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Cropping Systems and Agro-Management Practices in relation to Soil Carbon in the Temperate Regime of Uttarakhand

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Abstract

The Indian Himalayan region has a distinctive entity as the variations in topographic features occurring along its three dimensional framework that is latitudinal, longitudinal and altitudinal causes diversity in climate and habitat conditions within the region. A large section of the central Himalayan region (Uttarakhand), largely depends upon agricultural based activities for their livelihood. The soil particularly under rain fed agriculture is vulnerable to soil losses through combination of natural factors such as slopping topography, heavy seasonal rainfall and predominance of erosion prone soil and other anthropogenic factors. The present study attempts to document the traditional cropping systems and management practices so as to combat the environmental disturbances in order to maintain soil fertility. The study has been conducted in a few villages of Uttarakhand across the altitudinal gradient (600–2,200 m) covering important hill districts and their combined impact on soil fertility. Soil carbon is an important determinant of soil fertility due to its role in maintaining soil physical and chemical properties. In the present study, soil organic carbon was found to approximately range from 2.2% to 3.4%. Bulk density varied from 1.12g cm^3 to 1.34g cm^3. The legumes as well as the horticultural trees both have large root biomass and therefore, contribute to greater SOC content. TN was found to be significantly correlated to SOC ($r=.326$; $P<0.01$), implying that soil fertility is well maintained in the farming systems. Though the crop management practices are already followed yet, the improvements in farming systems and use of organic material/compost could add carbon to soils, improving the soil fertility.

Keywords: Soil organic carbon | temperate agro-ecosystems | management practices

Introduction

Agriculture today has become an activity of economic prosperity, nature conservation, and repository of genetic resources and most

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importantly, a way to alleviate the threats of climate change, while simultaneously meeting the food demand. The agro-ecosystems are not self sustaining and rely on natural processes for maintenance of their productivity, without adversely affecting the surrounding environment. The Indian Himalayan region has a distinctive entity as the variations in topographic features occurring along its three dimensional framework that is latitudinal, longitudinal and altitudinal causes diversity in climate and habitat conditions within the region. This leads to overwhelming richness of biodiversity elements and to their uniqueness. According to Mohanty and Singh (2014), though the agriculture sector utilizes only 13% of the geographical land, it provides employment to almost half of the workers in the state.

Conventional agricultural practices have caused a significant decrease in soil organic carbon (SOC) and large fluxes of carbon dioxide and other green house gases (GHG) to the atmosphere (IPCC, 2007). Adoption of recommended soil and crop management practices thus, can help in resequestration of carbon. Uttarakhand offers a vast scope for cultivation of diverse crops viz., cereals, millets, legumes, vegetables, fruits, oilseeds etc. including certain wild edible species. Agriculture has been the primary occupation of people since ages. A large section of the central Himalayan region in Uttarakhand population largely depends upon agricultural based activities for their livelihood.

The low productivity of cereals, oilseeds, etc. is a major hindrance in the food security of the region (Mehta, *et al.*, 2010). The soil loss has been regarded both by scientists and farmers as a major reason for declining soil fertility and crop productivity in the region. The soil particularly under rainfed agriculture is vulnerable to soil losses through combination of natural factors such as slopping topography, heavy seasonal rainfall and predominance of erosion prone soil and human factors such as intensive cultivation of land and erosion prone agricultural practices. Traditional agriculture of this region is now weakening, due to variety of socio-cultural changes among rural communities and shrinkage in the natural resources, is one of the major concerns. A very frequent example is that of reduction in the duration of wheat crop by 15–20 days due to rise in temperature **(**Chijioke, *et al*., 2011). Cash crops like pulses, oilseeds and vegetables can be produced widely, keeping the climate and terrain in view (Sati, 2005). Improved crop growth and development can be achieved by appropriate cropping practices like adequate water supply, organic farming, use of crop residues (Wang *et al.* 2010). The study to document the traditional cropping systems and management practices of Uttarakhand has been conducted in a few villages across the altitudinal gradient (600–2,200 m) covering important hill districts of Uttarakhand. The manuscript focuses on the most common and extensively cultivated specific crops along this altitudinal gradient, the management practices followed in order to maintain soil fertility.

