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Article

Soil Properties Linking to Climate Change Mitigation and Food Security in Nepal

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Abstract: Crop productivity is directly dependent to soil fertility. High soil organic carbon (SOC) content in soil is vital as it leads to improved soil quality, increased productivity, and stable soil-aggregates. In addition, with the signing of the climate agreement, there is growing interest in carbon sequestration in landscapes. This paper looks at how SOC can be increased so that it not only contributes to reduction of CO_2, but also translates to increased food production thereby enhancing food security. This synergy between mitigation and enhancing food security is even more relevant for mountain landscapes of the Hindu Kush Himalayan (HKH) region where there remains huge potential to increase CO_2 sequestration and simultaneously address food security in the chronic food deficit villages. Soil samples were collected from seven transects each in Bajhang and Mustang and from 4 land use types in each transect. Samples of soils were taken from two depths in each plot; 0-15 cm below the soil surface and 15-30 cm below the soil surface to compare the top soil and subsoil dynamics of the soil nutrients. The lab analysis was performed to assess the soil texture, soil color, soil acidity in 'power of hydrogen' (pH), macro-nutrients as soil fertility. Secondary data was used to analyze the level of food deficit in the villages. The result shows that most of the sample soils from Mustang were clay (82.1%) which is 46 samples out of 56. The pH value of soil from Bajhang ranged from 5.29 to 9.09. The pH value of soil ranged from 5.65 to 8.81 in Mustang. SOC contents of sampled soils from Bajhang ranged from 0.20% to 7.69% with mean amount of 2.47% ± 0.17. SOC contents of sampled soils from Mustang ranged from 0.51% to 8.56% with mean amount of 2.60% ± 0.25. By land use type, forest land had the highest carbon (C) content of 53.61 t ha^{-1} in Bajhang whereas in Mustang, agricultural land had the highest C content of 52.02 tons ha^{-1}. Based on these data, we can say that there is potential for increasing SOC through improved soil health and crop production and soil. Sustainable soil management should be practiced for higher productivity. Livestock may also provide farmyard manure, which can be used to fertilize cultivated soils, which increases soil productivity. Increasing productivity would aid in increasing the access and availability of food in these mountain villages.

Keywords: crop production, soil management, soil organic carbon, soil productivity

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1. Introduction

It is estimated that around 12,000 to 18,000 Giga tons (Gt.) of carbon (C) is stored in soils worldwide and it is twice the amount that is stored in all terrestrial plants in the form of organic C which is a major source of green house gases (GHGs) [1]. The soil pool is 3.3 times the size of the atmospheric

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pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt) [1]. C sequestration has the potential to offset fossil fuel emission 5- 15% of global fossil fuel emission [2]. It has been reported that the average soil organic carbon (SOC) level in South and South East Asia is 8.7 kg/m which is much lower than the global average of 11.3 kg/m [2]. Also the production of major cereal crops in Nepal are virtually stagnant for over the past 15-20 years and the productivity of these crops are well below those of its neighboring countries [3]. The main reasons for the low yield are believed to be the lack of replenishment of SOC and inadequate and inappropriate use of fertilizers [4-6].

According to Ministry of Agricultural Development (MoAD), the World Food Program of the United Nations (UNWFP) and the Food and Agriculture Organization (FAO), in Nepal, 40 districts out of 75 are food insecure, far and mid-western regions in particular being more vulnerable [7]. Food systems also have enormous potential to mitigate climate change, however, particularly at the production end of the food chain. Moreover, many of the most effective mitigation measures also represent highly effective adaptation strategies, especially for commercial agriculture. Investing in wider adoption of best practices for mitigation in the food and agriculture sector could therefore have multiple payoffs for food security, including contributing to the stability of global food markets and providing new employment opportunities in the commercial agriculture sector, as well enhancing the sustainability of vulnerable livelihood systems.

