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Role of Mycorrhiza in Maintaining Carbon Stocks in Disturbed and Undisturbed Ecosystems of Central Himalayan region

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ABSTRACT

Carbon management is one of the most relevant issues among the environmentalists, today. A viable option for reducing atmospheric CO_2 may be carbon sequestration by agricultural and forested regions. Forest ecosystems represent 60% of the terrestrial carbon budget, which suggests that forest management and forest disturbances may have a profound effect on carbon cycling. Mycorrhiza contributes to many soil characteristics such as organic carbon content, carbon sequestration, retention of moisture and thus, somehow, affects the climatic pattern. It receives 10 to 20% of the carbon fixed by its host plant. As such, it could potentially sequester a significant amount of carbon in ecosystems. An integrated study to assess the carbon stock in the soil has been conducted in the pine and oak forests of the central Himalayan region of Nainital hills and was compared with that of the agricultural soil with emphasis on mycorrhiza. It was found that the value for carbon stock was highest ($4.84 g/cm^3$) in oak soil where the mycorrhizal spore count was greater. Lowest stock ($2.21 g/cm^3$) in agricultural soil also corresponded with poor spore count.

1. Introduction

Rhizosphere ecology of terrestrial ecosystem have a bearing on the soil ecosystem including microbial associations, populations and nutrient concentrations. The interactive influence of soil fungi with plants, generally called as the mycorrhizal association is observed in 80% of terrestrial plants that facilitate plant uptake of soil nutrients in exchange for plant carbohydrates. As much as 20% of the total carbon assimilated by plants may reportedly be transferred to the fungal partner. Agriculture being a dynamic ecosystem provides enormous opportunities for estimation of carbon particularly in the soils (Lal *et al.,* 1995). It is thus unanimously agreed that absorbing CO_2 from atmosphere by physiological system and biomass of the plants, and moving finally transferring into the soil can be an effective way of removing large volumes of the major greenhouse gas (CO_2) from the atmosphere into the biological system that is enabled by mycorrhizal association. The present study therefore aims at assessment of carbon stock in the soil from pine and oak forests and a comparison with agricultural soil with a special emphasis on mycorrhizal association in the hilly terrain of Uttrakhand in the Indian Himalayan region.

2. Materials and Methods

The present field study was conducted in the Kumaun region of the Himalayan range dominated by pine and oak forests in the Nainital hills. An agricultural field was also selected for comparison purpose (Table 1).

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Table 1. Showing the details of site locations

Sites	Latitude	Longitude	Altitude
Oak	29º20'8.85N	$079^0$28'.8.95E	1278m-2198m
Pine	29º20'9.56N	$079^0$28'.861E	1154m-1200m
Wheat	29º20'5.12N	$079^0$28'.3.78E	800m-1090m

Vegetational analysis of the herbaceous undergrowth followed standard procedure (Misra, 1968) determining various phyto-sociological attributes such as density, frequency, abundance, dominance and important value index (IVI). Shannon-Wiener diversity index and Simpson's index of dominance were also calculated. At each site 10 quadrats of size (50cm x 50cm) were laid down randomly for data collection. Soil samples were collected from the selected sites at a depth of 0-15cm after the removal of surface litter layer and the vegetation. Sampling was done in zig-zag manner and 5 representive composite samples were collected which, in turn, were composed of sub-samples. Dried samples were sieved and stored in plastic bags for further chemical analysis. The samples were collected monthly and analysed for soil organic carbon (Walkley and Black Titration), total nitrogen (Kjeldahl's method), pH (pH meter Systronics India Model 324), available phosphorus (Olsen's Method) Spectrophotometer Varian 50 Bio), potassium content (Flame photometer Systronics, India 361), moisture content, bulk density, mycorrhizal spores (wet sieving method). Statistical analysis was done wherever applicable.

3. Results and Discussion

Climate and Phytosociology of ground flora

The study area experiences between subtropical to temperate climate on high elevation (more than 2000m). The mean annual temperature in summer ranges from 10.6^{O}C to 26.7^{O}C and in winters, it varies from 2.8°C to 15.6°C. Rainfall begins earlier in the month of June and continues up to the end of September. Nainital records heavy rainfall in these months mainly because of the local rain. During winter, rains create a considerable fall in temperature. Snowfall is recorded during January - February. Detailed questionnaire at grass root level was conducted considering the related information of resources, like population, cattle population, water supply, vegetation and agricultural practices, quality and quantity of resources, the distance to collecting resources and the future planning *etc.* The result showed that a very large area of the study site was covered under oak forest, but the spread of the forest area is not confined to a single place. It is not uniformly distributed since in hills the topography is quite different.

