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## Carbon sequestration with special reference to agroforestry in cold deserts of Ladakh

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**Global warming risks from emissions of greenhouse gases (GHGs) by anthropogenic activities have increased the need for the identification of ecosystems with high carbon sink capacity as an alternative mitigation strategy of terrestrial carbon sequestration.**

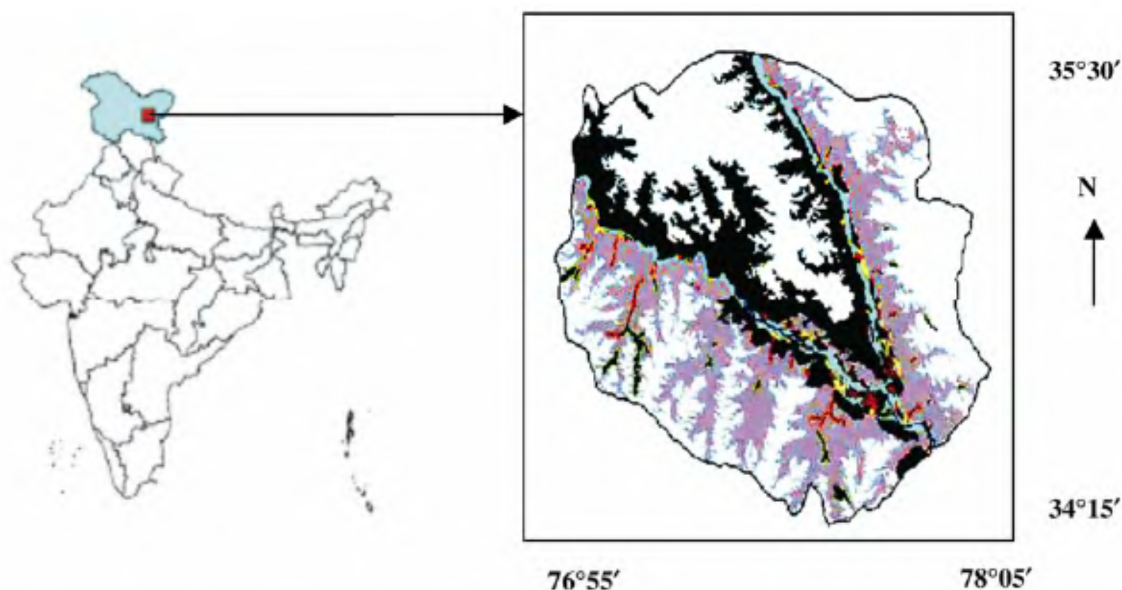
**The agroforestry sector has received recent attention for its enormous potential carbon pools that reduce carbon emissions to the atmosphere. The Nubra Valley (Trans-Himalayan region) is covered with more than 575,000 agroforestry plantations (willow and poplar). These species have been found to sequester more than 75,000 tonnes of carbon. Every year these plantations are contributing 400 tonnes of leaf litter to the ground, which is one of the best sources of soil organic carbon. This communication attempts to suggest some appropriate management practices to improve soil organic carbon pools by analysing available information of agroforestry plants in the Nubra Valley by quantification of biomass contribution by willow and poplar species within the valley and CO<sub>2</sub> sequestration rates by the living biomass.**

**Keywords:** Agroforestry, carbon sequestration, carbon sinks, cold desert lands, global warming, Trans-Himalayas.

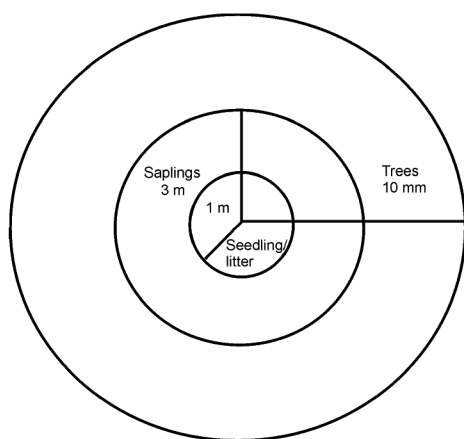
THERE is much concern that the increasing concentration of greenhouse gases (GHGs) in general, and carbon dioxide in particular, in the atmosphere contributes to global warming by trapping long-wave radiation reflected from the earth's surface<sup>1</sup>. Carbon sequestration, i.e. capturing and securing carbon that would otherwise be emitted and remain in the atmosphere might be a suitable alternative to control atmospheric emission of carbon. Plants capture CO<sub>2</sub> during photosynthesis and transform it to sugar and subsequently to dead organic matter. As the trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases, the increase in atmospheric CO<sub>2</sub> is mitigated<sup>2</sup>. The ability of these plantations to sequester carbon has received renewed interest, because carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emissions of GHGs through the clean development mechanism (CDM) according to the Kyoto Protocol<sup>3</sup>. Following the Kyoto Protocol, many studies on carbon sequestration have been carried out in African countries. However, there is a dearth of studies in Asian countries, particularly in high altitude with special reference to agroforestry. Keeping this in view, the present study was carried out extensively for a number of agroforestry plantations (willow and poplar) and their sequestered carbon stock in the Nubra Valley, Trans-Himalayan cold desert.