Thus, the proposed study shows the pilot research on the contribution of soil productivity and C sequestration for food security and mitigation in two sample districts: Mustang, and Bajhang. Mustang lies in the Chitwan Annapurna Landscape (CHAL) whereas Bajhang lies in the Sacred Kailash Landscape. The study specifically attempts to assess the soil properties of both the sites which includes total nitrogen (TN), exchangable potassium (EK), available phosphorus (AP), cation exchange capacity (CEC), SOC, bulk density (BD) and the production level of local farmers. There is scope of up scaling the study approach in other landscapes of the Hindu Kush Himalayan (HKH) where food security and mitigation potentials can be addressed simultaneously. The study will contribute to the information required for developing NAMA activities and also contribute in the nationally determined contributions (NDCs) of Nepal to formulate the mitigation goals and strategies as the Agreement also emphasized the need to protect vulnerable ecosystems, and the need to ensure food security while mitigating the climate change as well as to contribute to the formulation of National Adaptation Plan (NAP) which is in the process in Nepal.

2. Materials and Methods

Transect selection

Transects were selected covering the major complexities in Nepal including the ranges of low altitude (Terai and Siwalik) to the high altitude (High Mountain). From the perspective of resource assessment, different management systems were also covered where ever possible such as protected forests, community forests, government forest, irrigated agricultural land, non-irrigated agricultural land, grassland/rangelands and agroforestry practices if any.

Soil sampling

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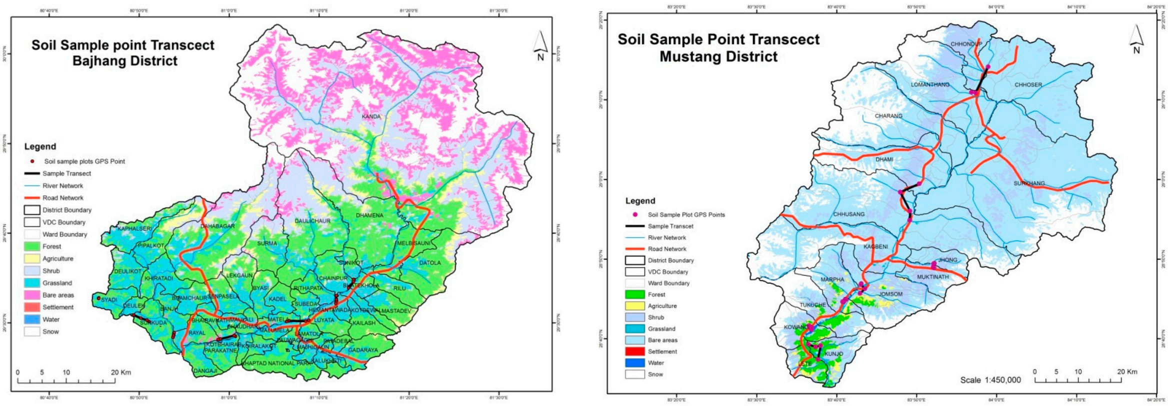
Soil samples were collected from seven transects each in Bajhang and Mustang (Figure 1 (a) and (b)). The transects covered four land use types; barren land, agricultural land, orchard land/forest land and degraded shrub land. Altogether 28 plots (4- land use types in each 7- transect) were selected for the sample collection along the Seti River and Kali Gandaki river correspondingly. Samples of soils were taken from two depths in each plot; 0-15 cm below the soil surface and 15-30 cm below the soil surface. From each plot the samples were collected by using a core and ring sized 5cm diameter and 5.5 cm length. Also, the loose samples from both depths i.e. 0-15 and 15-30 cm were taken for analysis of macro soil properties.



(a) (b)

Figure 1. Study sites with sampling plots (**a**) Sample points in Bajhang district; (**b**) Sample points in Mustang district.

Direct sampling method was followed to collect soil samples. For the process of stratified random sampling, the transect survey line area was further divided into different strata based on the prior knowledge of the land use types and topographic positions. Over all three types of land use system were surveyed which are forestland, agricultural land and grass land as they are the potential to the C sinks. In each of this land use system, two aspect classes: north and south and two elevations classes: above 1500 m and below 1500 m were selected.

Sample analysis

Data collected from samples were transported for well handling and storage to Aquatic and Environment Center (AEC) laboratory at Kathmandu University, Dhulikhel, Kavre, Nepal for the analysis. Standard methods were followed for the analysis of the physical and chemical parameters of the soil samples which are given below.

