SOIL CARBON AND NUTRIENT STATUS OF RANGELAND IN UPPER MUSTANG

MENUKA MAHARJAN

TRIBHUVAN UNIVERSITY
INSTITUTE OF FORESTRY
POKHARA, NEPAL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WATERSHED MANAGEMENT

FEBRUARY 2010

Soil carbon and nutrient status of rangeland in upper Mustang

Researcher
Menuka Maharjan
Institute of Forestry
Pokhara, Nepal

Supervisor
Dr. Keshab. D. Awasthi
Associate Professor
Institute of forestry
Pokhara, Nepal

Co-Advisors
Dr. Keshab Raj Pande
Associate Professor
Institute of Agriculture & Animal Science
Rampur, Chitwan

Mr. Bishnu Prasad Shrestha
Assistant Forest Officer
Salyan, Nepal

Tribhuvan University
Institute of Forestry
Pokhara, Nepal

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Watershed Management

---

February 2010

February 2010
Tribhuvan University
Pokhara, Nepal
Nepal2009mustang@gmail.com, menuka_maharjan@yahoo.com

Tribhuvan University
Institute of Forestry, Office of The Dean
P. O. Box 203, Pokhara, Nepal
Web Site: www.iof.edu.np

Citation

Maharjan, M., 2010. Soil Carbon And Nutrient Status OF Rangeland In Upper Mustang, Nepal. M.Sc Watershed Management Thesis, Tribhuvan University, Institute of Forestry, Pokhara, Nepal.

Date: 10 February, 2010

LETTER OF ACCEPTANCE

The thesis attached hereto, entitled **“Soil Carbon and Nutrient Status of Rangeland in Upper Mustang** prepared and submitted Menuka Maharjan in the partial fulfillment of the requirement for the degree of Master of Science in Watershed Management is hereby accepted.

…………………………….……..

Keshab D. Awasthi, Ph.D

(Supervisior)

Associate Professor

Institute of Forestry

Pokhara, Nepal

DECLARATION

I, Menuka Maharjan, hereby declare that this research report entitled **“Soil Carbon and Nutrient Status of Rangeland in Upper Mustang”** is my own work and all other sources are duly acknowledged.

…………………………………

Menuka Maharjan

M. Sc in Watershed Management

Institute of Forestry

Pokhara, Nepal

ACKNOELEDGEMENTS

It would like to express heartfelt gratitude and appreciation to my advisor Dr. Keshab D. Awasthi Institute of forestry, Pokhara and Co-advisor Dr. Keshab Raj Pande, Associate Professor, Institute Agriculture and Animal Science and Mr. Bishnu Prasad Shrestha ,Assistant Forest Officer, District Forest Office, Salyan for their continuous supervision, guidance encouragement, valuable suggestions since the proposal preparations to report finalization.

Special gratitude goes to Annapurna Conservation Area Project (ACAP) for granting me financial support to conduct this research in Lo-manthang, Upper Mustang. I appreciate Mr. Yajna Prasad Timilsina, Reader, Institute of Forestry, Pokhara Campus for his valuable suggestions during data analysis and Dr. Krishna Raj Tiwari, Associate Professor, Institute of Forestry, Pokhara Campus for providing guidance during field work. I am thankful to Mr. Narayan Gautam, Faculty of Institute of Forestry, Pokhara Campus for his suggestions during data analysis and report writing. I am very thankful to Mr. Hitman Kunwar, staff, Institute of Forestry, Pokhara Campus, for providing me necessary equipment for soil sampling and my field research assistances from ACAP office for helping me to collect soil sample. Special thanks go to Mr. Buddi Bahadur Pant, Lumle Agriculture Research Center, Kaski for chemical analysis of soil at labotary.

I can't forget the names of my friends like Bishnu Singh Thakuri, Neeru Thapa, Bishnu Devkota, Manij Upadhaya and other classmates who directly and indirectly gave advices and suggestions concerning the research work.

At last, I owe a sincere gratitude to my family for their continuous encouragement and support in completing this research.

Menuka Maharjan

February, 2010

ABSTRACT

The research **"Soil Carbon and Nutrient Status of Rangeland in Upper Mustang"** was conducted in Lo-manthang VDC of Upper Mustang (September, 2009). The study aimed at assessing the soil carbon and nutrient status of rangeland in Upper Mustang.

Stratified random sampling method was used for soil quality index and soil carbon stocks. Soil samples were taken from soil profile up to 60cm depth at interval of 20 cm. Soil quality index was interpreted by using scoring method developed by National Agriculture Research Council (NARC) and using equation.

Soil of the study area was basic in nature. The dominant textures were sandy loam and loamy sand. Biomass was gradually increased at north aspect with increasing altitude whereas at south aspect biomass was increased up to 3650m and then gradually decreased. Biomass was high at South/3650m (39.75 ton/hectare). Soil quality index values were good at N/3850m, S/3850m, N/3650m, S/ 3650m, N/3450m but fair at S/3450m. All Soil quality index values fall under good class except 0.68 which came under fair class.

Available phosphorus and available potassium was high at north aspect but total nitrogen was high at south aspect. Both total nitrogen and available phosphorus found high at 3650m. Available potassium was gradually decreased with increasing altitude. Total nitrogen, available potassium and available phosphorus were gradually decreased with increasing soil depth. Nitrogen, phosphorus and potassium status found good in the study area.

Bulk density was high at north aspect (1.91 gm/cm^3) than south aspect (1.82 gm/cm^3). Bulk density was increased with increasing altitude from 3850m to 3450m. There was gradual increased in bulk density with increasing soil depth. Bulk density was 1.68 gm/cm^3 at 0-20cm followed by 1.82 gm/cm^3 at 20-40cm and 2.09 gm/cm^3 at 40-60cm soil depth. Soil organic carbon content was high at south aspect with the content of 36.24t/ha followed by 36.02/ha at north aspect. Soil organic carbon content was high at south aspect with the content of 36.24t/ha followed by 36.02/ha at north aspect. Soil organic carbon content was high at lower altitude than higher altitude. Similarly soil organic carbon was high (42.40t/ha) at 0-20cm followed by 33.95 t/ha at 20-40cm and 32.05 t/ha at 40-60cm soil depth.

Keywords: Soil quality index, Soil organic carbon, Biomass, Texture class

ACRONYMS

ACAP	Annapurna Conservation Area Project
NARC	Nepal Agriculture Research Council
SQI	Soil Quality Index
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
CO_2	Carbon Dioxide
C	Carbon
TN	Total Nitrogen
AP	Available Phosphorus
AK	Available Potassium
BD	Bulk Density
t/ha	tonne /hectare
m	meter
cm	centimeter
N	North
S	South
MS-Excel	Microsoft Excel
NGO	Non Governmental Organization
SPSS	Statistical Package for Social Sciences
VDC	Village Development Committee
Sq. meter	Square meter
SE	Standard Error of Mean
IoF	Institute of Forestry
UMCAMP	Upper Mustang Conservation Area Management Plan
$LSD_{0.05}$	Least Significant Difference

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter One: Introduction

1.1 Background

1.1.1 Soil Carbon Sequestration

Carbon sequestration in soils is based on the assumption that fluxes or movements of carbon from the air to the soil can be increased while the release of soil carbon back to the atmosphere is decreased. Instead of being a carbon source, soils could be transformed into carbon sinks, absorbing carbon instead of emitting it. Soil carbon is an important part of terrestrial carbon pool (Lal and Kimble, 1998) and soils of the world are potentially viable sinks for atmospheric carbon (Lal et al., 1998; Bajracharya et al., 1998a; Singh and Lal, 2001). Kirschbaum (2000) estimated that world's soil contain about 1500Gt of organic carbon to a depth of 1m and a further 900Gt from 1-2 m. However, soil is deteriorating at an alarming rate in developing countries like Nepal due to land use changes (IPCC, 2000), lowering C sequestration. The complex mechanisms and processes regulating C sequestration in soil are inadequately understood (Lal et al., 1995: Bajracharya et al., 1998; Post and Known 2000). Soil organic carbon (SOC) content exhibits considerable variability both spatially and horizontally according to land use and vertically with in the soil profile. The SOC diminished with depth regardless of vegetation, soil texture ,and clay size fraction (Trujilo et al.,1997).Removal of trees from the forest displaces a large amount of sequestered carbon and consequently reduces C held in terrestrial biomass (Glaser et al., 2000;IPCC,2000).The negative impact of deforestation on SOC decrease in more pronounced in the upper soil layer (Sombroek et al.,1993).Gradual conversion of forest and grassland to cropland has resulted in historically significant losses of soil carbon worldwide(Lal,2002).

Soils store 1.5 $*10^{18}$ g of organic carbon (C) globally—about twice as much C as is found in the atmosphere and three times the quantity contained in terrestrial vegetation (Schlesinger, 1997). Intensive cultivation can also decrease soil C, contributing to terrestrial net fluxes of C to the atmosphere and decreased net primary productivity (Burke and others 1989; Johnson 1992). Thus, changes in this huge pool of C could mitigate or exacerbate the rise in atmospheric carbon dioxide (CO_2) (Schlesinger 1990, 1999; Nadelhoffer and others 1999) but reforestation and afforestation may have the greatest potential for changes in land use to offset increasing CO_2 emissions (Vitousek 1991; Brown and others 1992; Moffat 1997; Bruce and others 1999).

The amount of organic carbon contained in soils depends on the balance between inputs of organic material (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and loss of carbon through decomposition. The quantity and quality of organic matter inputs, and their rate of decomposition, are determined by the combined interaction of climate, soil properties, and land use. Land use practices such as clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net flux of carbon to or from soils. Deforestation may contribute to the loss of soil C by changing the balance between biomass production and decomposition. Tropical deforestation may be a net source of 0.2×10^{15} g C y $^{-1}$, with up to 25% coming from soils (Houghton 1994, 2000). Some land-use practices (such as low-tillage, legume based, or manure application agriculture) can increase soil C storage relative to conventional agri-culture cultural systems (Paustian and others 1997; Drinkwater and others 1998).

Carbon sequestration in soils is a climate-change-mitigating strategy based on the assumption that movement, or flux, of carbon from the air to the soil can be increased while the release of carbon from the soil back to the atmosphere is decreased .This transformation has the potential to reduce atmospheric CO_2, thereby slowing global warming and mitigating climate change .One possible mechanism for mitigating CO_2 emission is therefore its sequestration, or redistribution from the air to soils, terrestrial biomass, geologic formations, and the oceans. Carbon sequestration can be appropriate from both an environmental and a socioeconomic point of view. The environmental perspective includes the removal of CO_2 from the atmosphere, the improvement of soil quality, and the increase in biodiversity (Batjes and Sombroek, 1997; Batjes, 1999; Lal et al, 1999).

1.1.2 Soil Quality Index

Soil quality index is increasingly proposed as an integrative indicator of environmental quality (NRC, 1993), food security and economic viability (Lal, 1999). Therefore, it would appear to be an ideal indicator of sustainable land management. It helps to assess changes in dynamic soil properties caused by external factors. It identifies problem areas and assesses differences between management systems and is valuable to measure the sustainability of land and soil management systems now and in the future (Doran et al., 1994). It is used for assessing the overall soil condition and response to management, or resilience towards natural and anthropogenic forces. Soil quality index may be inferred from various soil indices derived from physical, chemical or biological attributes that reflect its condition and response.

