount of soil organic matter (SOM). According to the approximation: SOC x 1.72 = SOM (Young and Young 2001). There are two ways in which SOC is stored in soil (Bardgett 2005): soil microbial biomass and easily decomposed plant residues. Carbon is exchanged between the soil and the atmosphere through the process of photosynthesis and decomposition. Plants absorb CO_2 and retain carbon while releasing oxygen through the process of photosynthesis. Carbon, which is retained by plants, is then transferred to the soil via roots during the decomposition of plant residues.

Continuous cultivation of agricultural lands without adequate measures to conserve the soil and replenish organic matter and nutrients leads to a reduction in soil organic carbon

(SOC) contents and ultimately its productivity. Ideally, healthy soils consist of an optimum level of SOC though fluctuations are common in actively managed lands such as agriculture fields. Conventional farming practices often lead to loss of SOC due to extraction or removal of biomass (stumps, roots etc) that would serve a source of organic matter. Accordingly, the conversion of natural land systems (e.g., from forests to agricultural lands) is a major contributing factor to CO_2 emissions. In contrary to this, well managed soils have great potential for storing carbon in the form of SOC which has a double benefit of carbon sequestration and enhancing soil quality.

Distribution of SOC varies in accordance to the type~~s~~ of land uses, inputs to the soil and natural factors including climate and vegetation. SOC is vital for sustaining agriculture productivity that chiefly depends on both the inherent soil type and crop management practices affecting depletion or replenishment of organic matter over the years. This study aims to assess SOC distribution on selected farmlands of Nepal's mid-hills, where farmers have adopted an approach of sustainable soil management practice in non-irrigable hill terraces called *bari* in comparison with those of surrounding conventional bari and forest lands where no such interventions are made.

2.1 Objectives

- To document and analyze SOC status in farmlands (SSMP and non-SSMP) and community managed forest areas in SSMP sites.
- To assess carbon capture and storage (sequestration) potential through sustainable soil management practices in upland agriculture lands of Nepal.
- To analyze policy prospects of benefiting local farmers from global climate funds for contribution to GHGs reduction.

2.2 Hypothesis

Based on the aforementioned objectives of the research, the hypotheses set to this study are:

- ■ SSM practices in the mountain agriculture lands contribute to enhance SOC stocks in comparison to similar lands where no such interventions are made.

- Among three land use categories, community managed forests, SSM practice agriculture land, and conventional agriculture practice lands, the SOC stocks follows the order of Forests>SSM agriculture land>non-SSM agriculture lands.

2.3 Rationale for the Study

Development of SOC database contributes to overcome the serious information gap of SOC status and its dynamics in various mid hills agriculture lands of Nepal that has been a major constraint for policy decisions to claim international climate funds for carbon sequestration or planning SOC restoration programs for sustainable soil management. Majority of Nepal's mountain farmers eke out their livelihoods through subsistence agriculture practices in the non-irrigated uplands locally known as *bari*. Several studies (Regmi *et. al*. 2005, Bajracharya and Atreya 2007, SSMP 2009, and, Dahal and Bajracharya 2011) have highlighted efforts of the mountain farmers in maintaining soil quality against degradation of soil fertility, surface erosion, and landslides. Among other actions, they use farm yard manure (FYM) in *bari* every year that contributes to maintain or enhance soil organic matter, thus, sequestrating carbon in the form of soil organic carbon or SOC. The FYM is prepared with waste biomass from agriculture fields and forest litter mixed with dung from livestock. These are few of their good practices that they are doing from generations, on which there are limited studies regarding impacts of such practices on soil carbon pool.

A study by Bajracharya and Atreya (2007) clearly indicated that the SOC pool is growing in the *bari* lands where sustainable soil management practices were adopted, and, there is a good prospect of benefiting the mountain farmers through international climate finance for carbon sequestrating in their fields. One of the key recommendations of the study is to carry out further studies on status of SOC and compare the same to various land use conditions of the country. This study is built on the concept of the earlier studies intending to evaluate whether the soil organic carbon pools are really increasing in the fields where sustainable agriculture practices were undertaken compared to those where no such practices are employed. In this background, this study will fill up the gap of research based information required for taking policy decisions in favour of claiming climate finance to support the mountain farmers who are contributing to enhance carbon pools through SSM practices.

2.4 Scope and Limitations of Study

Scope of this study has its significance on generating the much sought scientific information required to support policy decisions in favour of low-income mountain farmers who have adopted sustainable soil management (SSM) practices in Nepal. Though SSM practices have been promoted for decades to maintain soil quality and enhance productivity of the land, studies conducted elsewhere have clearly indicated that SSM practices also contribute to prevent losses of soil organic matter and enhance soil organic carbon pool. Therefore, findings of this study have significance to make a policy decision whether agriculture sector of Nepal can stake a claim for accessing international climate funds to compensate the SSM practicing farmers for contributing to reduce carbon emissions and enhancing SOC pools.

Limitations of this study include its limited coverage areas in 4 VDCs one each from Baglung, Dhading, Kavre and Okhaldhunga districts, one time field survey and inadequate baseline information from past studies to compare the results. Nevertheless, the findings provide baseline information for future research and indicate a huge scope through which Nepal can stake claim for the benefit of carbon emission reduction from international climate funds.

CHAPTER 2

REVIEW OF LITERATURE

According to Lal (2004a), most agricultural soils have lost 30 to 40 metric ton of carbon per hectare, and their current reserves of soil organic carbon are much lower than their potential capacity. The primary mechanism of storage of organic carbon in the soil is through tying it up in the form of soil organic matter (SOM). SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes and carbon associated with soil minerals. Carbon can remain stored in soils for millennia, or be quickly released back into the atmosphere depending on natural and anthropogenic factors. Climatic conditions, natural vegetation, soil properties, drainage and management all affect the amount and length of time carbon is stored. In agricultural systems, the amount and length of time carbon is stored is determined primarily by how the soil resource is managed. A variety of agricultural practices that can enhance carbon storage have been identified. The adoption of good farming practices to develop a more productive and sustainable agriculture, can also remove carbon dioxide (CO_2) from the atmosphere, thus contributing to climate change mitigation.

Agriculture lands rich in soil organic matter have important productivity and resilience benefits. These benefits include improvement in soil quality, increase in use efficiency of inputs, reduction in soil erosion and sedimentation, and decrease in non-point source pollution. Restoring quality of degraded soils is essential for achieving sustainable food security that eventually requires soil carbon sequestration as an essential prerequisite. Soil carbon sequestration can be a win–win strategy to mitigate climate change by offsetting anthropogenic emissions, improving the environment, especially the quality of natural waters, enhancing soil quality, improving agronomic productivity, as well as enhancing food security.