Similar results were obtained for pine forest though, in case of pine, uniform distribution of land was observed rather than patches. The most probable reason could be the invasiveness of pine. The forest area is widespread but not so uniform due to anthropogenic activities *viz.* road construction in the hills, settlement by certain farmers and at certain places the hill was totally degraded. The reason could be forest fire, overgrazing, landslides. Agricultural fields were seen near the settlement regions and since the study period was from January to April (winter season), wheat was the crop. A total of 9 and 6ground flora species were recorded in Pine and oak forests respectively. The IVI value under pine forest ranged from 162.63 to 9.65 and that in oak forest ranged from 185.43 to 11.55.From the phyto-sociological analysis of the ground flora, it is evident that greater number of species was found under the canopy of pine forest as the canopy is needle-leaved and broken. Greater litter fall on the floor of pine forest enabled abundance of herbaceous plants in the pine forest, as compared to the oak forest. Oak forest evidently supports lesser number of herbaceous plant species. The soil pH under the forested sites was over 7 that could be the possible reason for the occurrence of fewer numbers of species under oak forest (Eycott*et al.,* 2006).Species richness of pine forest along with elevation varying from 1800 m to 1500 m at central Himalaya was compared to judge the ecological significance by Kharkwal and Rawat (2005).

A total of 56 species comprising 51 genera and 28 families were recorded. Asteraceae and Lamiaceae were found to be the most dominant species. This is in support of the present study as well. The two most dominant species in terms of IVI values, recorded under pine forest were *Cyanodon dactylus* and *Artemesia vulgaris* and lowest value recorded was for *Cocculus lausifolius,* while in terms of density most dominant species were *Cyanodon dactylus* and *Ageratum haustonianum* and least dominant was *Cocculus lausifolius* in the month of May (Figure 1). The most dominant species in terms of density and IVI recorded in February were *Cyanodon dactylus* and *Salvia coccinea,* while least dominant was *Artemesia nilagarica.* When abundance values were considered, *Cyanodon dactylus* was again recorded the maximum, followed by *Ageratum haustonianum* and lowest for *Artemesia nilagarica.* The two most dominant species in terms of IVI values recorded under Oak forest were *Cyanodon dactylus* and *Lantana camara* and lowest was for