- Soil texture: Soil textural class was determined by Soil hydrometer method [8]
- Bulk Density: Bulk density was determined by Core method [9]..
- Soil organic matter and organic C: Organic matter was determined by Dry combustion method [10].
- pH: pH was determined using pH Probe method 1:1 soil: water ratio [11].
- Total nitrogen: Total nitrogen was determined using Kjeldahl method [12].
- Available phosphorus: Available phosphorous was determined using Modified Olsen's method [13].
- Exchangeable potassium: Exchangeable potassium was determined using Ammonium acetate method [14] followed by AAS.

Survey and questionnaire/Social data collection

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Household questionnaire survey, key informants survey and group discussions were held for social data collection. One key informant survey and six focus group discussions were carried out in each transect, from where the samples were collected. In household questionnaire survey, both open and closed ended questions were included. A well formatted questionnaire survey was prepared after the site visiting. Mostly senior persons and educated ones of the family were appointed in the survey. Most of the questions were related to agricultural and forest management system, its farming system and utilization system, productivity of agricultural plots and its sufficiency to family members, change in climate and its local level impacts.

The objectives of the discussion included; existing farming practice, crop productivity and food security situation; Farmer's responses on their experience with current farming practices; Local experiences on climate change condition and its impacts on soil fertility and existing forest land, agricultural land and bare lands use.

Key informants selected during the survey were ex-service holders, local teachers, social mobilizer for the queries related to the study. Similarly, for focus group discussion which includes 5 – 10 participants, mostly straight forward and open ended questions were raised. Teachers, local persons, experienced persons on soil conservation, community forest chairman, and others participants who are engaged with related national and international non-governmental organizations (I/NGOs) were preferred for data collection during focus group discussion.

Statistical data analysis

The data generated from the laboratory analysis and those obtained from the field itself on forest bio-physical and soil properties were analyzed using the appropriate correlation and analysis of variance (ANOVA). The results derived were related with climate change mitigation and resource security issues in terms of soil fertility and nutrients.

3. Results and discussion

3.1. Results

3.1.1 Demographic characteristics of Bajhang and Mustang:

Table 1 Social Demographic characteristics of Bajhang and Mustang

Districts	Total Population	Literacy rate	Major Occupation	Land Holding Capacity
Bajhang	195,159	55.50%	Agriculture, Labor	0.4 0.6 ha.
Mustang	13,452	66.2%	Agriculture, Animal herding	From 0.1 – 0.2 up to 3 ha.
	Source: CBS, 2011 [15]			Source: Field data, 2015

Table 1 Shows the general demographic characteristics of the study sites i.e. Bajhang and Mustang. It also shows the literacy rates and land holding capacities of the both districts.

3.1.2 Occupation:

Main occupation of the people of Mustang and Bajhang districts are agriculture, especially potato, barley and maize in the lower altitudes. Lately, growing vegetables and apple fruit have increased in

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Mustang whereas Bajhang is confined to traditional subsistence agriculture practices. Mustang being a tourist destination has the benefit of additional opportunities from tourism.

Generally, average land holding capacity in Bajhang district varies from 0.4 to 0.6 hectare (ha.) per household. The variation of land holding capacity is seen to be affected by castes of the people and also equally due to altitudinal reasons In Mustang district, the land holding capacity of each household varied a lot. People with small land area only have less than a ha. whereas people, mainly of Chhongu village on average owned 1.25 to 3 ha. of land per household.

3.1.3 Soil Properties

- Soil Physical properties of Bajhang and Mustang

Texture of the soil is one of the key foundation creations in the part of soil classification. The texture analysis indicates soil degradation and self-attachment characteristics. Fertility rate of soil also depends on soil texture.

Table 2 Soil characteristics of Bajhang and Mustang

District	Soil characteristics	Most found soil texture
Mustang	Loam, silt loam, silty clay loam, sandy clay loam and clay	58.9% of the samples (33 out of 56) were found to be silt loam
Bajhang	Silt loam, sandy loam, sandy clay loam, clay loam, clay and sandy clay	82.1% of the samples (46 out of 56) were found to be clay

- Soil Color

Soil color generally helps in the identification and characteristics of different types of soil. Generally soil color differs according to different land use system and depth. Soil in agricultural land is dark in black than others. The identification of soil color was done by Munsell color chart.