Materials and Method

Site Description*:* The study villages in different altitudes (600–2,200 m) of Uttarakhand lie between the lesser and the greater Himalayas. Above this altitude, mostly there is no permanent settlement. The inhabitants migrate to the lower regions during the winter (November–March) when the rainfall is less and the temperature drops down to -10°C. The area under study covers three districts of Kumaun region namely Nainital, Almora and Bageshwar and one district in the Garhwal region namely Pauri (Table 1).

Village	District	Latitude	Longitude	Altitude
Kaindul	Pauri	N 30°00’15.28”	E 8°37’10.53”	587.5-834.06 m asl
Maichun	Almora	N 29°37’59.8”	E 79°46’57.3”	1492-1664 m asl
Ramgarh	Nainital	N 29°27’28.6”	E 79°35’58.2”	1624-1884 m asl
Shama	Bageshwar	N 29°58’31.7”	E 80°02’46.3”	2039-2178 m asl
Lamudyar	Almora	N 29°37’31.4”	E 79°46’17.2”	1620m asl

Table 1: Study Villages in Uttarakhand Himalaya

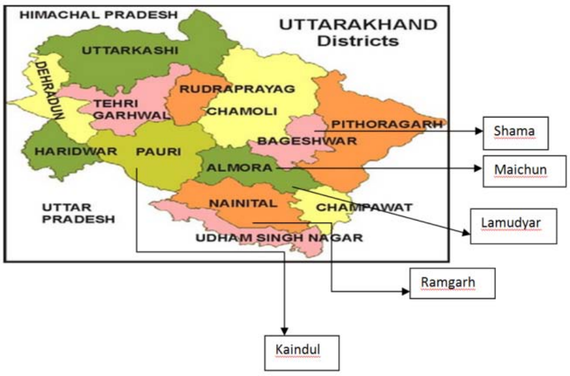

Fig. 1: Showing different study sites along the altitudinal stretch

Fig. 2: Showing the soil sampling in one of the study sites (Shama)

Fig. 3: Showing the harvesting of *Eleusine coracana* during sampling in one of the study sites (Kaindul)

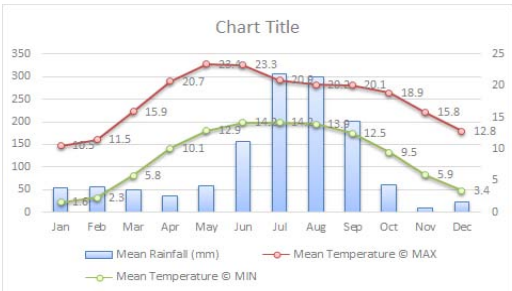

Fig. 4: Showing average temperature and rainfall profile of Mukteshwar for all the months during 1901-2000, Source: IMD

Data Collection & Sampling

The data was collected on cropping systems and management practices through personal visit to the concerned study areas and by circulating the structured and un-structured questionnaire among the knowledgeable elderly people who had past experiences of cropping, men and women who currently worked in the fields. Additionally, participatory rural appraisal (PRA) was used to obtain authentic information regarding the crops grown and management practices followed to prevent the production loss and maintain the soil fertility. The soil samples were collected in a zig zig manner at two depths viz. 0-15 cm and 15-30 cm from fields and brought to laboratory for further analysis. The sampling was done in two different seasons viz. kharif and rabi at the time of harvesting of the crops.

Results and Discussion

The survey conducted in the above mentioned districts of Uttarakhand provided for valuable information regarding the cropping systems and farming practices carried out to manage agriculture. The cropping calendar of the major crops has been described in Table 2 and 3. The common varieties have also been mentioned (Table 4). The most extensively cultivated crops have been mentioned here.