In recent decades, SOC has received growing attention in relation to CO_2 emissions reduction from agriculture lands. It is also a vital component of soil for maintaining sustainable productivity of farming systems. Soils high in organic carbon generally indicate good quality, therefore, it is desirable to maintain an optimum level that requires careful land use and management practices. Failure to lock carbon in the soil would lead to the release of the same to the atmosphere in the form of carbon dioxide. The beneficial effects of soil organic carbon (fresh organic matter, as well as humus) include enhancing nutrient availability to plants, increasing aggregate stability, improving moisture retention capacity and boosting microbial diversity and activity. Lal (2004b) points out that soil organic carbon generally depletes through: (1) the long-term use of extractive and intensive farming practices, and (2) the conversion of natural ecosystems (such as forest lands, prairie lands, and steppes) into croplands and grazing lands. Such a conversion depletes the soil organic carbon pool by increasing the rate of conversion of soil organic matter to carbon dioxide (CO_2), thereby reducing the input of biomass carbon and accentuating losses by erosion.

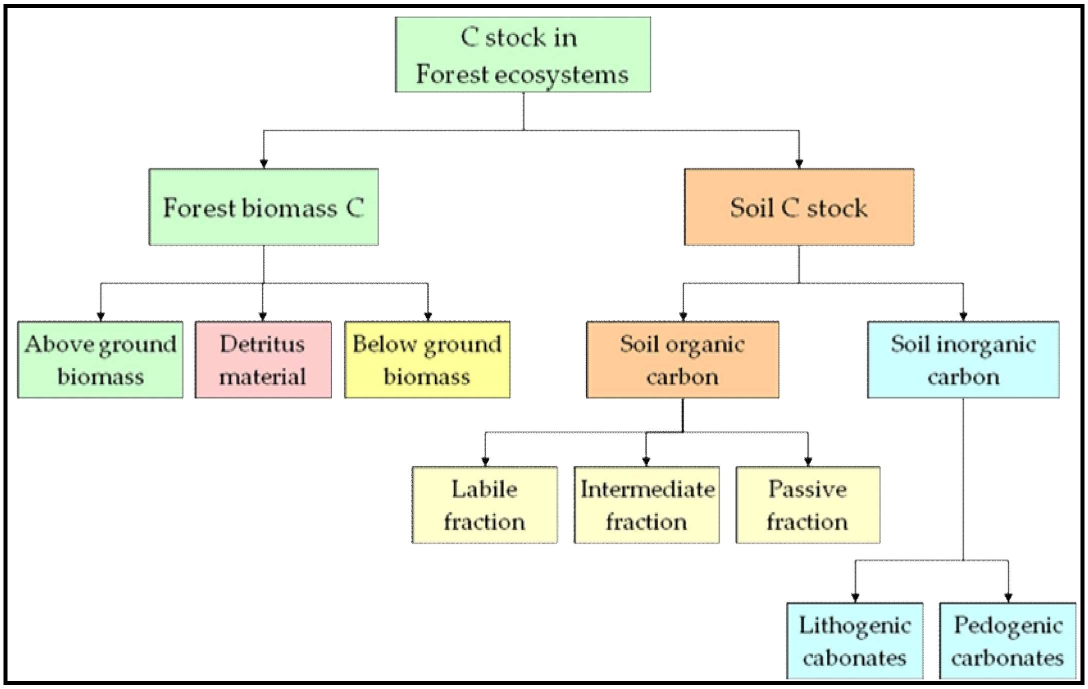

Figure 1 : Components of the terrestrial carbon stock (Lal, 2005)

SOC distribution depends upon various biotic and abiotic factors, such as micro-climate, faunal diversity, land use, and management. Leaf litter and root exudates inputs play a major role in forest soil, while agricultural practices such as tillage, farmyard manure and compost additions, fertilizer inputs and the return of crop residues determine the SOC dynamics in cultivated soils. Lal (2009) suggested that increasing organic carbon pools in the soil beyond a threshold level (about 1.2 % in the surface layer) is essential to enhancing soil quality, increasing agronomic productivity, and improving quality of natural waters. The author also emphasized that the strategy of carbon sequestration in soils and biota is cost effective, safe, and has numerous co-benefits over leaving carbon in the atmosphere or sequestering it in geologic and oceanic strata. Biotic, or plant-based, sequestration is based on a natural process whereby CO_2 is photosynthesized into organic substances and stored for the long term in plant products and soil organic matter. The natural rate of photosynthesis in the global biosphere is about 120 billion metric ton of carbon per year. Fossil fuel combustion emits about 8 billion metric ton of carbon annually, and deforestation and land-use conversion emit another 1.6 billion to 2 billion metric ton of carbon per year, resulting in a total of 9.6 to 10.8 billion metric ton of carbon emissions per year (Lal, 2009). Thus, if roughly 8% of the carbon being photosynthesized within the biosphere is sequestered in the soil and biotic pools, the global carbon budget would be balanced.

2.1 SOC Stocks in Mountain Agriculture Lands

SOC enrichment leads to improvement in soil quality, increase in agronomy/biomass productivity and improvement in use efficiency of inputs (e.g. fertilizer, water). The beneficial effects for agricultural production of soil organic carbon (fresh organic matter, humus) are well known for perennial nutrient sources for plants, increased aggregate~~s~~ stability, increased moisture storage capacity and increased microbial diversity and activity. In conclusion, higher percentages of SOC generally improve the chemical, physical and biological characteristics of soil.

Traditionally, Nepali mountain farmers have tilled the hillsides and valley bottoms over centuries to grow grain such as rice, wheat, millet, barley, and buckwheat. Maize is grown throughout the region, often in mixed cropping systems. The farmers have shaped the slopes into cascades of terraces that support crops and distribute irrigation water. Because of the steepness of the land and the erosive force of the monsoon rain, loss of topsoil is an ever-present problem (ICIMOD 2005).

Being an agriculture-dominated country, a significant number of mountain farmers in Nepal have used farm-yard manure (FYM) as the major source of plant nutrients based on traditional knowledge and techniques followed for generations. In the past, this contributed to the maintenance of a balanced input-output ratio of SOC. In Nepal, the majority of farmers (>85%) apply farmyard manure and/or compost in their fields (Maskey et al. 2002). However, a decline in the soil organic carbon pools is observed due to changes in land use, intensive cultivation, and poor organic manure management (Gami et al. 2001; Upadhyay et al. 2005). Traditionally, farmers rely upon compost or FYM, made of forest litter, crop residues as well as animal manure to replenish croplands, and followed a less intensive and more sustainable fallow farming system, producing only two crops in an annual cropping cycle. In recent years however, the majority of farmers have switched to conventional usage of chemical fertilizers and intensified cropping systems with 3 or more crops per year (Dahal and Bajracharya, 2011).

Intensified vegetable cropping systems with up to 4 crops grown in the annual cropping cycle have become commonplace, especially in peri- and semi-urban areas close to highways and urban markets. The production of major cereal crops has been virtually stagnant over the past 15 to 20 years and the national average yields of maize, wheat and rice are well below the attainable and experimental yields; and, the productivity of these crops are well below those reported in neighbouring countries (Kaini 2004). The main reasons for low yields are believed to be the lack of replenishment of soil organic matter and soil nutrients, and inadequate or inappropriate use of fertilizers (Bajracharya 2002, Regmi et al. 2005, Karki 2006). Over the past few decades, there has been a notable shift in cropping patterns due to increasing food and cash-crop demands along with availability of agro-chemicals though supplies are often interrupted. This has led to diminishing productivity and fertility of arable lands (Bajracharya 2002).