Soil quality is the "capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Soil quality is a dynamic interaction between various physical, chemical and biological soil properties, which are influenced by many external factors such as land use, land management, the environment and socio-economic priorities. Soil quality is considered a key element of sustainable agriculture (Warkentin, 1997) because it is essential to support and sustain crop, range and woodland production and helps maintain other natural resources such as water, air and wildlife habitat Therefore an integrated soil quality index based on the weighted contribution of individual soil property to maintain the soil quality may serve better indicator of soil quality for different land uses. Soil texture, drainage conditions, slope and aspect are not well correlated with climatic parameters, but vary with land uses and control soil organic carbon (SOC) fate (Awasthi et al., 2005; Tan et al., 2004), because it is related largely to vegetation and topographical features (Franz Meier et al. 1985).

1.1.3 Rangeland

Rangelands are usually the piece of open land with natural vegetation used for grazing by livestock whose types and quality are determined by altitude and climate.

Rangelands of Upper Mustang are major source to sustain livestock as well as people's livelihood as they are rich in medicinal and aromatic plants and Trans-Himalayan biodiversity. They are also sources of other natural resources, tourism, carbon sink, valuable cultural landscape, place for recreation and aesthetic value, and beautiful scenery. Overall, rangeland ecosystems are an interconnected community of living things, including human, livestock, vegetation, interacting with the physical environment. Much of the Mustang landscape is dominated by pastures but the prevailing harsh climatic condition doesn't permit to grow sufficient grasses in these lands (Kunwar, 2003). Agricultural production in these areas is very limited due to scarcity of water, lack of proper irrigation, low temperature for longer periods and low rainfall.

The rangelands not only provides grazing lands for livestock but also supports large number of rare and endangered plants, animals and birds. Plant species such as *Caragana* spp., *Lonicera* spp., *Stipa* spp., *C*arex spp., *Kobresia pygmea*, *Kobresia felicina*, *Lagotis* spp., *Thymus linearis*, *Corydalis* spp., *Delphinium* spp., and *Meconopsis* spp. characterize the rangelands (Chetri and Gurung, 2004). The rangelands also supports unique assemblage of rare and endangered species – Tibetan Argali (*Ovis ammon hodgsonii)*, Tibetan Gazelle (*Procapra picticaudata),* Kiang (*Equus kiang),* Blue sheep (*Pseudois nayaur)* and their predators - Snow Leopard *(Uncia uncia)*, Lynx *(Lynx lynx isabellinus)*, Red Fox (*Vulpes vulpes),* Himalayan Brown bear (*Ursus arctos)* and Grey Wolf *(Canis lupus)* (Pokhrel, 2006).

1.2 Problem Statement and Justification

Soil is viable sink of atmospheric carbon. Several studies have indicated that the global potential for enhancing carbon storage in forest and agricultural ecosystem may be as much as 60-90 pentagram of C (De Jong et al., 1999). Lal (2002) has also observed that about 60 to 70% of the carbon can be sequestered through adoption of recommended soil and crop management practices in land where soil has lost 25 to 40 mg C ha^{-1} of their original pool, upon conversion from natural to agricultural ecosystem. Estimation of carbon stock in soil is burning issues now a days but no one knows what amount of carbon is sequestrated in soil of Rangeland. The finding of research will give the amount of carbon in soil of rangeland and its contribution in carbon sequestration.

Upper Mustang has its own unique socio-cultural, biological and geomorphologic diversity. Economically the main occupation of Mustang is agro pastoral system. However agricultural production being limited due to lack of sufficient water for irrigation and harsh climatic conditions (Kunwar, 2003), livestock grazing is the main source of earning livelihood. Rangeland of Upper Mustang is under heavy grazing pressure and grazing takes place throughout the year. Researchers have identified that overstocking (overgrazing) in the rangelands is the main factor causing deterioration of rangelands (Miller, 1996; Schaller and Gu, 1994; Wang *et al*., 2002).

Nepal's largest pasture/rangeland lies in the High Mountains. The rangelands are located at remote area, high elevation and subject to harsh climatic conditions. So managing rangelands and planning for sustainable rangeland and pastoral development in high altitudinal region are challenging and they have been neglected to a greater extent by research and development agencies in Nepal. Accessible pasture/rangelands are under severe grazing pressure. These high altitude rangelands should be given a high priority for sustainable management. On the other hand, these pastures/rangelands form the head of watersheds, which initiates the streams or rivers extending towards lower altitude, mid-hills and Terai. The better management of these highland pastures would help to protect the unexpected melting of ice, snow or glaciers from Himalayas. The protection and sustainable management of pasture/ rangeland also support livelihoods of local people through livestock rearing or collecting and marketing wild foods and vegetables such as mushrooms, bamboos shoots, medicinal plants etc (Pant & Devkota, 2007).

The productivity of rangeland in Upper Mustang is decreasing day by day due to low rainfall and overgrazing so people are leaving agro pastoral occupation and searching alternative source of income to sustain their livelihood.

The study will provide information on the distribution and status of major nutrients, SOC and other soil properties that ultimately shows the productivity of rangeland in Upper Mustang. This finding will help the local people to know the status of soil and its effect on vegetation of rangeland. So my findings will help to take the necessary steps to improve low quality soils, conserve the high quality soils and maintaining the productivity of rangeland. In the long run the study will help to bring improvement in soil quality and betterment in rural people's socio-economic status.

1.3 Objectives

1.3.1 General Objective

The general objective of study was to assess the soil carbon and nutrient status of rangeland in Upper Mustang.

1.3.2 Specific Objectives

The specific objectives were

- Quantify the soil carbon of rangeland.
- Determine soil quality index of rangeland.
- Quantify forage biomass of rangeland.

Chapter Two: Literature Review

Rangelands are among the most important agricultural ecosystems in the Himalayas (Blamont, 1996; Dunn et al., 2003). Rangelands play an important role, in determining the socioeconomic condition of rural people (HMGN/NPC, 1993). The grasslands not only support a large number of plant and animal species, they also provide a livelihood for mountain people. There are possibly 10 million people residing on the mountain grazing lands in the Himalayas and on the Tibetan Plateau who are dependent upon livestock for their livelihoods (Miller, 1995). In these areas grazing presents the only way at present to convert primary production to secondary products such as meat and milk products and non food products such as fiber, hide and manure – all important products for the subsistence livelihood in this region (Miller,1995). Heavy livestock grazing is thought to lead to a decline in range condition; reducing or removing grazing pressure assumed plant succession processes would restore the range to its previous state (Miller, 1996).

Out of total rangelands in Nepal, the highest area of rangelands lies in High Himal and High Mountains which is 50.72% and 29.11% respectively, (NBS, 2002).

Rangelands in Nepal are under heavy grazing pressure, thereby causing the depletion of the resources which has resulted into feed shortage and hence the livestock productivity (Jha, 1991). Over 7,242 hectares of high altitude pastureland have been developed and 20,000 hectares of private land have been transformed for various forage crops throughout Nepal (NPC, 1998).Grazing is a year round threat to many of the productive protected areas in the Terai whereas it is more of a seasonal threat in the high elevation pastures in the Himalayas (Heinen and Kattel, 1992).Livestock overgrazing minimized the availability of forage to wildlife leading to degradation of grazing land (Kunwar, 2003).

Well managed rangelands have diversified grass species and higher carrying capacity (Hermans and Vereiujkan, 1995). Use of Rangeland for enhancing the animal production is viewed as a means of improving the quality of rural life (UNEP, 1979). Livestock overgrazing minimized the availability of forage to wildlife leading to degradation of grazing land (Kunwar, 2003).Rangelands are showing signs of rapid deterioration leading to high altitude desertification (Pradhan and Hitchcock, 2000). Low range productivity and high livestock utility in the Himalayan region make the pastoralists maintain the largest possible herds (Goldstein and Beall, 1990).

Although more than 48% of the land area in the Himalayan region of Nepal along with its northern border with Tibet is occupied by natural grassland vegetation (LRMP, 1986), the high quality pasture in Upper Mustang is found in limited areas. The people of Upper Mustang have their own traditional system of pasture management but the management system tends to fall outside the carrying capacity concept (Craig, 1996). In Upper Mustang both summer and winter pastures are suffering from overgrazing due to lack of pasture management plan (Kunwar, 2003).Researcher had also reported that grazing affects species composition and species diversity. Herbivores have pronounced effect on plant establishment, growth and reproductive success. They also have substantial effects on plant forms. Among the most conspicuous effects of large mammalian grazers upon grasslands is a drastic reduction of above ground biomass (Karki, 1997).

An integrated soil quality index based on the weighted contribution of individual soil property to maintain the soil quality may serve better indicator of soil quality for different land uses. Soil quality index is useful way to determine land deterioration or improvement. Land uses and elevation play important role in enhancing SOC and nutrients hence affecting the soil erosion rates. Lower annual average temperature, retarding the decomposition rate might also have resulted in greater amount of SOC stock at higher elevation. About one third of the total SOC and nutrient concentration was located in the upper 15cm soil depth. There was strong correlation between SOC content and slopes showing the steeper the slopes lower the carbon content. The study demonstrated that slope position and aspect also played important role in SOC sequestration, with higher SOC in the north facing and lower slope position (Awasthi, 2004).

A decline in soil quality as a result of soil degradation is a serious problem affecting food production in the Himalayan region. A quantitative and qualitative assessment of soil quality could provide important information for sustainable land management in mountain farming.

Soil organic carbon and total nitrogen were found to be lower in forestland than on Bari land. Farming activities ,such as collection of forest fodder and litter for livestock feed, bedding , and the making of compost , which was eventually applied to Bari and Khet land as a nutrient source, are likely to have led to low Soil organic carbon accumulation in the forest and the enrichment of Bari land (Tiwari, 2008).

World soils contain an important pool of active carbon that plays a major role in the global carbon cycle (Lal, 1995, Melillo et al., 1995, Prentice et al., 2001). Soils store two or three times more carbon than that exists in the atmosphere as CO_2 and 2.5 to 3 times as much as that stored in plants (Post et al., 1990, Houghton et al., 1990). Through increases in organic matter, soils may sequester atmospheric carbon dioxide emitted by anthropogenic sources (Post et. al., 1990, Tian et. al., 1998, 1999). At present, the uncertainty in understanding the role of soils in the global carbon cycle is mainly due to the poor understanding of the spatial distribution and dynamics of soil organic carbon (Torn et al., in Earth's 1997). The large, unknown C sink (1.8 Pg) in the global balance of CO_2 atmosphere suggests a role for the world soils in the further understanding of the processes involved in carbon emissions and sequestration (Lal et al., 1995a, b, Melillo et al., 1995).

