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Status of Carbon Sequestration in different land use systems of North West Himalayan Region: a perspective

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ABSTRACT

The Northwest Himalayan tract configured by unstable slopes and hilly terrains are more prone to degradation and soil erosion compared to other parts of the country. This degradation problem makes it more vulnerable to the impacts of climate change. This paper analyses critically the type of land management practices at farm scale which results in loss of soil C and tries to evaluate the coping strategies which can be adopted at farmers scale for improving C sequestration as well as preventing land degradation. The changes in land use pattern (from forest to other anthropogenic uses) are recognized as the key driving force for loss of soil organic C (SOC) in the hilly terrains. Among the various land use systems compared and evaluated the practice of agroforestry in farm land emerged as the best for enhancing the C sequestration potential of both above and below ground biomass. Among the various systems or species evaluated bamboo (*Dendrocalamus strictus*) had the highest C sequestration potential (12.27 Mg C ha^{-1} y^{-1}) followed by Dalbergia sisoo (2.73 Mg C ha^{-1} y^{-1}), Poplus deltoids (2.75 Mg C ha^{-1} y^{-1}), *Manigifera indica* (1.43 Mg C ha^{-1} $y^{-1)}$, Pecan nut, guava (0.96 Mg C ha^{-1} y^{-1}) and bhimal (0.81 Mg C ha^{-1} y^{-1}) which are commonly grown in the North West Himalayas. The Kotha Tarli watershed located in the Lower middle Himalayas where C stocks were evaluated also showed similar patterns with forest having the highest soil organic C stock followed by agriculture and scrub land. Thus, adoption of agroforestry practices in arable land or plantation of horticulture, fodder or grasses in the scrubs and degraded areas are promising alternatives to prevent land degradation and abate the effects of climate change.

1. Introduction

Soil organic carbon (SOC) is the major terrestrial pool of C which quantifies to 1500 Pg and is estimated to be almost double the C present in the atmosphere (Eswaran *et al.,* 2000). However, following the industrial revolution in 1750, the post-industrial era has seen a massive increase in the atmospheric CO_2 concentration which has increased by 31 percent, mainly due to increase in the fossil fuel combustion and changes in the land use pattern. Almost half to two third of the SOC has been lost to the atmosphere due to land use changes and intensive agricultural practices which is estimated to be 78±12 Pg of C which has been released to the atmospheric pool (Lal, 2004). At present, the CO_2 concentration has reached 400 ppm with an annual increment rate of 0.4 percent or 2.0-2.5 ppm (NOAA, 2016). This unprecedented increment in the CO_2 concentration has aggravated the phenomenon of global warming, which is a major challenge for mankind in the current scenario. The Sixth Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) states that for combating the demon of climate change all ratified countries needs to work towards the goal of keeping global warming below 2°C while making efforts to limit temperature increase to 1.5°C (www.ipcc.ch). Under such circumstances increment in SOC through C sequestration is a true win-win situation. The process of transferring atmospheric CO_2 into such pools with very high

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Mean Residence Time (MRT) such that it has less chances of getting re-emitted back to the atmosphere is defined as C sequestration (Lal, 2007). When the soil acts as a sink for storage of the C it is referred to as soil C sequestration. The atmospheric CO_2 can be stored for a longer time period by this process and also results in increment in the SOC concentration. Soil carbon sequestration is one of the mitigation strategies towards climate change, the other being use of more energy efficient fossil fuels or lowering the overall consumption of fuels. Compared to the later strategy as an alleviation option to offset ill impacts of increased CO_2 concentration, the former is more cost effective and has several other co-benefits. In the soil system C can be sequestered by adoption of restorative land uses and recommended management practices (RMP's) in agricultural fields. One-third to one-fourth of the annual increment in atmospheric CO_2 can be arrested through the adoption of various RMP's which amounts to 0.9±0.3 Pg C year-1 (Lal, 2004). This is expected to have a positive impact on the soil C budget and help in restoration of degraded lands, enhance the biomass production and improve the overall quality of the soil.