Highlighting the prospect of carbon storage at famers' level in Nepal, Atreya et al (2006) reported that soil erosion and intensive tillage in mid-mountain farmlands of Nepal led to a loss of SOC 188 Kg $ha^{-1}y^{-1}$ in the farmlands under conventional tillage practice while the same was 126 Kg $ha^{-1}y^{-1}$ under non-conventional tillage practice. The study noted that reduced tillage could be a viable strategy to reduce SOC loss, and thereby, to reduce CO_2 emissions while saving plant nutrients in the soil. Sitaula et al (2004) confirmed that SOC loss due to soil erosion is the major source of CO_2 emissions from soil. This implies that control of soil erosion from farmlands is important to reducing SOC losses and eventually emissions of CO_2.

Shrestha et al. (2004) reported similar results in a mountain watershed of Nepal, and related SOC to FYM input by the farmers. The growth and function of vegetation depends on the availability of plant nutrients in the soil, whilst SOC distributions depend on the input received from the vegetation grown. The input can be from above-ground leaf litter and/or the fine below-ground roots (Bloomfield et al. 1996) and their decomposition rates are governed by microbial activity. The chemical composition of vegetation determines the residence time of organic carbon in the terrestrial ecosystem (Rasse et al. 2006). High SOC is a characteristic of soil conditions and structure that creates a favorable habitat for plants. Singh (2007) estimated total stocks of organic carbon in above-ground and below-ground in the three Indian Himalayan states, namely, Jammu Kashmir, Uttarakhand and Himachal Pradesh, to be around 700 Mt C ha^{-1} where as the soil stock in the alpine meadows of these states is 2.99 billion Mt of carbon from 69,034 Km^2.

2.2 Benefits to Farmers through Adoption of Sustainable Soil Management Practices

Accumulation of carbon dioxide in the atmosphere beyond its natural threshold level has triggered climate change for which agriculture land is a major source of emission. Conversely, the agriculture land has could be part of solution than a problem if the conventional farming practices could be changed into sustainable soil management practices through adoption of SSM techniques. As explained in earlier sections, such practices do exist in Nepal and other parts of the world rather in small scale, thus, need to be promoted through appropriate policy interventions. FAO (2001) and Bajracharya and Atreya (2007) has worked out a chart (figure 1) highlighting some key global to local scale activities.

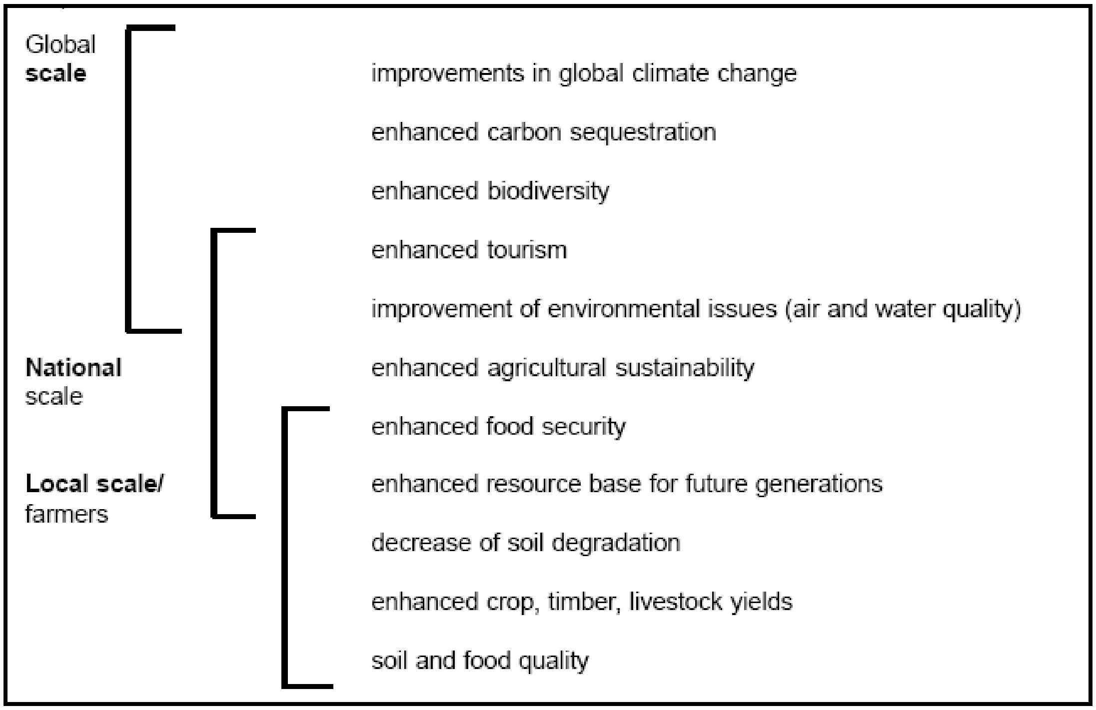

Figure 2: Principal Benefits of sustainable soil carbon sequestration at various spatial scales (Adapted from FAO, 2001, cited in Bajracharya and Atreya, 2007).

Bajracharya et al (2007) substantiated the prospect of benefiting Nepali farmers from SSM practices by estimating total SOC in upland agriculture land of Nepal. The study put the final figure of total SOC to be around 37.8 million metric ton, which is based on CBS (2003) that shows total upland agricultural land in Nepal is a little more than one million hectares. The land area was multiplied by the average carbon density to calculate total amount of SOC stored in the hills to calculate the total SOC. The study also put the figures of market value of the SOC to be between US $ 4.43 and 7.25 million on the basis of a rate of US$ 2.5 per ton C.

Spatial distribution of SOC varies in accordance to the amount of biomass deposited or removed from the soil along with landforms and soil properties. In the rain-fed agriculture land of hill regions, the replenishment is usually poor where farmers tend to harvest crop grain along with straw leaving behind only roots. Gradual loss of SOC contents lead to impoverishment of the soil. Bajracharya and Sherchan (2009) pointed out that restoring SOC along with other nutrients in the mountain agriculture lands of the Himalaya is essential for food security as well as reducing greenhouse gas emissions from soils.

Temperature and moisture, which vary with altitude, are major climatic factors responsible for determining the decomposition rate of organic carbon (Amundson 2001). Chhabra et al. (2003) reported SOC pools (1 m depth) in Indian forests between 70 Mg ha^{-1} to 162 Mg ha^{-1}, which are significantly higher than those found in this study (16 to 23 Mgh^{-1}). The differences may be attributed to the shallow soil of Nepali forest ecosystems selected for this study, which are mostly within 30 cm depth and only few up to 60 cm.