Table 3 Soil colors in Bajhang and Mustang

Land use system	**Soil Color (Bajhang)**	**Soil Color (Mustang)**	**No of plots (Bajhang)**	**No of plots (Mustang)**
Agriculture land	Black (4), Reddish brown (2), Brown (1)	Black (4), Grayish white (1), Brown (1)	7	6
Forest land	Brown (5), Reddish brown (1)	Grayish white (1), Black (2), Brown (2)	6	5
Grass/grazing land	Black (2), Reddish brown (1), Brown (3)	Black (2), Yellow (1). Brown (2)	6	5
Degraded/barren/shrub land	Black (1), Reddish brown (1), Brown (3)	Black (2), Yellow (3), Brown (2)	5	7
Orchard	Black (1)	Brown (1)	1	1

Soil colors in Bajhang and Mustang shows that variation in soil type is high in Bajhang and leaned towards Black and Brown whereas Mustang has Grayish and Brown soils (Table 2).

- Chemical parameters

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A total of 56 soil samples (including both top and sub soil) were collected from Bajhang and Mustang and analyzed following standard laboratory techniques. The results are tabulated below.

Table 4 Chemical and physical properties of soils in Bajhang and Mustang

		pH	OC (%)	Total N (%)	Available P (ppm)	Exchangeable K (me/100g)
Bajhang	**Mean ± St. error**	7.21 ± 0.16	2.47 ± 0.17	0.18 ± 0.01	111.34 ± 10.05	0.15 ± 0.01
	Minimum	5.29	0.20	0.04	10.94	0.03
	Maximum	9.09	7.69	0.68	359.70	0.38
Mustang	**Mean ± St. error**	7.89 ± 0.08	2.60 ± 0.25	0.18 ± 0.02	77.43 ± 9.41	0.26 ± 0.02
	Maximum	8.81	8.56	0.8	361.20	0.79
	Minimum	5.65	0.51	0.02	1.49	0.05

The chemical and physical properties of soils in Bajhang and Mustang are presented here in the tables. Results shown in Table 4 are discussed in following paragraphs.

1. pH value

Soil provides plants with essential nutrients like Calcium (Ca), Nitrogn (N), Phosphorus (P), Potassium (K), Magnesium (Mg) which is affected by the acidity of the soil (pH) [16]. In case of strongly acidic soil, agricultural lime and animal manures can be applied to avoid further increase in soil acidity. Most of the soil samples were found to be alkaline which lowers the availability of many soil nutrients like iron, zinc, copper and manganese. So, in order to meet a healthy crop production quantity, efforts should be made to lower the pH of soil. According to Oosterbaan [17], the causes of soil alkalinity are natural or they can be man-made. The natural development is due to the presence of soil minerals producing sodium carbonate upon weathering. The man-made development is due to the application of irrigation water (surface or ground water) containing a relatively high proportion of sodium bicarbonates. According to him, alkaline soils can be reclaimed with grass cultures, ensuring the incorporation of much acidifying organic material into the soil, and leaching of the excess sodium (Na). Deep plough and incorporating the calcareous subsoil into the topsoil also helps to normalize the acidic and alkalinity of the soil. It is also possible to reclaim alkaline soils by adding acidifying minerals like pyrite (FeS_2). If necessary, gypsum (calcium sulphate, $CaSO_4$) can also be applied as a source of Ca(++) ions. Oosterbaan [17] adds that in order to reclaim the soils properly, one needs prohibitively high of doses of amendments. Most efforts are therefore directed to improving the top layer only, as the top layer is most sensitive to structure deterioration [17].

2. Total nitrogen (TN)

According to Silva and Uchida (2000), moderate amount of nitrogen is needed for all of the enzymatic reactions in a crop which is also a major part of the chlorophyll molecule and is therefore necessary for photosynthesis. N also improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops [18]. N deficiency causes early maturity in some crops, which results in a significant reduction in yield and quality. In order to overcome such problem, according to Regmi et al. [19], TN can be increased by the continuous application of Farm-Yard-Manure (FYM) which is recorded to have increased from 0.09 to 0.17% in long-term application.