The North West Himalayan region which expands over three states in India, *i.e.* Jammu and Kashmir, Himachal Pradesh and Uttarakhand are hilly states where soil erosion is the major degradation factor. Water erosion is the major cause of land degradation in India which is most prevalent in these states. Lal, 2004 estimated that in India water induced soil erosion leads to loss of 29.8 Tg C y-1. Assuming that 20 percent of the lost C is mineralized, 6 Tg C y-1 is lost to the atmosphere and enriches the CO_2 concentration. Thus, loss of soil C along with loss of sediment is a devastating problem for the North West Himalayan region. The mountain system being young is subjected to various natural disturbances which are further aggravated by the anthropogenic interferences. Reduction in forest cover and land use changes converting forest land for agriculture and pasture further alleviates the problem of C losses from soil and stumbles towards land degradation. Thus, identifying land uses best suited for the Himalayan agro-ecosystems and replacing existing land uses with more sustainable, C positive land uses would help to prevent the rapid loss of C and arrest further land degradation. Replacement of the existing land uses and adoption of alternate land uses would not only benefit the environment but add to the economic benefits of the farmers of this region as well. In this paper we have tried to identify and review the different land use systems in the three North West Himalayan states and compare their C stocks and C sequestration potential for the policy makers to popularize and propagate the most effective land use systems.

2. Factors effecting SOC depletion

The organic C content of any soil is a function of several factors. The interplay of climate (temperature and precipitation), soil texture, soil pH, vegetation, micro-organisms and topography along with land management practices determines the quantity and quality of the organic matter present at any given place (www.fao.org). Keeping all the above factors constant, the land management practice in recent times have become most crucial in controlling the SOC content at any place, as more land is brought under human management due to increasing population pressure and food demands. Thus, among the several factors which causes depletion of SOC, land use changes has been identified as the prime cause. Meta-analysis of several C stock data revealed changes in land use pattern as the most important cause for depletion in soil carbon stock (Guo and Gifford, 2002). Shift in land use from pasture to plantation causes a depletion of 10 percent, and if native forest land is brought under plantation crops the decline is by 13 per cent (Guo and Gifford, 2002). When native forest land is brought under arable crop cultivation the C stock changed by 42 percent, while maximum depletion (59 percent) in C stock was reported due to conversion of pasture into cultivated land. Thus, the anthropogenic activities leading to enhanced interference of human kind with nature is the root to the problem of SOC depletion and deterioration of the quality of land (Lal, 2004). Besides the changes in land use pattern other factors which accentuates CO_2 emission to the atmosphere are burning of biomass, intensive tillage practices and ploughing of land (Reicosky *et al.,* 2002), draining of natural wet lands and marshes, low input subsistence agricultural practices and shifting agriculture generally prevalent in the hilly areas (Tiessen *et al.,* 2001). All the factors significantly impact the soil C mineralization by affecting several soil properties. Both the practice of crop residue burning and intensive tillage operations depletes the soil moisture, increases soil temperature and favour the mineralization of C. Drainage of wet lands also have similar influence on the soil.

While the mineralization process is dominant in non-sloping relatively flatter landscapes for loss of C from soil, in the sloping terrains erosion is the major cause for depletion of SOC (Rasmussen *et al.,* 1998). Water erosion and related processes can emit up to 1.14 Pg C into the atmosphere (Lal,2001) which ultimately results land degradation. The land degradation process causes chain reaction of lower biomass productivity, lower input of plant residue in soil, reduced microbial activity and further deterioration of the land quality (Lal, 2004).

However, it is projected that by practicing reverse processes the soil C stock can be re-built and soils can be made to act as a sink for absorption of the liberated C into the atmosphere. The C stocks were enhanced by 19 percent when crop land was converted to pasture while changing crop land to secondary forest land 53 per cent increment in the C stocks were reported (Guo and Gifford, 2002). Thus, soil carbon sequestration can be a reality though it varies spatially and temporally as guided by the management practices and strategies adopted to do so.