The Nubra Valley in Ladakh comprises the Valley of Shyok River from its acute-angled bend down to its confluence with Nubra and further towards Indus (Figure 1) with Khardung-La pass (5605 m asl) as gate way of the valley. The area lies between two great mountain ranges, i.e. Ladakh (on the south) and Karakoram (on the north) with approximately 34°15'45"–35°30'N lat. and 76°55'–78°05'E long. There is a great variation in altitude and it ranges approximately between 2700 and 6000 m asl. The

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**Figure 1.** Land use and land cover map of Nubra Valley showing sampling sites (remote sensing data by Joshi *et al.*<sup>18</sup>).



**Figure 2.** Methodology adopted for vegetation analysis.

climate of the region is extremely cold and is characterized by high wind velocity which continues throughout the year causing great variation in temperatures. Winter temperature goes below zero (minimum  $-25^{\circ}\text{C}$ ) and summer temperature is as high as  $38^{\circ}\text{C}$ . Precipitation is scanty with less than 80 mm per annum. The valley remains cut off from other parts of the country during winter months due to extreme weather conditions. Soil samples were collected from different regions of the valley to study the soil nutrient status. The samples were dried at  $45^{\circ}\text{C}$  until constant weight for chemical analysis. The pH of the samples was determined with an ion-specific electrode<sup>4</sup>. Electrical conductivity (EC) and the percentage of organic carbon were determined with the method of Walkley and Black<sup>5</sup>. Total N, P and K concentration analysed by standard methods<sup>6,7</sup>.

The present survey was conducted in 30 villages covering complete area of the Nubra Valley. International Forestry Resources and Institutes (IFRI) method was adopted

for collecting botanical information<sup>8</sup>. Sampling plots of regular shape of dimensions 10, 3 and 1 m radii, nested within each other were drawn randomly in every village of the study area (Figure 2). Plots of 1 m radius to observe seedlings and amount of fallen leaf litter, 3 m radius plots for saplings of 2.5–10 cm DBH (diameter at breast height) and plots of 10 m radius for the study of trees ( $\leq 10$  cm DBH). In each plot, the following algometric measurements were obtained from field sampling of each tree: tree height ( $H$ ), DBH, diameter of canopy or crown in two perpendicular directions and percentage of foliage cover in the crown or canopy ( $F_c$ ).

Total sequestered carbon stock of willow and poplar species was analysed through non-destructive, morphometric measurements and algometric equations relating to total ground biomass, carbon percentage and density of the wood of the plants studied<sup>9</sup>. Total ground biomass was determined through combined analysis of above ground biomass (AGB), below ground biomass (BGB) and tree canopy biomass values corresponding to each tree species measured. AGB was morphometrically measured with volume of the above ground plant and wood density, whereas volume =  $A_b \times H \times K_c$ , where  $A_b$  is the basal area,  $H$  is the height, and  $K_c$  is a site-dependent constant<sup>10</sup>. BGB was calculated with the formula given by MacDicken<sup>11</sup>. The biomass of foliage cover of each tree was determined with the help of crown volume calculation<sup>12</sup>, where crown volume =  $V(\text{m}^3) = \pi \times d_b^2 \times H_c / 12$  ( $\pi = 3.141592$ ;  $D_b$  the diameter of the crown;  $H_c$  the height from the ground to the base of the crown). Carbon percentage of the wood was calculated with the help of total organic carbon (TOC) analyser.