At present, the uncertainty in understanding the role of soils in the global carbon cycle is mainly due to the poor understanding of the spatial distribution and dynamics of soil organic carbon (Torn et al., 1997). The large, unknown C sink (1.8 Pg) in the global balance of CO_2 atmosphere suggests a role for the world soils in the further understanding of the processes involved in carbon emissions and sequestration (Lal et al., 1995a, b, Melillo et al., 1995).

By knowing the stock of carbon we can predict how much carbon has been sequestrated. Carbon sequestration can be appropriate from both an environmental and a socioeconomic from the point of view. The environmental perspective includes the removal of CO_2 from atmosphere, the improvement of soil quality, and the increase in biodiversity (Batjes and Sombroek, 1997, Batjes, 1999, Lal et al., 1999). Socioeconomic benefits can be reflected through increased yields (Sombroek et al., 1993) and monetary incomes from potential carbon trading schemes (McDowell, 2002). Carbon sequestration projects could also enhance local participation and understanding of sustainable forest management practices (Tschakert, 2001). ''Soil carbon sequestration'' implies removal of atmospheric Carbon dioxide by plants and storage of it as soil organic carbon. The strategy is to increase SOC density in the soil, improve depth distribution of SOC and stabilize SOC by encapsulating it within stable micro-aggregates, so that carbon is protected from microbial processes or as recalcitrant carbon with long turnover time (Lal, 2004).

The carbon sequestration potential of grasslands are highly dependent on site-specific variables, such as vegetation, soil types, climate, and land use history. The first step of the analysis was to identify the productivity of the grasslands from literature , and then to stratify the permanent grassland areas into broad classes as delineated by Chen et al. (1998), i.e., into high yield ,fair yield, and low yield grassland types. Since most of the studies reviewed report significant degradation in the region caused by overstocking, the default value for grazing management was used for the purpose of this study, reduced accordingly dependent on the productivity (high yield class=2.16, medium yield class=1.43,low yield class=0.71).The annual carbon sequestration potentials within rangelands for Nepal is 2.1 million t CO_2 .China possesses the highest annual potential with 64.1million t $CO_{2,}$followed by Afghanistan (19.8 million t CO_2) and India (19.1 million t $CO_{2)}$ (ICIMOD, 2009).

Soil organisms are creatures that spend all or part of their lives in the soil environment. Soil is one of the nature's most diverse and complex ecosystems. The macro invertebrates found in the soil especially earthworms, play very important role in soil quality maintenance. These cause important effects both on soil properties and on the functioning of larger ecosystems. The activities of these organisms greatly affect both physical and chemical conditions in the soil, especially in the upper 15 to 35 cm of soil. The macronutrients; nitrogen (N), phosphorus (P) and potassium (K) frequently are the first to become deficient in the soil because they, especially N and K are required by plants in the largest quantities (Bandel et al, 2000).

Pasture lands cannot be managed through continuous grazing. For the management of forage growth controlled grazing should be employed (Beetz, 2001). By improving the forage conditions number of native prey species can be increased and thus livestock depredation can be lessened (Jackson et al., 2002).

Indigenous rangeland management activities are practiced in Upper Mustang like rotational grazing, levying of fines for herders caught grazing outside their designated village grazing areas. But the traditional management system alone is not adequate to produce more forage in overgrazed and overpopulated rangeland (Thapa, 1990).

Despite their extent and importance the dynamics of the rangeland ecosystems in the Hindu-Kush Himalayan –Tibetan Plateau region are still poorly understood. Questions concerning how rangeland vegetation functions and the effect of grazing animals on the ecosystem in these mountain rangelands remain unanswered for the most part .The socio-economic dimensions of the pastoral productions are also not well known. This lack of information limits the proper management and sustainable development of rangelands (Miller, 1996).

Chapter Three: Study Area

3.1 Study Area

3.1.1. Geographic Location

It lies in the northern part of Mustang District approximately at 83° 45' to 84° E and 29° 04' 12" to 29° 18' N. It is known to the world as The Walled City since the settlement is surrounded by wall. To its North is Chhonup VDC, in South Surkhang VDC, in East Surkhang VDC and in West Ghami VDC The altitude range of Lo-manthang VDC is 3200m to 6500m. There are altogether two permanent settlements in Lo-manthang VDC.

3.1.2 Climate

The climate of the area can be characterized as cold desert, desiccated by strong winds and high solar radiation. The climate is sub-alpine, and has a maximum and minimum temperature of 26.8°C and 9.9°C in July and 10.7°C and -5.8 °C in November of 2005. The whole area remains under snow for 4 – 5 months from November to March. Total annual rainfall is less than 200 mm and more than half of the total precipitations occur as snow during the winter months. The region falls under the Dhaulagiri–Annapurna mountain rain-shadow zone.

3.1.3. Soil

Most of the geology is alluvial, colluvial, morainal depositional surfaces and steeply to very steeply sloping Mountain terrains (LRMP, 1987). Ammonites (*saligram*), fossilized molluscs, which are considered as key fossils from the evolutionary biology point of view and venerated by the Hindus are only found in the Upper Mustang area in the country.

3.1.4 Population and Households

Total population of Lo-manthang VDC is 848 in 180 households with an average size of 4.7 (CBS, 2001).

3.1.5 Biodiversity

The habitat diversity mainly includes patches of forests (mainly of *Juniperus spp*., *Betula* spp. and *Populus ciliata*)**,** dry alpine scrubland, alpine meadows and Tibetan desert steppe. In addition, agricultural lands, settlements, aquatic bodies, cliff and caves are significant habitats of the area (Shah, 2003). Cliffy areas are good habitat of blue sheep (*Pseudois nayaur*).

3.1.5.1. Flora

The vegetation represents high altitude grasslands that are Tibetan in characters (Stainton, 1972). The natural forest is dominated principally by *Juniperus squamata*, *Juniperus wallichiana*, and *Betula utilis.* Plantations are carried out exclusively of *Salix* spp. and *Populus ciliata, Juniperus indica, Hippophae tibetana, Rhododendron lepidotum, Lonicera obovata, Ephedra gerardiana, Spiraea arcuata, Cotoneaster* spp., *Caragana* spp., *Berbaris* spp., *Artemisia* spp. are dominant plant species of the dry alpine scrubland habitat which lie between 2,900-4,000m throughout the area. All high altitude pastures above 4,000m consist of alpine meadows. Many herbs and grass species constitute vegetation of this habitat.

3.1.5.2. Fauna

The pastures, besides serving as grazing ground for the livestock favours a number of rare and endangered Trans-Himalayan wild animals. Surveys related to fauna of the area reviewed by Shah and Rayamajhi (2005) confirm the presence of 18 species of butterfly, single species of fish, 2 species of amphibian, 2 species of reptile, 99 species of bird, and 29 species of mammal.

Upper Mustang harbours 11 species of bird and 10 spp. of mammal listed in different appendices of the CITES. Six of the mammal spp. recorded from the area are protected by HMG Nepal, National Parks and Wildlife Conservation (NPWC) Act 1973 and 7 are included in different threat categories of the Red Data Book of IUCN. Five spp. of butterfly, extinct mollusca spp. (saligram), 2 spp. of frog, 1 spp. of reptile, 2 spp. of birds - Tibetan sand grouse, *Syrrhaptes tibetanus* and Eurasian eagle owl sub species, *Bubo bubo hemachalana* - and 7 species of mammal found in the area have so far not been recorded from any other part of the country (UMCAMP, 2005). The area also serves as corridor for many passage and trans-Himalayan migratory birds (Pokhrel, 2006).

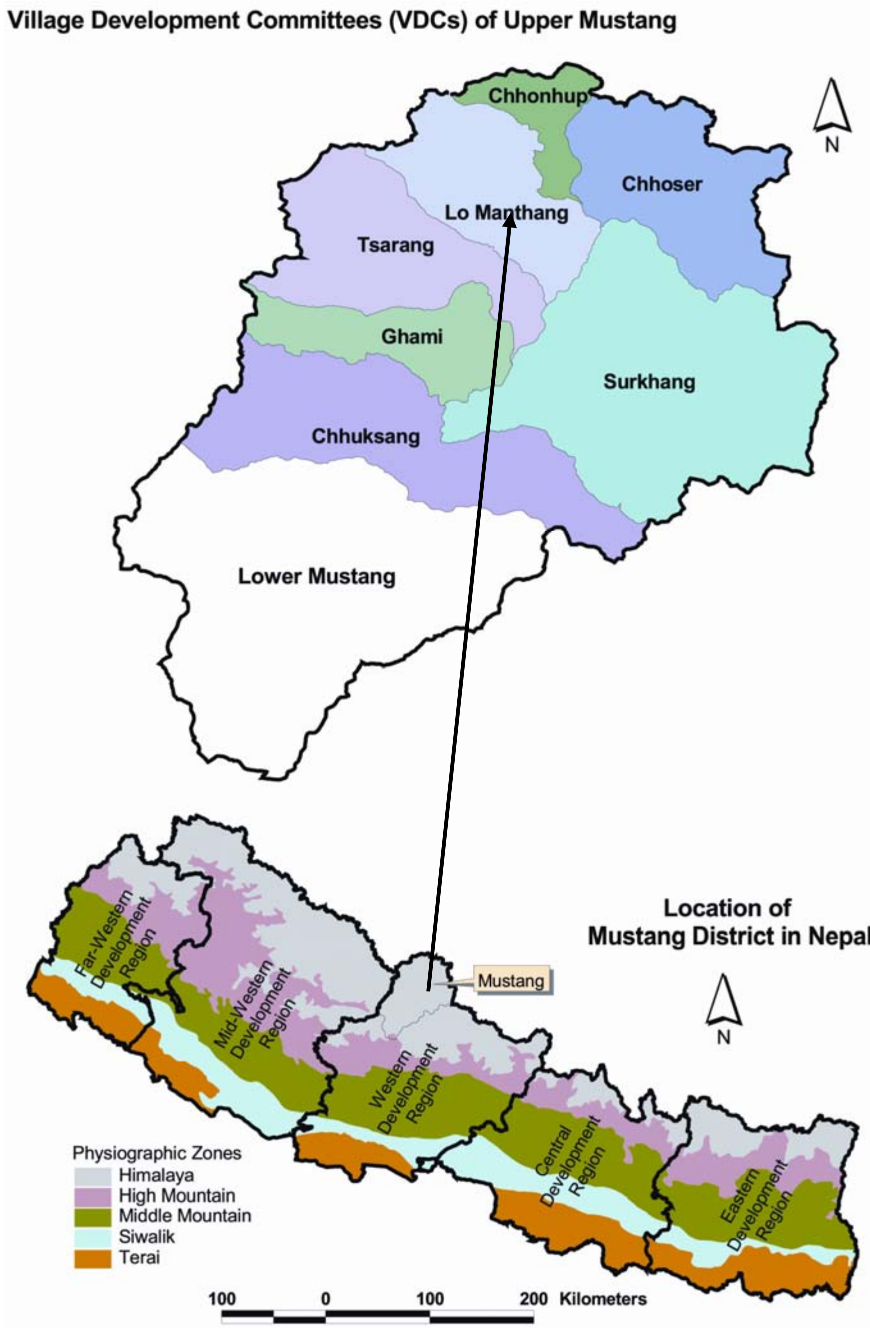

Figure 1: Map of the study area

Source: ACAP, 2001

Chapter Four: Methodology

4.1. Data Collection

4.1.1. Sampling Design

Plots having a size of 1m*1m were taken under consideration which was standard size for study of rangeland vegetation (Kent and Coker 1995; Bhattarai et al.2004).The stratified sampling method was adopted for the study. The starting point was selected randomly and would be considered as centre point. After selecting the center point, two plots each having fifty meter perpendicular distance from center line were fixed. Subsequently, the remaining task was carried out to congregate biophysical parameters. For soil sampling, north and south aspect were taken. In case of altitude, 3850m, 3650m and 3450m were taken. The three replication of soil samples were taken from each strata for computing nutrient as well as carbon stock measurement.