3. Factors affecting carbon storage by soils

All soils have a finite capacity to sequester organic C (Six *et al.,* 2002). The decomposition of different SOC pools is most often fitted into first order kinetics which assumes a linear relationship between added organic inputs and increment in soil organic C (Paustian *et al.,* 1995; McGill, 1996). However, though it explains the increment in SOC to some extent but the C dynamics of long term experiments in soils with high C concentration have failed to fit to this model (Campbell *et al.,* 1991; Paustian *et al.,* 1997). Thus, besides C input factors such as soil texture, clay content, silt content, nature of clay, soil aggregation are also important in deciding the actual amount of C stored by any soil (Six *et al.,* 2002). Therefore, the projected figures for C sequestration are often too ambitious compared to the actual scenario existing under field conditions. Based on the different natural and managed conditions each system would have a potential or maximum capacity to sequester C where it reaches saturation and ceases to improve further despite additional C inputs (Ingram and Fernandes, 2001). The potential, attainable and actual C sequestration values for different land use systems would help to provide a conceptual framework for developing management strategies for the same.

4. C sequestration potential of different agro-ecological regions in India

India with a total geographical area of 329 Mha has a wide variety of soil and climatic conditions. The entire country is divided into 20 agro ecological regions and 60 agro ecological sub regions (Ghajbiye and Mandal, 2000). Majority area of the country lies between the Tropic of Cancer and Tropic of Capricon which classifies most of the soil “tropical” in nature (Pal *et al.,* 2015). There are five bioclimatic zones characterized by the Mean Annual Rainfall (MAR) (Bhattacharjee *et al.,* 1982). They are arid hot and cold (MAR < 550 mm), semi-arid (MAR 550-1000 mm), sub humid (MAR 1000 - 1500 mm), humid to per humid (MAR 1200 – 1300 mm) and costal (MAR 900-3000 mm). The predominant soil orders in the country are *viz.* Inceptisol (39.4 %), Entisol (23.9 %), Alfisol (12.8 %), Vertisol (8.1%), Aridisol (4.1%), Ultisol (2.6%) and Mollisol (0.5%) (Bhattacharya *et al.,* 2009). These soil orders distributed in different bioclimatic zones and under different natural and managed ecosystem conditions have varying potential of sequestering soil organic and inorganic C. The SOC stock within 150 cm soil depth is 29.9 Pg which is lower than the soil inorganic C (SIC) stock (33.9 Pg). However, when only top 30 cm soil depth is considered the SOC stock is almost double the SIC stock (Pal *et al.,* 2015). The Indian soils stores 27% of the SIC of the world (Lal, 2004).

These varied soil systems along with the diverse agro-climatic situations have different rates at which they can sequester C. Out of the total land area a major portion is affected by various degrading processes. The harmonized data set by National Rainfed Area Authority (NRAA, 2008) after converging reports from wide sources shows 120.72 Mha area of the country affected by various types of degradation. Restoration of these degraded lands through proper management practices holds promising capacity to sequester up to 7-10 Tg C yr^{-1}. Since majority of the area is affected by water erosion, these areas holds maximum prospective to sequester C at the rate of 2.92-3.94 Tg C yr^{-1} (Lal, 2004). The mean soil organic C sequestration potential of Indian soils lies in the range of 12.71-16.50 Tg C yr^{-1} which is inclusive of the C sequestered through restoration of degraded lands. Among the different bioclimatic zones maximum rate of sequestration is projected for the perhumid and humid regions (Lal, 2004). However, the sub humid and semi-arid regions occupies maximum area which enables them to sequester highest amount of C (2.33 - 5.18 Tg C yr^{-1}) (Lal, 2004).