The vegetation of this zone is characterized by scattered low bushes, sparsely covered grasslands, herbaceous formations, sedge meadows and stony deserts. This

valley is not only ecologically sensitive but also economically most backward<sup>13</sup>. Development and conservation of agroforestry will be fundamental in achieving sustainable development in the Ladakh area. This zone predominated at high altitudes around the major peaks of the mountains. The landscape is characterized by vast glaciers, boulders and sheer cliffs. The vegetation is largely xerophytic although moist areas are found beneath glaciers, snowfields and along the river banks of Nubra and Shyok; majority of the plant species are being used for their medicinal properties<sup>14</sup>. In recent years, this area is exposed to tourists and other anthropogenic activities like fuel burns, vehicle transports, Bhukaris (traditional wood-fed heaters), etc. On a longer timescale, the uplift of the Himalaya and Tibetan Plateau is argued to have affected the regional as well as global climate due to draw-down of carbon dioxide by silicate weathering<sup>15,16</sup>. Nepal Himalayan region was observed with  $1.47 \times 10^6 \text{ Mg yr}^{-1}$  of carbon emitted into atmosphere due to land-use changes<sup>17</sup>. Cold arid bioclimate constituting 29% of the total arid ecosystem of the country has a share of 60% of total soil organic carbon (SOC) stock of the arid bioclimate<sup>18</sup>. The valley has not been explored adequately for carbon sequestration analysis due to its remoteness.

Table 1 shows that the soils of the valley have adverse physicochemical properties, such as low N, P and K values with less than 1%, loose sandy loam texture, high percentage of stones and granules, low water holding capacity (15.80–21.2%) and high bulk density (1.4–1.9  $\text{g cm}^{-3}$ ). Low soil fertility of the valley may be a result of uneven distribution of plantations or sparse vegetation. These soils could have a chance to improve their fertility by planting sustainable native agroforestry species<sup>19</sup>. Trees can maintain sustainable bionetwork through numerous processes such as the maintenance of soil organic matter, rhizosphere growth and improved soil biological activity<sup>20</sup>. In a given time, new self-sustaining leaf litter, litter fall, decomposing microorganisms and uptake of nutrients through root rhizosphere can be created by trees which help in soil fertility improvement with improved organic carbon, micronutrients, nitrogen, phosphorus, potassium, etc.<sup>21</sup>.

Both poplar and willow are common and highly sustained tree species in the valley, belong to the family Salicaceae with two species of poplar, viz. *Populus alba*, *P. nigra* and four species of willow, viz. *Salix alba*, *S. angustifolia*, *S. elegans* and *S. fragilis*. Most of the plantations are being grown along with agricultural lands. The present survey revealed that only 7–8% of plantations have been contributed by the Forest Department and the remaining plantations were initiated by the villages out of their own interest. Hunder, one of the surveyed villages, was observed with the highest number of plantations with willow (82,860) and poplar (55,240). Willow plantations dominated in Hunder, Disket, Panmik, Parta-

pur, Pinchemik, Summor, Taksha and Udmaru with more than 15,000 plantations, whereas poplar plantations were observed less in number when compared to willow plantations in most of the areas (Figure 3). A total of approximately, more than 575,000 plantations were observed with willow (65%) and poplar (35%) in all studied villages of the Nubra Valley. The variation in plantation numbers in studied villages has been affected by several factors, i.e. altitudinal variation, lack of sufficient irrigation and finally public awareness. Some villages like Turtuk, Thakshi and Youlkam were observed with huge number of fruit orchards, viz. apricot, apple, walnut, mulberry and grapes. Locals were also engaged in two cropping seasons in a year, due to favourable climatic factors like lower altitude (<2400 m asl), irrigation, temperature, etc. and this may be one of the reasons behind lesser number of willow and poplar plantations observed in these villages.

Willow and poplar are highly sustained species of this valley. However, poplar plantations were observed with less frequent at higher altitudes (>4500 m asl). Other than these two species, some bushes like *Atriplex hortensis*, *Ephedra gerardiana*, *Hippophae rhamnoides*, *Sophora moorcroftiana*, *Tanacetum tibeticum*, *Rosa webbiana*, *Berberis ulcina*, *Myricaria germanica*, *Tamarix gallica* also have the potential to gain biomass and sequester carbon in larger quantities. Farm planting is an old practice in the Nubra Valley, especially in the villages of Partapur, Skampuk, Hunder, Summur, Turtuk, Unmaru. The raising of fruit trees in the kitchen gardens and agriculture fields is also a well-established tradition of the valley. Many different kinds of fruits are grown in the valley including apricots, cherries, mulberries, plums, apples, grapes, pears, peaches, pomegranates and walnuts.