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3. Available Phosphorous (AP)

One of the reasons for level of P being high in most of the sampled soils could be the application of large amount of organic manure on agricultural fields. Also, other nutrients for example like nitrogen are lost in huge amount through leaching but not phosphorous. Also, according to Tisdale et al. (1985), very little of P is lost by crop removal, therefore, it can be understood that P added as fertilizer can accumulate in the soil for longer time than other nutrients [20].

4. Exchangeable Potassium (EK)

According to Silva and Uchida (2000), unlike N and P, K does not form any vital organic compounds in the plant. However, the presence of K is vital for plant growth because K is known to be an enzyme activator that promotes metabolic activities [18]. It has also been shown to improve disease resistance in plants, improve the size of grains and seeds, and improve the quality of fruits and vegetables.

5. Soil Carbon Content (SOC)

Table 5 Soil Organic Carbon (SOC)* of soils in different Land use type in Bajhang and Mustang

Sites	Forest land	Grass land	Agricultural land	Barren land
Bajhang	53.61 ± 5.81	53.49 ± 5.18	48.81 ± 7.54	45.31 ± 10.75
Mustang	40.41 ± 9.64	33.92 ± 8.49	52.02 ± 7.74	32.50 ± 6.39

*values are in t ha^{-1}

In comparison, agricultural and grass land soils of both the districts were as good as their respective forests soils in terms of soil C content. The lowest mean C content was found to be in barren land for both the sites. Forest have the highest mean C on Bajhang and in Mustang, agricultural land has the highest mean value of C stored in soils (Table 5). According to Adams's (n.d.) compiled work, forests soil have the capacity to store more than 100 t ha^{-1} of C. In our study, the C stored by forest soils is low in both the sites suggesting that agriculture and grass lands are storing SOC more effectively [21].

3.1.4 Change in food culture and habits

In mountain regions of Nepal which includes districts like Bajhang has high capacity of production for maize (*Zea mays*) and other cereal crops. Similarly, this place is highly fertile for '*bethe*' (*Chenopodium album*, Lamb's Quarter) and *'Jau' (Hordeum vulgare*, Barley*)* production. But nowadays, these crops have been replaced by rice (*Oryza sativa)*, wheat (*Triticum aestivum*) and potato (*Solanum tuberosum*).

Local person of the area explains that three decades ago, they use to rare domestic animals and depend on dairy products from these animals and go to forest and pasture land to collect be the for their meal. They also used to eat rusted maize or finger millet (*Eleusine coracana)* local made bread for snacks. He explains that nowadays, the meal has been replaced by wheat and rice. The snacks have also been replaced by instant noodles.

This change shows two parallel parts; one due to the change in monitory flow at houses and other due to flowing culture with modern habits. Similarly this replacement by modern food items is also due to easiness and low time consuming for their cooking.

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One participant of group discussion said that three to four decades ago, people (their father-grandfather) of these areas used to rare domestic animals for dairy product and have *'Bethe'* as well as *'Jau'* and *'Fapar' (Fagopyrum esculentum,* Buckwheat*)* to prepare local breads as their major food items. But nowadays due to rice and wheat feeding trend, they neither feed on traditional food items nor can they cultivate assessable amount of rice and wheat in their farm land.

4. Discussion

4.1 Crops Production

From the field survey carried out in various VDCs of Bajhang and Mustang districts, wide variation in crop production was found along with the dominant species in forest land. Efforts can be made to increase the production which can help people sustain as well as to produce crops commercially. Management practices can be adopted to increase the area under production and also, productivity can be improved on existing farmland. Not only sustaining life but increasing productivity on existing agricultural land also avoids greenhouse gas emissions. Diversity in agricultural production is one key to productivity, as it enables risk management and preserves potentials for adaptation and change. Monoculture of producing only crops, but no livestock, or only livestock and no crop should now be discouraged. All the people mainly farmers should now learn the benefits of raising livestock rather than other herds as it provides multiple goods, such as food, wool, hides, etc. In case of famine, when crops are not sufficient to ensure food safety, livestock can be used as food. Livestock may also provide manure, which can be used to fertilize cultivated soils, which increases soil productivity. On the other hand, in an agricultural system based only on raising livestock, food has to be bought from other farmers, and wastes produced cannot be easily disposed of. Production has many functions, and diversity is the foundation of such production.