Cropping Systems

I. *Major Cereal Crops:* Cereal crop cultivation has not been the traditional practice in the hilly terrains originally. But, in the due course of time, with the advancement of technology (Green revolution) when the agriculture sector gained grounds in India and food security remained no more major threat to the nation, cultivation of cereal crops in the hilly districts of Uttarakhand began. Today, the farmers prefer growing cereal crops to millets as it not only meets their food demand but also helps them economically. The major cereal crops cultivated are wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays*), barley (*Hordeum vulgare*), amaranth (*Amaranthus caudatus*), buckwheat (*Fagopyrum esculentum*) and chenopodium (*Chenopodium album*).

II. Millets: Millets have been the traditional crops of the state since ages. Their cultivation and production both have been found to be resilient to the changing climate. But the farmers do not prefer growing millets in quantities as high as cereal crops in the recent past because they do not get good market value for these crops. Millets are nutritious as well. Their cultivation must be enhanced. The major millets grown are finger millet (*Eleusine coracana*), barnyard millet (*Echinochloa crus-galli*), sorghum (*Sorghum vulgare*), proso millet (*Panicum miliaceum*).

III. Pulses: Pulses occupy an important part of food crops cultivated in Uttarakhand since they not only meet the food demand, but also enrich the soil fertility and provide for good economic value. Pulses are generally grown in combination with other millets or cereal crops. The major pulses grown are soybean (*Glycine max*), kidneybean (*Phaseolus vulgaris*), blackgram (*Vigna mungo*), horsegram (*Macotyloma uniflorum*), pigeon pea (*Cajanus cajan*), lentil (*Lens culinaris*), chick pea (*Cicer arietinum*), cowpea (*Vigna Unguiculata*).

IV. *Vegetables:* The cultivation of vegetables helps farmers to ensure food security. The most commonly grown vegetables include cabbage (*Brassica oleracea* var. *capitata*), cucumber (*Cucumis sativus*), tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), carrot (*Daucus carota*), radish (*Raphanus sativus*), jack fruit (*Artocarpus heterophyllus*), pumpkin (*Cucurbita moschata*), meetha karela (*Cyclanthera pedata*), broad bean (*Vicia faba*), lai (*Brassica juncea* var. *rugosa*).

V. Spices: Spices are widely cultivated in the state. These include turmeric (*Curcuma longa*), ginger (*Zinziber officinale*), cleome (*Cleome viscosa*), onion (*Allium cepa*), garlic (*Allium sativum*), fenugreek (*Trigonella foenum-graecum*), coriander

(*Coriandrum sativum*), dalchini (*Cinnamomum tamala*), hemp (*Cannabis sativa*).

VI. *Oilseeds:* Oilseed cultivation is also a common practice in Uttarakhand. The commonly grown oilseeds are yellow sarson (*Brassica juncea*), brown sarson (*Brassica juncea*), toria (*Brassica campestris*), perilla (*Perilla frutescens*).

VII. *Fruit Crops:* Horticulture has been a practice in Uttarakhand since ages. The climate and soil type favors the cultivation of fruit crops widely. The citrus fruits are most extensively grown and provide for economic prosperity. These are orange (Citrus sinensis), lemon (Citrus limon), walnut (Juglans regia), chestnut (Castanea sativa), apple (Malus domestica), pear (Pyrus communis), peach (Prunus persica), apricot (Prunus armeniaca), plum (*Prunus domestica*).

VIII. *Wild Edible Species:* A total of 94 wild edible species are found in Uttarakhand, out of which 67 are fruits and 27 are vegetables**.** The wild species help the farmers to support the livelihood and most importantly meet the economic needs.

Month/ Crop	**Wheat**	**Barley**	**Lenti**	**Maize**	**Finger millet**
January					
February	Weeding	Weeding	Weeding		
March	Flowering	Flowering	Flowering		
April	Fruiting	Fruiting	Fruiting		
May	Harvesting	Harvesting	Harvesting		
June				Ploughing/ Sowing	Ploughing/ Sowing
July				Weeding	Weeding
August				Flowering	Flowering
September				Fruiting	Fruiting
October	Plowing	Plowing	Plowing	Harvesting	Harvesting
November	Sowing	Sowing	Sowing		
December					