Bajracharya (2006) estimated that nearly 80 % of the demand of chemical fertilizers and pesticides can be reduced through applications of farmyard manure and compost along with urine collection and application and the use of organic biopesticides. This study revealed that in the 15 programme districts, where the average land holding is 0.62 hectare, the total amount of SOC stored in the SSMP improved FYM household's land has been estimated in the range from 1.77 million tons to 2.90 million tons. Intensive tillage and continuous removal of biomass from agricultural fields often lead to gradual decline of SOC. Removal of SOC from a soil ultimately leads to the emission of CO_2 into the atmosphere. Contrary to this, inputs of biomass in the forms of farmyard manure consisting of forest litters, agricultural waste and animal dung contributes to enhanced soil organic matter levels. SOC is essentially the decomposed biomass of plant and animal material transformed and assimilated within the soil over years.

Beyond the local and national scale, Lal (2004a) reported that the rate of soil carbon sequestration through the adoption of recommended management practices (RMPs) on degraded soils ranges from 100 kilograms per hectare (kg/ha) per year in warm and dry regions to 1,500 kg/ha per year in cool and temperate regions. Furthermore, the study reveals that the technical potential of soil organic carbon sequestration through adoption of RMPs for world cropland soils (1.5 billion hectares) is 0.4 billion to 1.2 billion mt of carbon per year. Examples of soil and crop management technologies that increase soil carbon sequestration include no-till (NT) farming with residue mulch and cover cropping; integrated nutrient management (INM), which balances nutrient application with judicious use of organic manures and inorganic fertilizers; various crop rotations (including agroforestry); use of soil amendments (such as zeolites, biochar, or compost); and improved pastures with recommended stocking rates and controlled fire as a method of rejuvenation. Thus, enhancing soil organic carbon involves adding the maximum amount of soil organic matter to the soil. SSMP is one such approach for converting degraded soils into restorative land that also contributes to increasing the soil carbon pool. While no single technology is appropriate for all soils, climates, or cropping and farming systems, the goal then should be to identify site-specific technologies that create a positive soil carbon budget.

Enabling farmers to adopt SSM practices would help reach the dual purposes of reducing rural poverty and contributing to emission reduction in developing countries. It is therefore in the interests of the global climate community to support the initiative for making the global climate funds accessible to the farming communities which are willing to adopt SSM techniques. Though there are a wide range of low-carbon technologies and innovative practices in use, inadequate scientific studies on dynamics of soil carbon bases and other GHG gases in Nepal's agriculture system is evident. For example, ICIMOD (2008) have enlisted 9 different approaches of improved agro-practice management and 21 technologies as effective ways for improving livelihood of low income farmers of mid hill Nepal, but the same are not analyzed from the perspective of GHG gas emissions. In the emerging context, there is potential for reducing soil organic carbon losses and investigating the possibility of claiming carbon emission reduction credits which might be traded like any other farm produce. Additional income can be an important incentive for the resource poor farmers in developing countries to invest in soil restoration. Furthermore, measuring and monitoring protocols for assessing change in carbon pools at the landscape, farm, and regional scales are available to facilitate carbon trading. The greatest potential for sequestration is in the soils of those regions that have lost the most soil carbon. These are the regions where soils are severely degraded and have been over-exploited with extractive farming practices over a long period.

2.3 Key Features of Sustainable Soil Management Practices

Unlike the conventional agricultural practices that often lead to impoverishment of soil quality and reduced productivity of lands, locally improved techniques such as sustainable soil management practices adopted by farmers in selected parts of mountain districts of Nepal are reported to be a remedy to the problem caused by the conventional one (SSMP, 2009). Based on the report by SSMP (2009) the key features of the sustainable soil management (SSM) approach are listed below:

a) Improvement in the quality of farm yard manure (FYM) through the five step actions as follows:
   i) Maintenance of a well managed heap or pit properly protected from the sun using a protective cover, usually plastic, bamboo or foliage roof.
   ii) Protection from the rain, run-in and run-on water,
   iii) Proper drainage, collection, and storage of cattle urine through simple redesign to, or improvement of, the cattle shed,
   iv) Regular turning of the FYM, and maintenance of the FYM in a moist condition before carrying it to the field,
   v) No exposure to the sun of the small FYM heaps in the field prior to application - again covering is crucial.
b) The use of cattle urine as a fertilizer, plant tonic and bio-pesticide.
c) The combining of the above practices with inclusion of legumes, fodder, and forage plants into the rotation.
d) The incorporation of vegetables and other cash crops into the cropping systems.

Box 1: Distribution of SOM in different soil types

Soil organic matter is a stable, complex mixture of dark amorphous and colloidal substances modified from original tissue or synthesised by soil organism called **humus**. Humus is not a single substance, but a mixture of complex compounds. It is thought to consist of:

- Fulvic acid –low molecular weight; light coloured; acid & alkali soluble
- Humic acid—medium molec. Wt. & colour; alkali soluble, acid insoluble
- Humin—highest molecular wt.; darkest colour; acid & alkali insoluble

Humus has high CEC (150-300 cmolc/kg), low plasticity & cohesion. The carbon-nitrogen ratio of soils range from 8:1 to 15:1, being most frequently between 10:1 and 12:1 compared to higher values for plant material and slightly lower for microbes (4:1 to 9:1). C:N ratio is important because of competition for N among organisms when plant residues are added, leading to temporary nitrate depression; and also because N influences the maintenance of soil OC levels (soil C:N ratios remain relatively constant).

Source: Extracted from Brady (1995)

The key research question of this study is: what is the difference in SOC status between the agriculture lands where improved soil management practices applied, and those of conventional one where no such practices were adopted? Answering to this question require a comprehensive understanding of the dynamics of Nepal mountain farming systems in which forests is an integral part. This study has attempted to address the research question by analyzing the SOC status in the three land use categories – non-irrigable upland agriculture land (*bari*) with sustainable soil management practices (SSMP), non-irrigable upland agriculture land (*bari*) with conventional soil management practices (Non-SSMP) and community managed forests (local forest). A review of past studies undertaken in Nepal mid hills and other parts of the Himalaya provide a useful reference for enhancing knowledge of agriculture soil dynamics and emissions of carbon dioxide from agriculture lands.

CHAPTER 3

METHODS AND MATERIALS

Farm fields were sampled for collection of soil (core and composite) samples from 0–15, 15–30, 30–60, and 60–100 cm depths, or down to the bed rock from three types of lands– non-irrigable agriculture land (bari) with sustainable soil management practices (SSMP), bari with conventional soil management practices (Non-SSMP) and community managed forests (local forest). Among the agriculture land, first *bari* or rain-fed upland terraces were chosen where SSM practices were performed. As control sites, surrounding *bari* lands were chosen where no-SSM practices were performed. Likewise, samples were taken from the forests on which the SSM practicing households depend for their household, livestock and farm needs. The sampled points were recorded using handheld GPS (geographic positioning system) equipment for a future reference.