5. The North West Himalayan Region

The Himalayan ranges spreads extensively from the North West to the North East region of the country covering almost 12 states. Out of the total geographical area of 329 Mha, the hill and mountain ecosystem occupies 54 Mha (Siddhu and Surya, 2014). The North West Himalayan tract covering the three states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand has a geographical extent between 28° 43’ N to 37° 05’ N latitude and 72°02’ E to 81°02’ E longitude, covering an area of 33.12 M ha (Siddhu and Surya, 2014). The MAR ranges from <100 mm in the cold desert areas to as high as >1600 mm in the state of Uttarakhand. The bioclimatic zones mainly observed are cold arid, temperate to subtropical temperate. The temperature regime varies from Cryic to Hyperthermic while moisture regime extends from arid to sub humid. The hill and mountain ecosystem of the North West Himalayas are highly fragile and vulnerable due to its topography, climatic conditions, demography and several other factors. The hilly terrain accompanied with steep slope makes the soils of this region highly susceptible to erosion by different eroding agents. Thus, preventing erosion and subsequent land degradation is the major challenge in these hilly tracts. The soil erosion is also the major cause for loss of C along with nutrients from these soils. Successful controlling of erosion and preventing loss of top soil and nutrients would thus help to improve the concentration of soil C and improve the productivity and quality of the soil. Bhattacharya *et al.* (2008) worked out the C stocks of the different agro ecological regions of the entire country. For the North West Himalayan region covering the three states the SOC stock (0-1.5 m depth) is 4.387 Pg, SIC stock of 6.763 Pg and total C stock of 11.15 Pg which accounts for 14, 19 and 16 % of the SOC, SIC and total C stocks of the country respectively. The cold arid bio climate of the North West Himalayas accounts for almost 11% of the total SOC stock of the country. The sub-zero temperature accompanied with hyper arid climatic conditions is the major reason for enhanced SOC in this region (Bhattacharya *et al.,* 2008). Besides the soil C stocks, the forests are also a major potential source for sequestering atmospheric C in the above ground biomass. The forest plays a very essential role in combating the phenomenon of climate change by reduction of emissions through degradation and deforestation (Sheikh *et al.,* 2011). The North West Himalayan region has a forest cover of 11.83 % of its total area with a mean C stock of 688 Mt estimated during 2004 to 2008 (FSI, 2009). Out of the different forest zones in India, the North Western Himalayan region shows incremental effect in biomass C mainly due to dense vegetation and lesser human interference in the forests (Sheikh *et al.,* 2011). Thus, both below ground C sequestration through storage of C in soil systems and above ground C storage in the biomass through adoption of alternate land use systems are important practice to reduce the impact of climate change.

6. C sequestration in different land use systems of North West Himalayan Region

The forest plays the heart of the Himalayan eco-system and holds the key to prevent degradation, soil erosion and improve soil organic C content. According to the State of Forest Report (SFR, 2017) the total area under forest cover in Himachal Pradesh is 27.12%, Uttarakhand 45.43% and Jammu & Kashmir 10.46% which is far away from the required forest cover of 66% in the hill states according to the National Forest Policy, 1988. Thus, increasing the forest cover and *vis a vis* checking land degradation offers a sustainable solution in improving the SOC content and also mitigate impact of climate change by sequestering C in the biomass. For evaluating different land-use systems for their C sequestration potential a detailed review was done. The studies by different researchers are present in Table 1.

Khaki *et al.* (2016) compared six different agro forestry systems of comparable age in the Poanta Valley, Himachal Pradesh. Pure forest system of Shorea robusta exhibited the maximum soil C concentration (1373 Mg C ha^{-1}) between 0-20 cm depth followed by the hortisilvipastoral system which comprised of mango, poplar and natural grasses. The least SOC concentration (599 Mg C ha^{-1}) was obtained in Silvipastoral system with Dalbergia sisoo and natural grasses. Goswami *et al.* (2014) evaluated eight different land use systems for their C sequestration potential. The land use with agroforestry component was more competent in sequestering C compared to pure agriculture, abandoned land or pure grass land. Among the different agroforestry species commonly grown in Central Himalayan Region of India Dalbergia sisoo (2.73 Mg C ha^{-1} y^{-1}) and Poplus deltoides (2.75 Mg C ha^{-1} y^{-1}) had the maximum C sequestration rate, while mango (Mangifera indica) among the fruit trees had the highest C sequestration potential (1.43 Mg C ha^{-1} y^{-1}) (Kanime *et al.,* 2013). Poplar based agroforestry system along with wheat had soil C fixation rate of 1.62 Mg C ha^{-1} y^{-1} (Chauhan *et al.,* 2010). Comparison of different tree species native to the North West Himalayan region shows that Alnus nitida maintained the maximum C density in soil, while Ulmus vilosa had the maximum C sequestration and mitigation potential (Devi *et al.,* 2013). Tree species such as Quercus leucotricophora, Pinus roxburghii, Acacia catechu, Eucalyptus teriticornis, Ulmus vilosa maintained similar C density in the soil. However, the rate of C sequestration varied significantly with maximum potential exhibited by Ulmus vilosa (3.26 t ha^{-1} y^{-1}) and minimum by Albizia procera (1.77 t ha^{-1} y^{-1}). Singh and Rawat (2013) reported that Quercus leucotricophora predominant at higher elevations (1800-2100 m) in the Kumaon region of Uttarakhand maintained maximum C concentration in soil between 0-10 cm depths. Pecan nut is a widely grown nut species in the Indian Himalayan tracts and growing it this along with wheat gave maximum above ground biomass (56.5 t ha^{-1}) and maximum C stock (25.3 t ha^{-1}) when compared to lentil + pecan nut (Yadav *et al.,* 2017). The foothills of Shiwaliks in the Jammu and Kashmir state of India showed highest organic C stocks (both labile and non-labile) in the forest system (47.5 Mg ha^{-1}), followed by horticulture (42.4 Mg ha^{-1}) while degraded land and agricultural field maintained similar C stocks (35.1 and 36.3 Mg ha-1 respectively) (Sharma *et al.,* 2014). The strong correlation between land use and C stocks compared to soil properties like texture, cation exchange capacity indicated more pronounced influence of land use on soil C storage.