4.2 Climate change mitigation and SOC

In order to allow soils to store organic C effectively and contribute to climate change mitigation, efforts should be made to increase the C containing capacity of soils. According to IFOAM (2009), with the right type of agriculture, emissions leading to climate change can be minimized and the capacity of nature to mitigate climate change can be harnessed to sequestrate significant quantities of atmospheric carbon dioxide – especially in the soil. The potential for soil sequestration depends greatly on a number of variables including the soil type, climate, land-use history, and the farming system adopted – especially the availability and quantity of C rich components used in the system such as compost, manure, perennial plants, pastures and trees [22].

According to Chan (2008), there are a wide range of management options and farming practices that can increase SOC levels by either increasing inputs or decreasing losses. Inputs can be increased by direct additions of organic materials, composts, manure and other recycled organic materials. There are many other management practices that can be implemented which can increase soil organic C containing capacity which can ultimately assist in mitigating climate change like retaining forest slash and crop residues, applying fertilizer to overcome nutrient deficiencies, selecting cropping, forest or pasture systems that will maximize plant growth, minimizing cultivation disturbance to reduce mineralization and erosion losses and modifying grazing management to maintain pasture cover, thereby minimizing erosion losses and maximizing organic input to soil [23].

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4.3 Climate change mitigation, food security and land use type

From the study, both in Bajhang and Mustang , the highest mean SOC was found to be in the forest land followed by grass land and the lowest in the barren land. The mean SOC data obtained from the study sites suggest that forests and grass land has the high potential to sequester C and ultimately contribute to mitigate climate change. However, the variation in SOC according to land use types was found to be non-significant. Past studies also suggest that land-use change from forest to abandoned farmland significantly reduced the organic C accumulation in the soil [24]. The results of the present study provide insight into the potential benefits of forest and grass land to act as C sinks, indicating that, when agricultural practices are stopped, the abandoned farmlands are led to a shift in vegetation composition in the sense that agricultural productions are replaced by shrub and grass dominated communities. Such shifts boost the capability of the atmospheric C to be fixed in these types of ecosystems. Consequently, the potential of forest and grassland in C sequestration should be considered for appropriate management in order to maximize CO_2 sequestering as well as to balance CO_2 emissions.

On the basis of climate change mitigation by C sequestration, forests and grass land are the optimum type of land use. If food security is to be considered, the best land use practice is agriculture. In order to create a *win–win* situation for both the nature and the humans, agroforestry seems to be a possible option so that both nature and human can endure and grow in harmony. Other studies also suggest agroforestry as an alternative to just forestry or just agriculture [25]. Like few other land use options, agroforestry has real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource base of rural landscapes. It has a key role to play in landscape level mitigation schemes under the REDD+ concepts. For the local people whose livelihoods are threatened by climate change and food security, agroforestry offers a pathway toward more resilient livelihoods [26].

5. Conclusions

From this study, we have seen that agriculture is the main occupation of the people of both Bajhang and Mustang district which is the basis for their survival. Moreover, agriculture is the supplier of nutrition to the human beings which affects the daily life of people in many ways, both directly and indirectly.

Most of the soils from our study areas were alkaline which should be treated properly in order to increase the availability of other soil nutrients like iron (Fe), zinc (Z), copper (Cu) and manganese (Mn) whose availability is hindered by alkaline soils. Most of the soils in both the districts were found containing low total N which needs sufficient nitrogen content to meet a desired level of crop production. The K content of most of the samples was also low. These nutrients should be made sufficient through various organic and inorganic external sources which can be prepared in the household itself or can even be bought. Available P was very high in most of the study sites. Application of organic manures for agricultural purpose is one of the reasons of P being high and also, unlike other nutrients, P is not lost readily or in heavy amounts. The organic C content of almost all the sampled soils were low and needs addition of more organic manure and compost.