Table 2: Cropping calendar of major crops cultivated in all the study site

Month/ Crop	Barnyard millet	Paddy	Amaranth-us	Black gram	Soybean	Kidney bean
January						
February						
March						
April						
May						
June	Ploughing/ Sowing	Ploughing/ Sowing	Ploughing/ Sowing	Ploughing/ Sowing	Ploughing/ Sowing	Ploughing/ Sowing
July	Weeding	Weeding	Weeding	Weeding	Weeding	Weeding
August	Flowering	Flowering	Flowering	Flowering	Flowering	Flowering
September	Fruiting	Fruiting	Fruiting	Fruiting	Fruiting	Fruiting
October	Harvesting	Harvesting	Harvesting	Harvesting	Harvesting	Harvesting
November						
December						

Table 2: Cropping calendar of major crops cultivated in all the study site

Months/Crop	Apple	Peach	Plum
January	Grafting	Weeding	Weeding
February			
March		Flowering	Flowering
April	Flowering	Fruiting	Fruiting
May	Fruiting		
June		Harvesting	Harvesting
July			
August	Harvesting		
September			
October			
November	Sowing	Sowing	Sowing
December	Weeding	Grafting	Grafting

Table 3: Cropping calendar of Horticultural Crops cultivated in the study sites

Crops	Old Varieties	New Varieties
Wheat	Mundri, Jalandhari, Jhisva, Lalnoi, Safednoi	Same
Barley	Local Seeds	Local Seeds
Lentil	Local Seeds	Local Seeds
Maize	Hagol, Pichol	Same
Finger millet	Dhuni, Lumari, Gadhav, Nagchuni, Putaki	Same
Barnyard millet	Local Seeds	Local Seeds
Amaranthus	Local Seeds	Local Seeds
Paddy	Hansraaj, Naulia, Jumawati, Gorakhpuri, Chena, Usa 33, Kaalijum, Jethi, bona, Nandini, Suryav, Saav, Oot, Chintafali, Batasu, Gadav	Bonya, Bhabhari, Rajasthani, Sathi, Kasturi, Dunda
Kidney bean	Local Seeds	Local Seeds
Soybean	Local Seeds	Local Seeds
Black gram	Local Seeds	Local Seeds
Apple	Jonathan, Delicious old, KingDavid, Rimar No. 12, No. 103, No. 88, Harapichola No 45, Binoki, Feni, Beauty Bar, American Bar, Amri, Meenakumari, Royal delicious, Lalmeetha No. 2, Chakalua	New feni, New delicious, Brown delicious, Saktiuphaar, Feni
Peach	Tatapari, Paragreen, Gobariadhu, Goladhu, Peelaadu, Earlysafeda, Baisakhi, Alexander	Red June, Early June, Asadia, Paradelux, Chaubatia, Necteen

Table 4: Varieties of major crops cultivated in all the sites

Crop Management Practices

An ideal cropping system should produce and simultaneously remain the surplus amount of biomass or organic carbon in the soil Wang, *et al.* (2010)**.** High production and maintenance of soil fertility are the objectives of any crop management system. The hill agro-ecosystems possess specific geographic and climatic conditions such as topography, aspect, slope, temperature, moisture, elevation and soil type, the combination of which requires an accurate management of farms for adequate production. Soil carbon is an important determinant of soil fertility due to its role in maintaining soil physical and chemical properties. The need of the hour is to develop management practices that assist in sequestering carbon into the soil and simultaneously maintain the crop productivity. Several management practices have been followed in the hilly terrain to maximize production, prevent the crops against pests and other climatic threats and simultaneously maintain soil fertility.

I. *Terrace Farming:* One of the most common agricultural practices of hilly regions is terrace farming followed in order to prevent removal of soil against soil erosion during heavy rains and strong winds. The soil drained from a field is collected in another field lying below. The steps help to prevent the top fertile layer of soil from getting removed. As such, the soil organic matter that is essentially higher in the upper layer of soil remains intact maintaining soil fertility.