Wood and timber produces are likely to play an important role in the material economy of the society. It has been suggested that the demand for biomaterials may increase thus increasing the production rates of forests and plantations through more intensive management<sup>22,23</sup>. The CDM proposed in Article 12 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change, will allow developing countries to sell or trade project-based carbon credits, such as Carbon Emission Reduction Credits (CER credits), to or with industrial

**Table 1.** Physicochemical properties of soils of the Nubra Valley

Parameter	Variation
Bulk density ( $\text{g cm}^{-3}$ )	1.4–1.9
Maximum water holding capacity (%)	15.80–21.2
pH	4.90–8.10
Electrical conductivity (dS/m)	0.38–0.80
Organic carbon (%)	0.168–0.78
Total nitrogen ( $\text{mg kg}^{-1}$ )	0.47–0.78
Total phosphorus ( $\text{mg kg}^{-1}$ )	0.52–0.69
Total potassium ( $\text{mg kg}^{-1}$ )	0.67–0.74

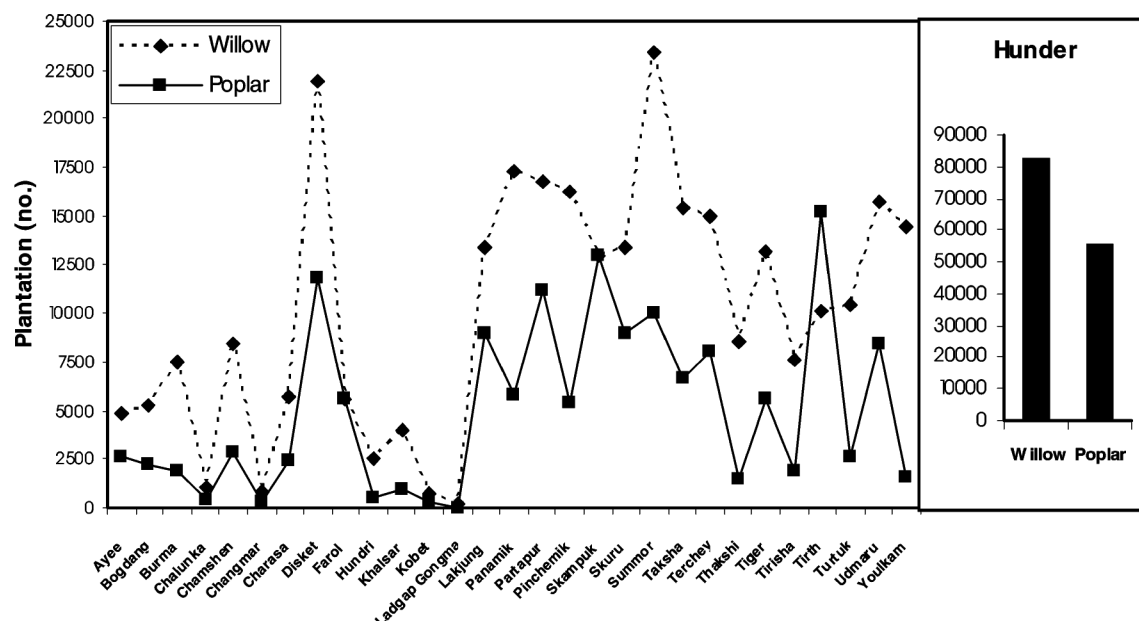


Figure 3. Villagewise list of willow and poplar plantations.