4.1.2 Sample Plot Measurement

Plants cut close to the ground surface, separated on the basis of palatability and collected in plastic zipper bag. Fresh weight of the species based on palatability measured on the spot. The samples of the total specie clipped. In order to reduce the moisture contents, the collected samples were air dried for 48 hrs and transported to Institute of Forestry, Pokhara for dry weight measurement. The samples were oven dried at 70^{0}C for 24 hrs for dry weight measurement and the dry biomass percentages calculated using the formula:

4.1.3 Soil Sampling

For carbon stock and nutrient profile was dug at centre part of the plot up to 60cm depth. Soil samples at different depths (0-20cm, 20-40cm, 40-60cm) were taken. A core ring sampler (4.8 cm dia. and 10 cm long) was used for bulk density

4.1.4 Soil Properties under Study with Methods of Measurement

The different parameters that were used to assess soil quality index of different land uses were shown in Table 1.

Table 1: Soil properties under study with their methods of measurement

Soil properties	Methods
Physical	
Bulk density	Core sampling method (Blake and Hartge, 1986)
Texture	Hydrometer method
Chemical	
pH	Glass calomel pH meter
Organic matter	Colorimetric method (Anderson and Ingram, 1993)
Total Nitrogen	Kjeldahl method (Bremner and Mulvaney, 1986)
Available Phosphorus	Olsen's and Somers method (1982)
Available Potassium	Flame Photometer method (1986)
Biomass	(Zobel, et al,. 1987)

Soil samples were analyzed under the facilitation of Regional Soil Laboratory at Lumle, Pokhara to assess the status of major physio-chemical properties. SQI was interpreted based on the analysis of soil samples collected from the site.

4.1.5 Secondary Data Source

Secondary informations were collected from related articles, libraries (IoF, NARC and ACAP), web-sites etc.

4.2 Data Analysis

4.2.1 Conversion Factor for Organic Matter (%) to Organic Carbon (%)

Organic matter (%) converted into Organic carbon (%) by using the given formula below (Milne, 2008)

$$\text{Organic carbon (\%)} = \frac{58 \text{ x Organic matter (\%)}}{100}$$

4.2.2 Soil Organic Carbon

Total soil organic carbon calculated by using the formula given below (Pearson et al., 2007)

C (t/ha) **= [(**Organic carbon content %* soil bulk density (gm/cm^3)*thickness of horizon (cm)]*100

In this equation % C must be expressed as a decimal fraction

Total carbon stock = soil organic carbon of all horizons.

4.2.3 Bulk Density

Soil BD determined using core sampling method (Blake and Hartge, 1986). Oven dried (at 105^0 temperature) soil samples used for moisture correction. The dried soils were sieved through a 2mm sieve and weighed and weight of stones recorded for stone correction. Following formula used to calculate the bulk density using stone correction (Pearson et al, 2005)

$$\textbf{Bulk density (gm/cm}^3\textbf{)} = \frac{\text{Oven dry weight (gm/cm}^3\text{)}}{\text{Core volume (cm3)} - \dfrac{\text{Mass of the coarse fragments (gm/cm}^3\text{)}}{\text{Density of rock fragment (gm/cm}^3\text{)}}}$$

Where, the coarse fragments were >2mm. The density of rock fragments was 2.65gm/cm^3

4.2.4 Soil Quality Index

Soil Quality Index values as proposed by Bajracharya et al., (2006) calculated by using the following equation.

SOI = $[(a \times R_{STC}) + (b \times R_{pH}) + (c \times R_{OC}) + (d \times R_{NPK})]$……………………………i

Where,

$R_{STC,}$ = assigned ranking values for soil textural class

R_{pH} = assigned ranking values for soil pH

R_{OC} =assigned ranking values for soil organic carbon

R_N =assigned ranking values for nitrogen,

R_P =assigned ranking values phosphorus

R_K =assigned ranking values for potassium

And a=0.2 b=o.1 c=0.4 and d=0.3 are weighted values corresponding to each of the parameters.

4.2.5 Scoring Method

The scoring method developed by Nepal Agriculture Research Council used to interpret Soil Quality Index. It was based on assigned range of values suggested by Nepal Agriculture Research Council. For commonly used soil parameters in Nepal.

Table 2: Various soil parameters and ranking values

Parameters	Ranking values				
	0.2	**0.4**	**0.6**	**0.8**	**1**
Soil textural class	C, S	CL, SC, SiC	Si, LS	L,SiL,SL	SiCL, SC
Soil pH	<4	4.1-4.9	5-5.9	6-6.4	6.5-7.5
Soil organic carbon in %	<0.5	0.6-1	1.1-2	2.1-4	>4
Fertility (NPK)	Low	Mod Low	Moderate	Mod. High	High
SQI	V. poor	Poor	Fair	Good	Best

C- Clay S- Sand CL- Clay loam SC- Sandy Clay
SiC- Silty Clay Si- Silt LS- Loamy sand SiL- Silty loam
SL- Sandy loam LS- Loamy Sand SiL- Silty loam SL-Sandy loam
SiCL- Silty clay loam SCL- Sandy Clay loam
SQI- Soil Quality Index

Table 3: Interpretation for soil pH

pH	Range
<4.5	Strongly acidic
4.5-5.5	Moderately acidic
5.5-6.5	Weakly Acidic
6.5-7.5	Nearly Neutral
>7.5	Alkaline

Table 4: Interpretation table for soil fertility

OM (%)		TN (%)		AP (kg/ha)		AK (kg/ha)	
Range	level	Range	level	Range	level	Range	level
<2.5	Low	<0.1	Low	<31	Low	110	Low
2.5-5	Medium	0.1-0.2	Medium	31-55	Medium	110-280	Medium
>5.0	High	>0.2	High	>55	High	>280	High

Source: NARC, 1993

The texture of the soil was determined from the relative distribution of sand, silt and clay in the sample.

4.2.6 Biomass Estimation

The collected samples were oven dried at 70^0C for 24 hrs for dry weight measurement and the dry biomass percentages calculated using the following formula:

% dry Biomass = Dry weight/Fresh weight x 100 (Zobel et al,. 1987)

4.3 Statistical Analysis

Data analysis carried out using SPSS and Microsoft Excel. Descriptive statistics used to produce tables, bars while inferential statistics also used to test the relationships between different variables under study. One-way ANOVA was carried out to test the variation of different properties of soils with respect to different factors under study. Multiple comparisons of means were carried out using $LSD_{0.05}$.

Chapter Five: Result and Discussion

5.1 Phyico-chemical Properties of Soil

pH (8.7) was high at N/3650m and S/3450m followed by S/3850m and S/3650m (8.6) and N/3450m (8.5), N/3850m (8.4) as shown in Table 5. The soil of the study was basic in nature. Due to low rainfall the soil of the arid region is basic in nature. There was no significant difference in pH value at different altitude and aspect.

Organic matter was high at S/3650m (2.30%) followed by N/3850m (1.97%), N/3450m (1.87%), S/3450m (1.79%), S/3850m (1.27%) and N/3650m (1.11%) as shown in Table 3. All these values fall under low class as shown in Table 2c. OM was found high at S/3650m due to high clay content as well as the highest Biomass content at this aspect and altitude. Low decomposition rate and microbial activity due to low temperature caused the high OM content compared to other aspect and altitude. OM was found significantly different at different soil depth which was shown in Appendix1.

High TN (0.27%) was at N/3450m followed by N/3650m (0.2%), N/3850m (0.19%), S/3450m (0.18%), S/3850m (0.17%) and S/3450m (0.16%) as shown in Table 3. All these value fall under high class according to Table 4.

AP was high at N/3650m with value (83.33 kg/ha) followed by S3850m (73.37kg/ha), S/3650m (72.23kg//ha), N/3450m (66.67kg/ha), N/3850 (65.57kg/ha) S/3450m (34.43kg/ha) as shown in Table 5. All these values fall on high level according to Table 4. Due to high pH value, AP was found high in the study area.

Soil pH plays very crucial role in phosphorus availability. The reason for the higher phosphorus content on Bari land could be due to the higher levels of pH (Table 5) and the high soil organic matter content that improved the general soil condition and provided some phosphorus to the soils (Regmi et al., 2004).

Phosphorus movement is heavily influenced by soil properties and land management practices such as cropping and tillage. Most soils have a large capacity to retain phosphorus. Even large additions of phosphorus will be mostly retained by soils provided there is adequate contact with the soil (Lowell Busman et al, 1998). As phosphorus is not available in the mineral form, Franzluebber et al. (2001) mentioned that redistribution of extractable phosphorus in the agriculture soils is direct effect of surface placement of manure and crop residue that leads to accumulation of soil organic matter and microbial biomass near the surface. In case of Nepal as we do not have phosphate rocks low level of AP in forest might have resulted due to this reason.

AP was high at N/3450m (947.67kg/ha) followed by N/3650m (721.13kg/ha), S/3650m (612.10kg/ha), N/3850m (559.90kg/ha), S/3450m (558.77kg/ha) and S/3850m (423.23 kg/ha) as shown in Tables 5 .All these values fall in high level according to Table 4. Low level of AK might have resulted due to sparse vegetation as found in the field observation. Available potassium is high due to the presence of mica in the study area (LRMP, 1986). The dominant texture classes sandy loam and loamy sand. Loamy sand texture class was found at N/3850m followed by sandy loam text class at S/3850m. Similarly, sandy loam texture class was found at N/3650m, N/3450m and loamy sand texture class at S/3650m, S/3450m.