II. *Crop Rotation:* Crop rotation is one of the most effective measures for improving the biomass production and soil carbon sequestration. Legumes substantially reduce the nitrogen input as chemical fertilizers, thereby reducing the fossil fuel consumption in the production of fertilizers ((Wang, *et al.*, 2010 and Zentner *et al*., 2001). Besides, appropriate crop rotation also increases soil productivity and biomass production that would otherwise decrease due to an infestation increase in weeds, diseases and insects. Organic matter decomposition rate and mineralization of SOC can be decreased by increased cropping intensity (Dumanski, *et al*., 1998). In a long term study, it was found that the corn-soybean systems had the greatest productivity and returned largest crop residues to the soil when compared to monoculture of corn or soybean (Drinkwater *et al*., 1998). In the areas studied, crop rotation was found to be a regular practice in the rainfed fields, wherein, cultivation of rice-*eleusine* crop rotation system was frequent in all the villages.

III. *Crop Residues:* This is one of the most common soil management practices followed in the hilly regions to improve the soil fertility and maximize production. The crop residues that remain in the field after harvesting are either burnt or directly mixed with the soil. This incorporates with the soil and with the passage of time gets humified and adds to soil organic matter thus, improving the soil fertility.

IV. *Organic Farming:* In hills, use of chemical fertilizers and pesticides is minimum. Manure is added mixed with crop residues in several villages. There is also a practice where farmers prepare vermicompost. The largely rain-fed agriculture and very low use of chemical fertilizers and pesticides, provides an opportunity to develop environment and farmer friendly organic farming that provide better value in the market. This practice has been the source of food security for small and marginal farmers in terms of safe, multiple and nutritious food.

V. *Intercropping:* Intercropping is done through various methods viz. row intercropping, strip intercropping, mixed cropping and relay intercropping depending on the type of crop and cropping goals. Intercropping in general can improve the crop productivity due to better efficiency of utilization of sunlight by various plants. Frequently, in the hilly regions, corn is grown with climbing beans that provide for improved productivity of beans as they can take advantage of space and sunlight. Besides soil fertility is maintained simultaneously due to the legumes. There are a number of successful selections for mixed cropping systems in agriculture such as wheat and chickpea; peanut and sunflower; soybean and pigeon pea; wheat and mustard; barley and chickpea and cotton and peanut *etc***.** (Anon, 1990)**.** Mixed cropping is an effective approach to optimize ecosystem for maximum plant production. It has been practiced in several countries like India, China. Horrocks *et al*., 2004, revealed mixed cropping system in early New Zealand, Gunes *et al*., 2007, stated mutual benefits in mineral nutrients and soil moisture by mixed cropping in Europe. In the rainfed system, rice cultivation is done such that barnyard millet is cultivated at the boundaries to maximize production. In irrigated fields, rice cultivation is surrounded by soybean cultivation.

Cover Crops: Cover cropping is an effective approach to improve biomass production as well as soil organic carbon storage. In temperate regions, winter cover crops, such as rye, ryegrass, clover, pea, oats, vetch are commonly grown that survive through the mild winter and again grown in spring to cover the bared lands during off season. SOC increased by 6-8% by cover crops at 0-10 cm (Sainju *et al.*, 2006). *Chenopodium* is often grown as a cover crop for a period of two months before the sowing of wheat in the hilly regions of Uttarakhand.