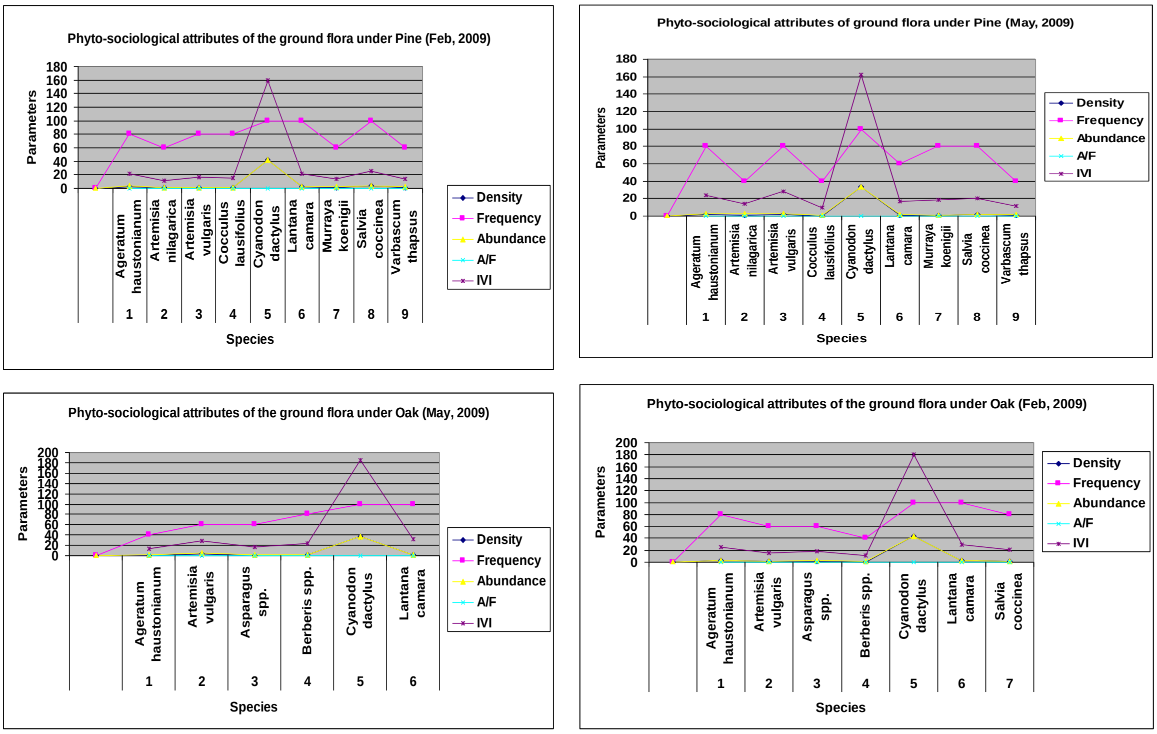


Figure 1. Phytosociology of ground flora in oak and pine forests

Ageratum haustonianum while in terms of density most dominant were *Cyanodon dactylus* and *Artemesia vulgaris* and least were *Ageratum haustonianum* and *Asparagus* spp. in the month of May (Figure 1). As per February data, the most dominant species recorded in terms of density as well as IVI were *Cyanodo ndactylus* and *Lantana camara* and least dominant was *Berberis* spp. When abundance values were considered, *Cyanodon dactylus* was again higher, followed by *Artemesia vulgaris* and lowest was *Asparagus spp*. in the month of May, while *Cyanodon dactylus*, followed by *Ageratum haustonianum* were recorded maximum and *Artemesia vulgaris* lower in February. Asteraceae was the most dominant family. The occurrence of regular distribution indicates competition between the individuals (Odum, 1996). Thus, *Lantana camara* under oak forest is reported to be an exotic species. Under pine forest, *Artemesia vulgaris* and *Ageratum haustonianum* were the exotic ones. The general preponderance of contagious distribution in vegetation has also been reported by Kershaw (1973), Singh and Yadava (1974) and Verma *et al.* (2004).Kumar *et al.* (2005) also observed contiguous distribution of herbaceous vegetation in the temperate forest of Garhwal Himalaya. The values for index of diversity (H), species richness (d) and concentration of dominance (c) are shown in the table 2 and 3. The index of diversity (Shannon-Wiener index, H) of the ground flora was greater under *Pine* (2.36307) in May and (2.3752) in February as compared to Oak (1.81974) in May and (1.98322) in February. The similar pattern was observed for species richness (Margalef, 1958) of ground flora under both the sites *viz.* Pine (2.12436) in May and (1.983896) in February while Oak (1.317353) in May and (1.518509) in February. The pattern for the values of concentration of dominance (Simpson's index) was different from above two parameters. The value of concentration of dominance was greater for Oak (0.414068) in May and (0.388057) in February as compared to Pine (0.313692) in May and (0.313327) in February. This shows that not much difference has been created due to the seasonal change. The data shows almost same pattern for both the seasons *i.e.* summer (May) and winter (February). Species diversity is an important parameter to show the restoration of the system due to the tree species. Pine forest showed greater value for index of diversity hence the more stable existed under site as compared to oak (Table 2).

Table 2. Species Diversity (H), Species Richness (d) and Concentration of Dominance (C) at different study sites (May,2009)

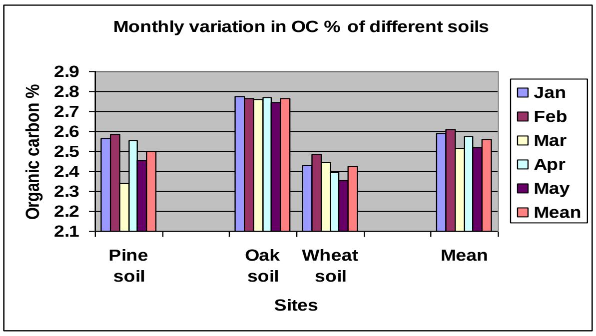
Sl. No.	Site	H	d	C
1.	Pine	2.36307	2.12436	0.31369
2.	Oak	1.81974	1.31735	0.41406