Table 5: Physico-Chemical properties of soil at different aspect and altitude

Aspect/ Altitude	pH	OM	TN (%)	AP (kg/ha)	AK (kg/ha)	Particle size distribution (%)			T C
						Sand	silt	Clay	
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	
N/3850m	8.4 ± 0.1	1.97 ± 0.16	0.19 ± 0.21	65.57 ± 8.6	559.90 ± 225.37	77.53 ± 2.5	20.99 ± 2.61	1.47 ± 0.95	LS
S/3850m	8.6 ± 0.06	1.27 ± 0.11	0.17 ± 0.14	73.37 ± 8.82	423.23 ± 169.32	71.32 ± 0.29	27.22 ± 0.29	1.46 ± 0.0	SL
N/3650m	8.7 ± 0.05	1.11 ± 0.88	0.2 ± 0.08	83.33 ± 5.10	721.13 ± 169.32	71.65 ± 0.48	27.05 ± 0.53	1.3 ± 0.98	SL
S/3650m	8.6 ± 0.05	2.30 ± 0.35	0.16 ± 0.43	72.23 ± 3.99	612.10 ± 241.53	73.76 ± 0.48	24.39 ± 1.13	1.85 ± 0.72	LS
N/3450m	8.5 ± 0.88	1.87 ± 0.33	0.27 ± 0.17	66.67 ± 13.85	947.67 ± 381.01	70.65 ± 0.86	27.78 ± 0.77	1.57 ± 0.11	SL
S/3450m	8.7 ± 0.88	1.79 ± 0.57	0.18 ± 0.14	34.43 ± 5.89	558.77 ±238.14	74.43 ± 1.63	4.33 ± 1.57	1.24 ± 0.72	LS

* TC=Textural class; LS= Loamy sand; SL= Sandy loam

5.2 Soil Carbon Sequestration

5.2.1 Bulk Density

Bulk density was high at north aspect than south aspect. BD (1.91 gm/cm^3) was found at north aspect followed by 1.82 gm/cm^3 at south aspect as shown in Table 6. This result showed that soil was good in south aspect than north aspect which proved by high Biomass content at south aspect.

Table 6: Bulk density (gm/cm^3) at different aspect

Aspect	Mean	Minimum	Maximum	Range	SE
North	1.91	1.58	2.30	0.72	.074
South	1.82	1.49	2.29	0.8	.095
Mean	1.86				

BD was increased with increasing altitude from 3850m to 3450m. At 3450m, BD was found 1.80 gm/cm^3 at 3450m followed by1.82 gm/cm^3 at 3650m and 1.97 gm/cm^3 at 3450m as shown in Table 7.

Lower value of BD is the indication of the soil suitability for growth of vegetation because with increasing in BD soil compactness is also increased that make soil unfit for vegetation growth. This problem can be reduced by good tillage practice, less use of machinery equipment, high use of farm yard manure.

Table 7: Bulk density (gm/cm^3) at different altitude

Altitude(m)	Mean	Minimum	Maximum	Range	SE
3450	1.80	1.49	2.14	.65	.099
3650	1.82	1.54	2.08	.54	.080
3850	1.97	1.58	2.30	.72	.128
Mean	1.86				

There was gradual increased in BD with increasing soil depth. The minimum BD was found at top level the soil. BD was 1.68 gm/cm^3 at 0-20cm followed by 1.82 gm/cm^3 at 20-40cm and 2.09 gm/cm^3 at 40-60cm soil depth as shown in Table 8. The top soil had low BD indicated that soil was good for vegetation growth compared to other soil depth.

ANOVA test showed that BD was significantly different at different soil depth which was shown in Appendix1 .LSD $_{0.05}$ showed that BD was significantly different between

0-20 and 40-60cm,20-40 and 40-60cm soil depth but no significant difference was found with other soil depth ($p \leq 0.05$) as shown in Appendix 1.

Table 8: Bulk density (gm/cm^3) at different soil depth

Soil Depth	Mean	Minimum	Maximum	Range	SE
0-20cm	1.68		1.89	.40	.069
20-40cm	1.82	1.58	2.14	.56	.085
40-60cm	2.09	1.76	2.30	.54	.082
Mean	1.86				

The Bulk density depends on several factors such as compaction, consolidation and amount of SOC present in the soil but it is highly correlated to the organic carbon content (Morisada et al., 2004, Leifeld et al., 2004). This may be probably as a result of lower organic matter contents, less aggregation, fewer roots and other soil-dwelling organisms, and compaction caused by the weight of the overlying layers (Brady and Weil, 2002).

5.2.2 Soil Organic Carbon

The Soil organic carbon content was high at south aspect with the content of 36.24t/ha followed by 36.02/ha at north aspect as shown in Table 9. There was no significant different in SOC at different aspect, altitude and soil depth ($p \leq 0.05$).

Awasthi (2004) reported that SOC was found high at north aspect and lower positions. But SOC was high at south aspect, it was due to high plant biomass and low at north aspect due to steep slope which was prone to erosion hence were depleted in SOC.

SOC is high when there is high amount of biomass present. But it is not only one factor that affects SOC sequestration. There is other factors like temperature of the place because lesser will be the temperature of the place, higher is the SOC sequestrated. In alpine region, the temperature is very less which retard the microbial activity. Due to less microbial activity, there is less degradation and released of nutrients required for plant growth. And due to lack of required nutrients, plants growth will be less and can't use the carbon stock present in soil. SOC in the alpine region is greater than other region which is viable sink of atmospheric carbon in the absence of forest.

Table 9: Soil organic carbon (t/ha) at different aspect

Aspect	Mean	Minimum	Maximum	Range	SE
North	36.02	22.68	52.16	29.48	3.56554
South	36.24	21.12	52.97	31.85	3.72812
Mean	36.13				

The Soil Organic Carbon content was high at lower altitude class (37.50 t/ha) as shown in Table 10. However, Smith et al, (2000) reported that SOC was increased with elevation in semi-arid environment due to increase in precipitation, decrease in temperature and production of greater amount of plant biomass at higher elevations. But due to steep slope which accelerated soil erosion was responsible for reducing SOC at higher altitude.

Table 10: Soil organic carbon (t/ha) at different altitude

Altitude(m)	Mean	Minimum	Maximum	Range	SE
3450	37.50	21.12	52.16	31.04	5.41367
3650	35.07	22.68	52.97	30.29	5.13697
3850	35.82	29.31	46.00	16.69	2.74949
Mean	36.13				

SOC was high (42.40t/ha) at 0-20cm followed by 33.95 t/ha at 20-40cm and 32.05 t/ha at 40-60cm soil depth as shown in Table 11. SOC was gradually decreased with increasing soil depth.

Awasthi (2004) reported that about one third of the total SOC and nutrient concentration was located in the upper 15 cm soil depth. There was strong correlation between SOC content and slopes showing that steeper the slopes lower the carbon content.

This study also showed that SOC was high at top soil due to presence of vegetation at top soil compared to other two soil depth which had no vegetation except root of the vegetation.

Table 11: Soil organic carbon (t/ha) at different soil depth

Soil Depth	Mean	Minimum	Maximum	Range	SE
0-20cm	42.40	26.19	52.97	26.78	4.65
20-40cm	33.95	23.69	44.68	20.99	3.57
40-60cm	32.05	21.12	46.00	24.88	4.15
Mean	36.13				

5.3 Status of Nutrients at different aspect, altitude and soil depth

5.3.1 Total Nitrogen

Total nitrogen was high at south aspect (0.19%) than north aspect (0.20%) as shown in Table 12. SOC was high at south aspect which was correlated with high nitrogen stock due to high clay content and Biomass showing high SOC and nitrogen stock. Both OM and SOC found higher at south aspect than north aspect indicate high nitrogen because nitrogen content was closely linked with the presence of organic matter in the soil.

Table 12: Total nitrogen (%) at different aspect

Aspect	Mean	Maximum	Minimum	Range	SE
North	0.19	0.23	0.16	0.07	.008
South	0.20	0.34	0.14	0.20	.021
Mean	0.19				

TN was high at 3650m (0.22%) followed by 0.19% at 3450m and 0.17% at 3850m as shown in Table 13.There was fluctuation in TN at different altitude. Due to presence of deep rooted vegetation, TN was high at 3650m altitude.

Table 13: Total nitrogen (%) at different altitude

Altitude(m)	Mean	Maximum	Minimum	Range	SE
3450	0.19	0.23	0.16	.07	.01
3650	0.22	0.34	0.16	.18	.02
3850	0.17	0.23	0.14	.09	.01
Mean	0.19				

Total nitrogen was high at 0-20 cm (0.23%) followed by 0.20% at 20-40 cm and 0.16% at 40-60 cm soil depth as shown in Table 14. TN was gradually decreased with increasing soil depth. Vegetations present in the top soil were the main cause of this result.

ANOVA table showed that TN was significantly different at different soil depth which showed in Appendix 1. $LSD_{0.05}$ test showed that TN was significantly different between 0-20 and 40-60cm soil depth but no significant different was found with other soil depth as shown in Table 15.

Table 14: Total nitrogen (%) at different soil depth

Soil Depth	Mean	Maximum	Minimum	Range	SE
0-20cm	0.23	0.34	0.19	0.15	0.02
20-40cm	0.20	0.28	0.16	0.12	0.02
40-60cm	0.16	0.19	0.14	0.05	0.01
Mean	0.20				

Table 15: LSD $_{0.05}$ for Total nitrogen (%) at different soil depth

Factors	Paris compared	Mean difference	Standard error	Significance
	0-20 and 20-40cm	0.33	0.24	1.85
TN	0-20 and 40-60cm	0.68*	0.24	0.01
	20-40and40-60cm	0.35	0.24	0.17

* denotes the mean difference at $p \leq 0.05$

Total nitrogen in the soil is solicited because the nitrogen in the soils occurs in several forms band it takes into account all the nitrogen in organic and inorganic forms. Some scientists argue that TN does not give good indication of soil fertility because only a small portion of TN is available to plants. 2 to 3 % of TN is in the inorganic form, mostly ammonium ($NH4+$) and Nitrate ($NO3-$) which is only available to the plants (Bandel et al., 200; Marx et al., 1999). Others present a different view that organic and inorganic forms of nitrogen are always interchangeable and it would be better to consider the total nitrogen to investigate soil quality. Determination of Nitrate ($NO3\ -$) and Ammonium ($NH4+$) would not give an overall picture of the fertility, but give a snapshot of the N availability not only for plants but also, for micro-organisms in the soil (Truelsen and Lundsby, 2001).

5.3.2 Available Phosphorus

Available phosphorus was high at north aspect (71.86 kg/ha) followed by south aspect (60.01kg/ha) as shown in Table 16. This table showed that AP was found high at north aspect than south aspect.

Table 16: Available phosphorus (kg/ha) at different aspect

Aspect	Mean	Maximum	Minimum	Range	SE
North	71.86	93.30	46.70	46.60	5.72
South	60.01	86.70	23.30	63.40	7.18
Mean	65.93				

AP was varied at different altitude found high at 3650m (77.78 kg/ha) followed by 69.46 kg/ha at 3850m and 50.55 kg/ha at 3450m. Both TN and AP were found high at 3650m as shown in Table 17. High clay content at this altitude caused to show high TN and AP.

ANOVA table showed that AP was significantly different at different altitude shown in Appendix. $LSD_{0.05}$ test showed that AP was significantly different between 3450m and 3650m altitude where no significance difference found with other altitude ($p \leq 0.05$) as shown in Table 18.

Table 17: Available phosphorus (kg/ha) at different altitude

Altitude (m)	Mean	Minimum	Maximum	Range	SE
3450	50.55	23.30	93.30	70.00	9.86
3650	77.78	66.70	90.00	23.30	3.82
3850	69.47	50.00	86.70	36.70	5.80
Mean	65.93				

Table 18: $LSD_{0.05}$ for Available phosphorus (kg/ha) at different altitude

Factors	Paris compared	Mean difference	Standard error	Significance
AP	3450 and 3650 m	-27.23*	9.85	0.01
	3450 and 3850 m	-18.92	9.85	0.07
	3650 and 3850 m	8.32	9.85	0.42

* denotes the mean difference at $p \leq 0.05$

AP was gradually decreased with increasing soil depth. AP was found (75kg/ha) at 0-20cm followed by 65.01 kg/ha at 20-40cm and 57.78 kg/ha at 40-60 cm soil depth as shown in Table 19.