Sites	Crops	Depth	Bulk Density (g/cm3)	Texture	Moisture (%)	SOC (%)	OM%	TC/TN Ratio
Kaindul	*Eleusine coracana*	0-15	1.23	Silty loam	18.19	1.482	2.555	14.811
		15-30	1.21	Silty loam	18.27	1.131	1.95	9.143
	Vigna mungo	0-15	1.26	Silty loam	18.46	2.3595	4.068	7.438
		15-30	1.25	Silty loam	19.38	2.2815	3.933	7.356
	Oryza sativa	0-15	1.14	Loamy sand	18.24	1.638	2.824	10.056
		15-30	1.12	Loamy sand	18.28	1.7745	3.059	10.502
	Forest	0-15	1.34	Silty loam	22.46	1.872	3.227	7.625
		0-15	1.32	Silty loam	22.78	1.794	3.093	7.182
Lamudyar	*Amaranthus sp.*	0-15	1.24	Loamy sand	15.46	0.858	1.479	39.25
		15-30	1.24	Loamy sand	15.78	1.482	2.555	12.216
	Eleusine coracana	0-15	1.26	Loamy sand	16.48	0.741	1.277	9.42
		15-30	1.24	Loamy sand	16.96	1.092	1.883	8.103
	Forest	0-15	1.26	Loamy sand	19.44	1.755	3.026	5.128
		15-30	1.25	Loamy sand	19.68	1.209	2.084	5.451
Maichun	*Eleusine coracana*	0-15	1.24	Loamy sand	15.34	1.209	2.084	10.855
		15-30	1.22	Loamy sand	15.67	1.053	1.815	5.199
	Glycine max	0-15	1.24	Loamy sand	16.88	1.716	2.958	12.157
		15-30	1.23	Loamy sand	16.96	1.638	2.824	6.637
	Amaranthus sp.	0-15	1.26	Loamy sand	17.24	1.833	3.16	12.592
		15-30	1.24	Loamy sand	17.68	1.911	3.295	33.691
	Forest	0-15	1.28	Loamy sand	19.48	2.574	4.438	9.075
		15-30	1.26	Loamy sand	19.64	2.457	4.236	7.017
Ramgarh	*Malus domestica*	0-15	1.32	Silty loam	22.54	0.624	1.076	19.05
		15-30	1.32	Silty loam	23.46	1.014	1.748	12.076
	Prunus persica	0-15	1.3	Loamy sand	21.67	0.624	1.076	5.598
		15-30	1.3	Loamy sand	21.88	2.613	4.505	10.226
	Phaseolus vulgaris	0-15	1.28	Silty loam	19.34	2.457	4.236	11.338
		15-30	1.26	Silty loam	19.56	2.2425	3.866	14.306
	Forest	0-15	1.34	Silty loam	23.62	2.106	3.631	11.505
		15-30	1.32	Silty loam	23.48	0.624	1.076	13.225
Shama	*Eleusine coracana*	0-15	1.28	Silty loam	19.24	2.4375	4.202	11.092
		15-30	1.26	Silty loam	19.28	2.652	4.572	8.536
	Malus domestica	0-15	1.34	Silty loam	20.26	3.354	5.782	6.986
		15-30	1.32	Silty loam	20.29	3.003	5.177	13.514
	Phaseolus vulgaris	0-15	1.23	Silty loam	18.19	3.4125	5.883	8.486
		15-30	1.23	Silty loam	18.27	3.627	6.253	10.339
	Glycine max	0-15	1.24	Silty loam	19.46	3.081	5.312	8.54
		15-30	1.24	Silty loam	19.88	3.003	5.177	10.302
	Zea mays	0-15	1.18	Silty loam	17.68	1.716	2.958	14.39
		15-30	1.16	Silty loam	17.88	1.2675	2.185	9.355
	Forest	0-15	1.38	Silty loam	24.86	2.964	5.11	8.226
		15-30	1.36	Silty loam	25.54	2.886	4.975	13.465

Table 5: Showing details of physical parameters, SOC% and OM% analyzed in the soil samples in October.