Table 1. Carbon sequestration potential of different land use systems in the Northwest Himalayan region

Study area	Land use evaluated	C sequestration potential	Source
Kwalkahad watershed, Himachal Pradesh	Eight land use (agriculture, agrisilviculture, agrihorticulture, agrisilvihorticulture, agrihortisilviculture, silvipasture, grassland, abandoned land	Agrisilvihorti and agrihortisilvi had highest C seq potential (15 Mg ha^{-1})	Goswami *et al.* 2014
Central Himalaya, *Tarai region*	*Dalbergia sisoo* *Poplus deltoids* *Mangifera indica*	2.73 Mg C ha^{-1} y^{-1} 2.75 Mg C ha^{-1} y^{-1} 1.43 Mg C ha^{-1} y^{-1}	Kanime *et al.* 2013
Uttarakhand, Punjab	Poplar and wheat agroforestry system	1.62 Mg C ha^{-1} y^{-1}	Chauhan *et al.* 2010
Almora, Uttarakhand	Pecan nut and wheat system	1.67 Mg C ha^{-1} y^{-1}	Yadav *et al.* 2017
Indian Himalayas	Bhimal (*Grewia optiva*)	0.63 to 0.81 Mg C ha^{-1} y^{-1}	Verma *et al.* 2014
Dehradun, Uttarakhand	Guava (*Psidium guajava*)	0.96 Mg C ha^{-1} yr^{-1}	Rathore *et al.* 2018
Doon valley, Uttarakhand	Bamboo (*Dendrocalamus strictus)*	49.1 Mg C ha^{-1} (4 year old plantation)	Kaushal *et al.* 2016

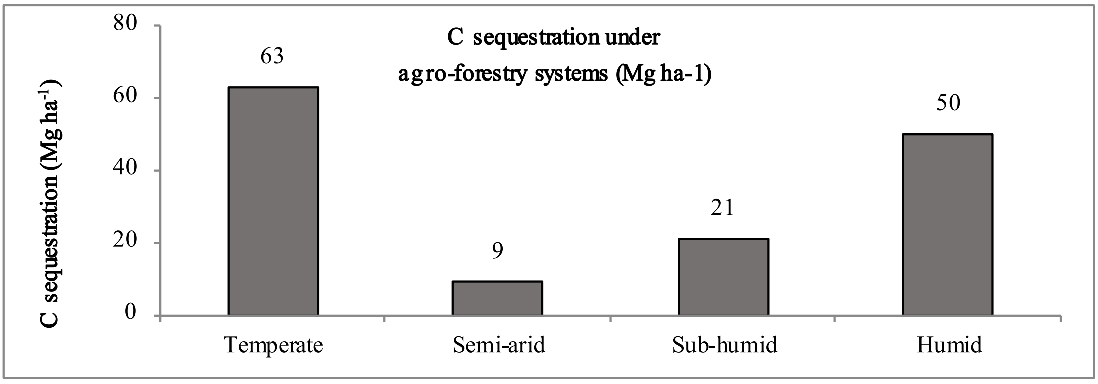

Figure 1. Carbon Sequestration potential in different regions under agroforestry system (Schroeder, 1993)