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From the soil data of both of our study sites, it is seen that the soils are not being able to sequester SOC up to their full potential. Efforts should be made to increase their potential and one of the easiest ways to do so is application of manures. The nutrient rich manures apart from being used to supply the soils with deficient nutrients can also be used to promote C sequestration by maintaining soil organic matter. Also, the correlation of SOC with other soil parameters like TN, AP, EK, pH and CEC should also be considered. From the study, it was found that SOC showed significant negative correlation with pH, bulk density and AP. Whereas, positive correlation was found with TN, EK and CEC which were also significant. As these nutrients content in the soil can be altered to some extent by human effort, they can be increased or decreased accordingly to favor the SOC content in the soil by soil amendments using FYM and Bio-Char. Climate change and food security both being global as well as local issues in the study sites, strategies to increase SOC in agriculture land especially will not only contribute to GHG mitigation but also enhance food production that help to address food security issues [27] particularly in remote mountain landscapes introducing high value cash crops i.e. 'Ground apple' (*Smallanthus sonchifolius*, Yacon) and 'Kiwifruit' (*Actinidia chinensis*). Under the Paris Climate Agreement, this approach is a truly low hanging fruit for the mountains landscapes where land is underutilized and there is ample scope to increase SOC that have multiple benefits.

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Author Contributions:

Dr. Shrestha led the study and contributed since the formulation of the research, field data collection, data analysis and articulation of the study together with finalizing the manuscript preparation. Ms. Bhandari contributed during the field data collection and drafting the paper at first level. Dr. Karky contributed on the streamlining the study and feedback on the draft of manuscript. Dr. Kotru has provided his critical suggestions on the study and manuscript.

Conflicts of Interest:

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security, Science, Vol. 304, 11 June 2004.
2. Dahal, N and Bajracharya, M. R. (2010) Prospects of Soil Organic Carbon Sequestration: Implications for Nepal's Mountain Agriculture, Journal of Forest and Livelihood 9(1).
3. Kaini, B. R. (2004).Increasing crops production in Nepal. In: Sherchan, D. P., Adhikari, K., Batsa, B. K. and Sharma, D. (eds.) Proceedings of 24th National Summer Crops Research Workshop on Maize Research and Production in Nepal 2004. National Maize Research Programme and Nepal Agriculture Research Council, Kathmandu, Nepal. 15-19.
4. Bajracharya, R. M., Sitaula, B. K., Shrestha, B. M., Awasthi, K. D., Balla, M. K. and Singh, B. A. (2004) Soil Organic Carbon Status and Dynamics in the Central Nepal Middle Mountains, Journal of Institute of Forestry, Nepal, No. 12.
5. Shrestha, B. and S. Brown. 1995. Land use dynamics and intensification. In Shrestha, B. and S. Brown. 1995. Land use dynamics and intensification. In Schreier, H, P.B. Shah, and S. Brown (eds.) Challenges in Mountain resource management in Nepal: Processes, Trends, and Dynamics in Middle Mountain Watershed. Workshop Proceedings.
6. UNEP (2012). Managing Soils for Multiple Economic, Societal and Environmental Benefits, The Benefits of Soil Carbon, UNEP Year Book 2012, pg: 28.
7. FAO (2009). Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. Food and Agriculture Organization, Rome, pp 84
8. Gee, G.W. and Bauder, J.W. (1986) Particle Size Analysis. In: A. Klute (ed.) Methods of Soil Analysis, Part 1 (2nd edition) Physical and Mineralogical Methods. American Society of Agronomy Monograph No. 9, ASA- SSSA. Madison. WI, USA, p. 383-411.
9. Blake, G.R., and Hartge, K.H. (1986) Bulk density. In: Page, A.L. (ed). Methods of soil analysis, Part 1 (2nd edition) Physical and mineralogical methods. American Society of Agronomy Monograph No. 9, ASA-SSSA. Madison. WI, USA, p. 363-376.
10. Nelson, D.W., and Sommers, L.E. (1982) Total Carbon, Organic Carbon and Organic Matter In: A. L. Page, R. M. Miller and D. R. Keeney, eds. Methods of Soil Analysis Part 2 (2nd edition) Chemical and Microbiological Properties, Monograph No. 9, ASA-SSSA, Inc., Madison, WI, USA, p. 539-580.
11. McLean, E.O. (1982) Soil pH and lime requirement. Methods of soil analysis Part 2 (2nd edition) Chemical and microbiological properties. American Society of Agronomy. Monograph No. 9. Madison (WI): ASA-SSSA, Inc., Madison, WI, USA, p. 199-224.
12. Bremner, J.M. and Mulvaney, C.S. (1982) Nitrogen Total. In: A. L. Page, R. M. Miller and D. R. Keeney, (eds.) Methods of Soil Analysis Part 2 (2nd edition) Chemical and Microbiological Properties. American Society Agronomy Monograph No. 9, ASA-SSSA, Inc., Madison, WI, USA, p.595-610.
13. Olsen, S.R. and Sommers, L.E. (1982) Phosphorous. In: A. L. Page, R. M. Miller and D. R. Keeney, eds. Methods of Soil Analysis Part 2 (2nd edition) Chemical and Microbiological Properties, American Soc. of Agron. Monograph No. 9, ASA-SSSA, Inc., Madison, WI, USA, p.403-416.
14. Rhoades, J.D. (1982) Cation Exchange Capacity. In: A. L. Page, R. M. Miller and D. R. Keeney, eds. Methods of Soil Analysis Part 2 (2nd Edition) Chemical and Microbiological Properties, American Soc. of Agron. Monograph No. 9, ASA-SSSA, Inc., Madison, WI, USA, p. 149-158.
15. Tripathi, B.P. (1999). Review on Acid Soil and its Management in Nepal, Lumle Seminar Paper, vol. 99/1.
16. Oosterbaan, R.J. (2003). Lecture note on Alkaline-sodic soils and Acid-sulphate soils, International Course on Land Drainage (ICLD), International Institute for Land Reclamation and Improvement (ILRI), Wageningen, Netherlands.
17. Silva, J.A. and Uchida, R. (2000). Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture, College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa.
18. Regmi, A.P., Pandey, S.P. and Joshy, D. (2000). Effects of Long-term Application of Fertilizers and Manure on Soil Fertility and Crop Yields in Rice-Rice-Wheat Cropping System in Nepal, Long-term Soil Fertility Experiments Paper Series 6, pg 120-138.
19. Tisdale, S.L., Nelson. W.L. and Beaton, J.D. (1985). Soil Fertility and Fertilizers, MacMillan Publishers Co., NY.