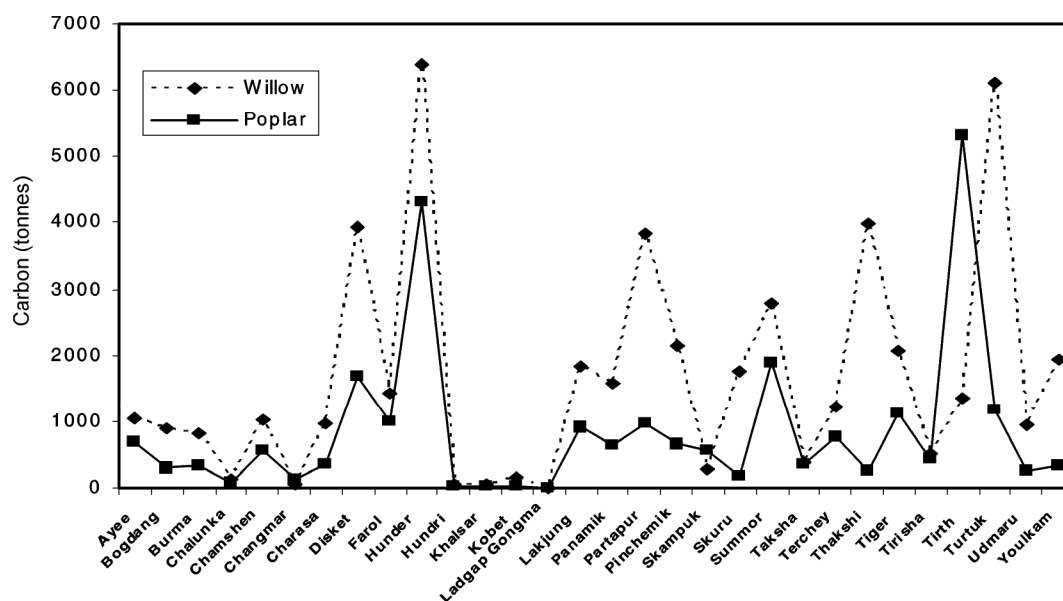
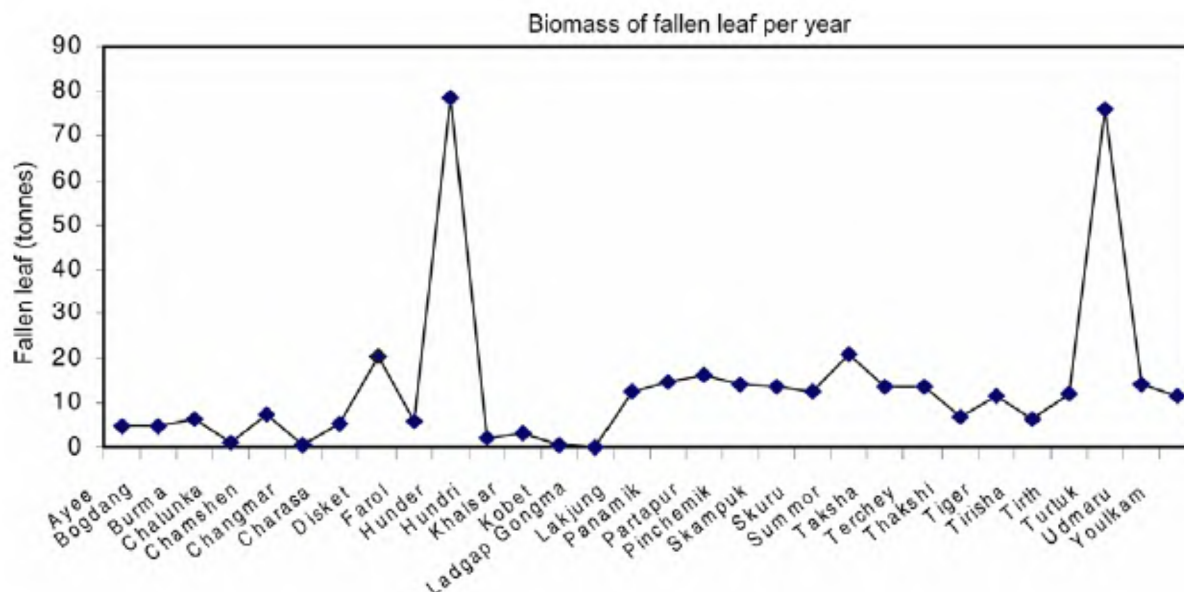


Figure 4. Sequestered carbon (tonnes) through living biomass.

countries, if adopted. CER credits could provide an incentive for participation in climate change mitigation<sup>3</sup>.

The carbon pool for Indian forests is estimated to be 2026.72 Mt. Estimates of annual carbon uptake increment suggest that Indian forests and plantations have been able to remove at least 0.125 Gt of CO<sub>2</sub> from the atmosphere and are also the major source of global carbon sinks<sup>24</sup>. In the present study, sequestered organic carbon in willow and poplar through living biomass had been observed and presented in Figure 4. Willow plantations of Hunder and Turtuk villages were analysed for maximum organic car-

bon pools of 6394 and 6100 tonnes respectively (Figure 4). In the village Turtuk, willow plantations were only 10,400 in number; however, most of them belong to older trees with larger girth diameter. Willow plant grows with maximum number of branches and greater crown canopy with lower height as compared to poplar. The variation in carbon sequestration capacity of these plantations depended on DBH, height, number of branches and crown canopy of individual plants. Increase in annual productivity of plantations directly indicates an increase in forest biomass and hence higher carbon sequestration potential.