Besides the horticultural or timber crops, fodder and fuel wood crops like *Bhimal* (*Grewia optiva*) is widely grown in the hilly states. The C sequestration rate of above ground biomass was 0.63 to 0.81 Mg C ha^{-1} yr^{-1} while the C stored in soil between 0-30 cm depth was 25.4 and 33.6 Mg C ha^{-1} for 4 and 23 year old plantation respectively (Verma *et al.,* 2014). Total C sequestered by a 14 yr old guava plantation when grown in degraded lands of the Doon valley, was 53.1 Mg ha^{-1} (39.5 Mg in soil up to 30 cm and 13.6 Mg in biomass) (Rathore *et al.,* 2018) which indicates a huge potential for guava to sequester C and mitigate impacts of climate change. The Northwest Himalayan tract is threatened by problem of land degradation due it the steep slopes and fragile landscape (Mandal *et al.,* 2017). The use of different grasses or bamboo in the degraded land is a major alternative land use to control land degradation, sequester C and make productive use of the hostile landscapes. The male bamboo species *Dendrocalamus strictus* is widely distributed in North India and the C stored in the above ground biomass was 8.39 Mg ha^{-1} and 49.1 Mg ha^{-1} for a young (1 year old) and mature (4 year old) plantation respectively (Kaushal *et al.,* 2014). Thus, bamboo is a highly preferred species for stabilization of degraded lands and arresting soil erosion in the hilly tracts of Himalayas where soil erosion is a major problem (Singh *et al.,* 2015). The most extensively preferred land use system for C sequestration is agroforestry with economic as well as environmental benefits. Wide adaptation of agroforestry is one of the suggested practices for greening India as published by the task force Report for greening India (Chauhan *et al.,* 2010). Agroforestry system is a low cost C sequestration alternative compared to pure forest establishment (Zelek and Shivley, 2003). The hilly regions with lower temperature and temperate climatic conditions are most potential for sequestering C through agroforestry systems. A comparative study by Schroeder (1993) reveals that agroforestry based land use systems in temperate regions can sequester up to 63 Mg C ha^{-1} in contrast to semi-arid, sub-humid and humid regions with potentials of 9, 21 and 50 Mg C ha^{-1} respectively

(Figure 1). Therefore, the temperate hill regions of Northwest Himalaya have huge capacity to sequester C by adopting agroforestry practice on a large scale and alleviate the consequences of climate change and prevent land degradation. It seems to be the best suited option for the unstable hilly tracts of North West Himalayas which is characterized by fragile ecosystem, land degradation problems, small land holdings of farmers, low input subsistence agriculture and poor agrarian economy. The Inter-Governmental Panel on Climate Change portrays agroforestry system as the best option to synergize between the adaptation and the mitigation action and has a technical mitigation potential of 1.1-2.2 Pg C in the terrestrial ecosystem over a time frame of 50 years (Murthy *et al.,* 2013).

7. C stock in the study area: Kotha Tarli watershed in Lower middle Himalayas

The C stock for surface soil layer (0-15 cm) was determined in the study area of Kotha Tarli watershed located in the lower middle Himalayan region of Dehradun, Uttarakhand. Land use had a significant impact on the oxidisable organic C and the C stock in the area (Figure 2 & 3). The major land use systems in the Kotha Tarli watershed are scrub, agriculture and the forest. The scrub area comprises of very sparse vegetation with shrubs and isolated trees and is mostly eroded. Agriculture is practiced in bench terraces, maize, ragi, ginger, chilli *etc.* are grown during the Kharif season and wheat, mustard, pea grown during Rabi season. The area is entirely rainfed and subsistence agriculture with nominal inputs in form of Farm Yard Manure (FYM) or compost is added to the field. The forest vegetation is dominated by oak (*Quercus leucotrichophlora*) with some patches of pine (*Pinus roxhburgi*). The C stocks of the soil (0-45 cm) (Fig 3) was significantly between forest, agriculture and scrub: forest (90.5 t ha^{-1}) > agriculture (44.3 t ha^{-1}) > scrub (34.0 t ha^{-1}). Though agriculture had higher C stock compared to the scrub area but it was not significantly different. The oxidisable organic C (SOC) for different land use systems was determined for 0-45 cm soil depth. Progressive decline in SOC was observed across the land use systems as for the C stock.