Sites	Crops	Depth	Bulk Density (g/cm3)	Texture	Moisture (%)	SOC (%)	OM%
Kaindul	Triticum aestivum	0-15	1.23	Loamy sand	17.16	0.897	1.54643
		15-30	1.21	Loamy sand	17.27	1.5015	2.58859
	Hordeum vulgare	0-15	1.26	Loamy sand	18.36	1.1505	1.98346
		15-30	1.25	Loamy sand	18.44	1.638	2.82391
	Forest	0-15	1.34	Silty loam	21.48	1.482	2.55497
		15-30	1.32	Silty loam	21.38	0.429	0.7396
Maichun	Triticum aestivum	0-15	1.24	Loamy sand	15.61	1.443	2.48773
		15-30	1.22	Loamy sand	15.82	1.287	2.21879
	Forest	0-15	1.28	Loamy sand	17.43	1.911	3.29456
		15-30	1.26	Loamy sand	17.84	1.677	2.89115
Lamudyar	Triticum aestivum	0-15	1.24	Loamy sand	15.58	2.1255	3.66436
		15-30	1.24	Loamy sand	15.19	2.418	4.16863
	Forest	0-15	1.26	Loamy sand	18.69	2.379	4.1014
		15-30	1.25	Loamy sand	18.79	1.131	1.94984
Ramgarh	Malus domestica	0-15	1.32	Silty loam	20.46	2.496	4.3031
		15-30	1.32	Silty loam	20.79	2.4375	4.20225
	Prunus persica	0-15	1.3	Silty loam	21.35	0.897	1.54643
		15-30	1.3	Silty loam	21.46	0.741	1.27748
	Triticum aestivum	0-15	1.28	Loamy sand	23.26	1.8915	3.26095
		15-30	1.26	Loamy sand	23.28	1.4625	2.52135
	Forest	0-15	1.34	Silty loam	25.38	2.2815	3.93331
		15-30	1.32	Silty loam	25.39	2.301	3.96692
Shama	Hordeum vulgare	0-15	1.28	Silty loam	19.24	2.067	3.56351
		15-30	1.26	Silty loam	19.28	1.833	3.16009
	Triticum aestivum	0-15	1.34	Silty loam	19.46	2.496	4.3031
		15-30	1.32	Silty loam	19.88	2.457	4.23587
	Lens culinaris	0-15	1.23	Silty loam	18.19	3.081	5.31164
		15-30	1.23	Silty loam	18.27	3.003	5.17717
	Malus domestica	0-15	1.24	Silty loam	20.26	2.9445	5.07632
		15-30	1.24	Silty loam	20.29	2.8665	4.94185
	Forest	0-15	1.38	Silty loam	25.68	2.457	4.23587
		15-30	1.36	Silty loam	25.88	2.223	3.83245

Table 6: Showing details of physical parameters, SOC% and OM% analyzed in the soil samples in May

	TN	TC	SOC	CS	BD
TN	1	.514**	.326**	.305**	-0.068
TC		1	.701**	.676**	0.024
SOC			1	.995**	.280**
CS				1	.372**
BD					1
** Correlation is significant at the 0.01 level (2-tailed); N=148					

Table 7: Showing the correlation among various soil parameters

Crop Type	N	1	2	3
Cereals	**2**	**26.76**		
Millets	**14**	**29.80**	**29.80**	
Forest	**10**		**35.01**	
Horticulture	**6**			**42.76**
Legumes	**10**			**45.39**
Sig.		**0.39**	**0.14**	**0.46**

Table 8: Showing carbon stock among various crop types

Sites	N	1	2	3
Lamudyar	**6**	**27.81**		
Kaindul	**8**	**31.30**	**31.30**	
Maichun	**8**		**36.04**	
Ramgarh	**8**		**37.74**	**37.74**
Shama	**12**			**43.66**
Sig.		**0.32**	**0.08**	**0.09**

Table 9: Showing variation of carbon stock among different sites (altitude)

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 48.402.

a. Uses Harmonic Mean Sample Size = 8.000.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = 0.05.

VI. *Hand tilling:* There is no use of mechanized farming in the hill agricultural ecosystems. The reason behind this is basically the hilly terrain and small land holdings where tractor and other large machineries cannot be used. This improves the soil fertility since the soil particles do not break so often and remain intact as aggregates. Hand tilling is often done to remove weeds (that releases some carbon from the soil but it is comparatively less than the mechanized farming).