3.1 Selection of Research Sites

The information and database from the Helvetas Swiss Intercooperation-funded Sustainable Soil Management Programme (SSMP) were instrumental in identifying the research plots. Four out of 15 districts in the mid-hills physiographic category were selected on the basis of background information where sustainable soil management practices were implemented for at least 5 years. The information database of farmers included name, location, type of land, and the years of participation in the programme. Among the 15 SSM programme districts, Baglung, Dhading, Kavre and Okhaldhunga districts were chosen for capturing optimum geographical coverage along the mountain region where population size of farmers who dependent on *bari* (non-irrigable upland agriculture lands) is still significant. Among the VDCs (village development committees), one VDC of each district was chosen for sampling where clusters of SSM-practicing households exist. Once the SSM plots were identified, the non-SSM and forests plots were chosen randomly taking SSM plots as reference.

Table 1: Location of Research Sites in Geographical Position Systems (GPS)

District	Land type	Altitud.	Latitud.	Longit.		District	Land type	Altitude	Latitud.	Longit.
Baglung	SSMP 1	1318 m	3133102	753064		Kavre	SSMP 1	1399 m	3055867	358527
Baglung	SSMP 2	1318 m	3133123	753055		Kavre	SSMP 2	1402 m	3055858	358509
Baglung	SSMP 3	1308 m	3133113	753087		Kavre	SSMP 3	1394 m	3055879	358490
Baglung	SSMP 4	1306 m	3133141	753069		Kavre	SSMP 4	1392 m	3055867	358487
Baglung	Non-SSMP 5	1181 m	3130410	754208		Kavre	Non-SSMP 5	1398 m	3056064	358687
Baglung	Non-SSMP 6	1188 m	3130425	754230		Kavre	Non-SSMP 6	1402 m	3056074	358688
Baglung	Non-SSMP 7	1195 m	3130468	754211		Kavre	Non-SSMP 7	1391 m	3055810	358349
Baglung	Non-SSMP 8	1201 m	3130481	754225		Kavre	Non-SSMP 8	1411 m	3055757	358374
Baglung	Forest 9	1139 m	3130365	754376		Kavre	Forest 9	1399 m	3055778	358386
Baglung	Forest 10	1147 m	3130381	754381		Kavre	Forest 10	1410 m	3055764	358350
Baglung	Forest 11	1194 m	3130381	754046		Kavre	Forest 11	1478 m	3055664	358099
Baglung	Forest 12	1166 m	3130173	754153		Kavre	Forest 12	1485 m	3055662	358077
Dhading	SSMP 1	590 m	3089459	294038		Okhaldhu.	SSMP 1	1137 m	3025497	444744
Dhading	SSMP 2	592 m	3089450	294037		Okhaldhu.	SSMP 2	1136 m	3025491	444725
Dhading	SSMP 3	590 m	3089446	294045		Okhaldhu.	SSMP 3	1171 m	3025756	444454
Dhading	SSMP 4	590 m	3089442	294035		Okhaldhu.	SSMP 4	1165 m	3025759	444458
Dhading	Non-SSMP 5	642 m	3089851	294438		Okhaldhu.	Non-SSMP 5	1132 m	3025398	444738
Dhading	Non-SSMP 6	642 m	3089835	294422		Okhaldhu.	Non-SSMP 6	1133 m	3025393	444760
Dhading	Non-SSMP 7	645 m	3089855	294455		Okhaldhu.	Non-SSMP 7	1174 m	3025470	444867
Dhading	Non-SSMP 8	647 m	3089866	294462		Okhaldhu.	Non-SSMP 8	1166 m	3025764	444468
Dhading	Forest 9	616 m	3089483	294100		Okhaldhu.	Forest 9	1194 m	3025428	444906
Dhading	Forest 10	618 m	3089469	294101		Okhaldhu.	Forest 10	1187 m	3025410	444904
Dhading	Forest 11	617 m	3089458	294105		Okhaldhu.	Forest 11	1188 m	3025386	444897
Dhading	Forest 12	615 m	3089479	294100		Okhaldhu.	Forest 12	1190 m	3025384	444898

3.2 Field Sampling Methods and Size

Soils samples were collected and analysed systematically from three categories of land-uses namely SSMP farmlands, conventional farmlands (non-SSMP), and community-managed forest in four districts of Nepal. The land categories were characterized by measurement of three major parameters: SOC (by dry combustion/loss on ignition method; Nelson and Sommers, 1982), Bulk Density (by core method; Blake and Hartge, 1986) and soil texture (by hydrometer method; Gee and Bauder;, 1986). During sample collection, details of soil profile, field conditions and GPS locations of the site were recorded. The collected soil samples from each farm plot were tested at the ISO accredited Aquatic Ecology Centre Soil and Water Analysis Laboratory at Kathmandu University with standard methods. Statistical data analysis techniques (ANOVA, correlation, regression) were used to interpret the results.

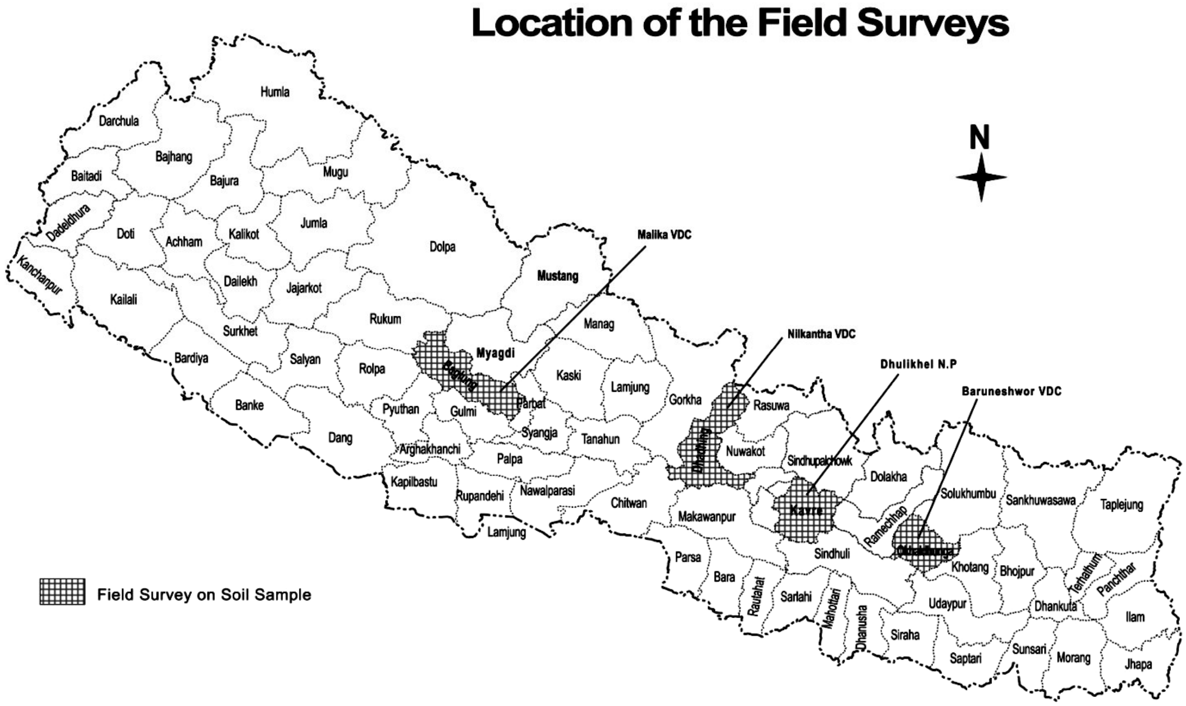

Figure 3: Map indicating districts where the field plots were located.