The SOC concentration across the land use system varied as: forest > agriculture > scrub. Also, the concentration of SOC decreased with soil depth and was lowest at 30-45 cm soil depth for all land use systems. However, all the land use systems had high oxidisable C which can be attributed to low temperature and high mean annual rainfall of the Kotha Tarli watershed. The present observations are similar to findings by other researchers (Goswami *et al.,* 2014) who reported maximum C stock under forest due to high litter fall and C input, negligible soil disturbance and erosion and less anthropogenic interferences.

8. Management strategies to enhance soil C sequestration

As discussed in the previous section agro forestry among the several land uses surely stands out as the best option for C sequestration both in the plant biomass and soil. However, soil being the largest deposit of terrestrial C often surpasses the capacity of the plants in the process. Goswami *et al.* (2014) reported the C stocks in soil (0-40 cm) depth exceeded the plant C stocks by a factor of 15.8. Besides agro forestry there are several other practices which could be included in a farmers schedule to enhance the C sequestration. The IPCC describes various strategies to mitigate the impact of CO_2 emitted from agricultural sector among which enhancing the potential of soil system as a major C sink is one. The conversion of atmospheric CO_2 into stable humus pool is a convenient and permanent solution to the problem than temporary sequestration in the above ground biomass by afforestation. The enrichment of soil organic carbon is a complex process and very easily said than done. The increased CO_2 concentration due to climate change and fertilization effect of CO_2 on the Net Primary Productivity (NPP) (Allen *et al.,* 1996; Bazzaz *et al.,* 1996) are two highly interlinked phenomenon which is likely to have profound impact on the C storage capacity of soil systems. On one hand the increased CO2 concentration will increase the global temperature as well as soil temperature leading to increased microbial activity, thus, promoting higher rate of decomposition provided nutrient and moisture is non-limiting (Kirschbaum, 1995).