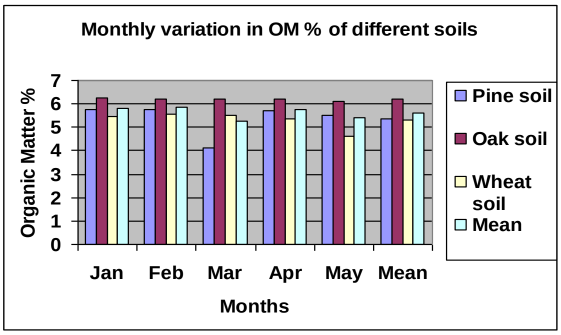
The value for concentration of dominance was lower for pine reflecting the fact that the ground under canopy of the forest was shared by many species. The oak forest site showed higher value of concentration of dominance and lower value of diversity index hence making it less stable compared to other. It can be said that pine forest could highly help in restoring the system in comparison to the oak forest. However, oak site was less efficient for system restoration under the similar climatic conditions. Soni *et al.* (1989) also found that planting of tree encourage the invasion of local species hence diversity of flora were found to be maximum under such plantation system as compared to barren land or grassland. The variation in species diversity reflects the varying degree of abiotic and biotic pressure (Sharma *et al.*, 2006).

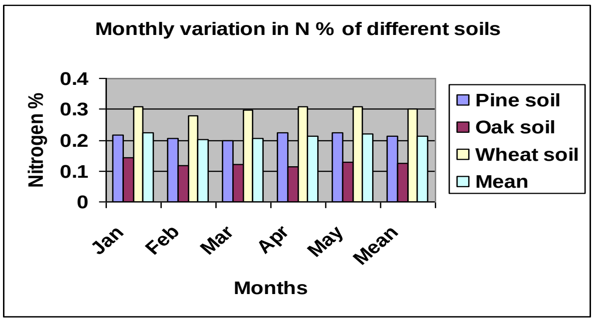
The oak forest site showed lower index of biodiversity, might be grazed frequently by the cattle in the study area. Thus the anthropogenic pressure was found to be disturbing the invasion of local species under the oak site. Further the livestock might not find it easier to climb the hill covered under Pine forest as compared to oak (though situated at a greater height) due to the slippery pine needles.

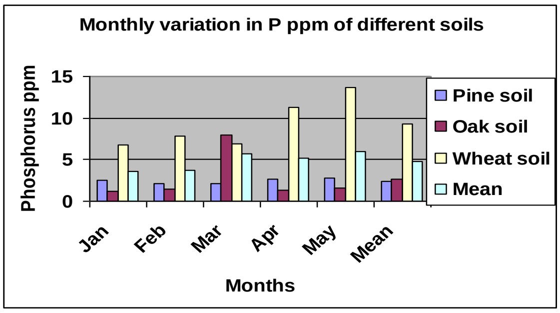
Table 3. Species Diversity (H), Species Richness (d) and Concentration of Dominance (C) at different study sites (Feb, 2009)

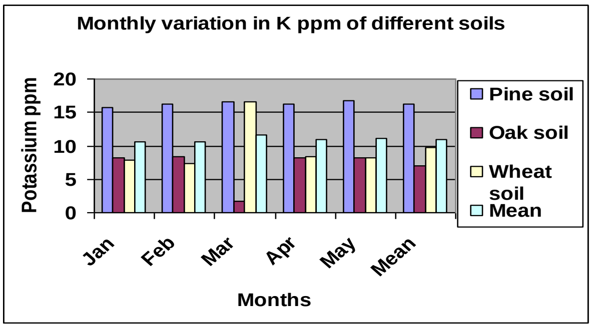
Sl. No.	Site	H	d	C
1.	Pine	2.37520	1.98389	0.31332
2.	Oak	1.98322	1.51850	0.38805