Peer-reviewed version available at *Environments* **2017**, *4*, 29; doi:10.3390/environments4020029

20. Adams, J. (1997) Estimates of Pre-anthropogenic Carbon Storage in Global Ecosystem Types, Oak Ridge National Laboratory, Retrieved from http://www.esd.ornl.gov/projects/qen/carbon3.html.
21. CBS (2011) National Populatio n and Housing Census 2011 (National Report), Central Bureau of Statistics, Government of Nepal, Kathmandu, Nepal
22. IFOAM (2009). The Contribution of Organic Agriculture to Climate Change Mitigation, International Federation of Organic Agriculture Movements, EU Group.
23. Chan, Y. (2008). Increasing Soil Organic Carbon of Agricultural Land, Prime fact 735, Department of Primary Industries, New South Wales.
24. Zuazo, V.H., Rodriguez, C.R., Tavira, S.C. and Martinez, J.R.M. (2014), Linking Soil Organic Carbon Stocks to Land-use Types in a Mediterranean Agroforestry Landscape, Jor. Agr. Sci. Tech, vol 16. pp 667 – 679
25. Mbow, C., Noordwijk, M.V., Luedeling, E., Neufeldt, H., Minang, P.A. and Kowero, G. (2014). Agroforestry Solutions to Address Food security and Climate Change Challenges in Africa, Science Direct, vol. 6, February 2014, pp 61–67.
26. Lal R. (2014). Societal Value of soil carbon. Journal of Soil and Water Conservation, Vol 69(6):186A-192A Soil and Water Conservation Society. www.swcs.org
27. IUSS Working Group WRB. (2014). World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps: World Soil Resources Reports No. 106. FAO, Rome.