All together 127 samples were collected from four districts (Table 2). In each of these districts, three plots were identified in SSMP, non-SSMP and forestlands. For each plot, there were four replications of 1m depth or down to rock whichever comes first. Of the 1m thickness of soil, four sampling layers were designed with 0-15cm, 15-30cm, 30-60cm and 60-100cm. Thus, the total sample size was the product of 4 districts*3 plots*4 replications*4 layers, which is 192. While collecting actual samples, however, only 127 were available. This implies that a number of sampled plots were of shallow depth, far less than the maximum depth of 100 cm. In fact, the thicknesses of majority of selected forest plots were up to 30 cm whereas those in SSMP and non-SSMP were up to 60cm.

Table 2: Sample size distribution by depth wise and types of land use- forest, SSMP and Non-SSMP

Depth	Frequency	Percent
0-15	43	34
15-30	42	33
30-60	27	21
60-100	15	12
Total	127	100

Land use type	Frequency	Percent
SSMP	46	36
Non- SSMP	47	37
Forest	34	27
Total	127	100

3.3 Calculation of Soil Carbon Pool

The total pool of soil carbon (TPSC) is expressed as Mega grams per hectare for a specific depth was computed as a product of C concentration, bulk density, and depth (Pearson et al., 2007) as follows:

TPSC = SC/1000X BDX SD X10000 Mg ha^{-1}

Where TPSC = total soil carbon pool, Mg ha^{-1}, SC = concentration of soil C, gkg^{-1} soil, BD = bulk density, gcm^{-3},

SD = soil depth, m.

In addition to other essential properties, soil bulk density and carbon concentration were assessed. The carbon stocks in the soil profiles under different land uses were estimated. The findings were analyzed in comparison with those of similar other studies in the past such as the one by Bajracharya and Atreya (2007).

CHAPTER 4

RESULTS AND DISCUSSION

In this section, analyses of the results are interpreted in terms of soil bulk density, SOC concentration and estimation of SOC stocks (volume) in the respective sampled plots. Correlation of SOC distribution with respect to physical and chemical characteristics of soils, namely, soil texture (clay, silt and sand), pH value, conductivity and potassium (K) were performed. These results are compared with relevant past studies published in various journals and conference proceedings as applicable.

4.1 Soil Bulk Density

Soil bulk density (BD) indicates compactness of soil which is essential to estimate SOC volume. Of the sampled plots, the mean BD was 1.2 gcm^{-3} while the minimum and maximum values were 0.79 gcm^{-3} and 1.56 gcm^{-3}. Among the three land categories – SSMP, Non-SSMP and forest, the mean BD was essentially same for SSMP and Non-SSMP with the values of 1.25 gcm^{-3} and 1.23 gcm^{-3}, but lower in forest soil with 1.11 gcm^{-3}. This implies that soils were more compact in agricultural lands compared to those of adjacent forests. Also, lower BD in the surface layer forest soils can be expected due to higher SOM contents compared to agricultural soils.

Table 3: Status of Soil Bulk Density and Standard Deviation of the sample plots

District	Bulk Density (g/cm3)			Coefficient of Variation (%)		
	SSMP	Non SSMP	Forest	SSMP	Non SSMP	Forest
Baglung	1.27	1.23	1.21	11	20	22
Dhading	1.29	1.28	1.11	14	16	17
Kavre	1.26	1.08	1.01	10	7	15
Okhaldhunga	1.16	1.21	1.07	9	15	12
Mean	1.25	1.20	1.10	11	15	16

The mean BDs in SSMP, non-SSMP and forest soils are 1.25, 1.2 and 1.1 g/cm^3 respectively that clearly shows a decreasing order of BDs in the three categories of land uses (Table 4.1). Likewise, the coefficient of variation in SSMP, SSMP, non-SSMP and forest soils are respectively 11%, 15% and 16%. This indicates greater consistency in SSMP soils than rest two.

Analysis of the samples also confirmed a steady increase of BD values from top to bottom layers with 1.17, 1.19, 1.25 and 1.28 gm/cm-^{3}, respectively from 0-15, 15-30, 30-60 and 60-100 cm depths. This is consistent with general principles of soil compactness - the deeper the layer the denser the soil.

The mean BD values among the SSMP, Non-SSMP and forest are 1.17, 1.21 and 1.13 gcm-^{3} respectively. This indicates that the soils of the top layer in SSMP and forest are less compact than non-SSMP. However, in the deeper layers, the BD (or compactness) of SSMP soils is higher than non-SSMP and forest. This was likely due to the fact that the effect of SSM practices was limited to the topsoil, but these effects were not seen at greater depths in the profile.

4.2 Spatial Distribution of SOC

Analysis of the SOC survey data revealed that the mean concentration of SOC across the sampled plots was 1.5%. Among the three categories of land uses, the mean SOC is highest in the SSMP plots (1.7%) followed by the forest plots (1.3%), and then the non-SSMP plots (1.2%). Based on individual samples, the highest concentration (3.68%) was observed in an SSMP plot while the lowest (0.19%) was noted in a non-SSMP plot. There was a steady decline of SOC concentration from surface to deeper layers as recorded in table 2. The mean concentration of the 0-15 cm layer is 1.85%; this declines to 1.13% at the lower layer of 60-100cm. The rapid decrease of the sample count towards the lower layers was evident in the case of forest soils where the majority of plots are less than 30 cm depth. The count of forests samples from 0-15 cm layer to 30-60 cm layer dropped from 14 to 3 indicating a shallow nature of forest soil. Further below to 60-100 cm layer in forest, no soil sample could be obtained. Among the SSMP and non-SSMP plots, the number of samples in the deepest layer (60-100) was nearly half to those of top layer.

SOC concentration was generally higher in the forest top soils compared to agriculture land, although the fact that the forest soils in the hills are shallow (often no more than the depth of 30 cm) limits the prospect of storing large SOC stocks. On the other hand, a deeper soil profile allows the agriculture lands to have larger overall SOC stocks despite the lower concentration level than in forest surface soils.