**Figure 5.** Leaf litter production rates in different villages of Nubra Valley.

Approximately, more than 75,000 tonnes of carbon has been sequestered and stored in the form of living biomass through plant organic carbon (POC) by these two agroforestry species, i.e. willow and poplar.

The total amount of C produced by decomposition of plant litter is primarily determined by the amount of litter present. Carbon loss from litter decomposition is largely determined by the amount of decomposing litter<sup>25</sup>. The vegetation of study area is of deciduous type with every year leaf fall occurring in winter season. As a result of the deciduous nature of plantations, it was observed that every year these plantations produce more and more amount of leaf litter (Figure 5). Hunder, Turtuk, Summor and Disket villages were analysed with maximum amount of leaf litter with 79, 76, 21 and 20 tonnes respectively (Figure 5). Soil organic matter is recognized as being crucial to soil quality and to the regulation of many soil functions<sup>26</sup>.

The decay of organic matter is critical to mineralization and nutrient cycling in ecosystems. Energy and nutrients obtained by plants eventually become incorporated in detritus that provides the resource base of complex food webs in soil<sup>26</sup>. The present study also reports that approximately 360 tonnes of leaf litter is being produced every year. Litter decomposition is a useful biological indicator involving the interaction of vegetation, soil nutrient availability, micro- and macro-fauna and microbial populations. Most of the Ladakh soils were observed with 0.01% and 0.06% organic carbon, 0.3% and 2.1% calcium carbonate at the depth of 0.3 and 1.5 m respectively<sup>18</sup>. Macro-arthropods like millipedes, centipedes, insect larvae, termites, ants and others have the ability to modify soil structure by decreasing bulk density, increasing soil pore-space, mixing soil horizons and improving

aggregate structure<sup>27</sup>. Carbon in the form of carbon dioxide is currently accumulating in the atmosphere at the rate of about 3.4 Pg/yr (1 Pg = 1 billion tonnes) as a result of fossil fuel combustion and land-use change<sup>1</sup>. The Intergovernmental Panel on Climate Change (IPCC) estimated that it may be possible, over the course of the next 50–100 years, to remove between 40 and 80 Pg of the carbon by sequestering it through agroforestry<sup>28</sup>. Therefore, agroforestry would be one of the interesting areas of research in land-use related to carbon sequestration, for various reasons. First, the surface involved is considerable and the rate of carbon gain is relatively high ( $0.2\text{--}3.1\text{ t ha}^{-1}\text{ yr}^{-1}$  according to IPCC<sup>29</sup>). Second, it can mitigate the important CO<sub>2</sub> emission resulting from deforestation<sup>30</sup>. Third, it could provide a sustainable system from technical, ecological and economic points of view.

Poplar and willow have proven to be the most successful and popular sustained species of this valley. In consideration of interventions aimed at sequestering CO<sub>2</sub>, initial emphasis is likely to be placed more on afforestation of poplar, willow and bushes like *Hippophae rhamnoides* along the river belt lands of both Shyok and Nubra. Emphasis should also be placed on the 'grow-and-harvest' approach, in which trees are not to be harvested till they reach maturity, so that locals can earn income with the sale of timber, and fuel woods to meet their livelihoods. In this area, people used to burn fallen leaves, due to lack of decomposing bacteria or delay in decomposition. It resulted in poor SOC (0.168–0.78%), low soil nutrients like nitrogen (0.47–0.78 mg kg<sup>-1</sup>), phosphorus (0.52–0.69 mg kg<sup>-1</sup>) and potassium (0.67–0.74 mg kg<sup>-1</sup>; Table 1).

This communication also suggests that carbon sequestration through cultivation of cold resistant agroforestry

species like willow and poplar can also restore degraded lands and improve SOC along with global carbon dioxide mitigation. These results conclude in part that growing biomass to sequester carbon is a grow-and-store process for sustainable development. A few recommendations are as follows:

- Promotion and awareness of plantation programmes of sustainable native species.
- Introducing new and innovative funding mechanisms for the villagers who manage and improve carbon sequestration through agroforestry.
- Enhancing baseline information on the litter decomposing fauna of Ladakh by conducting biodiversity assessments.
- Providing composting pits along with sustainable micro/macro fauna and bacteria which can decompose litter.

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