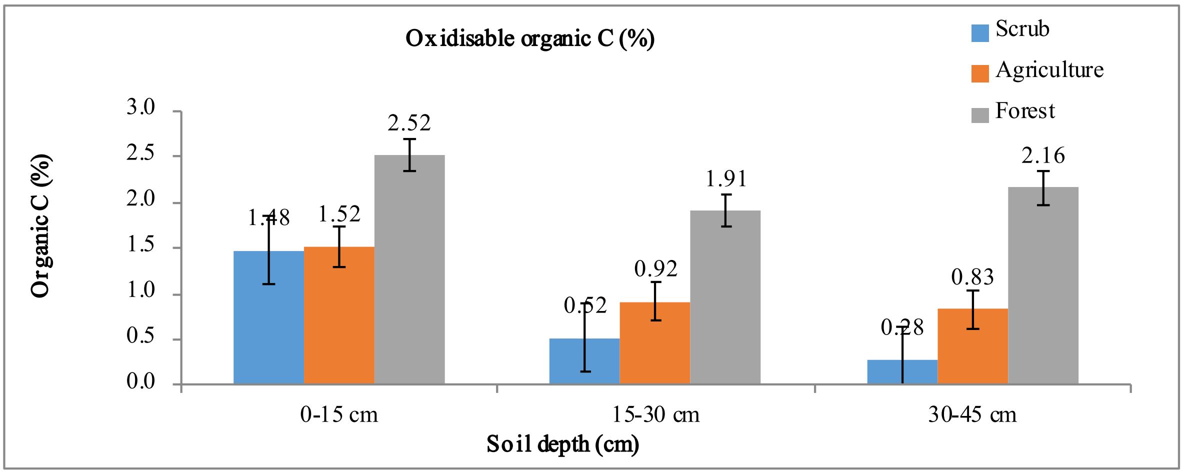

Figure 2. Oxidisable Organic C (%) in different landuse of Kotha Tarli watershed

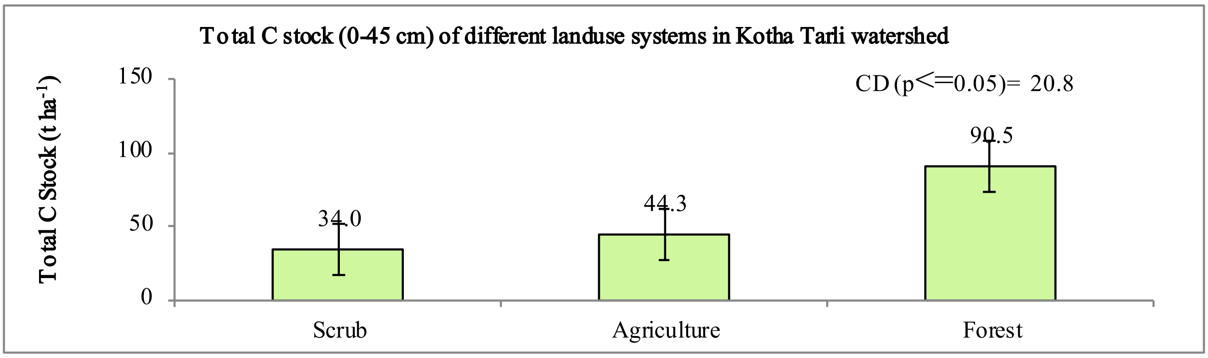

Figure 3. Carbon stock (t ha^{-1}) in surface soil (0-45 cm) in major land use systems of Kotha Tarli watershed

Therefore, sequestration is not going to happen under such circumstances. However, Goldewijk *et al.* (1994) used modelling approach to show the impact of increased temperature and moisture on soil respiration (*i.e.* C decomposition) would be less than that on NPP due to CO2 fertilization. This would ensure storage of SOC. Also, upon CO_2 enrichment in the atmosphere, plants will have higher concentration of C to N, raised C:N ratio and higher lignin fraction which ultimately leads to reduced decomposition and increment in soil C (Ball, 1997). Therefore, though C sequestration is a management strategy to combat climate change, the increased CO_2 concentration can have positive impacts on C storage by soil systems. However, this is subjected to various extraneous and environmental factors with great degree of temporal and spatial variation. The management strategies adopted for C sequestration should not only focus on storage of SOC but also reduce the net release of all greenhouse gases into the atmosphere (Post *et al.,* 2004). The various land management practices is effective in increasing C storage in soil by 0.44-0.88 Pg C per year across the world with a temporal stability sustaining over a 50 year time frame (Cole, 1996). The major processes which ensures sequestration are (1) enhancing the rate of organic matter inputs (2) partitioning of added C in more passive pools (3) Increasing the residence time of all or selected C pools (Post *et al.,* 2004). All the three processes in conjunction can help to increase the C status of the North West Himalayan region as a whole.

9. Conclusion

Carbon sequestration is not only an environment friendly option to negate the impacts of climate change but it also provides good economic opportunities of fund generation by carbon trading. In the Himalayan region, where felling of live/green trees is banned, the C trading business through agroforestry practices can be adopted at a large scale for generation of revenue for the farmers (Goswami *et al.,* 2014). In this regards, states like Himachal Pradesh has already taken initiatives and signed agreement with the World Bank in 2011 to bring an area of 4003 Mha under the Clean Development Mechanism (CDM) Project (Project Design

Doc, 2011) with the aim to conserve natural resources and improve the livelihood of small and marginal farmers. For the North West Himalayan region in particular the impact of climate change is going to be more severe because of the fragility and quasi stable nature of the ecosystem. Thus, carbon sequestration strategies need to be adopted at large scale through proper education and awareness of the farming communities towards the consequences of climate change. Integrated farming system approach with changes in land use systems holds the key in ensuring higher C sequestration in this ecosystem, which would not only alleviate impacts of climate change but also prevent land degradation, improve quality and productivity of the soil and secure the livelihood of farming community.

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