Table 4: Distribution of SOC concentration across depth in SSMP, Non SSMP and Forest lands

Soil Depth (cm)	**SOC concentration (%) in the three land use type**												**Depth wise mean**
	SSMP				**Non-SSMP**				**Forest**				
	Count	Min	Max	Mean	Count	Min	Max	Mean	Count	Min	Max	Mean	
0-15	14	0.92	3.38	2.1	14	1.2	2.22	1. 7	14	1.3	2.69	1.9	1.85
15-30	14	0.45	3.09	1.7	14	0.9	3.68	1.5	13	0.83	2.65	1.5	1.54
30-60	12	0.29	2.26	1.6	12	0.89	2.29	1.3	3	1.6	2.49	1.9	1.45
60-100	8	0.75	2.04	1.4	7	0.19	1.85	0.9	Nil	Nil	Nil	Nil	1.13
Mean of land use category				1.7				1.2				1.3	1.5

Table 2 data shows the mean SOC concentration 1.5%. These results were comparable to a similar study by Bajracharya (1999) in central Nepal, that estimated 1.8% SOC concentration in the rain-fed upland and 4% in forest. Another study by Balla et al. (2000) estimated SOC concentration in the rain-fed agriculture lands of Kali Khola Watershed and Andheri Khola Watershed in the range of 0.8 to 1.4% and 0.75 to 1.1%, respectively. However, in the forests the SOC concentrations were significantly higher ranging between 1.4 to 4.6%. Likewise Tripathi (2003) estimated 2.1% SOC in the rain-fed agriculture lands of the western hills of Nepal. Another study by Vaidya et al. (1995) in the western hills of Nepal found 1.2% in rain-fed. Research undertaken by Bontalakoti et al. (2000) in a rain-fed agriculture field of the Indian Himalaya found 1.7% concentration of SOC, which is similar to the finding of this research. Thus, the overall soil carbon status of soils in the study districts appear to be low, hence there is a good potential to increase organic carbon contents and thereby enhance carbon stocks in both agricultural and community forest soils in the mid-hill regions of these districts.

4.3 Total SOC Stock

Based on the SOC survey in the four districts, namely, Baglung, Dhading, Kavre and Okhaldhunga, the average SOC stocks in the SSMP land were in the range of 20 - 44 Mgha^{-1}. In non-SSMP and locally managed forests, the ranges are 15 Mgha^{-1} - 38 Mgha^{-1}, and 16 - 23 Mgha^{-1}, respectively. There were significant differences of SOC stocks across four depth layers from 0cm to 100cm. However, the orders of differences were non-uniform. In the case of the top layer (0-15cm), the SOC stocks in SSMP ranged between

22 Mgha^{-1} and 47 Mgha^{-1}, in non-SSMP between 23 Mgha^{-1} and 39 Mgha^{-1} and, in the case of forests the same was between Mgha^{-1} 25 and 42 Mgha^{-1}. In general, the order of richness of SOC stocks was SSM>Non-SSM>Forests with few exceptions (Table 3). This was also true among soil layers as majority of sampled sites showed higher SOC than the respective lower one.

Table 5: SOC Stocks in Four Districts of Nepal.

Baglung	**SOC Stock (Mgha^{-1})**				
	0-15 cm	**15-30 cm**	**30-60 cm**	**60-100 cm**	**Mean**
SSMP	39	32	42	15	29
Non SSM	36	34	54	80	48
Forest	33	28	30	0	23
Dhading					
SSMP	29	25	53	71	45
Non SSM	22	11	32	17	20
Forest	25	39	0	0	16
Kavre					
SSMP	27	34	44	27	33
Non SSM	23	23	15	0	15
Forest	37	31	0	0	17
Okhaldhunga					
SSMP	47	39	48	42	44
Non SSM	39	35	62	0	34
Forest	42	33	0	0	19

Source: Field Survey, 2011.

Of the 100 cm depth of soil, which was categorized into four layers (0-15 cm, 15-30 cm, 30-60 cm and 60-100cm from the top), SOC pools, as anticipated, again generally followed the trend of being high in the top layers, and, gradually decreasing to the deeper layer or higher depth. However, there were a few exceptions, possibly due to mixing and incorporation of organic matter during tillage or terrace formation.

The mean SOC stock per ha, down to 100 cm, varied spatially according to land-use types, being largest in non-SSMP land (48 Mg ha^{-1}) in Baglung followed by SSMP lands in Dhading (45 Mg ha^{-1}) and Okhaldhunga (43 Mg ha^{-1}) (Table 3). In the case of Kavre, SSMP and non-SSMP stocks are 33 Mg ha^{-1}and 15 Mg ha^{-1}respectively which are quite significant. Thus, the spatial distribution of different land uses was also reflected in the SOC pools.

4.4 Correlations between SOC and Soil Properties

Table 4 shows the correlations of SOC with other physical and chemical parameters namely, bulk density (BD), soil moisture content (SMC), cation exchange capacity (CEC), soil texture (clay, sand, silt), soil pH, exchangeable potassium (K) and depth. The correlation chart reveals that the correlation between SOC abundance and clay-rich soil is highly significant. The analysis clearly showed a significant positive correlation of SOC concentration with pH value. This indicates that high SOC soil have beneficial effect on soil pH. Likewise, there were significant positive correlations of cation exchange capacity and potassium with SOC indicating that increases in SOC has a positive effect, thereby, enhancing CEC and potassium content.

On the other hand, there was a significant negative correlation of depth and SOC concentration clearly indicating the deeper soil has lower SOC density. This is as expected since there is less addition of organic matter and less biological activity deeper in the soil profile. On the contrary, SOC abundance had a highly significant negative correlation with sandy soils. This reflects the fact that SOC tends to be associated with clay particles, hence soil with substantial clay content also had a high SOC percent, while sandy soils had less SOC accumulated. In relation to potassium distribution, a significant positive correlation with SOC was observed although no clear explanation could be offered.

The results presented in the table 4 demonstrate significant correlations of SOC with other major chemical and physical parameters, which are preferable for agriculture soil. The abundant SOC of a soil naturally enhances CEC and neutralizes pH level. The negatively significant correlations of SOC with bulk density indicate that rich SOC make soil fray or less compact, which is a desirable condition for an agricultural land. However, the SOC impacts on soil moisture content (SMC) could not be established as there was no significant correlation between SMC and SOC.

4.5 Analysis and Discussion

The key finding of this study is the distribution scenario of SOC stocks across the four hill districts of Nepal. District-wise analysis of SOC stocks shows that all SSMP lands hold higher SOC volumes compared to non-SSMP and forests soils in all districts. One important point noticed through this analysis is the difference between SOC concentration and SOC stocks. SOC stocks represent the total volume of organic carbon stored in the given depth per unit area of land, while the concentration of SOC measures its richness in the given sample as expressed in % or gkg^{-1}. SOC stocks are thus the product of SOC concentration and area and depth of sampled location. In the case of forests, where despite high SOC concentration, the stocks were lower than the other two land use types mainly because of the shallow soil depth of forest lands which are often limited to steep slope of mountains. On the contrary, the SOC stocks are high in agriculture soils, despite lower concentrations of SOC compared to the forests, mainly because of greater soil depth. In forests, most of the samples were available only up to 30 cm (or two layers), while the majority of agriculture lands had three layers of samples (up to 60 cm), and some up to 100 cm.