Awasthi (2004) reported that nutrient stock was found high at top soil which was found true in this study also where AP was high at 0-20cm soil depth similarly AK and TN was also found high at the same soil depth.

Table 19: Available phosphorus (kg/ha) at different soil depth

Soil Depth	Mean	Minimum	Maximum	Range	SE
0-20cm	75.00	43.30	93.30	50.00	7.44
20-40cm	65.01	36.70	86.70	50.00	8.20
40-60cm	57.78	23.30	80.00	56.70	8.42
Mean	65.93				

5.3.3 Available Potassium

Available Potassium was high at north aspect (742.90kg/ha) followed by south aspect (531.37kg/ha) as shown in Table 20. This result showed that AK status was quite good in the study according to Table 4.

Table 20: Available Potassium (kg/ha) at different aspect

Aspect	Mean	Minimum	Maximum	Range	SE
North	742.90	266.70	1643.00	1376.30	147.93
South	531.37	283.30	1083.00	799.70	102.91
Mean	637.13				

AK was gradually decreased with increasing altitude. AK was high at 3450 m (753.22 kg/ha) altitude followed by 666.62kg/ha at 3650m and 491.57kg/ha at 3450m as shown in Table 21. From Table 4 it was concluded that AK status was good at all altitudes.

Table 21: Available potassium (kg/ha) at different altitude

Altitude (m)	Mean	Minimum	Maximum	Range	SE
3450	753.22	283.30	1643.00	1359.70	218.95
3650	666.62	283.30	1083.00	799.70	134.15
3850	491.57	266.70	1003.00	736.30	107.71
Mean	637.13				

AK was gradually decreased with increasing soil depth. AK was high at 0-20cm (1052.50kg./ha) followed by 20-40cm (528.90kg/ha) and 40-60cm (330kg/ha) soil depth as shown in Table 22.The decreasing trend of AK was quite high according to depth of the soil but AK status was good at different soil according to Table 4.

ANOVA table showed that AK was significantly different at different soil depth which showed in Appendix 1. $LSD_{0.05}$ test showed that AK was significantly different between 0-20 and 20-40 cm,0-20 and 40-60 cm soil depth but no significant difference was found with other soil depth as shown in Table 23.

Table 22: Available potassium (kg/ha) at different soil depth

Soil depth	Mean	Minimum	Maximum	Range	SE
0-20cm	1052.50	503.00	1643.00	1140.00	147.69
20-40cm	528.90	360.00	870.00	510.00	77.58
40-60cm	330.00	266.70	486.70	220.00	33.13
Mean	637.13				

Table 23: LSD $_{0.05}$ for Available potassium (kg/ha) at different soil depth

Factors	Paris compared	Mean difference	Standard error	Significance
AK	0-20 and 20-40cm	523.60*	138.87	0.00
	0-20 and 40-60cm	722.50*	138.87	0.00
	20-40 and 40-60cm	198.90	138.87	0.17

* denotes the mean difference at $p \leq 0.05$.

5.4 Soil Quality Index at different aspect and altitude

Soil quality index scores of different aspect and altitude, which was varied from 0.68 to 0.76. Based on the SQI scores class, fair SQI was found at S/3450m and good SQI at

N/3850m, S/3850m, N/3650m, S/3650m, N/3450m as shown in Figure 2. SOI was found good at most of the aspect and altitude except S/3450m which had fair SQI. This was due to good content of different nutrient (N, P,K) in the study area. SQI was fair due to low nutrient status at S/3450m.

Soil Quality Index Previous studies in Nepal have focused on changes in soil organic matter, N, P and K for evaluating the soil quality and much less attention has been paid to a comprehensive assessment of soil quality changes (Awasthi, 2004).In this study physical and chemical properties have been used to assess soil quality index. The SQI reflects the relative soil quality of different land uses.

Waymann (1991) reported that Bari lands are more degraded than Khet lands in Jhiku Khola watershed and argued that microclimatic conditions, soil erosion and leaching on slopes are the factors for declining the soil quality in the higher altitude Bari lands. Comparing the SQIs between the free grazing, managed and undisturbed forests, the results validated that anthropogenic disturbances and heavy grazing could significantly lower the soil quality levels.

Awasthi (2004) reported that SQI value was the highest at undisturbed forest land (0.69) and lowest at Khet land (0.17) in Mardi watershed of Middle Mountain. Forest was about twice as high as that of forest with free grazing, because in the latter forest category people extract firewood, timber, leaf litter and fodder leading to the negative impact on soil quality. Khet lands with lowest SQI score indicated immediate need for soil restoration and fertility management practices for sustainable productivity.

Tiwari (2008) reported that SQI for Bari lands scored highest (0.59) followed by forestlands (0.45) and Khet lands (0.23) in Pokhre Khola watershed of Middle Mountain. Based on score classes, Khet lands fall into the degraded class whereas, forestlands and Bari lands are at risk.

In rangeland of Lo-manthang, SQI classes were found good except at S/3450m where fair class found due to low nutrient status. Compared to Middle Mountain, soil status was good in rangeland due to presence of biomass, good status of nutrient, animal’s dung and less anthropogenic activities.

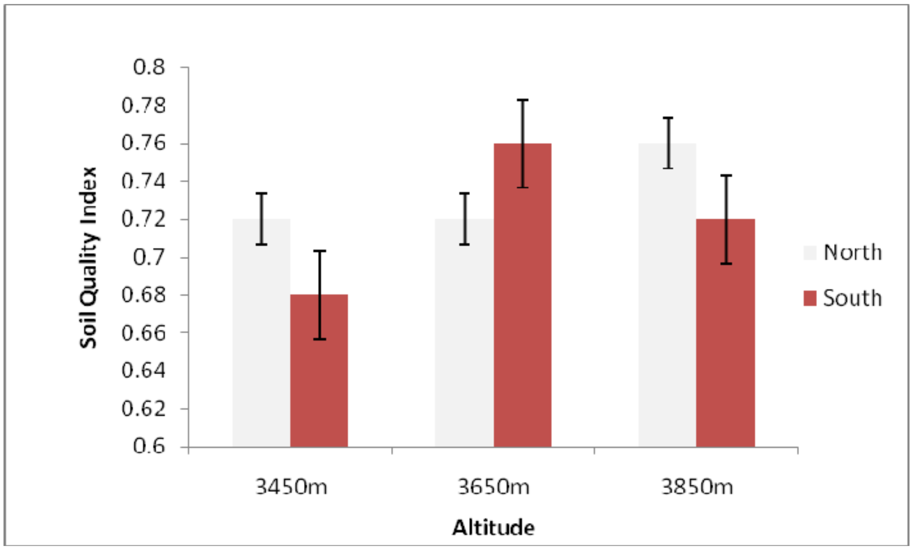

Figure 2: Soil Quality Index at different aspect and altitude

5.5 Biomass at different aspect and altitude

The maximum biomass (39.75 t/ha) was found at S/3650m whereas the minimum biomass (23.03 t/ha) was found at N/3450m as shown in Figure 3. At north aspect, trend of biomass was in increasing order. At south aspect trend was varied, biomass was increased from 3450m to 3650m and then decreased from 3650m to 3850m.

Biomass is depending upon major factors like temperature, microbial activity, moisture content, photosynthesis and available nutrients. Higher will be the temperature the place, higher will be the microbial activity which released the necessary nutrients for plant growth that increase the productivity. Upper Mustang has alpine and arid climate so the microbial activity is less causing low release of required nutrients reducing plant growth. Now days the productivity of rangeland is reducing day by day due to less moisture content affected by low rainfall. If the productivity of rangeland is high that indicated by biomass content grazing capacity is also high. So the manure produce by cattle are also high helping to increase the productivity of land.

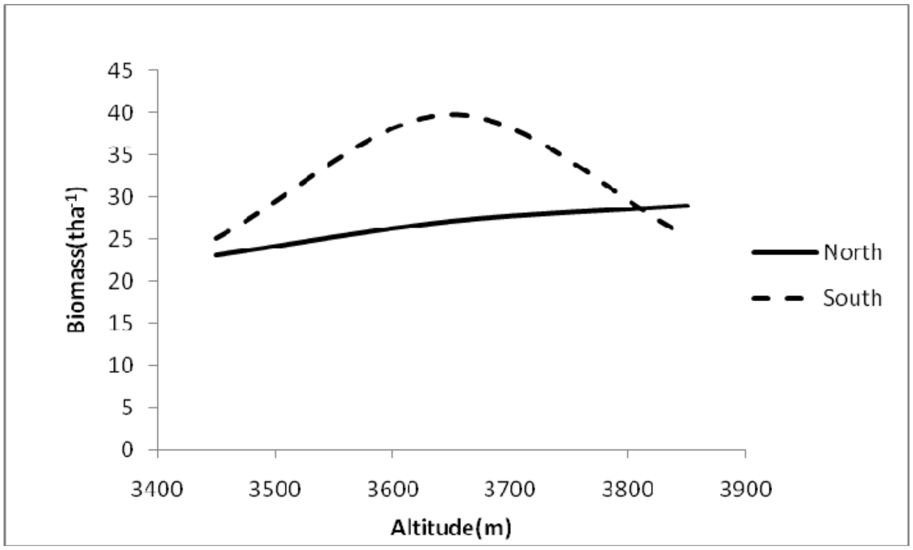

Figure 3: Biomass at different aspect and altitude

Chapter Six: Conclusion, Recommendation and Limitation

6.1 Conclusions

Sandy Loam and Loamy sand were dominant soil texture found in the study area. Basic nature of soil was found in the study area .There was a gradual increased in the BD with the increase in the soil depth. Soil properties like BD, OM, TN, AK and AP were found significant different.

SOC and nutrient status was high at top soil (0-20cm).The soil nutrient (N, P, K) status was good in the study area.SQI values were good at N/3850m, S/3850m, N/3650m, S/ 3650m, N/3450m but fair at S/3450m. Biomass was high at S/3650m. Biomass was gradually increased at north aspect with increasing altitude whereas at south aspect biomass was increased up to 3650m and then gradually decreased.

6.2 Recommendation

- Further research on biophysical and ecological aspect of Rangeland in Upper Mustang.

6.3 Limitations

- Soil is a multidimensional function, and this study couldn't cover all the aspects.
- The soil samples were taken up to 3850m due to weather condition of the study area.

References

ACAP/KMTNC, 2001. The status of rangeland resources in Upper Mustang. King Mahendra Trust for Nature Conservation/Annapurna Conservation Area Project/Upper Mustang Biodiversity conservation project. Report series 5.

Awasthi, K.D., 2004. Land use change effect on soil degradation, carbon and nutrient stocks and greenhouse gas emission in mountain watersheds. Agricultural university of Norway.