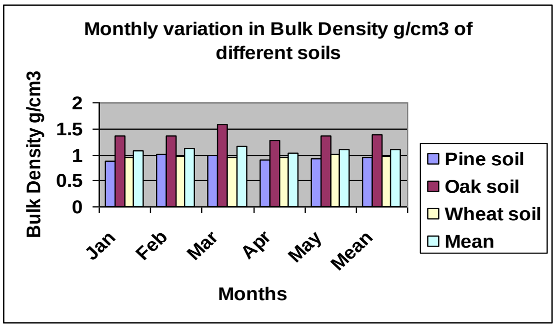












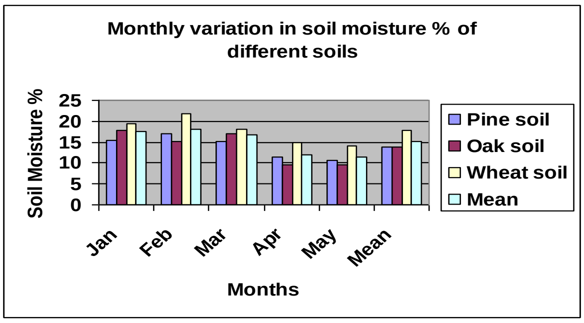


Figure 2. Soil Carbon and Nutrient concentration

It is evident from the Table 2 that index of similarity of ground flora under pine forest with that of oak forest was greater in the month of February (winter) *viz.* 0.625 than May (summer) *viz*. 0.54.

Soil Carbon and Nutrients

The soil organic carbon at the pine forest ranged from 1.87% to 2.90% during the whole study period. The study was conducted for five months *viz.* January to May and it was observed that not much fluctuation occurred in the data recorded for these five months. In case of oak forest the soil organic carbon ranged from 2.68% to 2.85%. The highest value for organic carbon was recorded in oak soil and lowest in wheat in which it ranged from 2.31% to 2.55%.

Table 4. Values of Index of similarity and index of dissimilarity of Pine with Oak

Sl. No.	Months	Index of similarity	Index of dissimilarity
1.	May	0.540	0.460
2.	Feb	0.625	0.375

Ganuza and Almendros (2003) found that temperature was one of the main factors controlling the organic carbon level in soil. Also the substitution of forest with pasture leads to the increase in the soil organic carbon. Yakimenko (1998) observed that the values for soil organic carbon were always higher in upper horizons of grass land in comparison to woodland in Russia due to rapid decomposition of grasses in the upper horizons of soils. The carbon content differed significantly ($P<0.05$) among all the study sites however the difference between the months was found not significant. A similar trend was observed for soil organic matter (SOM) as well. However, it differed significantly ($P<0.01$) for months and was found highly significant ($P<0.05$) among all sites. The interaction between sites and months was also highly significant. Comparing to soil C, nitrogen concentrations registered a totally different record. For instance, wheat field soil contained highest percentage of nitrogen (0.31%), while oak soil had only 0.11%. The ANOVA values showed that the nitrogen differed significantly ($P<0.05$) among all sites as well as for months. A similar trend was shown by phosphorus also (Figure 2). This might favour the presence of greater number of mycorrhizae in oak soil. Potassium was greater in pine soil (16.9 ppm) and lowest in wheat field (7.2 ppm).Bulk density and carbon stock in the soil was greater in oak forest (Figure 2). Pine and wheat soil showed almost similar values 0.86 to 1.10 g/cm^3. This indicate that oak trees help in soil biological processes that help SOM build up, owing to its residue quality and greater decomposition rates (Maithani *et al.,* 1998).