Table 6: Correlations analysis for the major physical and chemical characteristics of sampled soils

		BD	SMC	Clay	Sand	Silt	pH	**SOC**	Depth
SMC	Correlation	0.057							
	N	127							
Clay	Correlation	0.098	.301(**)						
	N	127	127						
Sand	Correlation	-0.087	-.293(**)	-.479(**)					
	N	127	127	127					
Silt	Correlation	-0.031	-0.071	-.660(**)	-.344(**)				
	N	127	127	127	127				
pH	Correlation	270(**)	.276(**)	.360(**)	-.187(*)	-.225(*)			
	N	127	127	127	127	127			
SOC	**Correlation**	**-.343(**)**	**-0.017**	**.267(**)**	**-.231(**)**	**-0.088**	**.213(*)**		
	N	126	126	126	126	126	126		
Depth	Correlation	236(**)	.187(*)	.320(**)	-0.083	-.271(**)	0.169	**-.347(**)**	
	N	127	127	127	127	127	127	**126**	
CEC	Correlation	-0.142	.224(*)	0.074	-.336(**)	0.194	0.105	-0.157	-0.129
	N	85	85	85	85	85	85	85	85
K	Correlation	0.008	-0.032	.275(*)	0.125	-.377 (**)	.470(**)	**.333(**)**	-0.038
	N	83	83	83	83	83	83	**83**	83

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at 0.05 level (2-tailed). Field Survey, 2011.

The range of SOC stocks in different land use and land management categories is close to the findings of similar past studies conducted in the hilly regions. Bajracharya et al (2004) estimated SOC stocks in mid hills of Nepal approximately 423.7 Mt C. The study also found SOC concentration lower in the non-irrigable upland or *bari* which was between 1 and 2%. In the irrigable land, however, the SOC concentration was a bit higher in the range between 1.5 to 2.6%. The study also shows the concentration of SOC in forest and shrub land (2.0% and 2.3% respectively) higher than those of cultivated land in the top layer (1-30 cm). Shrestha and Singh (2008) found higher SOC stocks in the rain-fed upland (bari) compared to irrigated low land (khet), which is attributed primarily to fertilizer and FYM inputs by the farmers as they tend to apply more FYM to *bari* due to the proximity to their homesteads.

The results of this study were also comparable to earlier studies in other parts of the mountain. For example, a study by Shrestha and Singh (2008) in Pokhare Khola Watershed in Kaski District (Nepal) found SOC stocks higher in the non-irrigable upland (*bari*) in the order of 15.7 ± 1.5 kg C m^{-2} than the irrigable lowland (*khet*). The study also compared the stocks among varies land use types and found the results in the order of bari>dense forest>khet>mix forest>degraded forest. Depth wise, the total SOC stock in the whole watershed was distributed deposited 36%, 32%, and 32% were in the 0–20, 20–40, and >40 cm, respectively.

CHAPTER 5

CONCLUSIONS AND POLICY RECCOMMENDATIONS

Soils serve as both sources and sinks of CO_2 to the atmosphere. They have, therefore, a great potential to reduce emissions and enhance carbon sequestration through better soil management. In recent years, soil organic carbon (SOC) has received worldwide attentions in the context of international policy agendas of CO_2 emission. Thus, retention of SOC is vital not only for maintaining productivity and sustainability of farming systems but also for reducing the rate of CO_2 emission. Soils either sequester carbon from atmosphere through photosynthesis process of plants and subsequently retaining biomass residues in the soil, or they release into the atmosphere depending on land management and land use practices. Soils with rich organic carbon levels generally indicate high fertility and therefore desirable to maintain an optimum level that requires a careful land use and management practices. Recognising the importance of SOC dynamics in alleviating the rate of atmospheric CO_2 increase, the potential to sequester carbon has become a topic of deep interest among researchers and policy planners.

Agriculture lands with rich soil organic material have important productivity and resilience benefits. These benefits include improvement in soil quality, increase in use efficiency of inputs, reduction in soil erosion and sedimentation and decrease in CO_2 emissions from agriculture land. Food security cannot be achieved without restoring the quality of soils, for which soil carbon sequestration is an essential prerequisite. Soil carbon sequestration can be a win–win strategy to mitigate climate change impacts by offsetting anthropogenic emissions, improving the environment, especially the quality of natural waters, enhancing soil quality, improving agronomic productivity and thereby advancing food security. Without an internationally binding treaty for climate change abatement, however, it is unlikely that an effective national or sub-national policy for emission reduction in the agriculture sector will emerge.

The agriculture sector in developing countries offers a significant potential for reducing emissions from soils and enhancing sustainable productivity of the land through SOC enrichment. Though agricultural lands are accounted as part of the climate change problem for contributing GHG emissions (about 13.5 percent), it may also be part of the solution, offering promising opportunities for mitigating GHG emissions through carbon sequestration, enhanced soil and land use management and biomass production (IFPRI 2009). Climate change threatens agricultural production through higher and more variable temperatures, changes in precipitation patterns and increased number of extreme events such as droughts and floods. Therefore, recognising the roles of the agriculture sector is essential to address the climate change challenges from the sub-national to the international level. In this context, there is a potential of reducing soil organic carbon losses that can be produced into carbon emission reduction credits and traded like any other farm produce. Additional income can be an important incentive for poor farmers in developing countries to invest in soil restoration.

In Nepal, mountain farmers traditionally use locally prepared compost manure in a regular fashion that contributes, among others, to enrich soil with soil organic compound (SOC). Hill farmers of the Himalaya locally prepare composts with forest litter and agricultural waste along with animal dung. This study confirms that SOC stocks are higher in bari lands compared to forest and followed the order SSMP>non-SSMP>forest. Among the layers, the SOC stock was highest in the top layer followed by second, third and forth lower layers. The SOC distribution had significant correlations with clay content, potassium and pH value of the soil. However, the SOC abundance was negatively correlated with bulk density, sand content and depths. The study confirmed that well managed *bari* lands with SSMP approaches can be more effective than conventional farming practices in accumulating organic carbon in soil.

Analysis of SOC pools between *bari* with and without SSMP revealed that the former consists of higher SOC stocks than the latter. The forest land had the least total SOC stock despite generally higher SOC contents in the surface layer (topsoil) due to shallow soil depth. Among the three land uses, the mean SOC concentration was highest in SSMP areas (1.7%) followed by forest (1.3%) and non-SSMP (1.2%) areas. Likewise, the SOC stocks in the top layer (0-15cm) were between 22 Mgha^{-1} and 47 Mgha^{-1} in SSMP category, between 23 Mgha^{-1} and 39 Mgha^{-1} in non-SSMP and between Mgha^{-1} 25 and 42 Mgha^{-1} in forest soils.

This study confirmed that the effects of SSM practices would create not only favorable soil conditions to agriculture lands but also enhance stocks of SOC that helps addressing global concern of reducing carbon dioxide from land use sector. There are policy implications of these findings through which agriculture sector can access global climate funds for adopting SSM practices as a cure for both adaptation to climate change and mitigating of greenhouse gases.

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Glimpses of Study Activities in Photographs

Photograph 1: A SSMP plot in Okhaldhunga

Photograph 2: Soil sampling equipment at a forest plot

Photograph 3: Sample collection on progress near Dhulikhel

Photograph 4: Samples exposed to air drying before lab analysis

Photograph 5: Lab testing of sample on progress

Photograph 6: Lab testing of sample on progress