Awasthi, K.D., Singh, B.R., Sitaula, B.K., 2005. Profile carbon and nutrient levels and management effect on soil quality indictors in Mardi watershed of Nepal. ACTA Agriculture Scandinavia section B-soil and plant.

Bajracharya, R. M., Lal, R., Kimble, J.M., 1998a. Long term tillage effect on soil organic distribution in aggregates and primary particle fractions of two Ohio soils. In : Lal, R., Kimble, J.M., Follett, R.F., and Stewart, B.A.,(eds.)Management of carbon sequestration in soil, pp 113-123.CRC Press ,Boca Raton, FL, USA.

Bajracharya, R.M., Lal, R., Kimble, J. M., 1998b. Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion pH and landscape position. In: Lal, R., Kimble, J. M., Follett, R.F., and Stewart, B.A,(eds.) Soil processes and the carbon cycle, pp 353-367.CRC press, boca raton, FL,USA.

Bajracharya, R.M., Sharma, S., Dahal, B.M., Sitaula, B. K., and Jeng, A., 2006. Assessment of soil quality using physiochemical and biological indicators in a mid-hills watershed of Nepal.

Bandel, A., B.R.and Meisinger, J.J., 2000. Basic principles of soil fertility I: plant nutrients. In fact sheet 639. Maryland cooperative extension. University of Maryland, Maryland.

Batjes, N.H., 1999. Management options for reducing CO2 concentrations in the atmosphere by increasing carbon sequestration in the soil. Dutch national research programme on global air pollution and climate change & technical paper

30 410-200-031. International soil reference and information centre, Wageningen, pp114.

Batjes, N.H., and Sombroek, W.G., 1997. Possibilities for carbon sequestration in tropical and subtropical soils. Global change biology 3, pp 161–173.

Batjes, N.H., 1996. Total carbon and nitrogen in the soils of the world. Eur. J. soil. sci. 47, pp 151–163.

Beetz, A., 2001. Sustainable pasture management, livestock system's guide.<http:// attar.ncat.org/livestock.html>

Bhattarai, K.R., Vetas O.R. and Grytnes, J.A., 2004. Variation in plant species richness of different life form along a subtropical elevation gradient in the Himalayas, East Nepal.

Blake, G.R., and Hartege, K.H., 1986. Bulk density. In: page, A.L. (Eds). Methods of soil analysis part 1,2nd. Physical and mineralogical methods agronomy monographs. ASA; SSSA. Maidson. W1. pp 425-442.

Blamont, D., 1996. Upper Mustang's shifting animal husbandry practices. In: Miller, D.J Craig, S.R. (Eds.), Rangelands and pastoral development in the Hindu Kush – Himalayas, ICIMOD, Kathmandu, Nepal, pp. 171-191.

Brown, S., Lugo A.E., Iverson, L.R., 1992. Processes and lands for sequestering carbon in the tropical forest landscape. Water air soil poll 64:139–55.

Bruce, J.P., Frome M., Haites, E., Janzen, H., Lal, R., Paustian, K., 1999. Carbon sequestration in soils. J soil water conserve 54:382–9.

Burke, I.C., Yonker, C.M., Parton, W.J., Cole C.V., Flach K., Schimel DS., 1989. Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. Soil sci soc Am J 53:800–5.

Chetri, M., Gurung, C.R., 2004. Vegetation composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. In: Jincheng, Z., Xiangdong, Z., Jianlin, H. & Zhihua, C. (Eds.), Yak production in central Asian Highlands, proceeding of the fourth international conference on Yak. Sichuan publishing group, Sichuan publication house of science and technology, pp. 235-244.

Chen, Y. Fischer, G., 1998. A new digital geo-referenced database of grassland in China. International institute for applied systems analysis interim report, IR-98-062.Laxenburg (Austria): IIASA.

Craig, S., 1996. Pasture management, indigenous veterinary care and the role of the horse in Mustang, Nepal. In: Miller, D.J. & Craig, S.R. (Eds.), Rangelands and pastoral development in the Hindu Kush – Himalayas, ICIMOD, Kathmandu, Nepal, pp. 147-170.

Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A., 1994. Defining soil quality for a sustainable environment. Soil sci. soc. Am. Spec. Pub. No.35. pp. 244.

Doran, J.W., and Parkin T.B., 1994. Defining and assessing soil quality. P. 3-21. In J.W. Doran et al. (ed) Defining soil quality for a sustainable environment. Soil sci. soc. Am. Spec, Publ.35.

Doran, J.W., and Parkin T.B., 1996. Quantitative indicators of soil quality: A minimum data set. p. 25–37. In J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality. Soil sci. soc. Am. Spec Publ. 49

Drinkwater LE, Wagoner P, Sarrantonio M., 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262–5

Dunn, M.A; G. Dunn; Reeder, J. & Fraser, G., 2003. Ecological sustainability of rangelands. Arid land research and management. 17, 369-388.

Franxmeier, D.P., Lemme, G.D., and Miles, R.J., 1985. Organic carbon in soil of north central United States. Soil sci soc.Am.J.49:702-708.

Glaser, B ., Turrion, M.B., Soloman,D., Ni,A.,Zech, W., 2000. Soil organic matter quantity and quality in mountain soils of the Alay range, Kyrgyzia, affected by land use change. Biol fert soils 31:407-413.

Goldstein, M.C., Beall C., 1990. Nomads of western Tibet: The survival of a way of life. Univ. California press, Berkeley.

Heinen, J.T. and Kattel, B., 1992. Parks, people and conservation: A review of management issues in Nepal's protected area.

Hermans, C and Verejken, P., 1995. Grazing animal husbandry based on sustainable nutrient management. Agriculture ecosystems and management 52:213-222.

HMGN/ NPC, 1993. Nepal environmental policy and action plan: Integrating environment and development. HMG/N Environment protection council, Kathmandu, Nepal.

Houghton, RA., 1994. The worldwide extent of land-use change. Bio science 44:305–13.

IPCC, 2000. The Intergovernmental panel on climate change, special report on land use, Land-use change and forestry. Cambridge university press, Cambridge, UK.

Jackson, R., C. Richard, C. and Gurung, P., 2001. Enhancing participatory assessment capacity in rangeland management and livestock wildlife interactions. Research report series 3.King Mahendra Trust for Nature Conservation/Annapurna Conservation Area Project/Upper Mustang Biodiversity Conservation Area Project. Japan. Geoderma 119, pp 21-32.

Jackson R., Wangchuk, R., Hillard, D., 2002. Grassroots Measures to protect the endangered snow leopard from herder retribution: Lessons learned from predator – proofing corrals in Ladakh, www. snow leopard conservancy.org

Jha, S.G., 1991. An appraisal of the existing farming system in the hills of Nepal and potential interventions to solve the perceived problems. M. Sc. Thesis, The University of Edinburgh, Scotland, United Kingdom.

ICIMOD, 2009. Potential for carbon finance in the land use sector of the Hindu Kush-Himalayan Region. Kathmandu: ICIMOD

Johnson, DW., 1992. Effects of forest management on soil carbon storage. Water air, soil poll 64:83–120.

Karki, J.B., 1997. Effects of grazing, utilisation and management of the grasslands of Royal Bardia National Park, Nepal. Dissertation submitted for partial fulfillment of the Master's Degree in Wildlife Science, Saurashtra University, Rajkot, India.

Karlen, D.L., Mausbach M.J., Doran J.W., Cline R.G., Harris R.F., and Schuman G.E., 1997b. Soil quality: A concept, definition, and framework for evaluation. Soil sci. soc Am. J. Kathmandu.

Kent, M and Coker, P., 1995. Vegetation description and analysis. A practical approach. John Wiley and Sons Inc. USA.

Kirshbaum, M.U.F., 2000. Will changes in soils organic carbon act as a positive or negative feedback on global warming? Biogeochemistry 48(1):21-51.

Kunwar, P.B., 2003. People –wildlife conflict in the Upper Mustang of Annapurna Conservation Area. Dissertation submitted for the partial fulfillment of the requirement of the Master of Science in Forestry (M.Sc. Forestry), Tribhuvan University, Institute of Forestry, Pokhara, Nepal.

Lal, R., 2002. Soil Carbon dynamics in cropland and rangeland. Environ pollution 116:353-362.

Lal, R., 2004. Soil carbon sequestration to mitigate climate change. Carbon management and sequestration center, School of Natural Resources, The Ohio State University, OARDC/FAES, 2021 Coffey road, Columbus, OH 43210, USA.

Lal, R., 2000. Soil carbon dynamics in cropland and rangeland. Environ pollut.116.353-362.

Lal, R., 2002. Soil carbon dynamics in cropland and rangeland. Environ pollut116:353-362.

Lal, R., Hassan, H.M., and Dumanski, J., 1999. Desertification control to sequester C and mitigate the greenhouse effect. In: proceedings of St. Michaels workshop on carbon.

Lal, R., Kimble, J., and Follent, R.F., and Stewart, B.A., 1995. World soils as a source or sink for radiatively active gases. In: Lal, R., and Stewart, B.A.(ed) Soil management and greenhouse effect, pp1-8 Lewis publishers, boca raton, FL, USA.

Lal, R., Kimble, J., Stewart, B.A., 1998. Land use and C pools in terrestrial ecosystems. In: Lal, R., Stewart, B.A.,(eds.)Management of carbon sequestration in soil,pp1-10 CRC Press, Boca Raton, FL, USA.

Liefeld, J., Bassin, S., and Fuhrer, J., 2004. Carbon stock in Swiss agriculture soils predicted by land use soil characteristics, and altitude. Agriculture, ecosystem and environment.

LRMP, 1986. Land resources mapping project, His Majesty Government of Nepal, Kathmandu, Nepal.

LRMP, 1987. Land resources mapping project, His Majesty Government of Nepal, Kathmandu, Nepal.

McDowell, N., 2002. Developing countries to gain from carbon- trading fund. Nature 420:4.

Melillo, J.M., Kicklighter, D., McGuire, A., Peterjohn, W., and Newkirk, K., 1995. Global change and its effects on soil organic carbon stocks. In: Dahlem conference proceedings, John Wiley and Sons, New York, pp 175–189.

Milne, Eleanor., 2008.Soils, land use and land cover change, natural resource management and policy and climate change. www.google.com (encyclopedia of earth.

Miller, D.J., 1995. Herds on the move. Winds of change among pastoralists in the Himalayas and on the Tibetan plateau. ICIMOD discussion paper series no. MNR95/2.

Miller, D.J., 1996. New perspectives on range management, pastoralism, and their implications for HKH- Tibetan plateau rangelands. In: Miller, D.J., Craig, S.R. (Eds.), Rangelands and pastoral development in the Hindu Kush – Himalayas. Proceedings of a regional expert's meeting, ICIMOD, Kathmandu, Nepal, pp. 7-12.

Morisada, K., Ono, K. and Kanomata, H. 2004. Organic carbon stock in forest soils in Japan. Geoderma 119, pp 21-32.