Soil Carbon Status

Organic matter substantially increases the proportion of micro pores, greatly improving the water holding capacity of soil. Soil organic content relies on other factors like temperature, precipitation and on particle size or texture of the soil. The soil was analyzed for organic carbon and basic characteristics such as moisture, texture, bulk density, organic matter and C/N ratio. The results have been presented in the table below (Table 5 & 6). Major physical components of soil fertility are soil texture, soil structure for a particular soil type. The moisture content in the soil was found to be higher in the forest and horticulture system than in agricultural system. The values ranged from 15.34 % to 25.54% with highest in the forest and lowest value was recorded in agricultural crop (*Eleusine coracana*). Soil texture was found to vary from loamy sand to silty loam among different sites. Also fields having silty loam soil showed high percentage of carbon approximately ranging from 2.2% to 3.4%. Bulk density varied from 1.12 to 1.34g cm^3. The results showed that soil organic carbon values were recorded to be highest in the soil of Shama, followed by Ramgarh. On applying correlation, it was found that the above mentioned parameters are significantly correlated at 0.01 level of significance. But, application of partial correlation showed that the individual effect of the above parameters is not significant. It is the combined effect that is responsible for correlation. TN was found to be significantly correlated to SOC ($r=.326$; $P<0.01$), implying that soil fertility is well maintained in the farming systems.

It was found that the cropping systems involved in the cultivation of leguminous crops showed comparatively higher values for SOC. This could be due to improved biomass production and fixation of nitrogen by rhizobium bacteria. Similar studies have been conducted by Zentner *et al*. (2001) and Zentner *et al*. (2004) in which they found that growing legumes can reduce the fossil fuel consumption in manufacturing fertilizers by reducing the nitrogen input as chemical fertilizers. A study by Drinkwater, 1998 indicated that the corn-soybean rotation system had the highest productivity as compared to the monoculture. Thus, crop rotation especially with legumes can enhance crop productivity as well as soil fertility. The legumes as well as horticultural trees both have large root biomass and therefore, contribute to greater SOC content. The forests of Shama (Bageshwar) and Ramgarh (Nainital) are purely dominated by oak trees while Maichun (Almora) and Lamudyar (Almora) possess blend of pine as well as oak forests. Kaindul (Pauri) is surrounded by mixed forests. Thus, it would rightly be said that topography, aspect and precipitation play a major role in determining the soil type of a region that governs the soil fertility.

On applying Duncan's test, the mean values of carbon stock was found to be highest in the soil cultivated with legumes (45.396), followed by horticulture (42.764). The values of carbon stock were found nearly same in the cereals (26.763) and millets (29.807) with forest showing the medieval values (35.019). Similarly along the altitude Duncan's test shows the mean values of carbon stock were found to be highest in the soil of Shama (43.66488292), followed by that of Ramgarh (37.74). The values of carbon stock were found nearly same in the other three sites with lowest at Lamudyar (27.81). This implies that among the cropping systems, leguminous crops showed the highest value for carbon stock while among the sites, the village at highest altitude showed the carbon stock values better.

Conclusion

Uttarakhand is a fast growing state in the ecologically-fragile western Himalaya. Soils of Uttarakhand under different ecozones have lost a significant amount of carbon and, therefore, offer a great potential for rehabilitating these areas. The estimates of carbon release and sequestration from the agro ecosystems are lacking in this region. Environmental factors such as temperature, moisture and soil type greatly affect the stability of organic carbon in plant residues or in soil carbon pool. In recent years, zero tillage along with the conservation agricultural practices have been suggested for enhancing the soil carbon status. Some of the strategies for improvement of carbon sequestration potential are no-till farming with crop residue mulch and cover cropping (conservation agriculture), integrated nutrient management (INM) including use of compost and manure, and liberal use of bio-solids. Though the crop management practices are already followed yet, the improvements in farming systems and use of organic material/compost could add carbon to soils. Enhancing carbon stock in different agro ecosystems has the potential for environmental, economic and soil benefits for local people. It could increase benefits for farmers as well as mitigate global warming, at least in the coming decades until alternative energy sources are developed. A realistic estimate of the carbon sequestration potential at regional or national scales requires integrating the effects of various factors that affect carbon inputs to and loss from soils and accounting the inherent high spatial heterogeneity and temporal variability.

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Abbreviations

GHG- Green House Gases

IPCC- Intergovernmental Panel on Climate Change

PRA- Participatory Rural Appraisal

SOC- Soil Organic Carbon

OM- Organic Matter

C/N-Carbon/Nitrogen ratio

CS- Carbon Stock

TC- Total carbon

TN- Total Nitrogen

BD- Bulk Density

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