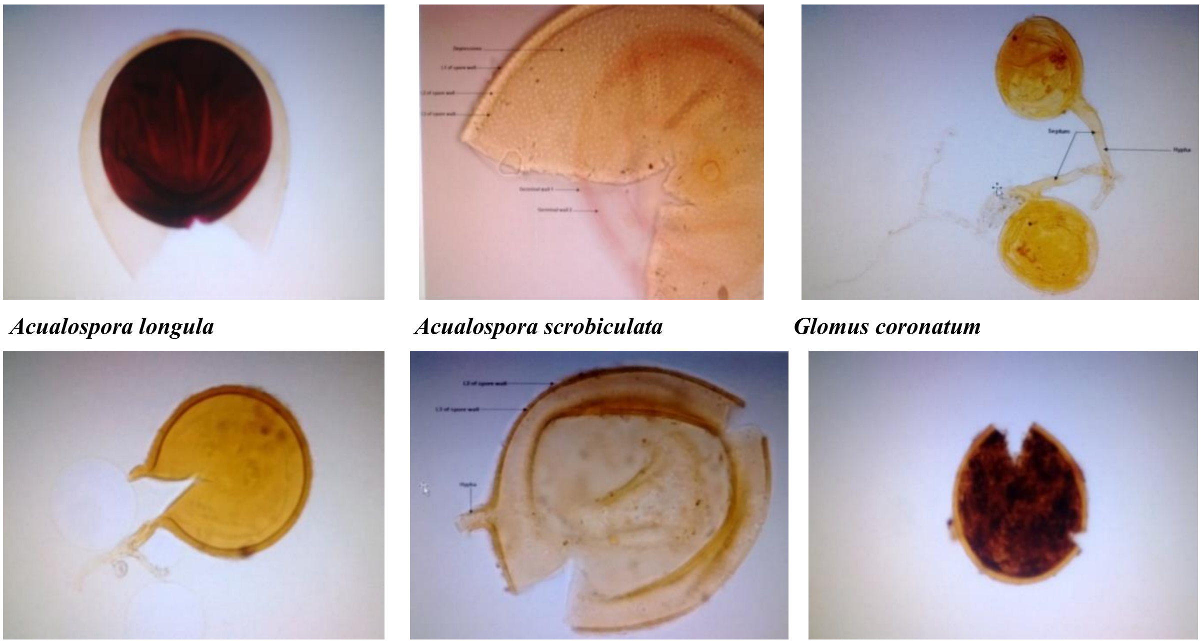
Dynamics of Mycorrhizal Spores

The mycorrhizal diversity observed in the study sites was recorded highest in the oak forest soil (around 10 species per gram). It was almost similar for pine soil but it was recorded to be lowest in the wheat field soil (around 6 species per gram). For each 5g soil, 48, 44 and 26 spores were recorded in the soil of pine, oak and wheat field soil respectively with the help of wet sieving method (Table 5). The spores were then identified using compound DIC microscope. Not all spores could be identified as some of the spores were quite old and others were laden with debris. The healthy spores were only identified and presented here. Overall, a good diversity of spores could be recorded that shows convenient microclimatic conditions in the sites supporting the growth of arbuscular mycorrhizal fungi. Further, presence of mycorrhizal spore increases the fertility of the soil and makes it more productive. In this study, oak soil that had higher spore registered lowest phosphorus. On the contrary, the wheat field soil having the least spore count contained greater phosphorus concentration and a similar result was observed for nitrogen as well.

Table 5. AMF density and Carbon Stock (up to 15 cm depth)

	Oak forest	Pine forest	Wheat field
AMF (Spores/5g soil)	47.33	43.33	26.66
C Stock (Mg/ha)	67.5	38.0	35.2

Data on conservative soil properties such as texture, pH and exchangeable cations were collected to check the extent to which all variation in biodiversity can be attributed to land use and management and the study shows that soil organic matter content and bulk density are likely to be influenced by land use, and may themselves become factors influencing development of vegetation and ecosystem function. The microorganisms like mycorrhiza play a significant role in the maintenance of soil fertility by enhancing the soil organic carbon content. It may also be concluded that the highest value recorded for carbon stock in the oak soil may be somewhat due to the presence of diverse mycorrhizal spores in it (Figure 3.).An inverse relation was observed between the concentration of phosphorus and number of mycorrhizal spores in the soils studied.



Acualospora longula *Acualospora scrobiculata* *Glomus coronatum*

Glomus etunicatum *Glomus intraradices* *Glomus microaggregatum*

Figure 3. Mycorrhizal spores identified from sites

The significance of the present study can be utilized in maintaining the integrity of forests in the hills as an undisturbed area with regard to carbon dioxide mitigation scenario by the government sector and especially, the oak forests, which are supposed to be the “King of Hills”, though their number is decreasing at quite a high rate. The medicinal and economical value of some of the herbaceous undergrowth of pine and oak forest should not be overlooked. With the effort to properly manage the forest land and avoid extensive cutting down of trees, overgrazing, forest fire *etc*. will not only act as natural biological scrubber of CO_2, but also help to increase forest cover, vis-a-vis improve soil organic carbon and fertility to awaken the hill ecosystems in the Indian Himalayan region.

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