Nadelhoffer KJ, Emmett BA, Gunderson P, Koopmans OJ, Schleppi P, Tietema A, Wright RF. 1999. Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. Nature 398:145–8.

National Research Council, 1993. Soil and water quality: an agenda for agriculture. National academy press, Washington, DC, 516 pp.

NBS, 2002. Rangelands management of high altitude rangelands/grasslands.

Brady N. C., Weil, R. R., 2002. The Nature and Properties of Soil. pp139.

Pant B., Devkota, B.2007. Status of rangeland in Shey-Phoksundo National Park and its buffer zone area.

Parr, J. F., Papendick R.I., Hornick S.B,. and Meyer R.E., 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture.

Paudel, G.S. 1997. Integration of forest and rangeland management for livestock development in the hills of Nepal. M.Sc. Dissertation, NR 97-16, AIT, Bangkok, Thailand.

Paudel, K. P., 2006. Institutions, Environmental Entitlements and pastoral Management: A Case of Nyishang, Trans Himalayan Region, Manang District, Nepal. MPhil thesis submitted at the Dept. of Geography, University of Bergen, Norway.

Paustian K, Andren O, Janzen H, Lal R, Smith P, Tian G, Tiessen H, van Noordwijk M, Woomer P., 1997. Agricultural soil as a C sink to offset CO2 emissions. Soil use manage 13:230–44.

Pearson, T.R., Brown. S.L., and Birdsey, R.A., 2007. Measurement guidelines for the sequestration of forest carbon, general technical report, USAD forest service.

Pearson, T.R.H., Brown, S., Ravindranath, N.H., 2005. Integrating carbon benefit estimates into GEF projects. Capacity development and adaptation group guidelines. UNDP Global Environment facility, bureau of development policy, New York, USA.

Pokhrel, A., 2006. An assessment of rangeland and pastoral production system, Upper Mustang, Institute of Forestry, Pokhara, Nepal.

Population Census Report, 2001. Central Bureau of Statistics, His Majesty Government of Nepal.

Post, W. M., Kwon, K.C., 2000. Soil carbon sequestration and land use change: processes and potential. Global change 6:317-327.

Post, W. M., Kwon, K.C., 2000. Soil carbon sequestration and land use change: processes and potential. Global change 6:317-327.

Post, W.M., Peng, T.H., Emanuel, W.R., King, A.W., Dale, V.H. and Angelis, D. L., 1990. The global carbon cycle. Am. sci. 78, pp 310–326.

Pradhan.S.L. and Hitchcock. D.K., 2000. Yak production and range management in the himalaya mountain range of Nepal.

Regmi, B.D and Zoebish, A.M., 2004. Soil fertility status of Bari and Khet land in a small watershed of middle hill region of Nepal. Nepal agric. Res. J. Vol. 5, 2004.

Richard, C., Basnet. K., Sah, J.P., Raut, Y., 2000. Grassland ecology and management in protected areas of Nepal. Mountain parks. Volume III. ICIMOD, Kathmandu, Nepal.

Schaller, G.B., Gu, B., 1994.Comparative ecology of ungulates in the basin of northwest Tibet. National geographic research and exploration 10, 266-293.

Schlesinger WH., 1990. Evidence from carbon sequence studies for low carbon-storage potential of soils. Nature 348:232–24.

Schlesinger WH., 1997. Biogeochemistry: an analysis of global change. 2nd ed. San Diego: Academic Press.p.156.

Schimel, D., Melillo, J., Tian, H., McGuire, D., Kicklighter, D., Kittel, T., Rosenbloom, N., Running, S., Thornton, P., Ojima, D., Parton, W., Kelly, R.,

Sykes, M., Neilson, R. and Rizzo, B., 2000. Contribution of increasing C ecosystems in the United States. Science 287, 2004–2006.

Schmidt, M., 1991. An evaluation of the resources and forest soil fertility of a Mountain watershed in Nepal using GIS techniques. In soil fertility and erosion issues in the Middle Mountains of Nepal. Workshop proceeding, Jhikhu Khola. April 22-25.pp. 244-252. ISS/UBC/IDRC, Kathmandu.

Shah, K. B., 2003. Basic training in wildlife management techniques and biodiversity survey of the Upper Mustang Area. Phase II final report. An unpublished report submitted to King Mahendra Trust for Nature Conservation/ Annapurna Conservation Area Project/Upper Mustang Biodiversity Project.

Shah, K. B., Rayamajhi, S., 2005. Annapurna Conservation Area Upper Mustang Biodiversity Conservation Plan 2005-2009. King Mahendra Trust for Nature Conservation/Annapurna Conservaiton Area Project/Upper Mustang Biodiversity Conservation Project. Unpublished report.

Shrestha, P. B., 2008. An analytical study of carbon sequestration in three different forest types of mid hills of Nepal. Tribhuvan University, Institute of forestry, Pokhara, Nepal.

Singh, B. R., Lal, R., 2006. Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. Environ Int 32(6):781-796.

Singh, B.R., Lal, R., 2001. The potential of Norwegian soils to sequester carbon through land use conversion and improved management practices. Ohio States University, USA.

Sombroek, W., Nachtergaele, F., Hebel, A., 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. Ambio 22:417-426.

Sombroek, W.G., Nachtergaele, F.O. and Hebel, A., 1993. Amounts, dynamics and SSSA. Maidson. W1. pp 425-442.

Thapa, M.B., 1990. People's participation in range management: The case of Mustang, Nepal. Master's Thesis, University of the Philippines, Los Banos.

Tschakert, P., 2001. Human dimensions of carbon sequestration: a political ecology approach to soil fertility management and desertification control in the old peanut basin of Senegal. Arid lands newsletter May–June.

Tian, H., Melillo, J.M., Kicklighter, D.W., McGuire, A.D., Helfrich, J., Moore III, B. and V¨or¨osmarty, C. J., 1998. Effect of interannual climate variability on carbon storage in Amazonian ecosystems. Nature 396, 664–667.

Tiwari, K.S., 2008. Land management and soil conservation options for sustainable agriculture production in a middle mountain watershed of central Nepal. Ph.D Thesis, Norwegian University of Life Science, Norway.

Torn, M.S., Trumbore, S.E., Chadwick, O.A., Vitousek, P.M., Hendricks, D.M., 1997. Mineral control of soil organic carbon storage and turnover. Nature 389, pp 170–173.

Trujilo, W., Amezquita, E., Fisher, M.J., Lal, R., 1997. Soil organic carbon dynamics and land use in the Colombian savanna I. Aggregate size distribution. In: Lal, R., Kimble, J. M., Follett, R.F., Stewart, B. A., (eds.)soil processes and the carbon cycle .CRC Press, FL, Boca Raton, USA, pp 267-280.

UMACMP, 2005. Upper Mustang Area Conservation Management Plan. King Mahendra Trust for Nature Conservation/Annapurna Conservation Area Project/Upper Mustang Biodiversity Conservation Project. Unpublished report.

UNEP, 1979. Report on nongovernmental organization activities on environmental issues related to UNEP Programme. Environmental liaison center Nairobi, Kenya.

Vaidya, A., Turton, C., Joshi, K.D. and Tuladhar, J.K., 1995. A systems analysis of soil fertility issues in the hills of Nepal: implications for future research. In Schreier, H., Shah, P.B., and brown, S. (ed); Challenges in mountain resource management in Nepal. Processes, trends and dynamics in Middle Mountain watersheds. Proceedings of a workshop held in Kathmandu, Nepal 10-12 April, 1995, pp. 63-80. ICIMOD/IDRc/UBC, Kathmandu.

Vitousek PM., 1991. Can planted forest counteract increasing atmospheric carbon dioxide? J environ qual 20:348–54.

Wang Y., Shiyomi M., Tsuiki M. Yu X., Yi R., 2002. Spatial heterogeneity of vegetation under different grazing intensities in the Northwest Heilongjiang Steppe of China. Agriculture, Ecosystems and Environment 90, 217-229.

Waymann, S., 1991.Land use intensification and soil fertility in agriculture land: A case study in the Dhulikhel Khola watershed. In: Shah, P.B. (ed) soil fertility and erosion issues in the middle mountain's of Nepal. Workshop proceedings Jhikhu Khola watershed April 22-25, pp 253-258.

Warkentin, B.P., Fletcher, H.F., 1977. Soil quality for intensive agriculture. Intensive watershed in Nepal using GIS techniques. In soil fertility and erosion issues in the Middle Mountains of Nepal. Workshop proceeding, Jhikhu Khola. April 22-25.pp. 244-watershed of Nepal.

Weltz, M., Dunn, G., Reeder, J., Fraser, G., (2003). Ecological sustainability of rangelands. Arid land research and management, 17, 369-388.

Zobel, D.B., Jha, P.K., Yadav, U.K.R., Behan, M.J., 1987. A practical manual for ecology. Ratna book distributors, Kathmandu, Nepal.

Appendix 1

A. ANOVA for OM (%) of at different soil depth

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.63	2	1.31	4.78	0.02
Within Groups	4.13	15	0.28		
Total	6.76	17			

B. $LSD_{0.05}$ Test for OM at different soil depth

Factors	Paris compared	Mean difference	Standard error	Significance
OM	0-20 and 20-40 cm	.5950	.30	0.68
	0-20 and 40-60 cm	.9233*	.30	.00
	20-40 and 40-60 cm	.3283	.30	.29

* denotes the mean difference at $p \leq 0.05$

C. ANOVA for BD at different soil depth

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.518	2	.25	6.85	.00
Within Groups	.566	15	.03		
Total	1.084	17			

D. $LSD_{0.05}$ Test for BD at different soil depth

Factors	Paris compared	Mean difference	Standard error	Significance
BD	0-20 and 20-40 cm	-.13	0.11	0.24
	0-20 and 40-60 cm	-4083.00*	0.11	0.00
	20-40 and 40-60cm	-.27*	0.11	0.02

*denotes the mean difference at $p \leq 0.05$

E.ANOVA for TN (%) of at different soil depth

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.01	2	0.01	4.06	0.04
Within Groups	0.03	15	0.00		
Total	0.04	17.00			

F. ANOVA for AP (kg/ha) at different altitude

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2337.323	2	1168.66	4.015	0.04
Within Groups	4365.677	15	291.04		
Total	6703.000	17			

G. ANOVA for AK (kg/ha) at different soil depth

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1671448.84	2	835724.42	14.44	0.00
Within Groups	867879.58	15	57858.64		
Total	2539328.42	17			

H. Soil Quality index and Biomass at different aspect and altitude

Aspect	Altitude(m)	SQI value	SQI	Biomass (t/ha)
North	3450	0.72	Good	23.03
South	3450	0.68	Fair	25.08
North	3650	0.72	Good	27.07
South	3650	0.76	Good	39.75
North	3850	0.76	Good	28.9
South	3850	0.72	Good	25.31

Appendix 2

Some Photo Plates

Photo 1: Study site

Photo 2: Equipments used during field work

Photo 3: Research Assistant taking soil samples

Photo 4: Researcher taking soil sample during field work

Photo 5: Beautiful Himalayan Range view from Lo-manthang

Photo 6: Beautiful snap of Himalaya on the way to Lo-manthang